The use of viticultural terroir units for demarcation of geographical indications for wine production in Stellenbosch and surrounds

by

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Dissertation presented for the Doctoral Degree of Agricultural and Forestry Sciences at
Stellenbosch University
April 2005

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DECLARATION

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

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SUMMARY

Due to increased consumer demand for products labelled by origin, and the requirement that these labels are a guarantee of both quality and product character, there is an increasing global focus on delimitation of denominations of origin. The integrity of denominations of origin and their defensibility can be ensured through the use of terroirs as a basis for delimitation.

The aims of this study were to establish the dominant environmental criteria that affect the viticultural behaviour and wine character of two important cultivars (Cabernet Sauvignon and Sauvignon blanc) in the Stellenbosch Wine of Origin District, to use an appropriate methodology to identify viticultural terroirs in this district based on these criteria and with the use of a geographic information system, and finally to use these viticultural terroirs to identify denominations of origin within the same area.

A terroir can be defined as a grouping of homogenous environmental units, or natural terroir units, based on the typicality of the products obtained. Identification and characterisation of terroirs depends on knowledge of environmental parameters, the functioning of the grapevine and the characteristics of the final product. Field studies, resulting in point data, are necessary to investigate the functioning of the grapevine but in order for this information to be of use within zoning studies it must be placed in a spatial context.

As a first phase in data acquisition, the Stellenbosch Wine of Origin District was characterised and natural terroir units were identified using existing digital data and a geographic information system. A natural terroir unit (NTU) can be defined as a unit of land that is characterised by relatively homogenous topography, climate, geological substrate and soil. A total of 1389 NTUs were identified in the Stellenbosch Wine of Origin District (84 537 ha). The identified NTUs were homogenous with respect to terrain morphological unit, altitude, aspect and soil type. Each of the identified units was further described with respect to the extent of the expected sea breeze effect and, for certain of the soil types, the associated parent material.

As a second phase of data acquisition, a network of plots of Sauvignon blanc and Cabernet Sauvignon were delimited in commercial vineyards in proximity to weather stations and their viticultural and oenological response monitored for a period of seven years.

Regression tree analyses were performed on the complete data set and the relative importance of the environmental and management related variables determined for each dependent variable. Excepting for scion clone, which had a high relative importance for bunch mass of Sauvignon blanc and yield to pruning mass index of Cabernet Sauvignon, no other non-environmental variable included in the analyses appeared to have a strong effect on grapevine performance and wine

character. The performance of Cabernet Sauvignon was affected by the potassium content of the subsoil and the climate of the season. The performance of Sauvignon blanc appeared to be related to soil texture, wind exposure and temperature, both during the green berry growth stage and the month prior to ripening. From the results presented, it appears that environmental parameters have an overriding effect on the performance of both Cabernet Sauvignon and Sauvignon blanc, but that these two cultivars react differently to environmental stimuli.

A knowledge-driven model used the rules generated in the regression tree analyses to directly classify natural terroir units with respect to expected response of Cabernet Sauvignon and Sauvignon blanc in the Stellenbosch Wine of Origin District. The natural terroir units were thus grouped into terroir units that were homogenous with respect to predicted viticultural and oenological response for each cultivar.

The use of representative sites to determine the response of the grapevine to its environment is time consuming and costly and limits terroir studies to research related investigations. Vineyard managers were therefore surveyed with respect to the functioning of established Sauvignon blanc vineyards in the Stellenbosch Wine of Origin District in an attempt to obtain the necessary data. Comparison of the data generated with these questionnaires to measured data in commercial vineyards suggested that the vineyard managers were able to characterise the performance of vineyards with respect to vigour, signs of drought stress and yield. Each vineyard was mapped and the responses were linked to modelled environmental variables. Classification and regression trees were used to construct decision trees, which could be applied to environmental data in a geographic information system to determine viticultural terroirs for production of Sauvignon blanc. These terroirs, although fewer, were comparable to those generated using field data.

Data gathered during terroir studies, and the identified viticultural terroirs for Cabernet Sauvignon and Sauvignon blanc, were used to revisit the boundaries of the Stellenbosch Wine of Origin District and the Simonsberg-Stellenbosch ward. Modifications were proposed based on expected wine characteristics. Boundaries for two new wards in the Helderberg basin were proposed. It was also possible to identify vineyards within a ward for the production of terroir specific wines.

OPSOMMING

Toenemende verbruikersaanvraag vereis produkte waarvan die etikette nie net die oorsprong aandui nie, maar ook kan dien as 'n waarborg vir die produk se kwaliteit en kenmerkendheid. Hierdie tendens verklaar die toenemende wêreldwye fokus op afgebakende areas van oorsprong. Die integriteit van dié afgebakende areas van oorsprong sowel as hul verdedigbaarheid kan gewaarborg word deur terroirs as basis vir afbakening te gebruik.

Die doelstellings van dié studie was om die oorheersende omgewingseienskappe wat wingerdprestasie en wynkarakter van twee belangrike cultivars, naamlik Cabernet Sauvignon en Sauvignon blanc, in die Stellenbosch Wyn van Oorsprongsdistrik beïnvloed, te bepaal; tweedens om 'n toepaslike metodologie te gebruik om terroirs in die dié distrik te bepaal wat gebaseer is op die geïdentifiseerde omgewingseienskappe met die gebruik van 'n geografiese inligtingstelsel; en, ten slotte, om hierdie terroirs vir wingerbou te gebruik om afgebakende areas van oorsprong in dieselfde omgewing te identifiseer.

'n Terroir kan gedefinieer word as 'n samestelling van homogene omgewingseenhede, of natuurlike terroir-eenhede (NTE), wat gebaseer word op die kenmerkende eienskappe van die produkte wat daaruit verkry word. Identifisering en karakterisering van terroirs sal afhang van kennis van die omgewingsparameters, die funksionering van die wingerdstok en die eienskappe van die finale produk. Veldstudies waaruit puntdata verkry word, is noodsaaklik om die funksionering van die wingerdstok te ondersoek. Dit is egter noodsaaklik om eers hierdie inligting in ruimtelike konteks te plaas alvorens die inligting vir soneringstudies gebruik kan word.

As 'n eerste fase van datagenerering, was die Stellenbosch Wyn van Oorsprongsdistrik gekarakteriseer en NTE's geïdentifiseer deur gebruik te maak van bestaande digitale data en 'n geografiese inligtingstelsel. 'n NTE kan gedefinieer word as 'n landseenheid wat gekarakteriseer word deur 'n relatiewe homogene topografie, klimaat, geologiese substraat en grondtipe. 'n Totaal van 1389 NTE's is geïdentifiseer in die Stellenbosch Wyn van Oorsprongsdistrik (84 537 ha). Die geïdentifiseerde NTE's was homogeen met betrekking tot die terrein morfologiese eenheid, hoogte bo seespieël, hellingsaspek en grondtipe. Elk van die geïdentifiseerde eenhede was verder beskryf volgens die omvang van die seewind-invloed en, vir toepaslike grond tipes, die geassosieerde moedermateriaal.

As 'n tweede fase van datagenerering is 'n netwerk van persele van Cabernet Sauvignon en Sauvignon blanc afgebaken binne bestaande kommersiële wingerde in die nabyheid van weerstasies. Hul wingerd- en wynkundige respons is vir 'n periode van sewe jaar gemonitor.

Regressieboomanalises is gebruik om die volledige stel data te analiseer en om die relatiewe belang van omgewings- en bestuurspraktykverbonde veranderlikes te

bepaal. Die bostokkloon (wat 'n hoë relatiewe belang vir die trosmassa van Sauvignon blanc en die oes- tot snoeimassa verhouding van Cabernet Sauvignon het) is die enigste van die nie-omgewingsparameter wat 'n sterk invloed op wingerdprestasie of wynkarakter blyk te hê. Die prestasie van Cabernet Sauvignon is beïnvloed deur die kaliuminhoud van die ondergrond sowel as die seisoensklimaat. By Sauvignon blanc het dit voorgekom of die prestasie verband hou met grondtekstuur, windblootstelling en temperatuur tydens die groen fase van korrelgroei sowel as die maand voor rypwording. Alhoewel dit blyk uit die resultate dat omgewingsparameters 'n oorheersende invloed op die prestasie van beide Cabernet Sauvignon en Sauvignon blanc uitoefen, reageer dié twee cultivars verskillend op omgewingsprikkels.

'n Kennisgedrewe model waarvan die riglyne uit resultate van die regressieboomanalise saamgestel is, word gebruik om NTE direk te klassifiseer ten opsigte van die verwagte respons van Cabernet Sauvignon en Sauvignon blanc in die Stellenbosch Wyn van Oorsprongsdistrik. Die NTE is dus gegroepeer om terroir eenhede te vorm wat homogeen was ten opsigte van die verwagte wingerd- en wynkundige respons vir elke cultivar.

Die gebruik van verwysingspersele om die respons van die wingerdstok teenoor sy onmiddelike omgewing te bepaal, is tydrowend en duur en beperk sodoende terroir studies tot navorsing. Gevolglik is 'n opname onder wingerdbestuurders gemaak om inligting oor die prestasie van Sauvignon blanc in die Stellenbosch Wyn van Oorsprongsdistrik in te win en sodoende die nodige data te verkry. Na vergelyking van die ingewinde data, wat uit die opname verkry is, met gemete data vanaf kommersiële wingerde, kon afgelei word dat wingerdbestuurders by magte is om die prestasie van wingerde ten opsigte van groeikrag, tekens van droogtestres en opbrengs te karakteriseer. Elke wingerd is gekarteer en die respons is gekoppel aan die gemodeleerde omgewingsparamters. Klassifikasie en regressiebome is gebruik om besluitnemingsmodelle saam te stel wat toegepas kon word op omgewingsdata in 'n geografiese inligtingstelsel om terroirs vir die produksie van Sauvignon blanc te bepaal. Hierdie terroirs, alhoewel minder, was vergelykbaar met dié wat gegenereer was met behulp van veldstudies.

Data verkry met terroirstudies, sowel as geïdentifiseerde terroir-eenhede, was gebruik om die grense van die Stellenbosch Wyn van Oorsrongsdistrik en die Simonsberg-Stellenbosch wyk te herbepaal. Voorgestelde modifiserings was gebaseer op verwagte wyneienskappe. Grense vir twee nuwe wyke in die Helderbergkom is voorgestel. Dit was ook moontlik om wingerde binne 'n wyk te identifiseer vir die produksie van terroir-spesifieke wyne.

RESUMÉ

En raison de la demande accrue des consommateurs pour les produits de labels d'origine, et du besoin que ces labels soient une garantie à la fois de qualité et de caractère du produit, la question de la délimitation des appellations d'origine est d'intérêt global croissant. L'intégrité des appellations d'origine et leur crédibilité peut-être assurée à travers l'utilisation des terroirs comme base de délimitation.

Les objectifs de cette étude sont d'établir les critères environnementaux dominant qui affectent le comportement de la vigne et le caractère du vin de deux importants cépages (Cabernet Sauvignon et Sauvignon blanc) dans le District des Vins d'Origine de Stellenbosch ; d'utiliser une méthode appropriée pour identifier les terroirs viticoles dans ce district basée sur ces critères et l'utilisation d'un système d'information géographique ; et enfin, d'utiliser ces terroirs viticoles pour identifier les appellations d'origine à l'intérieur de cette même zone.

Un terroir peut-être défini comme un groupement d'unités environnementales homogènes, ou d'unités de terroir naturel, basé sur la typicité des produits obtenus. L'identification et la caractérisation des terroirs dépendent de la connaissance des paramètres environnementaux, du fonctionnement de la vigne et des caractéristiques du produit final. Des études de terrain, aboutissant à des données ponctuelles, sont nécessaires pour examiner le fonctionnement de la vigne ; mais pour que cette information soit utile au sein des zones d'étude, ceci doit être placé dans un contexte spatial.

La première étape dans l'acquisition des données, est la caractérisation du District des Vins d'Origine de Stellenbosch à l'aide de données numériques existantes et d'un système d'information géographique. Une unité de terroir naturel (NTU) peut-être défini comme une unité de terre qui est caractérisée par une topographie, un climat, un substrat géologique et un sol relativement homogènes. Un total de 1389 NTU (84 537 ha) a été identifié en fonction des unités morphologiques du terrain, de l'altitude, de l'exposition et du type de sol. Chaque unité identifiée a par la suite été précisée en fonction de l'ampleur de l'effet attendu de la brise de mer et, pour certains types de sol, de la roche mère qui lui est associé.

La deuxième étape dans l'acquisition des données est d'une part la délimitation d'un réseau de parcelles de Sauvignon blanc et Cabernet Sauvignon dans des vignes commerciales à proximité de stations météorologiques et, d'autre part, le suivi de leurs réponses viticoles et œnologiques pendant une période de sept ans.

Des analyses d'arbres de régression ont été utilisées pour analyser l'ensemble des données et déterminer l'importance relative des variables environnementales et de gestion relative. Mis à part le clone scion qui a une importance relativement élevée pour la masse des grappes de Sauvignon blanc et l'index rendement/poids de taille du Cabernet Sauvignon, aucune autre variable non-environnementale incluse

dans les analyses apparaît avoir un grand effet sur les performances de la vigne et le caractère du vin. La performance du Cabernet Sauvignon est affectée par la teneur en potassium du sous-sol et le climat de la saison. La performance du Sauvignon blanc semble être reliée à la texture du sol, l'exposition aux vents et la température, à la fois durant le stade de croissance des baies vertes et le mois précédent la maturation. A partir des résultats présentés, il semble que les paramètres environnementaux ont un effet prédominant sur la performance à la fois du Cabernet Sauvignon et du Sauvignon blanc ; mais que ces deux cépages réagissent différemment aux stimuli environnementaux.

Un modèle basé sur la connaissance et utilisant des règles générées dans les analyses de régression a été utilisé pour classifier directement les unités de terroir naturel en fonction des réponses attendues du Cabernet Sauvignon et Sauvignon blanc dans le District des Vins d'Origine de Stellenbosch. Les unités de terroir naturel ont ensuite été groupées dans des unités de terroir qui sont homogènes du point de vue des réponses viticoles et oenologiques prévues pour chaque cépage.

L'utilisation de sites représentatifs pour déterminer la réponse de la vigne à son environnement est un travail long et coûteux qui limite les études de terroir à des investigations de recherches apparentées. Par conséquent, les viticulteurs ont été questionnés à propos du fonctionnement des vignes de Sauvignon blanc établies dans le District des Vins d'Origine de Stellenbosch afin de tenter d'obtenir les données nécessaires. La comparaison des données issues des questionnaires aux données mesurées dans les vignes commerciales suggère que les exploitants viticoles ont été capables de caractériser la performance des vignes du point de vue de la vigueur, des signes de stress hydrique et des rendements. Chaque vigne a été cartographiée et les réponses ont été reliées aux variables environnementales modélisées. La classification et les arbres de régressions ont été utilisés pour construire des arbres de décision qui pourraient être appliqués aux données environnementales dans un système d'information géographique pour déterminer les terroirs viticoles propices à la production de Sauvignon blanc. Ces terroirs, même moins nombreux, sont comparables à ceux générés grâce aux données de terrain.

Les données rassemblées au cours des études de terroir et les terroirs viticoles identifiés pour le Cabernet Sauvignon et le Sauvignon blanc ont été utilisés pour reconsidérer les bordures du District des Vins d'Origine de Stellenbosch et du « quartier » de Simonsberg-Stellenbosch. Des modifications ont été proposées sur la base des caractéristiques attendues des vins. Des bordures pour deux nouveaux « quartiers » dans le bassin d'Helderberg ont été proposées. Il a aussi été possible d'identifier dans un « quartier » des vignes pour la production de vins spécifiques de terroir.

This dissertation is dedicated to Paul and Bridgette Carey.
Hierdie proefskrif is opgedra aan Paul en Bridgette Carey.

BIOGRAPHICAL SKETCH

Victoria Carey matriculated from Bergvliet High School in 1989. She studied BScAgric (Viticulture and Oenology) at Stellenbosch University, graduating *cum laude* in 1993. After a six-month period with the SESAME exchange program in Alsace, France, Victoria completed her BScAgric Hons (Viticulture) *cum laude* in 1995. She was employed by ARC Infruitec-Nietvoorbij from 1996 until June 2001, first as a junior researcher and then as a researcher. During this period, she completed her MSAgric degree, entitled "Spatial characterization of natural terroir units for viticulture in the Bottelaryberg-Simonsberg-Helderberg winegrowing area", graduating in March 2001. Victoria has been employed as a lecturer in viticulture at the Department of Viticulture and Oenology, Stellenbosch University since July 2001.

ACKNOWLEDGEMENTS

I wish to express my sincere gratitude and appreciation to the following persons and institutions:

Prof E Archer, **Dr G Barbeau** and **Mr D Saayman,** for expert guidance, without which I would not have been able to complete this dissertation

Winetech, **ARC Infruitec-Nietvoorbij**, **Stellenbosch University** and the **National Research Foundation** for financial support of these studies.

Dr Martin Kidd of the Centre for Statistical consultation, Stellenbosch University for his advice to use CART analyses and for these statistical analyses.

André Schmidt and **Kobus Theron** of ARC Infruitec-Nietvoorbij, and **Marina Bruwer** and **Zelmari Coetzee**, post-graduate students in the Department of Viticulture and Oenology, Stellenbosch University, for technical assistance.

Dr Valérie Bonnardot, for assistance with climatic analyses and the French translation of the summary.

Francois Knight and **Ryk Taljaard** of Agri-Informatics, **Dalene Opperman** of the Department of Agricultural Economics, Stellenbosch University and **Mike Wallace** of Department of Agriculture: Western Cape, for assistance with the compilation of digital data layers.

Grape and wine producers in the Stellenbosch area, for generous cooperation, both with respect to vineyards for field studies and the completion of surveys.

Stellenbosch University, for the granting me a research opportunity to complete this dissertation and my colleagues in the Department of Viticulture and Oenology, Stellenbosch University for shouldering my responsibilities during this allotted period.

The Wine of Origin Demarcation Committee and the UVV, INRA-Angers, for inspiration.

My parents, for making it financially possible for me to study viticulture and for their continued belief in my abilities.

My husband and daughter, for their support, understanding and love.

PREFACE

This dissertation will be presented as a compilation of seven chapters. Each chapter is introduced separately. The research results are presented in the form of scientific publications.

Chapter 1 **GENERAL INTRODUCTION AND PROJECT AIMS**

Chapter 2 **LITERATURE REVIEW**
Geographical indications and terroir: methods of demarcation for wine production

Chapter 3 **LITERATURE REVIEW**
History and environmental characterisation of Stellenbosch and surrounds

Chapter 4 **RESEARCH RESULTS**
The use of a geographic information system and reference plots to identify terroirs for viticulture in Stellenbosch and surrounds

Chapter 5 **RESEARCH RESULTS**
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CHAPTER 1

INTRODUCTION AND PROJECT AIMS

CHAPTER 1

...wine production is a complex dance with nature with the goal of interpreting or translating local ecology, displaying its qualities to best advantage
(Barham, 2003)

L'AOC, c'est l'âme d'un terroir et l'esprit d'une région
(Renou, 2001)

1.1 INTRODUCTION

South Africa is generally considered to be a young wine-producing country, but its history of wine production is as established as its history as a country. The first grapevines were planted by Jan Van Riebeeck in 1655, only three years after his arrival at the Cape. The wine industry gained international recognition in the early 19th century with the production of Constantia wines, which can probably be accepted as being South Africa's first geographical indication (Saayman, 1977). These Constantia wines were rated amongst the world's best, but a lack of legal protection of the production area and the advent of phylloxera and other diseases resulted in a decline in and consequent restructuring of the Cape wine industry. In the early 1940s, South African consumers began to move from brandy consumption towards natural wines of a higher quality and developed an increasing interest in the origin, vintage and cultivar of the product (Burger & Saayman, 1981). As information pertaining to the cultivar, vintage and origin was specified on the labels of the better-quality wines, so the need for protection of these claims arose and, in 1972, legislation was drafted based on the recommendations of a number of committees and with the support of the Viticultural and Oenological Research Institute (Saayman, 1999). Present-day Wine of Origin control legislation stipulates that no indication of origin, cultivar or vintage may be given unless the area has been demarcated and the wines have been produced strictly in terms of the control legislation (Kok, cited in Saayman, 1999). Areas are demarcated within the Wine of Origin Scheme under four categories, *viz.* regions, districts, wards and estates, with wards being the demarcated areas most stringently based on environmental attributes. The demarcation of wards is essentially based on the concept of land-type[1]. All soil and climatic factors possibly having an effect on wine character and/or quality, existing

[1] Within the definition of agricultural potential, land refers to the primary natural resources necessary for agriculture, namely climate, terrain form and soil (Mac Vicar *et al.*, 1974), and a land-type can therefore be defined as "a class of land over which the macroclimate, the terrain form and the soil pattern each displays a marked degree of uniformity". It will differ from another unit in terms of at least one of these parameters (Mac Vicar *et al.*, 1974), but is not necessarily defined as an uninterrupted unit of land.

cultural practices, existing experience and evidence that prove an area to be unique, geographical and other factors that contribute to the development of the traditional wine area, as well as the traditional name of the area are taken into account in the delimitation of wards (Saayman, 1999). Wards are demarcated, on application by the producers within a community, by a multidisciplinary demarcation committee within the structure of the Wine and Spirit Board (SAWIS, 2003). According to statutory regulations, when the term "Wine of Origin" appears together with the name of a production area, it confirms that 100% of the grapes used for the production of the wine come from that area (SAWIS, 2003).

The wine consumer is becoming increasingly interested in the origin of the product and looks for unique products that are characteristic of an area and of a high quality. Although the demarcated category of ward goes a long way towards meeting these needs, the land-type concept and, therefore, the ward represent relatively homogenous **patterns** and a more refined category is necessary to truly represent the terroir/vine/wine interaction on a vineyard level. The identification of natural terroir units (Laville, 1993) (a similar concept to ecotopes[2]) with specific application to viticulture is therefore an important step for South Africa in meeting the consumer challenge and reaching an important market (Carey, 2001).

Van Zyl (2000) has suggested that the Stellenbosch Wine of Origin District, for example, is no longer sufficient in terms of marketing and that more specific terroir-related denominations are needed. However, in his discussion of potential "appellations", he neglects to consider any terroir-related aspects other than the position in the landscape or geographic proximity. He ignores, for example, the difference in geological origin of soils within and without the Simonsberg-Stellenbosch Wine of Origin ward. There are also a number of producers who do not agree with the terroir concept, or believe that it is so intrinsically interlinked with the human factor that it is of no relevance for a so-called "new-world" wine-producing country such as South Africa. Fortunately, this viewpoint is on the decline and does not negate the number of producers who are interested in obtaining a more "site-specific" denomination for their wine. Over the past decade, there has been a proliferation of wines labelled with an attempt to indicate the vineyard site (within the existing regulations preventing the use of words indicating a geographical origin that has not been demarcated). From 2004, the need for appellation of single vineyards is being met outside of the wine of origin scheme and will be strictly regulated so as to prevent fraud. Because this concept has been market driven, however, it does not yet meet the need for the more limited and stringent, and possibly controlled, denominations of origin that have been identified by many producers (notably those

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[2] Land types are composed of units known as *ecotopes* (i.e. a particular habitat within a region or a climate-soil-slope class), which is a class of land defined in terms of its macroclimate (including slope aspect), soil and soil surface characteristics (mainly slope) and having a significant difference in yield potential compared to neighbouring units (MacVicar *et al.*, 1974, Schoeman & Mac Vicar, 1978).

of the Elgin Wine of Origin ward). Matthee (2001) has suggested that, because geographical indications are collective property, it is vital that producers within a region take ownership of and responsibility for the reputation of their geographical indication. He has challenged South African producers to upgrade their area of origin by taking responsibility for improving quality. One way of achieving this is through the demarcation of controlled appellations of origin. This level of demarcation has been provided for within the South African Wine of Origin scheme by legislation of the category “distinctive wines of origin”. It has, however, not been used as yet and the degree to which the terroir concept is integrated into it and the balance between natural and human factors have not yet been identified.

The Wine of Origin Scheme is dynamic and based on the best available environmental information and newest research results pertaining to the environment x wine interaction. As such, increasing awareness of the diversity of the South African winegrowing environments is resulting in increasingly stringent criteria for delimitation. The delimitation and characterisation of viticultural terroirs has therefore become a focal point of South African viticultural and oenological research. The significance of the environment for wine quality and character has long been recognised in South Africa and, in the early 1970s, a great deal of research was focussed on the interaction between environment and wine (*inter alia* Buys, 1971; Le Roux, 1974; Saayman, 1977). Unfortunately, due to the limited cultivar spectrum in South Africa at that time, this research could not be followed through to the natural outcome of delimitation of viticultural terroirs. The research baton was taken up again ca. 1994, following Resolution Viti 2/93 of the Office International de la Vigne et du Vin (OIV), and now forms a research programme of Winetech (Wine Industry Network for Technology and Expertise), to which this dissertation contributes.

1.2 PROJECT AIMS

This study necessarily tests a number of hypotheses. Firstly, it tests the hypothesis that grapevine performance, and thus berry composition and wine character, are characteristic of the vineyard environment (slope, elevation, soil characteristics, mesoclimate, etc.). The second hypothesis is that grapevine performance, and thus berry composition and wine character, are affected by constant environmental parameters and that these characteristics will be recognisable despite differences in vintage, viticultural practices, rootstock or scion clone. This hypothesis must be tested, as the South Africa wine industry is non-prescriptive with respect to cultivar choice and the use of specific viticultural and oenological technologies for specific demarcated areas, although there are certain legislated lists of permitted cultivars and prohibited technologies that must be adhered to. Finally, the hypothesis that environmental characteristics can be used to delimit areas resulting in similar characteristics for specific cultivars must be tested.

The objectives of this project are therefore:

1. to establish the dominant environmental criteria that affect the viticultural response and wine character of two important cultivars (Cabernet Sauvignon and Sauvignon blanc) in the Stellenbosch wine-producing area (84 537 ha),
2. to use an appropriate methodology spatially characterise viticultural terroirs in the Stellenbosch wine-producing area based on these criteria and with the use of existing digital data in a geographic information system and, finally,
3. to use these viticultural terroirs to propose denominations of origin within the same area.

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CHAPTER 2

LITERATURE REVIEW

Geographical indications and terroir: methods of demarcation for wine production

CHAPTER 2

2.1 INTRODUCTION

The concept of appellation or geographical indication stems from man's desire to individualise that which he produces, uses or consumes (Quittanson & Vanhoutte, 1963) and products have been denominated by origin since at least the fourth century BC (Bertozzi, 1995). According to Rangnekar (2003), geographical indications are increasingly being used to "secure" a link between the quality of the product and the origin of the product and, as such, they have value for "niche marketing, brand development and extracting value". Barham (2003) suggests that recent literature refers extensively to the growing consumer demand for products labelled by origin, which appears to be the result of the emergence of a new rural paradigm (literature cited in Barham, 2003). Labels of origin are able to link the production of the product to the social, cultural and environmental aspects of the site of production and thus also bring about an increased responsibility to that site (Barham, 2003). In order to be effective, these labels must be a guarantee of both quality and product character (Carbone, 2002). As a result, the INAO of France is increasingly being requested by countries around the world to assist in the identification of denominations of origin or geographical indications for various agricultural and artisanal products (Fanet, 2002a).

Denominations of origin or geographical indications are also intellectual property and must be protected as such (Rangnekar, 2003; Stern & Léger, 2000). The TRIPS agreement was signed in Marrakech on 15 April 1994 as an attempt to provide a "minimally internationally agreed basic level of intellectual property laws" (Stern & Léger, 2000). Although geographical indications (including appellations of origin) are protected, there is no common definition or set of rules regarding their implementation, which may lead to consumer confusion (Stern & Léger, 2000). There is also often a debate as to the relevance of geographic indications for new world countries as compared to old world countries, but it is in fact not easy to divide the systems of geographical indications of various countries into "old world" or "new world" (Stern & Léger, 2000), and other classifications have been used by various authors. The appellation of origin or geographical indication can, for example, be split into categories relating to their application, namely a **Latin form** and a **Germanic form** (Tinlot & Juban, 1998), or a **prescriptive** and a **permissive** form (Stern & Léger, 2000).

The **Latin form** of Tinlot & Juban (1998) and the **prescriptive form** of Stern & Léger (2000) depend heavily on the terroir (here described as being the natural factors), i.e. requiring a close association between the wine and the terroir concept. These two categories require an interplay between terroir and human intervention, which should result in the wines having a recognisable set of characteristics or *typicité* (Stern & Léger, 2000), with human intervention being the common usages resulting in the expression or enhancement of particular terroir characteristics (Tinlot & Juban, 1998). Rigorous production conditions are imposed, from the planting of the vines through to the bottling, labelling and selling of the wines (Tinlot & Juban, 1998; Stern & Léger, 2000). Some of the countries using the Latin or prescriptive form of geographical indications are France, Switzerland, Italy, Portugal, Spain, Greece and Argentina (Stern & Léger, 2000; Tinlot & Juban, 1998).

The **Germanic form** is usually applied in countries at the northern limits of viticulture (Germany, Austria, Hungary, Slovakia and the Czech Republic) (Tinlot & Juban, 1998). Here the producers themselves are responsible for the terroir choice (absolutely vital, as incorrect choice would result in incomplete ripening of the grapes) and the natural factors are encroached on heavily by human factors, such as cultivar choice (from a list of allowed cultivars) and date and method of harvest (Tinlot & Juban, 1998).

Stern & Léger (2000) describe a **permissive geographical indication**. In this system, terroir is not dealt with in any detail and it is rather the geographical source of grapes that is of concern (Stern & Léger, 2000). This is similar in concept to the **recognised geographical indication** of Tinlot & Juban (1998), which is essentially characterised by the choice between natural and human factors rather than their combination. Areas are demarcated on the basis of their natural factors or terroirs, without any restrictions being placed on cultivar choice, yield or type of wine. Quality rules may be imposed linked to the use of a geographical name, without fixing any restrictions other than administrative ones (Tinlot & Juban, 1998). In this category, Tinlot & Juban (1998) list the table wines of some European Union member countries (Italy, Portugal, Greece, Germany, Austria and Spain), Switzerland, USA, Uruguay and South Africa. These authors raise the question of whether or not some of these countries even fulfil the conditions for the recognised geographical indication or whether they would not be better categorised as a straightforward indication of source. Stern & Léger (2000) suggest that, although the permissive systems accept that "the origin of the wine is tied to the origin of the grapes", they are in fact missing the true meaning of the sentiment, which is that "the origin of the wine is tied to the origin of the grapes **which is tied to the terroir where the vine is growing**". In order to bring the prescriptive (of great value for the consumer) and the permissive (of greater ease for the producer) systems into alignment to prevent consumer confusion, Stern & Léger (2000) suggest an alternative, whereby grape sourcing is central to the geographical indication, but the question of terroir is "taken seriously and enforced". This would require that vineyards are inspected, soil samples taken, climates taken into consideration, etc.

Falcetti (1997) suggests that there is a dynamic of change between the more permissive viticultural systems, i.e. the systems that are more focussed on the cultivar, and systems with a well-established appellation scheme, which is related to the state of "evolution" of the viticultural industry. His suggestion is that it is normally in the phase of maturity that the concept of terroir is embraced for delimitation and protection (Fig. 2.1). Falcetti's positioning of South Africa within this lifecycle is perhaps debatable. New delimitations of denominations of origin are strongly based on environmental features, keeping the terroir concept in mind. Although the wines remain labelled by cultivar, there is a definite move amongst producers to produce wines that are typical of an area. This would suggest that South Africa has moved closer to the mature stage of viticulture.

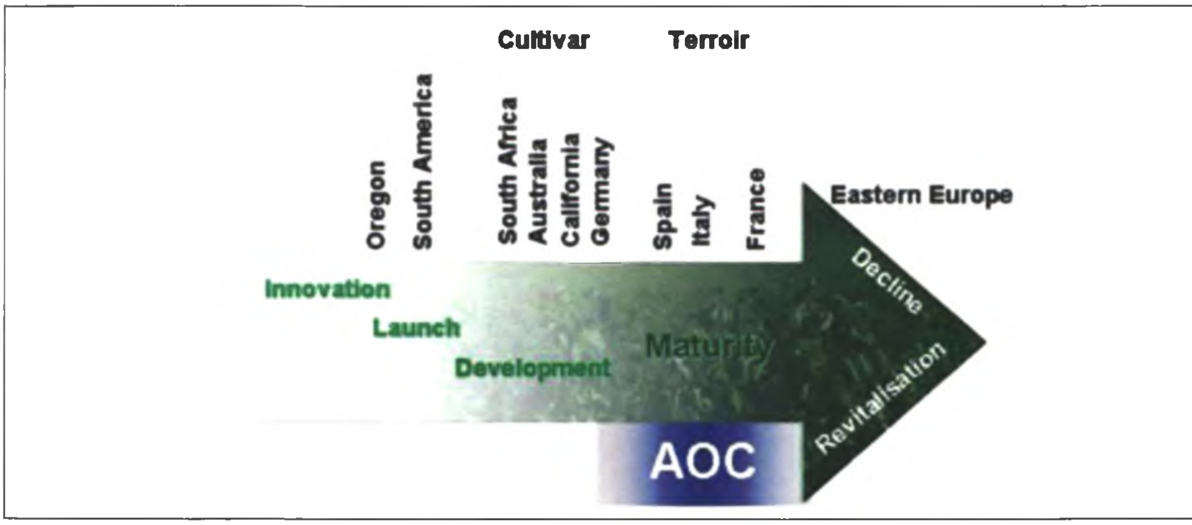

Figure 2.1 The positioning of countries within the lifecycle of vineyards in 1997 (redrawn from Falcetti, 1997).

Two types of markets can generally be recognised. The first is the market share for a wine based on certain norms, which are standardised, providing security of choice but negating provenance, for which price is the primary consideration, while the second is the type of market share that has developed on the basis of the concept of product origin, i.e. that a wine is the expression of the terroir from whence it originates, resulting in inimitable and specific sensory properties (Renou, 2001). According to Renou (2001), in a country such as France where it is impossible to compete within the global wine market on the level of low prices and sheer volume of trademark wine, it is necessary that the winemaker enforces the expression of the terroir in the final product. It is also difficult for South Africa to compete with large volumes of branded wines due to the diversity of grape-growing environments, and this argument may also be true for this country.

The word "terroir" is being used increasingly, whether it is for reasons of profit, sentiment or politics (Drouhin, 2001) and, subsequently, is unfortunately lessening in value and therefore remains contentious. The extent to which the producer's input should be included in the definition and thus in the demarcation of denominations of origin remains under discussion. The link between natural factors and wine "typicité" and quality is also not always clear. Terroir studies are usually time consuming and expensive and are thus slow to be accepted on any but a research level. However, even in countries without an appellation system, vineyards are not established haphazardly wherever they are able to bear fruit, but are rather generally limited to where wine of a certain level of quality is produced (Dubos, 1984). Land with a fairly good potential for viticulture has been identified, not necessarily consciously, and established under vineyards (Dubos, 1984). Probably because of this empirical nature of delimitation, the notion of terroir has become imprecise and, as a result, may be used erroneously, leading to a weakening of systems of denominations of origin (Laville, 1993).

This literature review will attempt to define a terroir concept, investigate the various methods of identifying terroir units and examine to what extent the terroir concept is included in some of the better known geographical indication systems worldwide in order to determine the most suitable method to identify terroirs and geographical indications for the Stellenbosch region.

2.2 VITICULTURAL TERROIRS

2.2.1 THE NOTION OF "TERROIR": A DEFINITION

According to Barham (2003), the notion of terroir historically refers to "an area or terrain, usually rather small, whose soil and microclimate impart distinctive qualities to food products". This is probably the general understanding of the concept of terroir, although, in practice, there are many connotations to the term. These have been described in four main categories by Vaudour (2001, 2003), namely material or nutriment terroir, spatial terroir, conscience terroir and slogan terroir. She describes the material terroir as the technological and agronomic aspects of the region, i.e. the natural potential of a given environment; the spatial terroir as the geographic territory that has crystallised through settlement, i.e. the historical geography of the region; the conscience terroir as the cultural identity of the region; and the slogan terroir as the definition and terroir theme used in marketing, i.e. symbolical aspects, and has suggested that the underlying theme is that of non-reproducibility or uniqueness. Vaudour (2003) has suggested that the most common usage of the word terroir is directed towards the rural life and agricultural production and furthermore, that the terroir concept directed towards viticultural zoning can be defined as a spatial and temporal entity of the cultivated environment, with homogenous or dominant characteristics with respect to grape composition, within a territory founded on social historical experience and cultivar related technical choices.

Morlat (2001a) describes the viticultural terroir as indicating two distinct groups of factors, namely natural factors (climate, soil and geology) and human factors (viticultural and oenological practices) (Fig. 2.2) and says that it is the extent to which these two groups of factors contribute to the definition of terroir that probably causes the greatest amount of argument, as well as the greatest resistance to the concept by the so-called "new world" wine-producing countries. The definition of Morlat (2001a) appears to be derived from the definition of Salette *et al.* (1998), who suggest that the terroir concept encompasses two complementary aspects, namely an extent of land that is considered in terms of its agricultural potential and a rural region that is considered to be the cause of the unique characteristics associated with those inhabiting or originating from the region. The first aspect is focussed on the knowledge of the physical characteristics of the terrain, i.e. a characterisation of the agricultural potential of an area, taking into account either favourable or constraining factors, while the second looks at the organisation and management of practices so as to best exploit the potential of the environment and to produce a wine that best realises its potential (Salette *et al.*, 1998). In other words, a terroir is a characterised agricultural ecosystem with the capacity to produce products with a unique character, but is also a complex system of interactions between various actions and practices employed by man, relating to both crop production and the physical environment, which is given value by means of a product to which it confers a unique character. This is also the terroir concept supported by the INAO (Fanet, 2002b).

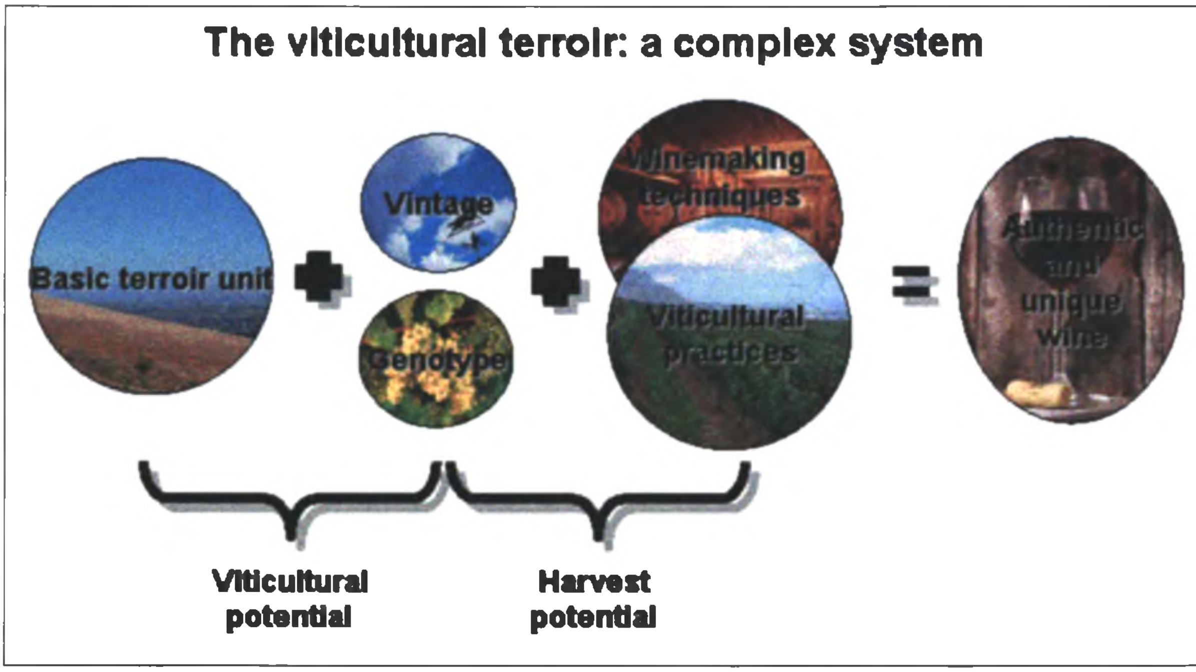

Figure 2.2 The chain of factors making up the complex system of the viticultural terroir (adapted from Morlat, 2001a)

A distinction between the basic terroir unit or natural terroir unit and the viticultural terroir unit has been suggested by a number of authors (literature cited in Deloire *et al.*, 2002). The basic terroir unit is the interaction between the mesoclimate (thus dependent upon topographical variation) and the soil and substratum across a series of vintages at the level of a vineyard or group of vineyards, while a viticultural terroir, as previously described (Fig. 2.2), is the interaction between the basic terroir unit, the cultivar and the viticultural and oenological practices. The basic terroir unit describes the smallest practical unit with a sufficient homogeneity to be considered as a functional unit of the terroir/grapevine/wine system and only encompasses natural environmental factors (Morlat, 2001a). Laville (1990) defines a terroir as “the collection of natural criteria that the viticulturist is not able to easily modify”. He also states that the terroir determines the originality and degree of consistency in quality of wines by means of its specificity and its constancy. On the basis of this definition, Laville (1993) distinguished between the natural terroir unit and the terroir, describing the natural terroir unit as a volume of the earth's biosphere that is characterised by a stable group of values relating to the topography, climate, substrate and soil, while the terroir is directly linked to the product and is thus a grouping of natural terroir units based on the typicality of the products obtained. Similarly, Dubos (1984) defines a terroir as a natural unit that is characterised by its agricultural potential on the basis of soil characteristics, exposition, climate and moisture regime.

The static variables of the basic terroir unit (Morlat, 1989) or elementary criteria of the natural terroir unit (Laville, 1990) can be considered to be those of climate (rainfall, air temperature, solar radiation, soil temperature, direction and intensity of dominant winds), relief (slope, exposition, insolation, landscape form) and substrate and soil (mineralogy, compaction, granulometry, soil water reserve, depth, colour) (Laville, 1993).

As can be seen from this discussion, there is as yet no uniform definition of the terroir concept, with the role played by the producer and production techniques being the factor under discussion. According to Laville (1993), it is a mistake to include the human practices and plant material that reveal the differences in the terroir definition, as these should constantly evolve as a result of constant and continuous experimentation, while the terroir units should be more stable, developing or changing very slowly within the geological framework. It is generally accepted that the terroir includes the natural factors of meso- or topoclimate, soil and geological substrate. These factors cannot easily be modified by man and, in fact, form the grapevine's ecosystem (Seguin, 1986). These natural factors confer an agricultural potential, which is reflected in the characteristics of the final product, resulting in unique wines of constant quality.

It is important to note that, despite their differences, all of these proposed definitions have similar foci, namely that there is a **homogenous** or **stable** group of natural factors that can be **delimited**, that these factors have the potential to produce an original or **unique** product and that this difference must be recognisable over time, which means that there is also a **temporal** aspect. In South Africa, there has not been a crystallisation of production techniques over time and producers have free choice as to which technology they adopt in the vineyard and in the cellar. More often than not, this choice is based on advice from industry consultants and the latest technology available, which means that optimum methods are generally used, although these may change on the basis of the latest information. It is therefore difficult to envisage the inclusion of viticultural and oenological management techniques in the definition of terroir under South African circumstances. Although management and cultivation practices do not form an intrinsic part of its definition, the concept of terroir cannot be viewed in isolation from them. A terroir could therefore possibly be defined as "*a delimited complex of natural environmental factors that either cannot be easily modified by the producer or that have been modified to their* *optimum extent, which will result in distinctive characteristics in the final product, resulting in distinctive wines with an identifiable origin across seasons with the aid of various management decisions".*

2.2.2 METHODS TO DELIMIT VITICULTURAL TERROIR UNITS

On the basis of this definition of terroir, it is necessary for every terroir study to include two consecutive or parallel stages of data acquisition, namely (a) the characterisation of the environment and the identification of homogenous environmental units (natural terroir units), taking all pertinent natural factors into account, together with (b) the characterisation of the viticultural and oenological potential of these units over time (Morlat, 2001a; Vaudour, 2003).

According to Falcetti (1994), the multi-criteria study of the natural environment in order to choose an optimal viticultural ecosystem is known as "zoning", which has spatial connotations and potential direct applications. In order to understand the functioning of the grapevine on a particular terroir for such a choice to be made, it is necessary to perform *in situ* studies that will result in point data. However, for this information to be of use within zoning studies, it must be placed within the context of the pertinent terroir in order to provide a spatial result (Vaudour, 2000; Vaudour, 2001). Laville (1990) emphasises the importance of medium-scale maps of terroir units over and above the establishment of the terroir x wine relationship in order to ensure the optimal placement of reference plots for studies on a large scale. Such maps can be used to locate excesses or deficits of certain of the criteria in order to determine remedies for the problems; to locate plots for potential separate vinification; for the selection of site and cultivar; to determine land use; and to modify delimited boundaries. Vaudour (2001) emphasises that these terroir maps must define a limited number of cartographic units, which are identified either as being noteworthy or as being spatially dominant.

The selection of a study method to identify terroirs is a delicate operation. The main difficulties of the approach lie in the large-scale temporal and spatial variation of a number of components of the terroir system, the large number of variables involved and the complexity of the chain of factors determining the quality and character of wines (Riou *et al.*, 1995). It is important that a criterion selected for the viticultural zoning of terroirs is pertinent with respect to grapevine physiology, has a compatible spatial variability and is easily acquired in the field (Riou *et al.*, 1995).

Due to the increasing popularity of the term "terroir" and the perceived added-value to the product through its use, a number of "terroir studies" have been launched globally (*inter alia* Morlat, 1989; Falcetti *et al.*, 1990; Laville, 1990; Lebon, 1993; Laville, 1993; Bogoni, 2000; Panont & Comolli, 2000; Carey, 2001; Tesic *et al.*, 2002a, Tesic *et al.*, 2002b; Bodin, 2003; Vaudour, 2003). According to Falcetti (1994), it is possible to characterise the different approaches to terroir studies by means of the complexity of the environment studied and the factors that are judged to be of fundamental importance for a given environment. It is therefore possible to subdivide all approaches according to the criteria used, namely bioclimatic, soil-related or nutritional, cultivar aptitude, computational or integrated approaches. Vaudour (2003) divides terroir studies into only two main categories, namely the geographical differentiation of the product (wine) or raw material (grapes) or the differentiation of the natural potential of the viticultural environment. For the purposes of this review, the classification of Falcetti (1994) will be used.

2.2.2.1 The bioclimatic approach

The bioclimatic approach is probably one of the earliest used to describe the viticultural environment and is the only true mono-disciplinary approach (Falcetti, 1994). A number of bioclimatic indices have been used to describe the viticultural environment, many of them based on temperature (*inter alia* Amerine & Winkler, 1944; Branas *et al.*, 1946; Constantinescu, 1967; Smart & Dry, 1980; Huglin, 1986; De Villiers *et al.*, 1996; Tonietto, 1999). The method with which viticulturists are most familiar is that of Amerine & Winkler (1944), who divided the region of California into five zones based on thermal time for the growing period, using a base temperature of 10°C. This index was adapted for the South Western Cape of South Africa by Le Roux (1974).

Generally, bioclimatic classifications have their greatest value for areas at the climatic limits for viticulture, especially the most northern extremes, where the low temperatures limit grapevine growth or where there is a risk of late spring frost (Falcetti, 1994). They are also useful on a macro-scale for the easy and rapid delimitation of vast zones (e.g. Riou *et al.*, 1994). A bioclimatic method, the so-called homoclime approach, is used by Smart (2004) to match climates of vineyard regions around the world based mainly on temperature and rainfall and, to a lesser extent, on sunshine and relative humidity, in order to determine the aptitude for cultivars and certain viticultural and oenological practices in newer areas.

The limitations of the bioclimatic approach are clear if the definition of terroir is kept in mind; it takes only one component of the terroir complex into account (ignoring the effect of soil, for example) and does not consider the genotype x environment interaction. The scale of the data is also a limiting with most ares being insufficiently covered by weather station networks.

2.2.2.2 The pedological and nutritional approach

The pedological and nutritional approach is based on the study of the soil, notably of its chemical and physical characteristics, geological origin and pedogenesis, and includes widely varying methodology (Falcetti, 1994). Initially, studies in this direction were focussed on the link between the chemical composition of the soil and the qualitative characteristics of the wine. Fregoni (1977) cites examples of areas where the chemical composition of the soil is correlated with wine quality, despite the lack of correlation between the chemical composition of the soil, leaves and grapes, which formed the basis for his soil mapping of numerous regions in Italy (Fregoni, 1973). A number of authors have found a positive correlation between the poorness of the soil at certain sites and the quality of the wines obtained from these sites (Dubos, 1984).

Numerous studies indicate that the soil water supply to the grapevine is one of the most important variables affecting the functioning of the grapevine, and thus berry composition and wine character and quality (Rankine *et al.*, 1971; Saayman, 1977; Saayman & Kleynhans, 1978; Seguin, 1986; Morlat *et al.*, 1992; Panont & Comolli, 2000; Choné *et al.*, 2001; Van Leeuwen *et al*,. 2003), and this has formed the basis of more complex methodology for terroir identification and characterisation (Morlat, 2001a).

The general outcome of these soil studies is a map of soil types or of the chemical or physical soil characteristics, and these maps often form one of the first steps in an integrated study of terroir characteristics.

2.2.2.3 Cultivar aptitude

Many studies have focussed on the adaptation of various cultivars to their growing environment through the evaluation of their viticultural aptitude and the resulting wine style and/or quality (Rankine *et al.*, 1971; Guinard & Cliff, 1987; McCloskey *et al.*, 1996; Hoppmann & Schaller, 2000; Conradie *et al.*, 2002; Tesic *et al.*, 2002a, Tesic *et al.*, 2002b). It is very important in this approach not to be exclusive in the identification of cultivar aptitude, but to rather follow the principle of Scienza, as cited by Falcetti (1994), namely that there are not good or bad cultivars, or good or bad sites, but rather interactions that are of greater or lesser value. This approach has been used extensively in Italy (Falcetti, 1994). In South Africa, a study of the interaction of Sauvignon blanc with the soil and climate of the vineyard (Conradie *et al.*, 2002) has formed, and continues to form, an important thrust of the terroir research programme.

The research team at Agro-Montpellier focuses its terroir research on the whole plant-berry approach (Deloire *et al.*, 2002), suggesting that it is justified for situations where soil and/or climatic data are not easily accessible at vineyard level, as this approach integrates the environmental context of the grapevine. However, these studies are focussed on an increased understanding of the physiology of the grapevine to provide advice on viticultural practices and winemaking techniques and to assist in harvest planning by a cooperative cellar, rather than on zoning *per se*.

2.2.2.4 The computational approach

The computational approach has become possible as a result of the development of powerful spatial computational software and the large databases of geographic data that are now available. Geographic information systems have formed a powerful tool in the analysis of viticultural environments in France (Laville, 1990; Laville, 1993), South Africa (Carey, 2001) and Germany (Michel *et al.*, 2002). The efficacy of this method is largely dependent on the homogeneity of data resolution (Falcetti, 1994).

The first step in such a study is to identify natural terroir units and it is only at a later stage that terroirs are delimited on the basis of these natural terroir units and their characterised production (Laville, 1993).

The computational approach is a rapid and relatively inexpensive exercise (Laville, 1993), but Morlat (2001a) has suggested that, although this method is rapid, it has a number of disadvantages with respect to the use of the results by viticulturists, namely the lack of consideration of the agronomic potential of the soils, an insufficient density of geological information, the dependence of the results on the quality of the base data and the fact that it is a purely statistical view of the terroirs and not a real image.

The BRGM method

The BRGM (Bureau de recherches géologiques et minières) method (Laville, 1990), which can be used in areas with delimited vineyards, in areas where vineyards have not yet been delimited and in areas where vineyards have not yet been established, is based on the use of reference zones. The delimited vineyard area of the AOC is used as reference zone where available, otherwise a natural region or reference zones from other viticultural regions can be used. This study method has four phases: the recording and localisation of viticultural and oenological practices, the collection and digitisation of data, the analysis and creation of a model associating the identified criteria with each other and, finally, the application of the model. On the basis of the experience of the local wine producers and the historical information on viticulture in the area, the major criteria defining the originality of the terroir are determined and a delimitation of each vineyard in each commune is performed based on these criteria. Following discussions with producers, this delimitation is finalised and forms the reference zone for the rest of the study. Once these reference zones have been delimited, all the necessary data (mostly climatic and topographic, perhaps geological) are gathered and digitised to a grid with a compatible resolution (usually 50 m by 50 m). These data are used to identify the most frequent value for each criterion in each reference zone by means of histograms. This provides an objective means to determine the specificity or originality of the reference zone, as well as indicating which criteria are significantly "homogenous" for each reference sector. Principal component analysis is used to estimate the relative role of each quantitatively significant criterion, enabling the weighting of the different criteria that will finally be combined. The calculation of the weighted Euclidean distance for the pertinent criteria results in a map of similarity with the reference sector for each grid. Following this, diverse classes of originality or homogenous quality are determined using the quantitative criteria, and these are finally integrated with soil units to give a map of terroir units.

An adjustment was made to this method when Laville distinguished between natural terroir units and terroirs (Laville, 1993) (Fig. 2.3). This is also a computational method and is based on raster data on a grid of 20 m to 50 m. The study area is

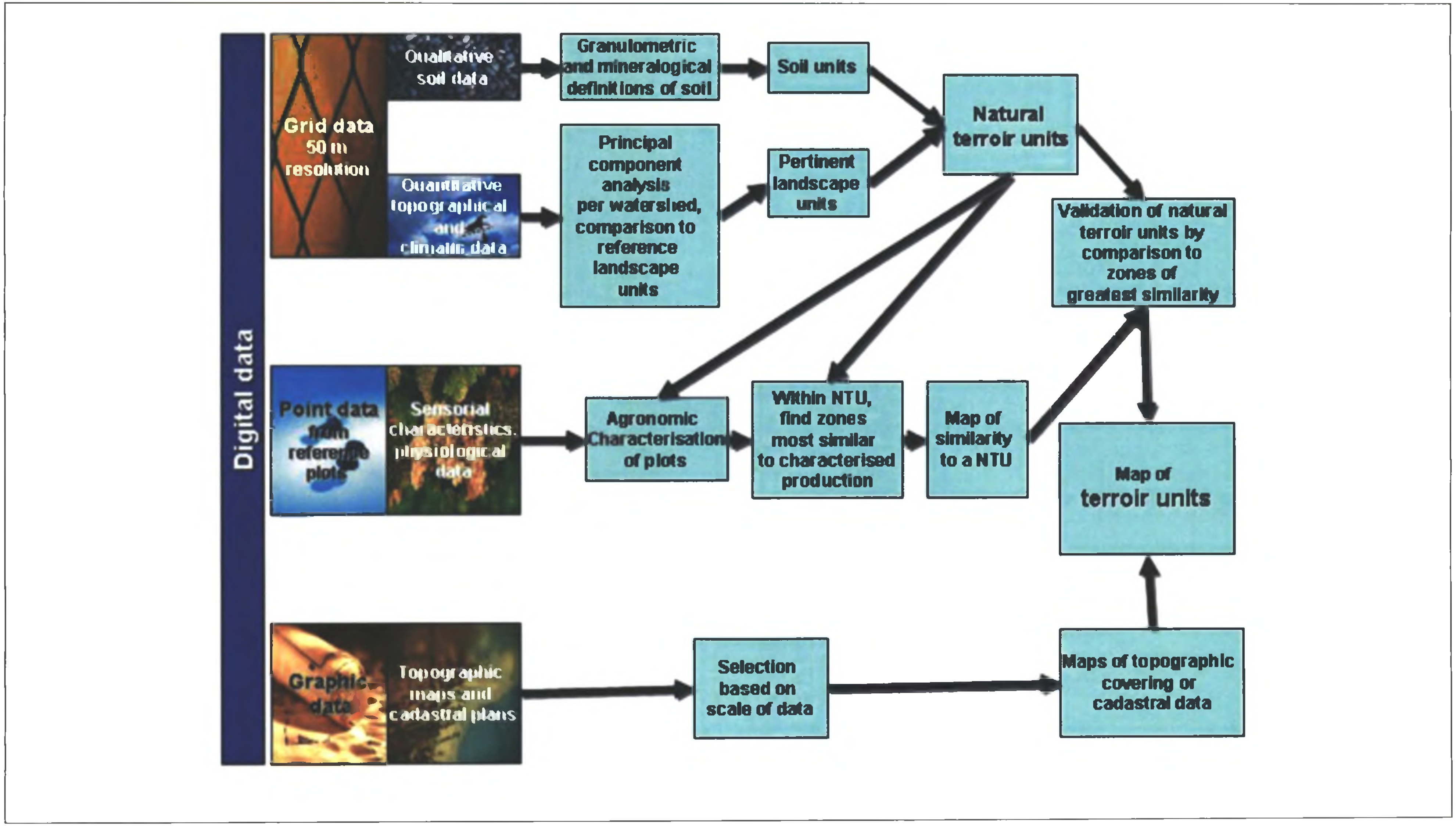

Figure 2.3 The stages in the determination of terroir units according to the BRGM method (adapted from Laville, 1993)

divided into water catchment regions and, for each of these areas, the natural grouping of climatic (rainfall, temperature) and topographic (altitude, slope, exposition, insolation) variables is determined on the basis of a principal component analysis of quantitative terroir criteria. Each cell that is poorly classified during this step is then classified into one of the identified dominant landscape units using the classification method of Bayes. Following the identification of landscape units, the qualitative terroir parameters, notably those of the soil and geology, are combined with this map to create a map of natural terroir units. During each of these steps, it is possible to subdivide the treatments on the basis of their position in the landscape and to select the most pertinent units obtained by PCA, the classification method of Bayes and the superposing of landscape units and soil units. Following this classification of natural terroir units, it is necessary to determine the effect of each unit on the functioning of the plant. This is based on the sensorial characteristics of a localised and representative sample of wines produced in the study area. The aggregation of this data results in the production of a map of terroir units. Validation of each natural terroir unit and terroir unit is obtained by means of a similarity analysis, i.e. a multi-criterion comparison of each grid cell in the study zone to the group of grid cells for which there is an agronomic or sensorial reference observation, as previously described by Laville (1990).

The BRGM method was applied to the three communes of Saint-Hilaire-d'Ozilhan, Castillon-du-Gard and Valliguières in the Rhône Valley (Vaudour *et al.*, 2002b). In this study, a 60 X 90 m digital elevation model (DEM) was used to derive elevation, slope inclination, mean southward aspect, mean westward aspect and theoretical sun exposure at summer solstice and autumn equinox, and this information was then used in a principal component analysis. Cells with the most frequent and significant correlation to the derived factors were used as training areas for a maximum likelihood classification. The results were interpolated to a 30 X 30 m grid and combined with a map of lithology (in 10 classes). All derived units with an area of less than 1 ha were eliminated. The map output was on the scale of 1:50 000. According to these authors, the resulting map did not meet the needs of the local cooperative cellar as the resolution was too coarse, the grid format did not provide boundaries and it was difficult to find obvious visual references to known sites.

The identification of natural terroir units in South Africa

Terrain morphological units (compiled by M. Wallace, Department of Agriculture: Western Cape, cited in Carey, 2001) formed the basis for the identification of natural terroir units in the Bottelaryberg-Simonsberg-Helderberg study area (Carey, 2001). Terrain morphological units (crest, scarp, midslope, footslope and valley bottom) are used within the land-type concept (MacVicar *et al.*, 1974) to describe certain landscape attributes, such as slope inclination and slope type, and, as such, have important implications for agriculture. These units were divided with the aid of altitude (100 m intervals) and aspect classes. The aspect categories were selected in order to represent the slope interception of sunlight and dominant winds and were divided into east (45° to 135°), south-west (135° to 270°) and north-west (270° to 45°, passing through 0°). The east-facing slopes warm earlier in the morning and cool earlier in the afternoon, while the south-western slopes are cooler due to the interception of the sea breeze in the early afternoon and the reduced interception of sunlight. The north-western slopes are the warmest due to being protected from the moderating influence of the sea to a certain extent and receiving the most direct radiation in the Southern Hemisphere.

Available digital soil data at a scale of 1:25 000 (Ellis & Schloms, 1975) and 1:50 000 (Ellis *et al.*, 1976), were classified into four broad soil groups and used to refine the determined slope-aspect-altitude units. These soil categories were based on the water-holding and drainage characteristics, as well as characteristics affecting root growth (Carey, 2001).

It is particularly difficult to associate geology with derived soils in the Stellenbosch winegrowing area due to the high degree of tectonic movement and mixing of parent material and the only soil group for which the geology of the parent material was therefore considered to be of obvious importance was that of residual soils. Available digital geological data (base scale of 1:250 000) were overlaid on the identified soil-landscape units and each of the units containing residual soils was characterised according to the associated dominant geological formation using five broad groups (Carey, 2001). All land unsuitable for viticulture was grouped, regardless of landscape position, aspect or altitude, i.e. valley bottoms, poorly drained alluvial soils, rocky outcrops and urban areas, and removed from the determination of natural terroir units. This resulted in a map of natural terroir units. A total of 203 units were identified, each described by a four-component key. It was suggested that the broad soil categories are sufficient for a medium-scale study as, due to the large degree of variation in soil characteristics over very short distances and the general need for deep soil preparation, intense soil surveys are generally performed on a farm level before vineyard establishment (Carey, 2001). Soil variation is also closely linked to position in the landscape and the identification of landscape units within a broad soil category will, to a certain extent, have accounted for soil variation within a soil association. These soil categories may, however, have been too broadly categorised and will require revision and validation. The extent of the effect of the ocean must also still be considered, as topography is not the only environmental factor affecting climatic variation within the study area. This study formed the first part of a terroir study and still requires viticultural and oenological validation in order to provide a description of the agronomic potential of the dominant natural terroir units, as well as for the production of a map of terroir units.

2.2.2.5 The integrated method

The use of the term “integrated” assumes that the criteria of climate, soil, geology and viticultural aptitude will be incorporated within a geographical information system in order to identify and characterise viticultural terroirs (Falcetti, 1994).

Ecogeopedological characterisation, INRA-Angers

The first integrated method of terroir studies was initiated by Morlat (1989) in the wine-producing regions of Chinon, Bourgueil and Saumur Champigny, which are characterised by a similar macroclimate. This method integrated the geologic age, lithology and petrographic nature of the parent material, the soil profile and the landscape or topography. Morlat (1989) named this sequence of factors an ecogeopedological sequence (illustrated in Fig. 2.4).

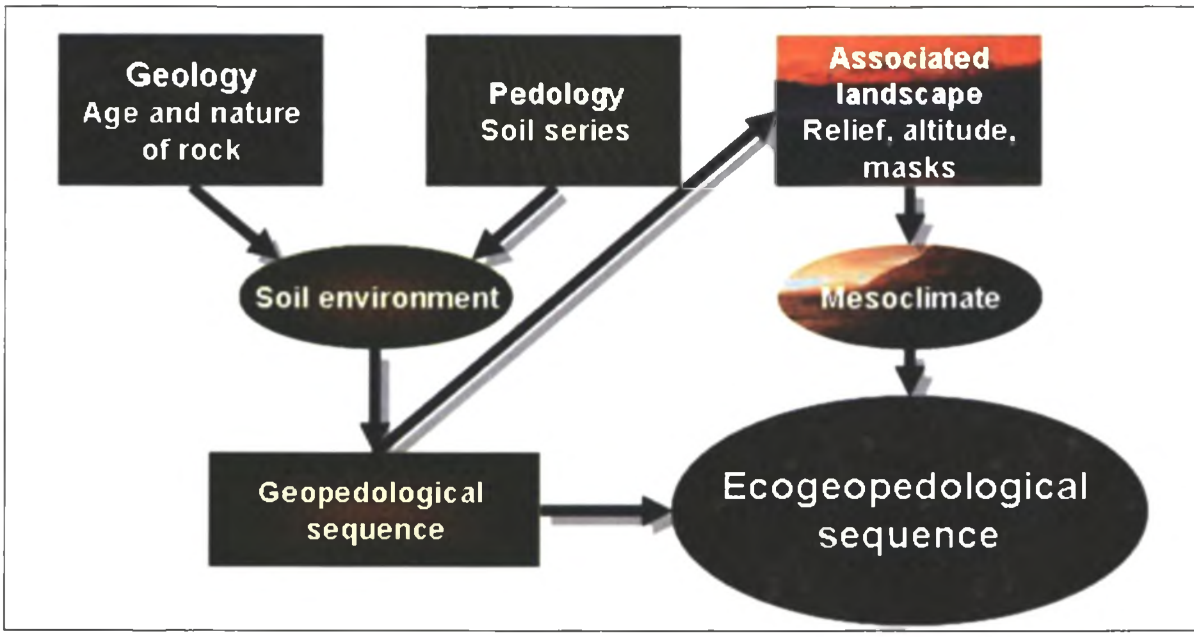

Figure 2.4 A diagrammatic representation of the concept of the ecogeopedological sequence (adapted from Morlat, 1989)

In-depth soil studies were undertaken to investigate the pedology and the agricultural potential of the soil (including root distribution) and these results were mapped on a scale of 1:10 000 or 1:25 000 (Morlat, 1989). Together with these studies, the topography and theoretical effects on mesoclimate were examined. A reference sequence was chosen as a comparative standard in order to describe the viticultural potential (Morlat, 1989). In a discussion of the methodology used, Morlat (1989) acknowledges that this method has certain limitations. Although this methodology is suited to regions where the macroclimate is fairly homogenous and where there has been little tectonic movement, in regions where there has been accentuated tectonic movement, the natural pedological sequence may have been disturbed and there may be a too dramatic variation in mesoclimatic characteristics. Also, it is not easy to apply this methodology to areas where there is a dramatic variation in geological material over short distances (Morlat, 1989).

Following the ecogeopedological sequencing of the region, it was necessary to test the validity of the method and, for this purpose, viticultural studies were undertaken. The study was conducted in the Loire Valley and a network of ca. 20 experimental plots was established in the area, with a number of them being established on the reference sequence, allowing for an examination into the intra-sequence variation in grapevine response (Morlat, 1989).

The study was extended to the regional level (study programme of "terroir d'Anjou" initiated in 1994) (Morlat, 2001a) to cover a total of 30 000 ha in Anjou (Morlat, 2001b). The terroir effect is accentuated in this area due to its limiting climatic conditions (Morlat, 2001a). The research programme had four main aims, namely to assist in the delimitation of appellations of origin on solid and explanatory scientific principles; to develop a method for characterising terroirs that is pertinent, easily performed and generalisable; to identify and determine the relevance of various natural factors in relation to the production of "terroir wines" that are truly typical and authentic; and finally, to establish a spatial database of most suitable agronomic and oenological practices for each terroir (Morlat, 1997). The terroir studies by the INRA-Angers team of researchers are therefore based on three principles, namely the "geopedological" characterisation of the environment by means of basic terroir units and augmented by climatic studies; an investigation of the response of the grapevine on the basic terroir units and, ultimately, the resulting wine characteristics, and the production of thematic maps on a large scale based on the functioning of the terroir units (Vaudour, 2003). It appears that three major ecophysiological variables are significant in the terroir x vine x wine system, namely the earliness of the growth cycle, the soil water supply to the grapevine and the vigour level, with the root profile being considered pivotal in the terroir effect (Morlat *et al.*, 1992; Barbeau *et al.*, 1998; Morlat, 2001b). The agropedological characterisation of the ecogeopedological sequence was achieved by means of a terrain model of environmental types that could be linked to soil variability and mesoclimatic variation (Morlat, 1996). Each one of the identified environmental types within this model can be considered to be a sufficiently homogenous territory, resulting in sufficiently homogenous ecophysiological functioning of the grapevine and wine style (Morlat, 2001a). Three main environmental units were identified on the basis of soil depth and the degree of weathering of the parent material, which is generally reflected in the clay content of the soil profile. These environmental units are labelled as "roche", "altération" and "altérite" (Morlat, 2001a). Combining this model with the parent material (stratigraphy and lithology) resulted in a scale of mapped units that can be used at the level of a vineyard block, as it describes the soil-climatic conditions that affect root development (Morlat, 2001a). This terrain model is adapted to soils that are formed *in situ* from the parent material (true for ca. 65% of the viticultural soil surface of Anjou) (Bodin & Morlat, 2002), although it can indirectly also take colluvial depositions into account (Morlat, 2001a). The climate and landscape components of the terroir system (altitude, landscape form, slope inclination and aspect, degree of openness of the landscape) were not used as key criteria for the identification of basic terroir units, as it was assumed that these components were included in the geological description to a certain extent, as well as in the agropedological description to a more limited extent (Morlat, 2001a). Comparing the results obtained from the model of environmental units and the associated landscape showed that, in most cases, there is a close relationship between the soil conditions and the altitude, terrain morphological position and degree of openness of the landscape (Morlat, 1997). In rare cases in the Loire Valley, when the slope inclination exceeds 10%, however, the basic terroir unit is divided into three subunits, namely a class with a slope inclination of greater than 10% facing 180°S, a class with a slope inclination of greater than 10% and facing 180°N and a class with a slope inclination of less than 10% (Morlat, 2001a). This is done because studies in Alsace (Lebon, 1993) showed the significant effect that slope exposition can have on climatic conditions, with consequences for berry composition. It is necessary to take the climatic components into account in order to understand the local climatic conditions of the terroir (Morlat, 2001a), and the concept of openness of the landscape was introduced by Lebon (1993) and Jacquet & Morlat (1997) in order to describe the influence of the environment on local climatic variation.

There are, therefore, three main, easily spatialised parameters that were used in the identification of basic terroir units in this study, namely stratigraphy, the petrographic nature of the parent material and the agropedological conditions or environmental units (Morlat, 2001b). The basic terroir units were firstly described by the geological and agropedological (see description in previous paragraph) conditions (Morlat, 2001a). This was followed by the traditional soil descriptions, namely profile description, geological origin, colour and depth of each horizon, texture of the fine soil, natural drainage characteristics and acid reaction, measured to a depth of 1,2 m (Morlat, 2001a). A separate basic terroir unit is recognised when there is a thick layer of colluvion (greater than 60 cm), resulting in the construction of a profile of two strata of differing parent material (Morlat, 2001a). Detailed soil profile studies were also performed on representative sites, allowing the description of the granulometry, chemical composition, apparent volumetric mass, structure, mechanical resistance to penetration, root profile and soil water reserve (Morlat, 2001a). With respect to the landscape, masking features within a radius of 50 m to 500 m were described by means of their distance from the observation point in eight compass directions, the position in the landscape was recorded and the altitude and slope exposition were noted (Morlat, 2001a). These studies were performed on a detailed (large) scale with an average of one observation point per hectare, resulting in cartography on a scale of 1:12 500. Digital aerial photographs enabled the delimitation of boundaries directly on the terrain. All the data were compiled within a Geographic Information System and database and finally published as maps on a scale of 1:15 000 and 1:25 000 (Morlat, 2001a).

As mentioned in the introduction to this section, it is also necessary to investigate the terroir effect on the reaction of the grapevine and, for this reason, a network of experimental plots was established, with the only variable being that of the terroir and all other possible variables being constant between the plots (Jourjon *et al.*, 1991; Morlat *et al.*, 1992). In addition to the measurements on a network of plots, a survey of producers in the region was undertaken to validate the concept of the basic terroir unit and to see whether the survey could be used to replace the use of experimental plots in order to determine the viticultural and oenological response on the basic terroir units (Morlat, 2001a). Questions relating to the grapevine and its management, the reaction of the grapevine to the terroir, the soil, climate and terroir characteristics, winemaking methods and the sensorial characteristics of wine were asked of each producer for each vineyard block, the exact locality of which was localised on a map (Thélier-Huché & Morlat, 2000; Morlat, 2001a). This survey was performed on a plot level (where a single basic terroir unit is dominant and occupies at least 50% of the area) and was performed for all producers in a commune (Morlat, 1997; Thélier-Huché & Morlat, 2000). Statistical analyses of the survey results at the level of the agropedological model (three environmental units), ignoring the basic terroir unit, as well as at the level of the basic terroir unit, suggested that, in the Middle Loire Valley, the criteria of soil depth and the intensity of decomposition of the parent material appear to have a greater impact than the geological system on the soil climate of the plots and, concomitantly, on the growth cycle (date of budburst) and vegetative development of the grapevine. The mesoclimate, however, was related equally to the geological system and the soil type and appeared to affect the choice of viticultural and oenological practices (Thélier-Huché & Morlat, 2000). Despite these results, the authors considered it necessary to establish a limited experimental network of plots, particularly to study the interaction between wine character and terroir and the reproducibility of the grapevine reaction within the larger basic terroir units, and to validate the advice maps presented to the producers of the region. A multi-site network of 21 plots with Chenin blanc and Cabernet franc varieties was therefore established across the two main geologic systems of Anjou in 2000, with three replicates for each basic terroir unit and cultivar (Bodin & Morlat, 2002).

A simpler method of using only the altitude and position in the landscape together with the surface condition of the soil (percentage stones) was attempted in one commune in order to deduce the environmental unit (agropedological conditions) and the results appear promising (Morlat, 2001a). Other attempts at simplifying the methodology include the development of predictor models, which allow the use of fewer sampling points as well their optimal positioning in the landscape. An example of one of these models is the use of laws governing the terroir x landscape relationship to distinguish between terroir units (Morlat, 1997). A further method used is one of mapping laws based on neighbourhood relationships, that are established in a reference sector, to automate the soil survey (Salvador *et al.*, 1997). This method can only be used on homogenous geomorphological environments, which the authors named "Small Natural Regions", and entails the determination of spatial correlations between the base terroir units and a previously mapped reference sector. Soils are mapped within a reference sector, where laws governing the soil distribution within the area (small natural region) are determined and mathematically formalised. The size of the reference sectors was ca. 425 ha and the validation sectors were situated within 7 km of the reference sectors (Salvador *et al.*, 1997).

Value is added to the mapping of natural terroir units through the determination of various variables directly related to the functioning of the grapevine by means of algorithms (e.g. maximum soil water reserve, vigour potential and earliness of the growth cycle) (Morlat, 2001a). Atlases of the basic terroir units and their measured and inferred characteristics, as well as maps of suggested rootstocks, cultivars and various management methods, were created on a scale of 1:25 000 and 1:50 000 for each commune of the study area (Morlat, 2001a). More recent studies have the aim of producing a guide for good practices in the Loire vineyards based on integrated grape production (Pasquini *et al.*, 2002).

The integrated method of INRA-Angers was also tested in Alsace (Lebon *et al.*, 1993). As previously mentioned, the use of the ecogeopedological system for describing terroir units is limited in areas that have been subjected to a large amount of tectonic activity. A further limitation is for sequences having a significant variability in landscape as a result of their situation on a slope and their exposition (Lebon *et al.*, 1993). However, the inclusion of factors affecting mesoclimatic variation (altitude, slope inclination and aspect) together with an index that determines the openness of the landscape and the distribution of the principle obstacles affecting air movement (Table 2.1) allow a fairly complete evaluation of the environment of a plot (Lebon *et al.*, 1993; Dumas *et al.*, 1997).

Table 2.1 Landscape description used by Lebon (1993) in Alsace as a component of basic terroir units

<table>
<tr><th>SAF[1]
IOP[2]</th><th>Section <180</th><th>Section 180 - 270</th><th>Section >270</th></tr>
<tr><td>10
9</td><td colspan="3">Landscape very open</td></tr>
<tr><td>8
7</td><td colspan="3">Landscape open
(with an indication of the orientation of the principal mask)</td></tr>
<tr><td>6
5</td><td colspan="3">Landscape fairly open
(with an indication of the orientation of the principal mask)</td></tr>
<tr><td>4
3</td><td colspan="2">Landscape closed with a principal mask</td><td rowspan="2">Very closed landscape</td></tr>
<tr><td>2
1</td><td>(with an indication of the orientation of the principal mask)</td><td></td></tr>
</table>

[1]SAF = Closed portion of compass directions

[2]IOP = $(100-\Sigma\theta_i)/10$; where i = 8 directions N, NE,.....NW and θ = angle from observation point to horizon of masking feature.

In this study, it was found that the use of an approach based on ecogeopedological sequences sufficiently characterised the variability of the environment (Lebon *et al.*, 1993). The use of a parameter to describe the orientation of the slope and the openness of the landscape appeared to resolve the difficulties of using the methodology of the INRA-Angers in areas with a complex topography. These results were partially validated through an investigation into the sensory expression of Gewürztraminer on diverse plots (Dirninger *et al.*, 1998).

The method to characterise viticultural terroirs developed in Anjou has also shown limitations for soils on soft, porous parent material and soils that have developed from alluvial deposits (Bottois *et al.*, 2002). These issues will be addressed through the study of a network of experimental plots in the Saumurois-Touraine region in order to better understand the water supply regime of these soils and the implications of this for the functioning of the grapevine (Bottois *et al.*, 2002).

Zoning by means of soil-landscape spatial analysis: the example of Côtes-du-Rhônes

Studies to delimit terroirs were initiated on a regional scale in the Côtes-du-Rhônes in the 1990s by the cooperative cellars for the purpose of assisting in harvest management within the communal territory (Fabre *et al.*, 1998, Vaudour *et al.*, 1998a). The study method was based on the concept of soil landscapes, which are the integration of soil horizons and landscape elements (i.e. vegetation effects, geomorphology of human activities, hydrology and parent material) enabling the prediction of a soil mantle (Vaudour *et al.*, 1998a; Vaudour *et al.*, 1998b) and the spatial organisation thereof (Vaudour *et al.*, 2002a). Hugget (1975) described the concept of soil landscape systems, which were an expansion of the catena concept. In his theoretical model of the soil system, Hugget (1975) proposed that the valley basin (in many respects similar to the erosional drainage basin, the only difference being that valley basins may be dry valleys) is the basic organisational unit of soil systems, with the soil skeleton and the soil solution being subsystems. He described a soil-landscape system as being "constructed of three-dimensional open systems whose boundaries are defined as drainage divides, the surface of the land and the weathering front at the base of the soil profile.....They are ... objective geographical bodies of soil which possess functional unity but not necessarily homogeneity of soil properties". The drainage divides determine the direction of overland flow and thus processes such as erosion transport and deposition (Wysocki *et al.*, 2000).

Landscape components were determined from topographic maps, stereoscopic panchromatic aerial photography, satellite images and digital elevation models. The soil surface covering for areas that had not yet been mapped was interpolated from general rules surmised from the mapped portions (Vaudour *et al.*, 1998a; Vaudour *et al.*, 1998b). Consequently, 15 to 20 qualitative variables were used to describe the soil landscapes, namely stoniness, rooting depth, presence of carbonates, dominant texture of the cultivated horizons, drainage capacity, cation exchange capacity, soil depth, active lime, reflectance of the soil surface on panchromatic aerial photography, geomorphology, associated cultivated and spontaneous vegetation, lithology, stratigraphic units and the shape and size of the plot (Vaudour *et al.*, 1998a; Vaudour *et al.*, 1998b; Vaudour, 2000), as well as to characterise each soil landscape by means of the modal value for slope inclination and altitude as determined with the aid of a digital elevation model (Vaudour, 2000). The soil landscapes were mapped on a scale of 1:25 000 (Vaudour *et al.*, 1998a; Vaudour *et al.*, 1998b). Vaudour (2000) presumed these soil landscapes to be similar to the basic terroir units of Morlat (1989), although she suggested that soil landscapes describe the whole viticultural landscape, while basic terroir units are focussed on the vineyard. Presumed viticultural terroir units were identified with the aid of factor and cluster analyses (Vaudour *et al.*, 1998a; Vaudour *et al.*, 1998b). Following the identification of these units, a frequency analysis of the grapevine response (berry analyses) over 15 years was performed on a network of plots that had been established to monitor the ripening of Grenache noir (Vaudour *et al.*, 1998a, Vaudour *et al.*, 1998b).

This study was initially carried out in the Valreas-Nyons area (Vaudour *et al.*, 1998a, Vaudour *et al.*, 1998b) and later extended to the entire southern portion of the Côtes-du-Rhône, with 60 000 ha under vines within the delimited area of 210 800 ha. Terroirs were determined on two spatial levels, either global or local (Vaudour *et al.*, 2002a). In order to study the larger area, preferential study zones (i.e. zones with a wealth of viticultural and soil data) were identified and studied in depth in order to determine the "laws" governing the organisation and characterisation of the terroirs so that these could be extrapolated to the entire area (Vaudour, 2000). This was achieved by means of digital analysis of SPOT images taken at the beginning of the growth period of the grapevine, which extrapolated terroirs previously identified in the study zone into the as yet unstudied areas (Vaudour, 2000). Cluster analyses of satellite images were used to identify nuclei that belonged predominantly to one soil group. These nuclei were well classified and could thus be extended throughout the Côtes-du-Rhône area (Vaudour *et al.*, 2002a). The spatial organisation of the soil landscapes was described by means of block diagrams, according to which a soil landscape is described as a group of soil landscape units in which a certain geological formation has resulted in a pedological system. Each soil landscape unit is a map unit that describes the dominant soil form, or perhaps a secondary soil form or soil association (Vaudour *et al.*, 2002a). Multivariate clustering was performed on the soil landscape units, as well as on the map polygons containing either a Shiraz or Grenache site, resulting in a map of potential global terroir units and a map of local terroir units respectively (Vaudour *et al.*, 2002a) The map of potential global terroir units can therefore be seen as a synthesis of soil-landscape units with a viticultural application. At least 60% of the identified units were validated with respect to the grape berry analyses of Shiraz and/or Grenache to form global terroir units (Vaudour *et al.*, 2002a).

Integrated terroir studies in Italy

An integrated zoning study was performed in Bolgheri, Tuscany over a three-year period and consisted of four phases (Bogoni, 2000). The first step entailed the accumulation of existing historical information on the region. This was followed by a soil survey on a scale of 1:10 000, resulting in the identification of landscape units that were sufficiently homogenous with respect to soil, mesoclimate, topography, slope inclination and exposition. These landscape units were described by means of detailed soil chemical and physical analyses throughout the profile. The third phase involved an investigation into the interaction between the grapevine (three cultivars) and the environment and included a quantitative descriptive analysis of wine from the experimental plots (replications of groups of five grapevines). The final phase of the study related to the compilation of thematic and advisory maps resulting from the statistical integration of all the data gathered.

The Franciacorta region in Italy is very hilly and thus very varied with respect to geology, landscape and soil (Panont & Comolli, 2000). An integrated study of the identification and characterisation of land suitability units (terroirs) was performed over three years on the basis of climatic, soil and viticultural and oenological data (Scienza *et al.*, 1999). This study method was also based on the concept of soil landscape units (on a scale of 1:25 000). A map of these units was used to integrate soil and agroclimatic parameters, as well as viticultural parameters determined in a genotype x terroir study, to identify vocational units on a scale of 1:50 000. Three large landscape units were identified initially, and these were then subdivided into seven viticultural soil landscape units, which became known as vocational units. For each vocational unit, the soil characteristics, viticultural potential and associated wine sensorial profile were described.

In Trentino, two cooperative cellars joined forces to stimulate terroir research in the region, covering an area of 2 000 ha of vineyards (Falcetti *et al.*, 1998). Existing maps and data for the region were accumulated, detailed soil analyses were performed and a cultivar adaptation study was performed over three years. A map of soil types was divided into areas of specific identity according to grape type, climate, soil characteristics and geology.

2.3 FROM TERROIRS TO DEMARCATED AREAS

The delimitation of geographical indications or appellations is not easy due to the variability of natural factors and, until recently, it has been fundamentally empirically based (Morlat, 2001a). The process of delimitation consists of the definition of boundaries of production, often of a large size, which are the result of a consensus between the technical criteria of the experts and the practical approach suggested by the producers (Riou *et al.*, 1995). As a result, a delimited appellation will often consist of more than one terroir, often with varying characteristics, and it is possible to identify several zones that are homogenous with respect to natural factors (Riou *et al.*, 1995).

Demarcation can have a significant impact on the economy of the land on either side of the boundary (Unwin, 1996). In Champagne, land that is AOC (appellation d'origine controlée) classified is 100 times the price of non-AOC land (Fanet, 2000). Demarcation may therefore be subject to corruption and social disruption (Unwin, 1996). To prevent this happening, it is important that the choice of criteria for the delimitation of boundaries is true and justifiable. It is also difficult to defend an appellation of origin or geographic indication that has not been based on the terroir structure of a region and the appellation thus becomes vulnerable (Laville, 1993). The terroir and appellation of origin are, however, not interchangeable concepts, as the terroir has a material reality, while the appellation of origin is an intellectual concept (Laville, 1993). Laville (1990) has suggested, *inter alia*, that terroir studies on a medium scale (1:25 000 to 1:100 000) are useful for the modification of a delimited area within the concept of geographical indications, be it the geographical area or the vineyard area.

2.3.1 GEOGRAPHICAL INDICATIONS AND APPELLATIONS OF ORIGIN: A DEFINITION

Three categories of geographical names can be distinguished: indications of source, geographical indications and appellations of origin (Lucatelli, 2000). The indication of source simply connects the product to a given region or place, while geographical indications and appellations of origin seek to show that specific characteristics of the product are linked to its geographic origin (Lucatelli, 2000). Geographical indications or appellations of origin are, therefore, basically "labels of origin" and can be used extensively for agricultural products (Barham, 2003), but have been defined in a number of ways. According to the Lisbon Settlement of 1958 (Laville, 1990), an appellation of origin is defined as "a geographic denomination of a country, a region or a locality serving to designate a product that is original and for which the quality or characteristics are exclusively or essentially due to the geographical environment, including natural and human factors". The OIV adopted the following definition in 1947: "a wine or an *eau de vie* may only be designated by an appellation of origin if this is consecrated by its use or certified renown. This renown must result from qualitative characteristics determined by the following factors: 1. the natural factors which play a preponderant role: climate, nature of the soil, cultivars, exposition. 2. the factors resulting from human intervention, which play a greater or lesser role: cultural and vinification methods" (Laville, 1990). An appellation of origin can be described as a name that evokes the originality of a product, guarantor of custom and renown, which is owned collectively and the source of which consists of a number of factors, both natural (area of production, cultivar, etc.) and human (cultivation, vinification, distillation, etc.) (Quittanson & Vanhoutte, 1963).

The Madrid Resolution of the OIV (1992) (Tinlot & Juban, 1998) distinguished between recognised geographical indications and recognised appellations of origin. Both are "the name of a country, the region or the place used in the designation of a product originating from this country, this region, this place or the area defined to this end under this name and recognised by the competent authorities of the country concerned". The difference, however, lies in that a recognised geographical indication for wines is "linked to a quality and/or a characteristic of the product attributed to a geographical environment including natural or human factors, and is dependent on harvesting of the grapes in the country, the region, the place or the area defined", while a recognised appellation of origin for wines "designates a product whose qualities and characteristics are exclusively or mainly due to the geographical environment including natural and human factors, and depends on harvesting as well as on transforming into the said product in the country, the region, the place or the area defined" (Tinlot & Juban, 1998). The appellation is a more stringent concept than that of geographical indication, as it requires a direct geographical name as denomination, that the whole production process must take place within the specified geographical area and that the product characteristics must be due essentially to the geographical environment (Lucatelli, 2000; Fanet, 2002a; Rangnekar, 2003). It is, in fact, integrated within the definition of geographical indications, which is in turn integrated into the definition of indications of source or provenance (Fanet, 2002a; Tinlot & Juban, 1998).

2.3.2 METHODS TO DELIMIT GEOGRAPHICAL INDICATIONS

It is important to emphasise that it is the specific characteristics of the natural environment that lead to a product that is recognisable and can be protected under an appellation of origin (Fanet, 2002b). The terroir forms an integral part of the appellation with the additional information of cultivar choice and viticultural and oenological practices (Dubos, 1984). Stern & Léger (2000) suggest that, in order for a geographic indication to have any form of integrity, assuring the consumer of an effective link between the product and its place of origin, the use of terroir must be enforced for the delimitation of geographical indications. They emphasise that the prescriptive form of geographical indication stipulates "a specific territorial delimitation based on terroir considerations". The European Union has laid down criteria that must be met by member countries in order to meet the requirements for "Quality Wines Produced in Specified Regions", with the control of origin being considered the most important, whereby grouping within a specific appellation must be based on similarity of soil, subsoil and climate (Casson, 1991). This system has been strongly influenced by the AOC system of France (Barham, 2003).

2.3.2.1 Controlled appellations of origin: France

The official INAO (Institut National des Appellations d'Origine) definition of an appellation of origin is that it is the denomination of a country, a region or a locality that serves to designate a product that originates from this area and of which the quality or its characteristics are caused by the geographical environment, including natural (climate, soil, vine varieties, orientation of the vineyard, etc.) and human factors (cultivar and rootstock choice, viticultural and oenological practices) (Sarfati, 2002). The AOC is a specific geographical origin with a collective right (applicable to all producers within the specified origin) and is applicable to products of a specific character and origin (Anon., 1975). The aim of the AOC is bi-purpose, a guarantee of origin and of quality (Renou, 2001). At its heart lies the concept of the terroir, but it remains a fusion between the terroir, genotype and viticultural and oenological tradition (local, loyal and constant use) (Renou, 2001). The *Vin de Pays*, on the other hand, is merely an indication of origin, i.e. it indicates that wine comes from a particular region, but it does not identify characteristics that are peculiar to this region.

Geographical names have been recognised in connection with viticultural production throughout French history, and may be linked to small or large areas (Vaudour, 2003). The appellation d'origine system, however, had its birth in 1905 with a decree to limit fraud relating to merchandise and food products, which led to the administrative delimitations of appellations (Fanet, 2002b). This decree, together with the subsequent decree of 1919, resulted only in an indication of provenance, however, rather than in true appellations, as boundaries were drawn without taking into account factors such as soil, cultivars and viticultural and oenological practices (Fanet, 2002b). Fanet (2002b) has suggested that this was because the link between quality and origin had not yet been established. Eventually, following further crises of overproduction, producers of high-quality wines requested that a special category be created within the appellation system where they would be able to lay down the various conditions of production and other factors that contributed to the specificity of these appellations, and the appellation of origin became the controlled appellation of origin on 30 July 1935 (Fanet, 2002b; Unwin, 1996). The AOC is administered by the Institut National des Appellations d'Origine (INAO), which was formed in 1935 as a result of the phylloxera crisis, the overproduction of wine and the fraudulent use of famous designations (Fanet, 2002b). In 1974, following suggestions by trade professionals, yield regulations were strengthened and improved (Anon., 1975). The AOC system, as a result of its heritage, includes many scales of delimitation and Vaudour (2003) divided it into a hierarchy of four levels: the regional appellations of origin; the independent sub-regional appellations of origin or regional appellations of origin with village sobriquets; communal appellations of origin; and sub-communal appellations of origin, including the *clos* and *crus*.

The primary step in the establishment of an AOC is the delimitation of the production area (Fanet, 2002b). For each production area, the cultivars, viticultural practices, maximum yield, minimum ripeness, specific oenological practices and precise criteria for labelling are indicated (Fanet, 2002b). The INAO makes a proposal to the state, which then publishes a decree concerning the delimitation of the AOC. The management of the AOC is delegated to the producer bodies of the region (Syndicats) (Sarfati, 2002).

A controlled appellation of origin consists of two elements: the geographical area and the delimited or vineyard area. The first encompasses the area of production of the AOC, which is the list of communes in which the full process of grape to wine production occurs, while the second refers to the area of production of the primary material, i.e. the grapes (Fanet, 2000). The areas of production in France are defined by the Land Registry, plot by plot (Anon, 1975). In order to delimit the vineyards with the right to AOC denomination, a detailed study must be undertaken, but first the area must achieve fame using the desired name for *Vin de Pays*. The recognition of an AOC is achieved when, in a given region, a number of particular environmental features have resulted in an original and typical product through the action of the producers (cultivar choice, viticultural practices, etc.) (Fanet, 2000). These particular environmental features are generally found within a number of administrative units. The delimitation of the vineyard area involves the delimitation of the physical environment, while the delimitation of the geographical area involves the identification of the administrative units in which these features are found and for which the same name is used to identify the wines. The criteria for definition are specific and do not necessarily remain the same between areas, but must in all cases be sufficiently descriptive and precise (Fanet, 2000).

To commence a survey, the producers within the region are asked how they would describe a wine that is typical of their potential appellation and where the best example of such a wine is to be found (Drouhin, 2001). This “noyau d’elite” (nucleus) corresponds to the portion of the production area in which all components representing the link with the terroir are to be found (e.g. physical environment, use of name, production methods, etc.). This segment must be studied in detail in order to define the criteria and principles for delimitation (Sarfati, 2002). All areas within the proposed appellation are then compared to this identified “reference point” based on pertinent environmental and cultural aspects and, where the degree of correlation is acceptable, it is accepted that the product has similar characteristics (Drouhin, 2001).

In the delimitation of the geographical area, it is important that the historical use of the future name of the appellation has been true for the respective administrative units. The administrative units in question are, in most cases, based on wine tasting and the presence of the pertinent environmental features used to distinguish the vineyard delimitation (Fanet, 2000). In other cases, however, the geographical area may be delimited according to a dominant geographical feature (i.e. a valley, hill, etc.) and contain varying climatic or geological features (Fanet, 2000), or the use of the name in question may be the only characteristic used to delimit a geographical area. The delimitation of vineyards is performed by a multidisciplinary committee of regional experts (viticulturists, oenologists, geologists, soil scientists, climatologists, etc.). The delimitation of the vineyards does not usually depend on only one criterion, but rather on a series, the relative importance of each of which may be adapted depending on the sector of the appellation in question. The most important features used for delimitation are geological characteristics (geological formations determine the soils present as well as the topography of the area), pedological sequences, climatic conditions (mostly related to optimal sunlight interception), topographic features (related to sunlight interception and the movement of soil water), viticultural potential (especially in the south of France) and historical land use. These suggest an intertwining of producer-related and natural factors for the delimitation of both vineyards and geographical areas. The factors may be qualifying or exclusionary (Drouhin, 2001). Within the hierarchy of delimited zones within a region, however, the closer the zone approximates the regional appellation, the more the factors for delimitation will depend on the viticultural potential of the area, while the smaller the delimited zone, the more the criteria related to common usage will predominate. In addition, the more recent the delimitation, the less the factors related to common usage will dominate and the more the viticultural potential of the region will dominate (Drouhin, 2001). The balance between the use of natural factors and human intervention in the delimitation of AOCs has been a thorny issue since the inception of the concept (Fanet, 2002b). From 1970 to 1990, the balance swung towards the natural factors due to the number of disputes regarding boundaries that had to be justified and the development of geographic information systems that allowed the spatial characterisation of natural factors (Fanet, 2002b). The defined criteria are not identical from one appellation to the next and are not always explicit, but one of the main strengths of the AOC system is the interaction or dialogue between the producers (*professionnels*) in the vineyard region and the scientific experts and authorities (Vaudour, 2003). Each AOC is individual and has its own criteria and, as a result, one can distinguish four main levels of interaction between natural and human factors in the delimitation of AOCs, namely (i) the AOC corresponds to a basic terroir unit and the role of the terroir is of primary importance in the delimitation of vineyard area (this is very rare), (ii) the AOC corresponds to a single geological formation and the role of the terroirs is once again of fundamental importance, (iii) the AOC stretches across a number of geological formations, in which case the human factor plays an important role and it is necessary to understand the history and natural development of the AOC (e.g. the Médoc) and (iv) inclusionary AOCs, which no longer have direct reference to the supporting terroirs and the delimitation is based solely on geographical or administrative characteristics (Fanet, 1998). Nonetheless, the human factors do not play a negligible role in present-day delimitations (Fanet, 2002b). The link between the product and the AOC is emphasised by the regulation introduced in 1974, whereby all wines that may benefit from the appellation must undergo sensory and chemical analyses (Vaudour, 2003)

The word "controlled" within the controlled appellation of origin refers to the regulations imposed by the INAO for each appellation. These regulations include the production area (which plots of land may be used for the production of appellation wine), the permitted grape cultivars, the specific must weights for freshly picked grapes, the allowed alcoholic strength, the maximum yield, the minimum vine age, the minimum vine density, the pruning method, the vine-training system, whether or not a certain level of irrigation is allowed and the precision of certain aspects of the winemaking method (Casson, 1991). The focus of the AOC wines is on the geographical origin and it assumed that the consumer will have a basic knowledge of the cultivars used and the resulting wine style, as this is not indicated on the label (Casson, 1991).

As most of the AOCs in France have developed over thousands of years, the reasons for their delimitation are not always clearly understood. An INAO-INRA research group was established to investigate why certain of the appellations have naturally crystallised over time and what role natural factors have played in their development (Fanet, 1998).

A cultural heritage: the example of Médoc

Médoc is covered by nine appellations: AOC Haut-Médoc (4 200 ha) to the south, AOC Médoc (4 700 ha) in the north-east of the peninsula, and seven "communal" AOC, of which four are perpendicular and contiguous to the estuary (Saint Estéphe, Pauillac, Saint Julien, Margaux) and two are situated in the heart of the AOC (Haut-Médoc and AOC Bordeaux) (Fanet, 1998). Although there are very clear geological boundaries formed by the terraces running parallel to the Gironde, the cultural heritage of the riverside communities has played a predominant role in the demarcation of the abovementioned appellations (Fanet, 1998). The Médoc viticulture forms a band of 5 km to 7 km in breadth and 70 km in length against the Gironde estuary, but this vineyard area is discontinuous as it is repeatedly interrupted by tributaries and marshes. Prior to the 17th century, it was not possible for the communities in-between the tributaries to communicate with each other in a north-south direction. This resulted in each community establishing its own port on the banks of the Gironde. Within each communal AOC, vineyards are established on the different terraces, each with its own cultivar, rootstock and winemaking technology and the AOC wine is a blend of the resulting different products (Fanet, 1998).

The delimitation of an appellation of origin: the example of AOC Saint-Bris

Not all AOCs have crystallised historically and socially, as is the case in Bordeaux. Vincent (2002) offers the example of the Saint-Bris AOC, which was delimited recently. Saint-Bris is situated in Burgundy and is the centre of the Sauvignon blanc winegrowing area in this region. It was initially demarcated as "Appellation d'Origine Simple" (until 1973) and thereafter as "Appellation d'Origine Vin Délimité de Qualité Supérieure" (from 1974). This demarcated area covered seven communes and many diverse expositions. The "Syndicat des producteurs du Sauvignon de Saint-Bris" requested accession to the AOC under the name of "Saint-Bris" in 1994. The procedure reached the stage of decree in 2002. In their request, the producers clearly expressed the desired characteristics of Sauvignon blanc wine from Saint-Bris, namely "a fresh wine, acidulous, with fruity aromas (citrus and blackcurrant buds), with reserved vegetative notes (asparagus, elder, capsicum) and often marked by a certain degree of minerality" (author's translation). This clear description, together with the knowledge of which sites typically produce these types of wine despite the general practice of malolactic fermentation (partial or complete), facilitated the investigatory process. This process involved a thorough assimilation of all geological, soil, topographical and climatic data, as well as the compilation of an inventory of each Sauvignon blanc vineyard in relation to its position in the landscape (notably slope inclination and exposition). It appeared from the comments of the applicants, and from the investigations, that the specified wine style was produced in situations where the climatic conditions are cool (on the plateau and on west- to north-east facing slopes), where there is a risk of spring frost and/or where the soils are deep and finely textured (i.e. warm slowly in the spring). The INAO established a list of criteria for the delimitation of the AOC Saint-Bris based on the above observations and *in situ* verification, namely that the production area be centred around the commune of Saint-Bris, with the possibility of including portions of adjoining communes if the production methods are similar to those identified; that the delimited areas be situated on one of two landscape positions, namely on a plateau or on north- (or possibly west) facing slopes of marl (calcareous clay); and that they meet certain soil requirements, namely colluvial material with a high clay and silt content, without stones or lime (chalk) and usually deep.

Boundary revision: the example of AOC Saint Joseph

At a time when mechanisation was becoming increasingly popular and manual labour increasingly expensive, there was a tendency in the INAO to allow the extension of production areas to terrains that were suitable for the cultivation of grapevines with available means (i.e. allowing for mechanisation and thus including flatter areas together with steeper slopes, for example AOC Côte-Rôtie and AOC Saint Joseph) (Fribourg, 2002). Fribourg (2002) describes the example of Saint Joseph in detail. It was initially delimited in 1956, with a boundary extension in 1969 resulting in an area extending over 26 communes. At this stage there was concern that the hillside viticulture, necessitating terracing with dry stone walls and not permitting any mechanisation, was not economically viable. As a result, the delimitation of the production area included the footslopes and plateaus together with the traditionally cultivated slopes (a total area of 6 844 ha). The ease of mechanisation resulted in a preference for planting on the flatter areas, and thus a change in wine characteristics. The producer syndicate requested a revision of the boundaries in 1986. The revision was based on the principal of Kuhnholtz-Lordat: the previously-mentioned "noyau d'elite" or "nuclei". The original or typical "nucleus" was identified, i.e. the commune of Tournon, from whence the name of the appellation originated, together with certain technical criteria that had to be met to a prescribed extent. This resulted in the retention of the well-exposed slopes, as well as certain other selected sites, which were deemed to result in the characteristic wine style. The procedure was completed in 1994. The production area was reduced from 6 844 ha to 3 400 ha, also resulting in the loss of AOC Saint Joseph status for 171 ha of vineyards. Knowing that vested interests could create a problem despite support for the process by the local producers, various compensatory measures were introduced, i.e. the excluded producers may use the AOC denomination until the removal of the vineyards in question or, at the latest, until the year 2021, and the excluded producers are allowed to plant within the newly delimited zone without having to first remove their other vineyards. In addition, public administrative organisations have assisted financially with the establishment of vineyards at certain strategic locations on the slopes, thus accelerating the restructuring of the traditional viticulture of the area. According to Fribourg (2002), this boundary revision has resulted in many advantages for the AOC, namely the maintenance of, or return to, the characteristic wine style of the region, an increase in the value of the product, which covers the increased cost of working the slopes, and the revival of the historical local image of the region.

2.3.2.2 Italy

Italy's vineyards were first delimited systematically in 1963, although the framework law had been promulgated in the 1930s, when some of the more famous areas were given legal recognition and protection (Thomases, 1994). There are three categories of geographical indication, namely Typical Geographical Indication (IGT), Controlled Designation of Origin (DOC) and Controlled and Guaranteed Designation of Origin (DOCG) (Lucatelli, 2000). According to Italian law, the term "designation of origin" refers to any geographical name of a viticultural area producing a product of quality and renown and belonging to a number of producers, and the geographical name following the letters DOC or DOCG may be followed by the name of the cultivar or other terms, while IGT are represented by a geographical name that corresponds to a very extensive viticultural area that may be specified by cultivar, type of wine or colour and may not use geographical names relating to DOC or DOCG (Lucatelli, 2000). Wines can obtain DOCG status after five years of DOC status, during which time the wines produced must have been of a high quality and have obtained national and international repute (Lucatelli, 2000). In the DOC and DOCG classifications, the production zones are delimited and the cultivars, alcoholic strength, total acidity, extract, maximum yield and viticultural and winemaking practices are specified (Casson, 1991; Thomases, 1994). The defined geographical area is, however, generally too large to give an indication of the quality of the product, and the established practices (therefore regarded as traditional and accepted as the regulatory practices for the new denominations) at the time of delimitation are focussed towards quantity rather than quality (Casson, 1991). An inability to guarantee the quality of the certified wines has led to disenchantment with the system by producer and consumer alike, apparently due to the allowance of too high yields and the over-generous delimitation of boundaries that include peripheral areas in the denominations (Thomases, 1994). In an attempt to remedy this situation, the existing law was modified in 1992 to allow the larger DOC zones to be broken down into sub-zones, townships, hamlets, micro-zones, individual estates and vineyards, with the smaller zones having stricter production limits and criteria, as well as the introduction of a broader class, known as Typical Geographical Indication (Indicazione Geografica Tipica) (Thomases, 1994). All vineyards within the demarcated area are included and, unlike the French system, there is no demarcated vineyard area (Thomases, 1994).

A national law revokes the designation of origin if it has remained dormant, i.e. used by less that 15% of the production, for a period of five years (Carbone, 2002). The reasons for low usage of denominations of origin in Italy can be grouped into two categories. Firstly, the fact that public administrations at the local level are often more involved in the delimitation than the producers themselves and, secondly, the fact that the very small production scale of the farms (an average size of 2.5 ha) limits their ability to label their product (Carbone, 2002).

2.3.2.3 Spain

The first law pertaining to designations of origin in Spain was established in 1933 and updated in 1970 (Lucatelli, 2000). It defined a Denominación de Origen as a "geographical name of a region, district, place or locality used to designate a product derived from grapes, wines and spirits originating in that area and having distinctive qualities and characteristics due mainly to the natural environment and to its preparation and cultivation". This law established the Instituto Nacional de Denominaciones de Origen (INDO) to regulate and monitor designations, as well as a regulatory authority for each designation (Lucatelli, 2000). Spain has a five-tiered system of wine classification, which includes the two categories of Denominación de Origen (DO) and Denominación de Origen Calificada (DOCa) (Mayson, 1994a). These areas are regulated by regional bodies that ensure that the growing, making and marketing of the wines comply with regional standards (Mayson, 1994a).

Rioja

Rioja was the first wine region in Spain to receive the designation DOCa (in 1991) (Mayson, 1994a). It is divided into three zones, Rioja Alta, Rioja Alavesa and Rioja Baja, which are based on terrain and altitude (Johnson, 2002). Each of these three zones has distinct climatic and soil patterns. Within the DOCa, the cultivars and maximum yield are stipulated. There are also strict regulations pertaining to wine production methods, specifying the shape and size of the barrels allowed for maturation, the minimum maturation period in oak for each officially recognised category of wine and the minimum maturation period in stainless steel or bottle before release (Mayson, 1994a).

2.3.2.4 Portugal

In Portugal, the denomination of origin was originally known as Regiã Demarcada, but after the country joined the European Union, its wine laws were revised and the denomination of origin is now known as Denominação de Origem Controlada (DOC). Cultivars, yields, alcoholic strength and maturation times are controlled within these denominations (Mayson, 1994b). There are a further two levels of classification, namely Indicação de Proveniencia Regulamentada (similarly regulated to the DOC) and Vinho Regional (Mayson, 1994b).

Douro

The region of the Douro was officially delimited by Royal decree in 1757 as a region for the production of dessert wine with a long tradition and unique qualities (Bianchi de Aguiar & Magalhães, 2002), making it one of the first examples of geographical delimitation. The vineyards were characterised on the basis of their production over a period of five years and the quality of their wines. Those vineyards that met the specifications for production of a high quality wine were inscribed as “Feitoria” (Bianchi de Aguiar & Magalhães, 2002). With the decree, certain limitations were placed on the production by the “Feitoria“ (e.g. the use of manure in the vineyards was forbidden, as was the addition of elderberries in the wine preparation – in fact, no elder tree was allowed within 20 km, and the blending of white and red cultivars was not allowed) (Bianchi de Aguiar & Magalhães, 2002). The delimitation of the Douro, therefore, resulted in one of the first controlled appellations of origin. In the 20th century, further delimitations of the region were made, together with adjustment to the rules regarding the production methods (Bianchi de Aguiar & Magalhães, 2002). The production area was limited to shale-derived soils at altitudes between 70 and 500 metres, a minimum degree of ripeness and maximum yield were specified and vineyards with too vigorous growth were excluded. A cadastral study allocating points for criteria related to the climate, the terrain and the plant for each vineyard was completed. On the basis of these points, the vineyards were divided into six categories, with the top category having a right to the production of “Porto” wines, while the other categories received the right to the production of other regional appellations (Bianchi de Aguiar & Magalhães, 2002). The Douro is divided into three sub-regions based on climatic characteristics: Baixa Corgo is the most westerly, with a strong maritime influence, Cima Corgo is in the centre of the region with terroirs that are considered to be best suited for the production of “Porto”, and Douro Superior is situated in the upper valley in a semi-arid, Mediterranean environment with a very high potential for the production of either fortified or natural wines of very high quality (Bianchi de Aguiar & Magalhães, 2002).

2.3.2.5 Tokay: Hungary

An even older example of delimitation is that of Tokay. The region of Tokay was first delimited in 1737 and a vineyard site classification, based on sensorial wine quality and soil and climatic characteristics, was first carried out in 1803. Later modifications took place, including one as recently as in 1999 (Botos & Bacsó, 2002). The wines are classified according to their degree of ripeness and degree of infection by *Botrytis cinerea*. In the Tokay region, the cultivars are limited to four for the production of the regional wine (Botos & Bacsó, 2002). Eighteen quality-related factors (including soil, temperature, area, exposition and altitude) have been used to score each vineyard site in Hungary, including in Tokay, and land that is homogenous with respect to these 18 characteristics has been identified (Botos & Bacsó, 2002).

2.3.2.6 Quality wine: Germany

Germany does not base the classification of its wines on geographic origin, but rather on the finished product (Hallgarten, cited in Unwin, 1996) or on the maturity of the grape at the time of picking (Casson, 1991). In practice, however, German wines are also described by place or origin, with the reputation of certain vineyards placing a premium on their wines (Unwin, 1996). The German wine law (1971) recognises both a hierarchy of wine regions and a hierarchy of wine qualities (Unwin, 1996), i.e. it recognises wines from official sites or groups of sites as Quality Wine (Qualitätswein bestimmter Anbaugebiete) and Quality Wine with special Attributes (Qualitätswein mit Prädikat) according to the ripeness of the grapes at the time of harvest (Jefford, 1993). Only the vineyards that have been precisely defined and registered as official sites or groups of sites are allowed to use these terms (Jefford, 1993). The smallest geographical unit is the single vineyard site (Einzellagen), which is usually greater than 4 ha in size (Johnson, 2002; Unwin, 1996), while groups of sites (Grosslagen) consist of single sites with similar geological and climatic conditions (Jefford, 1993; Unwin, 1996). In many cases, both Einzellagen and Grosslagen cross the boundaries of one or more villages, but there will always be a main village that will give its name to the wine (Jefford, 1993). The next level is that of districts (Bereiche), then Lände (only applies to quality levels just above the minimum), and finally Regions (Anbaugebiete) (Johnson, 2002). The category of Ursprungslage, in which the wine style, cultivar, acidity, alcoholic strength and residual sugar are specified, has been proposed as a replacement for the Grosslage (Robinson, 1994).

2.3.2.7 American viticultural areas

American viticultural areas (AVAs) were first created in 1978 and took effect in 1983 (Mendelson, 2002). American viticultural areas are delimited grape-growing regions that are distinguishable by geographical features and for which the boundaries have been recognised and defined, and are the most specific legally recognised appellations of origin in the United States (Spivey, 1998). Other levels of appellation in the United States are the country as a whole, a state, two or three states that are contiguous, a county or two or three counties in the same state. On a more detailed level, sub-appellations may be identified within the boundaries of existing AVAs, or even of existing sub-appellations, in order to make the designations more meaningful

(Spivey, 1998). Growers and vintners may present an application for multiple AVAs within the larger appellations (Mendelson, 2002). Beyond this, vineyards or specific vineyard blocks may be designated, although these are not highly regulated (Spivey, 1998). No additional standards are imposed (Spivey, 1998), but there is increasing producer-directed research towards determining the cultivar "vocation" of delimited areas (Mendelson, 2002). American Viticultural Areas must show evidence that the name of the area is locally and/or nationally known as referring to the area specified and that the geographical features (i.e. climate, soil, elevation, etc.) of the area are viticulturally distinct from surrounding areas (Spivey, 1998; Lucatelli, 2000). Boundaries are proposed by the applicants and these are presumed to be true, although in some cases the administering body (the U.S. Treasury Department's Bureau of Alcohol, Tobacco and Firearms) may adjust the proposed boundaries to better define an area viticulturally (Spivey, 1998). Spivey (1998) proposes that the AVA appellation system presupposes a degree of acceptance of the terroir concept, as soil similarities or differences have been used to extend or restrict the boundaries of proposed AVAs.

2.3.2.8 Geographical indications: Australia

The Australian geographical indications system was established in 1994 (Stern & Léger, 2000) after much debate as to whether the geographical indication system or the controlled appellation of origin system should be followed (Mackley, 2002). The decision for the geographical indication system was based on the fact that Australia does not have centuries of experience in viticulture and oenology, newer viticultural areas are continuously emerging and new viticultural and oenological practices are being developed (Mackley, 2002). The Australian geographical indication system has three levels of demarcation, namely region, sub-region and zone, with the sub-region being the smallest (Mackley, 1998). Each geographical indication must be registered by the Geographical Indications Committee (Mackley, 1998; Stern & Léger, 2000). The geographical indications must be "a single tract of land that is discrete and homogenous in its grape growing attributes to a degree that is substantial" (Mackley, 1998). A zone is an area of land without any particular qualifying attributes, a region is a single tract of land comprising at least five independently owned wine grape vineyards of at least five hectares each that is measurably discreet from surrounding regions and has measurable homogeneity in "grape growing attributes" across its area, while a sub-region, which is also a single tract of land comprising five independently owned wine grape vineyards of at least five hectares each and usually producing five hundred tonnes of wine grapes in a year, must be substantially discrete within the region and have substantial homogeneity in "grape growing attributes" over its area (Australian Wine and Brandy Corporation, 2004). The term Geographical Indication is defined in relation to wine in the Australian Wine and Brandy Corporation Amendment Act 1993 as "(a) a word or expression used in the description and presentation of wine to indicate the country, region or locality in which the wine originated; or (b) a word or expression used in the description and presentation of the wine to suggest that a particular quality, reputation or characteristic of the wine is attributable to the wine having originated in the country, region or locality indicated by the word or expression" (Lucatelli, 2000). The term geographical indication in Australia therefore covers both an indication of provenance and a designation of origin, although it does stipulate that the wine originates where the grapes are grown and not where the winery is located (Lucatelli, 2000).

When determining geographical indications, the history (general, grape growing and wine production), traditional use of the area and name, geology, climate, elevation, natural drainage, water availability and expected date of harvest of the grapes must be taken into consideration (Australian Wine and Brandy Corporation, 2004). As in the case of Coonawarra, when there are not distinct climatic variations to justify boundaries and when the soil type is not continuous and difficult to map, the history of the use of the name and traditional divisions of the area carry a greater weight in determining boundaries of a winegrowing region or geographic indication (AAP, 2002). According to Stern & Léger (2000), the process is inclusionary, i.e. whole areas are granted the right to use a registered geographical indication without any analysis of the soils, climates or terroir characteristics of the various areas within a defined region or sub-region.

2.3.2.9 Geographical denominations: South America

Argentina

Argentina is divided into three viticultural regions on the basis of significant ecological variation and the numerous Andes valleys (north-west, centre-west and south), which are in turn subdivided into sub-regions on the basis of diverse agro-ecological factors and administrative borders (Biaiñ de Martínez, 2002). In 1958, regional wines from La Rioja, San Luis, Catamarca, Córdoba and Jujuy y Salta were recognised by decree on the basis of agro-ecological conditions that resulted in wines with unique characteristics. Since the late 1980s, more focussed studies have been launched to examine the agro-ecological conditions of various areas in order to improve the distribution of noble cultivars in these areas, and these studies have led to the establishment of controlled appellations of origin (Biaiñ de Martínez, 2002). Finally, in 1999, a law was promulgated whereby norms for the designation of origin of wines and spirits of Argentinean origin were defined. This system defines three categories, namely the indication of provenance, the geographical indication and the controlled appellation of origin (Biaiñ de Martínez, 2002). The indication of provenance is the least exact and relates to an administrative or political delimitation that is smaller than the recognised national area of production and is only used for table or regional wines. The geographical indication is based on the TRIPS definition, while the AOC definition is similar to that officially recognised by the OIV (Biaiñ de Martínez, 2002). The geographical indication and the AOC both consist of a superimposed geographical area and a production area; the geographical area describes an area that has been delimited partially on the basis of administrative and historical boundaries, while the production area is more exact and is made up of a terroir or a group of terroirs within the geographical area for which the natural conditions are conducive to the production of high quality wines. For the delimitation of a production area, it is necessary for a producer or group of producers to submit an application and to present the soil and climatic studies that have been performed by organisations recognised by the Instituto Nacional de Vitivinicultura and any other pertinent information that may be required by this organisation for its deliberations (Biaiñ de Martínez, 2002).

Chile

The first designations of origin were established in Chile in 1979, but these designations underwent further refinement by means of the recognition of sub-regions and, in 1995, agro-ecological conditions for delimitation were specified that led to a system of viticultural regions, sub-regions, zones and production areas being delimited (Biaiñ de Martínez, 2002). This appellation system approximates more closely the definition of a geographical indication rather than a controlled appellation of origin.

2.3.2.10 The wine of origin scheme: South Africa

The first legislation relating to the Wine of Origin scheme in South Africa was drafted in 1972 on the basis of recommendations made by a number of committees and with the support of the Viticultural and Oenological Research Institute (Saayman, 1999). Current wine of origin control legislation stipulates that no indication of origin, cultivar or vintage may be given unless the area has been demarcated and the wines have been produced strictly in terms of the control legislation (Kok, cited in Saayman, 1999).

Areas are demarcated within the Wine of Origin Scheme into four categories, namely regions, districts, wards and estates, with wards being the demarcated areas most stringently based on environmental attributes. The demarcation of wards is essentially based on the land-type concept (MacVicar *et al.*, 1974). All soil and climatic factors possibly having an effect on wine character and/or quality, existing cultural practices, existing experience and evidence that prove an area to be unique, geographical and other factors that contribute to the development of the traditional wine area and the traditional name of the area are taken into account in their delimitation (Saayman, 1999). On application by the producers within a community, denominations of origin are demarcated by a multidisciplinary demarcation committee within the structure of the Wine and Spirit Board (SAWIS, 2003). For an area to be demarcated, a strong emphasis is placed on the local knowledge of experts and dominant environmental feature(s) are identified to form the basis for the demarcation of the area. There is, therefore, a degree of flexibility that depends on the area to be demarcated and the available information. Strong emphasis is placed on the origin of the grapes, as well as on the area of wine production, especially at the ward level. According to statutory regulations, when the term "Wine of Origin" appears together with the name of a production area, it confirms that 100% of the grapes used for the production of the wine come from that area (SAWIS, 2003). All wines are evaluated by a central, or in some cases decentralised, tasting panel of experts in order to ensure a minimum quality standard and expression of wine style (according to label, not origin). This system is therefore a system of geographical indications, with the category of ward possibly approximating an appellation of origin (not controlled).

2.4 CONCLUSIONS

The methods used to identify viticultural terroirs are numerous and divergent and few have been tested in more than one region. It is therefore difficult to identify a specific dominant methodology, although the integrated method appears to be the most comprehensive. It is clear, however, that it is important to delimit viticultural terroirs so that all pertinent environmental factors are considered, to realise that these environmental factors may vary slightly from region to region, but that rooting depth and soil water-holding capacity are dominant. Every terroir study based on the integrated method includes two consecutive or parallel steps, namely (a) the characterisation of the environment and the identification of homogenous environmental units (basic terroir units, natural terroir units) taking all natural factors into account, and (b) the characterisation of the viticultural and oenological potential of these units over time.

Few appellations are truly based on a single terroir and most contain more than one terroir, but there is no doubting the importance of the terroir concept for demarcation and the movement towards using viticultural terroirs as a basis for demarcation in order to ensure the integrity of the delimitation. If we try to identify a suitable methodology for the identification of viticultural terroirs in the Stellenbosch wine-producing region as a basis for the identification of geographical indications, it would appear that a medium scale (1:25 000 to 1:50 000) is the most suited for delimitation. For this author, it is clear that viticultural technology and wine production technology can not easily be included in the delimitation of viticultural terroir units in South Africa, although this point may provoke significant discussion. It is apparent that topography cannot be ignored due to the complex landscape of the area. Climatic interpolations have been little used in existing terroir studies and topography can be a pivotal criterion for both mesoclimate and soil distribution. The openness of the landscape is significant for both sunlight interception and wind movement and is therefore important as a terroir criterion within this region.

There are four levels of appellation in France, namely regional appellations of origin, independent sub-regional appellations of origin or regional appellations of origin with village sobriquets, communal appellations of origin and sub-communal appellations of origin, including the *clos* and *crus*. Of the three recognised levels of demarcation in the South African Wine of Origin scheme, the ward is the concept that conceptually most closely approximates the terroir concept and, in most cases, is spatially similar to that of the communal appellation of origin. It appears that the classification of sub-communal appellations is missing in South Africa. However, for such an appellation to be demarcated successfully there has to be acceptance of the importance of the "unique" and "typical" wine characteristics as an expression of the terroir. The desired wine type and the best example of its production must be identified by the producers within the area to be delimited and demarcation investigations can be based on this reference. The idea of such a reference also seems to be important in terroir studies.

It is possible to split a production zone and a delimited or vineyard zone. The vineyard zone can be demarcated and enforced much more stringently. This has potential for a multicultivar wine-producing region to produce cultivar wines on the best suited terroirs within a single production zone at a sub-communal level (or sub-ward level).

Where it is impossible to compete within the global wine market at the level of low prices and sheer volume of trademark wine, as appears to be the case for South African wine, it is necessary that terroir expression comes to the fore and that the product is branded by origin. In order for labelling by origin or geographical indications to have any integrity, the use of terroir for the delimitation of geographical indications must be enforced. This is, however, not always the case (e.g. the Geographical Indication of Coonawarra in Australia).

The method used to identify natural terroir units in South Africa must be adapted to include criteria reflecting the openness of the landscape and soil water availability. It must also be validated by means of viticultural and oenological studies. The method used for the Stellenbosch area can be equated to the computational approach and, in order for it to be complete, should not stand alone but should form part of an integrated study method. The validation of the computational method used with the identified adjustments and viticultural and oenological validation will result in an integrated system for the identification of viticultural terroirs, which could be used to identify cultivar-specific sub-communal appellations and to delimit the said viticultural areas as a refinement of the present Wine of Origin system in South Africa.

Despite the ancient knowledge that origin affects wine style and quality, the delimitation of homogenous areas for the production of wines with unique characteristics has only recently formed a scientific research focus, using a multitude of methods and with varying degrees of completeness. Consensus must yet be reached as to the definition of "terroir" and a standardised method for the delimitation of terroirs. Although the EU and TRIPS agreements have encouraged the formation of geographical indications or appellation systems in many countries, the lack of consistency undermines the concept as a whole and may lead to the disenchantment of the consumer. It is important, especially with regard to wine in the higher price brackets, to maintain integrity in labelling by origin, an integrity which can only be provided if the terroir concept is used as a basis for delimitation. This idea, which has been encouraged in South Africa since the inception of the Wine of Origin scheme, must be furthered to refine boundaries and to create a sub-communal appellation category based on viticultural terroirs.

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CHAPTER 3

HISTORY AND ENVIRONMENTAL CHARACTERISATION OF STELLENBOSCH AND SURROUNDS

CHAPTER 3

3.1 HISTORICAL BACKGROUND

An outpost of the VOC (Dutch East India Company) Cape was initially established at the Cape with the sole purpose of supplying ships of this company with fresh produce (Smuts, 1979), but the colonists were unable to produce sufficient supplies to meet their own needs, let alone to supply passing ships (Van Zyl, 1979). Simon van der Stel (of Constantia fame) became commander of this young, impoverished colony in 1679 and, within a few months of his arrival, travelled to the Hottentots Holland area to personally investigate the situation of a new settlement of grain farmers in this region. In his travel journal, he described a fertile valley with a stream (the Eerste River) and a wooded island, which he named Stellenbosch (Smuts, 1979). He invited colonists (Free-burghers) to settle on the banks of the Eerste River and, by 1685, most of the present-day well-known farms had been established, forming a circle around the island (Smuts, 1979), with maximum river frontage to ensure water rights (Van Huyssteen, 1983). Many of these original farms today fall within the municipal boundaries of Stellenbosch (Van Huyssteen, 1983). The initial production of this new colony was focussed on grain and cattle. However, free burghers were allowed to plant grapes for wine production, as long as they also produced grain (Van Zyl, 1979). Within 13 years of its establishment, Stellenbosch showed its great promise as a viticultural area, with a total of 233 200 vines planted, and this amount increased to 3 676 000 vines by 1794 (Van Zyl, 1979). Stellenbosch was thus established as an agricultural community (Smuts, 1979). Wine production increased dramatically in the early 19th century as a result of some of the British fleet being stationed at the Cape during the first and second periods of occupation. During this period, extensive plantings were undertaken and Stellenbosch farmers became true wine producers (Van Zyl, 1979).

Although the originally denominated Stellenbosch settlement was an island in the Eerste River, all land outside of the Cape Peninsula was initially (ca. 1685) seen as being part of the Stellenbosch district (Marx, 1929; Visagie, 1979). The first delineation of boundaries for the Stellenbosch district took place in 1711, when the courses of the Mosselbank River and the Kuils River (Fig. 3.1) were used to demarcate the boundary between the Cape district and Stellenbosch. This district was unmanageably large and, in 1839, Stellenbosch was reduced to near to its present size, finally losing Bellville in the early 1900s (Visagie, 1979) and Hottentots Holland in 1928 (Marx, 1929). The eastern boundary of the Stellenbosch district remained the same from 1839 to 1929 (Marx, 1929) and is still similar today (Chief Directorate: Surveys and Mapping, 2000). The boundaries of the district in 1928 were described by Marx (1929) as follows:

> "...in the south the district is bound by the Ocean in False Bay between the Steenbras River and the Eerste River. From this point the boundary runs

northwards more or less along the border of the Cape Flats until close to Durbanville, where it turns north-east. From here it does not follow a geographic separation, but rather the main train line between Cape Town and the Paarl until between Muldersvlei and Klapmuts, further south-eastwards across Simonsberg, over the Groot Drakenstein mountains, ...[and] over the Hottentots Holland mountains to the point of exit."

These boundaries do not appear to differ significantly from the administrative district of Stellenbosch or from the magisterial districts of Stellenbosch, Kuils River, Somerset West and Strand (Chief Directorate: Surveys and Mapping, 2000) (Fig. 3.1). The Stellenbosch district is naturally bounded by mountain ranges to the east and northeast, False Bay to the south and the sandy flats to the west, but the boundary to the north and north-west is less clear geographically.

Marx (1929) divided the Stellenbosch district into three natural regions, which are roughly indicated in Fig. 3.2:

1. **The sandy plain of the southwest:** this consists of the sand dunes and is of little economic or agricultural interest.
2. **The valleys, hills and mountain foothills:** This region consists of alluvial soils in the valleys and granite and Malmesbury shale on the hills and foothills. The transition from the valleys to the hills is almost unnoticeable.
3. **The mountains:** These consist mostly of sandstone, with soils of low fertility that are difficult to work.

According to Serton (1929), Stellenbosch retained its independence and individual character by resisting amalgamation into the greater Cape Town Metropolis, largely due to the presence of the "Cape Flats", the sandy coastal plain situated between Cape Town and Stellenbosch (Fig. 3.2). This remains the case today.

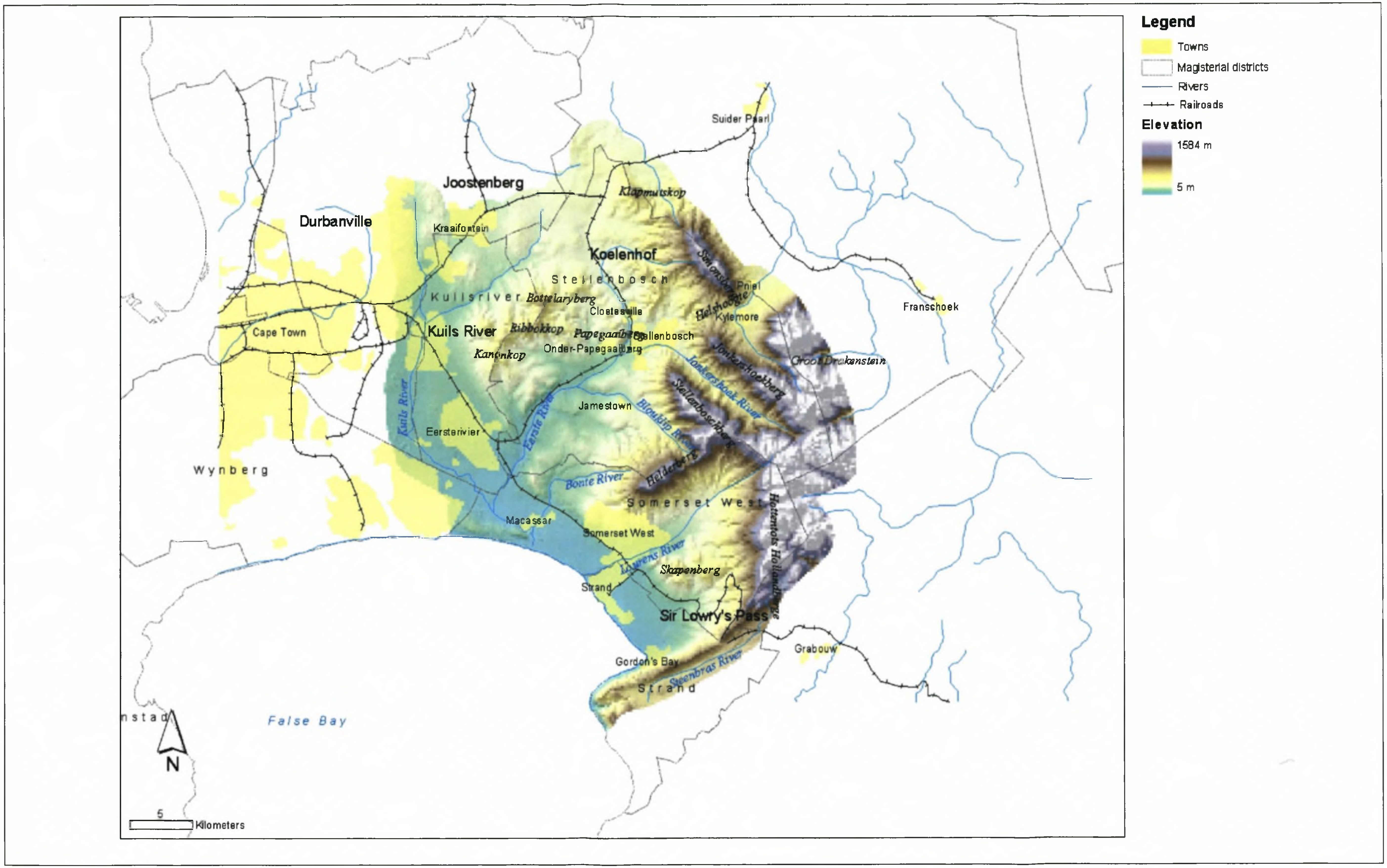

Figure 3.1 A map of the Stellenbosch, Somerset West, Kuils River and a portion of the Strand magisterial districts (1998) (colour-shaded areas), indicating major urban areas, topographical features, rivers and railways. Digital data obtained from the Chief Directorate: Surveys and Mapping and Agri-Informatics. Compiled by V Carey.

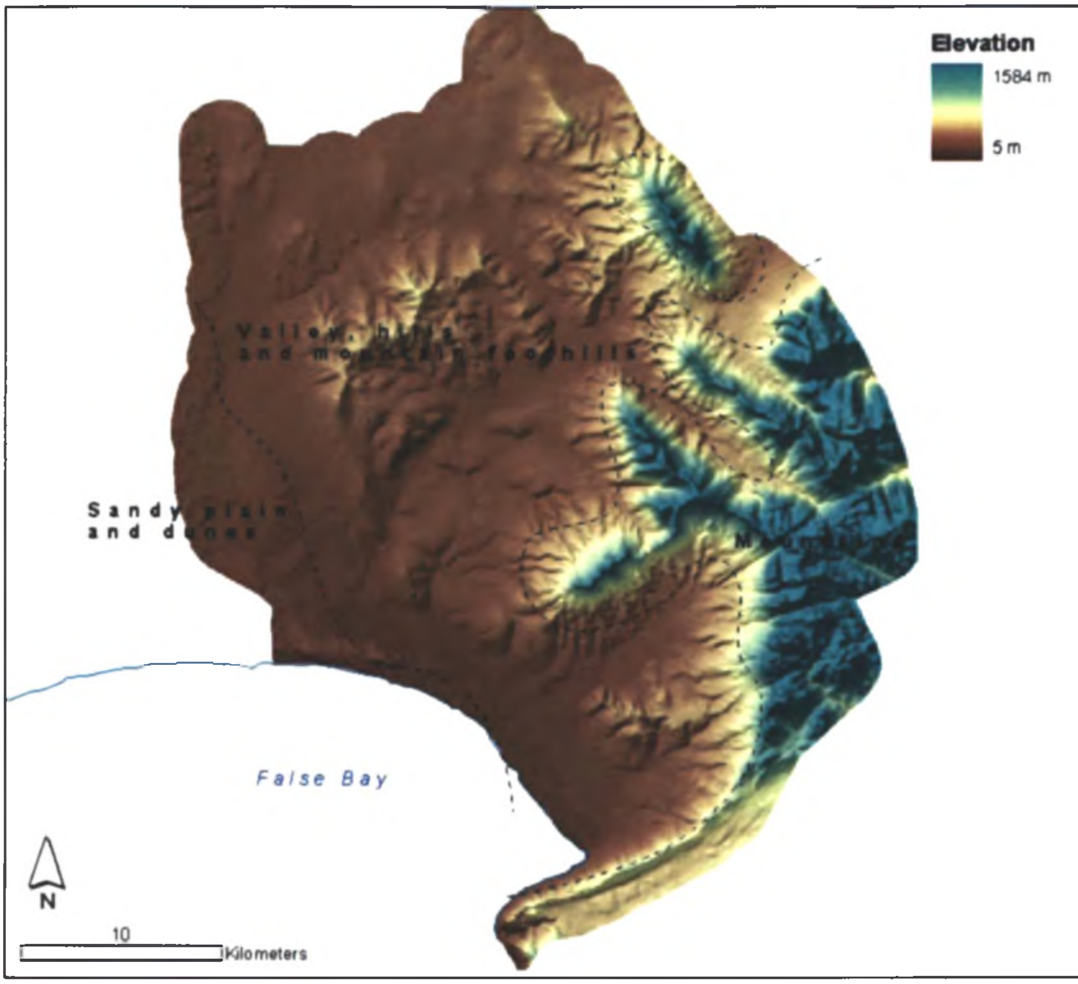

Figure 3.2 An approximate indication of the three natural regions in the Stellenbosch district as described by Marx (1929). Data obtained from Chief Directorate: Surveys and Mapping. Compiled by V. Carey.

3.2 DEMARCATION OF THE WINE OF ORIGIN DISTRICT: STELLENBOSCH

The Stellenbosch Wine of Origin District was demarcated on 16 June 1972 (date of appearance in the Government Gazette) at the inception of the Wine of Origin scheme in South Africa, with its boundaries being based on the administrative boundaries of the Stellenbosch district. The boundaries were reformed in 1980, 1991, 1995, 2002 and 2003 on application by producers. Five wine of origin wards were identified within the Stellenbosch Wine of Origin District prior to 2002, namely, Bottelary (1998), Papegaaiberg (1992), Devon Valley, Jonkershoek Valley (1991) and Simonsberg-Stellenbosch (1980) (Fig. 3.3). Wards are defined according to soil, climate and ecological factors and named according to a real geographical place name. These areas are demarcated on application by the producers. After demarcation, areas are allowed to develop to express their specific wine style and character, instead of having to prove their originality beforehand (Saayman, 1999).

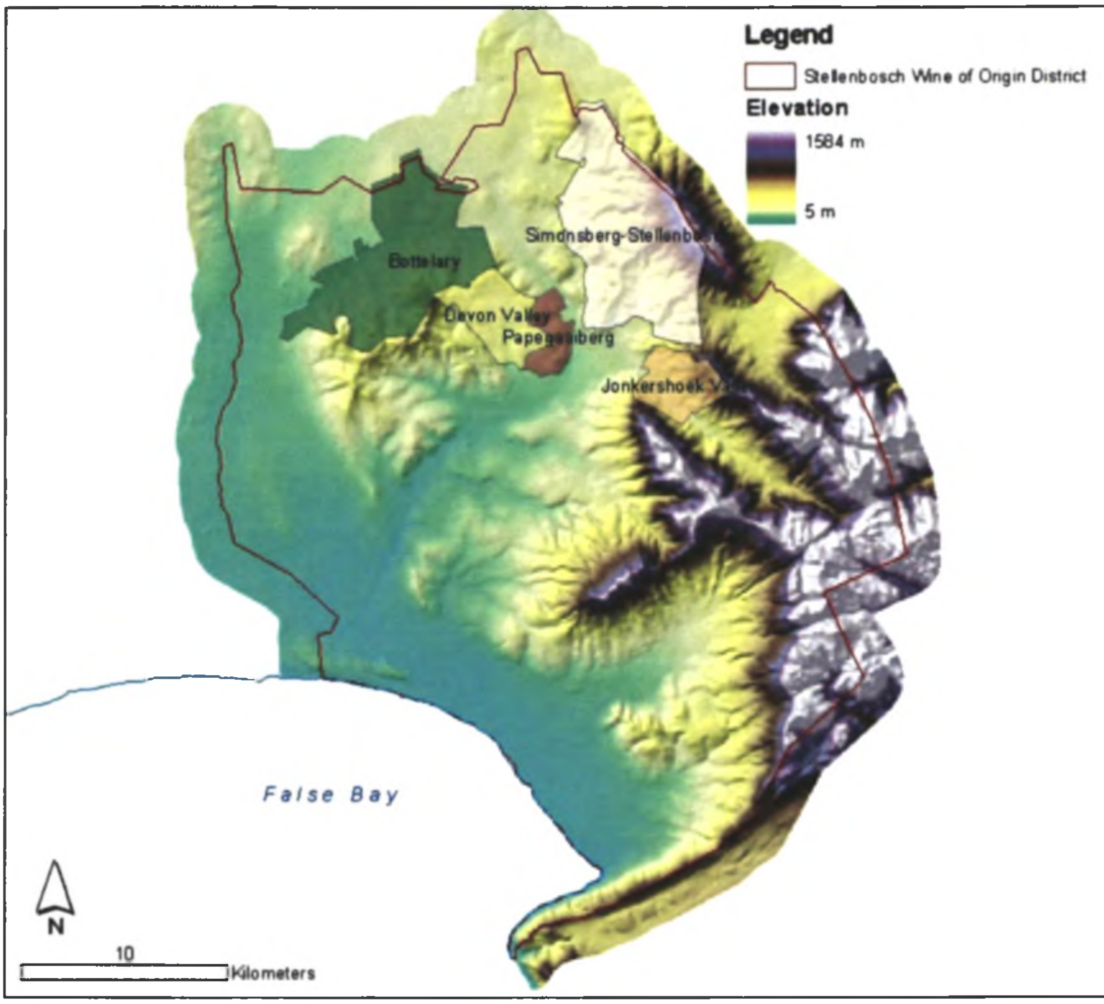

Figure 3.3 The Stellenbosch Wine of Origin District and wards (colour-shaded areas). The boundaries shown are those delimited prior to 2002, date of commencement of this dissertation. For positions of cadastral features, refer to Fig. 3.1. Data obtained from Chief Directorate: Surveys and Mapping, ARC Infruitec-Nietvoorbij and Agri Informatics. Compiled by V Carey.

3.3 CULTIVAR SPECTRUM AND VITICULTURAL PRACTICES

The Stellenbosch wine producing region (statistics include those of Durbanville and Constantia) currently contains 52 522 581 grapevines covering an area of 16 582 ha and representing ca. 16% of the country's vineyards, with the predominant cultivars being Cabernet Sauvignon (20% of the total hectares planted), Chenin blanc (16%), Sauvignon blanc (12%), Merlot (11%) and Shiraz (11%) (SAWIS, 2002). The vineyards are established mainly on slopes (mostly granite and hornfels) and topographically lower areas with underlying greywackes and shales, while vineyards at higher elevations on the mountain slopes are located near Table Mountain sandstones (Van Schoor, 2001). Soils in this area are geologically ancient and intensely weathered, resulting in increasing soil acidity with depth (Lambrechts, 1983).

Many of the vineyards are cultivated under dry land conditions, but irrigation is increasingly being used in order to prevent excessive water stress during the dry summer months. Deep soil preparation practices (up to 120 cm) are widely implemented prior to planting to alleviate chemical and physical limitations. Drainage and possibly ridging are implemented to increase the effective depth of the soils. Liming during soil preparation alleviates the acidity of the subsoils and phosphorous applications are invariably necessary. Vines are mostly spur pruned, although the bud load per vine may differ. A number of different training and trellising methods are used, including goblet vines, Perold trellis systems, and three-, four- and five-wire vertical trellise systems. Cordon height can vary between vineyards (60 cm to 90 cm), with resulting temperature differences in the bunch zone. Summer canopy management practices (shoot thinning, shoot positioning, tipping, leaf thinning) are increasingly carried out in order to obtain optimal sunlight penetration in the canopy.

3.4 GEOLOGY

The geological history, ca. 1 000 million years, of the South Western Cape coastal area includes sedimentary rock formation, granite intrusion, metamorphism, plate tectonic activity, mountain building, erosion and weathering (Van Schoor, 2001) (Fig. 3.4). The area is underlain by sedimentary formations of the Malmesbury group, which were deposited during the Precambrian Era, with subsequent compaction and indurations (Theron *et al.*, 1992). Tectonic movements during this period resulted in a mountain chain with a north-west trend. Intrusion of the Cape Granite Suite accompanied this folding (Theron *et al.*, 1992). The subsequent erosion and deposition of the Cape Supergroup sediments was followed by a period of orogeny during the Permian Period, with the consequent folding, uplifting and fracturing of formations. Sandstones and shales eroded, leaving remnants such as Simonsberg (Theron *et al.*, 1992).

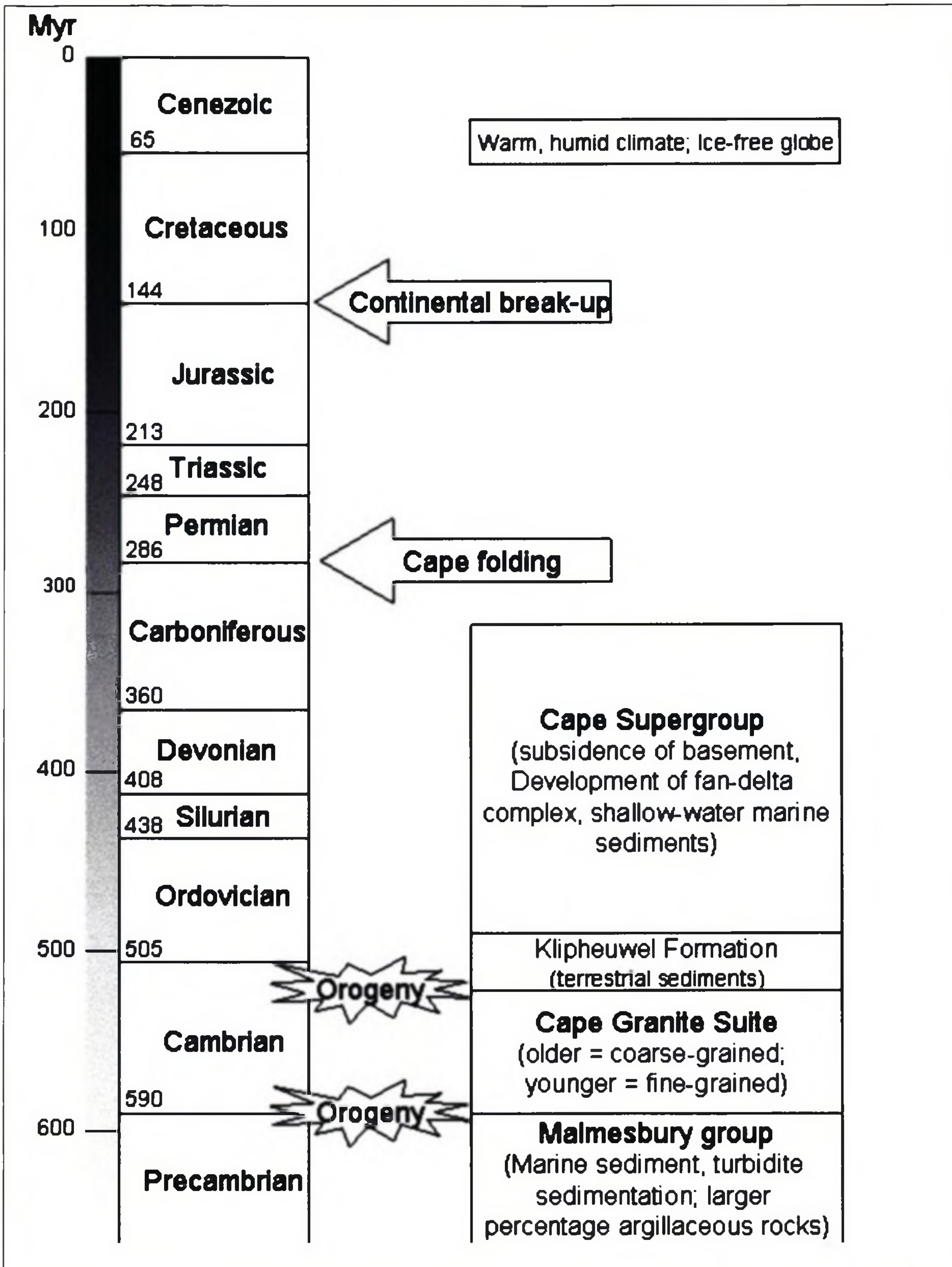

Figure 3.4 Geological time scale for events of relevance to the Stellenbosch Wine of Origin District (redrawn and adapted from Deacon, 1983)

The only source of spatial geological information is the 1:250 000 geological map series of the Council for Geoscience (Theron, 1990). Linked to this is a detailed description of the geology of the South Western Cape (Theron *et al.*, 1992), which, for the sake of clarity, is summarised in the following paragraphs.

MALMESBURY GROUP (980-830Myr) (Fig. 3.5)

The Malmesbury group (more than 6 km in thickness) is divided into two formations on the basis of differing facies, lithology and tectonic character. These two groups are separated by a major tectonic dislocation.

The **Tygerberg formation** (Tygerberg Terrane[1]) appears in the Stellenbosch district. It consists of alternating bands of greyish to greenish medium- to fine-grained greywacke[2], phyllitic shale[3], siltstone and immature quartzite. Contact metamorphic effects of the Cape granite intrusions can also be found at various localities in the Stellenbosch-Somerset West area. Close to granite contact, the Tygerberg formation has been transformed to massive bluish-grey hornfels[4].

The **Franschhoek formation** (Swartland Terrane) is found in a narrow north-westerly-oriented strip to the northeast of Stellenbosch and forms the range of hills beyond the Simonsberg. It consists of feldspathic[5] conglomerate[6] and grit horizons within a light-grey, medium-grained, feldspathic, sericitic[7] arenite[8] matrix. There is a

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[1] A terrane is a fault-bounded region that has a distinct stratigraphy, structure and geological history as compared to adjacent areas (Allaby & Allaby, 1999).

[2] Greywacke are texturally and mineralogically immature sandstones that contain more than 15% clay minerals. They may consist of angular to sub-rounded grains of quartz and feldspar, small pebbles and a fine matrix of clay minerals, chlorite and carbonate (Allaby & Allaby, 1999).

[3] Shales are otherwise known as mudstones (Zim & Schaffer, 1957). They are a fine-grained sedimentary rock that easily splits and are composed of clay-sized or silt-sized particles of unspecified mineral composition (Allaby & Allaby, 1999). Phyllite is a low-grade metamorphosed clay-rich sedimentary rock (e.g. shale) (Allaby & Allaby, 1999). Phyllitic shale is therefore a fine-grained metamorphic rock that retains its shale composition.

[4] Hornfels are clays or shales that have been metamorphosed and recrystallised through the action of heat from nearby igneous rocks (Zim & Shaffer, 1957; Allaby & Allaby, 1999).

[5] Feldspars are the most important group of rock-forming silicate minerals (Allaby & Allaby, 1999).

[6] The conglomerate consists of angular to semi-rounded particles of broken-down rock (clasts) of vein quartz, quartzite, chert, shale, arkose, greywacke and granite in a matrix of mainly mica and quartz (Theron *et al.*, 1992).

[7] Sericite is a white variety of muscovite or paragonite and is formed from the alteration of feldspar by either the action of very hot waters resulting from an igneous intrusion or later-stage weathering (Allaby & Allaby, 1999).

[8] Quartz and altered feldspar grains form the framework of arenite (Theron *et al.*, 1992), a subclass of sandstones with less than 15% of the rock being a mud matrix (Allaby & Allaby, 1999). These grains are angular and have undergone shearing (Theron *et al.*, 1992).

fault to the east and evidence of a fault in a north-westerly direction along the western margin of the Franschhoek formation. There is no evidence of an intrusive relationship between granite and these rocks. The conglomerate layers result in a series of parallel-trending ridges along the Stellenbosch base of the Simonsberg.

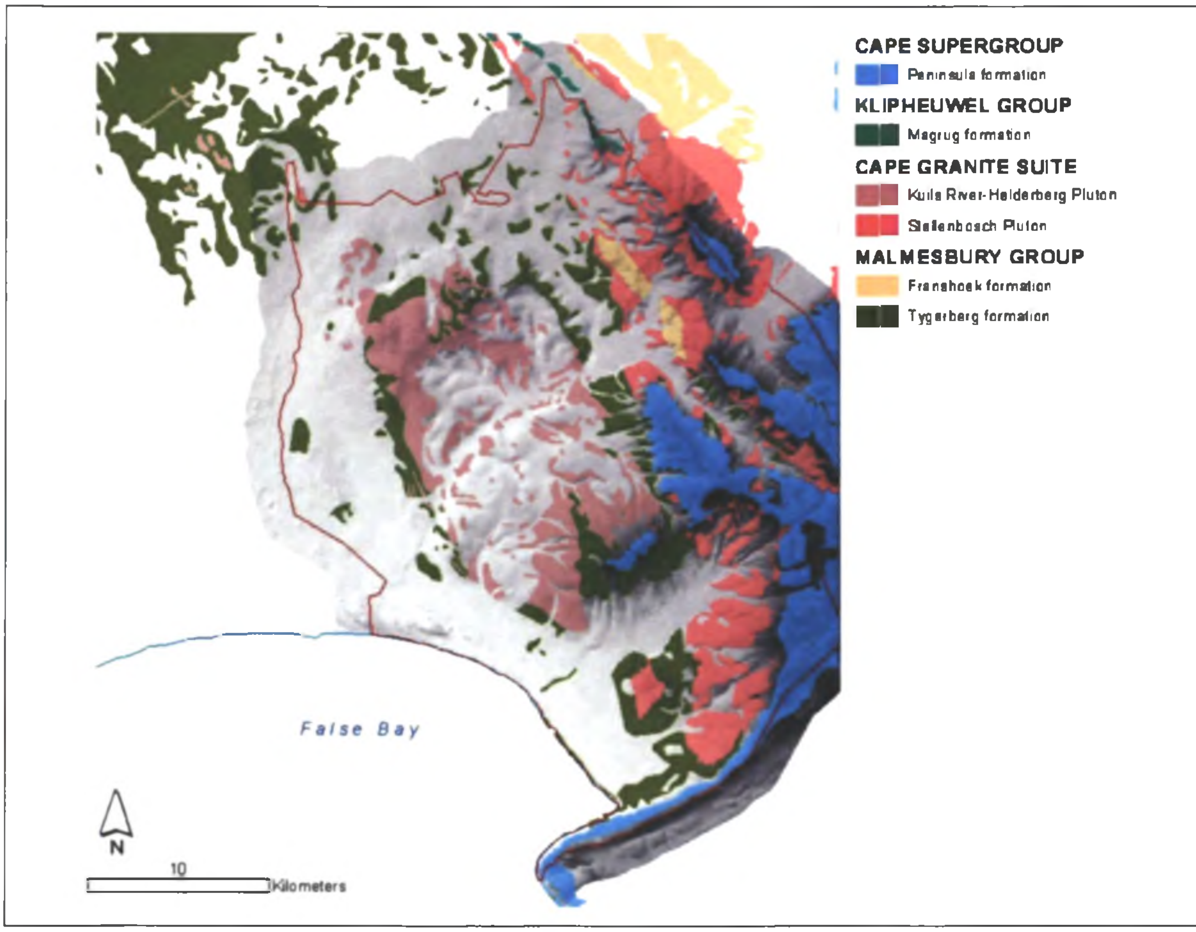

Figure 3.5 Simplified geology of the Stellenbosch Wine of Origin District constructed using digital data obtained from the Council for Geoscience in 2004, showing the pre-quaternary geological formations on a grey-scale hill-shaded background. For positions of cadastral features, refer to Fig. 3.1. Compiled by V Carey.

CAPE GRANITE SUITE (632-530 Myr) (Fig. 3.5)

The Cape granites intrude into the Malmesbury rocks, forming plutons. It is possible to recognise different varieties of granite in each pluton. Two plutons are present in the Stellenbosch surrounds.

The **Kuils River-Helderberg Pluton** is approximately 25 km by 11 km in dimension and is elongated in a north-westerly direction. It consists mainly of coarse-grained porphyritic [1] granite, a leucocratic [2] rock containing 42.5% K-feldspar

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[1] A porphyritic rock is one containing large and well-formed crystals (phenocrysts) set in a finer matrix (Allaby & Allaby, 1999).

[2] Leucocratic refers to the colour index of the rock, which in this case is light in colour (values between 5 and 30) (Allaby & Allaby, 1999).

(phenocrysts of 10-50 mm), 12.5% plagioclase, 26.25% quartz, 11.25% biotite and 7.5% muscovite. It forms the large exfoliated boulders along the Eerste, Blouklip and Bonte Rivers. Biotite-rich xenoliths[1] of a Malmesbury derivation occur erratically throughout the granite. This granite merges into the fine-grained variety in an easterly direction along the northern slopes of the Helderberg. Patches of the medium-grained variety occur sporadically in the coarse-grained variety. A fine-grained, leucocratic granite (36.35% K-feldspar, 17.5% plagioclase, 29% quartz, 5% biotite and 11.25% muscovite) occurs along the summits of Bottelaryberg and Kanonkop, the lower slopes of the Helderberg and near the Eerste River. To the south of Stellenbosch there is a north-westerly band (5.5 km by 1 km in dimension) of coarse porphyritic, biotite-rich granite that is intrusive into the Malmesbury sediments. It is separated from the fine-grained granite to the west by a faulted contact. A grey, sometimes slightly gneissic[2], hybrid granite to granite porphyry borders the pluton for ca. 4 km to the south of Stellenbosch town and to the east of the town of Eerste River. The north-western slopes of the Bottelaryberg have fine- to medium-grained leucocratic granite with tourmaline-rich nodules surrounded by white collars of coarsely crystalline feldspar, quartz and muscovite.

It is less easy to define the perimeter of the **Stellenbosch Pluton**, as it is fragmented to the north by a series of north-westerly faults and is overlain by the Table Mountain Group to the south and east. The Stellenbosch Pluton is characterised mostly by porphyritic, biotite, coarse-textured granite containing alkali-feldspar phenocrysts (30-80 mm). To the south of the Lourens River, the granitic outcrops consist mostly of a medium- to coarse-grained variety, sometimes containing pinkish alkali-feldspar phenocrysts, with darkly-coloured clots of biotite. On the south-western slopes of Skapenberg, a leucocratic, fine-grained, porphyritic granite is present. It contains scattered phenocrysts of pinkish alkali feldspar. Smaller bodies of fine-grained granite can be found within other granitic varieties along the upper reaches of the Sir Lowry's Pass River, the eastern slopes of Simonsberg and the Jonkershoekberg. On the Skapenberg, the granite is fine- to medium-grained, tourmaline rich with a low percentage of biotite and muscovite and containing black tourmaline nodules or veins. On the eastern side of the Jonkershoek valley, in Helshoogte and along the slopes of Simonsberg the coarse porphyritic granite has been shattered and is intensely sheared along a well-defined north-westerly-trending major fault zone. This rock may have a gneissose or cataclastic[3] structure, containing disrupted quartz and feldspar crystals and abundant sericite and biotite.

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[1] A xenolith is an inclusion of a pre-existing rock in an igneous rock. They often have rounded edges or have been metamorphosed (Allaby & Allaby, 1999).

[2] Gneissic is a general term applied to coarse-grained banded rocks that form during metamorphism when dark minerals (e.g. biotite) are separated from light coloured quartzo-feldspathic minerals (Allaby & Allaby, 1999).

[3] Cataclasite is rock that has been deformed by shearing and granulation (Allaby & Allaby, 1999).

KLIPHEUWEL GROUP (Cambrian, probably younger than 550 Myr) (Fig. 3.5)

The Klipheuwel group consists of pink to red-brown sandstones, grits, conglomerates and lilac to red shales and occurs within long narrow strips that have a north-westerly trend. The **Magrug** is the only formation present and consists of alternating conglomerate and coarse sandstone beds.

CAPE SUPERGROUP (Fig. 3.5)

Table Mountain group (Lower Ordovician, 493-468 Myr)

Within the Table Mountain group, the only formation found in the Stellenbosch surrounds is the **Peninsula formation**. It reaches thicknesses of up to 1.2 km in the Hottentots Holland Mountains. This formation is a uniformly light-grey, medium- to coarse-grained, well-bedded quartzitic sandstone and commonly has large scale trough and tabular cross-bedding with a southerly stream flow direction. It contains quartz grains, a small percentage of feldspar and occasional chert grains, with sericite and clay minerals as a matrix. Well-rounded, white vein-quartz pebbles are irregularly distributed in it. It may sometimes contain clasts of quartzite, granite and hornfels.

There is direct contact on the eastern flank of the Simonsberg with Pre-Cape rocks, a sporadic occurrence of thin arkosis, coarse sandstone and grit layers with granite, vein-quartz or Malmesbury hornfels pebbles. To the northern end of the Groot Drakenstein Mountains, south of Pniel and Kylemore, a basal conglomerate horizon contains blocks and boulders of granite, well-rounded pebbles and cobbles of vein-quartz with slabs of red-brown siltstone.

CENEZOIC DEPOSITS (Fig. 3.6)

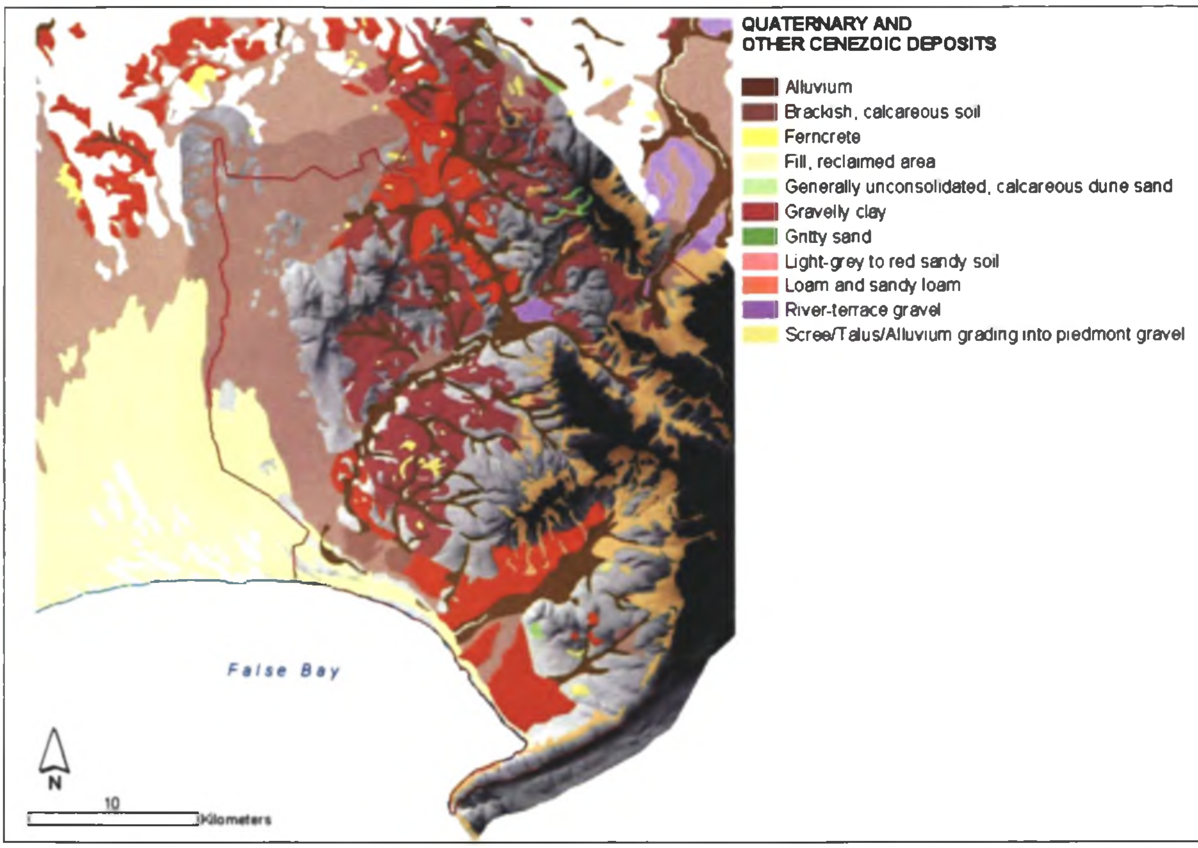

Figure 3.6 Simplified geology of the Stellenbosch Wine of Origin District constructed using digital data obtained from the Council for Geoscience in 2004, showing Quaternary and other Cenezoic deposits on a grey-scale, hill-shaded background. For positions of cadastral features, refer to Fig. 3.1. Compiled by V Carey

Quaternary deposits (the last 1.8 Myr)

The quaternary deposits consist mainly of aeolian sand, although there are some minor fluvial to marine deposits.

The **Springfonteyn formation** consists of the silica sand deposit characteristic of the Cape Flats (sandy plain indicated in Fig. 3.2). It is a light-grey sandy soil, although there may be some organic fines further inland.

The **Langebaan formation** consists of limestones and is found from sea level to higher than 200 m. The oldest dunes are heavily calcretised and topographically inconspicuous. They are covered by a 1 m to 2 m thick layer of leached quartzose sand on a base of hardpan calcrete. Along the southern Cape Flats, the calcretised dunes are found in a large-scale parabolic hairpin formation that runs parallel to the dominant south-easterly wind direction.

The **Witzand formation** consists of light-coloured, calcareous coastal dune sand. It differs from the Langebaan formation in that it is not consolidated underneath. It is the result of sand deflation from modern beaches that are not backed by cliffs and are exposed to southerly summer gales. The composition is that of a fine- to coarse-grained sand with a fairly high percentage of shell fragments.

Other Cenezoic deposits

Silcrete and **ferricrete** were formed near the surface by groundwater that concentrated iron oxide and/or silica derived from underlying weathered rocks. Silcrete is found on or in the neighbourhood of weathered Malmesbury rocks. It is a yellow to light-grey, fine- to coarse-grained, gritty or conglomerate rock. White vein-quartz pebbles are frequently found in the partly glassy, silica-rich matrix. Silcrete weathers into massive, smooth, partly rounded blocks with a curved-pattern (conchoidal) fracture. As the depth increases, the degree of silification decreases so that the rock becomes softer and eventually consists of only partially consolidated material. It is found mainly above the 60 m contour. Ferricrete, on the other hand, consists of loose nodules or fragments of a few millimetres to centimetres in diameter, or more compact zones of varying thickness.

Scree and pediment gravel fringe the mountain chains of the Cape Peninsula and can often mask the basal contact of the Table Mountain group. Scree may exceed 10 m in thickness and grades laterally into pediment gravel and coarse-grained sands. In the area between Somerset West and Stellenbosch there are outliers of scree on old land surfaces, resulting in extensive scree fans that have been dissected.

Terrace gravel has been formed in either fluvial or marine environments. There are three distinct fluvial terraces along the Eerste River. The first, 14 m above the river level, is the oldest and consists of basal, partly cemented conglomerate that is successively overlain by grit, sand and clay. The middle terrace, at 6 m, is nearly 1.2 km at its widest point and is covered by sand and boulders. The youngest terrace, at 4 m, is covered by dark alluvial sands. Small remnants of these terraces are scattered downstream along the Eerste River to Faure. Terrace gravel is also found on marine terraces that result from wave-cut platforms, benches, boulder-beach ridges, sea drifts, caves and undercut ledges.

Various soil types of the Cenezoic Era are present. A surficial cover has formed *in situ* on Malmesbury rocks during weathering. It may be yellow, red or brown in colour. It is clayey in texture and contains small nodules of ferricrete and fragments of vein quartz or sand grains. The partially consolidated basal layer rests on weathered rock. The weathering products of granite are reddish to light-brown in colour and are sandy to gritty and clayey in texture. This soil can be delineated over most of the area where granitic bedrock occurs. It may also contain thin layers of grit and pebbles. The clasts vary from vein-quartz to small granite pebbles that may be angular or rounded. They attain depths of between 1 m and 4 m in the Stellenbosch and Somerset West area, with a tendency to increase in thickness towards the valleys. In the area between Koelenhof and Joostenberg, the granite soils are transported and overlie Malmesbury and Klipheuwel bedrock. They fill old drainage channels that were incised into the underlying Malmesbury basement.

Where hummocks or hillocks of soil are present, they consist of a thin layer of soil on a discoidal (button-shaped) mass of indurated or partly indurated clayey soil. The underlying bedrock continues uninterrupted beneath the hillock. These hummocks or hillocks are attributed to ancient termite mounds and result in the "measled" appearance of the landscape. In South African parlance they are known as "**kraaltjies**".

Along the lower reaches of the Eerste River estuary near Macassar, a brackish, clayey soil of ca. 30 cm thick can be distinguished. It contains impure gypsum crystals.

Alluvium borders river courses to a width of anywhere between 100 m and 1 km. Its composition varies from being predominantly sandy (with a Table Mountain sandstone origin) to a clayey consistency (with a Malmesbury rock origin). It sometimes consists of only fine silt or sand, but may otherwise alternate with beds of gravel. In the Stellenbosch-Somerset West area, a dark coloured organic sand can be found, but this is limited to only a few metres above river level. Sandy alluvial deposits also border major streams of the Eerste and Lourens Rivers. The organic content decreases rapidly with the distance from densely vegetated mountainous areas. The alluvium of present-day floodplains covers similar old deposits.

3.5 TOPOGRAPHY

The elevation of the study area (Fig. 3.7) ranges from 5 m on the coastal plain to higher than 1 500 m above sea level in the Hottentots Holland Mountains. Most vineyards, however, are cultivated below 600 m and are closely associated with the hills and mountain footslopes present in the Stellenbosch Wine of Origin District (Fig. 3.7).

As the Western Cape has been affected by almost continuous ice-free erosion since ca. 200 Myr, the landscape is strongly affected by the underlying geology (Bargmann, 2003). The geomorphology has resulted in plains that are undulating or with straight slopes, and free-standing and undulating hills (Schultz, 1997) and mountains. Hills can be divided into the components of interfluve, which may develop into a saddle or crest, hillside (consisting of head slope, side slope and/or nose slope) and base slope (Wysocki *et al.*, 2000). Terraces are relatively level or only gently inclined, border a stream, lake or sea and consist of stream terraces and floodplain steps (treads and risers). Flat plains, such as the low-lying coastal plain of the Stellenbosch Wine of Origin District, are dominated by broad areas with low slope gradients, called talfs, closed depressions and slightly elevated areas called rises with slope gradients of less than 3% (Wysocki *et al.*, 2000).

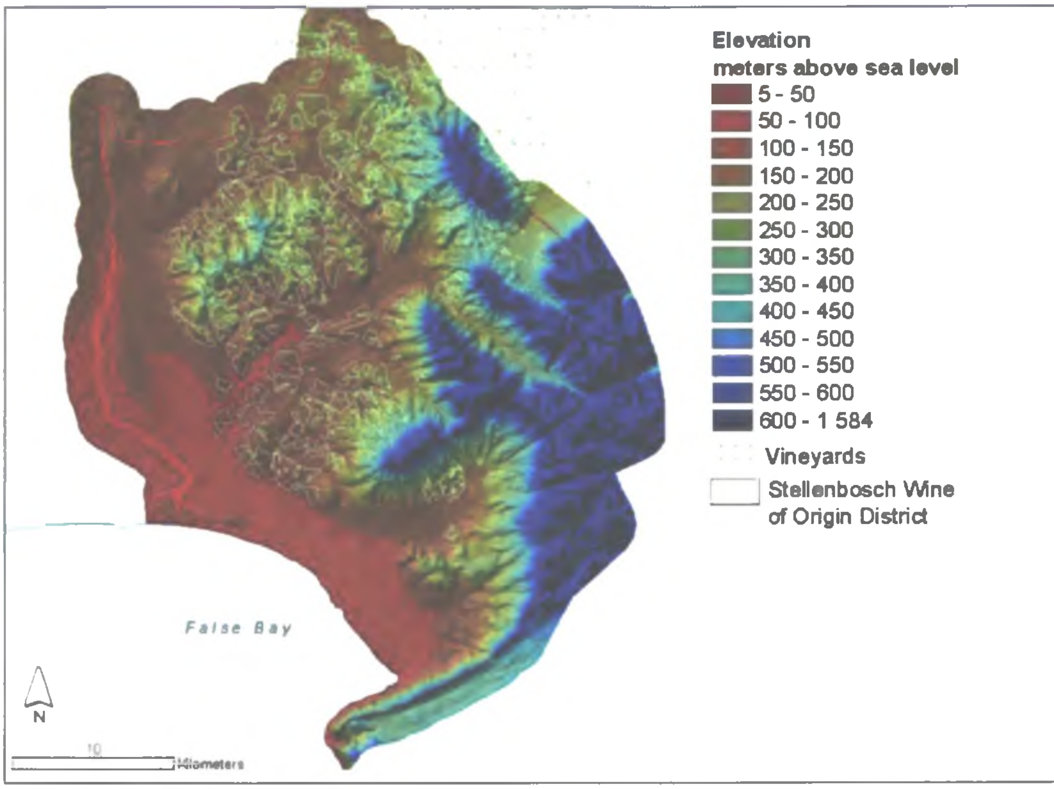

Figure 3.7 Map of elevation in the Stellenbosch Wine of Origin District, South Africa as determined from a 50 m Digital Elevation Model. For positions of cadastral features, refer to Fig. 3.1. Data obtained from Chief Directorate: Surveys and Mapping, ARC Institute for Soil, Climate and Water and Agri Informatics. Compiled by V Carey

The rapid changes in elevation result in varying slope aspects (Fig. 3.8). Slope aspect strongly affects the amount of direct solar radiation received by a slope, which in turn influences the soil (Wysocki *et al.*, 2000) and the aerial micro- or mesoclimates. This has consequences for soil formation and distinct differences in soils occur as a result of slope aspect (literature cited in Wysocki *et al.*, 2000). East-, north- and west-facing slopes will receive the most direct radiation in the Southern Hemisphere.

Slope aspect also has implications for exposure to dominant winds, which in the study area are gale-force north-westerly winds in winter and south-easterly winds in the spring and early summer. During the summer afternoons, differential pressures above the sea and land result in the development of a sea breeze, which brings cool, moist air overland (Bonnardot *et al.*, 2001, 2002b).

In the Southern Hemisphere, more radiation occurs on northerly aspects as the slopes become steeper, but less on southerly aspects (Schultz, 1997). There is, however, little influence of aspect on the radiation received by flatter slopes (Schultz, 1997). The effect of slope aspect on the interception of solar radiation is, therefore, more pronounced in areas with steeper slopes than in flatter areas. In the Stellenbosch Wine of Origin District, most of the study area has slopes of less than 5% (Fig. 3.9), although vineyards are more closely associated with slopes that range between 10% and 35%.

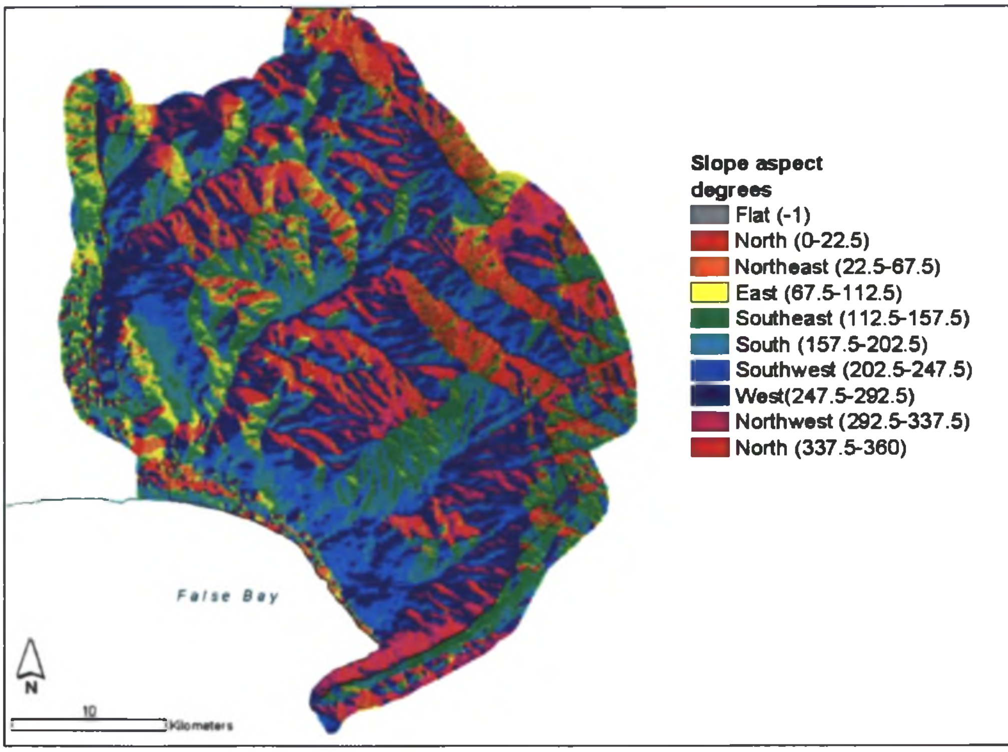

Figure 3.8 Map of slope aspect in the Stellenbosch Wine of Origin District, South Africa as determined from a 50 m Digital Elevation Model. For positions of cadastral features, refer to Fig. 3.1. Data obtained from Chief Directorate: Surveys and Mapping and Agri Informatics. Compiled by V Carey

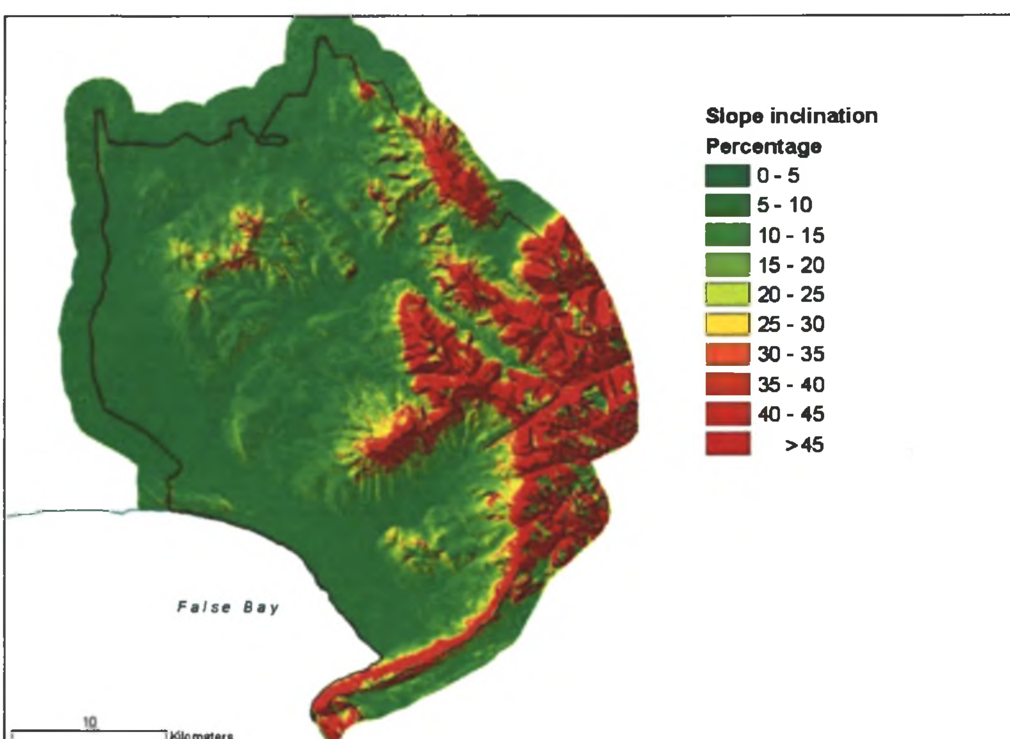

Figure 3.9 Map of slope gradient (in percentage) in the Stellenbosch Wine of Origin District, South Africa as determined from a 50 m Digital Elevation Model. For positions of cadastral features, refer to Fig. 3.1. Data obtained from Chief Directorate: Surveys and Mapping and Agri Informatics. Compiled by V Carey.

Slope profiles can be divided into segments based on slope shape and gradient (Wysocki *et al.*, 2000). Many different models, varying in complexity, have been proposed (MacVicar *et al.*, 1974; literature cited in Wysocki *et al.*, 2000). Within the South African land-type system, five units are recognised, namely crest, scarp, midslope, footslope and bottomland (or valley bottom) (MacVicar *et al.*, 1974) (Fig. 3.10). The crest position used in the South African system is similar to the summit and shoulder of Ruhe (decribed in Wysocki *et al.*, 2000), the midslope to the backslope, and the valley bottom or bottomland to the toeslope. The footslope has the same denomination.

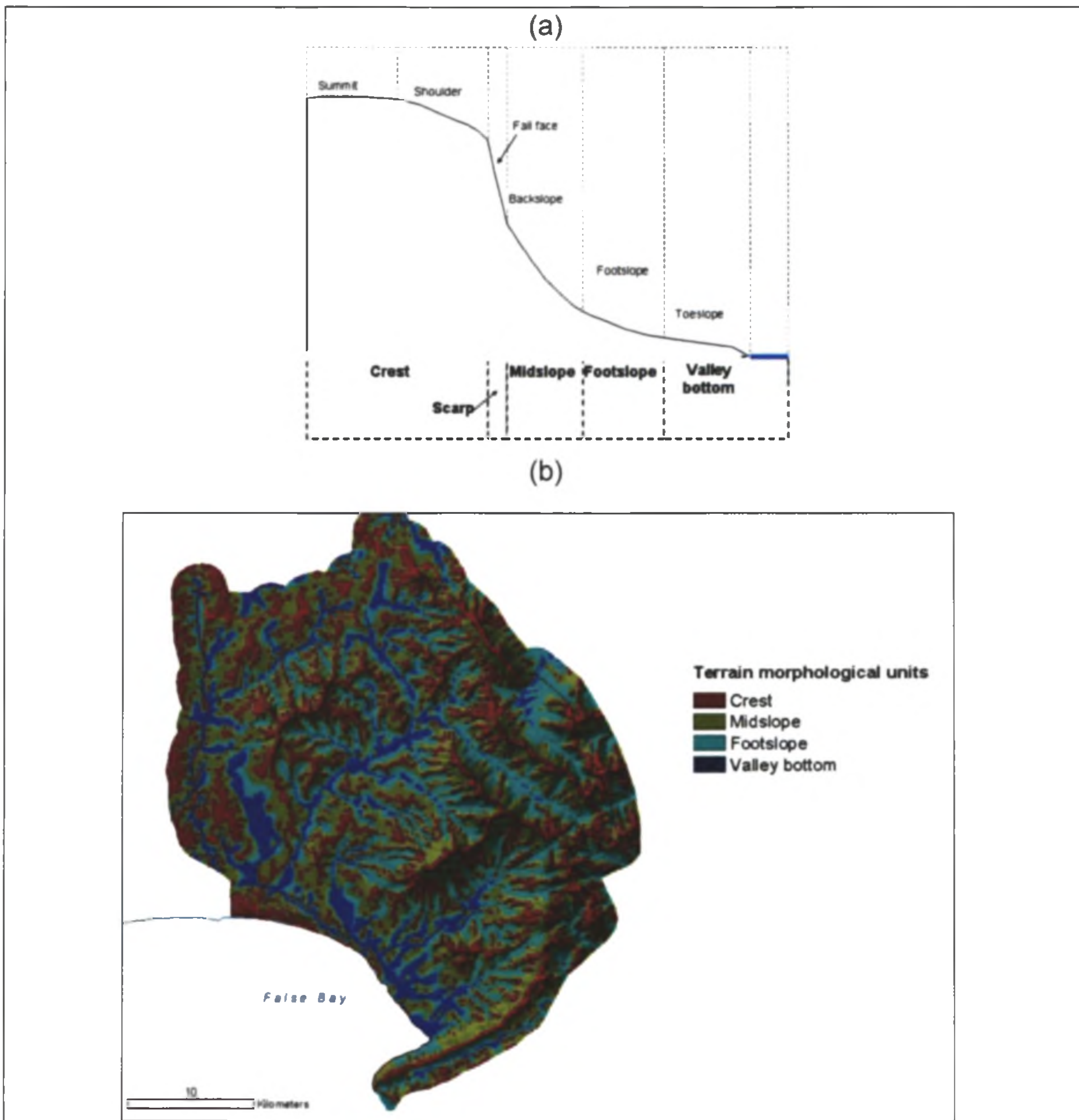

Figure 3.10 (a) Two-dimensional diagram of terrain morphological units described by Ruhe (Wysocki *et al.*, 2000) and MacVicar *et al.* (1974) (bold type). (b) The spatial distribution of terrain morphological units (MacVicar *et al.*, 1974) in the Stellenbosch Wine of Origin District, South Africa as determined from a 50 m Digital Elevation Model. (data layer compiled by M. Wallace, Department of Agriculture: Western Cape, 2003)

3.6 SOILS

The soils of the coastal area of the South Western Cape have developed over a long period of time, with much mixing and transport (marine, riverine and gravitational) of parent material having taken place (Van Schoor, 2001). The chemical and physical properties of the original rocks, together with the nature of disintegration of minerals and conditions in the surface mantle, e.g. pH, determine eventual soil texture and the availability of plant nutrients (Van Schoor, 2001). Granitic soils contain coarser fragments and generally have the highest potassium content (Wooldridge, 1988; Van Schoor, 2001), which is unbuffered (Wooldridge, 1988). Soils from Malmesbury rocks are more abundant in clay, silt and fine sand (Van Schoor, 2001). Sandstone-derived soils have more sand-sized particles and are generally poorly supplied with plant mineral nutrients. In the areas around Stellenbosch, granite-derived material fills old drainage channels in the Malmesbury basement, which, together with the folding of the Malmesbury formation and the presence of faults (especially to the north), affects the topography of the area and the soil characteristics (Van Schoor, 2001).

Soil boundaries on a mesoscale (ca. 1:25 000) approximate landscape units due both to topographic effects on soil formation (*via* differences in transfer of mass or energy) and the use of topographic features by a soil surveyor as boundaries (Wysocki *et al.*, 2000). The South African land-type concept (as described by MacVicar *et al.* and used by the ARC Institute for Soil, Climate and Water to map land-resources, 1974; Fig. 3.11 and Addendum 3.1) is a macroscale (1:250 000) application of this delineation. Soil forms are associated with positions on the hillside profile for specific landscape/climate/parent material combinations.

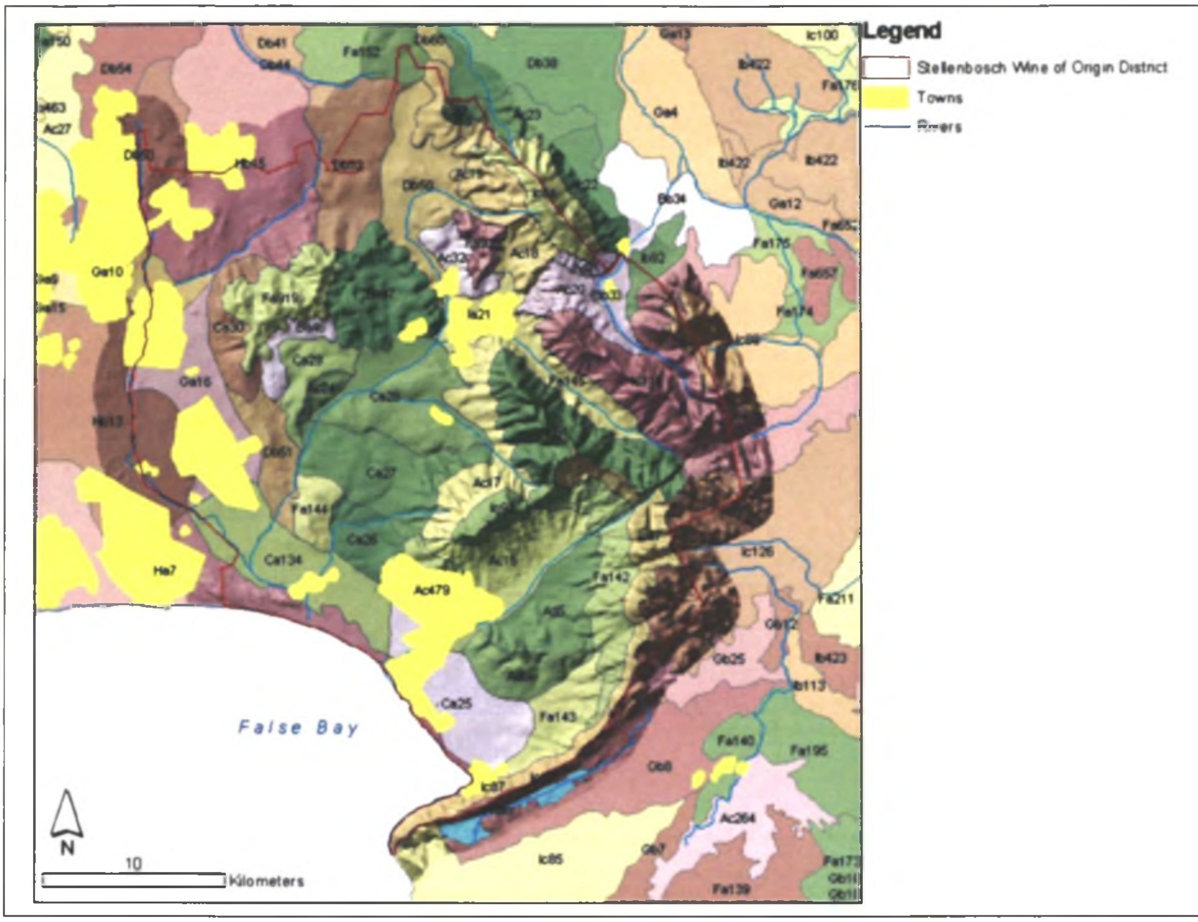

Figure 3.11 Land-types in the Stellenbosch Wine of Origin District. . Descriptions of the land-type codes are provided in Addendum 3.1. For positions of cadastral features, refer to Fig. 3.1. Digital land-type data obtained from the ARC Institute for Soil, Climate and Water. Additional digital data obfained from Chief directorate: Surveys and Mapping and Agri Informatics. Compiled by V Carey

It is clear from the land-type inventory and a Peri-Urban Soil Survey (Fig. 3.12) mapped on a scale of 1:25 000 and 1:50 000 by Ellis & Schloms (1975) and Ellis *et al.* (1976) respectively, that the most important soils found in the Stellenbosch Wine of Origin District belong to seven main categories: residual soils formed in situ on parent material; red and yellow apedal or neocutanic soils; "dry" duplex soils; "wet" duplex soils; duplex soils with a danger of high salinity; alluvial and other sandy soils; and poorly drained alluvial soils (Fig. 3.13).

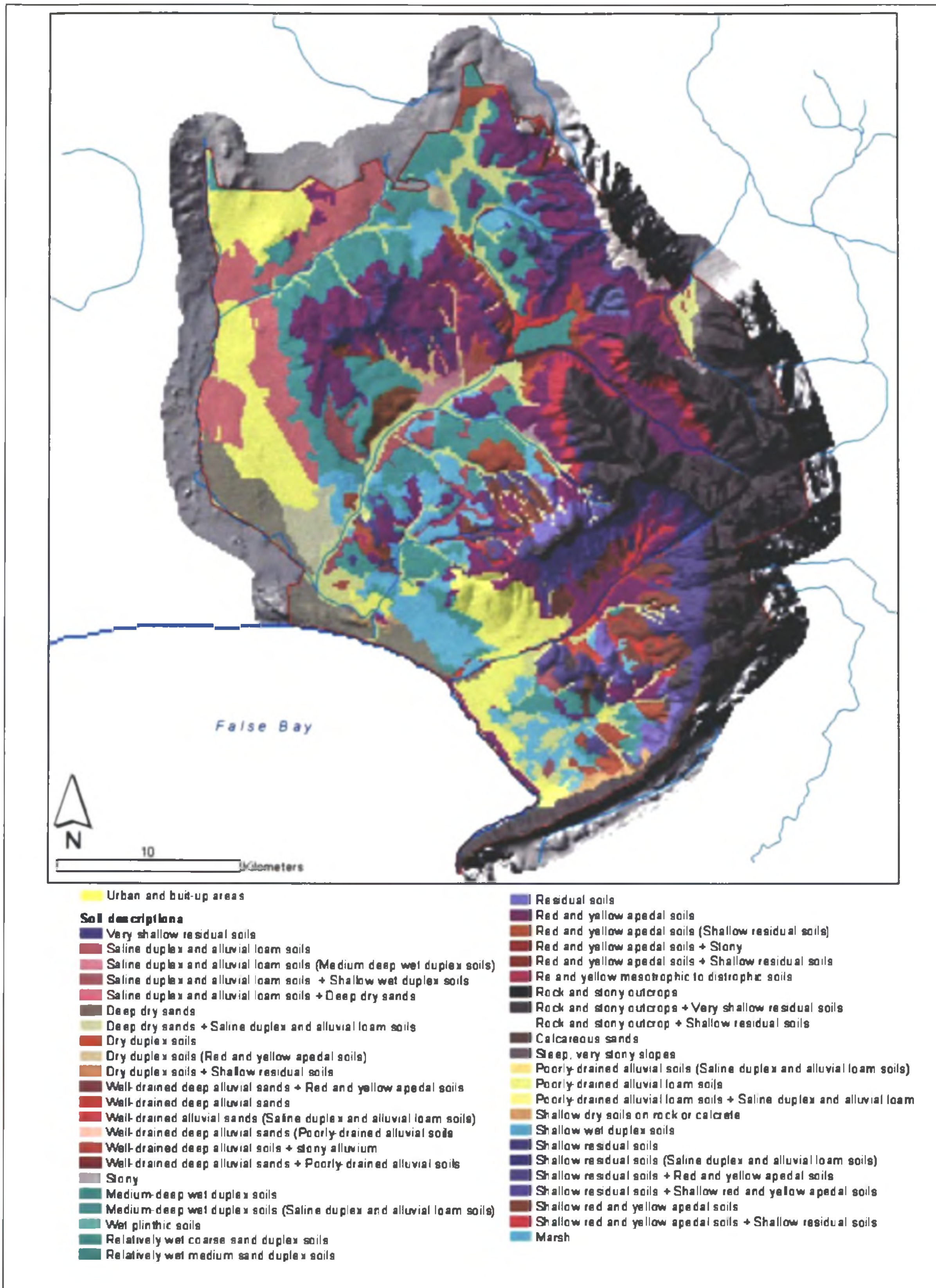

Figure 3.12 Descriptions of soils in the Stellenbosch Wine of Origin District. Compiled from Ellis & Schloms (1975), Ellis *et al.* (1976) and Ellis *et al.* (1980)

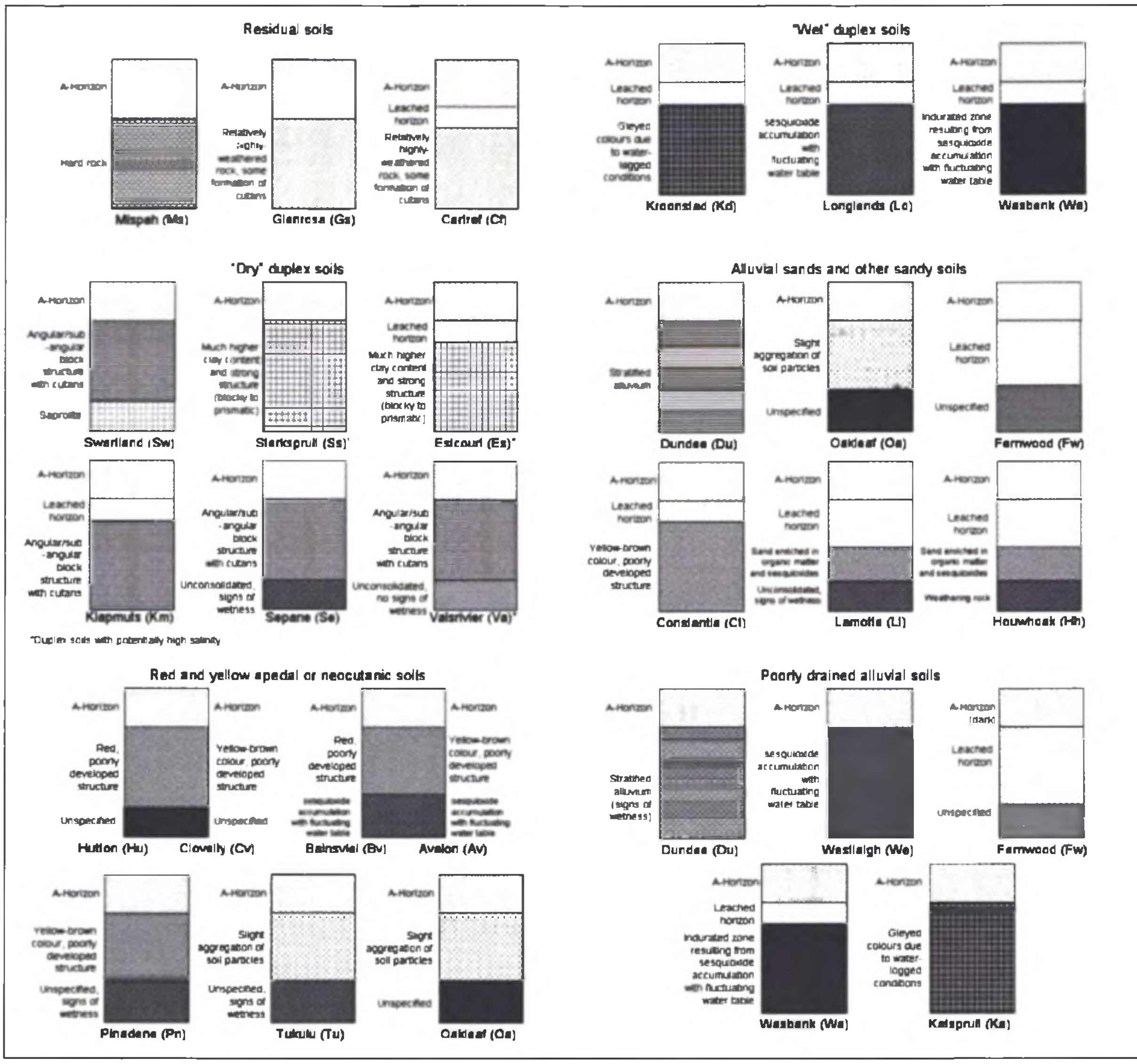

Figure 3.13 Soil forms (Soil Classification Working Group, 1991) in the Stellenbosch Wine of Origin District

The subcontinent was relatively stable by the beginning of the Cenezoic (65 Myr) and its form was similar to what it is at present (Hendey, 1983). The coastal lowlands have, however, been subjected to fluctuations in sea level that have affected their extent and form (Hendey, 1983). The soils were formed predominantly during the Cenezoic Era (Fig. 3.14) in association with sea-level and climatic changes. Climatic changes throughout the Cenezoic have affected the distribution and properties of soils and soil materials (Lambrechts, 1983).

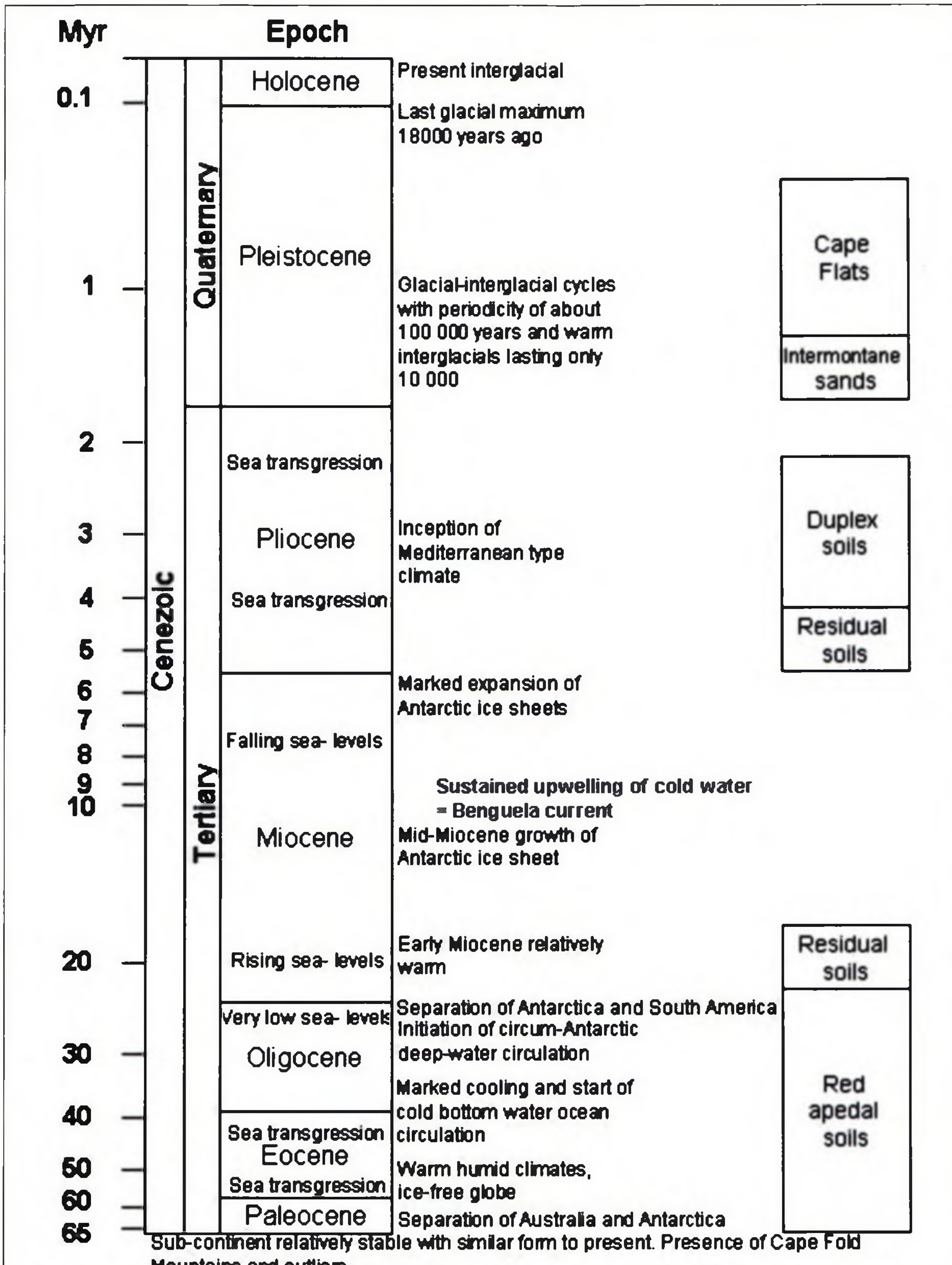

Figure 3.14 Events during the Cenezoic Era and age relationship of soil formations. Redrawn from Deacon (1983) and Hendey (1983)

The transgression and regression of sea levels during the Cenezoic caused changes in stream erosion base levels and landscape dissection (Lambrechts, 1983). Older soils were consequently stripped away and pre-weathered materials were exposed, together with the remodelling of earlier erosion surfaces. This resulted in the continuous exposure of new parent materials for soil-forming processes and the soils of the South Western Cape can therefore be considered as to be both young and old (Lambrechts, 1983).

The topsoil in this area varies widely in organic carbon content, colour, texture, structure, base status, mineral composition, etc., but commonly has no significant accumulation of organic material. The composition, texture and structure will depend strongly on the nature of the subsoil, as there is a natural genetic relationship between topsoil and subsoil (Soil Classification Working Group, 1991).

The characteristics of the subsoil are determined by the nature of the parent material and the pedogenetic processes that played a role in its development. The slope position determines, *inter alia*, the amount of erosion to which the bedrock is subjected, the flow of water, erosional transport and lateral sorting (Wysocki *et al.*, 2000). The complex topography of the Stellenbosch Wine of Origin District has implications for soil development.

The crest or summit is the least erosive part of a hill slope, with minimal erosional transport, and thus has soils with the greatest degree of profile development (Wysocki *et al.*, 2000). These soils are generally residual in nature and grade through various stages of weathering into hard rock, e.g. Ms, Gs, Cf (Soil Classification Working Group, 1991). The horizons that develop have a distinct affinity with the underlying parent material in terms of colour, structure or consistence. In some cases, a certain degree of illuviation and localisation of clay, sesquioxides and organic matter results in the formation of cutans, e.g. Gs. The generally impervious horizons of weathering rock can result in a temporary build-up of water after rain. These reductive conditions together with the lateral flow of water result in a loss of colouring materials (iron oxides and organic matter) and clay particles, resulting in a bleached horizon with a coarser texture, e.g. Cf (Soil Classification Working Group, 1991). The shoulder (part of the crest position of the South African terrain morphological units) has a greater degree of erosion and lateral flow of water and the soils tend to be similar to, but thinner, than the soils in the summit position (Wysocki *et al.*, 2000). On convex slopes where most of the pre-weathered substrate has been removed, shallow Mispah and Glenrosa soils will be found (Schloms *et al.*, 1983).

Surface runoff and erosional transport are greatest on the backslope (or midslope) and there may be some degree of lateral sorting (Wysocki *et al.*, 2000). The parent material consists of local creep or colluvium from nearby ferralitic environments and is moderately to highly pre-weathered (Schloms *et al.*, 1983). Well-drained conditions, caused by the slope gradient and form, result in an oxidising environment that gives red-brown, e.g. Hu, Bv to yellow-brown, e.g. Cv, Av, Pn, colours to the iron oxides coating the soil particles (Soil Classification Working Group, 1991). There is often only a weakly developed structure, if any, and the clay minerals are mostly of the 1:1 non-swelling types. This type of soil development may occur from any parent material, although it develops more easily from siliceous parent materials (granite, schist, gneiss, quartzite, sandstone and sandy deposits) than from basic parent materials (dolerite, basalt, gabbro and diabase). Yellow-brown colours tend to develop more easily from sands, sandstones, quartzites, shales and granites (lower ferrous iron reserve) and where there is a higher average moisture status of the horizon (Soil Classification Working Group, 1991). It is often difficult to distinguish the parent material of these soils, as there may be a large degree of mixing of parent materials on the slopes. These soils are intensely weathered and are relics of a past, high rainfall, tropical era (the Eocene, see Fig. 3.14). The primary silicates were broken down rapidly, with feldspathic minerals being weathered to kaolinitic clays and micaceous minerals to mica clays (Lambrechts, 1983). There was an almost complete loss of basic cations and much of the silica content due to drainage and leaching, resulting in generally acidic, stable, well-drained soils with a low base status and a good water-holding capacity (Lambrechts, 1983). These red apedal to neocutanic soils are widespread on high-lying pediment plains and dissected footslopes in the South Western Cape, characteristically at altitudes between 200 and 250 m (Schloms *et al.*, 1983).

Footslopes are concave and have lower gradients, resulting in increased sediment accumulation (Wysocki *et al.*, 2000). This sediment may be of sandstone or granitic origin and may have been alluvially or colluvially transported. It may also represent plain remnants of the Malmesbury Group (Schloms *et al.*, 1983). In some cases, this unconsolidated, transported material may have undergone a certain degree of aggregation of soil particles and development of cutans, e.g. Tu, Oa (Soil Classification Working Group, 1991). With the basement rock in these landscape positions being of a shale origin and the colluvium or alluvium being generally of a granitic or sandstone origin, the soils that developed have a coarsely textured topsoil, usually bleached, on a subsoil with a high clay content and signs of water inundation, e.g. Kd, Lo, Wa, the so-called duplex soils (Soil Classification Working Group, 1991). The subsoil may have gleyed characteristics or may have mottling or induration by sesquioxides in areas with a fluctuating water table. Duplex soils may also consist of coarsely textured topsoil on a strongly structured subsoil, e.g. Sw, Ss, Es, Km, Se, Va. In these soils, the subsoil has a blocky to prismatic structure, with the presence of obvious cutans on the soil peds or stones due to the enrichment of the horizon with clay by means of illuviation. On sandy parent materials in this landscape position, be they residual sandstone material, colluvial sandstone or young granitic material, a subsoil may become enriched with organic matter and sesquioxides by illuviation, with little or no clay accumulation. These soils tend to have a darker-coloured topsoil and subsoil and occur particularly under fynbos vegetation (Soil Classification Working Group, 1991).

On the toeslope (valley bottom), alluvial processes are the most significant and soils are generally moist and composed chiefly of alluvial sediments (Wysocki *et al.*, 2000). These soils may be dry sands or subjected to water inundation. The dry sands may show signs of the original depositional stratifications, e.g. Du, or may have lost signs of stratification and have undergone a certain degree of reorganisation of the soil particles, e.g. Oa (Soil Classification Working Group, 1991). In some cases there may have been a loss of iron oxides, silicate clay and organic matter in the horizon immediately below the topsoil, e.g. Fw. In positions with a more pronounced water table, a zone that has undergone sesquioxide accumulation and concentration, e.g. We, or become indurated with sesquioxides, e.g. Wa, or a gleyed horizon, e.g. Ka, will develop (Soil Classification Working Group, 1991).

3.7 CLIMATE

It was recognised from at least the early 1930s that distance from the sea exerts a strong influence on grape production in the South Western Cape (Theron, 1932) and it is still generally accepted that vines grown where they "can see the sea" will produce wines that are distinguishable from wines produced elsewhere (Saayman, 1977), although this has not yet been quantified. This section will investigate the global climate of the Stellenbosch Wine of Origin District and the mesoclimatic variation within the district as affected by topographic and oceanic influences.

The proximity to False Bay has a strong influence on the climate of this district, resulting in a Mediterranean-type climate (Kendrew, 1961) with mild winter temperatures, dominant winter rainfall and dry, warm summers (e.g., T01 in Fig. 3.15). The topography of the region has implications for sunlight interception (Wooldridge & Beukes, 2003) and, together with the proximity of the ocean, affects the onshore and offshore air movement (Bonnardot *et al.*, 2001; Carey, 2001). This results in diverse mesoclimatic conditions, which were described in detail by Carey (2001) for a portion of the Stellenbosch Wine of Origin District.

Spatial climatic data

The availability of spatial climatic data is limited in South Africa. A set of rainfall and temperature data is available for the whole of South Africa at a resolution of 1 min (ca. 1.7 km) and has been used to compile the Winkler Growing Degree-day index and mean February temperature for the South Western Cape (De Villiers *et al.*, 1996). This macroclimatic data is unsuited for a mesoclimatic study of the Stellenbosch Wine of Origin District

More recently, the three-dimensional Regional Atmospheric Modelling System (RAMS 4.3) (Pielke *et al.*, 1992; Cotton *et al.*, 2003), together with the RAMS/HYPACT Evaluation and Visualization Utilities (REVU) were used for mesoscale modelling of the sea breeze (Bonnardot *et al.*, 2002b). Due to the significance of the sea breeze for viticulture in the Stellenbosch Wine of Origin District, the determination of the extent of its effect has been a significant goal for the South African terroir research programme. The modelling program RAMS uses a system of nested grids to provide high spatial resolution for smaller areas within a larger domain, which has been modelled at a lower resolution. Three nested grids, 5 km, 1 km and 200 m, were used in the South Western Cape, focussing on the Stellenbosch area. These grids were situated within the computational domain of the coarse parent grid with a resolution of 25 km. Large-scale meteorological conditions were simulated at the level of the parent grid by integrating gridded values of humidity, wind speed and direction, air pressure and temperature (produced by the European Centre for Medium-range Weather Forecasting) for every six hours at 30 levels in the atmosphere up to 9000 m in RAMS. RAMS was initialised with upper atmospheric data obtained from Cape Town International Airport, as well as sea-surface temperature, topography, vegetation and soil data. Modelled values of temperature, relative humidity and wind speed were calculated for each hour of the day for each day of February 2000 (the month during which most grapes ripen) and hourly mean values were then determined for these parameters for the 1 km and 200 m grid (V. Bonnardot & S. Cautenet, personal communication, 2004).

Weather stations

A network of automatic weather stations has been established in the Bottelaryberg-Simonsberg-Helderberg study area since 1994 (Fig. 3.16 and Table 3.1). These weather stations are either microclimatic (situated in vineyard rows – T02, T03, T04, T05 and T06) or mesoclimatic (on open ground in the vicinity of vineyards) and represent various landscape positions. Weather stations T25 and T26 are mechanical weather stations and do not, therefore, record wind speed or direction. Hourly values are recorded for the parameters of temperature, dry and wet bulb temperature (or relative humidity), rainfall, radiation, sun duration, wind speed and wind direction. The temperature sensors are housed in a Stevenson screen 1.2 m above ground level and the placement of all sensors is standardised (Bonnardot *et al.*, 2004). The ARC Institute for Soil, Climate and Water, AgroMet, manages the climatic databank and supplied the data used in this study. The data from this network can be related directly to experimental plots within commercial vineyards within close proximity.

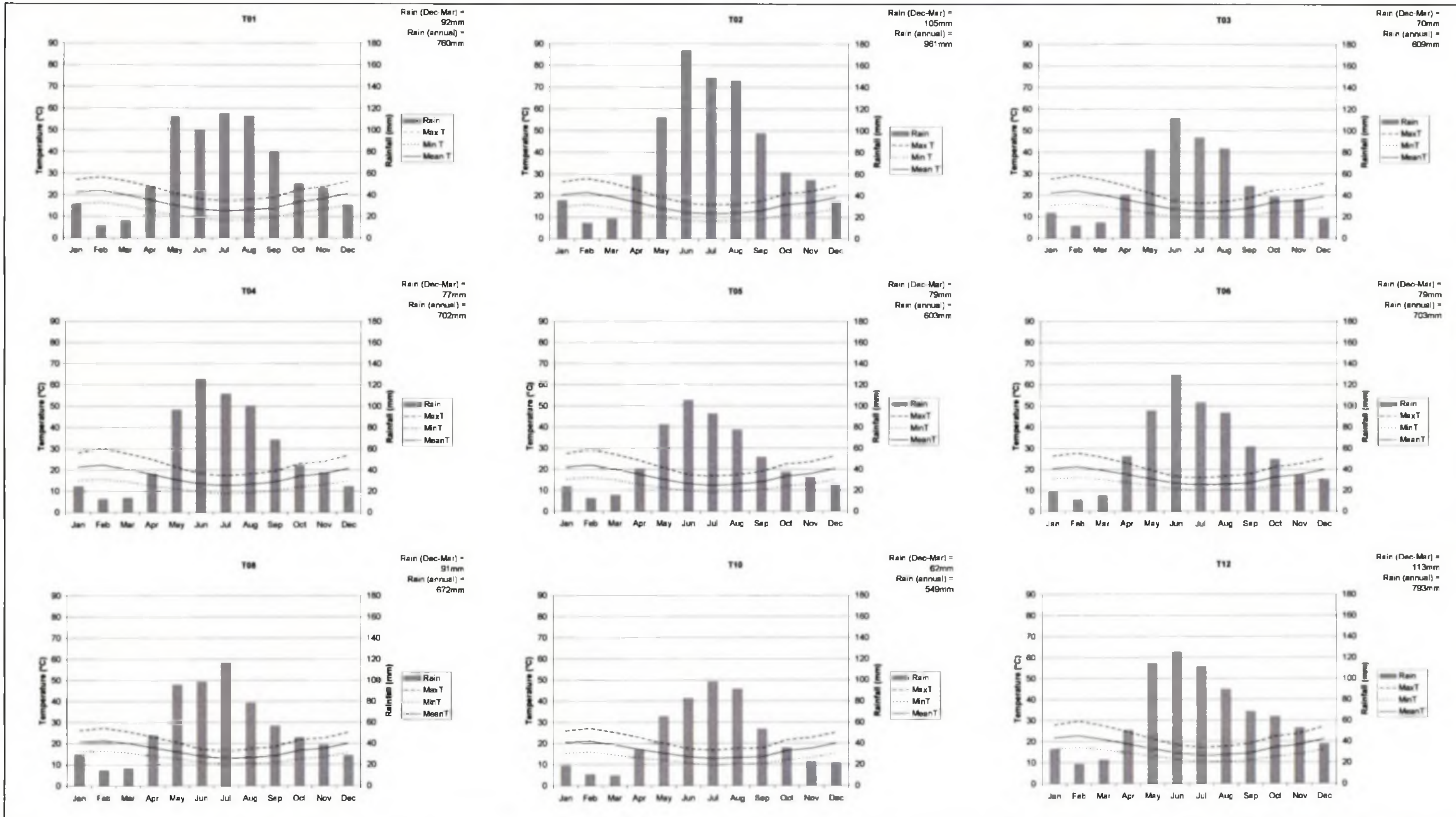

Figure 3.15 (Continued on following page)

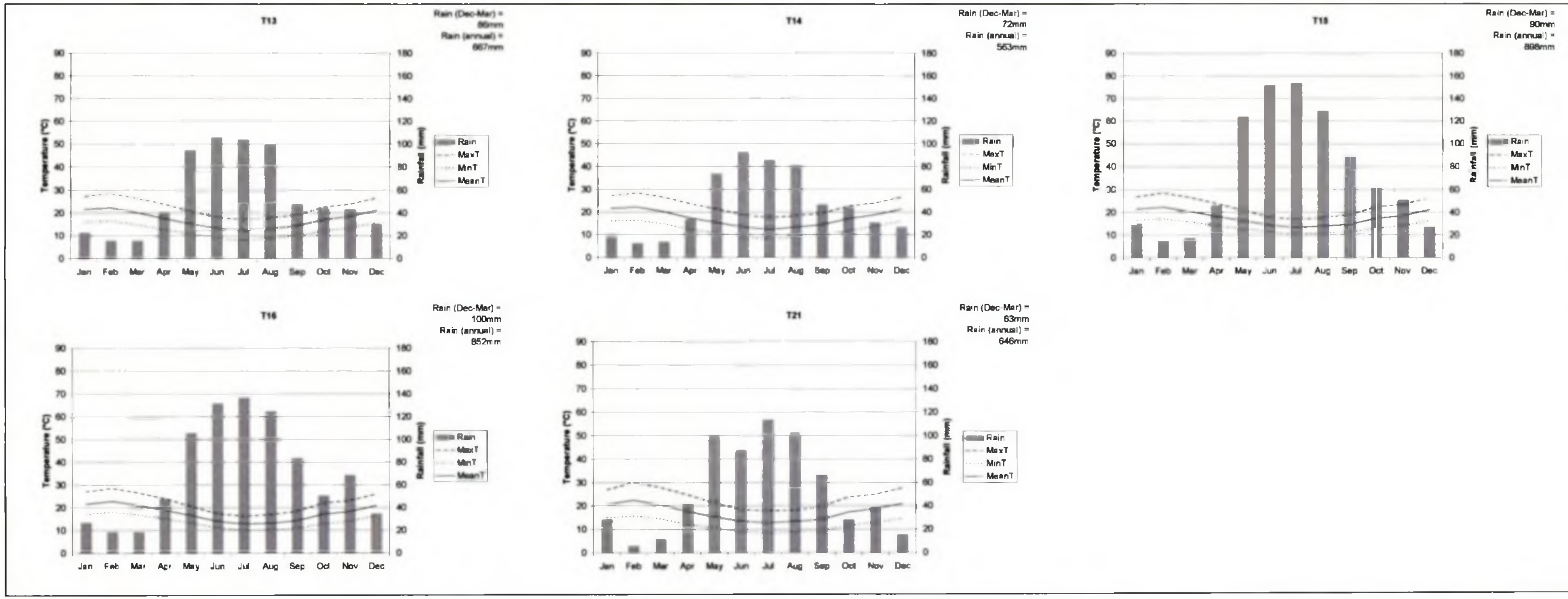

Figure 3.15 Long-term monthly minimum, mean and maximum temperatures and rainfall measured at automatic weather stations in the Stellenbosch Wine of Origin District. Compiled from data obtained from automatic weather stations within the ARC Institute for Soil, Climate and Water network (2003). The geographical positions of the weather stations are shown in Fig. 3.16

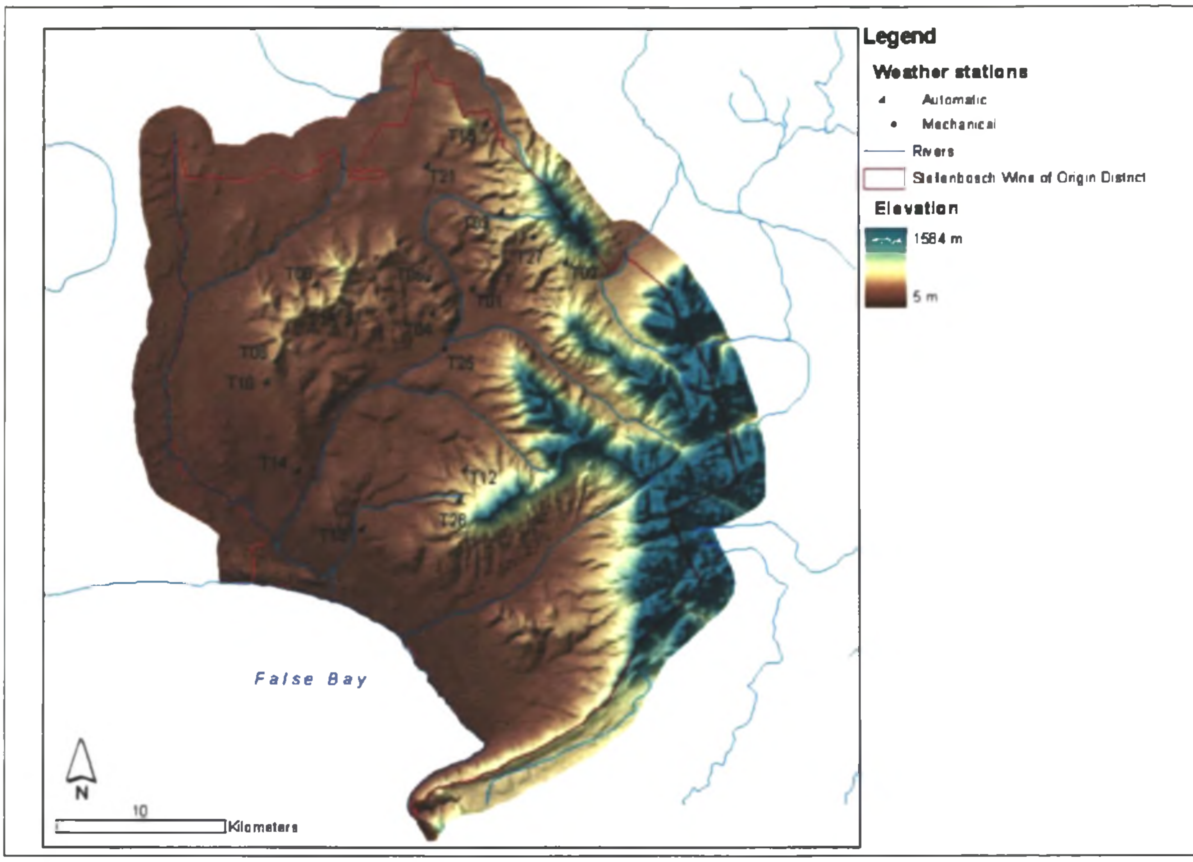

Figure 3.16 Positions of weather stations (Tn) within the Stellenbosch Wine of Origin District. Details of the weather stations are provided in Table 3.1. For positions of cadastral features refer to Fig. 3.1. Data obtained from Chief Directorate: Surveys and Mapping and Agri Informatics. Compiled by V Carey

Table 3.1 Description of the weather stations in the ARC ISCW-Agromet network in the Stellenbosch Wine of Origin District. Their geographic positions are shown in Fig. 3.16

AWS code	Area represented	Altitude (m)	Aspect	Slope (%)	Period for which data is available
T01	Stellenbosch	148	SW	3	1965-2002
T02	Helshoogte	413	SSE	5	1994-2002
T03	Knorhoek	342	NW	14	1994-2002
T04	Papegaaiberg	148	NW	10	1994-2002
T05	Devon Valley	210	WNW	12	1994-2002
T06	Kuils River	250	ESE	15	1994-2002
T08	Bottelary	235	N	9	1994-2002
T10	Kuils River	130	SW	9	1994-2002
T12	Helderberg	225	NNW	14	1994-2002
T13	Firgrove	56	WSW	5	1994-2002
T14	Faure	27	S	5	1994-2002
T15	Stellenboschkloof	153	S	15	1994-2002
T16	Klapmuts	260	NE	14	1994-2002
T21	Muldersvlei	177	NW	10	1997-2002
T25	Stellenbosch	92	NNW	10	1995-2002
T26	Helderberg	320	WNW	20	1999-2001
T27	Idas Valley	320	SW	13	1995-2000

Synoptic and local winds

At a synoptic level, strong to gale-force southerly or south-easterly winds blow in the summer, while strong northerly and north-westerly winds occur in winter (Kendrew, 1961; South African Weather Bureau, 1996). The mountain ranges in the South Western Cape cause the winds to blow along rather than across the coast, increasing their velocity. At the local scale, the proximity to the sea results in an interplay between land and sea breezes. Hot northerly and north-easterly "berg" (or mountain) winds may occur, usually in the morning, as the sea breeze neutralises them near the coast in the afternoon (Kendrew, 1961). An investigation of hourly wind speed data per compass direction for February 2000 showed that wind speed and direction are the result of a complex interaction between topography and relief, resulting in an interplay between the synoptic wind, up- and down-slope winds and the sea breeze (Carey, 2001). Wind velocity values of ca. 10 m/s were recorded during this month, with the highest values being recorded at weather station T08, situated in a crest position on the Bottelaryberg within the limits of the sea breeze effect (Carey, 2001). This weather station recorded the highest number of hours with a wind speed greater than 4 m/s and the highest mean maximum wind speed during February for the period 1995 to 2002 (Table 3.2).

Although a surface analysis of climatic surface data has shown that the sea breeze plays a significant role in the local environment (Bonnardot *et al.*, 2001), it is notoriously difficult to identify and draw a "limit" of the influence of the sea breeze on the basis of a surface data analysis alone and modelling methods have been used to examine the atmospheric profiles and explore sea breeze-induced patterns (Bonnardot *et al.*, 2002).

It has been shown that the sea breeze can penetrate up to 100 km from the sea, but that the associated effects on temperature and relative humidity decrease rapidly with distance from the coast (Bonnardot *et al.*, 2001). Topography has a significant effect on the inland penetration of the sea breeze, as well as on local circulation. Southern slopes, exposed to southerly winds, result in the formation of upward-moving cells (Bonnardot *et al.*, 2001) and thus higher relative humidity, lower temperature and stronger wind velocity values. The heating of land and slopes causes thermal convection and the blending of moist sea air and dry air from the land. This results in instability of the sea breeze, inclusion of dry air in the humid maritime layer, eventual disintegration of the sea breeze and a temperature increase with distance from the sea (Edinger, 1963). At this point there is a steep temperature gradient, resulting in notable temperature differences between south-facing and north-facing slopes. For the comparison of three different synoptic conditions, it was only on an overcast, cool day that the sea breeze effect was not modelled (Bonnardot *et al.*, 2002a). For a southerly synoptic flow, the sea breeze penetrated from the direction of False Bay, while for a northerly synoptic flow, the sea breeze penetrated from Table Bay in the west and, to a lesser extent, from False Bay in the south, with dramatic temperature effects (Bonnardot *et al.*, 2002a). The southerly synoptic airflow represents the conditions most generally found during the ripening period. The fullest extent of the sea breeze influx is usually seen between 15:00 SAST and 17:00 SAST (V. Bonnardot, personal communication, 2002). It appears that relative humidity values of 60% represent the limit of the sea breeze influence (S. Cautenet, personal communication, 2004). The influence of the sea breeze is "blocked" to the north-east as a result of the local flow of warm "inland" air down the Eerste River Valley. This results in higher relative humidity and lower temperature values over the Bottelary hills, the south-west and west of the Stellenbosch Wine of Origin District than further inland, upstream the Eerste River Valley, where it already blends with the warmer and drier continental air.

Temperature

The mean temperature of the warmest month (February) varies between 21.0°C and 22.7°C in Stellenbosch (Table 3.2). The winter temperatures are mild, with the mean daily temperature seldom dropping below 6°C. These mild conditions can have serious consequences for budburst, with insufficient cold resulting in delayed or uneven budburst in sensitive cultivars (Pienaar, 1988; Lavee & May, 1998), but there is no risk of frost in the autumn or spring.

The effect of the penetration of the sea breeze on summer temperatures is clear (Bonnardot *et al.*, 2001). It results in both a delay and a reduction in the daily maxima. In Table 3.2 it is noticeable that the automatic weather stations that are either placed at altitude (T02, T03, and T27) or within the limits of the sea breeze effect (T06, T08 and T10) record the coolest maximum temperatures during February. The warmest air lies in the Stellenbosch and Eerste River Valleys, reflected in the high February mean maximum temperatures recorded at weather stations T21 and T25.

Temperature-related indices were also determined for each of the weather stations in the Stellenbosch Wine of Origin District (Table 3.2). Nine of the 17 weather stations fall within Class III for the growing-degree day index (Le Roux, 1974). The weather stations at T04, T12, T13, T14, T16, T21, T25 and T26 fall within Class IV. The classification of T13 and T14 is surprising, as these weather stations are in positions relatively near to the coast (Fig. 3.16) and theoretically fall within the extent of the sea breeze effect. They may, however, be influenced by microclimatic conditions in their immediate proximity. The other weather stations classified in Class IV all fall outside the theoretical limit of the sea breeze influence. For the Huglin Index, where the maximum temperature has a heavier weighting, only T04, T12, T21 and T25, the weather stations positioned outside the limits of the sea breeze effect, fall within Class +2 (Tonietto & Carbonneau, 2004), which suggests that weather stations T13 and T14 do, indeed, benefit from the moderating influence of the sea breeze. Class +2 suggests that there may be periods of high temperature stress during ripening (Tonietto, 1999; Tonietto & Carbonneau, 2004). All weather stations are classified as having a moderate temperature during February (De Villiers *et al.*, 1996), the warmest month, and as having temperate nights (Class -1) (Tonietto & Carbonneau, 2004).

Table 3.2 Mean values for some climatic parameters and indices for the period 08/1995-03/2002 for the mechanical and automatic weather station (AWS) network in the Stellenbosch Wine of Origin District. Compiled from data supplied by ARC-ISCW AgroMet

AWS[I]	GDD[II] (Sep-Mar) (°C)	MFT[III] (°C)	Max. temp. (Feb) (°C)	HI[IV] (Oct-Mar) (°C)	CI[V] (Mar) (°C)	DI[VI] (Oct-Mar) (mm)	TVI[VII] (Jan) (°C)	TVI[VII] (Feb) (°C)	TVI[VII] (Mar) (°C)	Rainfall (Apr-Aug) (mm)	Rainfall (Dec-Feb) (mm)	Min. RH (Feb) (%)	Wind[VIII] $>4 m.s^{-1}$ (Dec-Mar) (hrs)	Mean max. wind speed (Feb) (m/s)
T01	1897 (III)	22.1	28.4	2322 (+1)	14.9 (-1)	-221 (+2)	39.8	37.6	37.1	496	75	43.9	793	5.4
T02	1700 (III)	21.3	27.7	2129 (+1)	14.2 (-1)	-106 (+2)	40.0	37.8	37.8	636	97	55.6	22	2.6
T03	1742 (III)	22.0	29.2		14.8 (-1)	-121 (+2)	40.0	39.5	38.7	401	66	52.6	42	2.4
T04	1955 (IV)	22.3	29.9	2422 (+2)	14.4 (-1)	-196 (+2)	42.8	41.4	40.5	501	71	51.3	58	3.1
T05	1878 (III)	22.0	29.1	2336 (+1)	14.8 (-1)	-188 (+2)	40.7	39.0	38.2	392	66	54.1	342	4.2
T06	1750 (III)	21.2	27.7	2165 (+1)	15.1 (-1)	-156 (+2)	36.7	34.5	32.1	497	68	50.1	351	4.2
T08	1800 (III)	21.2	27.1	2159 (+1)	15.5 (-1)	-150 (+2)	34.4	39.0	32.7	461	76	51.9	1138	6.4
T10	1750 (III)	21.0	27.1	2146 (+1)	14.7 (-1)	-198 (+2)	38.3	34.9	34.0	374	52	51.6	809	5.3
T12	2001 (IV)	22.7	29.5	2415 (+2)	16.1 (-1)	-154 (+2)	37.6	36.6	34.5	482	98	52.3	220	3.8
T13	1952 (IV)	22.2	28.4	2340 (+1)	14.7 (-1)	-173 (+2)	39.2	38.1	37.4	442	76	54.3	999	5.6
T14	1986 (IV)	22.2	28.4	2360 (+1)	14.6 (-1)	-202 (+2)	38.4	37	37.6	352	63	51.0	279	4.4
T15	1928 (III)	22.2	28.4	2277 (+1)	15.8 (-1)	-190 (+2)	37.6	35.4	34.1	600	74	52.0	592	5.0
T16	1981 (IV)	22.7	28.3	2329 (+1)	16.7 (-1)	-192 (+2)	36.4	34.0	33.0	534	83	52.7	819	5.5
T21	1997 (IV)	22.4	30.0	2499 (+2)	14.5 (-1)	-270 (+2)	44.7	41.4	41.4	447	57	45.7	526	5.0
T25	2073 (IV)	21.4	30.1	2900 (+2)	14.4 (-1)	-226 (+2)				511	63	33.6		
T26	1954 (IV)	22.5	29.3		17.4 (-1)					555	61	47.0	157	3.7
T27	1677 (III)	21.5	28.0	2363 (+1)	14.3 (-1)	-218 (+2)				575	77	38.0		
AVG	1887 (III)	21.9	28.6	2340 (+1)	15.0 (-1)	-182 (+2)				483	73	49.7	507	4.5

[i] The positions of the weather stations in the network are shown in Fig. 3.16 and particulars given in Table 3.2

[ii] GDD=Summation of temperatures above 10°C for Sep-March (Le Roux, 1974)

[iii] Mean February temperature (De Villiers *et al.*, 1996)

[iv] Huglin Index (Huglin, 1983; classification according to Tonietto & Carbonneau, 2004)

[v] Cool Nights Index (Tonietto, 1999; classification according to Tonietto & Carbonneau, 2004)

[vi] Dryness Index (Riou *et al.,* as reported in Tonietto, 1999. Classification according to Tonietto & Carbonneau, 2004)

[vii] Temperature Variability Index (Gladstones, 1992). Mean for period 1995 to 2000

[viii] Number of hours with a wind speed greater than 4m/s for the period December to March

Rainfall

The annual rainfall measured in the Stellenbosch Wine of Origin District varies between 549 mm at T05 (Devon Valley) and 961 mm at T02 (Helshoogte) (Fig. 3.15), with a typically Mediterranean distribution of dominant winter rainfall. The rainfall during the period December to February (ca. véraison to harvest) ranges between 52 mm at T10 and 98 mm at T12. This results in arid conditions during ripening and the Dryness Index calculated for all the stations falls within the category "very dry", i.e. Class +2 (Tonietto & Carbonneau, 2004). This results in frequent drought stress events in vineyards, necessitating the use of irrigation in many cases to ensure the ripening of grapes of high quality.

Relative humidity

The atmospheric relative humidity of the Stellenbosch Wine of Origin District is strongly affected by the movement of the sea breeze. The cool, moist air associated with the sea breeze moves along the coast and across the Bottelaryberg in the early afternoon, while the warm, dry inland air moves down the Eerste River Valley. This is, however, not reflected in the mean monthly minimum relative humidity values measured at the agroclimatic weather stations (Table 3.2). Rainfall during February would also have strongly affected these values. The agroclimatic stations where high rainfall values were recorded for the period December to February, e.g. T02, T12 and T16, also recorded high mean minimum relative humidity values for February (Table 3.2). The agroclimatic stations T25 and T27, both outside the limit of the sea breeze, did, however, record exceptionally low minimum relative humidity values (33.6% and 38% respectively).

3.8 SUMMARY

The cultivation of grapevines for the production of wine has been an integral part of the agricultural production of Stellenbosch from shortly after its establishment as an agricultural community. The area currently contains 16% of the country's vineyards, with the predominant cultivars being Cabernet Sauvignon, Chenin blanc and Sauvignon blanc. These vineyards are mainly situated between 60 m and 300 m above sea level on granite foothills associated with the mountains of the Table Mountain sandstone group.

The Stellenbosch wine-producing area has a complex topography, consisting of a combination of plains with a low or moderately undulating relief and free-standing or undulating hills with a moderately high relief. Two periods of orogeny (pre-Cambrian and Permian to Triassic), a fault system to the north and the different weathering potentials of the sandstone, granite and greywacke contribute to this topography, which affects sunlight interception and airflow, and thus temperature. Soil depth and type are also closely related to landscape position. One climatic aspect of particular interest is the occurrence of the sea breeze, the penetration of which is linked to the topography of the coastal area.

Topography, and in particular elevation, aspect and terrain morphological unit, therefore appears to play a central role in integrating the environmental characteristics of the Stellenbosch Wine of Origin District.

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CHAPTER 4

RESEARCH RESULTS

The use of a geographic information system and reference plots to identify terroirs for viticulture in Stellenbosch and surrounds

These manuscripts will be submitted for publication

CHAPTER 4

4.1 VITICULTURAL TERROIRS IN STELLENBOSCH, SOUTH AFRICA. I. THE IDENTIFICATION OF NATURAL TERROIR UNITS

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4.1.1 ACKNOWLEDGEMENTS

This publication is based on research that was financially supported by the Agricultural Research Council, Stellenbosch University, Winetech and the National Research Foundation under grant number 2053059. Any opinions, findings and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of these organizations.

Thanks are due to Mike Wallace, Dalene Opperman, Francois Knight and Ryk Taljaard for assistance with the creation of digital data layers.

4.1.2 ABSTRACT

A natural terroir unit (NTU) can be defined as a unit of land that is characterised by relatively homogenous topography, climate, geological substrate and soil. The mapping of NTUs is the first stage of data acquisition in a terroir study.

The aim of this study was to characterise the Stellenbosch Wine of Origin District using existing digital information and to identify NTUs using a Geographic Information System. The study area is bordered by mountains, situated close to the Atlantic Ocean and bisected by a river valley, resulting in notable spatial variation of all climatic parameters. The geology is complex due to the high degree of tectonic movement and mixing of parent material.

Terrain morphological units, altitude, aspect and soil type were used as primary keys for the identification of NTUs. Each of the identified units was further described with respect to the extent of the expected sea breeze effect and, for certain of the soil types, the associated parent material. A total of 1389 NTUs were identified in the Stellenbosch Wine of Origin District. Further understanding of their viticultural and

oenological aptitude should assist in the amalgamation of NTUs into units of greater economic importance.

Key words: Natural terroir units, Geographic Information System, topography, geology, soil

4.1.3 INTRODUCTION

Natural terroir units have been defined by Laville (1993) as "a volume of the earth's biosphere that is characterised by a stable group of values relating to the topography, climate, substrate and soil". Similarly, Morlat (1989) described the concept of the basic terroir unit (*unité terroir de base*). The grouping of such units in relation to the characteristics of the product obtained constitutes a terroir, i.e. the terroir cannot be defined in isolation from its product. Because the concept of the terroir relies on the intrinsic agronomic potential of the environment and is thus inseparable from the characteristics and "identity" of the final agricultural product, all studies to delimit terroirs will include two stages of data acquisition; firstly the mapping of pertinent environmental features in order to obtain relatively homogenous environmental units or natural terroir units and secondly a study of the reaction of the crop to these delimited units (Morlat, 1996).

The interaction of the grapevine with its immediate environment has long been a research focus in South Africa (Buys, 1971; Le Roux, 1974; Saayman, 1976; Saayman, 1977; Saayman & Kleynhans, 1978). The planting of cultivars directed towards quality wine production in the late 1980s lead to an increased focus on the implications of terroir for viticultural management and wine character and quality. This provided an impetus that lead to the initiation of a research program in this direction.

The high degree of topographic variation in the Stellenbosch Wine of Origin District and its proximity to the ocean provides many diverse environments for viticulture, making this region a complex study area. The Stellenbosch Wine of Origin District is characterised by a combination of plains with straight slopes and low relief, undulating plains with moderate relief and free standing and undulating hills with high relief (Schultz, 1997), resulting in a complex landscape. Topography is a static feature of the landscape and is described by altitude as well as the rate of change of altitude over distance and has thus components of slope form, slope inclination, slope aspect, altitude and relief (Schultz, 1997). Topography of a region is determined to a large extent by the geological formations present, with their inherent resistance to weathering being amongst the factors that shape the landscape (Wooldridge, 2000; Wooldridge, 2003). Topography also determines the local climate either directly as a result of the change in the incidence of the sun's rays on the earth's surface or indirectly as a result of altered soil drainage patterns, exposure to wind and ventilation (Crowe, 1971). Climate is one of the dominant soil forming factors (De Blij, 1983) and there exists thus an inherent relationship between soil and topography (Wysocki *et al.*, 2000). This is represented in the concept of a "catena", "a sequence of soils of similar age, derived from similar parent material, and occurring under similar macroclimatic conditions, but having different characteristics due to variation in relief and drainage" (Soil Classification Working Group, 1991). Variation in drainage characteristics of the landscape can be defined with the aid of terrain morphology, with each terrain morphological unit (crest, scarp, midslope, footslope, valley bottom) having associated slope inclinations and slope shape (Kruger, 1973).

This paper describes the first step of a study to identify viticultural terroirs in the Stellenbosch Wine of Origin District in South Africa. The aims included the characterisation of the study area using existing digital environmental data and the identification of natural terroir units using this data and a geographic information system. This followed an initial study in the Bottelaryberg-Simonsberg-Helderberg wine producing area in Stellenbosch (Carey, 2001).

4.1.4 MATERIALS AND METHODS

4.1.4.1 Study area

The study area included the Stellenbosch Wine of Origin District situated at 34°S, 19°E (Fig. 4.1.1). It covers an area of 84 537 ha, not all of which is suitable for agriculture. The Stellenbosch Wine of Origin District includes the south-western flanks of the Simonsberg (1390 m), the Jonkershoekberg (914 m), Stellenboschberg (1167 m) and Helderberg (1137 m), the western flanks of the Hottentots Holland mountains (1598 m), the Bottelaryberg hills (477 m), the Eerste River valley and coastal plain.

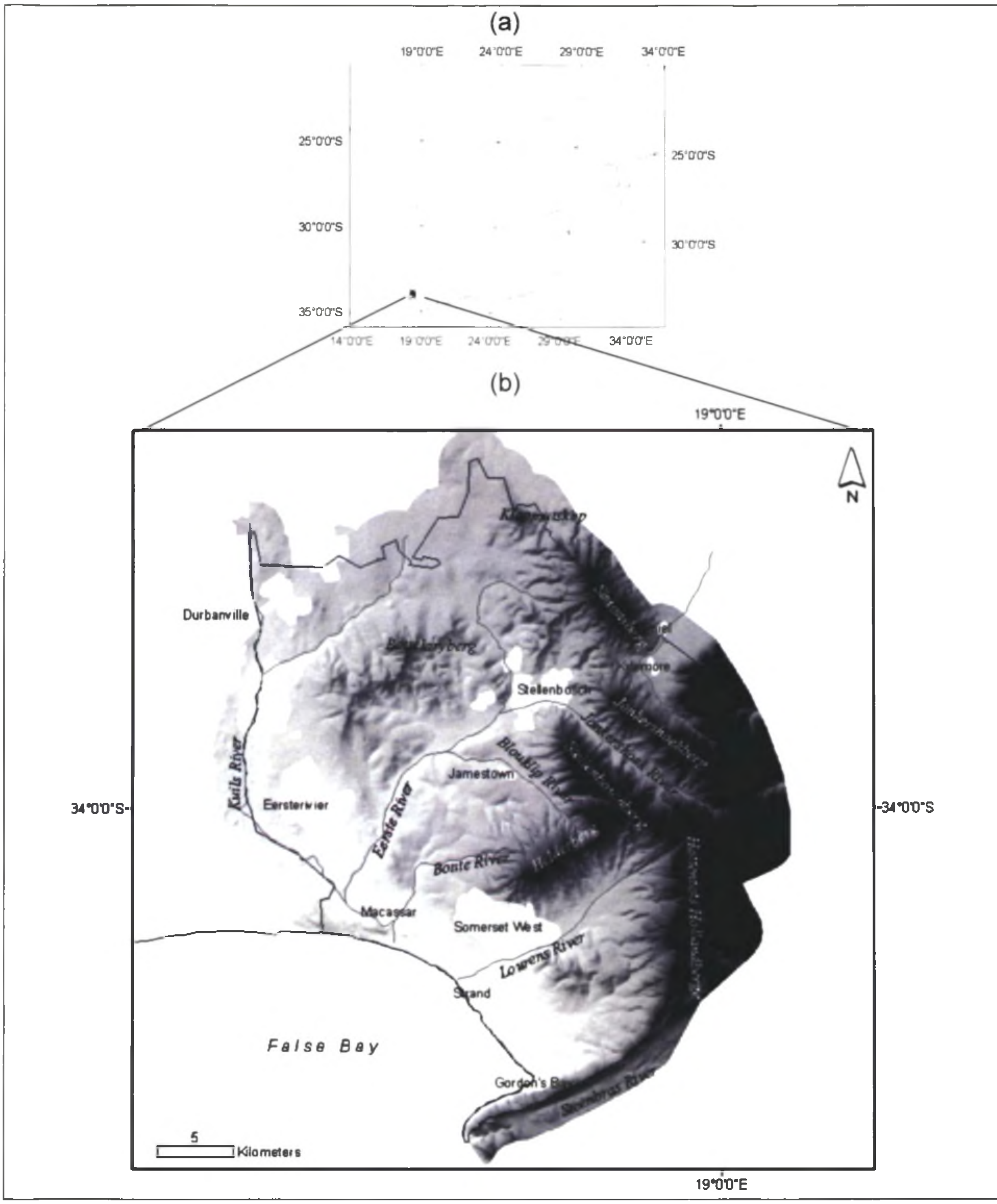

Figure 4.1.1 (a) The position of the Stellenbosch Wine of Origin District (black square) in South Africa. (b) The boundary of the Stellenbosch Wine of Origin District (solid black line)

4.1.4.2 Digital topographic data

A 50 m Digital Elevation Model (DEM) was used to determine elevation, aspect and slope inclination using Spatial Analyst™ in ESRI®ArcMap™ 8.2. A raster data layer of terrain morphological units (Kruger, 1973), determined from the same DEM, was obtained (M Wallace, Department of Agriculture: Western Cape, unpublished data, 2003).

4.1.4.3 Digital soil data

A digital soil map compiled from a Peri-Urban Soil Survey mapped on a scale of 1:25 000 and 1:50 000 by Ellis & Schloms (1975) and Ellis *et al.* (1976) respectively, was obtained. A digital map of soil associations of the Western Cape mapped on a scale of 1:250 000 by Ellis *et al.* (1980) was used to complete the data in mountainous areas of the study area.

4.1.4.4 Digital geological data

Digital geological data compiled from a 1:250 000 geological map of the Council for Geoscience (Theron, 1990), was the best available data for the study area.

4.1.4.5 Extent of the sea breeze effect

The extent of the sea breeze effect was estimated from relative humidity values at 15:00 SAST for the Stellenbosch region that had been modelled with RAMS (Regional Atmospheric Modelling System) (Pielke *et al.*, 1992; Bonnardot *et al.*, 2002; Cotton *et al.*, 2003) at a resolution of 1 km.

4.1.4.6 Identification of natural terroir units

The environmental variables of aspect altitude, terrain morphological units, soil and geology, were divided into classes (Table 4.1.1). Shape files were converted into rasters (50 m grid) where necessary using Spatial Analyst™ in ESRI®ArcMap™ 8.2. The terrain morphological units, aspect, altitude and soil classes, were combined into homogenous units using the Raster Calculator in Spatial Analyst™ in ESRI®ArcMap™ 8.2. Geology was only considered to be of relevance for soils falling within the classes of residual soils, freely drained structureless soils and dry duplex soils (see Table 4.1.2). As it was not sufficiently detailed, it was included by calculating the median for each "soil-landscape" unit using zonal statistics in Spatial Analyst™ in ESRI®ArcMap™ 8.2. A prefix of "s" was added if the NTU fell within the "limit" of the sea breeze influx.

4.1.4.7 Validation

Thirty-eight plots, representing various positions in the landscape, were used to examine the validity of the identified natural terroir units. Altitude and aspect were determined from 1:10 000 orthophotos obtained from the Chief Directorate: Surveys and Mapping. The terrain morphological position was described *in situ*. Soil profiles were classified using the South African Taxonomic system (Soil Classification Working Group, 1991) and the geological origin of the parent material was estimated by an experienced soil scientist (D Saayman, personal communication, 2000).

4.1.4.8 Significance of identified natural terroir units for viticulture

A map of vineyards (90% probability) was compiled from a classification of Landsat TM images (Capture date 23 November 2001) (JPA Van der Merwe, ARC Institute for Soil, Climate and Water, unpublished data, 2003). This map was used to determine the area of each natural terroir unit that was planted to grapevines in 2001.

Table 4.1.1 Classes and codes (bold type) for environmental variables used for the determination of natural terroir units in the Stellenbosch Wine of Origin District. Non-arable land, e.g. urban areas, marshlands, water, steep stony slopes, rock and stony outcrops, was excluded from the determination of natural terroir units

Environmental variable[1]				
Terrain unit	**Aspect (°)**	**Altitude (m)**	**Soil**	**Geology**
Crest **(c)**	Flat **FLAT**	≤100 **(1)**	Residual soils (shallow soils on hard or weathering rock) **(A)**	**Alluvium**
Scarp **(sc)**	0-45, 270-360 **(NW)**	>100; ≤200 **(2)**	Freely drained structureless soils **(B)**	**Silcrete**
Midslope **(m)**	45-135 **(E)**	>200; ≤300 **(3)**	Stony, freely drained structureless soils **(Bs)**	**Ferricrete**
Footslope **(f)**	135-270 **(SW)**	>300; ≤400 **(4)**	Dry duplex soils **(C)**	River **terrace** gravel
Valley bottom **(v)**	-	>400; ≤500 **(5)**	Stony complex of shallow residual and dry duplex soils **(Cs)**	**Scree**/talus/ alluvium grading into piedmont gravel or gritty sand
-	-	Alt>500 **(6)**	Medium deep wet duplex soils **(D)**	Quartzite, conglomerate and slate of the **Franschhoek formation**
-	-	-	Shallow wet duplex soils **(Dv)**	Shale, greywacke, quartzite and minor volcanic rocks of the **Tygerberg formation**
-	-	-	Well-drained deep alluvial soils **(E)**	Conglomerate, sandstone and minor shale of the **Magrug formation**
-	-	-	Poorly-drained alluvial and saline duplex and alluvial loam soils **(F+G)**	**Aeolian sands**
-	-	-	Excessively drained deep sandy soils **(H)**	**Brackish calcareous soil**
-	-	-	Shallow dry sands on rock or calcrete **(Hv)**	Weathering products of granite (gravelly clay) **(Qg)**
-	-	-	Red or yellow structureless soils with a plinthic horizon **(J)**	Weathering products of Malmesbury rocks (loam and sandy loam) **(Qgg)**
-	-	-	-	**Granite**
-	-	-	-	**Sandstone**

[1]These variables have no horizontal relationship

4.1.5 RESULTS AND DISCUSSION

4.1.5.1 Topography

In South Africa, terrain morphological units form the foundation for the identification of land types, "a class of land over which the macroclimate, the terrain form and the soil pattern each displays a marked degree of uniformity" (MacVicar *et al.*, 1974), and are thus used as the basis for identification of natural terroir units. The units of crest, scarp, midslope, footslope and valley bottom are recognised (Kruger, 1973). Within the Stellenbosch Wine of Origin District, 26.4% of the surface area is classified as crest, 40.4% as mid-slope, 22.8% as foot-slope and 10.4% as valley bottom.

Aspect categories were selected in order to represent the slope interception of sunlight and dominant winds and were divided into east (45° to 135°), south-west (135° to 270°) and north-west (270° to 45°, passing through 0°). East facing slopes warm earlier in the morning and cool earlier in the afternoon (Carey, 2001). South-westerly slopes are cooler due to interception of the sea breeze in the early afternoon (Bonnardot, 1997; Bonnardot, 1999; Carey, 2001; Bonnardot *et al.*, 2002) and reduced interception of sunlight (Wooldridge & Beukes, 2003). North-westerly slopes are warmest due to being protected to a certain extent from the moderating influence of the sea (Bonnardot, 1997; Bonnardot, 1999; Carey, 2001) and receiving the most direct radiation in the Southern Hemisphere (Schultz, 1997).

Temperature generally decreases with increasing altitude in the tropospheric layer. This temperature lapse rate varies with region and season (Schultz, 1997), but can be accepted as being approximately 0.3°C for every 100 m above sea level for South Africa (Le Roux, 1974). Overlaying the map of vineyards on the classified DEM shows that 99.9% of the vineyards in the Stellenbosch Wine of Origin District are situated below 500 m and that ca. 51% are cultivated between 100 m and 200 m. The effects of small differences in altitude are not known and most of the world's great table wines come from altitudes lower than 500 m (Gladstones, 1992). Altitude was therefore divided into 100 m increments up to an altitude of 500 m. A sixth category grouped altitudes higher than this level.

4.1.5.2 Soil

The available soil data is that of soil associations where soil forms (Soil Classification Working Group, 1977) were grouped based on depth, stoniness and general pedogenetic characteristics. Soil forms are expected to have a similar set of genetic processes regardless of parent material or mineral composition (Wooldridge, 1988). Sixteen soil associations, excluding areas classified as urban or marshland, are found in the Stellenbosch Wine of Origin District (Table 4.1.2). Some of these associations may be found together with other soil types. These associations were grouped to provide 12 classes. All urban areas, marshland, water, steep stony slopes and rock or stony outcrops were grouped together as unsuitable for viticulture.

Table 4.1.2 Predominant soil associations found in the Stellenbosch Wine of Origin District.

Soil association	% of area	Soil forms[1]	Viticultural potential[2]	Soil class
A. Shallow (<0.5 m) residual soils on hard or weathering rock	11.1	Mispah, Glenrosa, Cartref	These shallow soils have a low potential for growth vigour due to the limited area available for root growth and low soil water holding capacity.	1
Av. Very shallow complex of A	0.04			
B. Red and yellow freely drained structureless or weakly structured soils	17.3	Hutton, Clovelly, Avalon, Bainsvlei, Pinedene, Vilafontes	At similar texture and depth, these soils stimulate similar (and strong) growth vigour in grapevines. Good soil water holding capacity.	2
Bv. Shallow (<0.5 m) complex of B	0.2			
Bs. Stony complex of B	3.7			3
C. Dry duplex soils (Duplex refers to a clear textural change from topsoil to subsoil. The topsoil is sandy while the subsoil has a high clay content)	3.2	Swartland, Sterkspruit, Estcourt, Klapmuts, Sepane, Valsrivier	These soils are generally residual in nature and although shallow react well to deep soil preparation. Good soil water holding capacity.	4
Cs. Stony complex of C	0.0			5
D. Medium deep (0.5 m-1.0 m) wet duplex soils	12.4	Kroonstad, Longlands, Wasbank	Wetness can limit root growth in the early season, which may lead to water stress in the late summer due to insufficient root development and low soil water holding capacity.	6
Dv. Shallow (<0.5 m) complex of D	6.2			7
E. Well-drained deep (>1.0 m) alluvial sands	2.2	Dundee, Oakleaf, Fernwood (dark)	These sandy soils have a low water holding capacity	8
F. Poorly drained alluvial soils	7.2	Westleigh, Fernwood, Dundee, Katspruit, Wasbank, Champagne	These soils are not suitable for quality viticulture	9
G. Saline duplex and alluvial loam soils	7.3	Estcourt, Valsrivier, Klapmuts, Swartland, Sepane		
H. Deep (>1.0 m) dry sands on rock or calcrete	4.2	Fernwood (bleached)	These sandy soils have a low water holding capacity	10
Hv. Shallow (<0.5 m) complex of H	4.2			11
J. Wet plinthic soils	0.01	Avalon, Westleigh, Bainsvlei, Tukulu, Pinedene	These soils have a fluctuating water table, which may be positive under dry land conditions	12

[1]Soil Classification Working Group (1977, 1991)
[2]Van Zyl & Van Huyssteen (1979)

Vineyards in the Stellenbosch Wine of Origin District are predominantly cultivated on red and yellow, freely-drained, structureless or weakly structured soils and medium-deep wet duplex soils (Fig. 4.1.2).

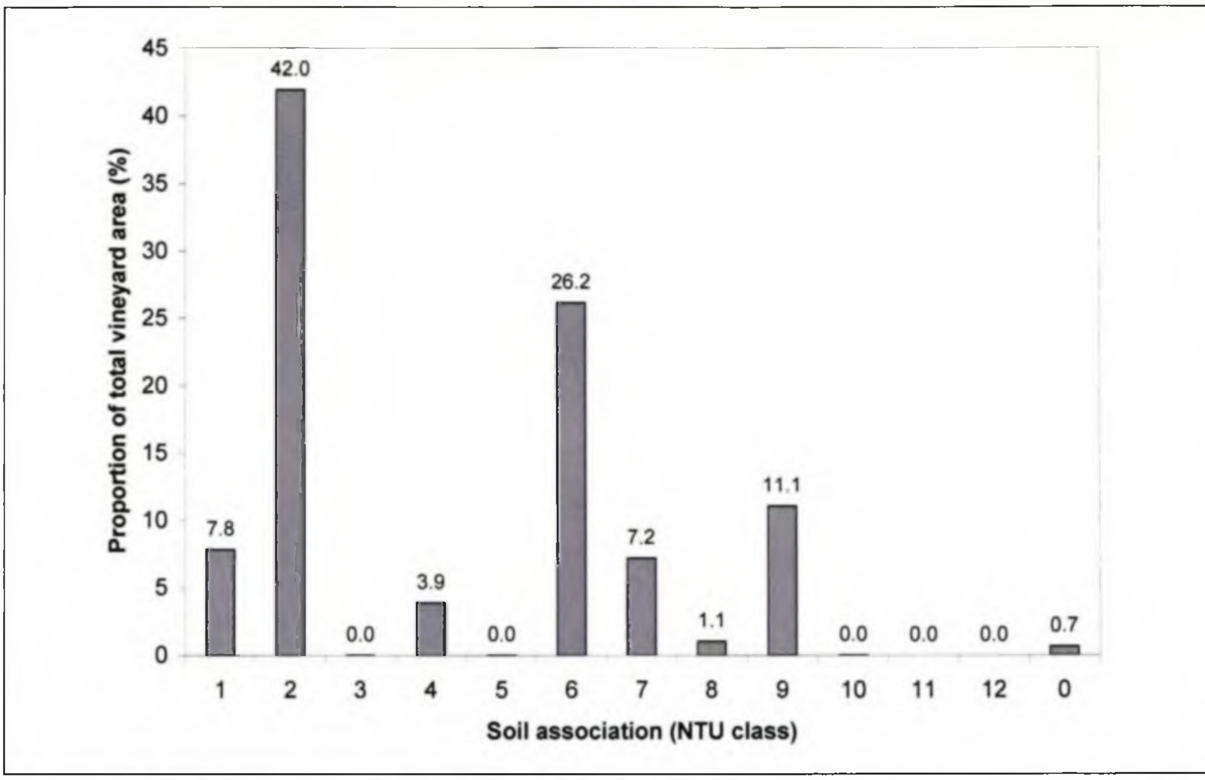

Figure 4.1.2 Soil class expressed as a percentage of the area cultivated under grapevines in the Stellenbosch Wine of Origin District (2001). Soil association classes are described in Tables 4.1.1 and 4.1.2.

4.1.5.3 Geology

The Stellenbosch Wine of Origin District has an underlying layer of sedimentary formations of the Malmesbury group, which were deposited during the Precambrian Era (Theron *et al.*, 1992). These underwent subsequent compaction and indurations. Tectonic movements during this period resulted in a north-west trending mountain chain. Intrusion of the Cape Granite Suite accompanied this folding. Two granitic plutons, with a coarse-grained texture, are present within the Stellenbosch Wine of Origin District. At the contact with the granite, the rocks of the Malmesbury Group were baked. The greywacke of the Stellenbosch-Somerset West area is representative of the contact metamorphic effect of the Cape granite intrusion. Subsequent erosion and deposition of the Cape Super Group sediments was followed by a period of orogeny during the Permian Period with consequent folding, uplifting and fracturing of formations. Sandstones and shales eroded, leaving remnants such as Simonsberg. Quaternary sediments and soils are also present throughout this region (Theron *et al.*, 1992).

The classification of the geological formations used in the identification of NTUs is shown in Table 4.1.1. Due to their similar texture, the granite of the two plutons was placed in one class. Scree, talus and alluvium that grades into piedmont gravel, were grouped with gritty sand, into which they grade on the mountain slopes. The aeolian sands of the Springfonteyn, Witzand and Langebaan formations (Theron *et al.*, 1992) were placed in the same class.

Geological parent material may affect the colour, texture and/or mineral composition of resulting soils. Sandstones are generally poorly supplied with plant mineral nutrients (Van Schoor, 2001). Soils from granite can be expected to contain coarser fragments, soils from Malmesbury rocks to be more abundant in clay, silt and fine sand and Table Mountain sandstone to result in more sand-sized particles (Van Schoor, 2001). Soil mineral composition affects the total potassium (K) content of soils, the K supplying power of soils and the ability of the soil to buffer K (Wooldridge, 1988). Plants grown on soils with a low K buffering capability may be subject to excessive K consumption (Wooldridge, 1988). Granitic soils generally have the highest potassium content (Wooldridge, 1988; Van Schoor, 2001), which is not well buffered, favouring rapid plant uptake (Wooldridge, 1988). It is however, particularly difficult to associate geology with derived soils in the Stellenbosch wine producing area due to the high degree of tectonic movement and mixing of parent material. *In situ* weathering of rocks is seldom the only source of soil formation and mixing of parent material can be considered significant (Van Schoor, 2001). The material from which the soil has developed often has a very different geological origin to that of the underlying "parent" material. Transported granitic soils can overlie Malmesbury bedrock (Theron *et al.*, 1992). Geology was therefore only considered to be of importance for residual soils, dry duplex soils and freely drained structureless soils, although even this last mentioned may consist of mixed parent material (Conradie *et al.*, 2002).

Vineyards in the Stellenbosch Wine of Origin District are cultivated predominantly on *in situ* weathering products of granite (gravelly clay) or granite, although also to a considerable extent on shale derived materials (Fig. 4.1.3.).

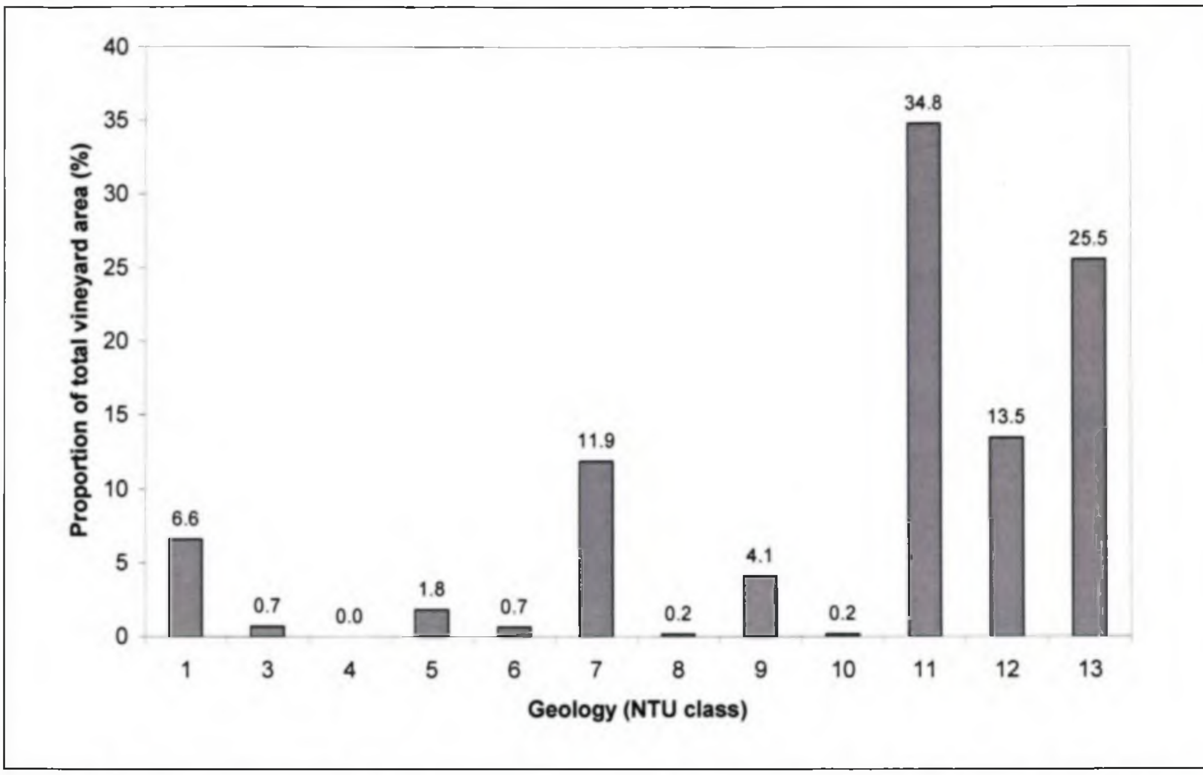

Figure 4.1.3 Geological class expressed as a percentage of the area cultivated under grapevines in the Stellenbosch Wine of Origin District (2001). Geological classes are explained in Table 4.1.1.

4.1.5.4 Extent of the sea breeze

The extent of the sea breeze is complex to determine. As the sea breeze penetrates overland, thermal convection from the land results in a blending of moist sea air and dry air from the land and therefore instability of the sea breeze. This results in dry air being included in the humid maritime air (Carrega, 1995) at the contact between maritime and continental air. The 55% to 60% relative humidity category appeared to represent this sea breeze "front" as its profile was affected both by the inflowing moist air from the ocean and the dry inland air (S Cautenet, personal communication, 2004). This front represents modelling for individual days in a single month (February 2000) (Bonnardot *et al.*, 2002), and can not be considered definitive, especially knowing that the topic is highly emotive amongst wine producers and holds quality connotations in the market place. A conservative estimate of the extent of the sea breeze effect was made using the 50% isoline as a guide. This erred on the side of inclusivity so as to accommodate potential spatial and temporal variability. Approximately one half of the Stellenbosch Wine of Origin District was included within the area that was considered to be affected by the sea breeze (Fig. 4.1.4).

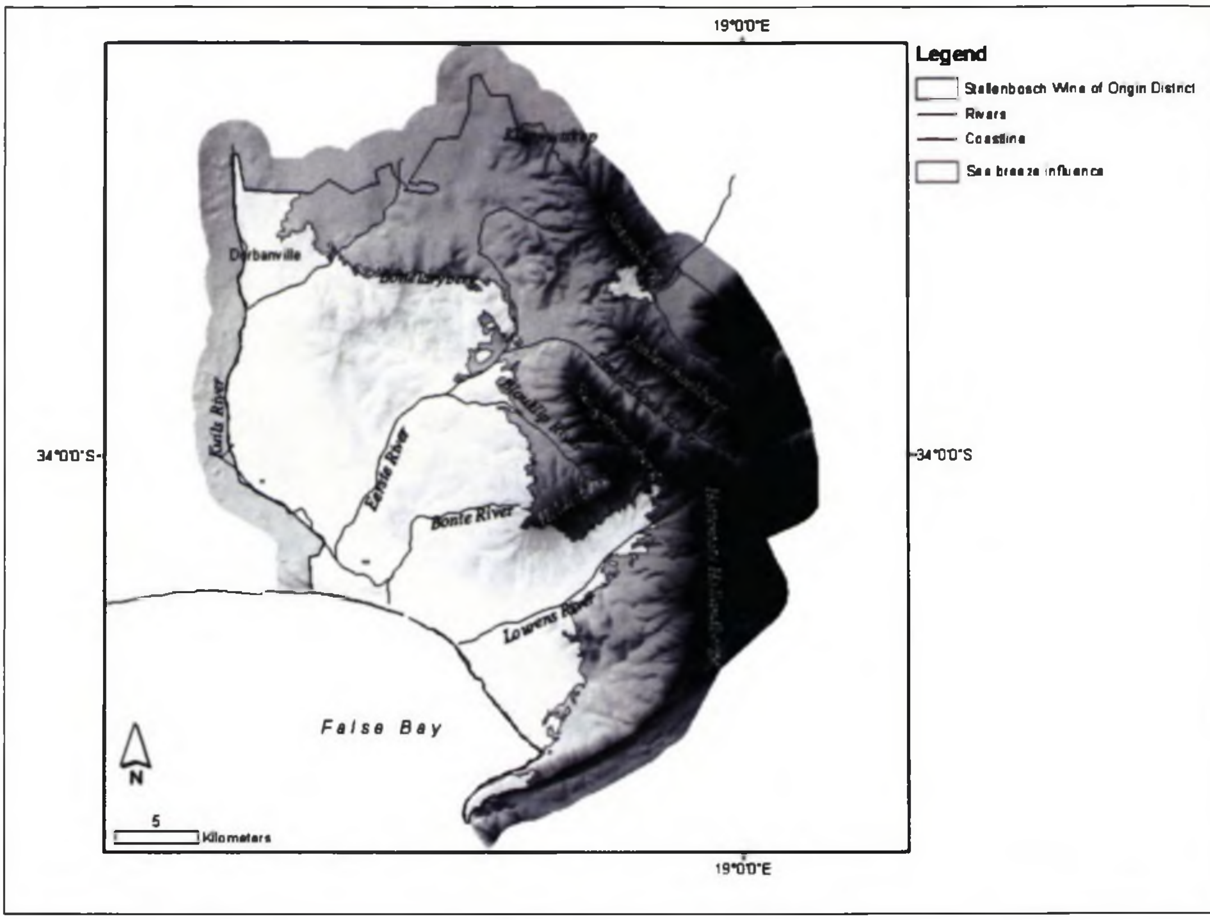

Figure 4.1.4 Extent of the sea breeze effect in the Stellenbosch Wine of Origin District estimated from modelled relative humidity values (RAMS generated) on a grid of 1 km at 15:00 SAST (Bonnardot *et al.*, 2002)

4.1.5.5 Natural terroir units.

Using the environmental variables given in Table 4.1.1, a total of 1389 natural terroir units (NTUs) were identified in the Stellenbosch Wine of Origin District (Addendum 4.1). The units have also been characterised with respect to dominant geological formation and effect of the sea breeze during February. Ground-truthing, by comparing field observations of characteristics of experimental plots in commercial vineyards with the identified NTUs, showed a 68% success rate. The failure to match field characterisation with GIS characterisation was mainly due to lack of agreement between soil types (9 out of 12 cases) and/or terrain morphological units (3 out of 12 cases). Only 466 terrain morphological units have a surface area of greater than 25 ha. In 2001, grapevines were cultivated on 778 of the identified NTU. Of these, 302 natural terroir units had a surface of greater than 25 ha. The 10 most prominent natural terroir units for viticulture and their characteristics are shown in Table 4.1.3. The descriptor of geology was excluded so as not to unfairly weight the soil types.

Table 4.1.3 Ten most prominent natural terroir units for viticulture in the Stellenbosch Wine of Origin District, South Africa.

NTU code	Characteristics	Area (ha)	Proportion of vineyard area (%)
mNW2D	North-westerly oriented midslopes between 100 m and 200 m altitude, with medium-deep, wet, duplex soils. Located outside the extent of influence of the sea breeze.	402.8	3.0
s_mSW2B	South-westerly oriented mid-slope positions between 100 m and 200 m altitude, with freely-drained, structureless or weakly structured soils. Located within the extent of influence of the sea breeze.	394.0	2.9
mSW2D	South-westerly oriented midslope positions between 100 m and 200 m altitude, with excessively medium-deep, wet, duplex soils. Located outside the extent of influence of the sea breeze.	343.1	2.6
mNW3B	North-westerly oriented midslope positions between 200 m and 300 m altitude, with freely-drained, structureless or weakly structured soils. Located outside the extent of influence of the sea breeze.	284.2	2.1
s_cSW2B	South-westerly oriented crest positions between 100 m and 200 m altitude, with freely-drained, structureless or weakly structured soils. Located within the extent of influence of the sea breeze.	276.3	2.1
s_mNW2B	North-westerly oriented midslope positions between 100 m and 200 m altitude, with freely-drained, structureless or weakly structured soils. Located within the extent of influence of the sea breeze.	268.2	2.0
s_mE2B	Easterly oriented midslope positions between 100 m and 200 m altitude, with freely-drained, structureless or weakly structured soils. Located within the extent of influence of the sea breeze.	259.3	1.9
s_mNW2D	North-westerly oriented mid-slope positions between 100 m and 200 m altitude, with medium-deep, wet, duplex soils. Located within the extent of influence of the sea breeze.	255.6	1.9
cNW3B	North-westerly oriented crest positions between 200 m and 300 m altitude, with freely-drained, structureless or weakly structured soils. Located outside the extent of influence of the sea breeze.	238.7	1.8
s_cNW3B	North-westerly oriented crest positions between 200 m and 300 m altitude, with freely-drained, structureless or weakly structured soils. Located within the extent of influence of the sea breeze.	220.5	1.7

4.1.6 CONCLUSIONS

Natural terroir units provide information in addition to what would be available from a map of soil associations. This information is of value for viticulture, as topography and proximity to the ocean affects wind exposure and temperature and geology the mineral composition, soil texture, water regulating properties and availability of soil nutrients. The number of natural terroir units for the Stellenbosch Wine of Origin District is, however, myriad and many of them are of a size that is not economically or practically viable. Further understanding of their viticultural and oenological aptitude should assist in the grouping of natural terroir units with a similar viticultural and oenological aptitude into larger, more viable units. This will be addressed in a companion paper.

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4.2 VITICULTURAL TERROIRS IN STELLENBOSCH, SOUTH AFRICA. II. THE INTERACTION OF GENOTYPE WITH ENVIRONMENT

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4.2.1 ACKNOWLEDGEMENTS

This publication is based on research that was financially supported by the Agricultural Research Council, Stellenbosch University, Winetech and the National Research Foundation under grant number 2053059. Any opinions, findings and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of these organizations.
Thanks are due to Dr Martin Kidd of the Centre for Statistical Consultation, Stellenbosch University, for statistical advice and analyses and A Schmidt and JCD Theron of ARC Infruitec-Nietvoorbij for technical assistance.

4.2.2 ABSTRACT

A terroir can be defined as a grouping of homogenous environmental units, or natural terroir units, based on the typicality of the products obtained. Terroir studies therefore require an investigation into the response of grapevines to the natural environment. A network of plots of Sauvignon blanc and Cabernet Sauvignon were delimited in commercial vineyards in proximity to weather stations and their response monitored for a period of seven years. Regression tree methodology was used to determine the relative importance of the environmental and management related variables and to determine regression trees for each dependent variable. Excepting for scion clone, which had a high relative importance for bunch mass of Sauvignon blanc and yield to pruning mass index of Cabernet Sauvignon, no other non-environmental variable included in the analyses appeared to have a strong effect on grapevine performance and wine character. The performance of Cabernet Sauvignon was affected by the potassium content of the subsoil and the climate of the season. The performance of Sauvignon blanc appeared to be related to soil texture, wind exposure and temperature, both during the green berry growth stage and the month prior to ripening. From the results presented, it appears that environmental parameters have

an overriding effect on the performance of both Cabernet Sauvignon and Sauvignon blanc but that these two cultivars react differently to environmental stimuli. It should therefore be possible to identify viticultural terroirs with specific agronomic potential for these two cultivars.

Key words: Terroir, Cabernet Sauvignon, Sauvignon blanc, soil, climate

4.2.3 INTRODUCTION

A terroir can be defined as a grouping of homogenous environmental units, or natural terroir units, based on the typicality of the products obtained (Laville 1993). It is, therefore, a representation of the agricultural aptitude of a site resulting from the interaction of its environmental features. These environmental features are climate (rainfall, relative humidity, air temperature, soil temperature, direction and intensity of dominant winds), topography (slope, exposition, sunlight exposure, landscape form) and soil (mineralogy, compaction, granulometry, soil water reserve, depth, and colour) (Laville 1993). The terroir definition prescribes a biphasic study, namely (a) the characterisation of the environment and identification of natural terroir units taking all relevant natural factors into account, together with (b) the characterisation of the viticultural and oenological potential of these units over time (Morlat 2001, Vaudour 2003). The first part of such a study for the Stellenbosch Wine of Origin District has been described in a companion paper (Chapter 4, section 4.1).

Cabernet Sauvignon and Sauvignon blanc have been the subject of a number of studies in South Africa (*inter alia* Archer & Strauss, 1989, Hunter *et al.*, 1991; Hunter *et al.*, 1995; Hunter & Ruffner, 1997, 2002; Marais *et al.*, 1999; Conradie *et al.*), but only those of Marais *et al.* (1999) and Conradie *et al.* (2002) have focused specifically on the interaction of *Vitis vinifera* (cv. Sauvignon blanc) with its growing environment. The significance of the viticultural environment for wine style and wine quality in South Africa has long been recognized (Theron, 1932; Le Roux, 1974; Saayman, 1977). This lead to the establishment of the Wine of Origin Scheme in 1973 (Burger & Saayman, 1981), creating the impetus for the present day terroir studies in South Africa, initiated by ARC Infruitec-Nietvoorbij. In 1995, a network of experimental plots was established in the Stellenbosch environs to aid in the identification of terroirs for viticulture.

Using these results, this paper describes and discusses the determination of the genotype x terroir interaction.

4.2.4 Materials and methods

4.2.4.1 Study area and vineyard sites.

The study was limited to the Stellenbosch Wine of Origin District, South Africa, situated at 34°S, 19°E (Fig. 4.2.1). Twenty reference plots each of Cabernet Sauvignon and Sauvignon blanc of ca. 30 vines per plot were delimited during 1995 in commercial vineyards for a study period of seven years (Fig. 4.2.1). Thirty of these experimental plots were within a radius of 1 km from a representative automatic weather station. Vine density, scion clone, rootstock, vine spacing, canopy height and irrigation practices were noted. Geographic co-ordinates, altitude, aspect and slope inclination were determined from 1:10 000 ortho-photos (Chief Directorate: Surveys and Mapping). The approximate minimum distance from the False Bay coast was determined in ESRI®ArcMap™ 8.2 and noted as distance from the coast.

4.2.4.2 Viticultural and oenological measurements

All vines were pruned to the norm of 16 buds per meter cordon within a four-week period. For each of these plots the dates of budburst, flowering and berries harvest-ripe (Coombe, 1995) were recorded when 50% of the monitored vines had reached the said stage. Pruning mass per meter cordon for 10 vines was determined. The canopy was evaluated at harvest using a score card adapted from Smart & Robinson (1991) and the yield per meter cordon for 10 vines was determined. A random standard sample of five bunches (Van Schalkwyk, 2004) was selected from amongst the bunches that had been harvested per plot for microvinification. Bunch characteristics (number of berries per bunch, bunch mass, mass of 100 berries) were determined for these samples. Musts were microvinified according to standard procedures (ARC Infruitec-Nietvoorbij) and sensorially evaluated ca. 6 months after harvest according to appropriate aroma categories from the Wine Aroma Wheel (Noble *et al*, 1987), using an unstructured line scale and an expert panel of between 12 and 14 judges. The wines were presented in one session per cultivar, with the two cultivars being presented to separate panels on consecutive days. Standard must and wine analyses were performed in a commercial laboratory.

4.2.4.3 Soil measurements

Soil profiles at each plot were examined in 2000 and described using the South African taxonomic system (Soil Classification Working Group, 1991). Standard soil chemical and physical analyses were performed in a commercial laboratory. On examination of the soil profiles, it was noted that for most of the plots grapevine roots only colonised the ploughed portion of the soil, and the depth of soil preparation was therefore assumed to be the effective soil depth.

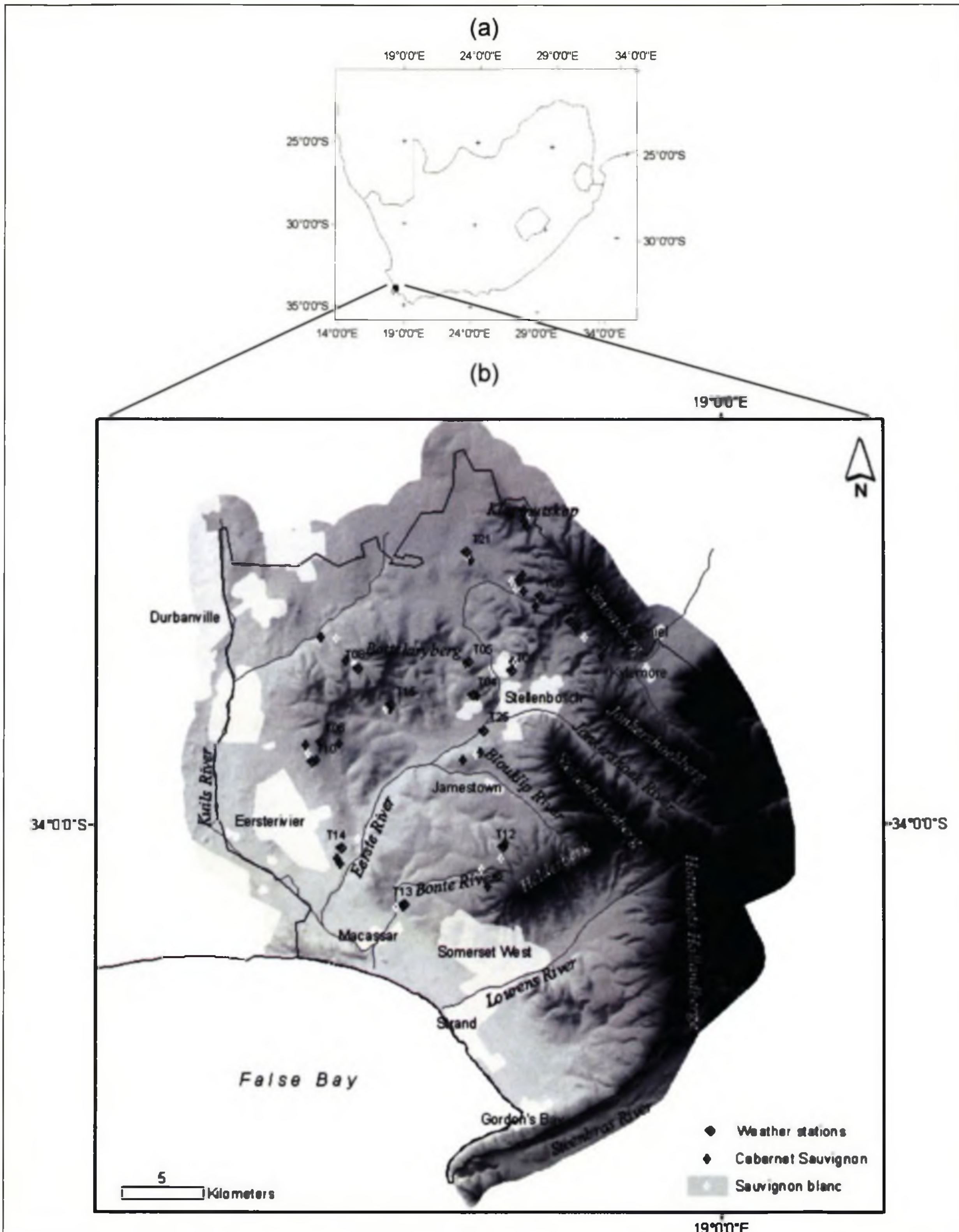

Figure 4.2.1 (a) The position of the Stellenbosch Wine of Origin District (black square) in South Africa. (b) The district boundary of the Stellenbosch Wine of Origin District together with the positions of weather stations (labelled Tn) and experimental plots of *Vitis vinifera* L. cvs. Cabernet Sauvignon and Sauvignon blanc.

4.2.4.4 Climatic measurements

A network of automatic weather stations (MCSystems) was established in 1995. Five of these weather stations were microclimatic and situated in the vineyard row while the remaining 11 were mesoclimatic and situated on open ground in the vicinity of vineyards. Data from mechanical weather stations (Agromet, ARC-ISCW) were used where available to complete the data set. For the automatic weather stations, the parameters of temperature, dry and wet bulb temperature or relative humidity, rainfall, radiation, sun duration, wind speed and wind direction were recorded every one-minute. These values were averaged or summed, depending on whether or not the parameter is cumulative in nature, for one-hour periods. The temperature sensors were housed in a Stevenson screen 1.2 m above the soil surface. The anemometer and pyranometer were situated at 2.0 m above the soil surface.

Mean monthly climatic data for automatic weather station T01 were used to compare the climate of each season during the seven-year study period.

Hourly climatic data were used to calculate a number of climatic variables. Mean maximum, mean minimum and mean temperature, number of hours with a wind speed greater than 4 m/s and rainfall were calculated for the period of October and November. Mean maximum, mean minimum and mean temperature, number of hours with temperature between 20°C and 25°C, number of hours with a wind speed greater than 4 m/s, maximum wind speed, mean wind speed, maximum, minimum and mean relative humidity, mean relative humidity at 15:00 SAST, radiation, hours of sunshine, growing degree days and evaporation were calculated for the month before harvest for each of the plots. In addition, the Huglin index (Huglin, 1986), Amerine and Winkler Growing Degree-day index, as adjusted for South Africa by Le Roux (1974), the dryness index (Tonietto, 1999, Tonietto & Carbonneau, 2004) and thermal variability index (Gladstones, 1992) were calculated.

4.2.4.5 Vineyard characteristics

Viticulture in South Africa is non-prescriptive and viticultural management strategies are thus diverse. The experimental plots were non-homogenous with respect to clone, rootstock, vine spacing, trellis system, irrigation and age. The variables irrigation, rootstock, scion clone, vine density, canopy height, trellis system and year of planting were therefore included in the analyses as management related variables (treated as independent) in order to test the relative importance of their influence.

The set of dependent and environmental and management related variables and related codes are given in Addendums 4.2 and 4.3

4.2.4.6 Missing data

Missing data resulted from accidental pruning or harvesting of experimental plots by producers, technical faults in automatic weather stations and/or lack of knowledge of producers regarding rootstock or scion clones.

4.2.4.7 Statistical analyses

Regression tree analyses (Breiman *et al*, 1984) were used to analyse the complete data set. A variable importance factor in terms of its effect on the response variable was derived once the tree was built. This variable importance was calculated based on the number of times the variable was used as splitting variable and how well it separated low values from high values (M Kidd, personal communication, 2004). (For the purpose of this dissertation, a more complete description of Classification and Regression Tree Analyses is provided in Addendum 4.4).

A method called bagging (bootstrapping) was used for determination of variable importance. This is a resampling technique where trees are built repeatedly on samples drawn randomly (with replacement) from the original sample. The relative importance for each variable was then calculated as the average variable importance for the individual trees (M Kidd, personal communication, 2004).

Each data point was plotted as a member of a terminal node of the pertinent regression tree in order to determine whether a climatic effect was predominantly seasonal or whether site climate also played a role.

4.2.5 RESULTS AND DISCUSSION

4.2.5.1 Climate of the vintage

The seven-year study period included vintages with diverse climatic conditions (Fig. 4.2.2). The 1996/1997 season was, for example, noticeably cooler than the seven-year mean throughout the season (Fig. 4.2.2a), while in the 1999/2000 season, a heat wave was experienced during December, resulting in a mean temperature that was 3.0°C warmer than the seven-year mean (Fig. 4.2.2a). The 2001/2002 season had higher rainfall than the seven-year mean during the growing period (Fig. 4.2.2b). Season was therefore expected to strongly affect the performance of Cabernet Sauvignon and Sauvignon blanc. This seasonal variability appears to corroborate the finding in the Rhone Valley that a study period of at least seven years is necessary to provide similar results to the long term mean (Vaudour, 2001).

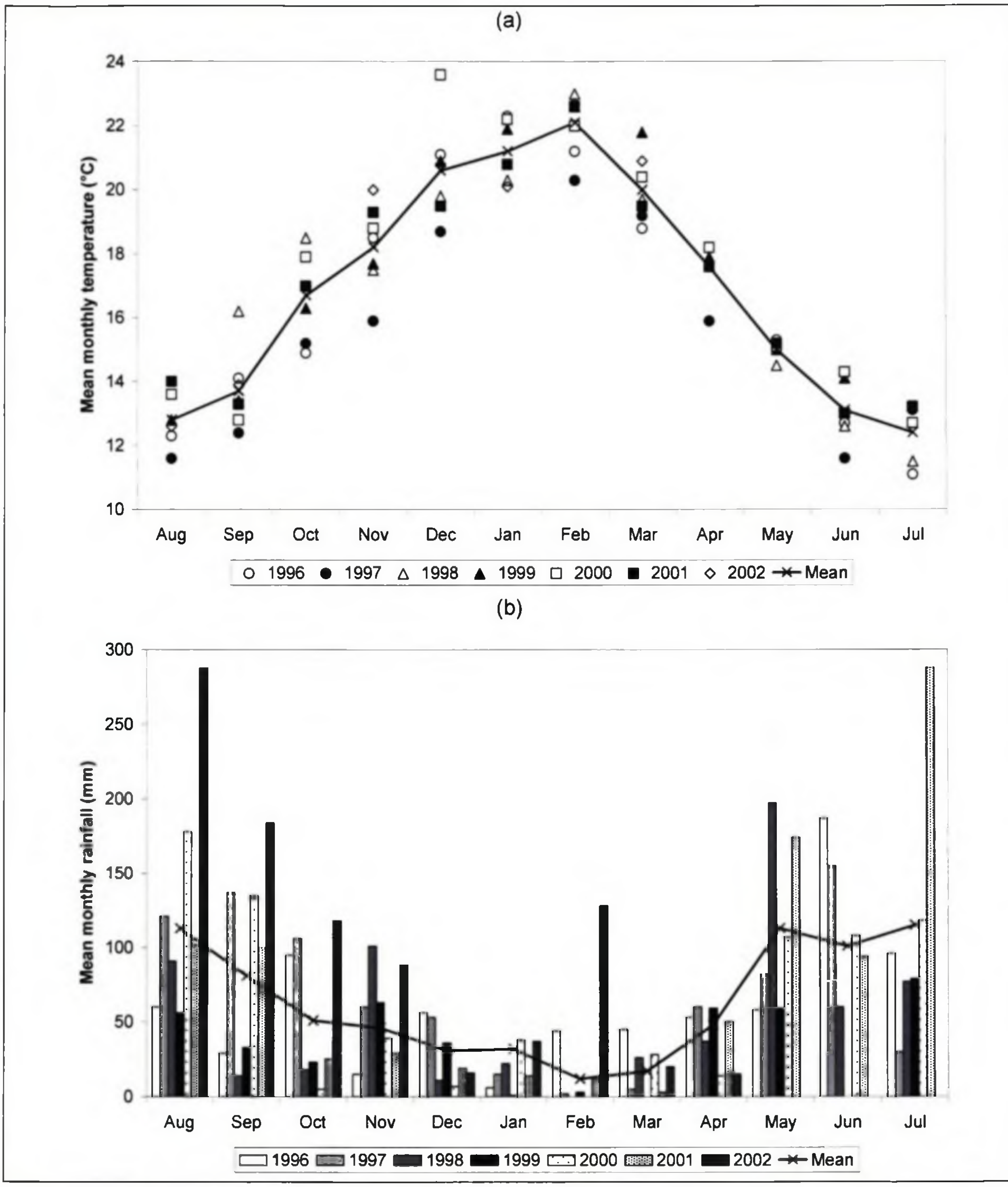

Figure 4.2.2 Mean monthly temperature (a) and rainfall (b) for each of the seven seasons of the study, compared to the seven-year mean measured at the automatic weather station at the Nietvoorbij campus of ARC Infruitec-Nietvoorbij (T01). The date in the legend indicates the harvest season, for example, 1996 represents the period from August 1995 to July 1996.

4.2.5.2 Parameters affecting the performance of Cabernet Sauvignon and Sauvignon blanc

The relative importance of the four most important environment or management related variables are given for each dependent variable of Cabernet Sauvignon and Sauvignon blanc in Table 4.2.1 to Table 4.2.6. Only “independent” variables with a relative importance of greater than 70% were considered to have any real importance in determining the dependent variable, unless they had a very narrow confidence interval (M Kidd, personal communication, 2004).

As the plot network was heterogeneous with respect to plant material and viticultural management practices, it was necessary to test whether these differences outweighed the effect of the environment on the performance of the two cultivars under investigation.

4.2.5.3 Contribution of genotype to viticultural and oenological performance

Three rootstocks were represented in this study, namely Richter 99, Richter 110 and 101-14 Mgt. Although these rootstocks are known to have different effects on grapevine growth and production (Pongrácz, 1983), the relative importance of rootstock did not exceed 9.4% for Cabernet Sauvignon or 28.1% for Sauvignon blanc. This may suggest that the rootstocks were chosen correctly for the respective soil types. Scion clone, however, had a greater relative importance with respect to distinguishing between viticultural and oenological performance. A relative importance of 81.8% was obtained for bunch mass of Sauvignon blanc (Table 4.2.2) and 85.1% for the yield to pruning mass ratio of Cabernet Sauvignon (Table 4.2.2). A relative importance of less than 70% was obtained for all other dependent variables.

4.2.5.4 Contribution of viticultural management to viticultural and oenological performance

The age of vines did not exceed a relative importance of 70% for any of the dependent variables of Cabernet Sauvignon or Sauvignon blanc, but was selected as a splitting variable in the final regression tree for the canopy index of Sauvignon blanc. Similarly, vine spacing did not exceed a relative importance of 70%, although it was selected as a splitting variable for bunch mass and capacity (*puissance*, Deloire *et al.*, 2002) of Sauvignon blanc, and must soluble solids of Cabernet Sauvignon. Canopy height, trellis system and irrigation did not have a relative importance greater than 70% for any dependent variable, nor were they selected as splitting variables in any of the regression trees.

4.2.5.5 Factors affecting the performance of Cabernet Sauvignon

Regression tree analyses indicated that the phenology, growth, yield, berry composition and wine related parameters of Cabernet Sauvignon were affected by the climate of the season, soil and topographic related site characteristics and scion clone.

The phenology of Cabernet Sauvignon was predominantly affected by seasonal climate with little to no contribution of site (Table 4.2.1). The timing of the variables having the highest relative importance did not necessarily coincide with the phenological event in question, e.g. the mean temperature during the month prior to ripening had a relative importance of 90.8% for flowering of Cabernet Sauvignon.

This can be ascribed to the significant correlation between the phenological stages of budburst, flowering and harvest ($p \leq 0.05$).

Table 4.2.1 Relative importance of the four most important variables affecting the phenology of Cabernet Sauvignon and Sauvignon blanc in the Stellenbosch Wine of Origin District, South Africa (An explanation of the variable codes is provided in Addendum 4.2)

Dependent variable	Environmental and management related variables (relative importance)	
	Cabernet Sauvignon	Sauvignon blanc
Flowering	**MeanT** (90.8%), **GDD** (89.7%), **MinT** (77.1%), MaxT (53.5%)	**Flo_MaxT** (97.3%), Flo_MeanT (96.9%), Winkler (75.2%), HI (67.9%)
Harvest	**Rad** (97.1%), Evap (72.2%), Sun (69.9%), GDD (50.9%)	**Flo_MaxT** (90.7%), Flo_MeanT (89.6%), Winkler (60.8%), **Rad** (53.2%)

Bold type represents predictor variables selected for final regression trees

A previous statistical study on the same set of dependent variables showed that yield:pruning mass ratio, capacity (or estimated total dry mass, Deloire *et al.*, 2002), must titratable acidity and soluble solids, wine pH, titratable acidity and density and the sensory score for wine astringency of Cabernet Sauvignon, were the variables with the greatest discriminatory value between sites (Carey *et al.*, 2003).

The yield:pruning mass ratio, an indication of the sink:source ratio, was significantly higher for scion clones CS 10 and CS 163 (Fig 4.2.3a). This appeared to be due to the effect of clone on yield (Table 4.2.2.), with the terminal node with the highest yield to pruning mass ratio being associated with significantly higher yield per meter cordon (data not shown). The capacity of the grapevines, on the other hand, was related to soil texture (Table 4.2.2. and Fig 4.2.3b), as represented by the percentage of the fine sand fraction present in the soil profile to a depth of 100 cm. The parent material contributing to the soils would be expected to affect the particle size distribution, although this may not always represent the underlying parent material (Conradie *et al.*, 2002). In general, though, it would be expected that soils originating from phyllitic shale (Tygerberg formation of the Malmesbury group) would weather into predominantly fine particles, followed by hornfels and finally granite (Conradie *et al.*, 2002). The group with the lowest percentage fine sand particles was represented by sites with granitic parent material. These sites were also associated with the highest medium and coarse sand contents, low silt content and variable but generally low clay content. The second group, with intermediate fine sand contents, represented the majority of experimental sites. The third group, with the highest percentage fine sand, was represented by sites with deep, highly weathered apedal soils. This relationship of fine sand content may, however, be disputable as the fine sand content had a similar relative importance to the S-value (total cation content) variable (both below 70%) and may well have effectively masked the S-value from inclusion within the final regression tree structure.

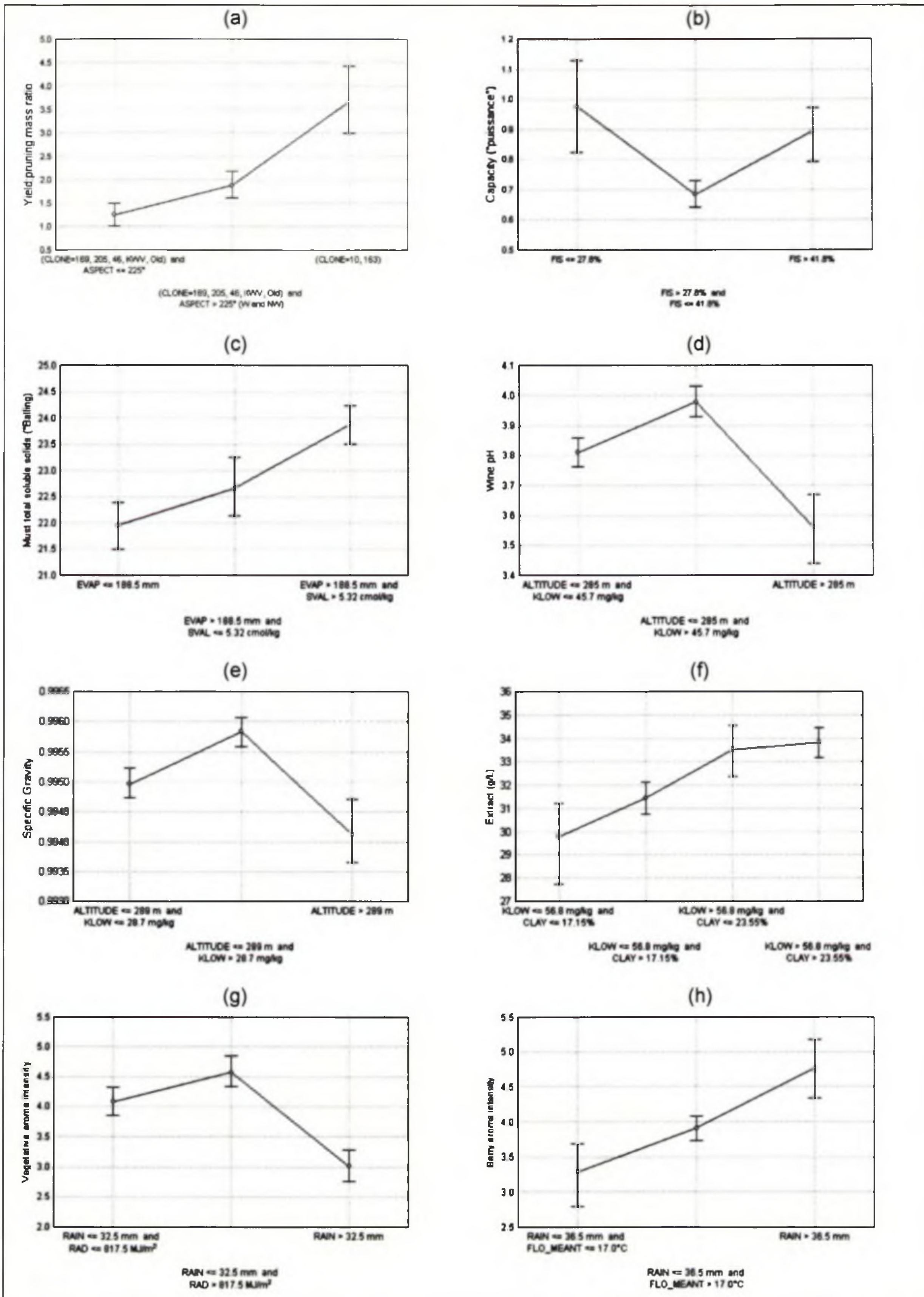

Figure 4.2.3 Bootstrap mean values for terminal nodes of final regression trees of selected viticultural and oenological variables of Cabernet Sauvignon, Stellenbosch. Vertical bars denote 0.95 bootstrap confidence intervals. (Explanations of dependent and predictor variables are given in Addendum 4.2)

Table 4.2.2 Relative importance of the four most important variables affecting the growth and yield of Cabernet Sauvignon and Sauvignon blanc in the Stellenbosch Wine of Origin District, South Africa (An explanation of the variable codes is provided in Addendum 4.2)

Dependent variable	Environmental and management related variables (relative importance)	
	Cabernet Sauvignon	Sauvignon blanc
Cane mass (kg/m cordon)	**MaxT** (68.5%), MeanT (52.5%), **clone** (32.7%), Flo_meanT (30.9%)	**Clone** (43.8%), clay_low (41.0%), stone (40.3%), **clay** (33.0%)
Canopy Index	Vine density (59.4%), **CoS** (51.7%), **Flo_meanT** (41.4%), Flo_maxT (34.1%)	**MeanT** (49.6%), **plant year** (46.6%), MaxT (46.6%), Flo_meanT (42.2%)
Yield (kg/m cordon)	**Alt** (60.1%), FiS (59.6%), **Clone** (47.8%), aspect (45.5%)	**Flo_WSgr4** (82.3%), WS (68.8%), **WSgr4**(62.3%), Soil_prep (30.3%)
No of berries per bunch	GDD (76.9%), **MeanT** (75.7%), Tgr30 (69.8%), T2025 (56.5%)	Flo_maxT (68.9%), **Flo_rain** (61.2%), **rad** (55.2%), Flo_meanT (42.2%)
Bunch mass (g)	**FiS** (48.7%), **Dist_sea** (40.9%), Evap (38.2%), Slope (34.8%)	**Clone** (81.8%), **vine density** (39.4%), K Low (37.3%), soil_prep (33.7%)
Berry mass (g)	Tgr30 (58.6%), GDD (57.1%), **T2025** (56.6%), Rad (54.3%)	Flo_maxT (89.5%), **Flo_rain** (73.6%), **Flo_meanT** (70.5%), rad (65.1%)
Yield: pruning mass ratio	**Clone** (85.1%), Soil pH (54.5%), dist_sea (50.5%), **Aspect** (43.2%)	Slope (73.5%), **dist_sea** (62.8%), clay (62.6%), **clay_low** (55.2%)
Capacity[1]	**FiS** (61.1%), S-Val (59.9%), Plant year (52.8%), MaxT (48.8%)	**WSgr4** (79.9%), **vine density** (61.7%), **WS** (61.0%), Flo_WSgr4 (51.9%)

Bold type represents predictor variables selected for final regression trees
[1]*puissance* (Deloire *et al.*, 2002)

Must analyses were predominantly affected by the climate of the season (Table 4.2.3), although these effects did not appear to have a high importance. Some vineyards were not able to ripen their fruit to the desired level of technological ripeness (ca. 24°B), resulting in significant differences ($p \leq 0.05$) between plots in total soluble solid content at harvest (results not presented). This may be due partially to the presence of leafroll infection, which is widely spread in all wine producing areas of South Africa (Pietersen, 2004). Leafroll infection holds consequences for the performance of grapevines, especially yield and berry composition (Goheen & Cook, 1959; Over de Linden & Chamberlain, 1970) and infected vineyards become more sensitive to abiotic stress situations (Carstens, 2002). However, not all sites included in the terminal nodes with low bootstrap mean total soluble solids (22.0°B) had visual symptoms of leaf roll and some of those that did have visual symptoms were included in the terminal nodes with higher bootstrap mean total soluble solids (22.7°B and 23.9°B). Grapes with low total soluble solids were generally left on the vines until the first autumn rains. As autumn approaches, evaporation decreases. As a result the vineyards that could not fully ripen their grapes were associated with lower evaporation rates during the month before harvest (Table 4.2.3 and Fig. 4.2.3c). The ability of a site to ripen grapes when evaporation rates were high was related to the depth-weighted mean S-value of the soil (Table 4.2.3 and Fig. 4.2.3c) in the final regression tree, although the relative importance of this variable was negligible. The

S-value of soils reflects the sum of exchangeable Ca, Mg, Na and K (Soil Classification Working Group, 1991) and has been found to be higher for soils derived from Malmesbury shale (Conradie *et al.*, 2002). S-value is also dependent on the clay content of the soil and shall thus represent, to a certain extent, the soil water-holding capacity (D Saayman, personal communication, 2004). The determination of soil water-holding capacity did not fall within the confines of this investigation but deserves further study due to its particular relevance for terroir studies (Saayman & Kleynhans, 1978; Seguin, 1986; Morlat *et al.*, 1992; Choné *et al.*, 2001; Van Leeuwen *et al*,. 2003). The more fertile soils (possibly with a better soil water-holding capacity) were associated with the terminal node having the highest total soluble solid content. The strong relationship between must titratable acidity and evaporation during the month before ripening (Table 4.2.3) appeared to be predominantly related to season. The terminal node with the highest mean total titratable acidity (8.9 g/L), and concomitantly the lowest values for evaporation, included predominantly data points from the 1997 season. It must be remembered that evaporation is a function of *inter alia* solar radiation, air temperature, vapour pressure and wind speed. The 1997 season was characterized by markedly cool conditions (Fig. 4.2.2a), and the effects of temperature on acidity have been well documented (Jackson & Lombard, 1993). The node with lower titratable acidity was associated with higher evaporation rates, which in turn are associated with higher air temperature and wind speed. A study in the Loire Valley (Barbeau *et al.*, 2003) has shown that higher wind speeds in the period prior to harvest reduced must acidity, and especially malic acid levels for red cultivars. The inclusion of evaporation as a predictor variable for must acidity in this study, may therefore be related to temperature and wind effects.

Table 4.2.3 Relative importance of the four most important variables affecting the chemical analyses of the must of Cabernet Sauvignon and Sauvignon blanc from the Stellenbosch Wine of Origin District, South Africa. (An explanation of the variable codes is provided in Addendum 4.2)

Dependent variable	Environmental and management related variables (relative importance)	
	Cabernet Sauvignon	Sauvignon blanc
TSS	**Evap** (56.5%), Vine density (34.3%), **S-value** (31.9%), clay (31.1%)	**Rain** (43.7%), **Flo_maxT** (39.6%), Flo_maxT (35.9%), Silt (28.95)
TTA	**Evap** (73.7%), Rad (58.6%), Tgr30 (44.8%), T2025 (41.3%)	**GDD** (39.1%), **rad** (38.7%), **MeanT** (35.6%), Flo_rain (31.7%)
pH	**Evap** (78.2%), Rad (59.3%), GDD (51.8%), T2025 (41.4%)	**Plow** (32.6%), S-val (31.1%), **dist_sea** (30.5%), Alt (28.1%)
Maturity index[1]	**Evap** (53.5%), vine density (42.0%), Rad (39.5%), Tgr30 (38.4%)	**Flo_rain** (47.1%), S-val (35.0%), rad (32.6%), **clay-low** (25.3%)

Bold type represents predictor variables selected for final regression trees

[1](Must TSS x 10)/MustTTA

Wine pH appeared to be strongly affected by site, with potassium content in the sub-soil, number of hours with a wind speed greater than 4 m/s during October and

November (the green stage of berry growth) and altitude being the environmental variables having the highest relative importance in the case of Cabernet Sauvignon (Table 4.2.4 and Fig. 4.2.3d). Although the number of hours with a wind speed greater than 4 m/s was not selected for the final regression tree, a relationship between wind exposure and wine pH has been shown on the same data set (Carey *et al.*, 2003). It appeared that increased wind exposure was associated with wines having a higher wine pH. Freeman *et al.* (1982) have suggested that any factor that reduces the photosynthetic activity of leaves will result in increased potassium accumulation in berries, with implications for wine pH. Such factors are wind exposure, water stress and excessive shading in the canopy. The results of the regression tree analyses suggest that the potassium content of the subsoil had a strong effect (Table 4.2.4 and Fig. 4.2.3d). The uptake of potassium ions by plant roots is determined by the plant available potassium levels of the soil, but also by the distribution and activity of grapevine roots, relative concentrations of other cations, rootstock and scion combination, berry growth, canopy microclimate and management practices (Mpelasoka *et al.*, 2003). Berry potassium content has been related to pH values in a number of studies (Hale, 1977; Boulton, 1980; Mpelasoka *et al.*, 2003). Up to half of the potassium in ripe berries may be located in the skin and at full ripeness skin tissue has a high leaching rate (Iland & Coombe, 1988). As the Cabernet Sauvignon was fermented on skins, a higher wine pH is probably associated with increased potassium concentrations in the skins and/or flesh of the berries. Potassium availability to the vine depends on *inter alia* soil characteristics related to the nature and degree of weathering of parent material (lit. cited in Mpelasoka *et al.*, 2003) and soil mineralogy (Wooldridge, 1988). Granitic soils generally have the highest potassium content (Wooldridge, 1988; Van Schoor, 2001), which is unbuffered and favours rapid plant uptake (Wooldridge, 1988), followed by shales, while sandstones are generally poorly supplied with plant mineral nutrients (Wooldridge, 1988; Van Schoor, 2001). Conradie *et al.* (2002) found, however, that potassium levels of subsoils in the Stellenbosch area could not be related to underlying geological formations, probably as a result of management practices (*vid.* Seguin, 1986). Altitudes of greater than 285 m were associated with the lowest wine pH values. Altitude has been associated with lower mean temperatures and higher kaolinite clay fractions in the South Western Cape, with implications for vegetative growth, fresh vegetative character and wine quality of Sauvignon blanc (Van Schoor, 2001), suggesting a possible combined contribution of temperature and soil origin to wine pH values in this study.

The titratable acidity of the Cabernet Sauvignon wine, on the other hand, was predominantly related to the climate, and especially temperature during the green berry growth stage (Table 4.2.4). Mean maximum temperature values for October and November that were greater that 22.6°C were associated with lower wine TTA values (results not presented). Ruffner (1982) noted that acid disappearance, mainly related to degradation or compartmentalization of malic acid, starts prior to the ripening phase under warm conditions.

Table 4.2.4. Relative importance of the four most important variables affecting the chemical analyses of the wine of Cabernet Sauvignon and Sauvignon blanc from the Stellenbosch Wine of Origin District, South Africa (An explanation of the variable codes is provided in Addendum 4.2)

Dependent variables	Environmental and management related variables (relative importance)	
	Cabernet Sauvignon	Sauvignon blanc
Specific gravity	**Alt** (71.5%), **Klow** (56.8%), Trellis system (44.3%), Flo_WSgr4 (42.4%)	**Slope** (59.8%), dist_sea (57.8%), **clay_low** (51.2%), alt (42.3%)
Alcohol	**Evap** (63.5%), Rad (42.5%), MeanT (34.6%), **Clone** (34.4%)	**Rain** (60.6%), **SI** (40.0%), Flo_meanT (31.9%), Flo_maxT (30.6%)
Extract	**Klow** (53.9%), soil pH (47.9%), Plow (40.0%), **clay** (33.5%)	**Klow** (34.3%), **S-val** (32.2%), Tgr30 (30.3%), Silt (30.1%)
ph	**Klow** (94.6%), Flo_WSgr4 (69.4%), **Alt** (65.8%), Slope (26.6%)	**MinT** (62.0%), MeanT (44.9%), Silt (42.0%), plant-year (41.6%)
TTA	MeanT (65.7%), GDD (54.4%), **Flo_maxT** (52.7%), MinT (44.5%)	**MeanT** (73.7%), **GDD** (61.3%), **MinT** (55.7%), MaxT (48.5%)
VA	**GDD** (66.4%), evap (60.1%), rad (57.6%), **Flo_meanT** (51.0%)	**MeanT** (62.7%), Tgr30 (56.7%), **Flo_rain** (56.0%), MaxT (55.2%)

*Bold type represents predictor variables selected for final regression trees.

For Cabernet Sauvignon, wine specific gravity, a measure of the concentration of matter, had a similar relationship to the environment as wine pH (Table 4.2.4), but was more sensitive to subsoil potassium concentrations, with the split occurring at a value of 28.7 mg/kg (Fig. 4.2.3e). Wine extract, too, was related to potassium content of the subsoil with the terminal split occurring at 56.8 mg/kg (Table 4.2.4). Higher values of subsoil K were associated with higher values for wine extract. Within each of these nodes, the depth-weighted clay content caused a further split, higher values being associated with wines with higher extract values (Fig. 4.2.3f).

No environmental or management variables exceeded a relative importance of 70% for the sensory characteristics of Cabernet Sauvignon (Table 4.2.5), but climate related variables appeared dominant. Plotting the individual data points as members of the terminal nodes for each sensory variable indicated that the climate effect was predominantly seasonal. Site related variables were included in the final regression trees, but they cannot be considered unequivocal. The lack of a clear site effect may be due to the short period (ca. six-months) between fermentation and sensory analysis as young wines can be dominated by common fermentation compounds. Nonetheless, it appears from the results of the regression tree analyses that rain during the month before ripening (berry and vegetative associated aromas) and the green growth period of the berry (floral and spicy associated aromas) played a role in determining the final wine aroma composition (Table 4.2.5).

Table 4.2.5 Relative importance of the four most important variables affecting the sensory analyses of Cabernet Sauvignon in the Stellenbosch Wine of Origin District, South Africa. (An explanation of the variable codes is provided in Addendum 4.2)

Dependent variable	Environmental and management related variables (relative importance)
Colour	**Clone** (37.3%), Flo_minT (31.0%), vine density (29.7%), **slope** (27.4%)
Astringency	**DI** (35.3%), Rad (31.5%), **dist_sea** (31.3%), alt (30.7%)
Acid	**Flo_meanT** (71.2%), Flo_maxT (62.6%), **MeanT** (55.9%), GDD (46.9%)
Fullness	**Clay** (51.7%), **S_val** (50.8%), clay_low (34.6%), **MaxT** (31.7%)
Berry	**Rain** (66.2%), MeanT (51.1%), GDD (49.7%), **Flo_meanT** (44.1%)
Vegetative	**Rain** (57.9%), MeanT (46.3%), GDD (39.6%), **Rad** (30.9%)
Floral	**Flo_rain** (56.1%), **MinT** (45.3%), **Flo_maxT** (34.8%), MeanT (29.8%)
Spicy	**Flo_rain** (69.9%), Alt (44.2%), **Flo_meanT** (32.0%), **Flo_minT** (31.8%)
Woody	**HI** (61.3%), Flo_maxT (50.8%), Flo_meanT (50.4%), Wink (41.1%)

Bold type represents predictor variables selected for final regression trees

The cultivar typical aroma of Cabernet Sauvignon can be described as having a fruit flavour of blackcurrants and green bell peppers (Robinson, 1996). A total of 48 aroma-active compounds have been distinguished in Cabernet Sauvignon wines (Kotseridis & Baumes, 2000). The vegetative notes (including descriptors such as bell pepper, herbaceous, freshly cut green grass, eucalyptus, mint, artichoke, hay and tobacco) (Noble *et al.*, 1987) could be attributed to aldehydes such as decanal and (E, Z) – nona – 2, 6 – dienal (Kotseridis & Baumes, 2000) as well as the well-documented methoxypyrazines (Roujou de Boubée *et al.*, 2000). In this study, in contrast to Roujou de Boubée *et al.* (2000), seasons or sites with a higher rainfall resulted in wines with a lower vegetative aroma intensity. The lower vegetative aroma intensity may be attributable to an overall low aroma intensity (not determined), but it may also be due to differential canopy management in an attempt to ensure more open canopies in rainy conditions. The relationship between higher levels of radiation during the month before harvest and increased intensity of vegetative aroma characteristics also contrasts with existing literature on the effects of radiation on methoxypyrazine levels (Marais *et al.*, 1999). The radiation values in this study refer to global radiation, which may have contributed to higher photosynthetic levels, increased vegetative growth and thus denser canopies. This variable does not have a high value of relative importance (Table 4.2.5) and its effect is not clear. It is also not known to what extent aldehydes, with a potentially different climatic response to that of methoxypyrazines, contribute to the vegetative aroma characteristics of Cabernet Sauvignon under South African conditions and deserves further study.

In contrast, Cabernet Sauvignon wines from seasons or sites with a higher rainfall during the month before harvest were described as having more intense berry aroma characteristics. Various studies (literature cited in Noble *et al.*, 1995) have suggested that berry aromas are associated with soils having a lower water-holding capacity. The authors postulated that this was related to reduced canopy growth on sand or gravelly soils resulting in a more open canopy and thus photodegradation of methoxypyrazines. No control was exercised over the canopy management practices of the producers in the study reported in this paper and it is common practice to break out leaves following rainfall during the period preceding harvest in order to limit the development of bunch rot. Higher rainfall during the month before harvest may therefore well have contributed indirectly to more open canopies via intervention of the vineyard manager. In seasons with normal rainfall, warmer temperatures during October and November were associated with more intense berry aromas

Fullness on mouth-feel was affected by clay content and S-value of the soil (Table 4.2.5), with wines from shale-derived soils, which have a higher clay content and higher S-values being fuller on mouth-feel. Although previous studies had suggested that the sensory score for astringency was a discriminating variable (Carey *et al.*, 2003), the relative importance of the predictor variables did not differ significantly and the resulting regression tree did not distinguish between groups (data not shown).

4.2.5.6 Factors affecting the performance of Sauvignon blanc

The performance of Sauvignon blanc was mainly affected by the climate of the season, site climate, genotype, management practices, topography and soil related factors. Discriminant analyses on the same data set (Carey *et al.*, 2003) indicated that pruning mass, yield, bunch mass, ratio of pruning mass to yield and cooked vegetative aroma intensity (asparagus/green beans/artichokes) were the dependent variables having the greatest discriminatory value between sites.

The phenology of Sauvignon blanc, similarly to Cabernet Sauvignon, was more affected by the climate of the season than site. The phenological stages that were monitored were highly correlated with one another and could be explained by the mean maximum temperature during the months of October and November (Table 4.2.1). Radiation contributed to the time of harvest. Sites that received a higher global radiation during the month prior to harvest were harvested earlier.

There was no clear discrimination between environmental or management related variables with respect to relative importance for pruning mass or canopy index (Table 4.2.2), but scion clone and depth-weighted mean percentage of clay in the soil profile were selected for the final regression tree for pruning mass. A heavy-textured soil (clay>25%), generally due to a high clay content in the sub-soil, was associated with reduced vegetative growth for selected clones. This may have been due to reduced root growth resulting from excessively compact sub-soils as above-ground growth generally directly reflects root volume (Archer & Strauss, 1991). In non-irrigated situations, however, a lower pruning mass would also be expected on sandy soils as a result of the lower soil water holding capacity, and increased water stress. In seasons without excessive heat, age of the vines determined the canopy index. Less dense canopies were associated with older vineyards (planted prior to 1984).

Yield per meter cordon was positively related to exposure of a locality to wind during the green berry growth stage (October and November) and during the month prior to harvest (Table 4.2.2), but this relationship contradicted existing literature (Fig. 4.2.4a). Protection of grapevines from wind has been associated with increased yield (Dry *et al.*, 1988; Hamilton, 1989; Dry & Botting, 1993; Bettiga *et al.*, 1997), but in the Stellenbosch Wine of Origin District, localities exposed for longer to wind velocities exceeding 4 m/s appeared to be associated with increased yield (Fig. 4.2.4a). Wind is one of the climatic variables having the highest degree of spatial variability (Dumas *et al.*, 1997; Carey, 2001) and in a region such as the Stellenbosch Wine of Origin District where wind is a common climatic phenomenon during the ripening period, site differences would appear to be stronger than seasonal differences. The higher yield was significantly correlated with higher bunch mass ($r = 0.58$, $p \leq 0.05$), which could be attributed to greater number of berries per bunch ($r = 0.59$, $p \leq 0.05$), although neither of these variables was associated with exposure to wind in the regression tree analyses (Table 4.2.2). Some studies have attributed the increased yield for protected vines to increased shoot numbers per vine (Bettiga *et al.*, 1997), which can be associated with increased pruning mass. A one-way ANOVA of the pruning mass values associated with the three terminal nodes of the regression tree for yield shown in Fig. 4.2.4a showed no significant difference between groups (data not shown). None of the plots studied in this investigation were exposed to excessively strong winds that resulted in marked loss of shoots, physical damage or noticeably poor growth and yield. Sheltered vines have been shown by Bettiga *et al.* (1997) to have larger primary and secondary leaves. This would contribute to increased shading in the canopy. Increased exposure to wind, with increased leaf flustering and smaller leaves, associated with wind exposure, can be expected to contribute to increased sunlight penetration in the canopy. This may have facilitated increased initiation of inflorescence primordia and translocation of carbohydrates to bunches. Midday leaf water potential values have been shown to be more negative for sheltered vines than exposed vines (Freeman *et al.*, 1982; Bettiga *et al.*, 1997). Therefore, stomatal closure, due to exposure to wind in excess of 4 m/s (Campbell-Clause, 1998), may have limited water stress at exposed plots, also contributing to higher yield.

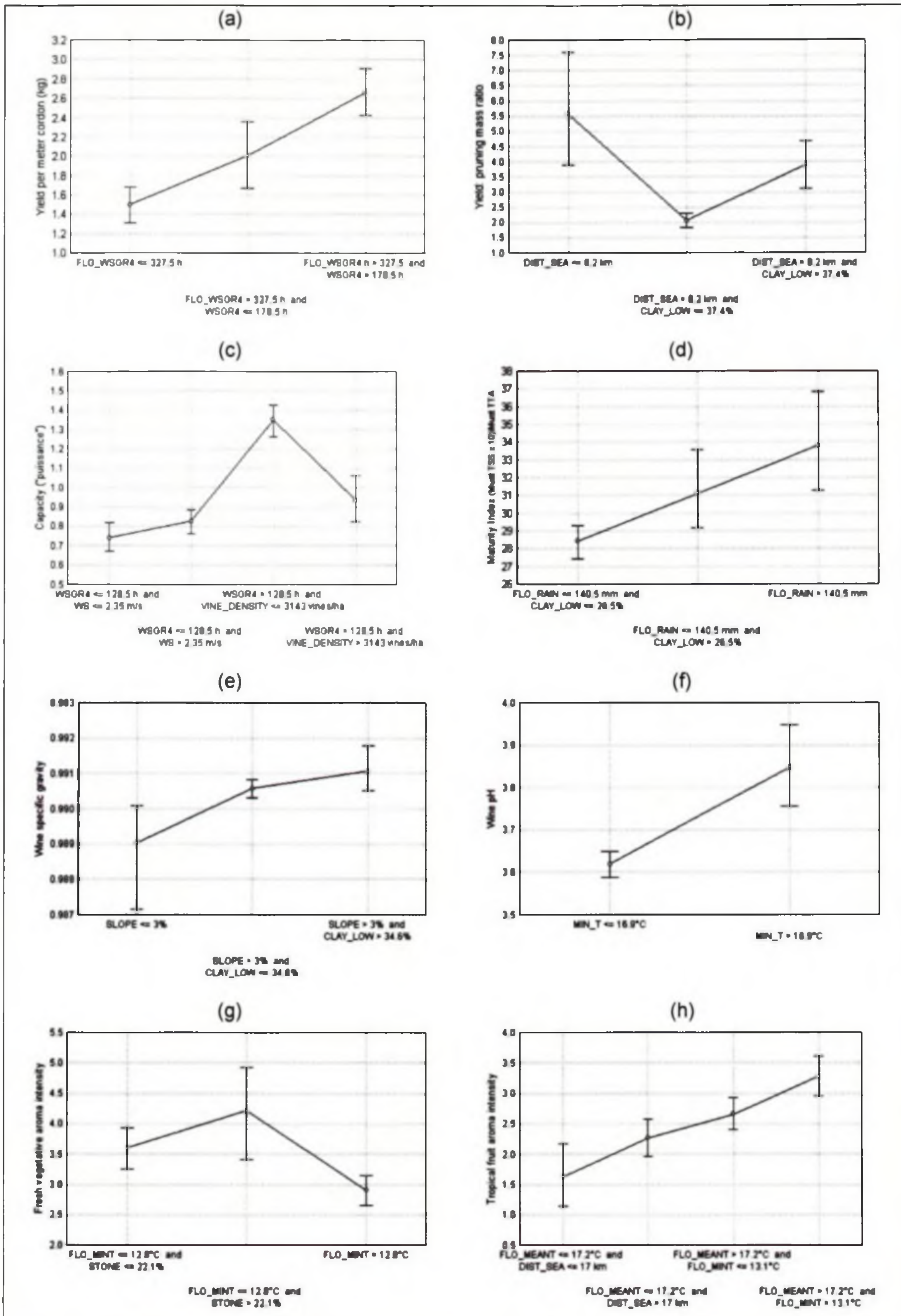

Figure 4.2.4 Bootstrap mean values for terminal nodes of final regression trees of selected viticultural and oenological variables of Sauvignon blanc, Stellenbosch. Vertical bars denote 0.95 bootstrap confidence intervals. An explanation of the variable codes is provided in Addendum 4.2.

The yield to pruning mass ratio (Fig. 4.2.4b) is a measure of the sink to source relationship in the grapevine. The majority of plots in the investigation were represented by the terminal node with the lowest mean value for yield:pruning mass ratio in Fig. 4.2.4b. The terminal node with the highest mean value for yield to pruning mass ratio, determined by proximity to False Bay, was represented by plots with predominantly low pruning mass (Fig. 4.2.4b). These vineyards are characterized by relatively sandy soils with a fairly high Na content on the coastal plain. The moist air from the sea that moves inland in the afternoon will be expected to have a fairly high salt content, which may also restrict vegetative growth. The terminal node that is characterized by plots that are situated further inland and having a depth-weighted clay content in the subsoil of greater than 37.4% (Fig. 4.2.4b), has a yield to pruning mass ratio that is predominantly affected by the yield of the vineyards, which in all cases is greater than 2 kg/m cordon. The dense, highly structured subsoil of these plots is expected to warm more slowly in spring, resulting in a slower initial growth phase and more open canopies during inflorescence initiation.

The capacity of the Sauvignon blanc vineyards was predominantly affected by exposure to wind in excess of 4 m/s, apparently via the positive effect on yield, although vine spacing did contribute to reducing the capacity of vineyards in exposed situations (Table 4.2.2 and Fig. 4.2.4c).

Plotting individual data points as members of terminal nodes indicated that must total soluble solids and titratable acidity were affected by the climate of the season, while must pH was related to site characteristics (Table 4.2.3). There was, however, no environmental or management related variable that had a high relative importance or that was clearly associated with these parameters. Although the maturity index (Table 4.2.3 and Fig. 4.2.4d) did not differ significantly between terminal nodes, plotting the must total soluble solids against the must titratable acidity for each group suggested that the terminal node with the lowest bootstrap mean for the maturity index (Fig. 4.2.4d) had the more ideal berry composition (degrees balling ca. 23°B, titratable acidity between 8 g/L and 9 g/L, pH values of below 3.5). This terminal node represented the majority of plots included in the investigation. The other two terminal nodes with less ideal composition were represented either by seasons with high rainfall during October and November, or plots with a clayey sub-soil.

The alcohol content of the Sauvignon blanc wines, volatile acidity and total titratable acidity were mainly related to climate (Table 4.2.4). The specific gravity of the wine appeared to be determined by position in the landscape. The lowest specific gravity was associated with wine from vineyards on the coastal plain (as represented by low slope inclination) (Fig. 4.2.4e). These vineyards are associated with sandy soils and an influx of moist sea air in the afternoon. Wine extract, similarly to Cabernet Sauvignon, was related to the potassium content of the subsoil (Table 4.2.4), although the relative importance of this variable was not high. It appeared that soils with higher levels of exchangeable cations, together with potassium, lead to wines with higher extract (results not presented). As mentioned previously, both the potassium content of the subsoil and the S-value (sum of exchangeable cations) can be related to parent material, with granite and shale derived soils having the highest values. Wines originating from vineyards on granite and shale-derived soils would therefore be expected to have a higher extract than those on sandstones.

Sauvignon blanc wine pH values, although affected to a certain extent by site, did not have a similar relationship to the environment as Cabernet Sauvignon. The minimum temperature during the month prior to harvest appeared to best separate plots with respect to wine pH for Sauvignon blanc (Table 4.2.4, Fig. 4.2.4f). Jackson & Lombard (1993) suggested that low night temperatures are necessary when day temperatures are warm for lower pH values and higher natural acidity. This is substantiated in this investigation as those plots having the highest minimum temperature prior to harvest had the highest wine pH (Fig. 4.2.4f). Wine pH was also positively correlated with pruning mass ($r = 0.41$, $p \leq 0.05$). This relationship is expected due to the well-known negative effects of canopy shading (Smart & Robinson, 1991). The temperature effect on titratable acidity was also clear (Table 4.2.4). The highest temperatures were associated with the lowest values of titratable acidity (data not shown).

The climate, and especially temperature, during the green stage of berry growth appeared to affect the sensory characteristics of Sauvignon blanc in the Stellenbosch Wine of Origin District (Table 4.2.6). Plotting the individual data points as members of terminal nodes of the regression trees for each of the sensory variables indicated that the effects were predominantly seasonal, although the effect of site climate was not negated. The characteristic green bell-pepper and grassy aromas related to the 2-methoxy-3-isobutylpyrazine (Allen *et al.*, 1991) were more intense for sites or seasons with lower pre-véraison minimum temperatures (Fig. 4.2.4g). The effect of temperature during ripening on methoxypyrazine concentrations is well documented (Allen *et al.*, 1988; Allen & Lacey, 1993; Marais *et al.*, 1999). To our knowledge, no data on the effect of temperature during the pre-véraison period on methoxypyrazine concentrations has been published. From data presented by Lacey *et al.* (1991) it appears that grapes from "cooler" regions and or seasons have higher levels of methoxypyrazines at comparably low total soluble solids values, which suggests that conditions during the pre-ripening period may influence the methoxypyrazine content prior to degradation as well as the degree of loss during ripening. No data was, however, presented on the climatic conditions during this pre-véraison phase. For a more acceptable wine, it is necessary that the typical grass-like aroma is balanced by other herbaceous and fruity aromas (Marais, 1994). The cooked vegetative aroma characteristics (asparagus/green bean) are typical of 2-methoxy-3-isopropylpyrazine (Allen *et al.*, 1988). In this investigation no environmental or management related variable had a high relative importance with respect to these aroma characteristics (Table 4.2.6). Although scion clone and altitude were selected as splitting variables, their scores for relative importance were low (Table 4.2.6). The tropical fruit (Fig. 4.2.4h) and spicy (results not presented) aromatic intensity increased with increasing temperature during the pre-véraison period. Fruity and tropical aromas appear to be related to monoterpenes and C_{13}-norisoprenoids (Sefton *et al.*, 1994). Marais *et al.* (1999) found that the tropical/fruity style of Sauvignon blanc was characteristic of warmer regions. This correlated with the higher relative concentration of total acid-released monoterpenes and C_{13}-norisoprenoids. The concentration of these compounds has also been found to increase with ripeness and increased sunlight penetration in the canopy (Marais *et al.*, 1999).

Table 4.2.6 Relative importance of the four most important variables affecting the sensory analyses of Sauvignon blanc in the Stellenbosch Wine of Origin District, South Africa. (An explanation of the variable codes is provided in Addendum 4.2)

Dependent variable	Environmental and management related variables (relative importance)
Acid	**Flo_minT** (86.1%), Flo_meanT (82.4%), Flo_maxT (62.3%), **Tgr30** (35.8%)
Fullness	Flo_meanT (52.8%), **Flo_minT** (49.6%), **Flo_maxT** (44.3%), MeanT (43.3%)
Fresh vegetative	**Flo_minT** (76.8%), Flo_meanT (62.0%), Flo_maxT (53.3%), **Stone** (25.7%)
Cooked vegetative	Trellis system (44.2%), **Clone** 937.5%), **Alt** (28.4%), FiS (25.5%)
Dried vegetative	**Dist_sea** (51.1%), **Flo_meanT** (42.6%), Flo_rain (39.5%), Flo_MaxT (37.8%)
Tropical fruit	**Flo_meanT** (70.9%), **Flo_minT** (70.7%), Flo_maxT (58.0%), **dist_sea** (29.5%)
Spicy	**Flo_meanT** (79.5%), Flo_minT (70.6%), Flo_maxT (55.6%), **Rad** (29.5%)
Caramel	**Rain** (42.7%), Flo_minT (30.3%), **Flo_rain** (30.0%), Flo_meanT (29.6%)

Bold type represents predictor variables selected for final regression trees

4.2.6 CONCLUSIONS

It would seem that environmental parameters have an overriding effect on the performance of both Cabernet Sauvignon and Sauvignon blanc, but that these two cultivars react differently to environmental stimuli (Fig 4.2.5 and Fig 4.2.6).

It appears that the potassium (K) content of the subsoil, possibly related to geological parent material, affected the performance of Cabernet Sauvignon in the Stellenbosch Wine of Origin district (Fig. 4.2.5). Soils derived from sandstone would be expected to have a reduced ability to ripen fruit. The wines from these vineyards would potentially have a lower wine pH, specific gravity and extract due to the lower expected K content. Grapes from vineyards on shale derived soils would be expected to ripen fully and result in wines that are fuller on mouth-feel. Granite derived soils on the other hand may result in Cabernet Sauvignon wines with a higher pH, specific gravity and extract due to the higher expected K content. It is, however, not possible to negate the contribution of fertilisation.

The climate of the season appeared to have a very strong influence on the aroma characteristics of Cabernet Sauvignon. Warmer sites during years with normal rainfall can be expected to result in more intense berry aroma characteristics.

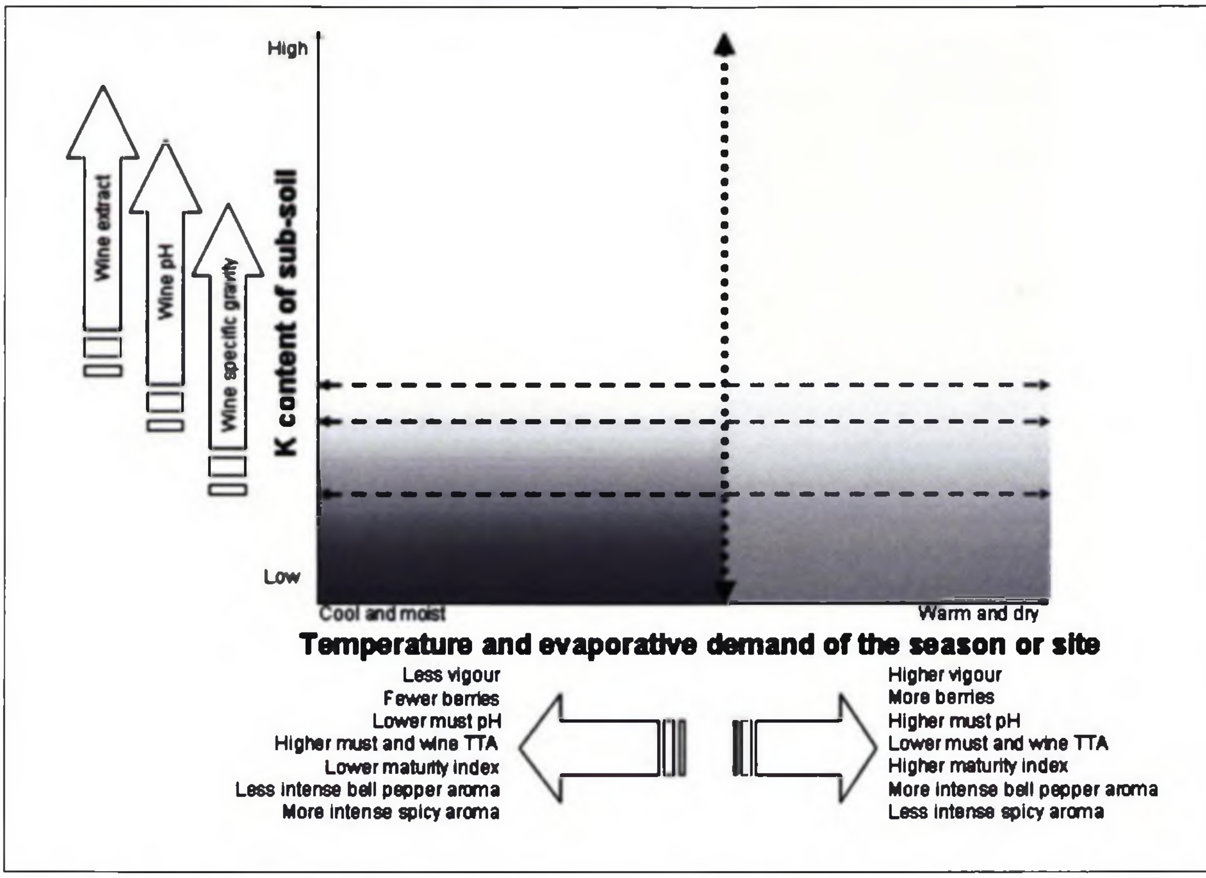

Figure 4.2.5 Summary of soil and temperature effects on the performance of Cabernet Sauvignon in the Stellenbosch Wine of Origin District.

The performance of Sauvignon blanc appeared to be related to soil texture, wind exposure and temperature, both during the green berry growth stage and the month prior to ripening (summarised in Fig. 4.2.6). The clay content of the subsoil could be related to pruning mass, yield:pruning mass ratio and maturity index. Vineyards on soils with a high clay content in the subsoil can be associated with less vigorous growth but a less ideal must composition (total soluble solids and total titratable acidity). Contrary to expectation, increased exposure to wind in the early part of the season was associated with higher yield. Lower minimum temperatures during the month prior to ripening ensured lower wine pH values. Lower minimum temperatures prior to véraison were associated with more intense bell-pepper and grassy aroma characteristics in the wines. Warmer sites and seasons were related to increased intensities of tropical fruit and spicy notes in the wines.

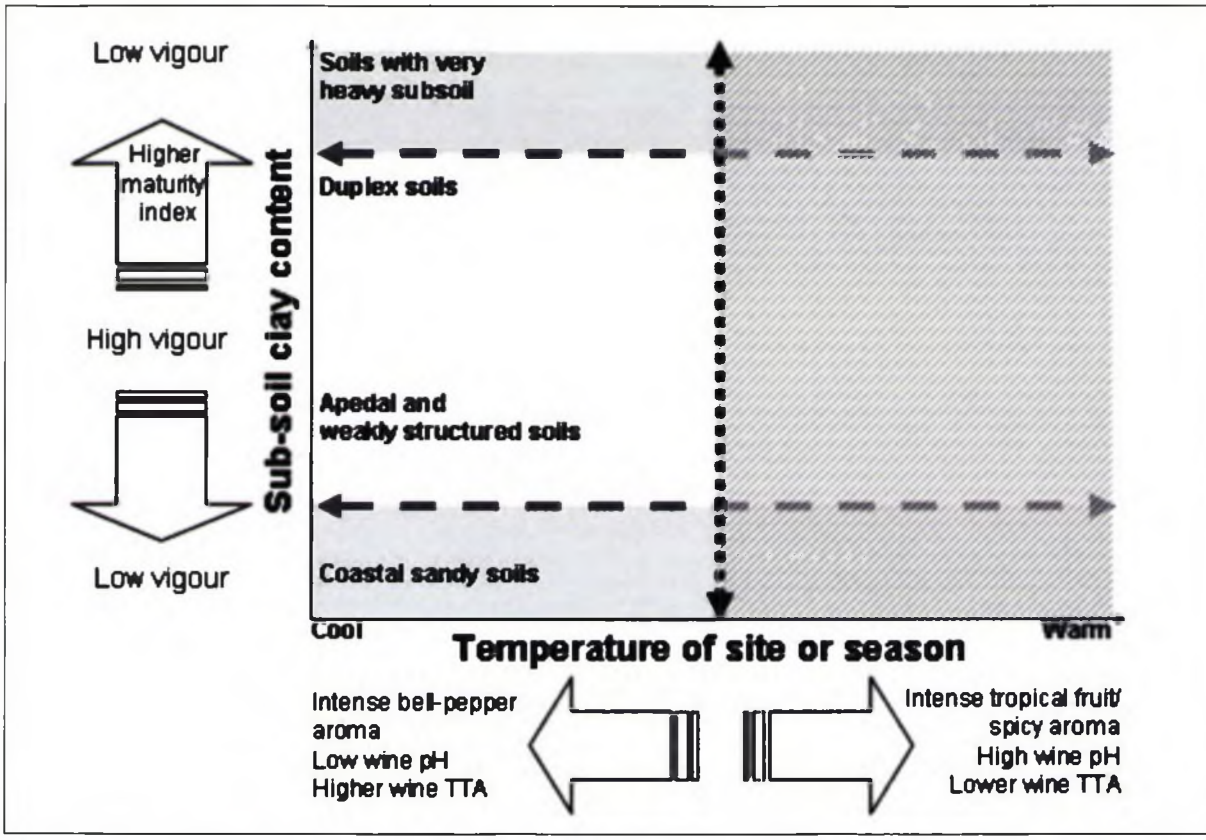

Figure 4.2.6 Summary of soil and temperature effects on the performance of Sauvignon blanc in the Stellenbosch Wine of Origin District.

The environmental effects on the performance of Cabernet Sauvignon and Sauvignon blanc in the Stellenbosch Wine of Origin District suggest that it will be possible to identify viticultural terroirs with specific agronomic potential for these two cultivars.

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4.3 VITICULTURAL TERROIRS IN STELLENBOSCH, SOUTH AFRICA. III. IDENTIFICATION AND CHARACTERISATION

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4.3.1 ACKNOWLEDGEMENTS

This publication is based on research that was financially supported by the Agricultural Research Council, University of Stellenbosch, Winetech and the National Research Foundation under grant number 2053059. Any opinions, findings and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of these organizations.
Thanks are due to Dr Martin Kidd for statistical analyses; A Schmidt and JCD Theron for technical assistance and Francois Knight, Ryk Taljaard, Dalene Opperman and Mike Wallace for assistance with the creation of digital data layers.

4.3.2 ABSTRACT

Identification and characterisation of terroirs depends on knowledge of environmental parameters, functioning of the grapevine and characteristics of the final product. Field studies, resulting in point data, are necessary to investigate the functioning of the grapevine but in order for this information to be of use within zoning studies it must be placed in a spatial context. A knowledge-driven model used the rules generated in regression tree analyses to directly classify natural terroir units with respect to expected response of Cabernet Sauvignon and Sauvignon blanc in the Stellenbosch Wine of Origin District. The natural terroir units were then grouped into terroir units that were homogenous with respect to predicted viticultural and oenological response for each cultivar.

Key words: Terroir, Cabernet Sauvignon, Sauvignon blanc, soil, climate

4.3.3 INTRODUCTION

A terroir can be defined as a natural unit that is characterised by a specific agricultural potential. The agricultural potential is imparted by natural environmental features, and is reflected in the characteristics of the final product (Dubos, 1984; Seguin, 1986; Morlat, 1989; Laville, 1993). Identification and characterisation of terroirs depends, therefore, on knowledge of environmental parameters, functioning of the grapevine and characteristics of the final product. Because the terroir concept relies on the intrinsic agronomic potential of the environment, and is thus inseparable from the characteristics and "identity" of the final agricultural product, all studies to delimit terroirs will include mapping of pertinent environmental features in order to obtain relatively homogenous environmental units, as well as a study of the reaction of the crop to these delimited units (Morlat, 2001; Vaudour, 2003). It is necessary to determine a hierarchy for the environmental factors with respect to their relevance to viticulture in the region, as well as to determine rules that may be used for spatialisation of the results. The criteria selected for viticultural zoning of terroirs must be pertinent with respect to grapevine physiology, have a compatible spatial variability and be easily acquired in the field (Riou *et al.*, 1995). Environmental variables that must be considered include those of climate (rainfall, radiation, air temperature, soil temperature, direction and intensity of dominant winds), relief or geomorphology (slope, exposition, insolation, landscape form), substrate or geology and soil (mineralogy, structure, granulometry, soil water regulation, depth, colour) (Laville, 1993).

In order to determine the functioning of the grapevine and the characteristics of the final product on a particular natural terroir unit, it is necessary to perform *in situ* studies resulting in point data, but in order for this information to be of use within zoning studies, it must be placed within the context of the pertinent terroir in order to provide a spatial result (Vaudour, 2000; Vaudour,2001). An environmental model to identify terroirs, therefore, consists of various logical arguments and processing methods. The first stage will generally consist of an empirical (i.e. deterministic) inductive model. Inductive arguments are evidence based (Skidmore, 2002). Field data are explored for possible patterns that can be used to derive a general statement with respect to viticultural or oenological response. Such data-driven statistical models are called "empirical" (Skidmore, 2002). Actual experience is used to substantiate beliefs. Statistical methods such as Classification and Regression Trees (CART) (Breiman, *et al.*, 1984; Skidmore, 2002) derive thresholds that can be used in empirical models. The second stage encompasses a knowledge-driven deductive model. A deductive argument is one that draws a specific conclusion from a set of general propositions that have been based on plausible physical laws (Skidmore, 2002). The new proposition (or conclusion to the argument) will necessary follow the premises (foregoing supposition), i.e. if you accept the premises then it would be contradictory to reject the conclusion (Skidmore, 2002). Knowledge driven models use rules generated from expert opinion or statistical induction (e.g. CART) to summarise relationships between dependent and independent variables, which can then be used to directly classify unknown spatial objects by deduction (Skidmore, 2002).

The first paper in this series detailed the delimitation of natural terroir units in the Stellenbosch Wine of Origin District and dealt with generation of a spatial data layer of natural terroir units with "unknown" aptitude for viticultural and oenological performance. The second paper discussed an investigation into the reaction of *Vitis vinifera* L. cvs. Cabernet Sauvignon and Sauvignon blanc to site environment. Regression trees were used to detail premises that can be used to derive statements or rules for further deductive arguments. This third paper has as its objective the integration of the natural terroir units (NTUs) and the reaction of the grapevine using a knowledge-driven deductive model to determine viticultural terroirs for the production of Cabernet Sauvignon and Sauvignon blanc grapes for wine production in the Stellenbosch Wine of Origin District.

4.3.4 MATERIALS AND METHODS

4.3.4.1 Study area

The study area covered the Stellenbosch Wine of Origin District situated at ca. 34°S, 19°E (Fig. 4.3.1).

4.3.4.2 Identification of natural terroir units

Natural terroir units were, in this study, considered to be land units that are practically homogenous with respect to terrain morphological unit, slope aspect, altitude, and broad soil category. They have further descriptors of geology for pertinent soil types and extent of sea-breeze effect. The procedure and data used to identify natural terroir units were described in detail in Chapter 4, section 4.1.

4.3.4.3 Field studies

Reference plots of Cabernet Sauvignon and Sauvignon blanc were delimited in commercial vineyards in 1995 in proximity to weather stations (Fig. 4.3.1). The study continued for a period of seven years (1995-2002). The viticultural and oenological measurements are outlined in detail in Chapter 4, section 4.2.

4.3.4.4 Digital data

A 50 m Digital Elevation Model (DEM) was used to determine elevation and slope inclination using Spatial Analyst™ in ESRI®ArcMap™ 8.2. A digital soil map compiled from a Peri-Urban Soil Survey mapped on a scale of 1:25 000 and 1:50 000 by Ellis and Schloms (1975) and Ellis *et al.* (1976) respectively was obtained. A digital map of soil associations of the Western Cape mapped on a scale of 1:250 000 by Ellis *et al.* (1980) was used to complete the data in mountainous areas of the study area. Digital geological data compiled from a 1:250 000 geological map of the Council for Geoscience (Theron, 1990), was the best available data for the study area.

Spatial climatic interpolations from a seven-year series of data from the automatic weather station network were obtained (Table 4.3.1) (F Knight, Agri Informatics, unpublished data, 2004).

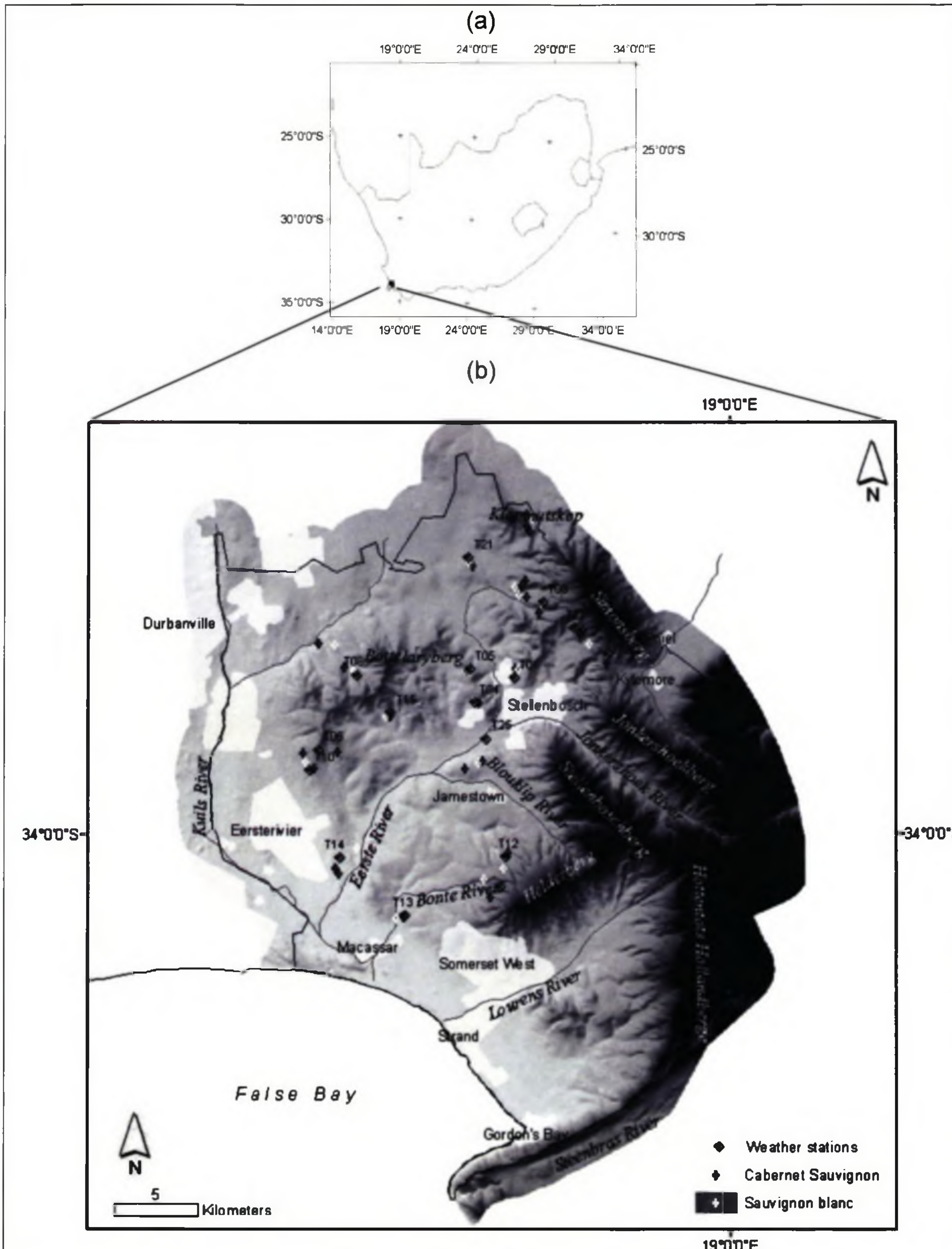

Figure 4.3.1 (a) The geographical position of the Stellenbosch Wine of Origin District (black square). (b) The district boundary of the Stellenbosch Wine of Origin District (solid black line) and the positions of plots and weather stations used in the data generation phase

Table 4.3.1 Regression based algorithms that were used to determine climatic variables from the automatic weather station network in the Stellenbosch Wine of Origin District (F Knight, Agri Informatics, unpublished data, 2004)

Variable	Algorithm
Rain $_{\text{Growing season}}$	(1/Solar radiation$_{315,15}$)^2 x (0.3 x altitude +200)
Rain $_{\text{February}}$	0.6 x Rain $_{\text{Growing season}}$
Rain $_{\text{March}}$	0.7 x Rain $_{\text{Growing season}}$
Rain $_{\text{October}}$	0.19 x Rain $_{\text{Growing season}}$
Rain $_{\text{November}}$	0.18 x Rain $_{\text{Growing season}}$
Rain$_{\text{mbh}}$ – Cabernet Sauvignon	(14/28 x Rain $_{\text{February}}$) + (14/31 x Rain $_{\text{March}}$)
Radiation$_{\text{mbh}}$ - Cabernet Sauvignon	Solar Analyst run on 28 February
Radiation$_{\text{mbh}}$ - Sauvignon blanc	Solar Analyst run on 6 February
Winkler Growing degree-day Index	-0.7614 x Altitude + 2016.8
Evaporation$_{\text{mbh}}$	-0.0596 x Altitude + 169.11
Wind exposure	Sum of (Solar radiation W,SW,S,SE)/4

mbh = month before harvest

4.3.4.5 Determination of the response of Cabernet Sauvignon and Sauvignon blanc to the site environment

Regression tree methodology (Breiman *et al.*, 1984) was used to derive decision trees for each dependent variable and the hierarchy of environmental and management related variables that affected the performance of Cabernet Sauvignon and Sauvignon blanc (Chapter 4, section 4.2).

4.3.4.6 Identification of viticultural terroirs

Relationships between predictor environmental variables and variables for which digital data layers were available, had to be determined. The relationship between soil-related parameters and the soil or geology class of the plot, as determined from the digital data layers was investigated by means of one-way ANOVAs (Statistica 6.1, StatSoft, Inc., Tulsa, USA) with the soil or geology class as categorical predictor. As the Winkler Growing Degree-day Index was the only temperature related variable for which a digital data layer was available, it was correlated with the temperature related predictor variables (weather station data) and regressions were performed using the General Regression Model in Statistica 6.1. Environmental data layers were divided into classes for each viticultural and oenological variable based on the decision trees that had been determined (see Results and Discussion). Median class values were calculated for each natural terroir unit using the zonal statistics function of Spatial Analyst™ in ESRI®ArcMap™ 8.2.

4.3.4.7 Significance of identified terroir units for viticulture

A map of vineyards (90% probability) was compiled from a classification of Landsat TM images (Capture date 23 November 2001) (JPA Van der Merwe, unpublished data, 2003). This map was used to determine the area of each terroir unit that was planted to grapevines in 2001.

4.3.5 RESULTS AND DISCUSSION

4.3.5.1 Determination of rules for the identification of viticultural terroirs for Cabernet Sauvignon

From the regression tree analyses discussed in detail in Chapter 4, section 4.2, it appeared that the potassium content of the subsoil affected the performance of Cabernet Sauvignon in the Stellenbosch Wine of Origin district. Sandstone soils are expected to have the lowest total soil potassium content, followed by shale derived soils and finally granite derived soils (Wooldridge, 1988). Following this evidence, vineyards on soils derived from sandstone would be expected to produce wines with a lower wine pH, specific gravity and extract. Vineyards on shale derived soils would be expected to ripen fully. Vineyards on granite derived soils, on the other hand, would be expected to produce wines with a higher pH, specific gravity and extract. Statistical analyses of the soil data from the experimental plots indicated, however, that the potassium content of the sub-soil did not differ significantly between soils associated with rocks of the Tygerberg Formation, granite, and the weathering products of Malmesbury rocks and granite, or between residual soils, red and yellow apedal to neocutanic soils and medium-deep wet duplex soils (data not shown). Sandy soils and soils derived from sandstone could not be included in the analysis due to lack of representation. This lack of an expected relationship was substantiated by Conradie *et al.*, (2002), who found that potassium levels of lower soil horizons in the Stellenbosch area could not be related to underlying geological formations, probably as a result of management practices (*vid.* Seguin, 1986). Amelioration prior to planting and annual fertilisation would be expected to dramatically influence the potassium contents of medium textured soils. It is, however, known that sandy soils (<10% clay) in the South Western Cape have generally low potassium contents and that potassium leaches rapidly from these soils (Conradie, 1994). It was, therefore, assumed that sandy soils (well and poorly-drained alluvial soils, excessively drained sandy soils and shallow dry sands), together with sandstone or scree (predominantly of sandstone origin, Theron *et al.*, 1992) related soils would have the lowest potassium contents. Soil clay content and S-value had been determined as predictor variables for fullness on mouth-feel. Neither of these variables was available from the existing digital soil data. However, all the plots classified in the node with low clay content were associated with granite of the Kuils River-Helderberg Pluton. Although the granite of the two plutons were not separated by means of their description within the digital geological data, the Kuils River – Helderberg Pluton fell predominantly within the extent of the sea breeze and could therefore be distinguished on a natural terroir unit level. Sandy soils, together with sandstone or scree related soils, were also included in this class as the associated soils were assumed to have low clay content. Although the S-value did not differ significantly with soil or geology class, medium-deep wet duplex soils had a lower mean S-value than residual or well-drained structureless soils.

Climate also appeared to have an influence on the must composition and aroma characteristics of Cabernet Sauvignon. Evaporation was related to must composition, possibly via temperature and wind related effects (see discussion in Chapter 4, section 4.2). Various temperature variables were used as predictors for wine attributes, but they were all significantly correlated with the Winkler Growing Degree-day Index (Table 4.3.2) and could, therefore, replaced with this index.

Table 4.3.2 Correlation coefficients of temperature variables with the Winkler Growing Degree-day Index for Cabernet Sauvignon

Variable	R	R^2	N	$p \leq 0.0001$
Mean maximum temperature (month before harvest)[1]	0.62	0.38	85	***
Mean minimum temperature (month before harvest)	0.61	0.37	94	***
Mean maximum temperature (October, November)	0.87	0.75	85	***
Mean temperature (October, November)	0.85	0.63	85	***

[1]The mean date of harvest for the seven-year period was used, i.e.14 March

The models used to determine the aptitude of the natural terroir units with respect to the various viticultural and oenological parameters of Cabernet Sauvignon, are given in Table 4.3.3.

4.3.5.2 Terroir units for Cabernet Sauvignon

Eighty-two viticultural terroirs for Cabernet Sauvignon production were delimited in the Stellenbosch Wine of Origin District (Addendum 4.5). Sixty-two of these terroirs are represented within the area planted to grapevines in 2001. The response of Cabernet Sauvignon to these terroirs varied between the following two extremes: terroir 1 - high yielding (>1.7 kg/m cordon), lower must acidity (ca. 7.5 g/L) and higher must pH (ca. 3.5) and maturity index (ca. 31), wine extract lower than 30 g/L, high wine pH (ca. 3.8), low wine acidity (ca. 6.2 g/L), not very full on mouth-feel, and a wine aroma with slightly more intense berry notes and less spiciness; and terroir 32 - Low yielding (<1.8 kg/m cordon), higher must acidity (ca. 8.9 g/L), lower must pH (ca. 3.2) and maturity index (ca. 25), wine extract higher than 30 g/L, lower wine pH (ca. 3.6), higher wine acidity (ca. 7.3 g/L), full on mouth-feel, less intense berry aromas and more intense spicy and floral aromas.

Table 4.3.3 Viticultural and oenological variables and their categories used in the determination of viticultural terroirs for the production of Cabernet Sauvignon

Variable	Class	Environmental variable	Expected response
Yield per meter cordon	1	Altitude ≤147 m	>1.7 kg for all clones
	2	Altitude 147.1 m - 181 m	1.1-1.8 kg depending on clone
	3	Altitude >182 m	< 1.8 kg for all clones
Must composition	1	$Evaporation_{mbh}$ ≤149 mm	Must TTA ~ 8.9 g/L Must pH ~ 3.2 Maturity Index ~ 25
	2	$Evaporation_{mbh}$ 149.1 mm - 156 mm	Must TTA ~ 7.5 g/L Must pH ~ 3.2 Maturity Index ~ 31
	3	$Evaporation_{mbh}$ >156 mm	Must TTA ~ 7.5 g/L Must pH ~ 3.5 Maturity Index ~ 31
Wine Specific gravity	1	Altitude ≤ 289 m; Geology = scree, sandstone or Soil = sandy	~0.9950 g/cm^3
	2	Altitude ≤ 289 m, Other soils	~0.9958 g/cm^3
	3	Altitude > 289 m	~0.9940 g/cm^3
Wine extract	1	Geology = scree, sandstone or Soil = sandy	Extract <30 g/L
	2	Other	Extract >30 g/L
Wine pH	1	Altitude ≤285 m, Geology = scree, sandstone or Soil = sandy	~3.8
	2	Altitude ≤285 , Other soils	~3.9
	3	Altitude >285 m	~3.6
Wine total titratable acidity	1	Winkler GDD ≤1869	~7.3 g/L
	2	Winkler GDD >1869	~6.2 g/L
Fullness on mouth-feel[1]	1	Geology = scree, sandstone, granite (Kuilsriver-Helderberg Pluton) or Soil = sandy and Winkler GDD ≤1846	~5
	2	Geology and Soil = other and Winkler GDD ≤1846	~4.4
	3	Soil =wet duplex soils	~5.1
	4	Soil = Residual or freely drained, structureless soils	~5.6
Berry aroma[1]	1	$Rain_{mbh}$ ≤36.5 mm, Winkler GDD ≤1832	~3.3
	2	$Rain_{mbh}$ ≤36.5 mm, Winkler GDD >1832	~3.9
Spicy aroma[1]	1	$Rain_{Oct,Nov}$ ≤42.5 mm	~1.4
	2	$Rain_{Oct,Nov}$ 42.6 mm - 60.5 mm	~2.0
	3	$Rain_{Oct,Nov}$ >60.5 mm	~0.7
Floral aroma[1]	1	$Rain_{Oct,Nov}$ ≤80 mm; Winkler GDD ≤1616	~1.1
	2	$Rain_{Oct,Nov}$ ≤80 mm; Winkler GDD >1616	~0.7
	3	$Rain_{Oct,Nov}$ >80 mm; Winkler GDD ≤1753	~0.3
	4	$Rain_{Oct,Nov}$ >80 mm; Winkler GDD >1753	~0.6

mbh = month before harvest
[1]Sensory score on a 10-point scale

These two extremes were not well represented in the Stellenbosch Wine of Origin District. Terroir 1 represented only 19 ha of coastal sandy soils on mid- to footslope positions with a north-westerly aspect. Terroir 32 represented 205 ha of pockets of granite-derived soils on high-lying north westerly upper midslope positions.

The prevalent terroirs for the production of Cabernet Sauvignon in the Stellenbosch Wine of Origin were terroirs 2 (14 248 ha) and 9 (9 799 ha). Very few vineyards were planted on terroir 2, which consisted predominantly of alluvial and Aeolian sand soils at low altitudes. terroir 9 was represented by wet duplex soils at altitudes below 200 m on varying expositions.

The terroir units having the greatest area planted to vineyards were terroirs 9, 17 and 54 (Table 4.3.4 and Table 4.3.5). It is world-wide phenomenon that, for easier mechanisation and thus easier/cheaper production, vineyards were increasingly planted on flatter areas. In the Stellenbosch Wine of Origin District, these areas are represented by terroirs 9 and 17. On the other hand, hillside vineyards have long been recognised for quality wine production, in this case represented by terroir 54.

Table 4.3.4 The 10 dominant terroir units for Cabernet Sauvignon based on vineyard plantings in 2001. (Classes for the viticultural and oenological variables must be interpreted together with Table 4.3.3)

Terroir	Area (Ha)	Berry	Extract	Floral	Fullness	Must composition	Spicy	Wine pH	Wine SG	Wine TTA	Yield
9	2494	2	2	4	3	3	3	2	2	2	1
15	177	2	2	2	2	3	3	2	2	2	2
16	446	2	2	4	2	3	3	2	2	2	2
17	1674	2	2	4	3	3	3	2	2	2	2
35	334	1	2	4	4	1	3	3	3	1	3
48	206	1	2	4	1	2	3	2	2	1	3
50	189	2	2	4	1	2	3	2	2	1	3
54	780	1	2	4	4	2	3	2	2	1	3
55	226	2	2	2	4	2	3	2	2	1	3
74	234	2	2	4	3	3	3	2	2	1	3

Table 4.3.5 The environmental characteristics of dominant terroir units for Cabernet Sauvignon

Terroir	Environmental characteristics
9	Lower-lying (<200 m above sea-level) lower mid-slope to valley bottom positions with wet duplex soils.
15	North-westerly upper mid-slope positions between 100 m and 200 m altitude, with residual to structureless soils of granite (Kuils River – Helderberg Pluton) origin and within the extent of the sea breeze influence.
16	South-westerly and easterly mid-slope positions between 100 m and 200 m altitude, with soils of granite (Kuils River – Helderberg Pluton) origin and within the extent of the sea breeze influence.
17	Wet duplex soils between 100 m and 200 m altitude, outside the extent of the sea breeze influence on varying expositions. Predominantly the northern part of the Stellenbosch Wine of Origin District, between the Bottelaryberg and Simonsberg
35	Residual or structureless soils between 300 m and 400 m altitude on mid-slope positions on the flanks of the mountains.
48	Residual or structureless soils of granite (Kuils River – Helderberg Pluton) origin between 200 m and 300 m above sea-level. Predominantly on easterly slopes on the Bottelaryberg.
50	Residual or structureless soils of granite (Kuils River – Helderberg Pluton) origin between 200 m and 300 m altitude. Predominantly on south-westerly slopes on Helderberg, Hottentots Holland mountains and Bottelaryberg.
54	Residual, dry duplex, or structureless soils between 200 m and 300 m altitude on the flanks of the mountains.
55	North-westerly upper mid-slopes between 200 m and 300 m altitude with residual or structureless soils (predominantly originating from rocks of the Tygerberg formation).
74	Wet duplex soils between 200 m and 300 m altitude. Predominantly on the north-western flanks of the Simonsberg, similar position to Terroir 17.

4.3.5.3 Determination of rules for the identification of viticultural terroirs for Sauvignon blanc

From the regression tree analyses performed in a first stage of this study (Chapter 4, section 4.2), it appears that the performance of Sauvignon blanc is predominantly related to soil texture, wind exposure and temperature, both during the green berry growth stage and the month prior to ripening.

The yield to pruning mass ratio and wine specific gravity and, to a lesser extent, pruning mass and maturity index[1], were related to the clay content of the lower horizons of the soil. It appeared from comparison of the subsoil clay content (depth-weighted mean between 35 cm and 70 cm) of the Sauvignon blanc reference plots and the digital soil and geological data, that soils associated with quaternary weathering products of Malmesbury rocks could be expected to have high clay contents (>34%) in the lower soil horizons.

Wind exposure affected both the yield of the vine and the capacity or total dry matter production (estimated with the formula of Deloire *et al.*, 2002), with increased exposure to wind in the early part of the season being associated with higher yield. Wind is one of the climatic variables with the greatest degree of spatial variation (Lebon, 1993; Carey, 2001) and as a result is not easy to model on a mesoclimatic

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[1] Maturity index = (must soluble solids x 10)/must titratable acidity

scale. The digital data layer used was estimated from the mean solar radiation for the wind directions W, SW, S and SE (FH Knight, unpublished data, 2004), which are the dominant summer wind directions in the South Western Cape (Kendrew, 1961).

Sauvignon blanc is notably sensitive to temperature, and lower minimum temperatures during the month prior to ripening were associated with lower wine pH values. In addition lower minimum temperatures prior to véraison were associated with more intense bell-pepper and grassy aroma characteristics in the wines. Warmer sites and seasons were associated with a higher intensity of tropical fruit and spicy notes in the wines. All temperature related predictor variables were significantly correlated with the Winkler Growing Degree-day Index (Table 4.3.6) and were therefore replaced with this index.

Table 4.3.6 Correlation coefficients of temperature variables with the Winkler Growing Degree-day Index for Sauvignon blanc.

Variable	R	R^2	N	$p \leq 0.0001$
Mean minimum $temperature_{mbh}$[1]	0.66	0.30	82	***
Mean maximum temperature (October, November)	0.87	0.75	82	***
Mean minimum temperature (October, November)	0.62	0.38	82	***
Mean temperature (October, November)	0.84	0.63	82	***

[1] The mean date of harvest for the seven-year period was used, i.e.20 February

The models used to estimate the viticultural and oenological performance of Sauvignon blanc in the Stellenbosch Wine of Origin District are shown in Table 4.3.7.

4.3.5.4 Terroir units for Sauvignon blanc

Two-hundred and thirty-five terroir units were identified for Sauvignon blanc wine production. Each of these terroir units can be considered to be homogenous with respect to the viticultural and oenological variables given in Table 4.3.7. The response of Sauvignon blanc to the environment was more clearly distinguishable with the regression trees, resulting in the inclusion of more environmental variables for the determination of terroir units. This, together with less overlap between the environmental variables, resulted mathematically in a greater number of terroir units.

Table 4.3.7 Viticultural and oenological variables and their classes used in the determination of viticultural terroirs for the production of Sauvignon blanc

Variable	Class	Environmental variable	Expected response
Flowering date	1	Winkler GDD ≤1729	~24-Nov
	2	Winkler GDD 1729.1 - 1919	~09-Nov
	3	Winkler GDD >1919	~03-Nov
Harvest date	1	Winkler GDD ≤1729	~11-Mar
	2	Winkler GDD >1729, $Radiation_{mbh}$ ≤817	~23-Feb
	3	Winkler GDD >1729, $Radiation_{mbh}$ >817	~17-Feb
Yield per meter cordon	1	Wind exposure ≤67	~1.5 kg/m
	2	Wind exposure 67.1 - 68	~2.0 kg/m
	3	Wind exposure >68	~2.7 kg/m
Yield : pruning mass ratio	1	Distance from sea ≤8 km	~5.6
	2	Distance from sea >8 km, soils derived from weathering products of Malmesbury rocks	~2.1
	3	Distance from sea >8 km, other soils	~3.9
Capacity[1]	1	Wind exposure ≤65	~0.7 kg/m cordon
	2	Wind exposure 65 - 67	~0.8 kg/m cordon
	3	Wind exposure >67	>1.0 kg/m cordon
Wine specific gravity	1	Slope ≤3%	~0.9890 g/cm^3
	2	Slope >3%, soils derived from weathering products of Malmesbury rocks	~0.9906 g/cm^3
	3	Slope >3%, other soils	~0.9911 g/cm^3
Wine pH	1	Winkler GDD ≤1967	~3.6
	2	Winkler GDD >1967	~3.8
Fullness[2]	1	Winkler GDD ≤1777	~5.9
	2	Winkler GDD 1777 - 1929	~5.3
	3	Winkler GDD>1929	~5.0
Fresh vegetative aroma[2]	1	Winkler GDD ≤1910, other soils	~3.6
	2	Winkler GDD ≤1910, stony complexes of structureless and residual soils	~4.2
	3	Winkler GDD >1910	~2.9
Dried vegetative aroma[2]	1	Winkler GDD ≤1856	~0.8
	2	Winkler GDD >1856, distance from sea ≤14 km	~1.5
	3	Winkler GDD >1856, distance from sea >14 km	~1.1
Tropical fruit aroma[2]	1	Winkler GDD ≤1867, distance from sea ≤17 km	~1.6
	2	Winkler GDD ≤1867, distance from sea >17 km	~2.3
	3	1867< Winkler GDD ≤1944	~2.7
	4	Winkler GDD >1944	~3.3
Spicy aroma[2]	1	Winkler GDD ≤1844, $radiation_{mbh}$ ≤744	~0.2
	2	Winkler GDD ≤1844, $radiation_{mbh}$ >744	~0.4
	3	Winkler GDD >1844	~0.6

mbh = month before harvest

[1]*Puissance* or estimated total dry matter production: 0.5xpruning mass + 0.2xyield (Deloire *et al.*, 2002)

[2]Sensory score on a 10-point scale

The two extremes were terroir 1 and terroir 233. Terroir 1 represented sites with potentially a late phenological cycle, low yield (ca. 1.5 kg/m cordon), high yield: pruning mass ratio (ca. 5.6), low total dry mass production (ca. 0.7 kg/m cordon), wine specific gravity of ca. 0.9911 g/cm^3, lower wine pH (ca. 3.6), wines that were fuller on mouth-feel, with moderate fresh vegetative aroma characteristics (bell pepper, grassy) and less intense dried vegetative (tea, tobacco) and tropical fruit aromas. This terroir was represented by high-lying (>500 m above sea level) north-westerly slopes on the Helderberg and Hottentots Holland mountains. The soils were residual with quaternary sandstone (scree) origin. This terroir covers ca. 346 ha but had no vineyard plantings in 2001. Terroir 233 is potentially associated with an early flowering period and mid-ripening period, high yield (ca. 2.7 kg/m cordon), moderate yield: pruning mass ratio (ca. 3.9) and high total dry matter production (>1.0 kg/m cordon). The wines would be expected to have a specific gravity in the region of 0.9911 g/cm^3, pH values ca. 3.6, be potentially less full on mouth-feel and have more dominant tropical fruit and spicy aromas. This terroir is found on low-lying south-westerly foot-slopes in the Eerste River valley in the immediate environs of Stellenbosch town, and has duplex or well-drained deep alluvial soils. This terroir covered only ca. 40 ha and also had no vineyards cultivated in 2001.

Similar to the terroirs for Cabernet Sauvignon, the largest terroirs for Sauvignon blanc identified in the Stellenbosch Wine of Origin District were the relatively flat coastal and valley sandy soils, but these were not planted to vineyards. One hundred and seventy-three of the terroir units were represented in the area cultivated under vineyards in 2001. The dominant terroir unit planted to vineyards was Terroir 108 (Table 4.3.8 and Table 4.3.9), which consisted of predominantly south-westerly slopes between 100 m and 200 m above sea level. The associated soils would be expected to have a low to moderately high clay content (≤34%) in the lower soil horizons. The expected viticultural response would be mid-season flowering and harvest, high yield (ca. 2.7 kg/m cordon), high yield: pruning mass ratio (ca. 5.6) and high dry matter production (>1.0 kg/m cordon). The associated wines would be expected to have a high specific gravity (ca. 0.9911 g/cm^3) and lower pH (ca. 3.6), be moderately full on mouth-feel and have a fairly complex aroma. The area covered by this terroir totals 3 679 ha, with an estimated 1 304 ha planted to vineyards.

A terroir that would be expected to yield a Sauvignon blanc wine with a high quality (high intensity of fresh vegetative, tropical fruit and spicy aromas, full on mouth-feel, low wine pH), but at the same time bearing a crop in excess of 2.0 kg/m cordon, would be located on the south-westerly upper midslopes of the Stellenboschberg, between 100 m and 200 m above sea-level on soils with a fairly high stone content. With the existing data an area of 17 ha was identified. South-western slopes are generally sought for the establishment of Sauvignon blanc vineyards in South Africa in order to ensure cooler ripening conditions. This is reflected by the dominance of Terroir 108, which represents south-westerly slopes below 200 m.

Table 4.3.8 The 10 dominant terroir units for Sauvignon blanc based on vineyard plantings in 2001. (Classes for the selected viticultural and oenological variables must be interpreted together with Table 4.3.7)

Terroir	Ha	Harvest	Yield	Capacity	Wine SG	Wine pH	Fullness	Fresh veg.	Dried veg.	Tropical fruit
37	1223	2	1	1	3	1	2	1	2	3
38	708	2	1	1	3	1	2	3	2	3
105	493	2	3	3	3	1	2	1	1	1
108	1304	2	3	3	3	1	2	1	2	3
109	674	2	3	3	3	1	2	3	2	3
124	447	2	3	3	3	1	2	1	1	1
140	419	3	1	1	3	1	2	1	1	1
152	548	3	1	1	3	1	2	1	1	1
174	442	2	1	1	3	1	2	3	2	3
176	684	2	1	1	3	1	3	3	2	4

Table 4.3.9 The environmental characteristics of dominant terroir units for Sauvignon blanc.

Terroir	Environmental characteristics
37	North-westerly slopes between 100 m and 200 m altitude. The associated soils are expected to have a low to moderately-high clay content (≤34%) in the lower soil horizons
38	Similar to Terroir 37 but situated slightly closer to the coast
105	South-westerly slopes between 200 m and 400 m altitude. The associated soils are expected to have a low to moderately-high clay content (≤35%) in the lower soil horizons
108	South-westerly slopes between 100 m and 200 m altitude. The associated soils are expected to have a low to moderately-high clay content (≤35%) in the lower soil horizons
109	Similar to Terroir 108, but situated slightly closer to the coast
124	South-westerly slopes between 200 m and 400 m altitude. The associated soils are expected to have a low to moderately-high clay content (≤35%) in the lower soil horizons
140	North-westerly slopes between 200 m and 400 m altitude, predominantly on the Helderberg, Hottentots Holland mountains and the Bottelaryberg. The associated soils are expected to have a low to moderately-high clay content (≤35%) in the lower soil horizons
152	North-westerly slopes between 200 m and 400 m altitude. The associated soils are expected to have a low to moderately-high clay content (≤35%) in the lower soil horizons
174	North-westerly slopes between 100 m and 200 m altitude. The associated soils are predominantly duplex or alluvial in nature.
176	Low-lying (<100 m altitude) easterly and north-westerly slopes on the coastal plain and in the river valleys. The associated soils are expected to have a low to moderately-high clay content (≤35%) in the lower soil horizons

4.3.6 CONCLUSIONS

Point data from field studies on the reaction of the grapevine to its site environment demonstrated relationships for Cabernet Sauvignon and Sauvignon blanc respectively. The use of regression tree methodology (CART analyses) enabled the definition of decision trees for spatialisation of this data. Each natural terroir unit could be evaluated with respect to its potential viticultural and oenological response and thus grouped to identify terroir units.

The two cultivars included in this study differed in their response to the environment, although both responded to soil, geology and climate related variables, thus the full complex of terroir factors. Many more terroir units were determined for Sauvignon blanc than for Cabernet Sauvignon, but this was probably due to the more distinct environmental response of Sauvignon blanc as compared to Cabernet Sauvignon and thus the inclusion of more viticultural and oenological variables in the model for determination of viticultural terroirs. The relationship of Cabernet Sauvignon with site environment was not always sufficiently clear to construct reliable decision trees and this limited the number of viticultural and oenological variables that could be included in the determination of the viticultural terroirs. This may have been due to the better adaptability of Cabernet Sauvignon to diverse, and warmer, environments than Sauvignon blanc.

The response of Cabernet Sauvignon to the environment was closely related to the potassium content of the sub-soil. Despite the implication of parent material in this response, the potassium content of the sub-soil appeared to be strongly affected by the agricultural usage of the land; to such an extent that the expected effects of the parent material of the soil are no longer visible. Potassium fertilisation of the soil may, therefore, alter the aptitude of the terroir for Cabernet Sauvignon wine production and deserves further study. The effects of potassium content cannot, however, be simplified into guidelines for fertilisation based on this relationship alone, as the crux of the terroir concept is the integration and interaction of its component parts. Due to the reliance of the modelled Winkler Growing Degree-days and evaporation on altitude, the main predictors of Cabernet Sauvignon performance in the Stellenbosch Wine of Origin District were altitude and soil type and origin.

The must composition of Sauvignon blanc (total soluble solids, must pH and must total titratable acidity) was not significantly related to any environmental parameters and it can therefore be assumed that no site had an inability to ripen Sauvignon blanc. With respect to other viticultural and oenological parameters, the interaction of Sauvignon blanc with the environment was more clear. The expected temperature response of the aroma profile and wine acidity parameters was once again shown and used in the determination of viticultural terroirs. Exposure to wind was also an important variable, but was not easily modelled due to its high degree of spatial variability and deserves further study.

Although these identified terroir units can only be considered preliminary, the methodology used has promising implications for different scales of study. Once the site specific decision trees have been constructed for the viticultural and oenological response of a cultivar, the spatialisation of the data should depend solely on the environmental data coverage, in particular the availability, resolution and accuracy of this data. Decision trees, therefore, have the potential to be applied from farm level to district scale for the identification of viticultural terroirs.

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CHAPTER 5

RESEARCH RESULTS

The use of local knowledge relating to vineyard performance to identify terroirs for Sauvignon blanc in Stellenbosch and surrounds

This manuscript will be submitted for publication

CHAPTER 5

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5.1 ACKNOWLEDGEMENTS

This publication is based on research that was financially supported by Stellenbosch University and the National Research Foundation under grant number 2053059. Any opinions, findings and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of these organizations.
Thanks are due to Dr M Kidd and Prof DG Nel of the Centre for Statistical Consultation, Stellenbosch University, for statistical advice and analyses. Ms Z Coetzee and Ms RJ Bruwer are thanked for their technical assistance.

5.2 ABSTRACT

The use of representative sites to determine the response of the grapevine to its environment is time consuming and costly and limits terroir studies to research related investigations. We surveyed vineyard managers on their perceptions of the functioning of established Sauvignon blanc vineyards in the Stellenbosch Wine of Origin District. Comparison of data generated with these questionnaires to measured data in commercial vineyards suggested that the vineyard managers were able to characterise the performance of vineyards with respect to vigour, signs of drought stress and yield. Each vineyard was mapped and the responses were linked to modelled environmental variables. Classification and regression trees were used to construct decision trees, which could be applied to environmental data in a geographic information system to determine viticultural terroirs for production of Sauvignon blanc.

Key words: Terroir, Geographic Information System, survey, vineyard managers, Sauvignon blanc

5.3 INTRODUCTION

A terroir can be defined as the ecosystem of the grapevine (Seguin, 1986), and it represents the agricultural aptitude of a delimited area. This aptitude results from interaction between the stable environmental features of the site and results in specificity of product (Morlat, 1989; Laville, 1990; Laville, 1993). As the product forms an integral part of the definition of terroir, the identification and characterisation of viticultural terroirs requires a thorough understanding of the reaction of the grapevine to its site environment, or the relevant natural terroir unit. This entails monitoring the performance of the grapevine at a number of representative sites for an extended period of time. At least seven-years of study are necessary in order to obtain a picture that is representative of the long term (Vaudour, 2001). These studies are time consuming and costly and limit terroir studies to research related investigations. Although some studies may be initiated to determine the viticultural potential of virgin areas, many are for existing wine producing regions with a long viticultural history. In the latter, a pool of existing empirical knowledge already exists amongst the producers of the region. A survey amongst producers was performed at a plot level in the Loire Valley to validate the existing identification and characterisation of terroirs and in an attempt to propose a way of simplifying the existing methodology (Thélier-Huché & Morlat, 2000; Morlat, 2001; Bodin, 2003).

The Stellenbosch Wine of Origin District has formed the focus of a number of terroir related studies in South Africa (Carey, 2001; Bonnardot *et al.*, 2002; Conradie *et al.*, 2002; Carey *et al.*, 2003; Carey & Bonnardot, 2004; Laker, 2004). These studies have used reference plots in commercial vineyards, spanning ten years. The Stellenbosch Wine of Origin District is an interesting study area due to its complex topography, geological history, soil distribution and proximity to the ocean. These parameters result in a complex environment for wine production.

The geological history, ca. 1 000 million years, of the South Western Cape coastal area, and thus the Stellenbosch Wine of Origin District, includes sedimentary rock formation, granite intrusion, metamorphism, plate tectonic activity, mountain building, erosion and weathering (Van Schoor, 2001). The geomorphology has resulted in plains that are undulating or with straight slopes, and free standing or undulating hills (Schultz, 1997). This complex topography has implications for sunlight interception (Wooldridge & Beukes, 2003) and together with the proximity to the ocean, affects the on-shore and off-shore air movement (Carey, 2001; Bonnardot *et al.*, 2002).

Soils of the coastal area of the South Western Cape have developed over a long period of time with much mixing and transport (marine, riverine and gravitational) of parent material having taken place (Van Schoor, 2001). The chemical properties of the original rocks, together with the disintegration of minerals and rizosphere conditions determine plant-available nutrients. The physical properties of parent rocks affect soil texture (Van Schoor, 2001).

Landscape affects vineyard cultivation practices, with many of the vineyards on the sandy plains being untrellised, while vineyards on the undulating hills and mountain slopes are vertically trellised. On shallow wet duplex soils, the top-soil may be ridged to provide sufficient rooting depth. Row direction is chosen to optimise wind-flow and sunlight interception.

The Stellenbosch wine producing region, including Constantia and Durbanville, is cultivated predominantly to Cabernet Sauvignon (21%), Chenin blanc (16%), Sauvignon blanc (12%), Merlot (11%) and Shiraz (11%) (SAWIS, 2002). Within the Stellenbosch Wine of Origin District there are 191 farms that cultivate Sauvignon blanc (1 655 ha) (SAWIS, personal communication, 2004).

This paper addresses the use of a questionnaire to tap the intrinsic knowledge of grape-buyers or vineyard managers in the Stellenbosch Wine of Origin District in order to see whether it is possible to use this knowledge to identify terroirs for production of Sauvignon blanc wines.

5.4 MATERIALS AND METHODS

5.4.1 KNOWLEDGE OF GRAPE-BUYERS AND VINEYARD MANAGERS

5.4.1.1 Cultivar and vineyard selection

The study area included the existing Stellenbosch Wine of Origin District (Fig. 5.1). *Vitis vinifera* L. cv. Sauvignon blanc is sensitive to environmental variation and has been the subject of a number of environment x genotype studies in the Stellenbosch area (Marais *et al.*, 1999; Conradie *et al.*, 2002; Carey *et al.*, 2003; Carey & Bonnardot, 2004). It was therefore selected as the subject of this investigation.

Vineyards falling under the jurisdiction of large commercial cellars were used as the initial sampling pool in 2003. In 2004, vineyard managers were approached directly to complete questionnaires. Although many Sauvignon blanc blocks were surveyed, it was considered important that the vineyards retained for field studies had comparable trellising systems and bud load, and thus canopy density, and were well established (8 to 15 years old).

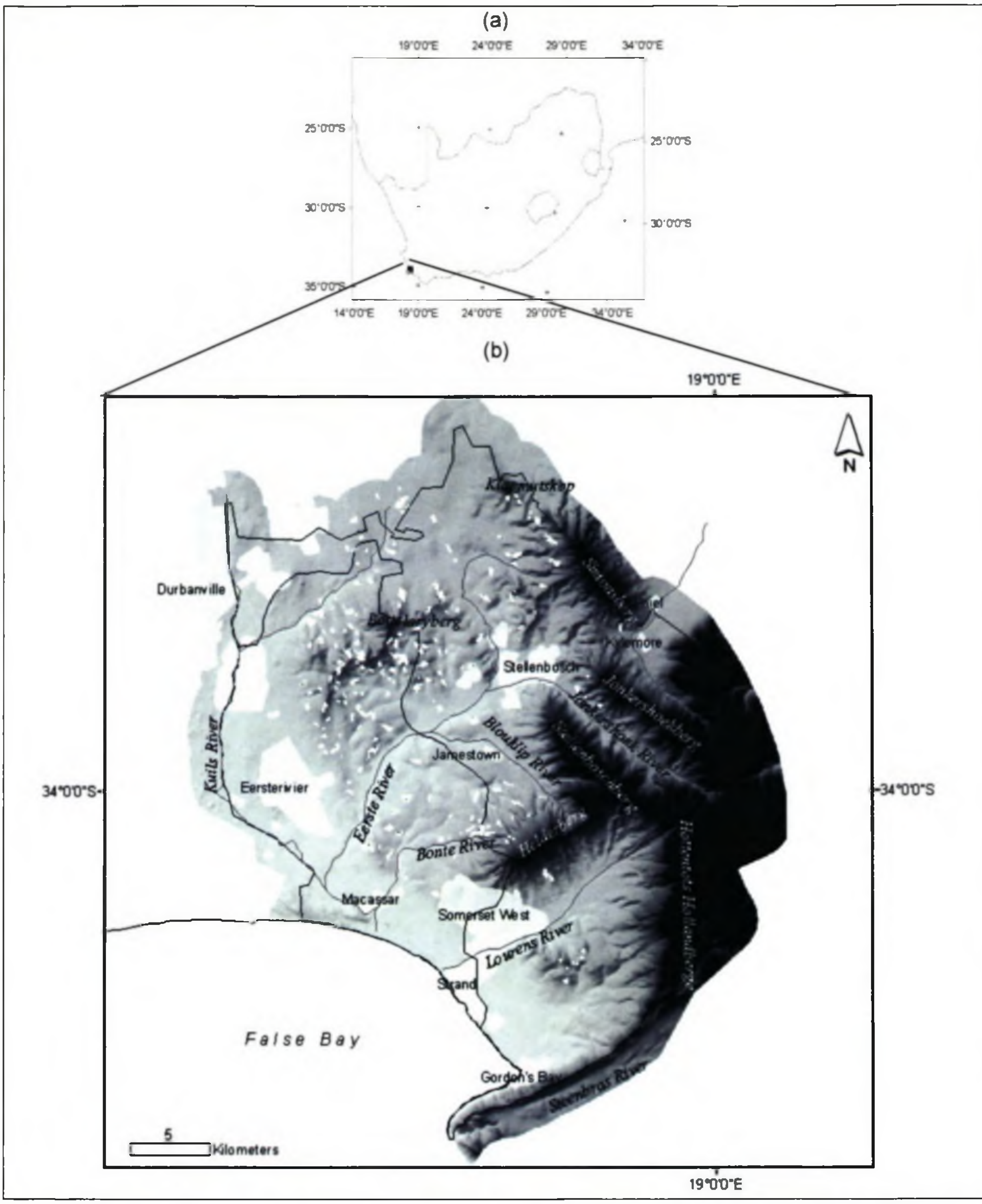

Figure 5.1 (a) Geographical position of the Stellenbosch Wine of Origin District (black square). (b) Geographical features of the Stellenbosch Wine of Origin District (solid black line). White polygons denote vineyards that were included in the survey

5.4.1.2 Survey amongst grape-buyers and vineyard managers

Grape-buyers from three large commercial co-operative cellars (during 2003) and vineyard managers (during 2003 and 2004) within the Stellenbosch Wine of Origin District were invited to participate in the survey. Questions soliciting a combination of unstructured line scale, multiple choice and free choice answers, were included. The categories included genotype, environmental characteristics (measured and perceived), management practices, perceived vegetative and reproductive performance and expected berry aroma characteristics (Table 5.1 and Table 5.2). Grape-buyers completed the surveys independently. A postgraduate student in viticulture facilitated the completion of the questionnaires by the vineyard managers in an attempt to ensure standardisation of responses.

Table 5.1 Categories and answer types included in a questionnaire on the performance of Sauvignon blanc presented to grape-buyers and vineyard managers in the Stellenbosch Wine of Origin District

Category	Answer type	Answer options or extremes
Wine style/quality	Open Answer	
Berry characteristics		
Aroma description	Open Answer	
Aroma consistency across seasons	Unstructured line scale	Variable / consistent
Acidity	Unstructured line scale	Low acid / Good acid
Sugar	Unstructured line scale	Obtained with difficulty / easily obtained
Vegetative characteristics		
Vigour in dry seasons	Unstructured line scale	Weak / Very strong
Vigour in wet seasons	Unstructured line scale	Weak / Very strong
Canopy density	Unstructured line scale	Sparse / Very dense
Signs of post-véraison stress	Unstructured line scale	Extremely stressed / No visual symptoms
Growth cycle	Unstructured line scale	Early / Late
Within-block variability	Unstructured line scale	Extremely variable / Homogenous
Shoot homogeneity	Unstructured line scale	Many shoots < 60 cm / Homogenous
Canopy management (Grape-buyers)	Unstructured line scale	Very Poor / Good
Canopy management (vineyard managers	Open answer	
Productive characteristics		
Yield	Unstructured line scale	Low / High
Bunch size	Unstructured line scale	Small / Large
Berry size	Unstructured line scale	Large / Small
Bunch compactness	Unstructured line scale	Loose / Compact

Table 5.2 Categories and answer types included in a questionnaire on the general viticultural management and environmental characteristics of Sauvignon blanc vineyards presented to grape-buyers and vineyard managers in the Stellenbosch Wine of Origin District

Category	Answer type	Answer options or extremes
General viticultural characteristics		
Clone	Open Answer	
Rootstock	Open Answer	
Irrigation	Choice	None / Conservative / Unrestricted
Cover crop	Choice	None / Natural weed growth / Cover crop every second row / Cover crop every row
Row direction	Open answer	
Trellis system	Open answer	
Cordon height	Open answer	
Canopy height	Open answer	
Vine training	Choice	Single cordon / Split Cordon / Guyot
Buds / meter cordon	Open answer	
Vine spacing (between and within row)	Open answer	
Soil preparation depth (Vineyard managers only)	Open answer	
Soil amelioration (Vineyard managers only)	Open answer	
Planting date	Open answer	
General environmental characteristics		
Altitude	Open answer	
Slope aspect	Open answer	
Soil water	Choice	Wet / Well drained / Dry
Soil temperature in spring	Choice	Cold / Warm
Wind exposure during ripening	Unstructured line scale	Protected / Exposed
Wind direction	Open answer	
Air temperature during ripening	Unstructured line scale	Cool / Hot

5.4.2 FIELD AND LABORATORY MEASUREMENTS

5.4.2.1 Grapevine measurements

At a post-véraison stage measurements of pre-dawn and midday leaf water potential, point quadrat canopy measurements, a visual assessment of canopy density using a score card adjusted from Smart & Robinson (1991) by Archer (2002) and visual monitoring of stress symptoms were made for 20 selected vineyards. At the same time potentially exposed leaf area was estimated (Carbonneau, 1995). At pruning, cane mass and mean cane length were measured.

Samples were taken before commercial harvest for sensorial and chemical analyses. A 20 kg bunch sample was randomly harvested, ensuring that bunches were taken from both sides of a row and from inside and outside the canopy.

5.4.2.2 Must extraction and analyses

Grapes were stored at 4°C for a maximum of 48 hours before processing. They were destemmed and crushed (Amos destemmer / crusher) before taking the first sample. Sulphur dioxide was added at 25 mg/L and the pomace macerated overnight at 15°C, where after the juice was extracted with a balloon press (Speidel Hydro presse 20L) before taking a second must sample. The free-run and first-press juice were collected and settled overnight at 15°C with addition of a commercial pectolytic enzyme preparation as per directions. The clear juice was racked.

Chemical analyses were performed using FOSS GrapeScan. The values for pH (pH 211 Microprocessor pH meter, Hanna instruments, Italy or Titrino 702 SM, Metrohm, Switzerland), total titratable acidity (Titrino 702 SM, Metrohm, Switzerland) and soluble solids (RR-1 Digital Refractometer, Atago, Japan) were verified.

5.4.2.3 Sensorial analyses of grape must

The clear juice was stored in 5 L plastic cans at -20°C. After defrosting at 0°C, the acid was adjusted to 6 g/L by addition of tartaric acid. Free SO_2 and ascorbic acid were adjusted to 30 mg/L. Sensory analyses were performed using generic descriptive analysis on the stored grape juice approximately 6 months after harvest. A panel of 10 judges was trained using aroma standards (Table 5.3) during five one-hour sessions. The tasting was structured as an incomplete block design with no more than five samples tasted in a session. The juice samples were presented as undiluted samples in blue glasses in random order to the judges. The block design was repeated twice. An unstructured anchored line scale was used to describe the aroma of the juice samples (Table 5.3).

Table 5.3 Final aroma standards used for training judges for descriptive analysis of Sauvignon blanc grape juice from plots in the Stellenbosch Wine of Origin District

Aroma		Standard[1]
"green"	Green pepper	Slice fresh green pepper, ca. 12 mm x 10 mm, steeped in juice, removed after ca. 45 minutes.
	Asparagus	1 mL brine of canned asparagus
	Green Fig	Piece of fig leaf and stem, ca. 2 cm x 5 cm, crushed
"tropical"	Pineapple	Flesh and juice of small piece of fresh pineapple
	Guava	Flesh and juice of small piece of fresh guava
	Tropical punch	3 ml "Medley of Fruits" (Ceres®)
Gooseberry		Two thin slices of frozen Cape gooseberry steeped in juice, removed after ca. 30 min.
Floral		4.5 mL Bottlegreen ® Elderflower cordial
Mushroom		Small piece squashed fresh mushroom
Dusty		50 mL water + tsp. Vacuum cleaner dust, microwave for 15 sec. Add 30 mL of resulting mixture to juice

[1] All standards were made up in 150 mL Sauvignon blanc juice.

5.4.2.4 Spatial data

Vineyard boundaries were digitised from 1:10 000 rectified images (Chief Directorate: Surveys and Mapping, Department of Land Affairs, South Africa). Altitude was determined with a hand-held GPS (Garmin 76s). The dominant soil class per vineyard was determined from a digital soil map compiled from a Peri-Urban Soil Survey mapped on a scale of 1:25 000 and 1:50 000 by Ellis & Schloms (1975) and Ellis *et al.* (1976), respectively. A 50 m Digital Elevation Model (DEM) was used to determine slope aspect, using Spatial Analyst™ in ESRI®ArcMap™ 8.2. The zonal median value was determined for each vineyard. Spatial climatic data was interpolated from data obtained from an automatic weather station network over a 7-year period in the Stellenbosch Wine of Origin District (F Knight, unpublished data). Zonal statistics in Spatial Analyst™ in ESRI®ArcMap™ 8.2 were used to calculate mean values of pertinent variables for each surveyed vineyard. Natural terroir units were determined by Carey *et al.* (Chapter 4, section 4.1).

5.4.2.5 Statistical analyses

Vineyards with multiple clones, rootstocks or planting date were recorded with each combination as a separate data row. Frequency analyses were performed on the environmental and management related parameters in the vineyard manager survey data. Correlation matrices were constructed to compare vineyard manager and grape buyer survey results with the respective field measurements. These analyses were performed using Statistica 6.1 (StatSoft, Inc., Tulsa, USA).

Classification and regression tree analyses (CART) (Breiman *et al*, 1984) were performed on dependent variables relating to the performance of Sauvignon blanc (Table 5.1) obtained from the survey amongst vineyard managers. The parameters of rootstock, irrigation, soil preparation depth, planting date, altitude, slope aspect, soil type, soil water, soil temperature in spring, wind exposure during ripening, wind direction and air temperature during ripening, as obtained from the survey results or digital data respectively, were used as predictor variables for these analyses. Calculations of variable importance were performed on the complete data set for each dependent variable. This variable importance was calculated based on the number of times the variable was used as splitting variable during tree construction and how well it separated the low values from the high values (M Kidd, personal communication, 2004). The data set was then split into a test and a training set. A final tree was built on the training set using predictor variables with the highest relative importance. The model was tested against the test set. A one-way ANOVA was performed on the terminal nodes for each dependent variable using Statistica 6.1.

5.5 RESULTS AND DISCUSSION

The three grape-buyers included in the survey completed questionnaires for a total of 33 vineyards. A total of 98 producers completed surveys directly. This covered 344 vineyards on 113 consolidated farms (1 105 Ha). Twenty vineyards were used for field measurements during the 2002/2003 season.

The wine style/quality was classified into the categories of ultra-premium, premium, good, standard or sparkling wine based on the description given by the producer. As the categories of ultra-premium, standard and sparkling wine categories were not well represented (n= 6, 14, 7 respectively), only the categories of premium and good wine were used in classification tree analysis. Berry aroma characteristics were classified into the categories of “green”, “tropical”, “fruity”, “floral”, complex (a combination of tropical or fruity and green aromas) or neutral. These were based on the free choice description provided by the vineyard manager or grape buyer. The categories of floral, fruity, and neutral were not well represented (n = 1, 19, 6 respectively) and were therefore not included in the classification tree analysis.

5.5.1 GENERAL INFORMATION ON SAUVIGNON BLANC IN THE STELLENBOSCH WINE OF ORIGIN DISTRICT

The size of the Sauvignon blanc vineyards surveyed in the Stellenbosch Wine of Origin District ranged between 0.1 ha and 24.3 ha (mean = 3.3 ha). The majority of existing Sauvignon blanc vineyards were planted between the years 1983 and 1986 and between 1995 and 1998 (Fig. 5.2). This reflects the cyclical popularity of Sauvignon blanc. Its sensitivity to *Eutypa lata* and tendency towards unfruitfulness because of dense canopies result in low yields after ca. year 12 of production (anecdotal information).

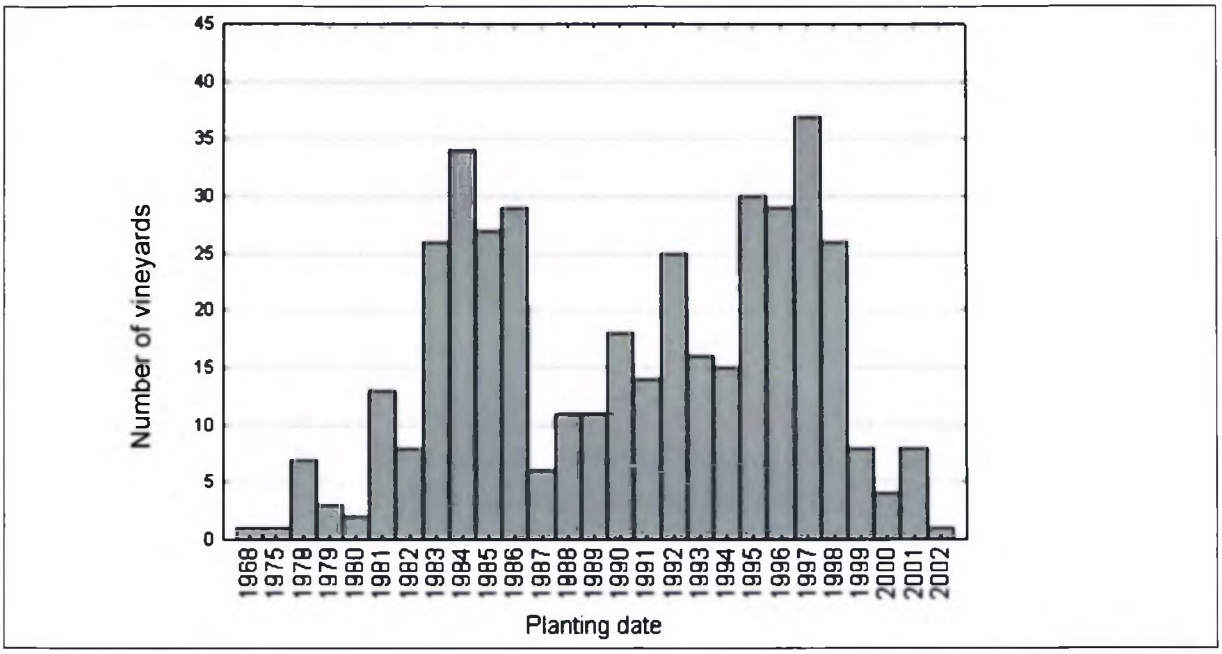

Figure 5.2 Frequency graph of number of Sauvignon blanc vineyards planted per year out of the surveyed pool (344 vineyards) in the Stellenbosch Wine of Origin District

Vineyard managers were not able to identify rootstocks for 30 of the vineyards that were surveyed. Of the known rootstocks, Richter 99 (40.2%) and Richter 110 (33.2%) were the most commonly used. A total of 25 scion clones were recorded during the survey, but for 226 of the vineyards the scion clone was not known. The "weerstasie" clone (a clone resulting from mass selection) (5.1%) and clone SB317 (5.1%) were the most commonly used.

The vineyards that were surveyed were situated between 37 m and 460 m above sea level with 52.1% being planted on slopes facing between south and west. Southerly and south-westerly slopes are the coolest slopes in the Stellenbosch district due to reduced sunlight interception (Schultz, 1997) and increased exposure to the cooling sea breezes off False Bay in the afternoon (Bonnardot *et al.*, 2001). Red and yellow apedal to neocutanic soils were the most widely utilised soils for Sauvignon blanc (45.3%). This type of soil may develop from various parent materials, although it develops more easily from siliceous parent materials (granite, schist, gneiss, quartzite, sandstone, sandy deposits) than from basic rocks (dolerite, basalt, gabbro, diabase) (Soil Classification Working Group, 1991) and it is often difficult to distinguish the parent material of these soils as there may be considerable mixing of parent materials on the slopes (Van Schoor, 2001; Conradie *et al.*, 2002). These deep soils are intensely weathered and are relics of a past, high rainfall, tropical era (Lambrechts, 1983). There was an almost complete loss of basic cations and much of the silica content due to drainage and leaching, giving rise to generally acidic, stable, well-drained soils with a low base status (Lambrechts, 1983) and a good water-holding capacity. These red and yellow apedal to neocutanic soils are widespread on high-lying pediment plains and dissected footslopes in the South Western Cape, having a clear association with altitudes between 200 m and 250 m (Schloms *et al.*, 1983). It is, therefore, not surprising that the soils planted to

Sauvignon blanc were mostly rated as being well-drained (83.2%) and cool in the spring (50.7%). The prevailing wind experienced, as perceived by the vineyard managers, was from a south-easterly direction. Gale-force south-easterly winds are characteristic of the late spring and early summer months (Kendrew, 1961; South African Weather Bureau, 1996), when they can cause physical damage to the grapevines.

Only 25.7% of the surveyed Sauvignon blanc vineyards in the Stellenbosch Wine of Origin District were completely unirrigated, with the majority (65.4%) receiving conservative irrigation. Drip irrigation was used in 37.6% of cases.

Most vineyards were trained to a 5-wire hedge trellis system (21%) with a split cordon, and 13.6% of the vineyards were untrained goblet vines. For the trellised vines, the cordon wire was generally placed between 0.6 m and 0.8 m above ground level (cumulative total of 68.2%), allowing between 1.0 m and 1.25 m canopy height (62.9%). The planting density was most commonly 1.0 m to 1.2 m within the row (cumulative total of 78.9%) and 2.7 m between rows (31.1%).

The depth of soil preparation was not known for 131 of the vineyards, but 62.6% of the remaining vineyards had undergone soil preparation to a depth of greater than 1 m prior to planting, together with the addition of lime and phosphate (83.4% of the vineyards where this information was known).

The majority of the vineyards (cumulative total of 68.5%) underwent at least suckering (shoot thinning) and tipping or topping, with a further 38.3% that underwent leaf removal and 15.9%, above that, bunch removal in addition to the previously mentioned actions.

5.5.2 COMPARISON OF SURVEYED DATA WITH FIELD MEASUREMENTS

Measured variables were compared to the perceptions of the vineyard managers and grape-buyers as to the viticultural performance of Sauvignon blanc vineyards in the Stellenbosch Wine of Origin District (Table 5.4).

It appears from these results that the vineyard managers were better able to assess the performance of Sauvignon blanc with respect to vigour, signs of post-véraison water stress and yield than the grape-buyers. Shoot homogeneity was positively and significantly correlated with mean cane length for both grape-buyers and vineyard managers. The score for signs of post-véraison stress given by the vineyard managers, was positively and significantly correlated with pre-dawn leaf water potential (Ψl). The visual symptoms noted on the reference plots, however, appeared to be related to pre-dawn and midday leaf water potential together, with visual symptoms of water stress (i.e. chlorotic and/or necrotic leaves present in the bunch zone, no active shoot growth, wilting of apical tendrils) being clear when predawn Ψl values approached -0.4 MPa and the midday Ψl was more negative than -1.0 MPa (Bruwer *et al.*, 2004).

Table 5.4 A comparison between perceptions of grape-buyers and vineyard managers of Sauvignon blanc in the Stellenbosch Wine of Origin District and field measurements from selected vineyards

Survey variables	Field and laboratory measurements	R^2 (vineyard managers)	R^2 (grape-buyers)
Acidity	Must pH prior to maceration	-0.38 (n=19)	-0.07 (n=15)
	Must pH post maceration	-0.27 (n=19)	-0.17 (n=15)
	Titratable acidity prior to maceration (g/L)	0.15 (n=19)	-0.10 (n=15)
	Titratable acidity post maceration (g/L)	0.03 (n=19)	-0.11 (n=15)
Ease to obtain sugar	Total soluble solids prior to maceration (°B)	-0.41 (n=19)	0.06 (n=15)
	Total soluble solids post maceration (°B)	-0.09 (n=19)	-0.25 (n=15)
Vigour in dry seasons	Score card	0.06 (n=19)	0.11 (n=15)
	Leaf layer number	-0.19 (n=19)	0.07 (n=15)
	Cane length (m)	**0.60**[1] (n=19)	0.46 (n=15)
	Internode length (mm)	0.37 (n=19)	**0.67** (n=15)
	Cane mass (g)	**0.47** (n=19)	0.36 (n=15)
	Number of lateral shoots per cane	0.39 (n=19)	0.50 (n=15)
	SFEp[2]	0.32 (n=19)	0.32 (n=15)
Vigour in wet seasons	Score card	0.06 (n=19)	0.16 (n=15)
	Leaf layer number	-0.19 (n=19)	0.32 (n=15)
	Cane length (m)	**0.59** (n=19)	0.44 (n=15)
	Internode length (mm)	0.35 (n=19)	0.47 (n=15)
	Cane mass (g)	**0.47** (n=19)	0.31 (n=15)
	Number of lateral shoots per cane	0.41 (n=19)	0.37 (n=15)
	SFEp	0.33 (n=19)	0.38 (n=15)
Shoot homogeneity	Cane length (m)	**0.51** (n=19)	**0.70** (n=15)
	Internode length (mm)	0.42 (n=19)	0.07 (n=15)
	Cane mass (g)	0.29 (n=19)	0.50 (n=15)
	Number of lateral shoots per cane	**0.49** (n=19)	0.37 (n=15)
	SFEp	0.29 (n=19)	-0.04 (n=15)
Canopy density	Score card		-0.23 (n=14)
	Leaf layer number		0.22 (n=14)
	Cane length (m)		**0.63** (n=14)
	Internode length (mm)		0.15 (n=14)
	Cane mass (g)		**0.57** (n=14)
	Number of lateral shoots per cane		0.45 (n=14)
	SFEp		-0.03 (n=14)
Signs of post-véraison stress	Predawn LWP (MPa)	**0.58** (n=18)	0.26 (n=14)
	Midday LWP (MPa)	0.31 (n=18)	0.47 (n=14)
Yield	Yield / ha (ton/ha)	**0.65** (n=18)	**0.58** (n=13)
Berry size	Berry mass (g/100 berries)	-0.23 (n=19)	-0.03 (n=15)

[1]Bold type indicates correlation coefficients that are significant at $p \leq 0.05$
[2]Potentially exposed leaf area (Carbonneau, 1995)

Berry acidity and ability to accumulate sugar did not correlate with must soluble solids, titratable acidity or pH and berry size was not well described. The latter may have been due to errors in completing the survey as berry size was consecutive to bunch size on the questionnaire but with an opposite scale. This opposite scale was an attempt to ensure that all responses considered positive for the production of Sauvignon blanc quality wine were situated to the right of the scale. Bunch size is not related to quality, but larger bunches would intimate better fertility and thus optimal canopy density. The perceptions of the vineyard managers and grape-buyers with respect to acidity and ease to obtain sugar were not well correlated with the field measurements, probably because the grape samples on which these analyses were performed had to be harvested before commercial harvest. For some vineyards this resulted in ripeness levels that could be considered below optimal as producers tend to harvest some Sauvignon blanc early in order to obtain strong green pepper and grassy notes for later blending purposes (anecdotal information). The analytical results may, therefore, not be a true reflection of the aptitude of a site for sugar accumulation and maintenance of a good acidity.

Although significant differences ($p \leq 0.05$) were found between samples with respect to "green" and "fruity" nuances, the argument above also holds true for aroma characteristics. Nonetheless, when compared to sensory data, nine out of 16 entries were considered to be correct with respect to berry aroma as perceived by vineyard managers and six out of 14 for grape-buyers (data not shown).

5.5.3 INTERACTION OF SAUVIGNON BLANC WITH THE ENVIRONMENT

The calculated relative importance values of the most relevant predictor variables (mostly perceived) for each dependent variable are given in Table 5.5.

Table 5.5 Relative importance of predictor variables for the perceived performance of Sauvignon blanc in the Stellenbosch Wine of Origin District

Dependent variable	Predictor variables with relative importance > 50%
Wine style/quality	Perceived air temperature during ripening (83.9%) Altitude (71.8%)
Berry characteristics	
Aroma description	Perceived air temperature during ripening (51.0%)
Aroma consistency across seasons	Perceived soil water status (68.3%)
Acidity	Soil class determined from digital data (81.9%) Perceived air temperature during ripening (69.7%) Altitude (52.2%)
Sugar	Perceived wind exposure (75.9%)
Vegetative characteristics	
Vigour in dry seasons	Planting date (78.8%) Slope aspect determined from digital data (60.8%)
Vigour in wet seasons	Planting date (64.5%) Perceived air temperature during ripening (63.0%) Slope aspect determined from digital data (59.4%)
Signs of post-véraison stress	Perceived wind direction (75.8%)
Growth cycle	Altitude (96.7%)
Within-block variability	Altitude (74.2%)
Shoot homogeneity	Altitude (64.0%) Perceived wind exposure (55.0%)
Productive characteristics	
Yield	Perceived wind direction (62.5%) Perceived air temperature during ripening (50.4%)
Yield variability between seasons	Slope aspect (78.6%) Perceived wind direction (56.2%) Perceived air temperature during ripening (54.8%)

The wine style or quality of Sauvignon blanc vineyards in the Stellenbosch Wine of Origin District appeared to be closely related to ambient temperature during ripening, as perceived by the vineyard managers. Cooler locations were associated with premium wine, while warmer locations were associated with a trend towards good wine production (Fig. 5.3). Comparison of the Winkler Growing Degree-day Index for the two terminal nodes showed a significant difference ($p \leq 0.05$) (data not shown).

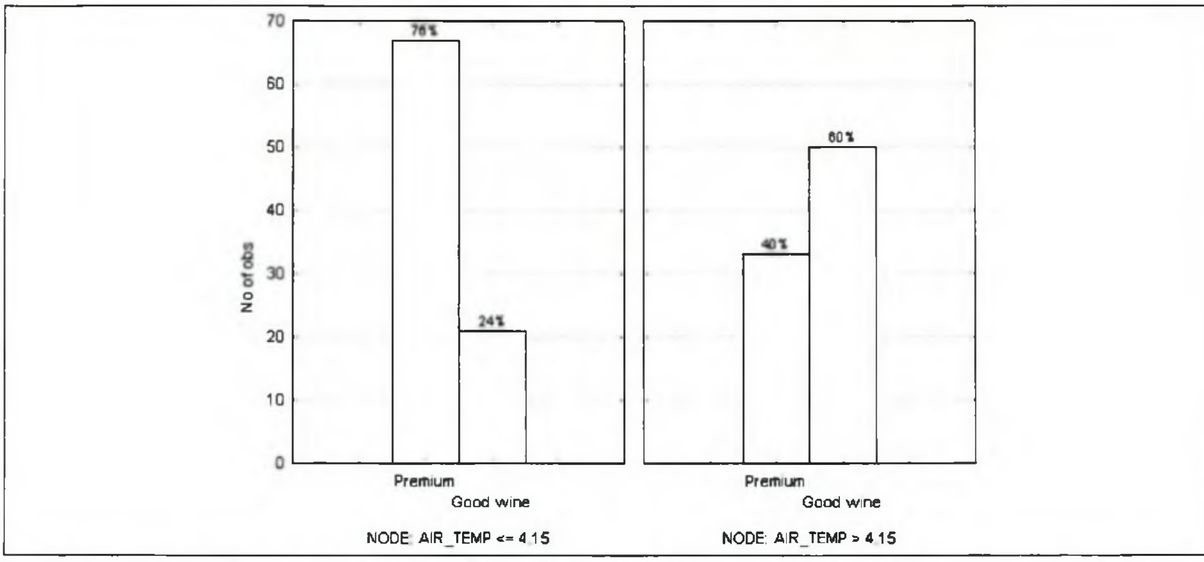

Figure 5.3 Terminal nodes of final classification tree (test data) for Sauvignon blanc wine style/quality as perceived by vineyard managers in the Stellenbosch Wine of Origin District. Differences are significant at $p \leq 0.0001$. The values for air temperature, predictor variable, represent the score on a 10-point unstructured line scale

For grape-berry aroma, on the other hand, the predictor of perceived wind exposure was selected for the final classification tree (Fig. 5.4). Comparison of the mean perceived air temperature during ripening for each of the three final nodes, however, showed a strong relationship to temperature with the node associated with reduced wind exposure (scores on an unstructured line scale <0.9) being associated with significantly warmer perceived ambient temperature during ripening (results not presented). This node was represented by predominantly tropical fruit aroma characteristics. The two nodes associated with moderate and high wind exposure were both associated with lower mean perceived ambient temperatures. Cooler temperatures with some wind exposure were associated with berries with predominantly green aroma characteristics. The effect of temperature during ripening on methoxypyrazine concentrations is well documented (Allen *et al.*, 1988; Allen & Lacey, 1993, Marais *et al.*, 1999). For higher quality Sauvignon blanc wines, it is necessary that the typical grass-like or "green" aroma is balanced by other herbaceous and fruity aromas (Marais, 1994). A greater exposure to wind was associated with complex aromas (i.e. a combination of green and fruity aroma characteristics). Fruity and tropical aromas appear to be related to monoterpenes and C_{13}-norisoprenoids (Lacey *et al.*, 1991; Sefton *et al.*, 1994). The concentration of these compounds have been found to increase with ripeness and increased sunlight penetration in the canopy (Marais *et al.*, 1999). Smaller leaves resulting from exposure to moderate to strong winds and flustering of the leaves may have resulted in increased sunlight penetration and higher levels of fruity and tropical aromas.

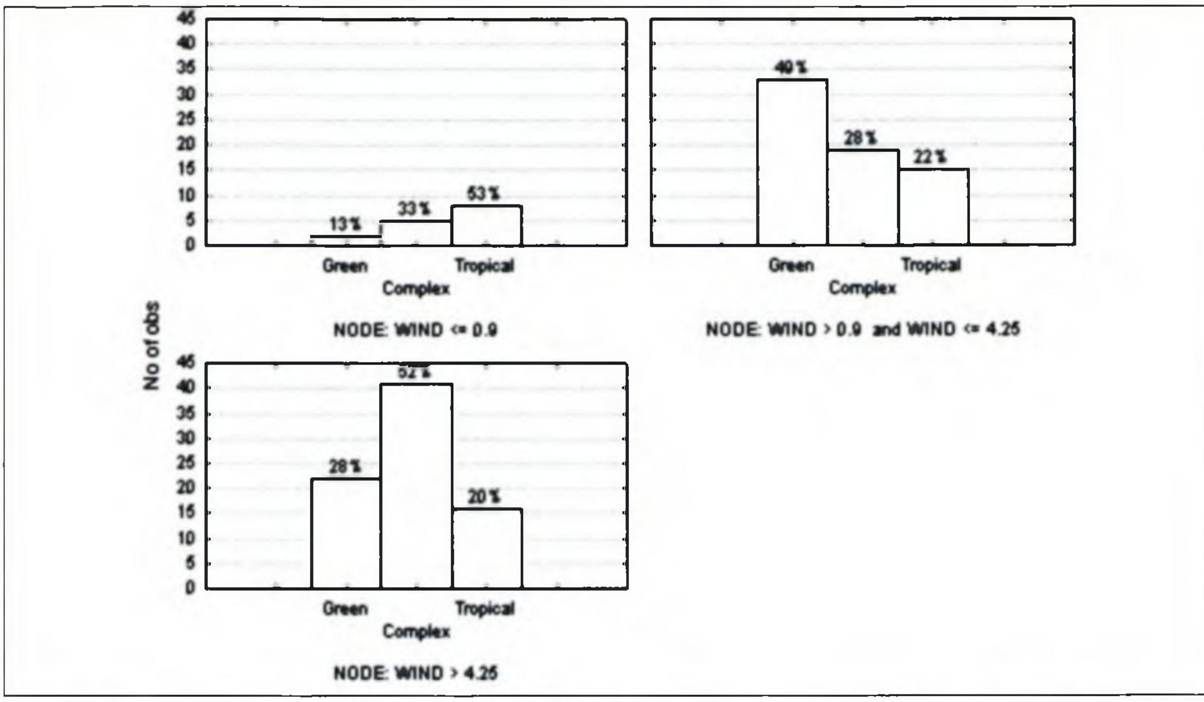

Figure 5.4 Terminal nodes of final classification tree for Sauvignon blanc berry aroma as perceived by vineyard managers in the Stellenbosch Wine of Origin District (test data). Differences are significant at $p \leq 0.05$. The values for wind, predictor variable, represent the score on a 10-point unstructured line scale

Vineyards that were situated on well-drained soils (generally red and yellow apedal to neocutanic soils) were associated with less variation in aroma characteristics between seasons. This was corroborated by the test data. Well-drained soils receive predominantly conservative irrigation, which together with their depth, drainage and water retention characteristics, provide a more constant environment despite seasonal climatic fluctuations. Wet (generally medium-deep duplex soils) and dry (predominantly rain-fed) soils were associated with increased seasonal variation in aroma characteristics. These results suggest that conservative irrigation is a necessity for residual and apedal to neocutanic soils to ensure consistency in berry aroma characteristics under the climatic conditions of the Stellenbosch Wine of Origin District.

Berry juice acidity was predicted by air temperature and soil type in the final regression tree, which was confirmed on the test data set ($p \leq 0.0001$). The first split occurred at a perceived ambient temperature during ripening of 2.7 (score on a 10-point unstructured line scale). Mean modelled values for the Winkler Growing Degree-day Index, as adjusted for South African conditions (Le Roux, 1974), differed significantly ($p \leq 0.0001$) between the two nodes (data not shown). The node with perceived ambient temperatures during ripening ≤ 2.7 had a mean value of 1844 degree-days. At higher perceived ambient temperatures during ripening, soil type played a complementary role in determining acidity. The lowest acidity levels were perceived for medium-deep, wet duplex soils and poorly drained alluvial soils, while higher acidity levels could be achieved for predominantly deep red and yellow apedal to neocutanic soils and residual soils. These soils are associated with higher altitudes (higher than 200 m above sea-level) than medium-deep, wet duplex and poorly drained alluvial soils. A positive association between altitude and wine acidity has been found in mountainous areas (Falcetti *et al.*, 1990; Bertamini *et al.*, 1999) and the relationship found in the regression tree may therefore be an indirect effect of altitude.

The ease with which sugar is obtained was predicted by perceived wind exposure. The vineyards that were best able to ripen their grapes ($p \leq 0.01$ for the test data) were vineyards that had a greater perceived exposure to wind, predominantly south-easterly winds. Exposure to wind limits growth (Dry & Botting, 1993; Bettiga *et al.*, 1997) and results in smaller primary and secondary leaves (Bettiga *et al.*, 1997). This increased exposure to wind implies a smaller canopy, concomitant reduced shading in the bunch zone and reduced vegetative competition for photosynthates.

Vigour in dry years was predicted by slope aspect, with the cooler easterly, southerly and south-easterly slopes being associated with increased vigour. Lower temperatures and reduced sunlight interception associated with easterly and southerly slopes would be expected to induce less water stress during dry years, thus preventing excessive reduction in vigour. This split was, however, only significant at $p \leq 0.1$ for the test data. Vigour in wet years was predicted by slope aspect and perceived ambient temperature during ripening. Higher temperatures were associated with reduced vigour. This model was significant ($p \leq 0.01$ for the test data) but the relative importance of the variables used in the model was fairly low (<70%). The first split (perceived ambient temperature during ripening = 4.8 on a 10-point unstructured line scale) was significantly associated with differences in altitude ($p \leq 0.001$). The node with perceived ambient temperature ≤ 4.8 had a mean altitude of 216 m, while the node with perceived ambient temperature > 4.8 had a mean altitude of 186 m. At lower temperatures (higher altitude), aspect interacted with temperature to create a second split, but the means of these nodes did not differ significantly (0.95 confidence interval) for the test data.

Signs of post-véraison water stress were predicted by dominant wind direction. This dominant wind direction, as detailed by the vineyard managers, appeared to relate to the zonal mean value of wind exposure determined for each vineyard, with higher values for wind exposure (>65%) being associated with winds from the SE, SW and S (Fig. 4.5). Vineyards where the dominant winds were from the south-east and south-west had fewer visual symptoms of water stress. South-easterly winds are dominant synoptic winds during the summer months (Kendrew, 1961; South African Weather Bureau, 1996) while south-westerly winds are common local winds resulting from differential heating of the land and sea (False Bay) masses. These local winds were found to occur for approximately 80% of the days in February 1997 (Bonnardot, 1997). Vineyards that receive wind from the south-east or south-west will, therefore, be expected to experience moderate to strong, but cool, wind on most days of the ripening period. Kobriger *et al.* (1984) found that exposure of shoots to moderate or strong winds under controlled conditions resulted in higher leaf water potential measurements for Carignane compared to control shoots. Similar results have been obtained under field conditions for Chardonnay by Freeman *et al.* (1982).

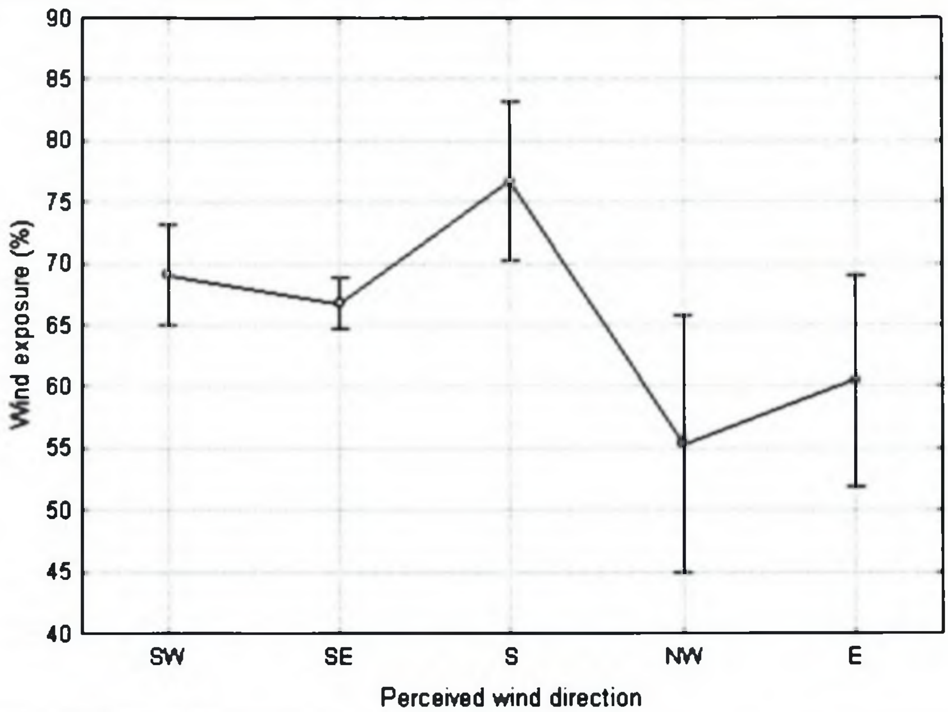

Figure 5.5 Mean scores for wind exposure as related to the dominant wind direction perceived by the vineyard managers for Sauvignon blanc vineyards in the Stellenbosch Wine of Origin District. Vertical bars denote 0.95 confidence intervals

Altitude strongly predicted the earliness of the growth cycle (Table 5.5 and Fig. 5.6). Higher vineyards (>247 m above sea-level) had a significantly later growth cycle than vineyards below this altitude (Fig. 5.6). Altitude was also selected as predictor for within-block variability with altitudes higher than 131 m being associated with more homogenous vineyards. The reason for this relationship is not clear but may be related to soil distribution, as variability in soil physical and chemical characteristics is one of the causes of intra-vineyard variability (Strever, 2003).

Shoot length homogeneity was predicted by altitude and perceived wind exposure of vineyards (confirmed on test data, $p \leq 0.0001$). Canopies with a large number of shoots shorter than 60 cm were associated with vineyards with little wind exposure. These vineyards were predominantly associated with poorly drained alluvial soils, but were represented by very few cases (5.8%). Increased exposure to wind, and altitudes higher than 126 m above sea-level, were also associated with a large number of shoots shorter than 60 cm. In this case the vineyards may have had less variability in shoot length, but generally shorter shoots.

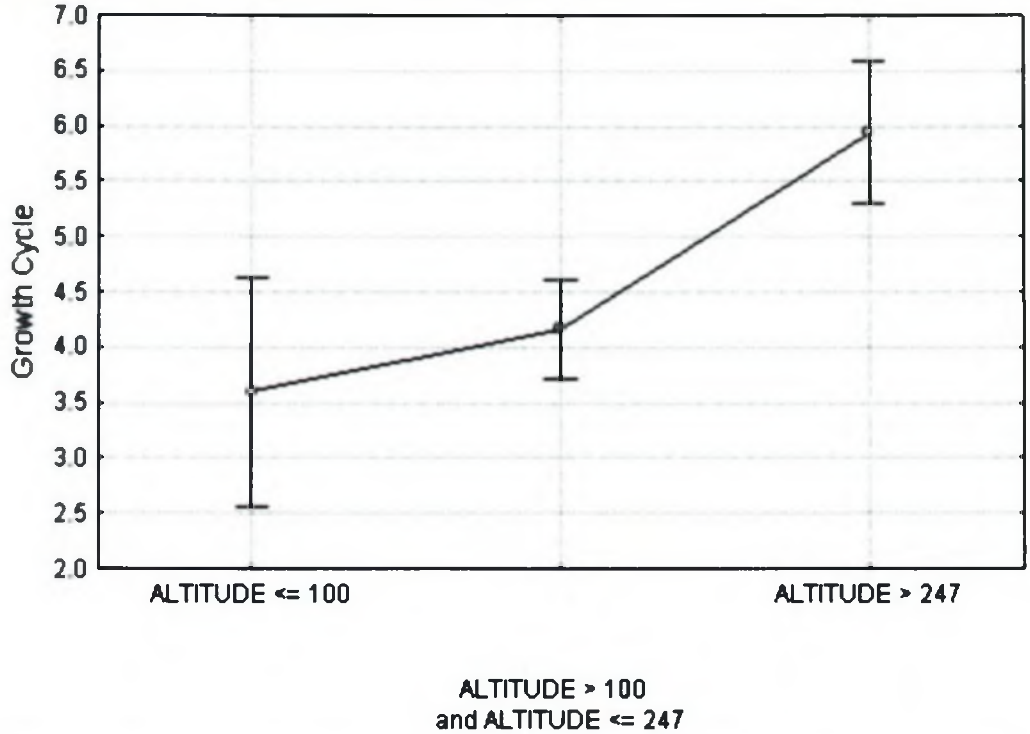

Figure 5.6 Mean scores (test data) for timing of the growth cycle of Sauvignon blanc in the Stellenbosch Wine of Origin District for the terminal nodes of the final regression tree The value for the growth cycle relates to the 10-point unstructured line scale, with the lowest score equating to earliest and highest score equating to latest. Vertical bars denote 0.95 confidence intervals

Yield was predicted by perceived ambient air temperature during ripening and dominant wind direction (Fig. 5.7). Neither of these variables had a high relative importance (Table 5.5) and the first split (perceived ambient temperature = 8.7 (score on 10 point unstructured scale) did not result in significant differences in mean yield (Fig. 5.7). The highest yields were associated with dominant winds from the south-east. South-easterly winds are associated with the highest wind speed during the summer months (Carey, 2001). Similarly in a 7-year field study on Sauvignon blanc in the Stellenbosch Wine of Origin District, it was found that increased yield per meter cordon was positively related to exposure of a locality to wind during the green berry growth stage (October and November) and during the month prior to harvest (Chapter 4, section 4.2).

Yield variability between seasons was related to slope aspect but the split between nodes could not be explained.

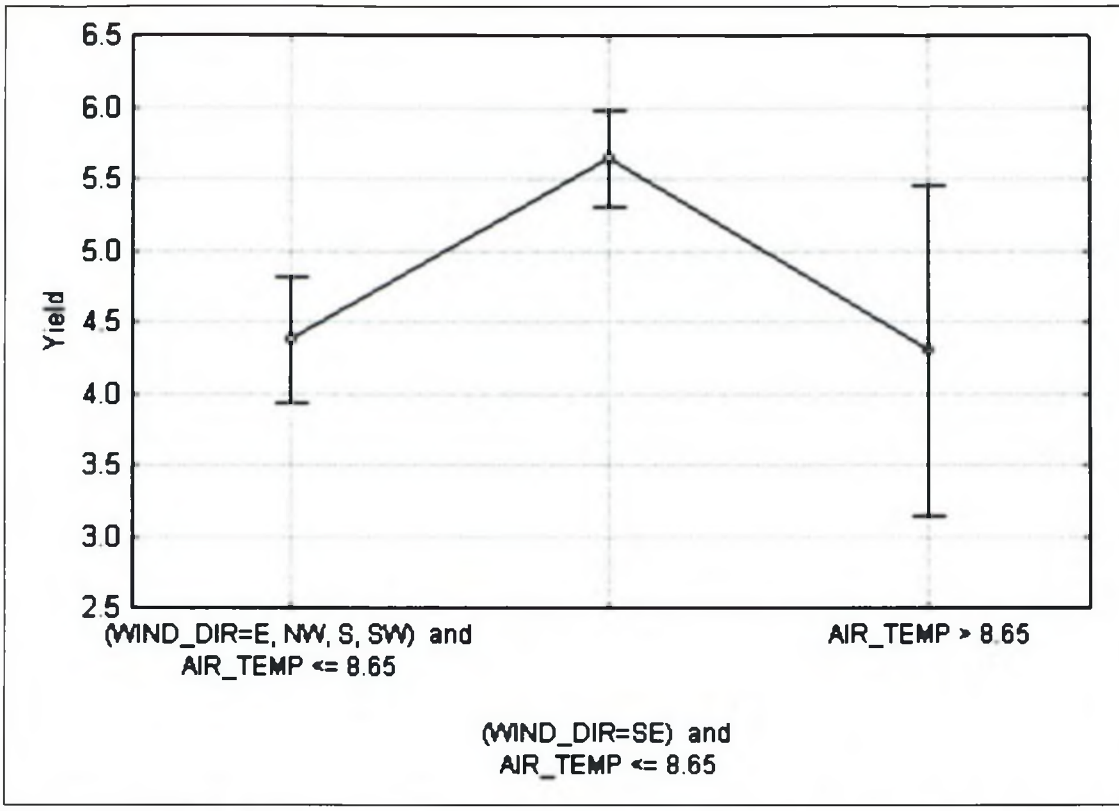

Figure 5.7 Mean scores (test data) for yield of Sauvignon blanc in the Stellenbosch Wine of Origin District for the terminal nodes from the final regression tree. The value for yield relates to the score on a 10-point unstructured line scale with the highest score equating to the highest yield. Vertical bars denote 0.95 confidence intervals

5.5.4 IDENTIFICATION OF VITICULTURAL TERROIRS FOR SAUVIGNON BLANC WINE PRODUCTION

Based on the results obtained with the CART analyses of perceived variables and the observed relationships with climatic and soil digital data, the variables of Winkler Growing Degree-day Index, wind exposure, altitude and soil type were used to determine terroir units for Sauvignon blanc wine production. Each variable was reclassified according to the categories given in Table 5.6. Natural terroir units were characterised according to these categories (zonal median values) and homogenous NTUs were grouped, resulting in 58 viticultural terroirs (Addendum 5.1), 39 of which were represented by the surveyed vineyards.

Table 5.6 Categories used for environmental variables in the prediction of viticultural terroirs in the Stellenbosch Wine of Origin District

Winkler Growing degree-day Index	Wind exposure (%)	Altitude (m)	Soil type
1 ≤1867	1 ≤65	1 ≤130	1 Shallow (<0.5 m), residual soils on hard or weathering rock
2 >1867	2 >65	2 >130, ≤247	2 Red and yellow freely drained structureless or weakly structured soils
		3 >247	4 Dry duplex soils (Duplex refers to a clear textural change from topsoil to subsoil. The topsoil is sandy while the subsoil has a high clay content)
			6 Medium-deep (0.5 m-1.0 m), wet duplex soils
			7 Shallow (<0.5 m) complex of wet duplex soils
			8 Well-drained, deep (>1.0 m), alluvial sands
			9 Poorly drained, alluvial soils

Comparison of means of the survey data for each of the viticultural terroirs represented by the surveyed vineyards, showed that these viticultural terroirs differed significantly in the expected viticultural response of Sauvignon blanc (Table 5.7).

Table 5.7 Univariate results from a one-way ANOVA on means for terroirs for Sauvignon blanc wine production in the Stellenbosch Wine of Origin District

Dependent variable (Perception of vineyard manager)	Variable mean[1]	df	*p*	% correct prediction[2]
Wine style or quality				60
Aroma consistency across seasons	7.0	24	n.s.	-
Acidity	7.2	24	***	75
Sugar	8.3	24	n.s.	-
Vigour in dry seasons	6.6	24	***	-
Vigour in wet seasons	6.2	24	**	-
Signs of post-véraison drought stress	6.8	24	**	52
Growth cycle	4.5	24	***	80
Within-block variability	6.3	24	n.s.	-
Shoot length homogeneity	6.6	24	*	64
Yield	5.0	24	n.s.	-
Yield variability	3.7	24	**	
Perceived wind exposure during ripening	4.7	24	*	-
Perceived ambient temperature during ripening	4.4	24	***	64

[1] Score on a 10 point unstructured line scale
[2] The mean per terroir was compared to the variable mean. Values higher than the mean were considered to equate to nodes with a higher score as determined in the CART analyses. For wine style/quality, the dominant category was assumed to be representative of the terroir and was compared to the predicted value.

5.6 CONCLUSIONS

Sauvignon blanc vineyards in the Stellenbosch Wine of Origin District are commonly planted on cooler slopes with deep red or yellow apedal to neocutanic soils. These positions generally induce a higher level of vigour, which is exacerbated by the relatively narrow in-row spacing that is commonly used. This requires fairly severe interference by the vineyard managers in terms of canopy management. The practice of deep soil preparation and availability of irrigation enables the vineyard manager to reduce the seasonal effect on aroma characteristics. These practices may to a certain extent mask the effects of terroir on the performance of the grapevine but the vineyard managers were nonetheless able to characterise Sauvignon blanc vineyards with respect to their expected vigour in dry and wet seasons, shoot length or homogeneity of shoot length, signs of post-véraison stress and yield using an unstructured line scale. Their ability to characterise the performance of the Sauvignon blanc vineyards was superior to that of the grape-buyers. Care must, however, be taken in the construction of the survey as the positioning of questions and the response extremes may have impacted on our results.

The viticultural and oenological aptitude of a site was closely related to temperature, exposure to dominant winds, height above sea level and soil type and these parameters could be used to determine viticultural terroirs for production of Sauvignon blanc wine. These viticultural terroirs appeared to predict to an acceptable extent the expected viticultural and oenological aptitude of a vineyard. Further study is required to reduce deviations and to test the validity of the delimitation with sensory analysis of commercial wines.

This study suggests that the intrinsic knowledge of vineyard managers may be useful as a first attempt to characterise the viticultural aptitude of an established viticultural region.

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CHAPTER 6

The identification of potential geographical indications for wine production in Stellenbosch and surrounds

This manuscript is written in the form of a publication that will form a discussion document

CHAPTER 6

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6.1 ACKNOWLEDGEMENTS

This publication is based on research that was financially supported by the Agricultural Research Council, University of Stellenbosch, Winetech and the National Research Foundation under grant number 2053059. Any opinions, findings and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of these organizations.

6.2 ABSTRACT

There is an increasing movement towards using viticultural terroirs as a basis for demarcation in order to ensure the integrity of delimitation, for which there must be an acceptance of the importance of the “unique” and “typical” wine characteristics as an expression of the terroir. South Africa has the Wine of Origin Scheme, in which demarcation is based on the best available environmental information, but without prior proof of unique wine styles. Data gathered during terroir studies and identified viticultural terroirs for Cabernet Sauvignon and Sauvignon blanc was used to determine the delimitation of boundaries of the Stellenbosch Wine of Origin District and wards within this district, based on expected wine characteristics. It was also possible to identify vineyards on a sub-ward level for the production of terroir specific wines.

Key words: Denominations of Origin, Stellenbosch, Wine of Origin Scheme, Terroir, Cabernet Sauvignon, Sauvignon blanc

6.3 INTRODUCTION

The concept of appellation or denomination of origin stems from man's desire to individualise that which he produces, uses or consumes (Quittanson & Vanhoutte,

1963) and wines have been denominated by origin since old-testament times (Bertozzi, 1995). In order to be effective, labels of origin must be a guarantee of both quality and product character (Carbone, 2002) and in this regard it is important to emphasize that it is the specific characteristics of the natural environment that lead to a product that is recognisable and that can be protected under an appellation of origin (Fanet, 2002b). The process of "zoning" will therefore involve a multi-criteria study of the natural environment (Falcetti, 1994). In the past, due to the lack of scientific evidence, delimitation was often based on obvious geographical boundaries but also strongly affected by political and/or administrative considerations.

As zoning or demarcation can have significant impact on the economy of land either side of the boundary, it may be susceptible to corruption and social disruption (Unwin, 1996). To prevent this happening, it is important that the choice of criteria for the delimitation of boundaries must be true and justifiable. It is also difficult to defend an appellation of origin or geographic indication that has not been based on the terroir structure of a region and the appellation thus becomes vulnerable (Laville, 1993). Stern & Léger (2000) suggest that in order for a geographic indication to have any form of integrity, assuring the consumer of an effective link between the product and its place of origin, the use of terroir for delimitation of geographical indications must be enforced. Despite most people probably agreeing with this statement, the notion of terroir, probably because of the empirical nature of delimitation, has become imprecise and as a result may be used erroneously, leading to a weakening of systems of denominations of origin (Laville, 1993).

Few appellations are truly based on a single terroir and most contain more than one terroir but there is no doubting the importance of the terroir concept for demarcation and the movement towards using viticultural terroirs as a basis for demarcation in order to ensure the integrity of the delimitation. The terms terroir and appellation of origin are, however, not interchangeable concepts as the terroir has a material reality, while the appellation of origin is an intellectual concept (Laville, 1993).

Three categories of geographical names can be distinguished; namely, indications of source, geographical indications and appellations of origin (Lucatelli, 2000). The indication of source simply connects the product to a given region or place while geographical indications and appellations of origin seek to show that specific characteristics of the product are linked to its geographic origin (Lucatelli, 2000). The Madrid Resolution of the OIV (1992) (Tinlot & Juban, 1998), distinguished between geographical indications and appellations of origin. Both are "the name of a country, the region or the place used in the designation of a product originating from this country, this region, this place or the area defined to this end under this name and recognised by the competent authorities of the country concerned". They differ, however, in that a recognised geographical indication for wines is "linked to a quality and/or a characteristic of the product attributed to a geographical environment including natural or human factors, and is dependent on harvesting of the grapes in the country, the region, the place or the area defined", while a recognised appellation of origin for wines "designates a product whose qualities and characteristics are exclusively or mainly due to the geographical environment including natural and human factors, and depends on harvesting as well as on transforming into the said product in the country, the region, the place or the area defined." The appellation is a more stringent concept than that of geographical indication as it requires a direct geographical name as denomination, that the **whole production process** must take place within the specified geographical area and it requires that product characteristics are **due essentially to its geographical environment** (Lucatelli, 2000; Fanet, 2002a; Rangnekar, 2003).

The first legislation to provide for a system of geographic indications in South Africa, the Wine of Origin Scheme, was drafted in 1972 based on recommendations of a number of committees and with the support of the Viticultural and Oenological research Institute (Saayman, 1999). Present-day Wine of Origin control legislation stipulates that no indication of origin, cultivar or vintage may be given unless the area has been demarcated and the wines have been produced strictly in terms of the control legislation (Kok, in Saayman, 1999). Areas are demarcated within the Wine of Origin Scheme under four categories *viz a viz* Regions, Districts, Wards and Estates. All soil and climatic factors possibly having an effect on wine character and/or quality, existing cultural practices, existing experience and evidence that proves an area to be unique, geographical and other factors that contribute to the development of the traditional wine area and the traditional name of the area are taken into account in their delimitation (Saayman, 1999). Denominations of origin are demarcated, on application by the producers within a community, by a multidisciplinary demarcation committee within the structure of the Wine and Spirit Board (SAWIS, 2003). For each area to be demarcated a strong emphasis is placed on local knowledge of experts and dominant environmental feature(s) are identified. There is, therefore, a degree of flexibility depending on the area to be demarcated and the available information. Strong emphasis is placed on the origin of the grapes as well as on the area of wine production, especially at the ward level.

In France there are four levels of appellations, namely regional appellations of origin, independent sub-regional appellations of origin or regional appellations of origin with village sobriquets, communal appellations of origin and finally sub-communal appellations of origin including the *clos* and *crus* (Vaudour, 2003). In the South African Wine of Origin system, of the three recognised levels of demarcation, the ward is the concept that closest approximates the terroir concept and is probably, in most cases, similar to that of the communal appellation of origin. It appears as if the classification of sub-communal appellations is missing in South Africa. It is, however, also clear that for such an appellation to be successfully demarcated, there must be an acceptance of the importance of the "unique" and "typical" wine characteristics as expression of the terroir.

An investigation into potential boundaries for a delimited denomination of origin will therefore encompass an investigation into the history of an area, its natural environmental features, any distinctive production practices and the dominant wine characteristics. This document will investigate the use of terroir units for Cabernet Sauvignon and Sauvignon blanc to delimit Wine of Origin districts and wards. The demarcation level of “region” within the Wine of Origin Scheme falls outside the confines of this study and will, therefore, not be addressed in this document.

6.4 MATERIALS AND METHODS

6.4.1 CADASTRAL INFORMATION

The 1:50 000 topographic sheets of 3318 DD STELLENBOSCH, the northern portion of 3418 BB SOMERSET WEST, 3418 BA MITCHELLS PLAIN and the eastern portion of 3318DC BELLVILLE (Chief Directorate: Surveys and Mapping, Mowbray) were used.

6.4.2 DIGITAL ENVIRONMENTAL DATA

A 50 m Digital Elevation Model (DEM) was used to determine elevation using Spatial Analyst™ in ESRI®ArcMap™ 8.2.

A digital soil map compiled from a Peri-Urban Soil Survey mapped on a scale of 1:25 000 and 1:50 000 respectively by Ellis & Schloms (1975) and Ellis *et al.* (1976) was obtained. A digital map of soil associations of the Western Cape mapped on a scale of 1:250 000 by Ellis *et al.* (1980) was used to complete the data in mountainous areas of the study area.

Digital geological data compiled by the Council for Geoscience from their 1:250 000 geological map (Theron, 1990) was used.

Spatial climatic interpolations from a seven-year series of data (1995-2002) from the automatic weather station network in the Stellenbosch Wine of origin District were obtained (F Knight, unpublished data, 2004).

6.4.3 EXISTING VINEYARDS IN THE STELLENBOSCH WINE OF ORIGIN DISTRICT

A map of vineyards (90% probability) was compiled from a classification of Landsat TM images (Capture date 23 November 2001) (JPA Van Der Merwe, unpublished data, 2003).

6.4.4 TERROIR UNITS

Terroir units as determined for Cabernet Sauvignon and Sauvignon blanc in the Stellenbosch Wine of Origin District (Chapter 4, section 4.3) were used as a basis for delimitation of Denominations of Origin. Because wine style or character is the central theme to the concept of “wards” or appellations, these terroir units were grouped to provide multi-terroir units with potential for production of a similar wine style. For Cabernet Sauvignon the categories of berry, spicy and floral aroma characteristics and fullness on mouth-feel were included, while for Sauvignon blanc fresh vegetative, tropical fruit, dried vegetative and spicy aroma characteristics and fullness on mouth-feel were used.

6.5 RESULTS AND DISCUSSION

It is proposed that, similarly to the French appellation system, each denomination of origin has a demarcated production zone and a demarcated vineyard area. In this way stricter control can be enforced over the vineyards entitled to the denomination without excluding cellars for wine production. This has potential for a multi-cultivar wine producing region to produce cultivar wines on best suited terroirs within a single production zone at a sub-ward level.

6.5.1 THE WINE OF ORIGIN DISTRICT - STELLENBOSCH

The criteria used within the existing scheme to demarcate a District are the macro-geographical characteristics such as mountains and rivers and the real geographical place name (SAWIS, 2003). Although a greater degree of heterogeneity is allowed with respect to soil types, it is expected that the delimited natural environment will dictate the production of wine with distinctive character (SAWIS, 2003).

6.5.1.1 History of the Stellenbosch District

The originally denominated Stellenbosch settlement was an island within the Eerste River, but all land outside of the Cape Peninsula was initially seen as being part of the Stellenbosch district (ca. 1685) (Marx, 1929; Visagie, 1979). The first delineation of boundaries of the Stellenbosch district took place in 1711, when the course of the Mosselbankrivier and the Kuilsrivier were used to demarcate the boundary between the Cape district and Stellenbosch. This district was unmanageably large, and eventually in 1839, Stellenbosch was reduced to near present size, finally losing Bellville in the early 1900s (Visagie, 1979) and Hottentots Holland in 1928 (Marx, 1929). The eastern boundary of the Stellenbosch district remained the same from 1839 to 1929 (Marx, 1929) and is still similar today (Chief Directorate: Surveys and Mapping, 2000). The boundaries of the district in 1928 as described by Marx (1929) do not appear to differ significantly from the administrative district of Stellenbosch or the magisterial districts of Stellenbosch, Kuils River, Somerset West and Strand (Chief Directorate: Surveys and Mapping, 2000). In 1929, Stellenbosch had retained its independence and individual character and resisted amalgamation in the greater Cape Town Metropolis due to the presence of the "Cape Flats", the sandy coastal plain situated between Cape Town and Stellenbosch (Serton, 1929). This remains the case today.

6.5.1.2 Geographic features of the Stellenbosch District

The Stellenbosch environs have a complex topography; a combination of plains with low or moderately undulating relief and free standing or undulating hills with moderately high relief (Fig. 6.1). This area is naturally bounded by mountain ranges to the east and north-east, False Bay to the south and the sandy flats to the west, but the boundary to the north and north-west is less clear geographically. It appears to divide into three natural regions (Marx, 1929). In the extreme south-westerly portion of the district, lie sand dunes, which are of little economic or agricultural interest. The area of greatest agricultural importance consists of alluvial soils in the valleys and soils derived from granite and Malmesbury shale on the hills and foothills. Finally the mountains consist mostly of sandstone remnants, with very shallow soils that are difficult to work.

6.5.1.3 The geographical area

In France, a controlled appellation of origin consists of two elements: the geographical area and the delimited or vineyard area. The first encompasses the area of production of the AOC, which is the list of communes in which the full process of grape to wine production occurs, while the second refers to the area of production of the primary material, i.e. the grapes (Fanet, 2000). The delimitation of the vineyard area involves the delimitation of the physical environment, while the delimitation of the geographical area involves the identification of the administrative units in which these features are found and for which the same name is used to identify the wines (Fanet, 2000). Cellar operations can take place throughout the production area, but only within the production area.

It is proposed that this system of a delimited vineyard area within a broader geographical area is followed in the Stellenbosch Wine of Origin District, as it allows for more pertinent inclusion or exclusion of vineyards based on environmental features than is made possible within the existing system of fixed boundaries. The production or geographical area of the district aims to incorporate the areas belonging to the historical Stellenbosch District, and which contain the environmental features of interest for viticultural and oenological production. In the case of Stellenbosch, these environmental features are the Eerste River valley, the Bottelaryberg hills and the foothills and arable slopes associated with the Simonsberg, Stellenboschberg, Jonkershoekberg and Hottentots Holland mountains. Following perusal of the historic boundaries, current administrative boundaries and broad geographic features, minor modifications to the Stellenbosch Wine of Origin District boundaries are proposed (Fig. 6.2).

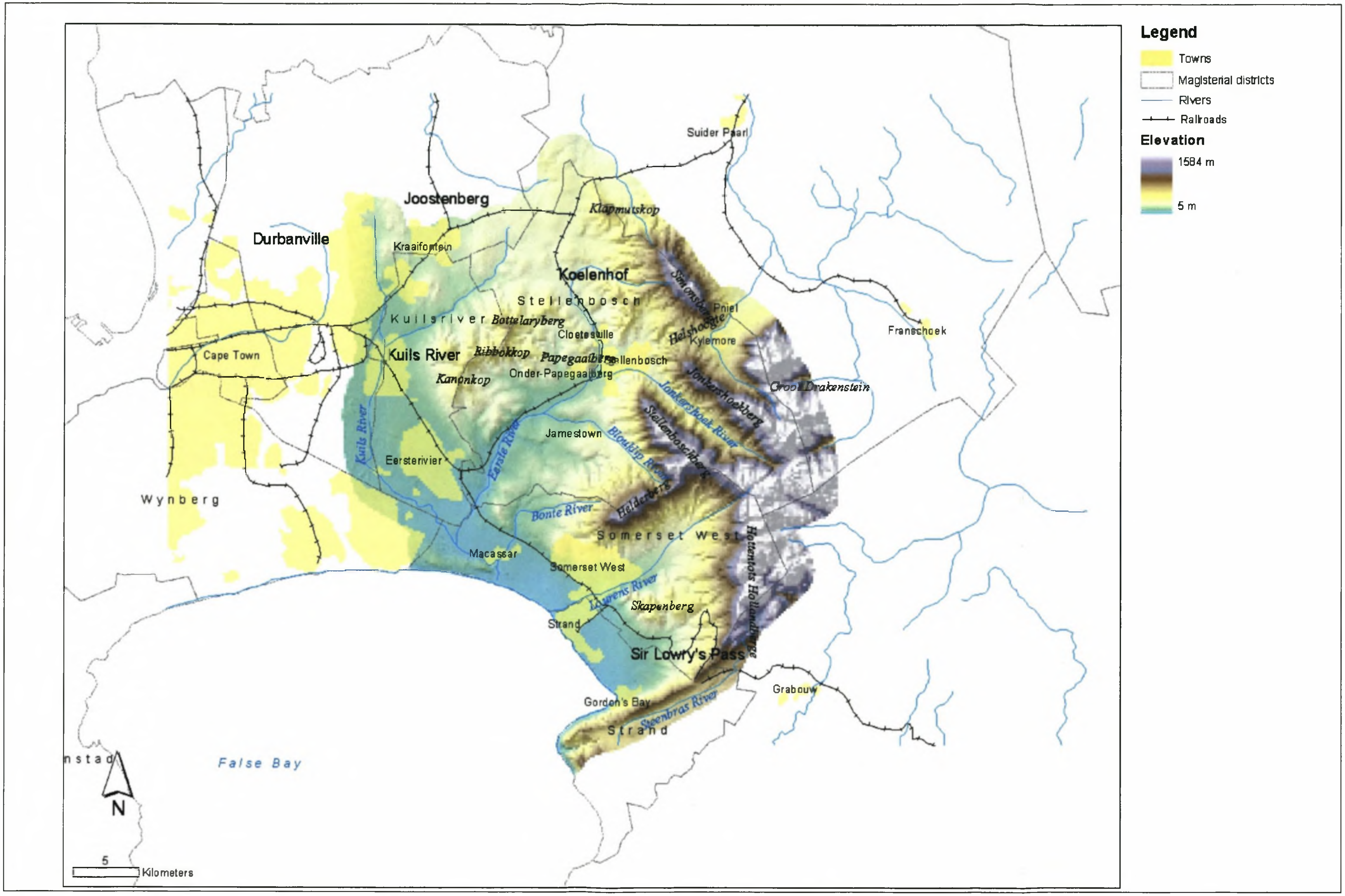

Figure 6.1 The main geographical features of the Stellenbosch environs. Data obtained from Chief Directorate: Surveys and Mapping and Agri Informatics. Compiled by V Carey

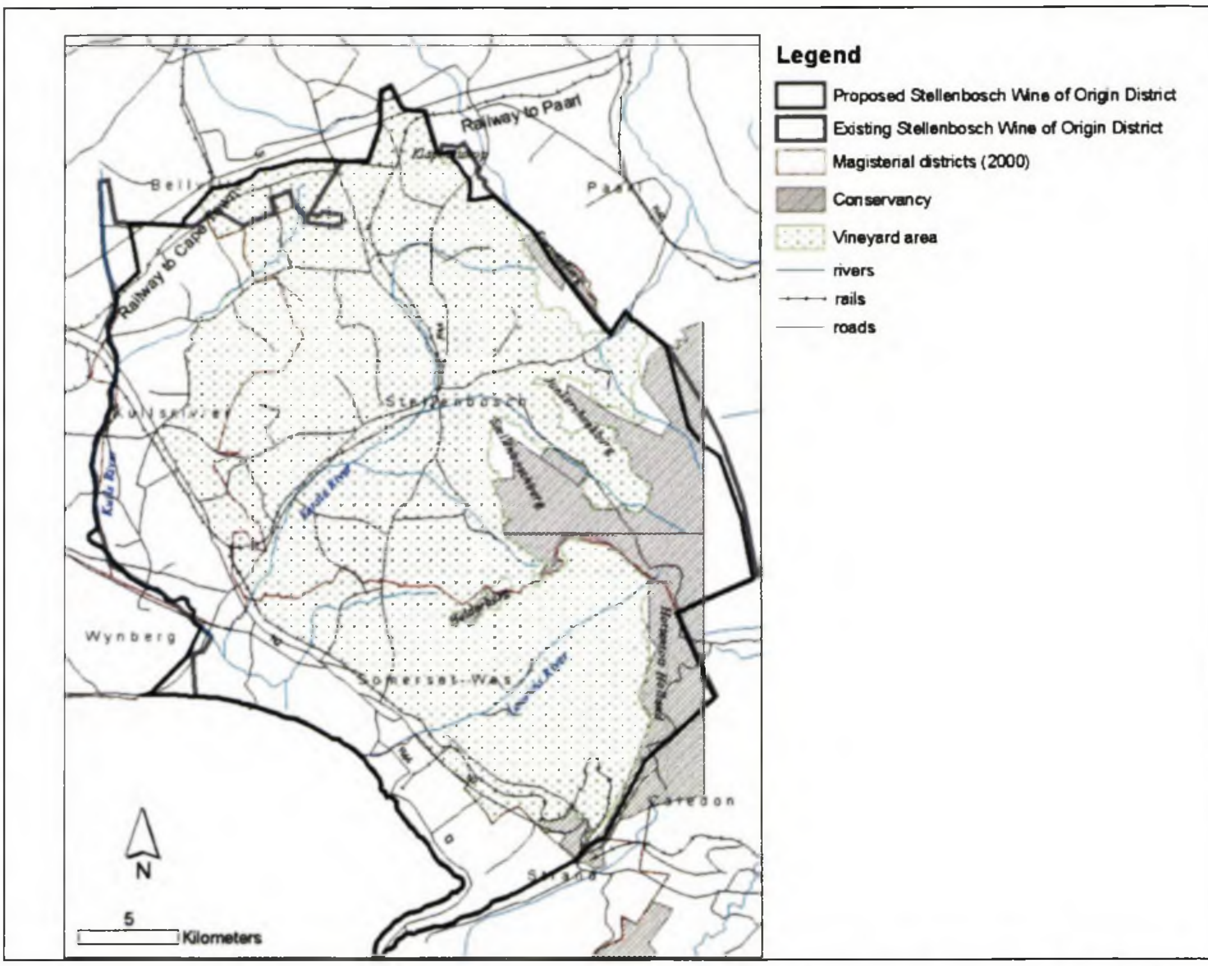

Figure 6.2 Existing Boundaries of the Stellenbosch Wine of Origin District (1998) and proposed boundaries for the production and vineyard areas. Data obtained from Chief Directorate: Surveys and Mapping, ARC Infruitec-Nietvoorbij and Agri Informatics. Compiled by V Carey

On the western boundary it is proposed that the new boundary follows the Somerset West magisterial district boundary from False Bay until it intersects the Kuils River. From this point it is proposed that the boundary follows the Kuils River, as a notable geographic feature, until the Stellenbosch magisterial district boundary, the main train line between Cape Town and Kuils River and the Kuils River intersect. The northern boundary is not clearly marked by geographic or cadastral features and should be based on the historical community and is returned to the boundary described by Marx (1929), namely the main train line between Cape Town and Paarl. Where the train line intersects the existing Wine of Origin district boundary, the proposed boundary follows the existing Wine of Origin District boundary until Klapmutskop (cf. Fig. 6.1.). Here the proposed boundary follows the Stellenbosch district boundary as it better represents the watershed of the Simonsberg/Klapmutskop range. From this point to the exit in False Bay, the proposed boundary follows the eastern boundaries of the Stellenbosch and Somerset West districts and divides the Strand district along the existing Stellenbosch Wine of Origin District Boundary.

6.5.1.4 The vineyard area

It was clear from the delimitation of viticultural terroirs for Sauvignon blanc and Cabernet Sauvignon (Chapter 4, section 4.3) that the aeolian sands along the coast and the western boundary of the Stellenbosch Wine of Origin District formed a distinct unit in comparison to the rest of the district. One of the largest terroirs for Cabernet Sauvignon in the Stellenbosch Wine of Origin district was Terroir 2. Very few vineyards were planted on this terroir unit, which consisted predominantly of alluvial and aeolian sandy soils at low altitudes. Similarly to the terroirs for Cabernet Sauvignon, the largest terroirs identified in the Stellenbosch Wine of Origin District for Sauvignon blanc were the relatively flat coastal and valley sandy soils, but these were not planted to vineyards.

The proposed delimited vineyard area of the Stellenbosch Wine of Origin District is thus centred on the Eerste River valley, the Bottelaryberg hills and the foothills and arable slopes associated with the Simonsberg, Stellenboschberg, Jonkershoekberg and Hottentots Holland mountains. As the Cape Flats, associated with silica sand deposits (Theron *et al.*, 1992), has been recognised as forming an obvious western boundary to the historical Stellenbosch District (Serton, 1929), it is suggested that all excessively drained deep sandy soils and shallow dry sands on rock or calcrete are excluded from the delimited vineyard area. The non-arable rock and stony outcrops associated with sandstone remnants and areas dedicated to conservation are also excluded. An approximate boundary was drawn using the 1:50 000 peri-urban soil survey data, the 1:250 000 geological data (Theron, 1990) and the surface cultivated under vineyards in 2001 as a basis. Geographical and cadastral features were used to delimit the contact between aeolian sands and duplex soils and it will thus be necessary that the soil type of any current or future vineyards that fall close to, or straddle, this boundary be investigated for inclusion or exclusion in the vineyard area. Very shallow soils and hard rock will be self limiting on the eastern boundary.

6.5.2. WARDS WITHIN THE WINE OF ORIGIN DISTRICT – STELLENBOSCH

When the boundaries of a ward are defined, all factors pertaining to the soil and climate are taken into consideration as they are considered to have an influence on the character of wine (SAWIS, 2003). The delimitation is based on best available environmental data. Dominant environmental attributes associated with a particular geographical location are identified empirically and boundaries are drawn using cadastral attributes that are easily identified (e.g. farm boundaries, roads, railways, rivers, watersheds). After demarcation, areas are allowed to develop and express their specific wine style and character instead of proving their originality beforehand (Saayman, 1999). Five Wine of Origin wards were delimited within the Stellenbosch wine of origin district prior to 2002, namely, Simonsberg-Stellenbosch (1980), Jonkershoek Valley (1991), Papegaaiberg (1992), Devon Valley (1996) and Bottelary (1998). Within the following sections the boundaries of an existing ward and proposed boundaries for a potential new ward will be discussed.

6.5.2.1 Modification of the boundaries of an existing ward

The Simonsberg-Stellenbosch ward was demarcated in 1980 to include the red, brown or yellow soils of granitic origin on the south-western face of the Simonsberg. This area has achieved renown and is recognised as being one of the best known and most highly regarded wards (Lloyd, 2004). Cabernet Sauvignon is recognised as being one of the best suited varieties (Van Zyl, 2000; Lloyd, 2004).

The terroir units for Cabernet Sauvignon representing the dominant wine style in this ward were identified as Terroirs 25, 34, 54 and 65 (53% of the arable area of the existing Simonsberg-Stellenbosch ward) (Fig. 6.3). Associated wines would be expected to have moderate berry and spicy aroma characteristics, little floral aroma, be full on mouth-feel and have a high extract. These terroir units were associated with residual or deep red / yellow apedal to neocutanic soils (excluding soils of sandstone or scree origin) at an altitude higher than 200 m above sea-level. Most of the area not included either had soils that were associated with scree or had medium-deep wet duplex to alluvial soils. It was not possible to distinguish between soils of granitic and shale origin with the given data, possibly due to the influence of long-term agricultural practices (Conradie *et al.*, 2002; Chapter 4, section 4.2) or to the considerable mixing of parent materials (Van Schoor, 2001; Conradie *et al.*, 2002).

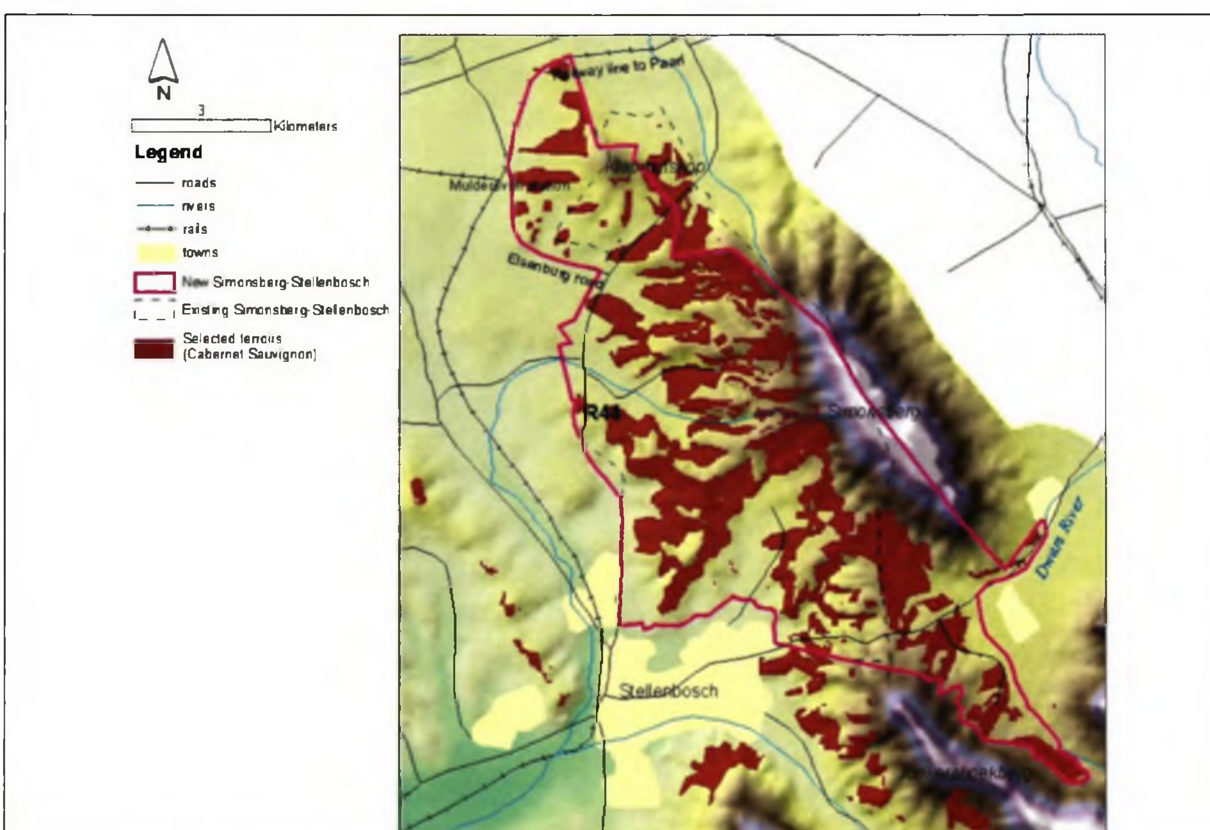

Figure 6.3 Map showing the existing and proposed boundaries of the Simonsberg-Stellenbosch Wine of Origin ward in relation to selected terroirs for Cabernet Sauvignon based on dominant wine sensorial properties. Data obtained from Chief Directorate: Surveys and Mapping, ARC Infruitec-Nietvoorbij and Agri Informatics. Compiled by V Carey

The identified terroirs for Sauvignon blanc show that within the original delimited area, ca. 39% of the arable portion (Fig. 6.4) can be expected to result in Sauvignon blanc wines that have a moderate fresh vegetative aroma with a not very intense tropical fruit aroma. These wines are expected to be fairly full on mouth-feel and the natural wine pH will be fairly low. The terroir units representing this wine style are Terroirs 7, 15, 27, 34, 61, 72, 79, 105, 124, 140, 148 and 152. A further 37% of the arable portion is expected to result in a similar wine style except that the tropical fruit aroma is expected to be more intense. This wine style is represented by Terroirs 9, 11, 16, 29, 54, 63, 80, 119, 127, 150, 154, 162 and 164. Similarly to the terroirs for Cabernet Sauvignon, this selected area includes predominantly residual or deep red / yellow apedal to neocutanic soils at an altitude higher than 200 m above sea-level. In this case, however, soils associated with scree were included. It was not possible to distinguish between geological soil origin for wine character with the existing data. Temperature (modelled as the Winkler Growing Degree-day Index) played a dominant role in the amalgamation of natural terroir units. This modelled data was based on elevation (Chapter 4, section 4.3). Most of the area not included in these selected terroir units had soil types ranging from medium-deep wet duplex to alluvial soils, although some had similar soil types to the selected units.

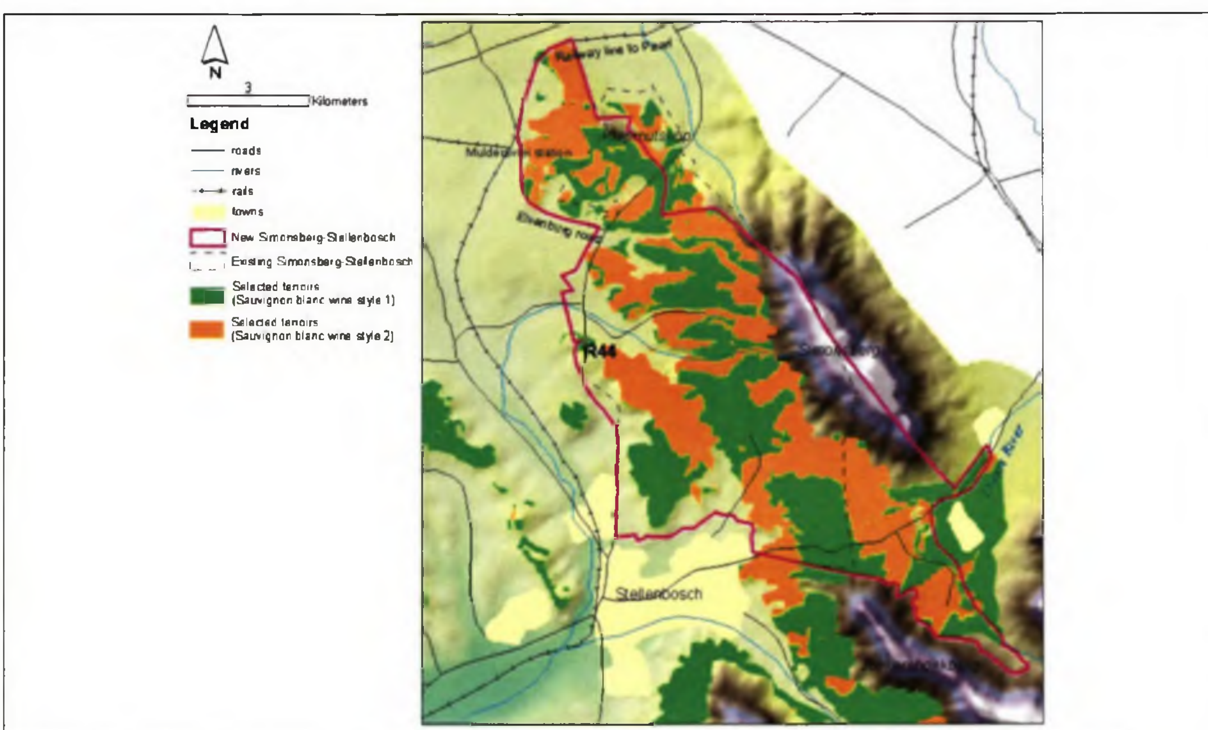

Figure 6.4 Map showing the existing and proposed boundaries of the Simonsberg-Stellenbosch Wine of Origin ward in relation to selected terroirs for Sauvignon blanc based on dominant wine sensorial properties. Wine style 1 refers to Sauvignon blanc wines that are expected to have a moderate fresh vegetative and not very intense tropical fruit aroma. These wines are expected to be fairly full on mouth-feel and the natural wine pH will be fairly low. Wine style 2 is similar except that the tropical fruit aroma is expected to be more intense. Data obtained from Chief Directorate: Surveys and Mapping, ARC Infruitec-Nietvoorbij and Agri Informatics. Compiled by V Carey

The existing boundaries of the Stellenbosch-Simonsberg Ward were based on environmental features that are expected to have an influence on wine style and quality, i.e. soil type, expected geological origin of soils, dominant slope aspect and watershed boundaries. These boundaries remain valid. The data for Cabernet Sauvignon and Sauvignon blanc that were used in terroir studies in the Stellenbosch Wine of Origin District (Chapter 4, section 4c) did not distinguish between granitic, shale and quaternary derived soils and the digital temperature data was based on elevation. It is not expected that the full effect of the sea breeze will reach the slopes of the Simonsberg (Chapter 4, section 4.1). Based on the distribution of the identified dominant terroir units for Cabernet Sauvignon and Sauvignon blanc an extension of the boundaries of the Simonsberg-Stellenbosch ward is proposed (Fig. 6.3 and Fig. 6.4). These extended boundaries remain based on the red, brown or yellow soils, although they may be of varied origin (excluding sandstone).

Where the existing boundary intersects the Elsenburg road, the new boundary is proposed to follow this Elsenburg road in a north-westerly and then northerly direction until it intersects the railway line north of Muldersvlei station. From this point the proposed boundary continues in a north-easterly direction, along the Muldersvlei-Paarl railway line until it intersects the Stellenbosch Wine of Origin District boundary. On the south-eastern side of the district, the proposed modification includes the north-eastern flank of Jonkershoekberg and the southern flank of Simonsberg until the Dwars River.

The vineyard area of the ward will have a self-limiting boundary based on very shallow soils and hard rock in the north-west. Vineyards near the remaining boundaries should be examined for conformity with respect to soil type, and vineyards on duplex soils should be excluded from the ward.

The validity of these extended boundaries will have to be tested with respect to expected wine style by means of sensory analysis of commercial wines. The south-easterly boundary extension crosses a watershed and temperature regime of this portion should be compared with that of the south-western flanks of the Simonsberg by means of temperature sensors.

It must be realised that the ward delimitation is based on wine sensorial attributes and that the vineyards associated with these wine styles may in fact have different phenology, yield, vegetative growth characteristics, etc. Knowledge of the position of the individual terroir units identified for Cabernet Sauvignon and Sauvignon blanc would provide additional information as to the expected performance of these cultivars within the identified wards and sub-wards. This knowledge would assist vineyard managers to adapt viticultural practices.

6.5.2.2 Delimitation of a new ward

The environmental features of the area surrounded by the Helderberg, Hottentots Holland mountains and False Bay (Fig. 6.5) were investigated to delimit new wards. This area contains the urban settlements of Somerset West, Gorden's Bay, Strand, Lwandle and Sir Lowry's Pass Village, and, in colloquial terms, is known as the Helderberg Basin. It is bisected by the Lourens River.

The elevation of this basin varies from less than 20 m above sea level at the coast to more than 1000 m above sea level in the surrounding mountains. The dominant soils are residual or structureless in nature, although alluvial soils occur in the river valley and wet duplex soils are found at lower altitudes, closer to the coast (Ellis & Schloms, 1975; Ellis *et al.*, 1976). The slopes of the Hottentots Holland mountains are dominated by quaternary scree which covers granite of the Stellenbosch Pluton (Theron *et al.*, 1992), while the slopes of the Helderberg have scree covering rocks of the Tygerberg formation, grading into weathering products of Malmesbury rocks (Theron, 1990). The Tygerberg formation is also found around the Skapenberg.

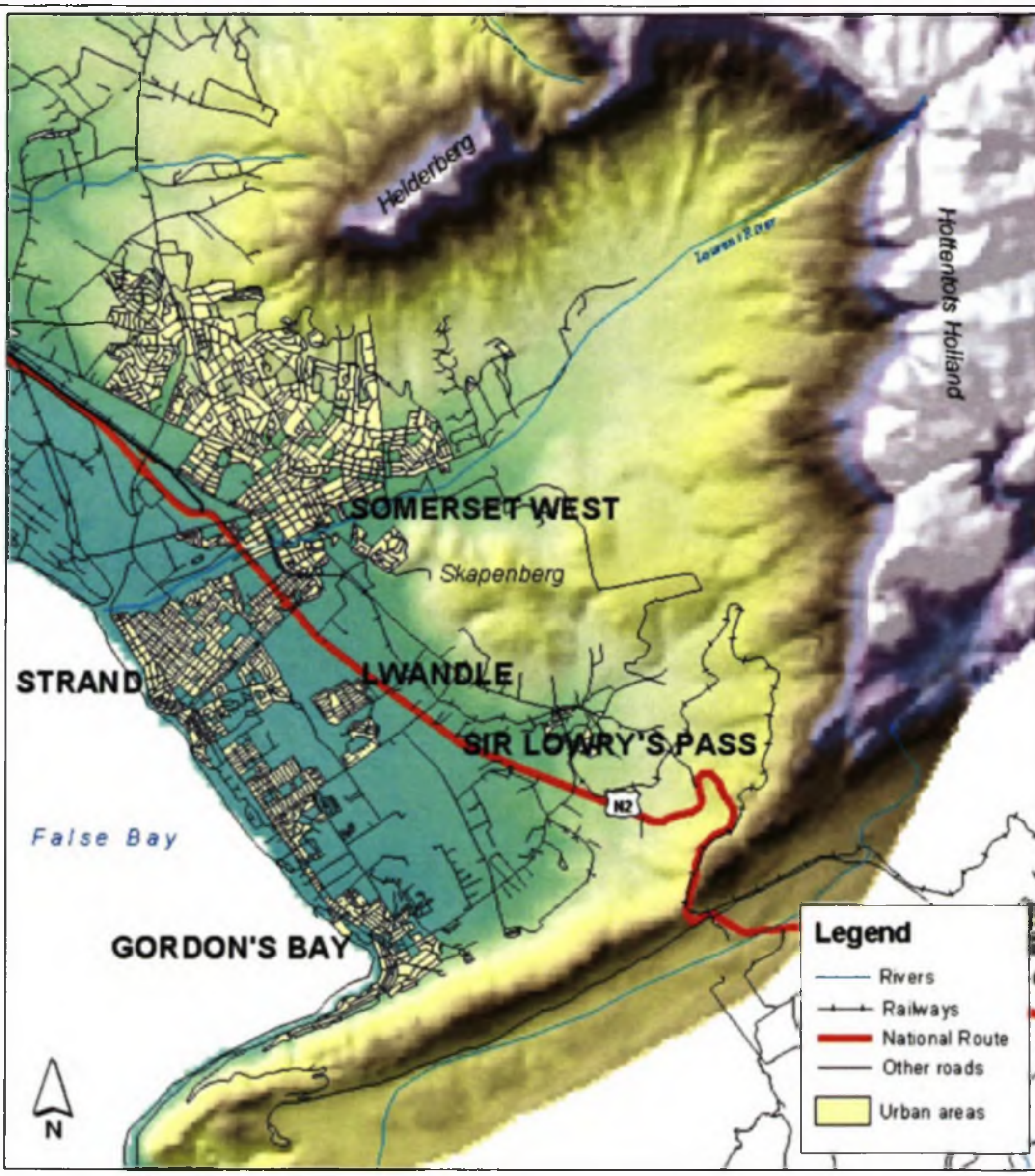

Figure 6.5 The Helderberg Basin. Data obtained from Chief Directorate: Surveys and Mapping. Compiled by V Carey

A shape file of approximate boundaries for three natural regions in this basin (the slope of Helderberg and the slopes of the Hottentots Holland were separated by the Lourens River, Skapenberg was kept apart) was created based on soil and geological data. Dominant terroirs for Sauvignon blanc and Cabernet Sauvignon were determined for each of these three areas, using discrimination between dominant geological formations and dominant slope aspects as points of departure. Comparison of the area covered by multi-terroir units with expected similar wine styles per natural region, showed that wine style was more closely related to differences in altitude than to these three regions (Fig. 6.6).

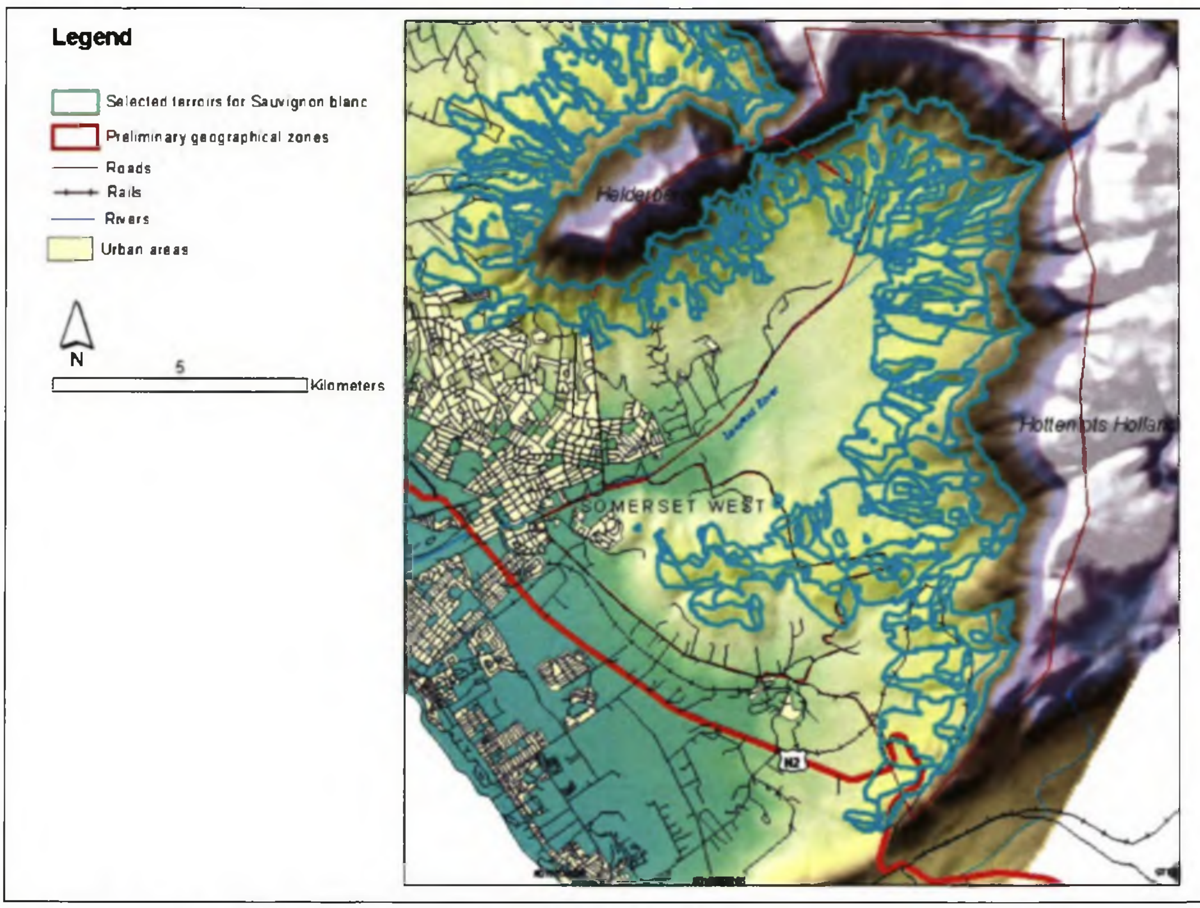

Figure 6.6 Selected terroir units for Sauvignon blanc wine production based on the dominant wine style for the natural region associated with the Hottentots Holland mountains. The associated Sauvignon blanc wine style is expected to have delicate aromas with dominant fresh vegetative characteristics, be moderately full on mouth-feel and have lower natural wine pH values. Data obtained from Chief Directorate: Surveys and Mapping, ARC Infruitec-Nietvoorbij and Agri Informatics. Compiled by V Carey

Terroir units with which dominant wine styles for Sauvignon blanc and Cabernet Sauvignon were associated, were then plotted. It was clear that the difference in wine style occurred in the zone between 200 m and 300 m above sea-level. Above this level, Sauvignon blanc wines would be expected to have delicate aromas with dominant, but moderate, fresh vegetative characteristics, be moderately full on mouth-feel and have a lower natural wine pH. Below this level, the wines would be expected to be more complex with more intense notes of tropical fruit, dried vegetative (e.g. tea) and spicy associated aromas, together with moderately high fresh vegetative aroma characteristics (e.g. bell pepper, grass). For Cabernet Sauvignon, on the terroir units above 300 m and associated with scree and sandstone derived residual and apedal soils, the wines would be expected to have moderate but dominant berry aromas and low extract. Between 200 m and 400 m and associated with residual or apedal soils of other geological origin, the wines would have slightly more noticeable floral notes, be full on mouth-feel and have a higher extract. Below 300 m, on slightly warmer landscape positions than the category above, the berry aroma would be expected to be more intense and dominant and the wines would be expected to be full on mouth-feel with a high extract. Altitude is the dominant environmental factor affecting wine style due to its relationship with temperature and soil type.

This analysis suggested that the three proposed regions would not result in noticeably different wine styles, and would contain diverse terroirs for production of Cabernet Sauvignon and Sauvignon blanc. The boundaries shown in Fig. 6.7 are therefore proposed to accommodate these different wine styles for the two cultivars studied. It is not easy to associate historical place names with these proposed wards due to the negative connotations of the name Hottentots Holland, and the fact that Lourens River, Lourensford and Vergelegen are existing brand names. Due to the close association of the lower lying ward with the town of Somerset West it is proposed that this ward is named Somerset West and that the higher lying ward takes the colloquial name of Helderberg Basin.

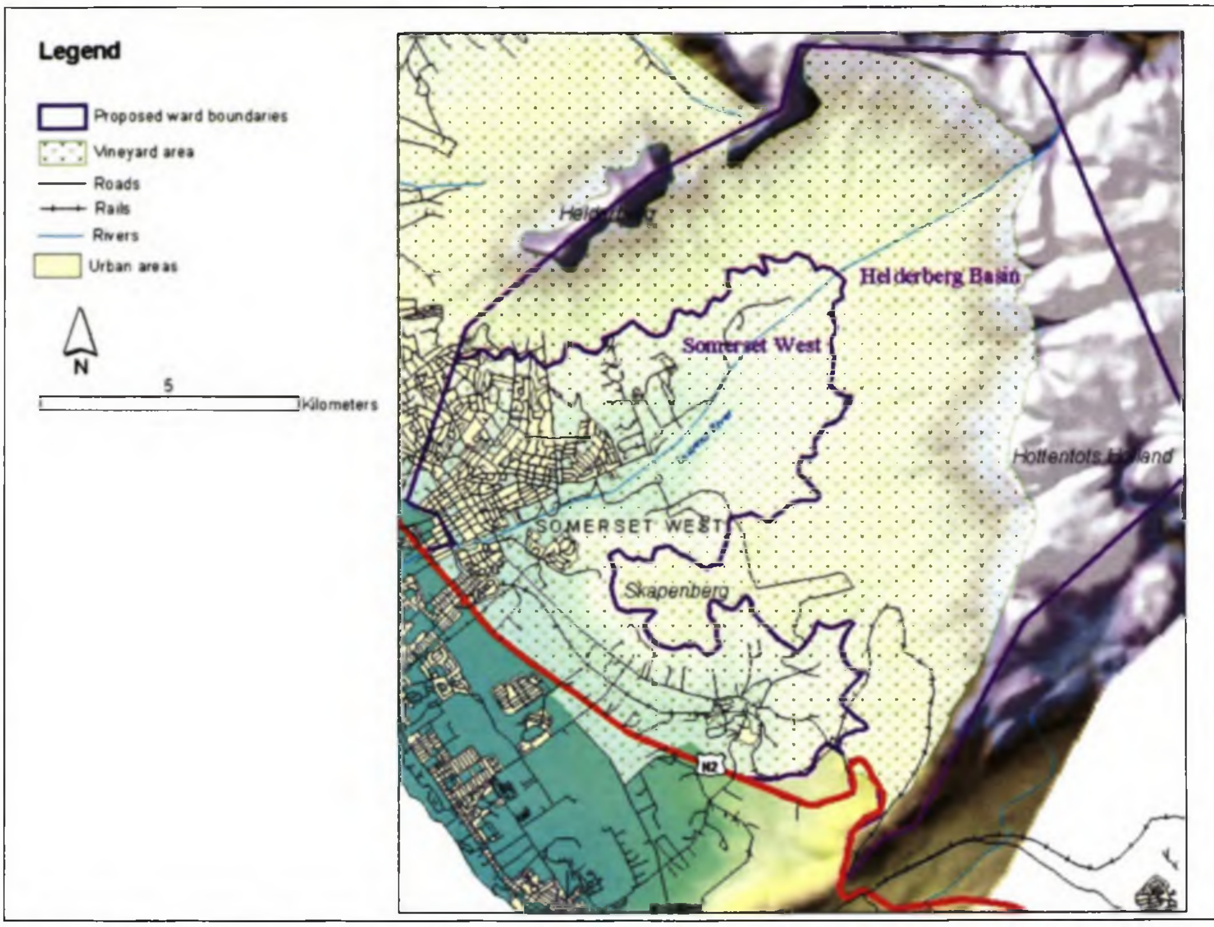

Figure 6.7 Proposed boundaries for wards in the Helderberg Basin, Stellenbosch Wine of Origin District. Data obtained from Chief Directorate: Surveys and Mapping, ARC Infruitec-Nietvoorbij and Agri Informatics. Compiled by V Craey

For the Helderberg Basin ward, 63.2% of the arable area will be expected to produce Sauvignon blanc wines that have delicate aromas, dominant fresh vegetative characteristics, are moderately full on mouth-feel and have a lower natural wine pH. For Cabernet Sauvignon two wine styles are associated with ca. 48% of the arable area. The first style would have moderate but dominant berry aromas and low extract (sandy soils), while the second would have slightly more noticeable floral notes, be full on mouth-feel and have a higher extract (residual or apedal soils of non-sandstone origin).

The Somerset West ward would be expected to produce a Sauvignon blanc wine (ca. 38% of the arable area) with moderate fresh vegetative aroma characteristics balanced by tropical fruit aromas, some dried vegetative and spicy notes and that is moderately full on mouth-feel. This same ward would also potentially produce two Cabernet Sauvignon wine styles (33.4% and 31.0% respectively), both having dominant berry aroma characteristics but the one being significantly fuller on mouth-feel (residual or apedal soils of non-sandstone origin) than the other (sandy soils).

The boundaries of the Helderberg Basin ward would, similarly to the Stellenbosch Wine of Origin District boundary, be self-limiting towards the mountain due to the presence of very shallow soils and hard rock. Vineyards planted in proximity to the lower boundary of the Somerset West ward would have to be monitored to ensure that no vineyards planted on sandy or duplex soils are included in the ward. Beyond these restrictions, it is proposed that all vineyards demarcated within a ward are entitled to the ward denomination and that further distinction between wine styles occurs on a sub-ward level.

The 1:250 000 geological map of the area (Theron, 1990) shows distinct differences in geology within these proposed wards. The existing data did not show an effect of geology on wine style for Cabernet Sauvignon or Sauvignon blanc and these geological differences were therefore not brought into reckoning. It will be necessary to establish whether these different geological formations do, in practice, affect wine style by means of sensory analysis of commercial wines from the proposed wards.

6.5.3 SUB-WARDS WITHIN THE WINE OF ORIGIN DISTRICT – STELLENBOSCH

As discussed in preceding paragraphs, one ward may have the potential to produce two or more cultivar-dependent wine styles. Knowledge of the spatial distribution of individual terroirs and of the expected functioning of the grapevine on these terroirs should therefore assist the vineyard manager to adapt his viticultural practices so as to ensure the production of the determined wine style. It will also be possible, on a sub-ward level, to delineate vineyards that fall specifically within a selected terroir unit for the production of terroir specific Cabernet Sauvignon or Sauvignon blanc wines, using 1:10 000 ortho-photos or GPS co-ordinates (Fig. 6.8).

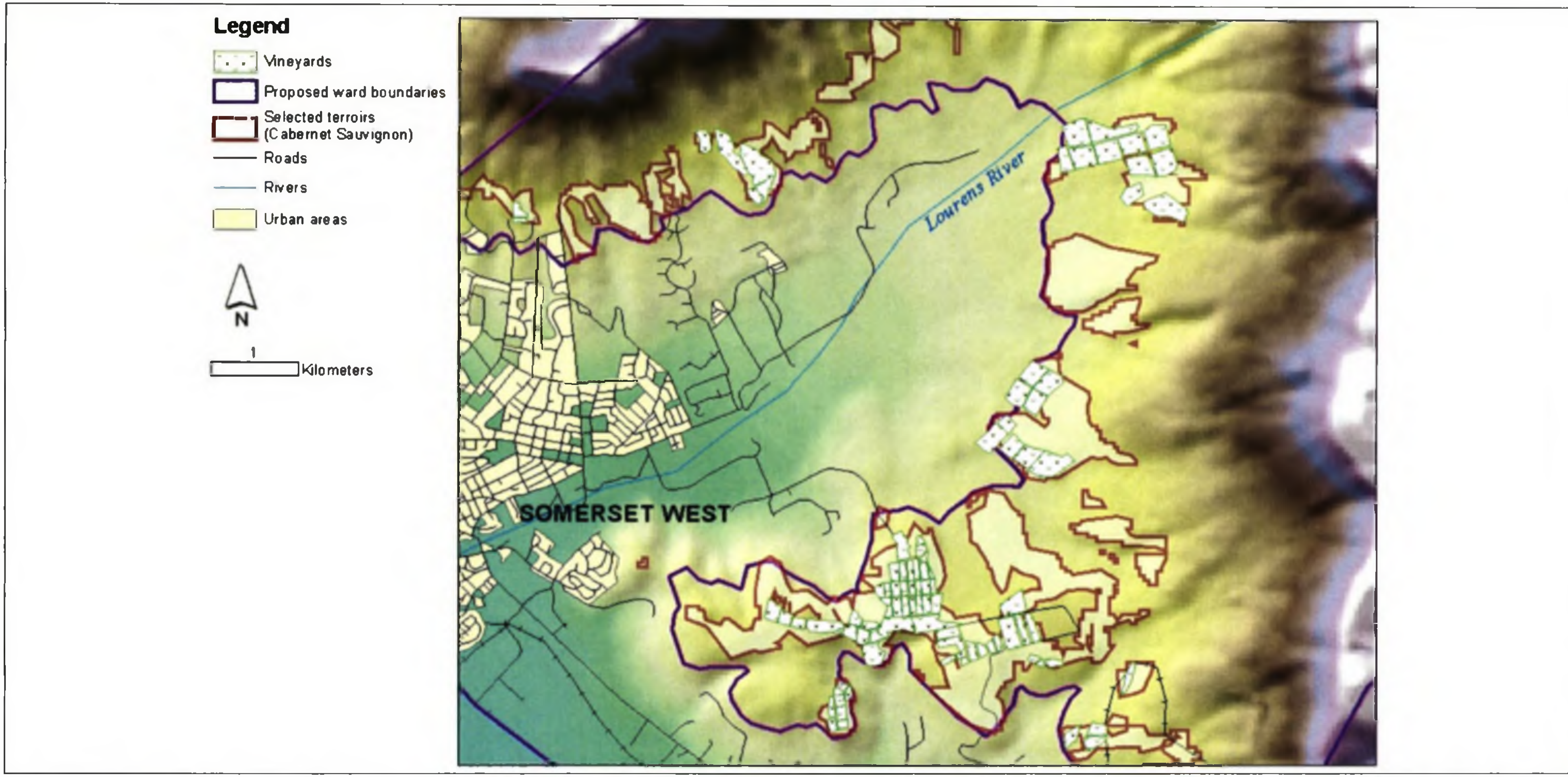

Figure 6.8 Vineyards delimited within the proposed Helderberg Basin ward for the production of a terroir specific Cabernet Sauvignon wine on a sub-ward level (Terroir 54). The wine would be expected to have dominant berry aroma aromas with noticeable floral notes, be full on mouth-feel and have a high extract. The yield would be expected to be low (<1.8 kg/m cordon). The pH of the must would be expected to be low, the titatratable acidity ca. 7.5 g/L, and the maturity index above 30, indicating in the Stellenbosch Wine of Origin District a less ideal must composition (Chapter 4, section 4c). The natural wine pH would potentially be high and the specific gravity low. Data obtained from Chief Directorate: Surveys and Mapping, ARC Infruitec-Nietvoorbij and Agri Informatics. Compiled by V Carey

6.6 CONCLUSIONS

For many of the South African wine-producing areas the only environmental data available are the 1:50 000 topographic maps and 1:10 000 orthophotos of the Chief Directorate: Surveys and mapping and the land-type inventory (1:250 000) of the Agricultural Research Council. Stellenbosch, however, has more detailed soil data (1:50 000 peri-urban soil survey) and an automatic weather station network and more detailed environmental data is thus available. One of the dominant characteristics of Stellenbosch is its diversity of viticultural environments resulting from the ancient geological history, complex topography and proximity to the ocean and, although more detailed than many other regions, even this data may not fully represent the full range of terroirs present in this region.

Viticultural terroir studies ensure a thorough knowledge of dominant environmental features in a region, facilitating the demarcation of district boundaries.

For delimitation at a District level, it is necessary to take historical community development as well as environmental features into account. Natural geographic entities such as mountains, rivers, etc. should, however, always take precedence over the historical administrative community in the delineation of these boundaries.

On a ward level, the use of viticultural terroirs to delimit boundaries ensures that these boundaries are based on the aptitude of the natural environment to produce a unique wine style. The identified dominant wine style may be associated with areas associated with other place names than that under investigation but in order for the ward to be delimited it must be linked to a real geographic place name. A ward is therefore a combination of the potential of the natural environmental features to produce a unique wine and a geographic place name.

Sometimes within a delimited ward, two or more slightly different wine styles may be associated, but it may be possible to dissociate these wine styles on a sub-ward level. At this level, viticultural terroirs make it possible to delimit vineyards with the potential to produce terroir-specific wines, or to divide a ward into functional units based on the viticultural response of the cultivars in question.

Although it is not possible to ensure that all denominations of origin, from a ward (or communal) level upwards to regional level, are linked to one specific terroir, it should be possible to ensure that, at least at the ward level, they are associated with a particular wine style. At a sub-ward level, only one terroir will be brought into question, but this terroir delineation will have to be cultivar specific as cultivars react differently to the given environmental attributes.

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CHAPTER 7

GENERAL DISCUSSION AND CONCLUSIONS

CHAPTER 7

7.1 INTRODUCTION

There appears to be a growing consumer demand for products labelled by origin (Barham, 2003). In order to be effective, these labels of origin must be a guarantee of both quality and product character (Carbone, 2002). As a result, there is an increasing global focus on the delimitation of denominations of origin. The South African Wine of Origin Scheme is dynamic and is based on the best available environmental information and newest research results pertaining to the environment x wine interaction. As such, the increasing awareness of the diversity of the South African winegrowing environments is resulting in increasingly stringent criteria for delimitation. In order for these criteria, and thus boundary definition, to have integrity, they must be based on the terroir concept. Research into the delimitation of viticultural terroirs in South Africa forms a research programme of Winetech (Wine Industry Network for Technology and Expertise). This dissertation contributes to this program.

The aims of this study were to identify the dominant environmental criteria that affect the viticultural behaviour and wine character of two important cultivars (Cabernet Sauvignon and Sauvignon blanc) in Stellenbosch and surrounds, to use an appropriate methodology to identify viticultural terroirs based on these criteria and with the use of a geographic information system, and finally to use these viticultural terroirs to identify denominations of origin within the same area.

7.2 GENERAL DISCUSSION

7.2.1 THE IDENTIFICATION OF TERROIRS FOR VITICULTURE USING FIELD STUDIES

In order to determine the functioning of the grapevine and the characteristics of the final product on a particular natural terroir unit (for a definition of this concept, refer to Chapter 2, section 2.2.1), it is necessary to perform *in situ* studies resulting in point data. In order for this information to be of use within zoning studies, it must be placed within the context of the pertinent terroir in order to provide a spatial result (Vaudour, 2000; Vaudour 2001). An environmental model to identify terroirs, therefore, consists of various logical arguments and processing methods.

The first stage of this study consisted of an empirical (i.e. deterministic) inductive model (Skidmore, 2002). Field data was explored for possible patterns that could be used to derive a general statement with respect to viticultural or oenological performance using the classification and regression tree methodology (CART) (Breiman, *et al.*, 1984). These results were used to derive thresholds that could be used in empirical models. The second stage encompassed a knowledge-driven deductive model. The rules generated from the statistical induction phase were used to summarise relationships between dependent and environmental variables. These rules were used to directly classify unknown spatial objects by deduction (Skidmore, 2002).

Viticulture in South Africa is non-prescriptive and viticultural management strategies are thus diverse. One of the hypotheses proposed in Chapter 1 of this dissertation was that grapevine performance, and thus berry composition and wine character, are affected by constant environmental parameters and that these characteristics will be recognisable despite differences in vintage, viticultural practices, rootstock or scion clone. This hypothesis could be tested by means of the determination of variable importance. Excepting for scion clone, which had a high importance for bunch mass of Sauvignon blanc and yield:pruning mass index of Cabernet Sauvignon, no other non-environmental variable included in the analyses appeared to have a strong effect on grapevine performance and wine character.

It appears that the potassium content of the subsoil affected the performance of Cabernet Sauvignon in the Stellenbosch Wine of Origin district (Fig. 4.2.5). Sandstone soils are expected to have the lowest total soil potassium content, followed by shale derived soils and finally granite derived soils (Wooldridge, 1988). Statistical analyses of the soil data from the experimental plots indicated, however, that the potassium content of the sub-soil did not differ significantly between soils associated with rocks of the Tygerberg Formation (shale), granite, and the weathering products of Malmesbury rocks and granite soils, or between residual, red and yellow apedal to neocutanic soils and medium-deep wet duplex soils. The potassium content of the sub-soil appeared to be strongly affected by the agricultural usage of the land; to such an extent that the expected effects of the parent material of the soil are no longer visible (*vid.* Seguin, 1986; Conradie *et al.* 2002).

The climate of the season appeared to have a very strong influence on the aroma characteristics of Cabernet Sauvignon. The different seasonal climates allow one, however, to investigate the response of a grapevine to a particular site under different climatic regimes, and can thus be useful in extrapolating data to climate/soil combinations that were not included in the field studies.

The performance of Sauvignon blanc appeared to be related to soil texture, wind exposure and temperature, both during the green berry growth stage and the month prior to ripening (Fig. 4.2.6).

From these results it would seem that environmental parameters have an overriding effect on the performance of both Cabernet Sauvignon and Sauvignon blanc, but that these two cultivars react differently to environmental stimuli.

Probably one of the most difficult tasks within a zoning study is the relation of the viticultural and oenological data to environmental data. It is necessary to determine a hierarchy for the environment factors with respect to their relevance to viticulture in the region, as well as to determine rules that may be used for spatialisation of the results. Traditional analyses of variance are difficult to use as it is not easy to lay out a trial with statistically correct repetitions and the inclusion of a number of vintages results in time scale data. Factor, principal component and discriminant analyses have been used in many studies, but these merely indicate an underlying structure to the data. Furthermore, any missing data, of which there may be many when working in commercial vineyards, results in the loss of the full row of data for the analysis. However, classification and regression tree analyses (Breiman *et al.*, 1984) would appear to overcome these limitations. In this study, the use of regression tree methodology (CART analyses) to determine the response of two cultivars to environmental parameters enabled the definition of decision trees for spatialisation of their response. The determination of the relative importance of the various environmental variables and the ability to determine the significance of differences between the derived plot groupings (terminal nodes of the regression trees) made it possible to select the variables where the environmental response was acceptably predicted. Each natural terroir unit (Chapter 4, Section 4.1) could be evaluated with respect to its expected viticultural and oenological response, based on the rules determined for these selected dependent variables, and thus grouped to identify terroir units. The identified terroir units were, therefore, homogenous with respect to predicted viticultural and oenological functioning.

7.2.2 THE IDENTIFICATION OF TERROIRS FOR VITICULTURE USING RESULTS FROM A SURVEY AMONGST VINEYARD MANAGERS

The use of representative sites to determine the response of the grapevine to its environment is time consuming and costly and limits terroir studies to research related investigations. As the Stellenbosch Wine of Origin District has a long history of vineyard cultivation and wine production, there is already a pool of existing empirical knowledge amongst the producers of the region. This intrinsic knowledge was tapped through the use of a questionnaire amongst grape buyers or vineyard managers in the Stellenbosch Wine of Origin District. Comparison of the data generated with these questionnaires to measured data in commercial vineyards suggested that the vineyard managers were able to characterise the performance of vineyards with respect to vigour, signs of drought stress and yield. As each vineyard could be plotted spatially, it was possible to link the responses to modelled environmental variables.

Classification and regression trees once again proved to be a valid methodology to determine decision trees for spatialisation of the results. The viticultural and oenological aptitude of a site was closely related to temperature, exposure to dominant winds, height above sea level and soil type and these parameters could be used to determine viticultural terroirs for production of Sauvignon blanc wine. Fewer terroirs were identified for Sauvignon blanc using this technique than with using decision trees based on field data gathered during a period of 7-years, but comparison of the resulting maps (Addendum 4.3.3. and Addendum 5.1.) showed that similar areas were identified as being distinct.

7.2.3 THE USE OF GEOGRAPHIC INFORMATION SYSTEMS IN TERROIR STUDIES

For many of the South African wine producing areas the only environmental data available are the 1:50 000 topographic maps and 1:10 000 orthophotos of the Chief Directorate: Surveys and Mapping and the land-type inventory (1:250 000) of the Agricultural Research Council. However, for Stellenbosch there are more soil data available (1:50 000 peri-urban soil survey) as well as an automatic weather station network and more detailed environmental data is thus available. One of the dominant characteristics of Stellenbosch is its diversity of viticultural environments resulting from the ancient geological history, complex topography and proximity to the ocean and, although more detailed than many other regions, even this data may not fully represent the full range of terroirs present in this region.

Certain problems with data have been identified as one of the overriding problems associated with GIS modelling (Bregt *et al.*, 2002). These problems may be associated with a lack of data, gaps in data coverage or the accuracy of the data being insufficient to answer questions.

In this study, digital environmental data also proved to be one of the major constraining factors. Although soil data was available at a suitable scale, it did not contain sufficient information and relevant soil characteristics had to be inferred per soil type based on known relationships or relationships estimated statistically with analytical data from the experimental plots. Digital geological data was not available at a suitable scale and only broad geological descriptions could be included.

Despite the presence of an automatic weather station network, modelling of climatic data on a meso-scale holds challenges that could not be met within the confines of this study. The modelled data that was used did not take the sea influence into account due to the paucity of weather stations in the coastal areas. Although RAMS analyses have been performed on a 200 m grid (Du Preez, Cautenet & Bonnardot, personal communication, 2004), this data is not yet available for a suitable period and it is not possible to perform these analyses at the grid scale of this study (50 m) for a large area.

These data “problems” limited the spatialisation of the viticultural and oenological response of Cabernet Sauvignon and Sauvignon blanc in the Stellenbosch Wine of Origin District, and the accuracy of the extrapolation may in some cases be questionable.

7.2.4 THE USE OF VITICULTURAL TERROIRS TO IDENTIFY DENOMINATIONS OF ORIGIN

There is an increasing movement towards using viticultural terroirs as a basis for demarcation in order to ensure the integrity of delimitation. It is clear that for such an appellation to be successfully demarcated, there must be an acceptance of the importance of the "unique" and "typical" wine characteristics as expression of the terroir. In the South African Wine of Origin Scheme, all soil and climatic factors possibly having an effect on wine character and/or quality, existing cultural practices, existing experience and evidence that proves an area to be unique, geographical and other factors that contribute to the development of the traditional wine area and the traditional name of the area are taken into account in their delimitation (Saayman, 1999). Denominations of origin are demarcated, on application by the producers within a community, by a multidisciplinary demarcation committee within the structure of the Wine and Spirit Board (SAWIS, 2003). The homogeneity of environmental features is assumed to ensure a distinctive product and these demarcated areas are therefore allowed to develop and express their "uniqueness" after delimitation.

The use of data and knowledge garnered during a terroir investigation makes it easier to understand the environmental and social structure of a wine-producing region, thus facilitating the delimitation of districts ("regional" level). The identification of terroirs for production of specific cultivars, with their associated wine styles means that it is possible to base delimitation on a ward or "communal" level on expected wine characteristics. This should, to a certain extent, ensure a certain level of homogeneity of product linked to a geographical place name. Viticultural terroirs also make it possible to identify vineyards for the production of "terroir specific" wines, although these units would appear to be cultivar dependent.

7.3 PERSPECTIVES AND DIRECTIONS FOR FUTURE RESEARCH

7.3.1 VALIDATION OF DELIMITED UNITS

Validation of the identified terroirs and denominations of origin did not fall within the confines of this study, but this does not negate their necessity.

The data generated from the network of experimental plots were based on measurements that were easily performed, as this study was a preliminary approach to determine the validity of terroir studies for the South African wine industry. Thus, although rationale for observed relationships of measured viticultural and oenological variables with site related environmental variables may be proposed, it is not possible to state with any certainty the reasons for a particular response. The measurement of ecophysiological parameters on reference plots (grapevine water balance, canopy development, dynamics of berry ripening, organic acid ratios, etc.) will facilitate improved understanding of the grapevine x terroir interaction. Measurement of viticultural and oenological variables on an alternative network of plots will also serve to validate or refine the decision trees constructed with the first set of data.

The denominations of origin must be validated on a commercial scale. This can be achieved by using existing data from wine awards systems, consensus of industry experts and by sensorial analysis of tank samples from vineyards within identified denominations of origin.

7.3.2 DIGITAL DATA

One of the greatest deficiencies of the identification of natural terroir units in this study was problems with digital environmental data. Issues related to soil data may be addressed by compilation and extrapolation of soil maps for individual farms into soil-landscape units by means of remote sensing, as performed by Vaudour for the Rhone Valley (Vaudour, 2000; Vaudour 2001). Issues related to climatic data are less easily addressed and deserve further study.

Soil potassium was identified as being a key predictor variable for the response of Cabernet Sauvignon to the environment. The known effect of soil parent material on the soil potassium content was not exhibited in this study and this made spatialisation of these results difficult. The relationship of soil potassium content with site related variables deserves further study in order to determine whether this variable can be controlled *via* fertilization or whether there are more complex factors at work, and to what extent rules for spatialisation can be constructed.

7.3.3 IMPLICATIONS OF CLIMATE CHANGE

Climatic variables of radiation, temperature and precipitation were identified as being significant contributors to the viticultural and oenological responses of Cabernet Sauvignon and Sauvignon blanc, and it can be assumed that this will be true for all cultivars. Although the change most commonly associated with the phrase "climate change" is surface warming, this change may also be manifested in other climate variables such as precipitation amounts and frequencies and solar radiation. If the regional consequences of global warming in terms of key climate-related parameters, such as solar radiation, temperature and precipitation, were better understood, it would be possible to adapt and respond to the possible impacts of these changes by means of terroir studies. As the decision trees determined in this study can be applied to various data layers, it will be possible to investigate future scenarios.

It is also important to remain cognisant that, even in the absence of global warming, annual climatic variability may result in variations in wine style. This should be recognised as the result of an interaction between terroir and vintage. The performance of a cultivar on certain terroirs may remain consistent across vintages, while considerable variation may be induced on others (Barbeau *et al.*, 1998).

7.4 CONCLUSIONS

Despite the ancient knowledge that origin affects wine style and quality, the zoning of homogenous areas for production of wines with unique characteristics has only recently formed a scientific research focus with a multitude of methods and varying degrees of completeness. It is important, especially within the higher wine price brackets, to maintain integrity in labelling by origin, an integrity which can only be provided if the terroir concept is used as a basis for delimitation.

The use of a survey amongst vineyard managers appeared to be a valid attempt at gathering important information on grapevine performance for terroir studies. This may be a useful exercise for a first attempt at zoning.

The use of classification and regression tree methodology (CART) on field or survey data appeared to be an valuable method or tool in the identification of viticultural terroirs. With CART it was possible to determine the hierarchy of environmental variables affecting the viticultural and oenological response of particular cultivars. The pertinent variables could then be built into decision trees that could be applied to digital environmental data layers within a geographic information system to identify cultivar specific terroirs. These identified terroirs could be grouped into multi-terroir units with an expected similar oenological response in order to provide a basis for the identification of wards (or communal level denominations).

Although it is not possible to ensure that all denominations of origin, from a ward (or communal) level upwards to regional level, are linked to one specific terroir, it should be possible to ensure that, at least at the ward level, they are associated with a particular wine style. At a sub-ward level, only one terroir will be brought into question, but this terroir delineation will have to be cultivar specific as cultivars react differently to the given environmental attributes.

It would appear from this study that the viticultural and oenological performance of a cultivar is predominantly affected by environmental site related parameters, and that this effect is stronger than any contribution by viticultural management decisions or practices. Environmental parameters could therefore be used to identify terroirs with the aptitude for a particular wine style. The identification of terroirs as a basis for denominations of origin would therefore appear to be a valid process within the South African wine industry.

7.5 LITERATURE CITED

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Addendums

ADDENDUM 3.1 Legend for land-types in Fig. 3.11. Compiled from the land-type inventory supplied by the ARC Institute for Soil, Climate and Water (2004)

Land type	Relief	TMU [1]	Soil forms[2] (% presence)	Dominant soil depth (mm)	Dominant soil texture	Geology
Ac 15	Open, high slopes on SE flank of Helderberg. Lourens River to SE.	1	Hu (70), Gs (30)	>1200	meSaLm – SaClLm	Varying
		3	Hu (47), Gs (41), Cv (12)	>1200, 300-400 (Gs)	me/fiSaLm – SaClLm	
		4	Cv (50), Hu(17), Gs (14), Av (19)	>1200	meSaLm – SaClLm	
		5	Oa (43), We (30), Du (17), Cv (5)	>1200, 200-300 (We)	fi/meSaClLm	
Ac 17	Open, high slopes of NW flanks of Helderberg and W slopes Stellenbosch Mountain	1	Rock (70), Ms (20), Gs (10)	50-300	meSaLm	Varying
		3	Hu (40), Gs (35), Cv (25)	800-1200+, 300-500	fi/coSaClLm-Cl	
		4	Kd (80), Hu (8), Cv (12)	600-1000	coSa – (co)SaLm	
		5	Oa (74), We (26)	>1200	Fi/meSaLm – SaClLm	
Ac 18	Open, high slopes on southern part of SW flank of Simonsberg	1	Gs (50), Hu (30), Cv (10), coarse deposits (10)	300-500	meSaLm – SaClLm	Granite, *in situ* weathering products of granite (Stellenbosch pluton)
		3	Gs (50), Hu (30), Cv (5), coarse deposits (15)	300-500	meSaLm – SaClLm	
		3(1)[3]	Hu (60), Cv (15), Oa (5), Av (5), Gs (15)	800-1200+	Fi/meSaClLm – SaCl	
		4	Cv (32), Hu (20), Kd (15), Oa (10), We (10)	800-1200+	meSaClLm – SaCl	
		5	Oa (55), Av (10), Kd (10), We (25)	800-1200+	meSaClLm	
Ac 19	Open, high slopes of northern part of SW flank of Simonsberg	1	Gs (50), Hu (30), Cv (10), coarse deposits (10)	300-500, 800-1200+	meSaClLm – SaCl	*In situ* weathering products of granite (Stellenbosch pluton)
		3	Hu (54), Gs (15), coarse deposits (15), Cv (10), Av (4), Bv (2)	800-1200+	fi/meSaClLm – ClLm	
		4	Cv (29), Hu (20), Av (16), Kd (15), We (10), Bv (10)	800-1200+	fi/meSaClLm – ClLm	
		5	Oa (55), We (30), Av (8), Kd (7)	>1200	meSaClLm	
Ac 20	Open, high hills of valley between Stellenbosch Mountain and Simonsberg	1	Gs (40), Hu (30), Rock, coarse deposits (20), Cv (10)	300-500, 800-1200+	meSaLm-SaCl	Gritty sand/scree overlying granite, weathering products of granite (Stellenbosch Pluton)
		3	Gs (40), Hu (30), Rock, coarse deposits (25), Cv (5)	300-500, 800-1200+	meSaLm-SaCl	
		3(1)	Hu (62), Cv (16), Av (5), Gs(17)	800-1200+	meSaClLm – SaCl	
		4	Cv (30), Av (20), Hu (20), We (15), Kd (10), Bv (5)	800-1200+	meSaClLm – SaCl	
		5	Oa (55), We (30), Av (8), Kd (7)	>1200	meSaClLm	

[1] Terrain morphological unit. 1 = crest, 3 = midslope, 4 = footslope, 5 = valley bottom
[2] Soil forms are described in Fig. 3.12
[3] 3(1) indicates a policyclical slope profile with age or height difference being indicated by an integer in parentheses

Land type	Relief	TMU	Soil forms (% presence)	Dominant soil depth (mm)	Dominant soil texture	Geology
Ac 21	Open, high S slopes of Simonsberg	3	Hu (45), Gs (27), Cv (11), rock (10), Av (2), Oa (5)	800-1200+	meSaClLm - SaCl	Gritty sand, scree covering granite, deposits of weathering products of granite (Stellenbosch Pluton)
		4	Hu (35), Cv (30), Av (25), Kd (10), We (10), Bv (5)	800-1200+	meSa(Cl)Lm - SaCl	
		5	Oa (65), We (25), Av (5), Kd (5)	800-1200+	meSaClLm	
Ac 24	Open hills, S of Bottelaryberg in Lynedoch area	1	Gs (50), Hu (30), Cv (15), rock (5)	300-500	fiSaLm – SaCl	Granite and weathering products of granite (Kuils River-Helderberg Pluton)
		3	Gs (35), Hu (30), Cv (20), rock (5), Oa (7), Av (3)	800-1200+	meSaClLm – SaCl,	
		4	Cv (40), Av (30), Hu (15), We (15)	800-1200+	meSaClLm – SaCl,	
		5	Oa (55), We (45)	>1200	meSaLm – SaClLm	
Ac 32	Open foothills of Simonsberg, N of Stellenbosch	1	Gs (54), Hu (34), Cv (12)	300-500	meSaClLm – SaCl	Rocks of Tygerberg Formation and surficial cover formed *in situ* on Malmesbury rocks
		3	Hu (60), Cv (18), Av (7), Gs (15)	800-1200+	fi/meSaClLm – SaCl	
		4	Cv (30), Av (25), Hu (32), Kd (15), We (10)	800-1200+	meSaLm – SaClLm	
		5	Oa (55), We (30), Av (8), Kd (7)	>1200	meSaClLm	
Ac 429	Open, high, SW slopes of Helderberg	3	Gs (49), Hu (31), Cv (20)	100-400	fiSaLm – SaClLm	Granite, deposits of weathering products of granite (Kuils River-Helderberg Pluton)
		4	Oa (32), Hu (27), Gs (16), We (15), Cv (10)	>1200	meSaLm - SaClLm	
		5	Oa (40), Hu (35), We (10), Av (10), Cv (5)	>1200	meSaLm - SaClLm	
Ad 5	Lower W-facing slopes of Helderberg basin, some high relief. Lourens River to NW	1	Gs (39), Rock (30), Cv (25), Ms (4), Hu (2)	300-500	fiSaClLm	Various
		3	Cv (59), Gs (23), Hu (10), Sw (8)	800-1200+	meSaClLm	
		4	Cv (59), Sw (16), Kd (15), Gs (8), Hu (2)	800-1200+	coSa - meSaClLm	
		5	Oa (53), Du (30), We (15), Cv (2)	>1200	Fi/meSaClLm	
Ad6	Open, high hills in SE of Helderberg Basin	1	Gs (69), Cv (25), Ms (4), Hu (2)	300-500	fiSaClLm - SaClLm	Various
		3	Cv (57), Gs (23), Hu (8), Sw (7), Cf (5)	800-1200+	meSaClLm	
		4	Cv (55), Sw (15), Kd (14)Gs (8), Cf (5), Hu (3)	800-1200+	coSa - LmSa (meSaClLm)	
		5	Oa (56), Du (26), We (16), Cv (2)	>1200	meSaClLm	
Ba 46	Open, high E – S slopes of Ribbokkop	1	Gs (30), Ms (25), Rock (10), Hu (15), Cv (5), Cf (15)	300-600	coSaLm - SaClLm	Granite, deposits of weathering products of granite (Kuils River-Helderberg Pluton)
		3	Hu (43), Cv (32), Bv (10), Gs (5), Oa (4), Av (3), Cf (3), We (2), Ms (2)	800-1200+	meSaClLm - SaCl	
		4	Hu (20), Cv (20), Av (20), We (15), Bv (10), Lo (10), Oa (5),	600-900	meSaClLm - SaCl/SaClLm	
		5	We (38), Oa (31), Du (11), Av (10), Lo (10),	300-500, 800-1200+	me/coSaLm - SaClLm	

Land type	Relief	TMU	Soil forms (% presence)	Dominant soil depth (mm)	Dominant soil texture	Geology
Ba 47	Open, high hills of Bottelaryberg and Papegaaiberg	1	Ms (20), Hu (20), Gs (20), Cf (15), Cv (10), Oa (5), Rock (5), Bv (5),	200-400, 800-1200+, 300-600	LmcoSa - SaLm, coSaClLm - SaCl, coSaLm - SaClLm	Mainly granite, deposits of weathering products of granite (Kuils River-Helderberg Pluton; also Tygerberg formation)
		3	Hu (43), Cv (32), Gs (5), Bv (5), Oa (4), We (3), Cf (3), Av (3), Ms (2)	800-1200+	coSaClLm - SaCl	
		4	Hu (20), Cv (20), Av (20), We (15), Bv (10), Lo (10), Oa (5)	800-1200+	coSaClLm - SaCl	
		5	We (38), Oa (31), Du (11), Av (10), Lo (10)	300-500, 800-1200+	coSaLm - SaClLm/SaClLm	
Bb 33	Footslopes and valley on NE flank of Jonkershoek Mountain	3	Coarse deposits (35), Cv (30), Av (10), We (5), Lo (5), Gs (5), Kd (5), Pn (5),	800-1200+	meSaLm - SaClLm	Gritty sand, scree and alluvium covering granite (Stellenbosch Pluton)
		3(1)	Kd (45), Lo (25), Fw (10), Oa (5), Ms (5), Pn (5), coarse deposits (5)	500-1000	meSaLm	
		4	We (24), Cv (10), Av (14), Lo (8), Fw (8), Pn (8), Oa (5), Gs (5), Ms (5), Kd (8), coarse deposits (5)	300-600	fiSaClLm - SaCl	
		5	Du (51), Oa (17), We (15), Fw (10), Lo (5), Kd (2)	800-1200+	fi/mesa - SaLm	
Ca 25	Flat coastal plain below Helderberg Basin	4	Kd (55), Es (14), Ka (12), Lo (10), We (8), Du (1)	400-600	Me/coSa - LmSa	Mainly surficial cover formed *in situ* on Malmesbury rocks, some quaternary deposits and alluvium
		5	Du (50), Ka (20), We (20), Lo (10)	>1200	Mesa - SaLm	
Ca 26	Bonte River valley and foothills of Helderberg	3	Kd/Wa (30), Kd/Wa/Pn (30), Kd/Lo/Es (10), We/Gs/Cf (10), Lo/Pn (5), Pn (10), Kd (5),	300-700	coSa - SaLm	Granite, deposits of weathering products of granite (Kuils River-Helderberg Pluton), some alluvium
		4	Kd/Wa (40), Bv/Oa (20), Kd/Wa/Pn (15), Kd/Ss/Es (10), Lo/Pn (10), Kd (5)	300-600	coSa - SaLm	
		5	We (55), Du/Lo (30), Bv/Oa (15)	200-400	mesa - SaClLm	
Ca 27	Valley and low hills extending from Eerste River to foothills of Helderberg	1	Gs (20), Ms (20), Kd/Wa (20), Cv (15), Hu/Bv (10), Cv/Av/Hu (5), Es (5), Cf (5)	300-400	me/coSaLm - SaClLm	Mainly granite, deposits of weathering products of granite (Kuils River-Helderberg Pluton), some ferricrete, alluvium
		3	Kd/Wa (35), Cv/Av/Hu (10), Av (10), Gs (10), Es (5), Lo (5), Ms (5), Pn (5), Cv (5), Hu/Bv (5), Cf (5)	200-600	coSa - SaLm	
		4	Kd/Wa (30), Cv/Av/Hu (10), Av (10), Pn (10), We (10), Es (10), Lo (10), Ms (5), Cv (5)	300-600	coSa - SaLm	
		5	We (55), Du/Oa (25), Lo (10), stream beds (10)	200-400	mesa - fi/coSaLm - SaClLm	

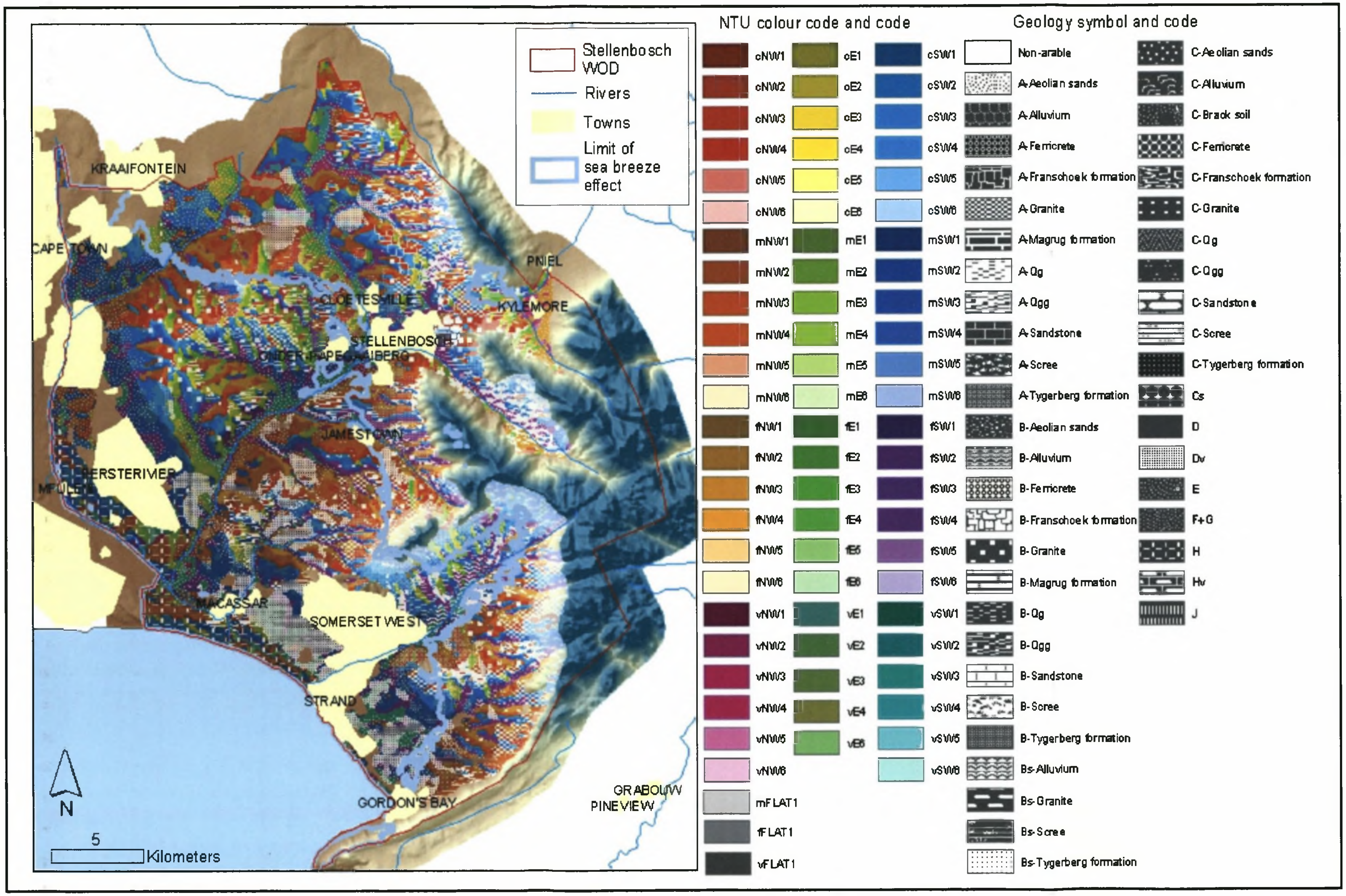
Land type	Relief	TMU	Soil forms (% presence)	Dominant soil depth (mm)	Dominant soil texture	Geology
Ca 28	Eerste River Valley, terraces and foothills of Stellenbosch Mountain	1	Gs (40), Ms/Hu (20), Hu (25), Kd/Wa (5), Cv/Hu (5), Sw (5)	250-350	me/coSa - SaLm	Granite, deposits of weathering products of granite (Kuils River-Helderberg Pluton), some quaternary deposits and alluvium
		3	Kd/Wa (45), Gs (10), Cv/Hu (10), Sw (10), Hu (5), Ms/Hu (5), Lo (5), Av (5), Pn (5)	300-450	coSa - LmSa	
		4	Kd/Wa (45), Lo (15), Av (15), Cv/Hu (10), Sw (7), Pn (5), Gs (3).	300-450	coSa - LmSa	
		4(1)	Lo (40), Kd/Wa (20), Av (20), Cv/Hu (8), We (5), Sw (4), Pn (3)	400-800	coSa - LmSa	
		5	We (40), Du/Oa (30), Lo (20), Kd/Wa (10),	300-600	Me/coSa - SaLm	
Ca 29	Uneven plain below Ribbokkop	1	Kd (30), Gs (20), Av (15), Ms (15), Es (10), Sw (5), Cv/Hu (5)	300-450	coSa - SaLm	Granite, deposits of weathering products pf granite (Kuils River-Helderberg Pluton)
		3	Kd (45), Es (15), Lo (10), Wa (10), Av (5), Sw (5), We (3), Ms (3), Gs (2), Cv/Hu (2)	300-450	coSa - SaLm	
		4	Kd (30), Wa (20), Lo (15), We (15), Es (10), Av (10)	300-450	coSa - SaLm	
		5	Du (50), Lo (25), We (25)	500-1200	LmcoSa - SaLm	
Ca 30	Lower footslopes on W flanks of Bottelary Hills in environs of Kuils River	1	Gs (73), Sw/Ss (17), Rock (6), Ms (4)	150-350	fi/coSa - SaLm	Various
		3	Ms (23), Kd (19), Wa (17), Sw/Ss (10), Gs (7), Fw/Lo (5), Fw (5), Cv (5), Hu (5), Av (3), Rock (1)	100-300	fi/mesa - SaLm	
		4	Kd (38), Wa (32), Ms (16), Fw/Lo (5), Fw (5), We (4)	700-900	coSa - LmSa	
		5	Oa (35), Du (35), We (30)	>1000	meSa - SaLm	
Ca 134	Coastal plain	4	Kd (45), Ka (20), Es (15), Wa/Kd (10), Lo (5), Ms (5),	400-800	me/coSa	Quaternary sand deposits, surficial cover formed *in situ* on Malmesbury rocks
		5	Lo/We (60), Du (20),Ka (10), Lo (10)	400-800	mesa - SaLm	
Db 50	Plain with low relief to NE of Bottelaryberg and W of Simonsberg	1	Kd (30), Sw (25), Hu (25), Ms (10), Wa (5), Ss (5)	300-450, 800-1200+	coSa - SaLm, ClLm - Cl, meSaClLm - SaCl	Various
		3	Kd (65), Ss (10), Ms (10), Sw (5), Hu (5), Wa (5)	300-450	coSa - SaLm	
		4	Kd (55), Ss (25), Sw (10), Va/Ka (5), Va (5)	300-450	coSa - SaLm	
		5	Du (30), Va/Ka (20), Va (20), Oa (20), Kd (10)	800-1200+, 350-450	fi/meSa - SaLm, ClLm - Cl	

Land type	Relief	TMU	Soil forms (% presence)	Dominant soil depth (mm)	Dominant soil texture	Geology
Db 51	Plain with low relief on W bank of Eerste River	1	Sw (40), Rock (25), Ms (15), Kd/Es (9), Gs (6), Hu/Cv (3), Cv (2)	200-600	ClLm - Cl	Granite (Kuils River-Helderberg Pluton) and rocks of Tygerberg formation
		3	Kd/Es (34), Kd/Lo (30), Sw (20), Hu/Cv (8), Gs (5), Fw (3)	300-500	me/coSa - LmSa	
		3(1)	Kd/Lo (25), Sw (20), Fw (20), Hu/Cv (16), Lt/Ct (15), Fw (4),	500-600, >1200	meSa - LmSa, ClLm - Cl	
		4	Kd/Lo (25), Kd/Es (20), Fw (20), We (15), Hu/Cv (5), Fw (5), Lt/Ct (5), Sw (5),	300-500, >1200	me/coSa - LmSa	
		5	Oa/Du (70), We (30)	800-1200+	meSa - LmSa	
Db 52	Plain with low relief to N of Bottelaryberg	1	Sw (50), Gs (40), Ss (5), Cv (5),	300-450	ClLm - Cl	Quaternary deposits and surficial cover formed *in situ* on Malmesbury rocks
		3	Sw (40), Ss (17), Gs (15), Es (13), Kd (10), Cv (5),	300-450	ClLm - Cl	
		4	Sw (35), Ss (20), Kd (20), Es (10), Wa (7), Gs (5), Cv (3)	300-450	ClLm - Cl	
		5	Oa (45), Va/Ka (20), Va (20), Du (10), Kd (5)	500-800	coSaLm - ClLm	
Fa 919	Open, high hills of Bottelaryberg and Ribbokkop	1	Gs (60), Ms (20), Rock (10), Cv (5), Hu (5)	250-350	coSaClLm	Granite (Kuils River-Helderberg Pluton), also rocks of Tygerberg formation
		3	Gs (45), Cv (15), Hu (15), Kd (10), Ms (5), Sw (5), Rock (5)	250-350	coSaClLm	
		4	Hu (25), Cv (25), Kd (15), Sw (10), Av (10), Gs (6), Oa (5), Rock (2), Ms (2)	800-1200+	coSaClLm - SaCl	
		5	Du (55), Av (15), Kd (10), Sw (10), Oa (10)	500-1200	LmcoSa - SaLm	
Fa 142	Midslopes on W flank of Hottentots Holland Mountains	3	Gs (37), Cv (30), Oa (18), Rock (6), Hu (5), Ms (4)	200-400, 400-800	me/coSa(Lm) — SaClLm	Granite (Stellenbosch Pluton) covered by gritty sand, scree
		4	Cv (40), Gs (20), Hu (20), Oa (10), Du (5), Ms (4), Rock (1)	400-800	meSaLm - SaClLm	
		5	Oa (75), Cv (10), Du (10), Hu (5)	300-500	meSaLm - SaClLm	
Fa 143	Midslopes on NW flanks of Hottentots Holland Mountains	3	Gs (35), Cv (22), Rock (15), Sw (10), Ms (10), Oa (6), Kd (2)	300-400	SaLm - SaClLm	Various
		4	Kd (49), Cv (10), Gs (6), Sw (15), Oa (5), D/Kd (15),	300-600	coSa	
		5	Du (54), Oa (26), We (20)	600-1200+	Fi/meSaLm - SaClLm	
Fa 144	Low, open hills between Eerste and Bonte Rivers	1	Gs (60), Rock (20), Ms (10), Hu (5), Cv (5),	400-500	fiSa - SaLm	Surficial cover formed *in situ* of weathering products of granite, rocks of Tygerberg formation
		3	Gs (47), Hu (15), Cv (14), Sw (10), Kd (9), Lo (5)	400-500	fiSa - SaLm	
		4	Lo (35), Kd (30), Va/Du (13), Cv (11), Sw (5), Hu (3), Gs (2)	500-1000	me/coSa	
		5	Lo (50), Va/Du (50)	500-1000, 500-900	me/coSa, meSaLm - SaClLm	

Land type	Relief	TMU	Soil forms (% presence)	Dominant soil depth (mm)	Dominant soil texture	Geology
Fa 145	Jonkershoek Valley	3	Gs (32), Oa (17), Cv (16), Ms (15), Rock (10), Sw (10),	250-350	SaLm - SaClLm	Various
		4	Kd (62), Cv (11), Sw (11), Ms (8), Gs (6), Rock (2)	300-450	coSa - SaLm	
		5	Du (52), Oa (27), We (21)	500-1200+	Me/coSaLm - SaClLm	
Fa 922	Foothills on SW flanks of Simonsberg in area of Cloetesville	1	Gs (35), Cf (30), Ms (20), Rock (15)	400-600	coSa - LmcoSa - SaClLm	Granite (Stellenbosch Pluton), rocks of Franschhoek formation
		3	Oa (25), Cv (25), Gs (20), Cf (15), Ms (5), Ss (5), Av (5)	600-1200+	coSaLm - ClLm, me/coSaClLm - SaCl	
		5	Du (80), Oa (15), Gs (5)	500-1200	LmcoSa - SaLm	
Ga 10 and Ga 16	E Cape Flats, very low relief	1	Fw (100)	>1200	Sa	Quaternary quartz sand (Springfonteyn formation)
		3	Fw (50), Lt (20), Kd (15), Lo (10), Du/Oa (5)	>1200	Sa	
		4	Kd (35), Du/Oa (32), Lt (25), Lo (8)	1000-1200	meSa	
		5	Du/Oa (65), Kd (20), Lo (10), We (5)	900-1200+	meSa	
Ha 7	Coastal dunes and marshes	1	Fw (94), Ms (6),	>1200	fi/coSa	Quaternary calcareous dune sand (Witzand formation)
		3	Fw (97), Lo (3)	>1200	fi/coSa	
		4	Fw (72), Lo (20),Ms (8),	>1200	Sa	
		5	Ms (40), Fw (35), Lo (25)	100-400, >1200	meSa - SaLm	
Hb 13	Cape Flats and sand dunes	1	Fw (95), Ms (5)	>1200	fi/coSa	Calcareous sand (Witzand formation) covering quartz sand (Springfonteyn formation)
		3	Fw (91), Ms (5), Lo (4)	>1200	fi/coSa	
		4	Fw (73), Kd (17), Lo (10)	>1200	fi/coSa	
		5	Lo (40), Lt/Du (20), Kd (15), Es (15), Fw (10)	>600	fi/meSa - SaLm	
Hb 15	Plain with low relief to NW of Bottelaryberg	1	Rock (45), Ms (25), Fw (15), Es (15)	100-400	meSa	Mainly quaternary quartz sand (Springfonteyn formation)
		3	Cv (25), Lt (20), Kd (15), Fw (15), Es (15), Ct (10)	800-1200	mesa	
		4	Ct (35), Kd (30), Fw (20), Lt (5), Cv (5), Lo (5)	800-1000	me/coSa	
		4(1)	Kd (40), Fw (35), Ct (10), Lt (5), We (5), Es (5)	800-1200	me/coSa	
		5	We (35), Fw (35), Kd (20), Lo (10)	200-600, 800-1200	meSa	
Ia 21	Stellenbosch valley and urban development	3	Sw (45), Ss (20), Av (15), Gs (10), We (10),	300-450	ClLm - Cl	Alluvium and terrace gravel
		4	Sw (50), Ss (30), Oa (10), Gs (5), We (3), Av (2)	300-450	ClLm - Cl	
		5	Coarse deposits: Du (58), Oa (35), Av (5), We (2)	500-1200+	me/coSa - SaLm	
		5(1)	Du (40), Oa (30), Ka (13), We (7), Av (5), stream (5)	500-1200+	me/coSa - SaLm	

Land type	Relief	TMU	Soil forms (% presence)	Dominant soil depth (mm)	Dominant soil texture	Geology
Ib 92	W slopes of Groot Drakenstein Mountains	3	Rock (73), Ms (20), Fw (7)	150-300	me/coSa - SaLm	Gritty sand, scree, terrace gravel
		4	Rock (45), Fw (22), Lo (10), Ct (9), Lt (9), Ms (5),	600-1200	me/coSa	
Ic 84	Crest and upper slopes of Simonsberg	1	Rock (90), Ms (10)			
		2	Rock (100)			
		3	Rock (80), Vf/Du (5), Ms (5), Cf (5), Gs (5)			
		5	Vf/Du (50), Cf (24), Ms (10), Gs (10), Rock (6)	200-600	me/coSaLm	
Ic 87	Ridge of Hottentots Holland Mountains near Sir Lowry's Pass	1	Rock (95), Ms (3), Cf (2)			Sandstone (Peninsula formation)
		2	Rick (100)			
		3	Rock (82), Du/Oa/Vf (8), Ms (5), Cf (5)			
		5	Du/Oa/Vf (70), Rock (10), Ms (10), Cf (10)	400-800	me/coSa - SaLm	
Ic 90	Crest and upper slopes of Klapmutskop	1	Rock (85), Ms/Gs (5), Cf (10)			Rocks of the Magrug formation
		2	Rock (100)			
		3	Rock (85), Ms/Gs (5), Cf (5), Du/Oa (5)			
		4	Du/Oa (40), Vf (20), Ms/Gs (15), Cf (15), Rock (10)	300-500	me/coSaLm	
Ic 91	Crest and upper slopes of Stellenbosch Mountain	1	Rock (88), Ms (5), Cf (5), Gs (2)			Rocks of the Peninsula formation
		2	Rock (100)			
		3	Rock (79), Ms (8), Cf (5), Oa (5), Gs (3)			
		5	Du (50), Oa (20), Gs (15), Ms (10), Rock (5)	300-500	LmcoSa - SaLm	
Ic 97	Upper slopes of Hottentots Holland Mountains	1	Rock (90), Ms (10)			Rocks of the Peninsula formation
		2	Rock (100)			
		3	Rock (75), Ms (10), Cf (15)			
		5	Rock (10), Ms (10), Du/Oa (80)	300-600	mesa - SaLm	
Ic 118	Crest and upper slopes of Jonkershoek Mountain and Groot Drakenstein Mountain	1	Rock (90), Ms (5), Cf (5)			Mainly rocks of the Peninsula formation
		2	Rock (100)			
		3	Rock (85), Ms (5), Cf (5), Oa (5)			
		4	Oa (25), Rock (20), Gs (20), Ms (15), Cf (10), Du (10)	50-300	meSa - SaLm	
		5	Rock (65), Ms (15), Cf (10), Du/Fw (10)			
Ic 126	Crests and upper slopes of Hottentots Holland Mountains	1	Rock (90), Ms (5), Cf (5)			Mainly rocks of the Peninsula formation
		2	Rock (100)			
		3	Rock (87), Ms (9), Cf (4)			
		4	Rock (40), Ms (15), Cf (10), Oa (10), Gs (10), Du (10)			
		5	Rock (50), Du (30), Oa/On/Fw/Lt/Hh/Kd (15), Ms (5)	100-200	me/coSa	

ADDENDUM 4.1 Map of natural terroir units in the Stellenbosch Wine of Origin District. Terrain morphological units are represented by c (crest), m (midslope), f (footslope), v (valley bottom). Aspect is represented by FLAT, NW (0°-45°, 270°-360°), E (45°-135°), SW (135°-270°). Altitude is represented by 1 (0-100 m), 2 (101-200 m), 3 (201-300 m), 4 (301-400 m), 5 (401-500 m), 6 (>500 m). Soil descriptions are provided in Table 4.1.2.



ADDENDUM 4.2 An explanation of the codes for environment and management related variables used in data analysis

Management		Terrain		Climate		Soil	
Irrigate	Dryland or irrigated	Aspect	Compass directions in degrees	Flo_maxT	Mean maximum temperature for October and November (°C)	Soil pH	Depth weighted mean of the subsoil I pH (0.3 m-1.0 m)
Rootstock		Slope	Slope inclination in %	Flo_minT	Mean minimum temperature for October and November (°C)	Stone	Depth weighted mean of the % stones in the profile (0 m-1.0 m)
Clone	Scion clone	Altitude	Height above sea level (m)	Flo_meanT	Mean temperature for October and November (°C)	Plow	Depth weighted mean of the subsoil phosphorous (mg/kg) (0.3 m-1.0 m)
Vine density	Number of vines per hectare	Dist_sea	Minimum distance from the coast (km)	Flo_rain	Rainfall for October and November (mm)	Klow	Depth weighted mean of the subsoil potassium (mg/kg) (0.3 m-1.0 m)
Canopy height	Height between cordon wire and top wire			Flo_WSgr4	Number of hours with wind speed greater than 4 $m.s^{-1}$ for October and November (hrs)	s-value	Depth weighted mean of the S-Value (exchangeable cations) (cmol/kg) (0 m-1.0 m)
Trellis system	Type of trellis system			MaxT	Mean maximum temperature during the 31 days prior to harvest (°C)	Clay_low	Depth weighted mean of the subsoil clay content (%) (0.35 m-0.7 m) (Tesic, 2003)
Plant year	Year in which planted			MinT	Mean minimum temperature during the 31 days prior to harvest (°C)	Clay	Depth weighted mean of the clay content (%) (0 m-1.0 m)
				MeanT	Mean temperature during the 31 days prior to harvest (°C)	Silt	Depth weighted mean of the silt content (%) (0 m-1.0 m)
				GDD	Total growing degree-days during the 31 days prior to harvest	FiS	Depth weighted mean of the fine sand content (%) (0 m-1.0 m)

Management	Terrain	Climate		Soil	
		T2025	Number of hours with a temperature between 20°C and 25°C during the 31 days prior to harvest	MeS	Depth weighted mean of the medium sand content (%) (0 m-1.0 m)
		Tgr30	Number of hours with a temperature higher than 30°C during the 31 days prior to harvest	CoS	Depth weighted mean of the coarse sand content (%) (0 m-1.0 m)
		Rad	Total radiation during the 31 days prior to harvest	Soilprep	Observed depth of soil preparation
		Sun	Total sunshine hours during the 31 days prior to harvest	SI	Site index (Tesic, 2003)
		WS	Mean wind speed during the 31 days prior to harvest (m/s)		
		WSgr4	Number of hours with a wind speed greater than 4 m/s during the 31 days prior to harvest		
		Evap	Evaporation during the 31 days prior to harvest (mm)		
		Rain	Rainfall during the 31 days prior to harvest (mm)		
		MinRH	Minimum relative humidity during the 31 days prior to harvest (%)		
		MeanRH	Mean relative humidity 31 days prior to harvest (5)		
		TVI	Thermal variability index (Gladstones, 1992)		
		HI	Huglin Index (Huglin, 1986)		
		Winkler	Winkler Index (Le Roux, 1974)		

Management	Terrain	Climate		Soil
		DI	Dryness Index (Tonietto & Carbonneau, 2004)	

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Gladstones J, 1992. Viticulture and Environment. Winetitles, Adelaide.

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Tesic D, Woolley DJ, Hewett EW & Martin DJ, 2002. Environmental effects on cv. Cabernet Sauvignon (*Vitis vinifera* L.) grown in Hawke's Bay, New Zealand. 1. Phenology and characterisation of viticultural environments. *Austr. J Grape Wine Res.* 8 (1), 15-26.

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ADDENDUM 4.3 Dependent variables used in data analysis

Viticultural performance		Oenological characteristics	
Budburst	Date of 50% budburst	Specific gravity	Wine specific gravity
Flowering	Date of 50% flowering	Alcohol	Alcohol (vol%)
Harvest	Date of harvest at full ripeness	Extract	Wine extract (g/L)
Pruning mass	Pruning mass per meter cordon (kg)	RS	Reducing sugars in wine (g/L)
Canopy index	1- [(score derived from a score card of canopy characteristics)/70]	Wine TTA	Total titratable acidity of wine (g/L)
Capacity	Total dry matter production (0.5xpruning mass + 0.2xyield) (Deloire *et al.*, 2002)	VA	Volatile acidity (g/L)
Bunch mass	Mean bunch mass (g)	Wine pH	pH of wine
No. berries	Mean number of berries per bunch	Fresh vegetative	Mean sensorial score[1] for green pepper, grassy aroma characteristics
Berry mass	Mass of 100 berries (g)	Cook vegetative	Mean sensorial score[1] for asparagus aroma characteristics
Yield	Yield per meter cordon (kg)	Dried vegetative	Mean sensorial score[1] for hay, straw, tea aroma characteristics
Ravaz	Ratio of yield to pruning mass	Spicy	Mean sensorial score[1] for black pepper, etc. aroma characteristics
MustTSS	Total soluble solids of must (°Balling)	Caramel	Mean sensorial score[1] for caramel aroma characteristics
MustTTA	Total titratable acidity at harvest (g/L tartaric acid)	Tropical fruit	Mean sensorial score[1] for guava, pineapple, granadilla aroma characteristics
MustpH	Must pH	Citrus	Mean sensorial score[1] for lemon, grapefruit aroma characteristics
Maturity index	(MustTSSx10)/MustTTA	Tree fruit	Mean sensorial score[1] for apple, peach, apricot aroma characteristics
		Floral	Mean sensorial score[1] for rose, violet aroma characteristics
		Colour	Mean sensorial score[1] for colour
		Vegetative	Mean sensorial score[1] for green pepper, tea, straw aroma characteristics
		Berry	Mean sensorial score[1] for strawberry, raspberry, blackberry, blackcurrant aroma characteristics
		Woody	Mean sensorial score[1] for coffee and medicinal aroma characteristics
		Dried fruit	Mean sensorial score[1] for berry jam and conserved fruit aroma characteristics
		Astringency	Mean sensorial score[1] for astringency

Viticultural performance	Oenological characteristics	
	Acid	Mean sensorial score[1] for acid balance
	Fullness	Mean sensorial score[1] for fullness on mouth feel

[1]Scored on a 10-point unstructured line scale

ADDENDUM 4.4 Classification and regression tree methodology (CART)

4.4.1 An overview of classification and regression tree (CART) methodology

Classification trees refer to the building of trees for categorical dependent (response) variables while regression trees are constructed for continuous dependent variables. CART is non-parametric and non-linear and can, therefore, accommodate both continuous and categorical predictor variables (Breiman *et al.*, 1984). This method is particularly well-suited to data-mining tasks and simple relationships between just a few variables can be discovered that could have gone unnoticed using other analytical techniques. (Breiman *et al.*, 1984). The classification or regression tree is also known as a decision tree (Skidmore, 2002).

Binary tree structured classifiers are constructed by repeated splits of subsets of a variable into two descendant subsets (Breiman *et al.*, 1984). Each ramification is defined by a decision rule (Schwarz, 1997). This process continues until the smallest possible subsets or nodes are obtained. The tree is then pruned back to until one is obtained with the lowest possible estimated mis-classification rate (Breiman *et al.*, 1984).

The simple structure of the final tree can, however, be deceptive as even if a variable is never represented, its effect may have been masked by other variables (Breiman *et al.*, 1984). One way of overcoming this is through the ranking of variables in terms of the potential effect or relative importance. Even though a variable may not occur in a final tree, its ranking may be high, indicating a masking effect (Breiman *et al.*, 1984).

4.4.2. Summary of regression tree methodology*

*Provided by Dr Martin Kidd, Centre for statistical consultation, Stellenbosch University, Private Bag X1, 7602 Matieland (Stellenbosch), South Africa

Case 1: One continuous independent variable(*x*)

The method selects a point x_s between the minimum and maximum of x that splits the data into two sets (or nodes in a tree). All the cases for which $x \leq x_p$ goes to the left node and all the cases where $x > x_p$ goes to the right node.

The point where the split is made is the point that most successfully separates the high response values from the low ones. This is done by minimising the variance of the response variable in each of the two sets.

The procedure above is then repeated for each of the two nodes. Thus a binary split is made on each node using the criteria mentioned above.

Stopping rules are used to decide when the splitting process should stop. For example a minimum number of cases per node can be specified, and if that minimum number is reached, the node will split no further. Also, if the reduction in variance of

y from a parent node to the child nodes is not "significant", it will stop splitting. Usually, stopping rules will be slack, so as to build a large tree. A process of pruning will then combine nodes and reduce the size of the tree to an "optimal" size.

Case 2: One categorical independent variable

In the case of a categorical independent variable, all combinations of binary splits of the levels of the variable are considered and the combination that most successfully separates the high response values from the low ones are used as splitting criteria. For example if a variable has three levels namely *a*,*b* and *c* then the following combinations of splits will be considered:

Left node	Right node
a	*b*,*c*
a,*b*	*c*
a,*c*	*b*

Case 3: More than one independent variable

The procedure described above is applied to each variable independently. Then the variables are compared with one another and the one that provides the best split over all the variables is used as the splitting variable.

Variable importance

A variable importance factor in terms of its effect on the response variable can be derived once the tree has been built. This variable importance is calculated based on the number of times the variable was used as splitting variable and how well it separated the low values from the high values.

4.4.3 Literature cited

Breiman L, Friedman JH, Olshen RA & Stone CJ, 1984. Classification and regression trees. Chapman & Hall, New York.

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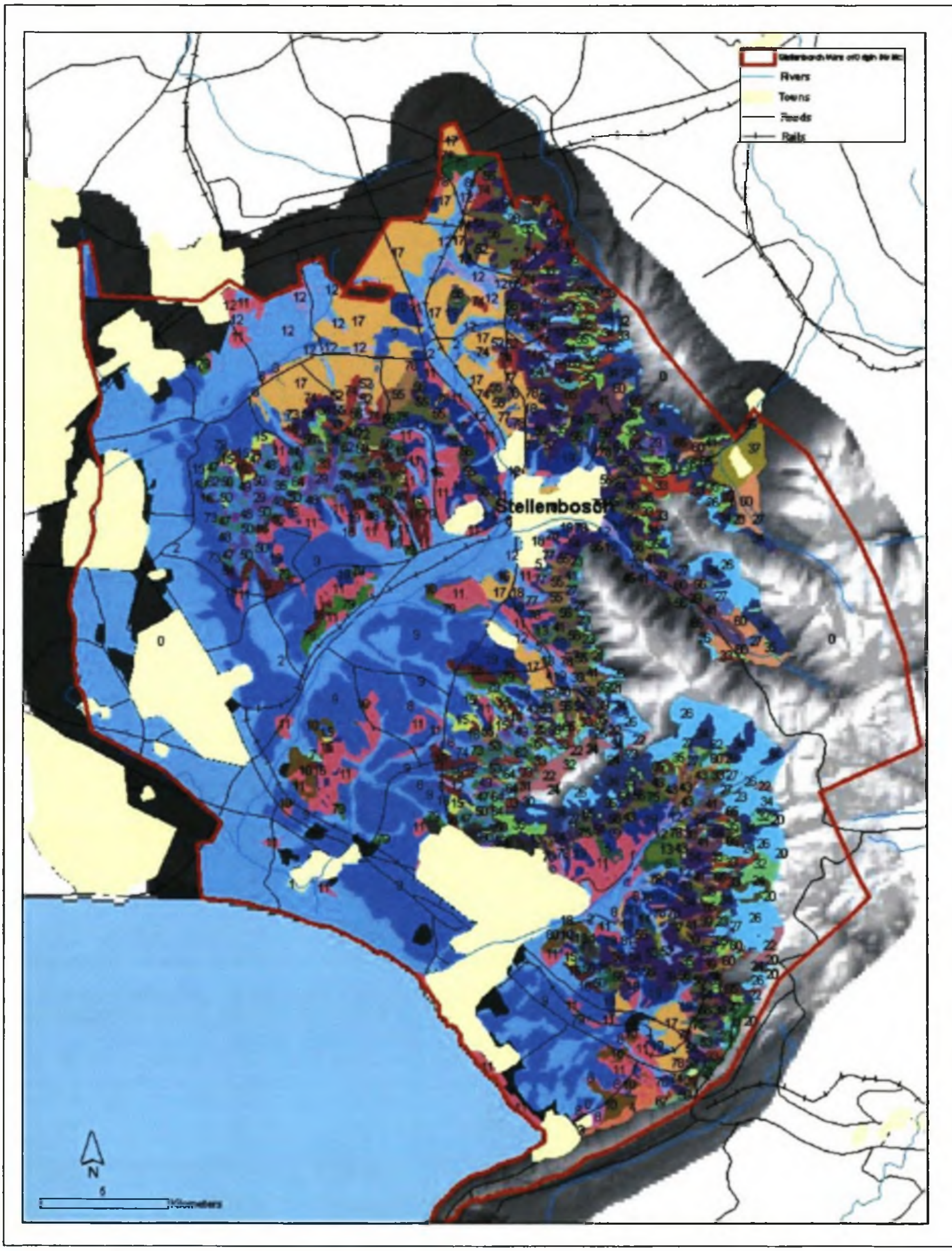
ADDENDUM 4.5 Map of terroirs identified for Cabernet Sauvignon in the Stellenbosch Wine of Origin District. Descriptions of associated viticultural and oenological performance are provided in Addendum 4.6.



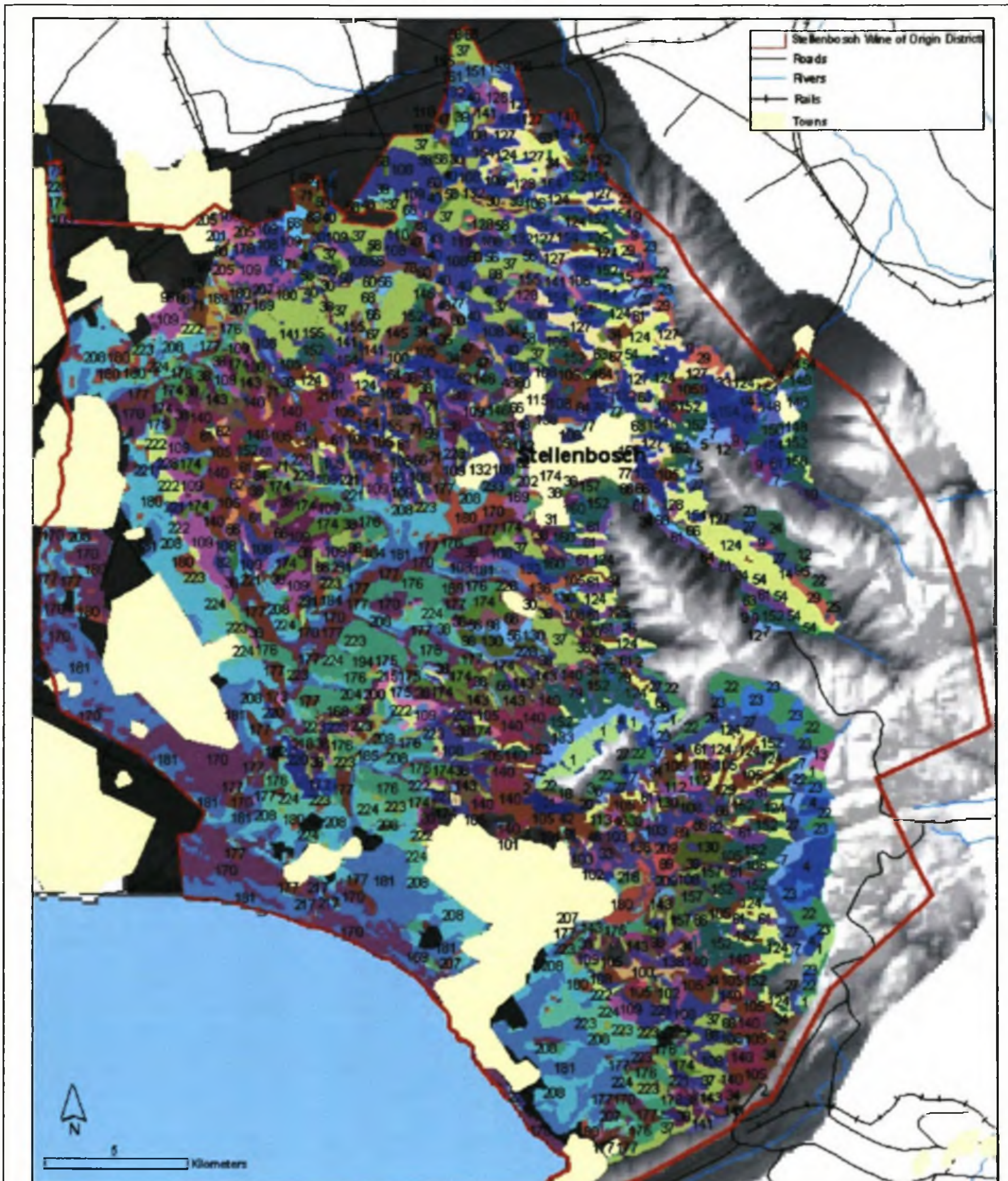
ADDENDUM 4.6 Properties of terroirs identified for Cabernet Sauvignon in the Stellenbosch Wine of Origin District. (Classes for the viticultural and oenological variables must be interpreted together with Table 4.3.3)

Terroir Unit	Berry aroma	Wine Extract	Floral aroma	Fullness	Must composition	Spicy aroma	Wine pH	Wine SG	Wine TTA	Yield
0	0	0	0	0	0	0	0	0	0	0
1	2	1	2	2	3	3	1	1	2	1
2	2	1	4	2	3	3	1	1	2	1
3	2	1	2	2	3	2	1	2	2	1
4	2	1	2	2	3	3	1	2	2	1
5	2	1	4	2	3	3	1	2	2	1
6	2	2	4	4	3	3	1	2	2	1
7	2	2	2	2	3	3	2	2	2	1
8	2	2	2	3	3	3	2	2	2	1
9	2	2	4	3	3	3	2	2	2	1
10	2	2	2	4	3	3	2	2	2	1
11	2	2	4	4	3	3	2	2	2	1
12	2	1	4	2	3	3	1	1	2	2
13	2	1	4	2	3	3	1	2	2	2
14	2	2	4	4	3	3	1	2	2	2
15	2	2	2	2	3	3	2	2	2	2
16	2	2	4	2	3	3	2	2	2	2
17	2	2	4	3	3	3	2	2	2	2
18	2	2	2	4	3	3	2	2	2	2
19	2	2	4	4	3	3	2	2	2	2
20	1	1	1	1	1	1	3	3	1	3
21	1	1	2	1	1	1	3	3	1	3
22	1	1	1	1	1	2	3	3	1	3
23	1	1	2	1	1	2	3	3	1	3
24	1	1	1	1	1	3	3	3	1	3
25	1	1	2	1	1	3	3	3	1	3
26	1	1	3	1	1	3	3	3	1	3

Terroir Unit	Berry aroma	Wine Extract	Floral aroma	Fullness	Must composition	Spicy aroma	Wine pH	Wine SG	Wine TTA	Yield
27	1	1	4	1	1	3	3	3	1	3
28	1	2	3	1	1	3	3	3	1	3
29	1	2	4	1	1	3	3	3	1	3
30	1	2	1	4	1	2	3	3	1	3
31	1	2	2	4	1	2	3	3	1	3
32	1	2	1	4	1	3	3	3	1	3
33	1	2	2	4	1	3	3	3	1	3
34	1	2	3	4	1	3	3	3	1	3
35	1	2	4	4	1	3	3	3	1	3
36	1	1	2	1	2	3	1	1	1	3
37	1	1	4	1	2	3	1	1	1	3
38	2	1	2	1	2	3	1	1	1	3
39	2	1	4	1	2	3	1	1	1	3
40	1	1	2	1	2	3	1	2	1	3
41	1	1	4	1	2	3	1	2	1	3
42	2	1	2	1	2	3	1	2	1	3
43	2	1	4	1	2	3	1	2	1	3
44	2	1	4	2	2	3	1	2	1	3
45	1	1	4	1	2	3	3	2	1	3
46	1	2	4	4	2	3	1	2	1	3
47	1	2	2	1	2	3	2	2	1	3
48	1	2	4	1	2	3	2	2	1	3
49	2	2	2	1	2	3	2	2	1	3
50	2	2	4	1	2	3	2	2	1	3
51	2	2	4	2	2	3	2	2	1	3
52	2	2	4	3	2	3	2	2	1	3
53	1	2	2	4	2	3	2	2	1	3
54	1	2	4	4	2	3	2	2	1	3
55	2	2	2	4	2	3	2	2	1	3
56	2	2	4	4	2	3	2	2	1	3
57	1	2	4	4	2	3	3	2	1	3
58	1	1	2	1	2	2	3	3	1	3

Terroir Unit	Berry aroma	Wine Extract	Floral aroma	Fullness	Must composition	Spicy aroma	Wine pH	Wine SG	Wine TTA	Yield
59	1	1	2	1	2	3	3	3	1	3
60	1	1	4	1	2	3	3	3	1	3
61	1	2	2	1	2	3	3	3	1	3
62	1	2	4	1	2	3	3	3	1	3
63	1	2	2	4	2	2	3	3	1	3
64	1	2	2	4	2	3	3	3	1	3
65	1	2	4	4	2	3	3	3	1	3
66	2	1	4	2	3	3	1	1	1	3
67	2	1	2	2	3	3	1	2	1	3
68	2	1	4	2	3	3	1	2	1	3
69	2	1	2	2	3	3	1	2	2	3
70	2	1	4	2	3	3	1	2	2	3
71	2	2	2	4	3	3	2	2	1	3
72	2	2	4	2	3	3	2	2	1	3
73	2	2	2	3	3	3	2	2	1	3
74	2	2	4	3	3	3	2	2	1	3
75	2	2	4	4	3	3	2	2	1	3
76	2	2	4	2	3	3	2	2	2	3
77	2	2	2	4	3	3	2	2	2	3
78	2	2	4	4	3	3	2	2	2	3
79	2	2	4	2	3	3	2	2	2	1
80	2	2	2	4	3	2	2	2	2	1
81	2	1	4	2	2	3	1	1	1	3
82	1	2	2	4	2	2	2	2	1	3

ADDENDUM 4.7 Map of terroirs identified for Sauvignon blanc in the Stellenbosch Wine of Origin District. Descriptions of associated viticultural and oenological performance are provided in Addendum 4.8.



ADDENDUM 4.8 Properties of terroirs identified for Sauvignon blanc in the Stellenbosch Wine of Origin District. (Classes for the viticultural and oenological variables must be interpreted together with Table 4.3.7)

Terroir unit	Flowering	Harvest	Yield	Yield: pruning mass ratio	Capacity	Wine specific gravity	Wine pH	Fullness	Fresh vegetative aroma	Dried vegetative aroma	Tropical fruit aroma	Spicy aroma
1	1	1	1	1	1	3	1	1	1	1	1	2
2	1	1	1	1	1	3	1	2	1	1	1	2
3	1	1	1	3	1	3	1	1	1	1	1	1
4	1	1	1	3	1	3	1	1	1	1	1	2
5	1	1	1	3	1	3	1	1	1	1	2	2
6	1	1	1	3	1	3	1	2	1	1	1	1
7	1	1	1	3	1	3	1	2	1	1	1	2
8	1	1	1	3	1	3	1	2	1	1	2	1
9	1	1	1	3	1	3	1	2	1	1	2	2
10	1	1	1	3	1	3	1	2	2	1	2	2
11	1	1	1	3	2	1	1	2	1	1	2	2
12	1	1	1	3	2	3	1	1	1	1	2	2
13	1	1	1	3	2	3	1	1	1	1	1	1
14	1	1	1	3	2	3	1	2	1	1	2	2
15	1	1	1	3	2	3	1	2	1	1	1	2
16	1	1	2	3	3	3	1	2	1	1	2	2
17	1	1	2	3	3	3	1	2	1	1	1	2
18	1	1	3	1	3	3	1	1	1	1	1	1
19	1	1	3	1	3	3	1	1	1	1	1	2

Terroir unit	Flowering	Harvest	Yield	Yield: pruning mass ratio	Capacity	Wine specific gravity	Wine pH	Fullness	Fresh vegetative aroma	Dried vegetative aroma	Tropical fruit aroma	Spicy aroma
20	1	1	3	1	3	3	1	2	1	1	1	1
21	1	1	3	1	3	3	1	2	1	1	1	2
22	1	1	3	3	3	3	1	1	1	1	1	1
23	1	1	3	3	3	3	1	1	1	1	1	2
24	1	1	3	3	3	3	1	1	1	1	2	1
25	1	1	3	3	3	3	1	1	1	1	2	2
26	1	1	3	3	3	3	1	2	1	1	1	1
27	1	1	3	3	3	3	1	2	1	1	1	2
28	1	1	3	3	3	3	1	2	1	1	2	1
29	1	1	3	3	3	3	1	2	1	1	2	2
30	2	2	1	1	1	1	1	2	1	2	3	3
31	2	2	1	1	1	1	1	2	3	2	3	3
32	2	2	1	1	1	2	1	2	1	1	1	3
33	2	2	1	1	1	2	1	2	1	2	3	3
34	2	2	1	1	1	3	1	2	1	1	1	2
35	2	2	1	1	1	3	1	2	1	1	1	3
36	2	2	1	1	1	3	1	2	1	2	1	3
37	2	2	1	1	1	3	1	2	1	2	3	3
38	2	2	1	1	1	3	1	2	3	2	3	3
39	2	2	1	1	2	1	1	2	1	2	3	3
40	2	2	1	1	2	1	1	2	3	2	3	3
41	2	2	1	1	2	3	1	2	1	2	3	3
42	2	2	1	1	2	3	1	2	1	1	1	2

Terroir unit	Flowering	Harvest	Yield	Yield: pruning mass ratio	Capacity	Wine specific gravity	Wine pH	Fullness	Fresh vegetative aroma	Dried vegetative aroma	Tropical fruit aroma	Spicy aroma
43	2	2	1	2	1	1	1	2	3	3	3	3
44	2	2	1	2	1	1	1	2	1	3	3	3
45	2	2	1	2	1	1	1	2	1	1	1	3
46	2	2	1	2	1	2	1	2	1	1	1	2
47	2	2	1	2	1	2	1	2	1	3	3	3
48	2	2	1	2	1	2	1	2	3	3	3	3
49	2	2	1	2	2	1	1	2	3	2	3	3
50	2	2	1	2	2	2	1	2	1	1	1	2
51	2	2	1	2	2	2	1	2	1	1	1	3
52	2	2	1	3	1	1	1	2	1	1	1	2
53	2	2	1	3	1	1	1	2	1	1	1	3
54	2	2	1	3	1	1	1	2	1	1	2	2
55	2	2	1	3	1	1	1	2	1	2	1	3
56	2	2	1	3	1	1	1	2	1	2	3	3
57	2	2	1	3	1	1	1	2	1	3	2	3
58	2	2	1	3	1	1	1	2	1	3	3	3
59	2	2	1	3	1	1	1	2	3	2	3	3
60	2	2	1	3	1	1	1	2	3	3	3	3
61	2	2	1	3	1	3	1	2	1	1	1	2
62	2	2	1	3	1	3	1	2	1	1	1	3
63	2	2	1	3	1	3	1	2	1	1	2	2
64	2	2	1	3	1	3	1	2	1	1	2	3
65	2	2	1	3	1	3	1	2	1	2	1	3

Terroir unit	Flowering	Harvest	Yield	Yield: pruning mass ratio	Capacity	Wine specific gravity	Wine pH	Fullness	Fresh vegetative aroma	Dried vegetative aroma	Tropical fruit aroma	Spicy aroma
66	2	2	1	3	1	3	1	2	1	2	3	3
67	2	2	1	3	1	3	1	2	1	3	2	3
68	2	2	1	3	1	3	1	2	1	3	3	3
69	2	2	1	3	1	3	1	2	2	3	3	3
70	2	2	1	3	1	3	1	2	3	2	3	3
71	2	2	1	3	1	3	1	2	3	3	3	3
72	2	2	1	3	2	1	1	2	1	1	1	2
73	2	2	1	3	2	1	1	2	1	1	1	3
74	2	2	1	3	2	1	1	2	1	2	3	3
75	2	2	1	3	2	1	1	2	1	3	2	3
76	2	2	1	3	2	1	1	2	1	3	3	3
77	2	2	1	3	2	1	1	2	3	2	3	3
78	2	2	1	3	2	1	1	2	3	3	3	3
79	2	2	1	3	2	3	1	2	1	1	1	2
80	2	2	1	3	2	3	1	2	1	1	2	2
81	2	2	1	3	2	3	1	2	1	2	1	3
82	2	2	1	3	2	3	1	2	1	2	3	3
83	2	2	1	3	2	3	1	2	1	3	2	3
84	2	2	1	3	2	3	1	2	1	3	3	3
85	2	2	1	3	2	3	1	2	2	3	3	3
86	2	2	1	3	2	3	1	2	3	2	3	3
87	2	2	1	3	2	3	1	2	3	3	3	3
88	2	2	2	1	3	1	1	2	1	2	3	3

Terroir unit	Flowering	Harvest	Yield	Yield: pruning mass ratio	Capacity	Wine specific gravity	Wine pH	Fullness	Fresh vegetative aroma	Dried vegetative aroma	Tropical fruit aroma	Spicy aroma
89	2	2	2	1	3	1	1	2	3	2	3	3
90	2	2	2	1	3	2	1	2	1	2	3	3
91	2	2	2	1	3	3	1	2	1	1	1	2
92	2	2	2	2	3	1	1	2	1	3	3	3
93	2	2	2	2	3	2	1	2	1	2	3	3
94	2	2	2	3	3	1	1	2	1	2	1	3
95	2	2	2	3	3	1	1	2	3	3	3	3
96	2	2	2	3	3	3	1	2	1	1	1	2
97	2	2	2	3	3	3	1	2	1	2	1	3
98	2	2	2	3	3	3	1	2	1	2	3	3
99	2	2	2	3	3	3	1	2	1	3	3	3
100	2	2	3	1	3	2	1	2	1	1	1	2
101	2	2	3	1	3	2	1	2	1	1	1	3
102	2	2	3	1	3	2	1	2	1	2	3	3
103	2	2	3	1	3	2	1	2	3	2	3	3
104	2	2	3	1	3	3	1	2	1	1	1	1
105	2	2	3	1	3	3	1	2	1	1	1	2
106	2	2	3	1	3	3	1	2	1	1	1	3
107	2	2	3	1	3	3	1	2	1	2	1	3
108	2	2	3	1	3	3	1	2	1	2	3	3
109	2	2	3	1	3	3	1	2	3	2	3	3
110	2	2	3	2	3	1	1	2	1	3	3	3
111	2	2	3	2	3	1	1	2	1	1	1	3

Terroir unit	Flowering	Harvest	Yield	Yield: pruning mass ratio	Capacity	Wine specific gravity	Wine pH	Fullness	Fresh vegetative aroma	Dried vegetative aroma	Tropical fruit aroma	Spicy aroma
112	2	2	3	2	3	2	1	2	1	1	1	2
113	2	2	3	2	3	2	1	2	1	1	1	3
114	2	2	3	2	3	2	1	2	1	1	2	3
115	2	2	3	2	3	2	1	2	1	3	3	3
116	2	2	3	2	3	2	1	2	3	3	3	3
117	2	2	3	3	3	1	1	2	1	1	1	2
118	2	2	3	3	3	1	1	2	1	1	1	3
119	2	2	3	3	3	1	1	2	1	1	2	2
120	2	2	3	3	3	1	1	2	1	2	1	3
121	2	2	3	3	3	1	1	2	1	3	2	3
122	2	2	3	3	3	1	1	2	3	2	3	3
123	2	2	3	3	3	3	1	2	1	1	1	1
124	2	2	3	3	3	3	1	2	1	1	1	2
125	2	2	3	3	3	3	1	2	1	1	1	3
126	2	2	3	3	3	3	1	2	1	1	2	1
127	2	2	3	3	3	3	1	2	1	1	2	2
128	2	2	3	3	3	3	1	2	1	1	2	3
129	2	2	3	3	3	3	1	2	1	2	1	3
130	2	2	3	3	3	3	1	2	1	2	3	3
131	2	2	3	3	3	3	1	2	1	3	2	3
132	2	2	3	3	3	3	1	2	1	3	3	3
133	2	2	3	3	3	3	1	2	1	1	1	2
134	2	2	3	3	3	3	1	2	2	2	3	3

Terroir unit	Flowering	Harvest	Yield	Yield: pruning mass ratio	Capacity	Wine specific gravity	Wine pH	Fullness	Fresh vegetative aroma	Dried vegetative aroma	Tropical fruit aroma	Spicy aroma
135	2	2	3	3	3	3	1	2	2	3	3	3
136	2	2	3	3	3	3	1	2	3	2	3	3
137	2	3	1	1	1	1	1	2	1	2	1	3
138	2	3	1	1	1	2	1	2	1	1	1	2
139	2	3	1	1	1	2	1	2	1	1	1	3
140	2	3	1	1	1	3	1	2	1	1	1	2
141	2	3	1	1	1	3	1	2	1	1	1	3
142	2	3	1	1	1	3	1	2	1	2	1	3
143	2	3	1	1	1	3	1	2	1	2	3	3
144	2	3	1	2	1	1	1	2	1	3	3	3
145	2	3	1	2	1	2	1	2	1	1	2	3
146	2	3	1	2	1	2	1	2	1	3	3	3
147	2	3	1	2	1	2	1	2	3	3	3	3
148	2	3	1	3	1	1	1	2	1	1	1	2
149	2	3	1	3	1	1	1	2	1	1	1	3
150	2	3	1	3	1	1	1	2	1	1	2	2
151	2	3	1	3	1	1	1	2	1	3	2	3
152	2	3	1	3	1	3	1	2	1	1	1	2
153	2	3	1	3	1	3	1	2	1	1	1	3
154	2	3	1	3	1	3	1	2	1	1	2	2
155	2	3	1	3	1	3	1	2	1	1	2	3
156	2	3	1	3	1	3	1	2	1	2	1	3
157	2	3	1	3	1	3	1	2	1	2	3	3

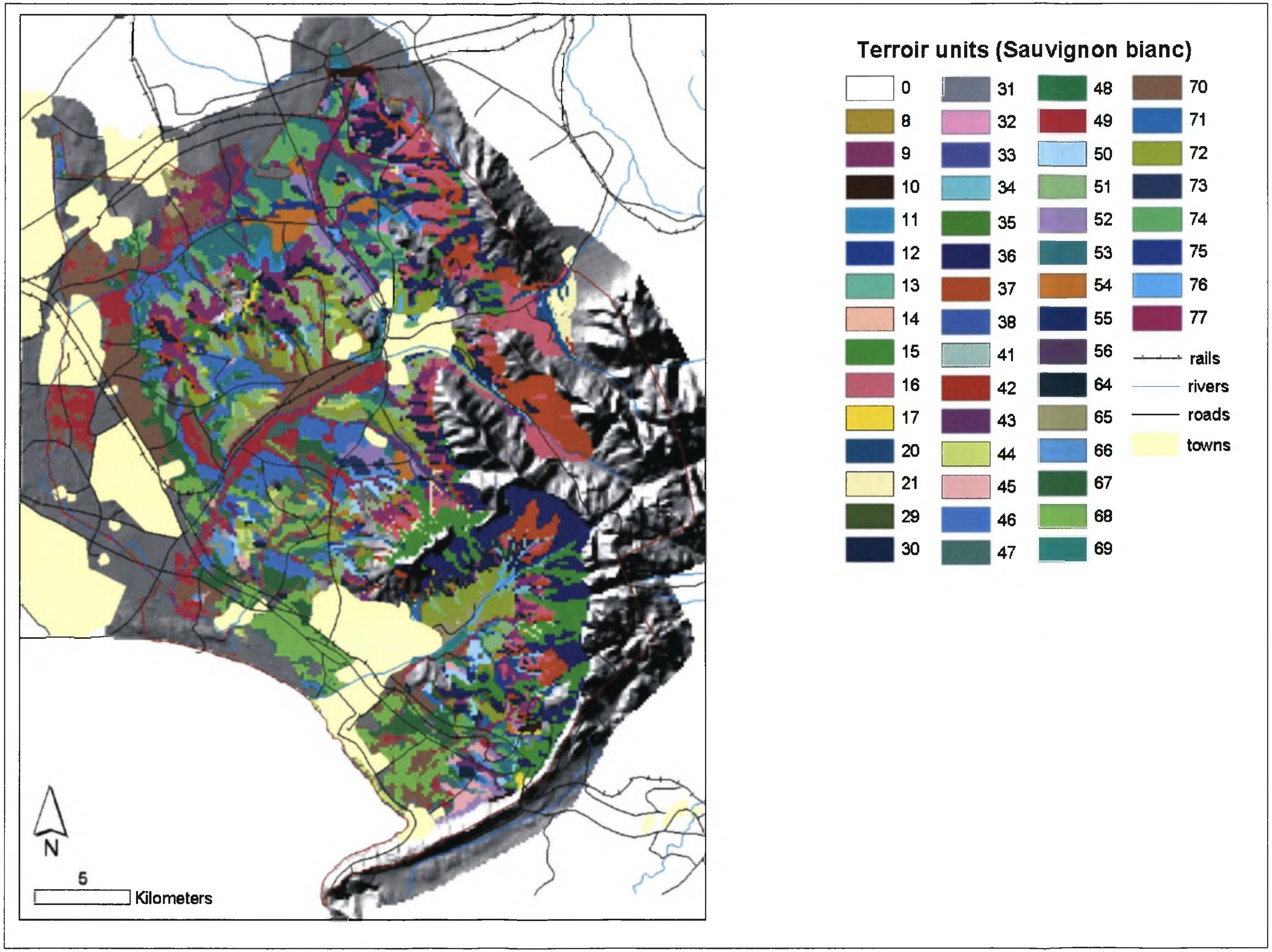
Terroir unit	Flowering	Harvest	Yield	Yield: pruning mass ratio	Capacity	Wine specific gravity	Wine pH	Fullness	Fresh vegetative aroma	Dried vegetative aroma	Tropical fruit aroma	Spicy aroma
158	2	3	1	3	1	3	1	2	1	3	1	3
159	2	3	1	3	1	3	1	2	1	3	2	3
160	2	3	1	3	1	3	1	2	1	3	3	3
161	2	3	1	3	2	1	1	2	1	3	2	3
162	2	3	1	3	2	1	1	2	1	1	2	2
163	2	3	1	3	2	1	1	2	1	1	1	2
164	2	3	1	3	2	1	1	2	1	1	2	2
165	2	3	2	3	3	1	1	2	1	1	2	3
166	2	3	3	2	3	2	1	2	1	1	1	2
167	3	2	1	1	1	1	1	2	3	2	3	3
168	3	2	1	1	1	1	1	3	3	2	3	3
169	3	2	1	1	1	1	1	3	3	2	4	3
170	3	2	1	1	1	1	2	3	3	2	4	3
171	3	2	1	1	1	2	1	3	3	2	3	3
172	3	2	1	1	1	2	1	3	3	2	4	3
173	3	2	1	1	1	2	2	3	3	2	4	3
174	3	2	1	1	1	3	1	2	3	2	3	3
175	3	2	1	1	1	3	1	3	3	2	3	3
176	3	2	1	1	1	3	1	3	3	2	4	3
177	3	2	1	1	1	3	2	3	3	2	4	3
178	3	2	1	1	2	1	1	2	3	2	3	3
179	3	2	1	1	2	1	1	3	3	2	3	3
180	3	2	1	1	2	1	1	3	3	2	4	3

Terroir unit	Flowering	Harvest	Yield	Yield: pruning mass ratio	Capacity	Wine specific gravity	Wine pH	Fullness	Fresh vegetative aroma	Dried vegetative aroma	Tropical fruit aroma	Spicy aroma
181	3	2	1	1	2	1	2	3	3	2	4	3
182	3	2	1	1	2	2	2	3	3	2	4	3
183	3	2	1	1	2	3	1	3	3	2	3	3
184	3	2	1	1	2	3	1	3	3	2	4	3
185	3	2	1	1	2	3	2	3	3	2	4	3
186	3	2	1	3	1	1	1	2	3	2	3	3
187	3	2	1	3	1	1	1	2	3	3	3	3
188	3	2	1	3	1	1	1	3	3	2	3	3
189	3	2	1	3	1	1	1	3	3	3	3	3
190	3	2	1	3	1	1	1	3	3	3	4	3
191	3	2	1	3	1	3	1	2	3	2	3	3
192	3	2	1	3	1	3	1	2	3	3	3	3
193	3	2	1	3	1	3	1	3	3	2	3	3
194	3	2	1	3	1	3	1	3	3	2	4	3
195	3	2	1	3	1	3	1	3	3	3	3	3
196	3	2	1	3	1	3	1	3	3	3	4	3
197	3	2	1	3	1	3	1	3	3	3	3	3
198	3	2	1	3	2	1	1	2	3	2	3	3
199	3	2	1	3	2	1	1	2	3	3	3	3
200	3	2	1	3	2	1	1	3	3	2	3	3
201	3	2	1	3	2	1	1	3	3	3	3	3
202	3	2	1	3	2	1	1	3	3	3	4	3
203	3	2	1	3	2	3	1	3	3	3	4	3

Terroir unit	Flowering	Harvest	Yield	Yield: pruning mass ratio	Capacity	Wine specific gravity	Wine pH	Fullness	Fresh vegetative aroma	Dried vegetative aroma	Tropical fruit aroma	Spicy aroma
204	3	2	1	3	2	3	1	3	3	2	3	3
205	3	2	2	1	3	1	1	2	3	2	3	3
206	3	2	2	1	3	1	1	3	3	2	3	3
207	3	2	2	1	3	1	1	3	3	2	4	3
208	3	2	2	1	3	1	2	3	3	2	4	3
209	3	2	2	3	3	1	1	2	3	2	3	3
210	3	2	2	3	3	1	1	3	3	3	3	3
211	3	2	2	3	3	1	1	3	3	2	3	3
212	3	2	2	3	3	3	1	3	3	3	3	3
213	3	2	2	3	3	3	1	3	3	2	3	3
214	3	2	3	1	3	1	1	2	3	2	3	3
215	3	2	3	1	3	1	1	3	3	2	3	3
216	3	2	3	1	3	1	1	3	3	2	4	3
217	3	2	3	1	3	1	2	3	3	2	4	3
218	3	2	3	1	3	2	1	2	3	2	3	3
219	3	2	3	1	3	2	1	3	3	2	3	3
220	3	2	3	1	3	2	2	3	3	2	4	3
221	3	2	3	1	3	3	1	2	3	2	3	3
222	3	2	3	1	3	3	1	3	3	2	3	3
223	3	2	3	1	3	3	1	3	3	2	4	3
224	3	2	3	1	3	3	2	3	3	2	4	3
225	3	2	3	3	3	1	1	3	3	2	3	3
226	3	2	3	3	3	1	1	3	3	3	3	3

Terroir unit	Flowering	Harvest	Yield	Yield: pruning mass ratio	Capacity	Wine specific gravity	Wine pH	Fullness	Fresh vegetative aroma	Dried vegetative aroma	Tropical fruit aroma	Spicy aroma
227	3	2	3	3	3	1	1	3	3	3	4	3
228	3	2	3	3	3	3	1	2	3	2	3	3
229	3	2	3	3	3	3	1	2	3	3	3	3
230	3	2	3	3	3	3	1	3	3	2	3	3
231	3	2	3	3	3	3	1	3	3	2	4	3
232	3	2	3	3	3	3	1	3	3	3	3	3
233	3	2	3	3	3	3	1	3	3	3	4	3
234	3	3	1	1	1	3	1	2	3	2	3	3
235	3	3	1	3	1	1	1	2	3	2	3	3

ADDENDUM 5.1 Map of terroirs identified for Sauvignon blanc in the Stellenbosch Wine of Origin District with survey data. The descriptions of the terroir units are given in Addendum 5.2 on the following page.



ADDENDUM 5.2 Properties of terroirs identified for Sauvignon blanc in the Stellenbosch Wine of Origin District with survey data

Code	Altitude	Soil	Temperature (GDD)	Wind exposure	Wine style / quality	Aroma variability	Growth cycle	Shoot variability	Visual symptoms of water stress	Yield	Acidity
8	130<Alt<247	Residual	<1867	<65	Good wine	reduced variation	earlier	shorter shoots	More stress symptoms	lower yield	higher acidity
9	130<Alt<247	Red & Yellow apedal	<1867	<65	Good wine	reduced variation	earlier	shorter shoots	More stress symptoms	lower yield	higher acidity
10	130<Alt<247	Dry duplex	<1867	<65	Good wine	reduced variation	earlier	shorter shoots	More stress symptoms	lower yield	lower acidity
11	130<Alt<247	Medium-deep wet duplex	<1867	<65	Good wine	greater variation	earlier	shorter shoots	More stress symptoms	lower yield	lower acidity
12	130<Alt<247	Shallow wet duplex	<1867	<65	Good wine	greater variation	earlier	shorter shoots	More stress symptoms	lower yield	higher acidity
13	130<Alt<247	Well drained deep alluvial sands	<1867	<65	Good wine		earlier	shorter shoots	More stress symptoms	lower yield	higher acidity
14	130<Alt<247	Poorly drained alluvial	<1867	<65	Good wine	greater variation	earlier	shorter shoots	More stress symptoms	lower yield	lower acidity
15	>247	Residual	<1867	<65	Good wine	reduced variation	later	shorter shoots	More stress symptoms	lower yield	higher acidity
16	>247	Red & Yellow apedal	<1867	<65	Good wine	reduced variation	later	shorter shoots	More stress symptoms	lower yield	higher acidity
17	>247	Dry duplex	<1867	<65	Good wine	reduced variation	later	shorter shoots	More stress symptoms	lower yield	lower acidity
20	>247	Well drained deep alluvial sands	<1867	<65	Good wine		later	shorter shoots	More stress symptoms	lower yield	higher acidity
21	>247	Poorly drained alluvial	<1867	<65	Good wine	greater variation	later	shorter shoots	More stress symptoms	lower yield	lower acidity
29	130<Alt<247	Residual	<1867	>65	Good wine	reduced variation	earlier	shorter shoots	Less stress symptoms	higher yield	higher acidity
30	130<Alt<247	Red & Yellow apedal	<1867	>65	Good wine	reduced variation	earlier	shorter shoots	Less stress symptoms	higher yield	higher acidity
31	130<Alt<247	Dry duplex	<1867	>65	Good wine	reduced variation	earlier	shorter shoots	Less stress symptoms	higher yield	lower acidity
32	130<Alt<247	Medium-deep wet duplex	<1867	>65	Good wine	greater variation	earlier	shorter shoots	Less stress symptoms	higher yield	lower acidity
33	130<Alt<247	Shallow wet duplex	<1867	>65	Good wine	greater variation	earlier	shorter shoots	Less stress symptoms	higher yield	higher acidity
34	130<Alt<247	Well drained deep alluvial sands	<1867	>65	Good wine		earlier	shorter shoots	Less stress symptoms	higher yield	higher acidity
35	130<Alt<247	Poorly drained alluvial	<1867	>65	Good wine	greater variation	earlier	shorter shoots	Less stress symptoms	higher yield	lower acidity
36	>247	Residual	<1867	>65	Good wine	reduced variation	later	shorter shoots	Less stress symptoms	higher yield	higher acidity
37	>247	Red & Yellow apedal	<1867	>65	Good wine	reduced variation	later	shorter shoots	Less stress symptoms	higher yield	higher acidity
38	>247	Dry duplex	<1867	>65	Good wine	reduced variation	later	shorter shoots	Less stress symptoms	higher yield	lower acidity
41	>247	Well drained deep alluvial sands	<1867	>65	Good wine		later	shorter shoots	Less stress symptoms	higher yield	higher acidity
42	>247	Poorly drained alluvial	<1867	>65	Good wine	greater variation	later	shorter shoots	Less stress symptoms	higher yield	lower acidity
43	<130	Residual	>1867	<65	Premium wine	reduced variation	earlier	longer shoots	More stress symptoms	lower yield	
44	<130	Red & Yellow apedal	>1867	<65	Premium wine	reduced variation	earlier	longer shoots	More stress symptoms	lower yield	
45	<130	Dry duplex	>1867	<65	Premium wine	reduced variation	earlier	longer shoots	More stress symptoms	lower yield	
46	<130	Medium-deep wet duplex	>1867	<65	Premium wine	greater variation	earlier	longer shoots	More stress symptoms	lower yield	
47	<130	Shallow wet duplex	>1867	<65	Premium wine	greater variation	earlier	longer shoots	More stress symptoms	lower yield	
48	<130	Well drained deep alluvial sands	>1867	<65	Premium wine		earlier	longer shoots	More stress symptoms	lower yield	
49	<130	Poorly drained alluvial	>1867	<65	Premium wine	greater variation	earlier	longer shoots	More stress symptoms	lower yield	
50	130<Alt<247	Residual	>1867	<65	Premium wine	reduced variation	earlier	shorter shoots	More stress symptoms	lower yield	
51	130<Alt<247	Red & Yellow apedal	>1867	<65	Premium wine	reduced variation	earlier	shorter shoots	More stress symptoms	lower yield	
52	130<Alt<247	Dry duplex	>1867	<65	Premium wine	reduced variation	earlier	shorter shoots	More stress symptoms	lower yield	
53	130<Alt<247	Medium-deep wet duplex	>1867	<65	Premium wine	greater variation	earlier	shorter shoots	More stress symptoms	lower yield	
54	130<Alt<247	Shallow wet duplex	>1867	<65	Premium wine	greater variation	earlier	shorter shoots	More stress symptoms	lower yield	
55	130<Alt<247	Well drained deep alluvial sands	>1867	<65	Premium wine		earlier	shorter shoots	More stress symptoms	lower yield	
56	130<Alt<247	Poorly drained alluvial	>1867	<65	Premium wine	greater variation	earlier	shorter shoots	More stress symptoms	lower yield	
65	<130	Red & Yellow apedal	>1867	>65	Premium wine	reduced variation	earlier	longer shoots	Less stress symptoms	higher yield	
66	<130	Dry duplex	>1867	>65	Premium wine	reduced variation	earlier	longer shoots	Less stress symptoms	higher yield	
67	<130	Medium-deep wet duplex	>1867	>65	Premium wine	greater variation	earlier	longer shoots	Less stress symptoms	higher yield	
68	<130	Shallow wet duplex	>1867	>65	Premium wine	greater variation	earlier	longer shoots	Less stress symptoms	higher yield	
69	<130	Well drained deep alluvial sands	>1867	>65	Premium wine		earlier	longer shoots	Less stress symptoms	higher yield	
70	<130	Poorly drained alluvial	>1867	>65	Premium wine	greater variation	earlier	longer shoots	Less stress symptoms	higher yield	
71	130<Alt<247	Residual	>1867	>65	Premium wine	reduced variation	earlier	shorter shoots	Less stress symptoms	higher yield	
72	130<Alt<247	Red & Yellow apedal	>1867	>65	Premium wine	reduced variation	earlier	shorter shoots	Less stress symptoms	higher yield	

Code	Altitude	Soil	Temperature (GDD)	Wind exposure	Wine style / quality	Aroma variability	Growth cycle	Shoot variability	Visual symptoms of water stress	Yield	Acidity
73	130<Alt<247	Dry duplex	>1867	>65	Premium wine	reduced variation	earlier	shorter shoots	Less stress symptoms	higher yield	
74	130<Alt<247	Medium-deep wet duplex	>1867	>65	Premium wine	greater variation	earlier	shorter shoots	Less stress symptoms	higher yield	
75	130<Alt<247	Shallow wet duplex	>1867	>65	Premium wine	greater variation	earlier	shorter shoots	Less stress symptoms	higher yield	
76	130<Alt<247	Well drained deep alluvial sands	>1867	>65	Premium wine		earlier	shorter shoots	Less stress symptoms	higher yield	
77	130<Alt<247	Poorly drained alluvial	>1867	>65	Premium wine	greater variation	earlier	shorter shoots	Less stress symptoms	higher yield	
78	>247	Residual	>1867	>65	Premium wine	reduced variation	later	shorter shoots	Less stress symptoms	higher yield	
79	>247	Red & Yellow apedal	>1867	>65	Premium wine	reduced variation	later	shorter shoots	Less stress symptoms	higher yield	
80	>247	Dry duplex	>1867	>65	Premium wine	reduced variation	later	shorter shoots	Less stress symptoms	higher yield	
81	>247	Medium-deep wet duplex	>1867	>65	Premium wine	greater variation	later	shorter shoots	Less stress symptoms	higher yield	
82	>247	Shallow wet duplex	>1867	>65	Premium wine	greater variation	later	shorter shoots	Less stress symptoms	higher yield	
83	>247	Well drained deep alluvial sands	>1867	>65	Premium wine		later	shorter shoots	Less stress symptoms	higher yield	
84	>247	Poorly drained alluvial	>1867	>65	Premium wine	greater variation	later	shorter shoots	Less stress symptoms	higher yield	
0	Not arable										