Spatial characterisation of natural terroir units for viticulture in the Bottelaryberg-Simonsberg-Helderberg winegrowing area

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I, the undersigned, hereby declare that the work contained in this thesis 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.

Summary

There is an increasing demand by the consumer for knowledge and understanding of the origin of each wine produced. This origin is directly linked to the interaction between the environment and grapevine, and therefore to the terroir. A terroir can be defined as a complex of natural factors being expressed through the final product and must therefore be studied in two steps, namely, the identification of relatively homogenous natural terroir units followed by their ecophysiological characterisation.

The aim of this study was to characterise the Bottelaryberg-Simonsberg-Helderberg winegrowing area according to existing digital information and to identify natural terroir units. The study area is situated to the southwest of Stellenbosch and covers an area of approximately 25 000 ha.

Topography is a static feature of the landscape and affects the sunlight interception by a slope, exposure of a site to winds and drainage of soil water and air. It forms an important component of the terroir concept and has a strong interaction with the environmental components of climate and soil. The study area is bordered by mountains and bisected by a river valley resulting in a large variation in aspect and altitude affecting both spatial and temporal temperature variability.

There is no doubt as to the important effect of climate on wine character and quality. A number of indices can be used to describe the regional climate. The study area has a Mediterranean climate with notable spatial variation of all climatic parameters due to its complex topography and proximity to the ocean.

The effect of geology on wine character is less clear but appears to act through its contribution to the physical properties of the soil. In the Bottelaryberg-Simonsberg-Helderberg study area the geology is complex 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.

Soil has a number of contributing factors affecting wine character and quality, *inter alia*, soil colour, temperature, chemical composition, depth and texture (affecting the water supplying properties of the soil). It is the last two that appear to have the most significant effect. Soil depth affects the buffer capacity of the soil to temper climatic extremes and the water supply has a well-recorded effect on vine growth and functioning. There is a high degree of soil variation in the Bottelaryberg-Simonsberg-Helderberg study area that is difficult to represent in soil associations. A pattern of soil distribution, however, can be noticed in relation to landscape variation.

Terrain morphological units, altitude and aspect were used as primary keys for the identification of natural terroir units. Broad soil categories and geological information were included at a secondary level. This resulted in 195 units. These natural terroir units will form the basis for future ecophysiological characterisation in order to determine possible future cultivar distribution as well as the terroir effect on wine character.

Opsomming

Daar is toenemende aanvraag vanaf die verbruiker vir kennis en begrip van die oorsprong van elke wyn wat geproduseer word. Die oorsprong is direk aan die interaksie tussen die omgewing en wingerd gekoppel, en daarom ook die terroir. Terroir kan omskryf word as die kompleks van natuurlike faktore wat in die finale produk uitdrukking vind en studies daarvan moet dus in twee stappe plaasvind, d.i. die identifisering van relatiewe homogene natuurlike terroir eenhede gevolg deur die ekofisiologiese karakterisering daarvan.

Die doel van die studie was om die Bottelaryberg-Simonsberg-Helderberg wynproduserende gebied te karakteriseer, met behulp van bestaande versyferde data en om natuurlike terroir eenhede te identifiseer.

Topografie is 'n vaste landskapskenmerk en beïnvloed sonligonderskepping deur hellings, blootstelling van 'n ligging aan wind en die dreinering van grondwater en beweging van koue lug. Dit is 'n belangrike deel van die terroir konsep en het sterk interaksie met omgewingsfaktore van grond en klimaat. Die studiegebied word begrens deur berge en is deursny deur 'n riviervallei, met groot variasie in helling en aspek. Beide hiervan beïnvloed die ruimtelike- en daaglik-variasies in daaglikse maksimum temperatuur.

Die belangrike effek van klimaat op wynkarakter en kwaliteit is duidelik soos weerspieël deur die beskikbaarheid van 'n aantal makroklimaatsindekse. Alle klimaatsparameters word deur topografie beïnvloed. Temperatuur en relatiewe humiditeit word ook deur afstand vanaf die see beïnvloed. Die studie area het 'n Meditereense klimaat, met merkwaardige ruimtelike variasie van alle klimaatsparameters.

Die effek van geologie op wynkarakter is minder duidelik, maar het waarskynlik 'n effek op die fisiese eienskappe van 'n grond. Die geologie in die Bottelaryberg-Simonsberg-Helderberg studiegebied is kompleks, as gevolg van die hoë graad van tektoniese beweging en vermenging van moedermateriaal. *In situ* vorming van gronde uit gesteentes vind selde plaas.

Grond het 'n groot aantal bydraende faktore, wat wynkarakter en -kwaliteit kon beïnvloed, onder andere, grondkleur, -temperatuur, -chemiese samestelling, -diepte en -tekstuur (wat die waterleweringsvermoë van die grond bepaal). Dit is veral laasgenoemde twee faktore wat blykbaar die mees opvallendste effek openbaar. Gronddiepte bepaal die buffer kapasiteit van die grond om klimaatsuiterstes te kan weerstaan en die waterleweringsvermoë het 'n alombekende effek op wingerdgroei en funksionering. Daar is 'n hoë graad van grondvariasie in die Bottelaryberg-Simonsberg-Helderberg studiegebied wat moeilik is om met grondassosiasies weer te gee. Daar is wel 'n patroon van grond distribusie wat verband hou met landskapvariasie.

Terrein morfologiese eenhede, hoogte en aspek is gebruik as primêre sleutels vir die indentifisering van natuurlike terroir eenhede. Globale grondkategorieë en geologiese inligting is op 'n sekondêre vlak gebruik. Dit het 195 eenhede tot gevolg. Die natuurlike terroir eenhede sal die basis vorm vir toekomstige ekofisiologiese karakterisering, om die terroir effek op wynkarakter te kan bepaal.

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"Wine is grape juice. Every drop of liquid filling so many bottles has been drawn out of the ground by the roots of a vine. All these different drinks have at one time been sap in a stick".

Hugh Johnson

"In an increasingly standardized, mechanized and computerized world, fewer and fewer things remain that are truly individual. Wine is one of them. Despite the high technology of its production, wine remains essentially a natural product, with infinite variation from area to area, maker to maker, grape variety to grape variety, and even bottle to bottle. It has subtleties and a sensual fascination which take it far beyond being a mere alcoholic beverage."

John Gladstones

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1. Introduction

The projected future scenario for local and overseas wine markets is pessimistic, but the emphasis on the concept of terroir in South Africa provides an advantage over other new world wine producing countries (Prof. P. Spies, Vision 2020 presentation to Winetech researchers, 28 September 2000). The desire of the producers to meet this marketing challenge by emphasising the origin of the product at a more detailed level than region was emphasized by Van Zyl (2000). He suggests that, for example, Wine of Origin Stellenbosch, is not specific enough to meet the demands of the discerning consumer. Terroir delimitation is becoming of greater interest for wine producers. This concept stresses that winemaking begins in the vineyard. Although there are many factors affecting the final wine character and quality (Fig. 1.1), the terroir, a stable set of environmental features, forms the base. Cellar technology has progressed to such an extent, that wine faults are seldom observed and it is possible to consistently produce wines of a high quality, maintaining cultivar characteristics in the process, if present in the raw material. However, no winemaker, no matter how gifted, can create a high quality wine of identifiable origin and with distinctive cultivar character from mediocre grapes of unknown origin.

The first South African wine was made by Jan van Riebeeck on the second of February 1659 (Robinson, 1994). His initial determination to produce wine at the Cape refreshment station was continued by other governors resulting in improvement and expansion of the embryo industry. As the colony opened up and new areas were discovered, so the wine industry developed to its present extent of over 100 000 ha (SAWIS, 2000). The initial expansion was based on ease of access and mainly focussed on fertile valleys, with rivers to provide irrigation in the more arid regions. Yield was predominantly the factor considered. However, when over-production became a problem in the early twentieth century, a move towards production focussed on quality began. This eventually resulted in the introduction of the Wine of Origin legislation in 1973. According to this legislation, 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 (Theron, 1998). There are four classes of demarcated areas with "Estate" being the smallest, followed by "Ward", "District" and finally "Region". "Region" and "District" are more administrative in nature but a "Ward" is defined according to soil, climate and ecological factors, and named according to a real geographical place name. These areas are demarcated on application by

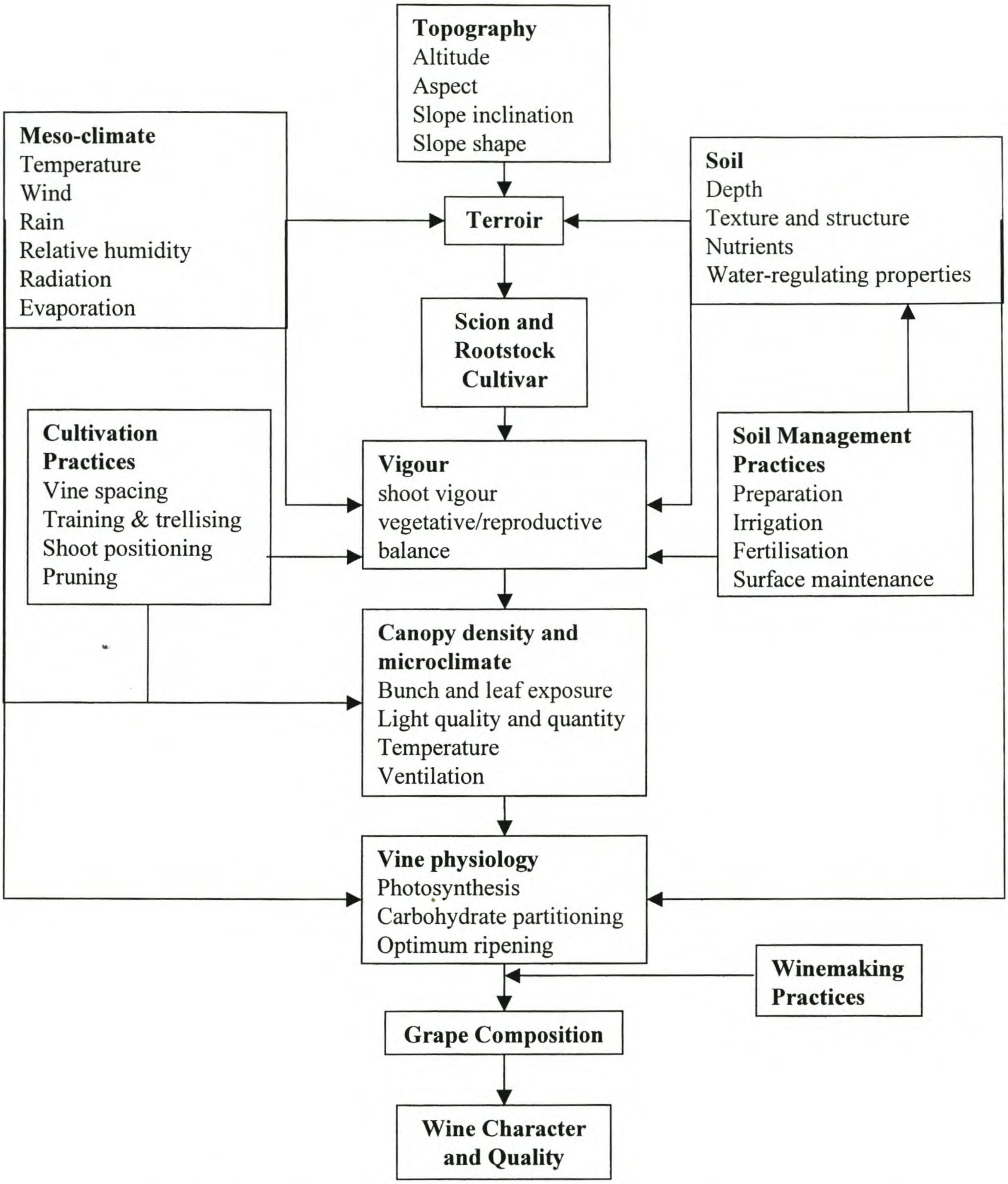


Fig. 1.1. The complex interaction between environmental and management factors affecting final wine character and quality (adapted from Jackson & Lombard, 1993, E. Archer, Department of Viticulture and Oenology, U.S., 1999. Personal communication).

the producers. After demarcation, areas are allowed to develop to express their specific wine style and character instead of proving their originality beforehand (Saayman, 1998). Due to South Africa being a relatively young wine producing country, such demarcation cannot be performed on an empirical basis, such as is possible in traditional wine producing countries (e.g. France), but must be theoretically based.

Although an Estate is a production unit and is easily demarcated, primarily based on ownership, it is not possible to apply this concept in all cases as co-operative cellars vinify a large proportion of the grapes originating over a wide area. "Wards" may contain different viticultural environments or terroirs and produce wines of different character despite their demarcation according to dominant environmental features. The wine consumer is interested in the origin of the product and looks for unique products, characteristic of an origin, and of a high quality. The identification of natural terroir units with specific application to viticulture is an important step in meeting the consumer challenge and reaching an important market.

Demarcation is also of international importance. After taking the reports and presentations of the Congress on the theme of "Criteria for differentiating and delimiting vitivinicultural zones and regions and the examination of the role played by natural and human factors", Madrid, 1992, into consideration, the General Assembly of the OIV passed resolution VITI 2/93 (Anon., 1993), which asks member Countries and international organisations to:

1. "Stimulate research on scientific methods by which to characterise and delimit homogenous viticultural zones that, without major human intervention, are capable of yielding original vitivinicultural products of quality;
2. Apply suitable methods of research and interpretation to take into account all the factors of the viticultural ecosystem including the characteristics of the soil, the climate, the interactions between variety and site and the effects of the human factors on the maturation and the quality of the grape."

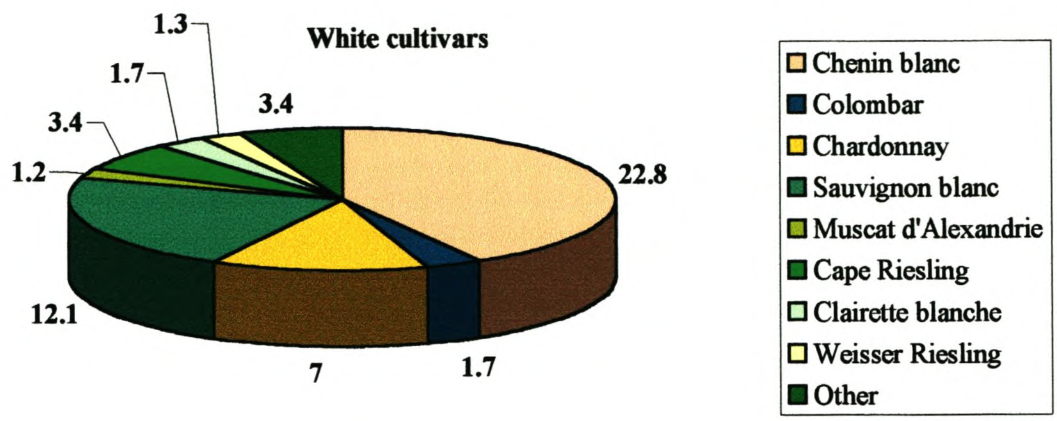
Due to the importance of the identification of relatively homogenous viticultural terroirs on both a national and international level, the funding organisation of the South African wine industry (Winetech) has contributed to the funding of a research project to identify preliminary viticultural terroirs in the South Western Cape wine-growing areas. This thesis contributes to the above-mentioned study. A study area in the Stellenbosch wine producing district has been selected for the purpose of the thesis.

Stellenbosch was first established as an agricultural community ca. 1680 under the governance of Simon van der Stel after he recognised the fertile valley as being suitable for agriculture (Johnson Barker & Balfour, 1992). The initial farming was mostly wheat production. It was in 1685 that the visiting commissioner general recommended that further vineyards be established. In 1806, Lady Anne Barnard apparently wrote of Stellenbosch that "wine is the chief produce of the land hereabouts, and a small piece of ground only being necessary to make a great deal of wine...but to what an extent the cultivation of wine might be brought here if the farmers were sure of a good market!" (Johnson Barker & Balfour, 1992). Cultivation of grapevines for the production of wine has therefore been an integral part of the history and culture of Stellenbosch from shortly after its establishment.

The Stellenbosch wine-producing region currently contains 16% of the country's vineyards with the predominant cultivars being Chenin blanc (23%), Sauvignon blanc (12%) and Cabernet Sauvignon (16%) (Fig. 1.2) (SAWIS, 2000). Predominantly dry white and red wines are made as well as a small amount of special late harvest and noble late harvest wines.

The aim of this study was twofold:

1. To accumulate existing digital data for the characterisation of the Bottelaryberg-Simonsberg-Helderberg winegrowing area.
2. To determine natural terroir units in the Bottelaryberg-Simonsberg-Helderberg winegrowing area with the aid of the most pertinent digital data and a geographic information system.



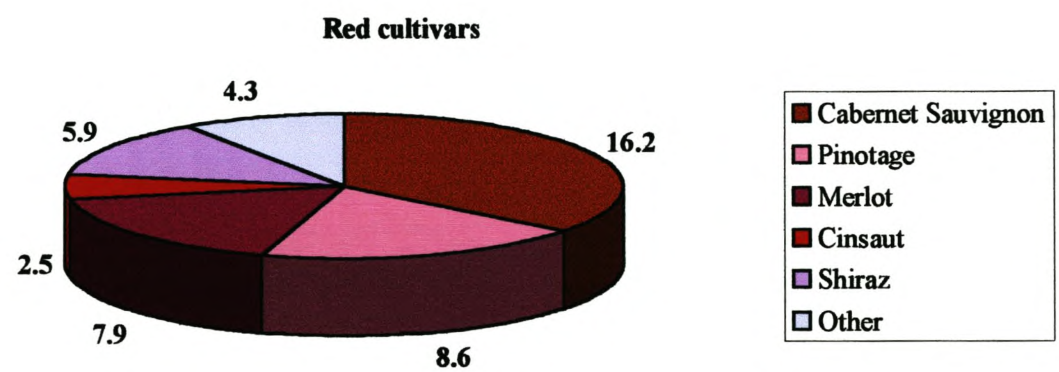


Fig. 1.2. The cultivar composition (%) for the Stellenbosch wine-producing region. Compiled from data obtained in SAWIS (2000).

2. Literature review on the terroir concept and its components

2.1 Definition of the terroir concept

Although the literal translation of the French term "terroir" is soil (Atkins *et al*., 1993), it is in reality a complex notion and means much more than this. The word "terrain" has been used as its equivalent in South African literature (De Villiers 1996, 1997; Carey, 1999, Carey & Bonnardot, 2000) but can result in confusion due to its inherent definition (i.e. "physical features of a geographical area, generally with a descriptive adjective" such as "hilly terrain"; Wilson, 1998). As described below, the French concept of "terroir" encompasses a broader spectrum of environmental components than the topographic elements included in the English "terrain". It is therefore suggested that the term terroir be maintained and will be used in this thesis.

Carbonneau (1993) suggests a number of different definitions related to the concept of terroir.

1. **Controlled appellation of origin** includes all the factors resulting in a product that is unique and identifiable, including environmental, historical, vegetal and technological. It is therefore a broader concept than that of the terroir as outlined below.
2. A **terroir** relates to the environmental factors resulting in a distinctive product. This can be further subdivided into:
    a. **Multisite terroir** where the identity of the product can be shared between a number of different sites, sometimes widely distributed.
    b. **Historic terroir** (or monosite terroir) where the terroir and geographic location are indivisible.
    c. **Original terroir** where it can be proven that only a single terroir is capable of producing the product in question.
    d. **Homogenous terroir** where similar terroirs are chosen in a homogenous manner to create a well characterised single product.
    e. **Composite terroir** where either a single terroir can result in a number of diverse products, or a number of elementary products must be combined to result in a final and complex single product.

Carbonneau (1993) also provided a so-called scientific definition of terroir, namely, the interaction between mesoclimate (or topoclimate) and terrain, where terrain includes the soil, substrate and geological parent material.

Laville (1993) distinguished between the natural terroir unit and the terroir. According to this author, the natural terroir unit is a volume of the earth's biosphere that is characterised by a stable group of values relating to the topography, climate, substrate and soil. A similar concept is embraced by the "Unité Terroir de Base" of Riou, Morlat & Asselin (1995), which represents an association of geological, soil and landscape components and for which the response of the vine will be considered reproducible for a given seasonal climate. Laville (1993) further explained that, on the other hand, the concept of terroir is directly linked to the product. For a certain type of agricultural production, a terroir is a group of the above-mentioned units defined in relation to the specificity of the products obtained. A natural terroir unit has an agronomic potential that is reflected in the characteristics of its products; resulting in the concept of terroir. Laville (1990) suggests that although varietals and rootstocks have become typical of an area of production, they are not true elements of the terroir but rather bear witness to an adaptation of production to the terroir. The definition given by Dubos (1984) is in a similar vein in that he states that a terroir is a natural unit characterised by means of its agricultural potential as perceived in its particularities of soil, aspect, climate and the degree of humidity.

A good terroir is considered to be one that ensures a slow but complete maturation of cultivars with a certain regularity of product from vintage to vintage (Şeguin, 1986).

In summary, a terroir can be defined as a complex of natural environmental factors, which cannot be easily modified by the producer. This complex will be expressed in the final product, with the aid of various management decisions, resulting in distinctive wines with an identifiable origin. Therefore the terroir cannot be viewed in isolation from management and cultivation practices, although they do not form part of the intrinsic definition.

This definition determines the manner of identifying terroirs: no single terroir component can be studied in isolation; rather the full complex of factors must be taken into account. There will be two steps to any such terroir study. Firstly, all the relevant natural factors must be identified and characterised in order to identify relatively homogenous natural units.

Secondly, the behaviour of the vine and the organoleptic qualities of the wine originating from these units must be determined over a period of time in order to group the natural units giving a similar expression into viticultural terroirs. This study entails the first step of a terroir study, namely the identification of the so-called natural terroir units.

2.2 Topography

Topography is a static feature of the landscape and is described by altitude as well as the rate of change of altitude over distance (Schultz, 1997). Gladstones (1992) hypothesised that the effect of topography on temperature variability is one of the main factors affecting the quality of grapes and wine and has suggested temperature adjustments for topographic and soil factors in order to make data from weather stations more applicable to vineyard sites. In the cool winegrowing regions, the mesoclimatic variability associated with different positions in the landscape was found to have a significant effect on the synthesis and degradation of malic acid, the formation of amino acids and the sugar content and growth of grapes (Becker, 1977). Topographic effects on climate can be indirect, due to soil drainage, exposure to wind and ventilation or due to the immediate effects of the change in the incidence of the sun's rays on the earth's surface (Crowe, 1971). The topography of the coastline will also influence the penetration inland of the sea breeze, the inflow (convergence) and outflow (divergence) of winds, number of sea-breezes experienced and, possibly, the onset time of sea breeze occurrence (Abbs & Physick, 1992).

2.2.1 Altitude

Altitude, aspect and inclination of the slope are the most important landscape attributes affecting mesoclimate (Dumas, Lebon & Morlat, 1997). Under alpine conditions in Trentino, with its associated complex topography, increasing altitude was found to be the factor most affecting viticulture. It significantly reduced yield, accompanied by a significant reduction in soluble solids and an increase in total titratable acidity and malic acid (Bertamini, Ponchia & Scrinzi, 1996). This was considered to be predominantly due to the effect of altitude on mesoclimate.

Temperatures generally decrease 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).

Although differences between seasonal temperatures for various Alsatian vineyards on different landscape positions were insignificant (below 1°C), differences were found for shorter periods depending on the weather type (Dumas, Lebon & Morlat, 1997). During cloudy conditions, air temperature was essentially linked to altitude with a temperature lapse rate of –0.6°C per 100 m. For variable conditions, it was difficult to establish a general trend due to the high degree of spatial and temporal variability of the climatic parameters. For clear conditions, night and day patterns differed. Cold air gravitated downwards at night, resulting in an accumulation at lower altitudes. It appeared that the degree of ventilation and the temperature at the soil surface contributed to the spatial variation of temperature at midday. In the morning and evening, however, the thermal gradient decreased with increasing altitude. Therefore, the effect of altitude on temperature can be reduced by an increase in radiation, warmer soil surfaces and lack of air movement. Similar results were found in Champagne (Cellier *et. al.*, 1998). An effect of altitude on temperature (-0.5°C per 100 m) was also noticed for the relatively flat landscape of the Loire valley and was considered the most important topographic feature having an effect on mesoclimate (Jacquet & Morlat, 1997). However, in this area, slope inclination and aspect did not have a sufficiently discriminatory value between base terroir units.

On lower and middle slopes of isolated and projecting hills, a thermal zone, a layer of warm night air above the cold air in the valley/flat area below, can develop (Gladstones, 1992). The temperature variation with altitude also appears to differ when slopes are exposed to a sea breeze. A RAMS model applied for 4 February 2000 in the extreme South Western Cape on a 1 km grid (Bonnardot, V.M.F., ARC-ISCW AgroMet, 2000. Personal communication) suggested that south facing slopes at the sea breeze front and receiving the influence of the sea breeze experience an increase in temperature as the altitude increases. This phenomenon lasts for a short period due to the continuous blending of air above the coastline and has been noticed in other studies (Carrega, 1995). It can be explained by the movement of dense, cool maritime air below less dense, warm air (Janoueix-Yacono, 1995) and depends on four factors (Bonnardot, V.M.F., ARC-ISCW AgroMet, 2000. Personal communication), namely, distance from the sea, topography, degree of penetration by the sea breeze and the blending of air above the coastline.

Atmospheric pressure, and therefore presumably the partial pressure of carbon dioxide, decreases as altitude increases. This eventually results in a lower water use efficiency and would probably result in a higher potassium accumulation in grapevines and an associated higher must pH at high altitudes (Gladstones, 1992). This author suggested that, although the effects of small differences in altitude are not known, most of the world's great table wines come from altitudes of lower than 500 m and that altitudes exceeding 500 m may not necessarily be a quality consideration. As the study on which these conclusions were based was equivalent to 4000 m above sea level, the effect of the reduced partial pressure of carbon dioxide can be considered negligible for the lower altitudes associated with viticulture and temperature will remain the overriding factor associated with differences in altitude.

Relief differs from altitude. It is the expression of the difference in altitude between the top of a slope or hill and the bottom (Schultz, 1997) and as such affects air movement and the accumulation of cold air, resulting in a thermal zone (Jacquet & Morlat, 1997).

2.2.2 Aspect

Changes in altitude result in different slopes and aspects with resulting changes in solar radiation interception and temperature (Schultz, 1997). East, north and west facing slopes will receive the most direct radiation in the southern hemisphere, with the greatest differences being found at high latitudes during spring and autumn. Northern and western slopes will be warmer than southern and eastern due to their higher interception of sunlight. Eastern slopes will, however, warm up faster than western slopes and cool earlier. In the northern hemisphere, when comparing south and north facing slopes (ca. 33% inclination), it was shown that southern slopes received higher radiation, followed by flat areas, followed by northern slopes. The difference was more pronounced in mid-winter than in mid-summer (Crowe, 1971). Gladstones (1992) suggested that aspects facing the sun are favourable even under hot conditions and ascribes this to the radiation of heat from the soil during the early morning, at night and during cloud cover and therefore less temperature variation. This author's opinions on the quality aspects of minimal temperature variability will be considered in section 2.3.1.1. More radiation occurs on northerly aspects as slopes become steeper but less on southerly aspects in the Southern Hemisphere (Schultz, 1997). There is, however, little influence of aspect on the radiation received by flatter slopes (Schultz, 1997). According to Huglin (1986), altitude can reduce and even annul the positive temperature effects resulting from favourable expositions under cool climatic conditions, while under hot conditions much advantage can be obtained by combining exposition and altitude to provide cooler ripening conditions. Aspect also affects the extent to which prevailing winds are experienced and windward facing slopes can force moist air to rise resulting in both a higher frequency and a higher quantity of rainfall (Schultz, 1997).

2.2.3 Slope inclination

The effect of slope inclination on sunlight interception is closely related to the aspect of the slope and has therefore been partially discussed under section 2.2.2. According to Dry & Smart (1988), slopes are considered to have a significant effect as far as sunlight interception is concerned at high latitudes (above 47°), when temperatures are limiting and when the sky is clear. Neither Australia (Dry & Smart, 1988), nor South Africa satisfies the first two criteria. Slopes also provide good internal drainage of the soil, preventing water logging, which affects the climate close to the soil (Schultz, 1997).

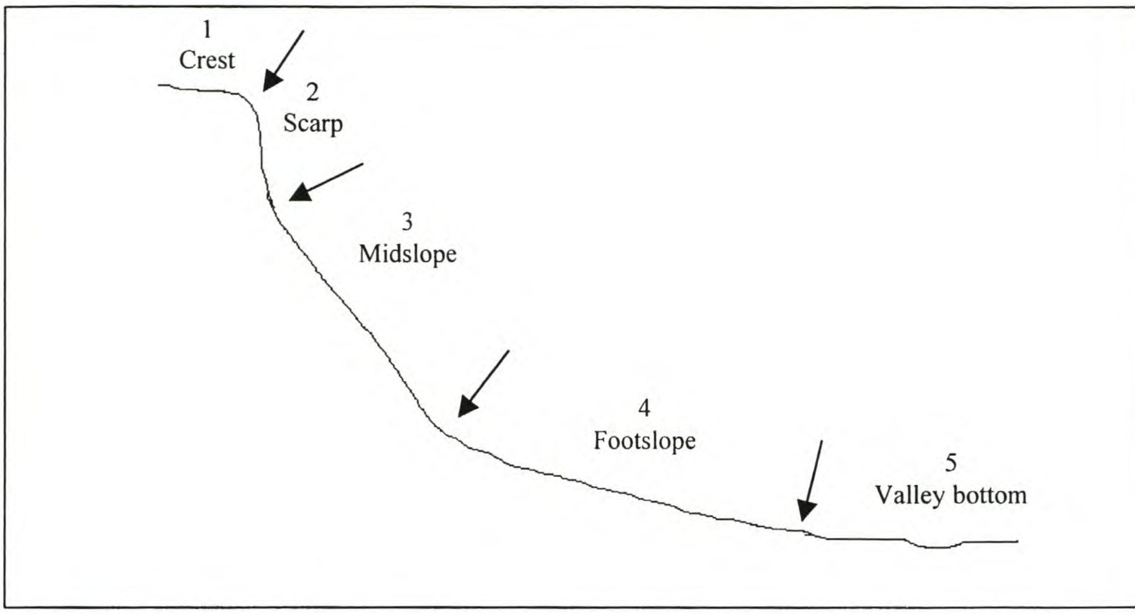
2.2.4 Slope shape

It can be generally accepted that convex landscape positions result in less day-night temperature variation in comparison to concave terrain forms (Branas, Bernon, & Levadoux, 1946). This is emphasised in valleys and gullies, but in all cases the altitude and exposure to wind have a decisive effect (Branas, 1974). Concave slopes often result in accumulation of soil moisture at the foot of the slope (Schultz, 1997).

2.2.5 Openness of the landscape

The variability in topography results in an open or closed landscape, affecting the ventilation of an area and sunlight interception. Masking features can, however, also be non-topographic of origin i.e. buildings, trees etc. The angle of openness of the landscape (Lebon, 1993) and landscape closing up index (Jacquet and Morlat, 1997) are two methods to determine the proportion of the sky obstructed by masking features as well as the nature and relative position of these features.

It is clear that altitude alone does not give a clear indication of the landscape characteristics. Landscape can be better defined with the aid of terrain morphology as described in Fig. 2.1. Here it can be seen that each terrain morphological unit has associated slope inclination and slope type characteristics.



Terrain Morphological unit	Crest	Scarp	Midslope	Footslope	Valley bottom
Symbol	1	2	3	4	5
Characteristics	0-7% slope	Steeper than 90%	20-75% slope	0-15% slope	Usually 0% slope (<3%)
	Mostly convex, sometimes straight	Straight	Mostly straight, sometimes concave	Mostly concave to straight	Straight to concave

Fig. 2.1. Terrain morphological units and their characteristics as defined by Kruger (1973).

2.2.6 Summary

Topography affects the amount of sunlight interception by a slope, exposure of a site to winds, drainage of soil water and the development of a thermal inversion layer. Increasing altitude tends to result in decreasing temperature, but this effect can be alleviated by an increase in radiation, warmer soil surfaces, poor ventilation and thermal inversion. Slope aspect affects temperature *via* sunlight interception, as well as exposure to winds and rainfall. Terrain morphology, due to its constituents of slope inclination and slope shape, affects temperature variability and soil water drainage. Relief is less easy to quantify but also affects mesoclimate. Meso- (or topoclimate), as affected by topographic variability, forms an important component of the terroir concept and has a strong interaction with other environmental components of climate and soil.

2.3 Climate

Climate is described in viticulture on three levels, namely macroclimate, meso (or topo) climate and microclimate. Macroclimate is the climate of a region, describing temperature variation on a small scale. Mesoclimate (or topo or site climate) differs from the macroclimate of the region due to differences in altitude, slope inclination, aspect or distance from large bodies of water. This type of climate usually describes the climate of a vineyard. The microclimate is the climate immediately within and immediately surrounding a plant canopy. Microclimate differences can occur within a few centimetres and seconds. These definitions (from Smart & Robinson, 1991) will be used in the rest of this thesis.

Although it is generally accepted in South Africa that vines cultivated where they "can see the sea" produce higher quality red wines than those further inland, and that vines grown on mid slopes and steeper foot slopes produce higher quality wines than those in lower lying positions (Saayman, 1977), no studies have yet been performed to study this phenomenon. These adages would, however, suggest a predominantly mesoclimatic effect on wine quality.

2.3.1 Temperature

As discussed in section 2.2., topography has an effect on temperature resulting in a variety of mesoclimates in a mountainous or hilly region. Large bodies of water also have a modifying effect on temperature due to their temperature inertia resulting in the reduction of both the diurnal temperature range and the variability of minimum and maximum temperatures (Gladstones, 1992). Bonnardot (1997) found a significant correlation between the distance from Table Bay and the time at which the daily maximum temperature occurred during February 1996. Statistical results showing the temperature increase with distance from the sea from this study were confirmed with numerical simulations (Planchon *et al.*, 2000).

2.3.1.1 Effect of temperature on grapevines and wine

Temperature is probably one of the most important parameters affecting the grapevine as it has an effect on almost every aspect of the vine's functioning. Literature concerning temperature effects has been studied in depth by a number of authors *inter alia* Le Roux (1974), Coombe (1987), Gladstones (1992) and Jackson & Lombard (1993). A summary of temperature effects on grape composition is given in Fig. 2.2 (Coombe, 1987). Gladstones

(1992) suggests that mean temperatures in the final ripening month of between 15°C and 21°C result in well balanced musts for dry or sweet wines, while 21-24°C is an ideal temperature range for ports, muscats and similar styles. Dry wines will generally need acid addition but can still be of a very high quality. The author also suggested that an optimum mean temperature for pigment formation is in the region of 20-22°C and a mean temperature range of 20-22°C in the month of ripening is optimal for physiological ripening in grapes and for the synthesis of colour, flavour and aroma compounds. According to Gladstones (1992), relatively constant, intermediate temperatures (optimal for photosynthesis) during ripening favour the biochemical processes of colour, flavour and aroma development in the berries. There should, therefore, be an optimum mean temperature during ripening combined with minimal day-night and day to day temperature variability during growth and ripening (Gladstones 1992). The effect of night temperature on anthocyanin synthesis appears to be partially dependant on the day temperature and on the temperature variability. A daily thermal amplitude of greater than 10°C greatly reduced fruit colouration (Kliewer & Torres, 1992). Jackson & Lombard (1993), however, suggested that low night temperatures are necessary when day temperatures are warm for lower pH values and higher natural acidity.

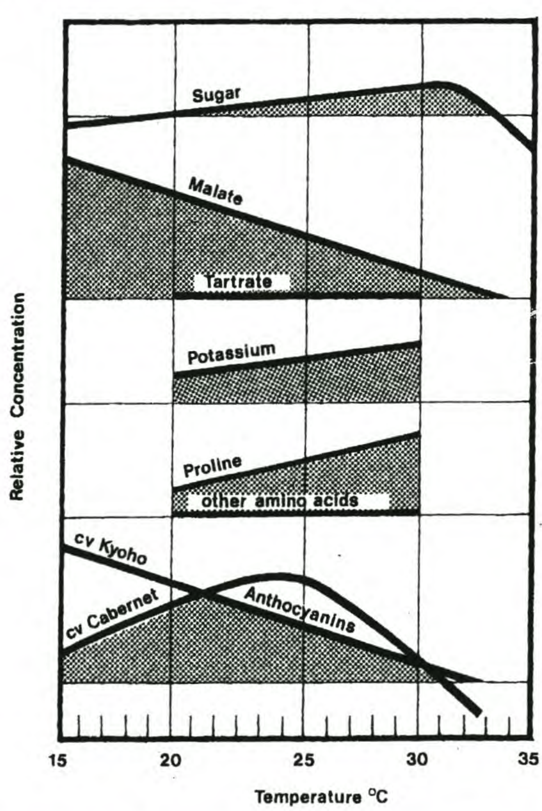


Fig. 2.2. Tentative diagram of generalised effects of temperature on the chemical composition of grape berries (Coombe, 1987).

2.3.1.2 Bioclimatic indices based on temperature

A number of bioclimatic indices have been used to describe the viticultural potential of a climate, many of them based on temperature (*inter alia* Branas *et al.*, 1946; Constantinescu, 1967; Winkler *et al.*, 1974; Smart & Dry, 1980; Huglin, 1986; Gladstones, 1992; De Villiers *et al.*, 1996; Tonietto, 1999). These indices have been developed to describe viticulture on a global scale (Branas *et al.*, 1946; Smart & Dry, 1980; Huglin, 1986; Gladstones, 1992; Tonietto, 1999), adapted for various countries (Le Roux, 1974; De Villiers *et al.*, 1996), developed for specific regions (Winkler *et al.*, 1974) or used only for a specific country (Constaninescu, 1967).

Heliothermic product

Branas *et al.* (1946) suggested the necessity of choosing climatic components and their combinations that have significance to describe the viticultural potential of an area. They found a close relationship between the heliothermic conditions of a site and the vegetative characteristics of grapevines grown in that area and proposed the following index to describe the viticultural potential of an area as well as the heliothermic requirements of cultivars. The index is calculated for the so-called annual favourable period, which will differ between site, cultivar and season. This period is the number of days during which the daily mean temperature exceeds or equals the "vegetative zero" i.e. the physiological base temperature, generally accepted as being 10°C. Although the "vegetative zero" value varies with season, a fixed value per cultivar can be established over a number of seasons for a specific site.

$$X.H.10^{-6}$$

where: $X = \sum(t_m - 10)$ for the favourable period (°C)

t_m = daily mean temperature (°C)

H = sun duration during the favourable period

The northern limit for viticulture is considered to be 2.6 units.

Day length is of less importance for lower latitudes and this index is therefore seldom used in the Southern Hemisphere.

Heliothermic index

The index used in this calculation is that of Huglin (IH), which attempts to relate the heliothermic conditions of a region over the growing season (September to March) to the potential of the region to ripen various cultivars (Huglin, as reported in Huglin, 1986).

$$IH = \sum_{01.10}^{31.03} \frac{[(Tm - 10) + (Tx - 10)]}{2} .k$$

where: IH = Huglin Index

Tm = daily mean temperature (°C)

Tx = daily maximum temperature (°C)

k = 1 for the South Western Cape (latitude ca. 33°S)

Coefficient k ranges between 1.02 to 1.06 for latitudes between 40° and 50°, and was introduced to accommodate for the greater day length and thus a high availability of photosynthetically active radiation at higher latitudes. As it has little significance for lower latitudes, a coefficient of one can be used for the South Western Cape (latitude ca. 33°S) (Huglin, 1986). Tonietto (1999) divided the Huglin index values into six classes of cultivation potential for grapevines (Table 2.1).

Table 2.1. Climatic classification of the cultivation potential according to the Huglin index (IH) (adapted from Tonietto, 1999).

HUGLIN INDEX	CLIMATE	VITICULTURAL POTENTIAL
IH1: 1400-1500	Very cool	Only very early cultivars can ripen. Hybrids resistant to cold can be used
IH2: 1500-1800	Cool	A large scale of cultivars can ripen
IH3: 1800-2100	Temperate	Late cultivars can reach maturity
IH4: 2100-2400	Warm temperate	No further heliothermic constraint for ripening
IH5: 2400-3000	Hot	Exceeds heliothermic requirements. Possible high temperature stress.
IH6: >3000	Very hot	Possibility of two harvests per year. Possible high temperature stress.

Cool nights index (Tonietto, 1999)

For the Southern Hemisphere, the mean minimum temperature of March is used as an indicator of night temperature in the cool nights index (IF - Tonietto, 1999) as many of the red cultivars ripen in March. Table 2.2 describes cultivation potential according to the mean minimum March temperature.

Table 2.2. Climatic classification of the cultivation potential according to the cool nights index (IF) (adapted from Tonietto, 1999).

MEAN MINIMUM MARCH TEMPERATURE (°C)	CLIMATE	CULTIVATION POTENTIAL
IF1: >18	Warm nights	High night temperatures throughout maturation period
IF2: 14-18	Temperate nights	Later cultivars ripen under conditions with cooler nights than earlier cultivars
IF3: 12-14	Cool nights	Ripening under cooler night temperatures
IF4: <12	Very cool nights	Critical night temperatures. Maturation depends on a sufficient heliothermic potential

Temperature variability index (Gladstones, 1992)

The temperature variability index for the growing season (Gladstones, 1992) is derived from the following formula

$$TVI = [(TD\max - TD\min) + (TM\max - TM\min)]$$

where: TD max and TD min are the mean daily maximum and minimum temperatures, TM max and TM min are the highest mean maximum and lowest mean minimum temperatures.

The higher the value obtained, the greater the temperature variability. Typical values for some inland Australian areas can be as high as 45, while typical values for most European viticultural areas are between 30 and 35.

Continentality (CTL)

This forms part of the climatic index of Smart & Dry (1980) and is calculated as the difference between the January mean temperature and July mean temperature. Five categories ranging from maritime (CTL<10°C) to very continental (CTL≥17.5°C) in 2.5°C increments were identified but no viticultural potential was associated with the grouping.

Growing degree days

Le Roux (1974) applied the heat summation technique of Amerine & Winkler (1944) to the South Western Cape.

$$GDD = \sum_{01.09}^{31.03} (Tm - 10)$$

where: GDD = Growing degree days (°C)

Tm = Daily mean temperature (°C)

The growing season was taken as September to March (inclusive of both months). The few available weather stations meant that indirect methods had to be used in order to determine the boundaries of the regions. Le Roux (1974) and De Villiers (1996) proposed the classification shown in Table 2.3.

Table 2.3. Climatic classification of regions for the South Western Cape viticultural areas (adapted from De Villiers, 1996).

DEGREE-DAYS (°C)	REGION	VITICULTURAL POTENTIAL
<1389	I	Quality red and white wine
1389-1666	II	Good quality red and white table wine
1667-1943	III	Red and white table wine and port
1944-2220	IV	Dessert wine, sherry and standard quality table wine
>2200	V	Dessert wine and brandy

Le Roux (1974) concluded that not all the classifications made were representative of the wine types expected from those areas. He recommended that the weather station network be increased and that plots should be monitored in order to determine the real applicability of the model. Another suggestion was that the mean temperature of the warmest month should be assessed for use as a demarcation criterion.

Mean February temperature (MFT)

These suggestions were addressed by De Villiers *et al.* (1996), who divided the South Western Cape into different climatic regions according to the mean February temperature, which was based on the concept of Smart & Dry (1980). These authors used the mean January temperature in Australia as it had a good correlation with the mean temperature of the warmest month for regions with the same continentality. De Villiers *et al.* (1996) decided to use the mean February temperature as it was the warmest month at 80 percent of the weather stations in the Western Cape and most grapes ripen during February and March and adapted the proposed viticultural potential classification for South African conditions (Table 2.4).

Table 2.4. Climatic classification of regions according to the mean February temperature (MFT) for the Western Cape viticultural areas (adapted from De Villiers *et al.*, 1996).

MFT °C	DESCRIPTION	POTENTIAL
17-18.9	Cold	High quality white table wine (High acids, low pH, excellent cultivar character)
19-20.9	Cool	High quality white and red table wines (High acids, low pH, excellent cultivar character)
21-22.9	Moderate	High quality red table wines (High acids, low pH, excellent cultivar character)
23-24.9	Hot	(Low acid, high pH)
>25	Very hot	(Low acid, high pH)

Bioclimatic index

Constantinescu (1967) described a more comprehensive climatic index to combine the ecological factors of temperature, insolation, rainfall and period of vegetative growth.

$$I_{bclim} = \frac{C_t \times Ci}{C_p \times 10} \; or \; \frac{\sum P \times \sum I_e}{\sum T_a \times N_{zva}} : 10$$

where:
- C_t Temperature coefficient
- Ci Insolation coefficient
- C_p Rainfall coefficient
- P Total rainfall
- I_e Total effective hours of insolation

T_a Sum of active temperatures (>10°C)

N_{zva} Number of days of vegetative growth

The optimum value for this index is 10 ± 5

The author suggested that for this index to be complete, a soil factor should be included. According to Huglin (1986), this index, although applicable for its country of origin, could not be used in many other countries and he suggests that the calculation of the components of evapotranspiration is the most rational way of integrating thermal, hydric and radiative conditions in a single formula.

2.3.2 Relative humidity and rainfall

Relative humidity and temperature determine the saturation deficit of the air, which is an important factor causing water stress in arid climates. Relative humidity has an effect on the photosynthetic rate when the soil water supply is limiting (Champagnol, 1984) and it has been shown that a high saturation deficit (associated with low relative humidity values and high temperatures) results in high berry pH values as well as reducing the growth and yield per unit water transpired (Gladstones, 1992). High relative humidity values can, however, increase disease incidence.

According to Champagnol (1984), maximum photosynthesis is achieved at values of 60-70% relative humidity. Gladstones (1992) associated relative humidity, in combination with other climatic factors, with various wine styles. In the range of 35% to 60%, the lower values were considered suitable for liqueur style wines while the higher values were associated with delicate white sparkling wines with some residual sugar.

Relative humidity

Smart & Dry (1980) use relative humidity values at 09:00 to compare regions. However, as it is the saturation deficit in the early afternoon that affects vine production and wine quality, Gladstones (1992) suggested that relative humidity at 15:00 is used to describe viticultural climates.

Aridity Indices

The index formulated by Riou in 1994, was reported and used by Tonietto (1999) for his global study of viticultural macroclimates.

$$IS = Wo + P - TV - ES$$

where: IS = Estimated soil water content at end of the six month period of 01 October to 31 March.

Wo = Initial soil water reserve available for uptake by the roots (assumed to be 200 mm for the sake of the global classification).

P = Total rainfall (mm) for the six month period of 01 October to 31 March.

TV = Potential transpiration (mm) by the vine for the six month period of 01 October to 31 March.

ES = Evaporation from the soil (mm) for the six month period of 01 October to 31 March.

$$TV = \sum_{01.10}^{31.03} (ETP.k)$$

$$ES = \sum_{01.10}^{31.03} (ETP / d).(1-k).JPm$$

where: ETP = Monthly evapotranspiration calculated according to the Penman formula (mm).

d = number of days in the month

JPm = Number of rain days estimated by monthly rainfall in mm/5

k = 0.1 for October, 0.3 for November and 0.5 for December to March.

The theory behind this formula has been discussed in detail by Tonietto (1999) and will not be further dealt with in this thesis. Tonietto's (1999) classifications are given in Table 2.5.

Table 2.5. Climatic classification based on Riou's aridity index (adapted from Tonietto, 1999)

ARIDITY INDEX (mm)	CLIMATE	POTENTIAL
IS_{00} >150	Humid	Excessive availability of water with respect to quality
IS_0 ≤150 >50	Sub-humid	Absence of drought
IS_1 ≤50 >-100	Moderate drought	Degree of drought favourable for maturity. Irrigation sometimes applied
IS_2 ≤-100 >-200	Severe drought	Pronounced drought, irrigation is mostly applied
IS_3 ≤-200	Very severe drought	Extreme deficits, irrigation is necessary for production

Another aridity calculation is that used by Smart & Dry (1980) in their climatic index. It is calculated for the growing season with the aid of the following formula:

$$\text{ARIDITY (mm)} = 0.5\text{Evaporation} - \text{Rainfall}$$

Values of lower than 199 mm describe a climate that is not arid while values of higher than 500 mm describe a very arid climate.

Bagnols & Gaussen (according to Galet, 1993) used climograms to determine arid months. These consist of graphs with two Y-axes, the first with temperature in °C and the second with monthly precipitation in mm (on a scale of double the temperature). A month is considered arid when the temperature curve passes above the rainfall curve.

2.3.3 Wind

Wind has both positive and negative effects for viticulture. Strong winds in spring and early summer can injure new growth and young bunches, as well as reducing fruit set. Moderate winds of higher than 3-4 $m.s^{-1}$ can result in closure of stomata in the leaves resulting in inhibition of photosynthesis (Freeman, Kliewer & Stern, 1982; Hamilton, R.P., 1989; Campbell-Clause, 1998). Air circulation, however, prevents high relative humidity and excessively high temperatures from developing in vine canopies.

Dumas, Lebon & Morlat (1997) found that in Alsatian vineyards, with associated complex topography, wind speed was the climatic parameter with the greatest spatial variability.

Where the masking features were sufficiently high, the wind speed was attenuated. Sites situated at higher altitudes experienced higher wind speeds, even in the presence of masking features. For sites with a relatively closed landscape, wind speed was reduced no matter the orientation of the wind or the altitude of the site. Jacquet & Morlat (1997) found that wind speeds were higher for stations situated at higher positions on gentle slopes, oriented towards the dominant winds. Due to the pronounced effect of masking features on ventilation characteristics of a landscape, Lebon (1993) formulated a method to characterise the openness of the landscape (as discussed in section 2.2.5).

Sea breeze

A sea breeze can be defined as a local wind occurring during the afternoon as a result of differential heating above the land and the sea (Bonnardot, 1997). It can be recognised by a change in direction and increase in wind speed in the afternoon. The sea breeze has an effect both on relative humidity and on diurnal temperature variation, resulting in lower temperatures and a temporal difference for the maximum temperature. Coastal sites have the benefit of dry land winds at night and moist sea breezes in the afternoon (Gladstones, 1992). These sea breezes not only result in reduced saturation deficit, but also a lower maximum temperature and slower decrease in evening temperature resulting in a longer period being optimal for photosynthesis and physiological ripening, while the increased relative humidity in the canopy is dissipated at night. Carrega (1995) found that after an initial increase in temperature (1.2°C over 1 km and 50 m altitude), the surface temperature decreased by 0.8°C over the next 6 km (and 200 m altitude). Reasons for the initial increase in temperature were discussed in section 2.2.1. 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).

2.3.4 Summary

There is no doubt as to the important effect of climate on wine quality and character. A number of climatic indices have been formulated to describe the potential of a region for viticulture. Many of these indices are based on temperature. These, however, only give a one-dimensional, macroscale view and it is important, therefore, also to include information pertaining to thermal amplitude and humidity in order to obtain a clearer picture.

All climatic parameters are affected to some degree by the topography of the region, resulting in notable spatial variation over short distances with wind speed having probably the highest degree of spatial variation. Temperature increases and relative humidity decreases with distance from the sea. Climatic studies on a regional scale should, therefore, take factors such as topography, distance from the sea and soil type into account.

2.4 Geology

Geology is considered by some authors to be the one of the most important static components of the terroir complex affecting the character and quality of the final product (e.g. Dubos, 1984) and has been used as a primary key to identify the "Unités Terroir de Base" in the Mid-Loire Valley (Morlat, 1996). Champagnol (1997) compared wines originating from terroirs with different parent material and compiled a simplified diagram of the interaction between wine aroma and tannic structure and the nature of the parent material (Fig. 2.3), but could not advance an explanation for these perceived differences. There is, however, no one single geological formation that results in wines of a high quality (Seguin, 1983) and in France grapevines can be found on almost every geological formation represented (Wilson, 1998). Seguin (1983) did, however, find that, although the wine may be of a constant high quality, there are discernible differences in aroma- and flavour characteristics as well as colour intensity of wines produced on different geological formations. It has been suggested that certain cultivars prefer certain geological formations (Fregoni, 1977; Seguin, 1986). Fregoni (1977) suggested that the geological origin, and even the age of the soil, influences the qualitative characteristics of wines. Huglin (1983) pointed out that soils originating from different parent material often have distinctive chemical compositions. As an example he stated that in Beaujolais, Gamay vines produce better quality wines on poorer soils stemming from granite and sandstone than on the deeper, rich soils from clay-limestone. However, he pointed out that other soil characteristics such as colour and texture also differ. From the literature it appears, primarily from the research by Seguin (1983, 1986), that the effect of geology on wine quality is mainly indirect and acts through its contribution to the physical properties of soils, affecting in turn the water supply to the vine.

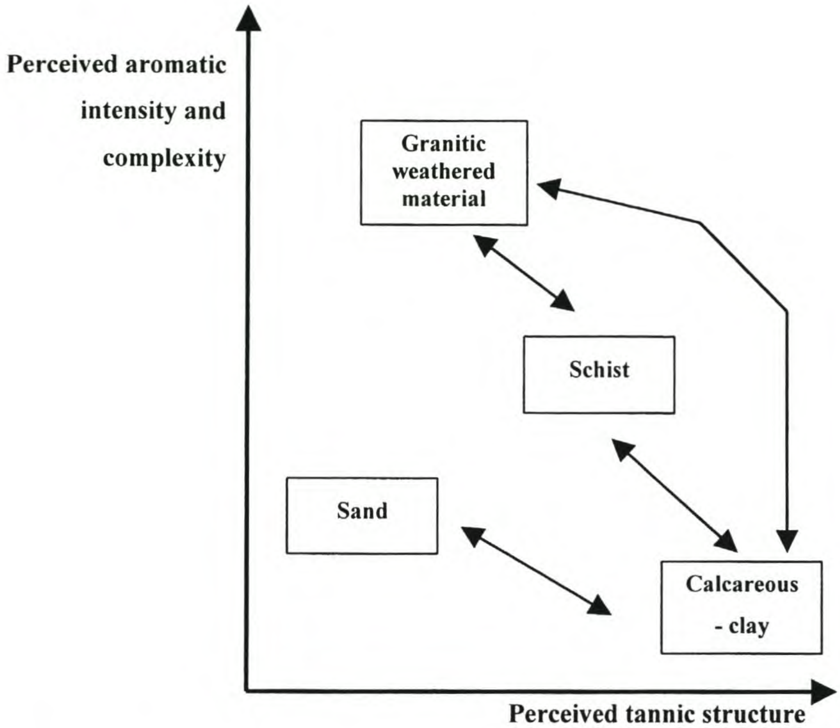


Fig. 2.3. Tentative diagram of effect of parent material on perceived wine aroma and tannic structure. Wines from experimental plots were compared in pairs (Champagnol, 1997).

2.4.1 Summary

Although geology is believed in some instances to be the most significant static terroir component, its effect on wine character is not clearly understood. Instinctively one believes that there must be an effect and the literature suggests that this effect is indirect, *via* the resulting potential soil water supply to the vine.

2.5 Soil factors

The effects of soil on wine character and quality is probably one of the most widely debated topics in viticulture. In France, the soil has been attributed the greatest influence in determining the qualitative potential of a viticultural environment (Fregoni, 1977; Huglin, 1983). Although the influence of the soil can often be confused with that of the cultivar/rootstock combination or the climate, different soils (discernable above other cultivation factors) are able to produce organoleptically differentiable wines (Fregoni, 1977). Amerine, Berg & Cruess (in Saayman, 1981) suggested that climate is the most important factor influencing viticulture in Europe and that soil affects quality by modifying the microclimate of the vine. As a result of research in America (Winkler *et al.*, 1974) and

Australia (Rankine *et al.*, 1971) it appears as if soil plays a subordinate role to climate in affecting wine quality in warmer regions. However, if one ignores extreme conditions, California has uniform, generally favourable soil within a region that may contribute to the observed predominant role of climate (Saayman, 1977). Saayman (1977) also points out that in the investigation performed in Australia by Rankine *et al.* (1971), the experimental outlay may have resulted in the confounding of the effects of soil and climate. Seguin (1986) suggests that there is no "hierarchy of crus" in "young" wine growing areas, i.e. those cultivars that are best adapted to local climatic and soil conditions have not always been discovered and terrain effects may therefore be distorted. Rankine *et al.* (1971) found that, in spite of no difference in wine quality, the soil type did influence the amounts of certain constituents of grapes and wine and factors such as soil depth, water holding capacity and drainage, rather than soil composition, had an effect. In South Africa it was found that soil had a definite effect on the quality of Chenin blanc and Cinsaut wines under the same climatic conditions but that the effect was not consistent over vintage years, suggesting an inter-relationship between soil and climate (Saayman, 1977). A similar interrelationship has been found with Sauvignon blanc under dry-land conditions in South Africa (Conradie, 1998).

Not only does soil temper climatic extremes, but climate is also one of the dominant soil forming factors (De Blij, 1983). Climatological information is inseparable from pedogenetic studies as climate and climate-dependant organisms are some of the most important factors affecting the formation of soil. In order for hard rock to be converted to soil, initial geochemical weathering must take place. This includes the processes of oxidation, reduction, hydration, solution and hydrolysis – all temperature and/or water dependent. Further pedogenetic processes are also usually climate dependant (J.J.N. Lambrechts, Senior lecturer Soil Science, U.S., 1993, personal communication). Soil distribution can therefore often be related to landscape positions. 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).

The effects of soils on grape composition and wine quality are complex in nature. Soil may affect nutrient availability, the microclimate due to its heat retaining and light reflecting capacity and root growth due to its penetrability or water availability (Jackson & Lombard, 1993).

2.5.1 Chemical composition and soil pH

A number of researchers have attempted to establish a correlation between the soil content of various assimilable ions and wine quality but, according to Seguin (1986), although tendencies may be established locally, they do not hold on a regional or worldwide basis. The chemical and physico-chemical properties of soils differ according to the soil origin but also due to management factors such as draining, liming, mineral fertilizers and organic or mineral additives (Seguin, 1986). The author suggests that this may occur to such an extent that in some cases soils no longer have their original characteristics.

Fregoni (1977) cited examples of areas where the chemical composition of the soil is correlated with the qualitative characteristics of the wine. In Northern Italy, for example, the cultivar Nebbiolo produces three distinct wines in a fairly limited zone with a uniform climate. The soil parent material differs. The quality of the wine decreased from Barolo to Barbaresco to Nebbiolo d'Alba. Concurrently, the following elements also decreased: active lime, potassium, boron, iron and manganese. Copper increased from Barolo to Nebbiolo d'Alba. It was also shown that the highest quality was obtained from vines with the highest concentration of microelements (Fe, Mn, Zn) in their leaves and grapes. The best wines from Barbaresco are produced from vines with leaves rich in both macro- and microelements. Fregoni (1977) did, however, point out that in spite of these correlations, there is not always a correlation between the chemical composition of the soil, leaves and grapes.

A number of authors have found a positive correlation between the poorness of the soil and the quality of the wines obtained from it (Dubos, 1984). A high nutritional status (with adequate moisture and temperature) has an indirect negative effect on wine quality in that it stimulates vigour, resulting in a high pH as well as affecting phenolic and aromatic compounds (Jackson & Lombard, 1993). High levels of nitrogen may increase berry susceptibility to rot, especially *Botrytis cinerea* (Jackson & Lombard, 1993). The nutrient requirements of the vine must, however, be met in order to ensure normal growth and reproduction. Conradie (1986) found that although the nitrogen supplying capacity of soils in the Western Cape deserves further study, it appears that the mineralising ability of soils containing one percent organic matter may be sufficient to satisfy the nitrogen demand of the grapevine. Also on soils with a minimum of 8% clay, leaching of nitrogen under Western Cape conditions does not appear to be excessive.

Nutrients absorbed in the proper quantity and ratio to each other and at a sufficient rate during the growth period will result in adequate growth (Danielson, 1972) but there are factors other than soil composition that affect nutrient uptake by plants. Release of nutrients from organic material and soil minerals is regulated by soil temperature, aeration and water supply (Danielson, 1972). The author explained that water logged, reducing conditions enhance the solubility of iron in the ferrous form, increase the soluble supply of phosphorous and restrict nitrification. The latter can lead to the accumulation of toxic quantities of nitrite. The exchange of adsorbed ions with those in solution fluctuates with the concentration of the solution (proportional to the soil water content) as long as the solution is not saturated. Furthermore, Danielson (1972) stated that soil physical characteristics can impede the maintenance of a solute concentration at the root through their effects on both root growth and nutrient movement in the soil solution. Although the nutrient supply can be modified by fertilisation, these elements tend to remain in the upper reaches of the soil.

If the soil physical conditions are favourable, a low level of assimilable nutrients in the upper soil layer will promote the spreading out of roots at a greater depth in search of elements (Seguin, 1986). This will improve the regularity of water supply to the vine. Even in rich soil, yield will not necessarily increase as one limiting factor, such as acidity, excessive potassium or nutrient deficiency, will cause the soil to act as if it is poor in all elements (Seguin, 1986).

Conradie (1988) estimated that 70% of the vines in the Western Cape are grown on soils with pH (KCl) values below 5.0. This author found that root development was restricted in acidic soils and this may have been be a response to an unfavourable physical structure, as well as aluminium toxicity. The free lime associated with higher pH values has an effect on the vine *via* its effect on the physical characteristics of the soil (Saayman, 1981). An acidic pH favours the absorption of micronutrients (excluding molybdene), while neutral and sub-alkaline pH favours the absorption of macronutrients. A pH below 4,8 results in symptoms of aluminium, manganese and copper phytotoxicity while a high pH (associated with a high active lime content) and high clay content have a negative influence on iron absorption (literature in Fregoni, 1977).

In the Douro valley (Portugal) wines are generally cultivated on acidic soils with pH values of 4.0-4.6 (Coutinho, Ahlrichs & Magalhaes, 1984). One of the most common symptoms observed in this region is that of boron deficiency but reduced vigour, low productivity and low calcium and magnesium leaf contents were also observed. The above authors linked the reddening and necrosis of the leaves to the acidity of the soils and resulting nutritional disequilibrium.

Bavaresco, Fregoni & Perino (1994) showed a large genetic variability between *Vitis* species in their degree of tolerance to lime induced chlorosis and suggested that it is likely that every species has its own genetic control of mineral nutrition in terms of nutritional requirements. This could be as a result of a genetically determined response of the grapevine roots to soil pH. The cultivar interaction is, therefore, vital in understanding this aspect of the soil effect on the vine.

Rankine *et al.* (1971) found that although soil type did not influence wine quality, soil depth, drainage and water holding capacity appeared to be more important than chemical composition in determining grape yields and composition. In Bordeaux, the chemical properties of the soils have been shown not to have a specific effect on the quality of wines if excessive nutrition of the vine does not result in excess vigour and if the vine does not suffer from toxicity or a serious deficiency of any element (Seguin, 1986). He concluded that with the knowledge at that period, it was "impossible to establish any correlation between the quality of wine and the soil content of any nutritive element, be it potassium, phosphorous or any other oligoelement". No literature from more recent years was found to contradict this statement.

2.5.2 Soil colour

The colour of soil is dependent on the parent material from which it was formed, as well as the pedogenetic factors that were and are operative (Saayman, 1981). Soil colour is significant in that (i) it influences the temperatures of the air closest to the ground as well as that of the soil, (ii) certain soil characteristics are associated with a specific colour and (iii) the quality and quantity of the reflected light may affect the leaf physiology. It is known that dark soils (damp, rich in iron oxides) absorb more solar radiation, while light soils (calcareous, stony, sandy) reflect the solar radiation (Fregoni, 1977).

Fregoni (1977) discussed results from experiments performed by various researchers with artificially coloured soils. The vines on dark soils had more vigorous growth but the yield was smaller due to coulure (berry shatter). The growth cycle duration varied with colour, the white soil resulting in the longest vegetative cycle. Some of the authors of these experiments (according to Fregoni, 1977) suggested that colour had two effects, namely, on the above ground growth and production and on root growth. Other authors (according to Fregoni, 1977) proposed, however, that the resulting soil temperature affected the onset of root activity rather than the above ground growth and production. Fregoni (1977) suggested that the colour and texture of the soil have an indirect effect on the biochemical processes occurring during the process of maturation. Jacquet & Morlat (1997) showed an interaction between the nature of the soil and the climate of the experimental plot in the Loire valley, due mainly to the relationship between the albedo (reflectance) of the soil and the global radiation, thermal conductivity and heat storage capacity. In recent artificial solarisation experiments in France, Sauvage *et al.* (2000) showed that both the quality and the quantity of reflected light have an effect on the relationship between sugar concentration of grape berries and their colour, with coloration being affected by the amount of reflected red light. The authors suggested that the effects were *via* the phytochrome system of the leaves. As a result they suggested that soil colour should become one of the descriptors of a terroir.

The above-mentioned observations are applicable to the cooler, northern viticultural regions and are not necessarily true of the warmer, southern areas. Saayman (1981) suggested that it is the implied soil characteristics that are more important than the colour itself. In high rainfall climates, red soils are associated with good soil drainage, while darker soils imply average to poor internal drainage. Light colours are usually indicative of extreme leaching and thus nutrient deficiencies. Gladstones (1992), however, also hypothesised about the effect of soil colour on wine quality in Australia, a warm country, and related it to the spectral quality of the radiated light. He suggested that the reflection of white, yellow, orange or reddish light could raise the red to far-red ratio with the resultant effects on the phytochrome system, resulting in increased fruitfulness and improved anthocyanin synthesis.

2.5.3 Soil temperature

Soil temperature is a function of the colour, texture and humidity of the soil. Fregoni (1977) suggested that soil temperature controls growth and absorption of the roots to such an extent that growth resulting from favourable soil conditions is more important for the nutrition of the plant and wine quality than the concentration of nutrients in the soil. Woodham & Alexander (1966) examined the effect of root temperature on the development of small fruiting Sultana vines. The vines were grown in culture solutions at 11, 20 and 30°C. Shoot, root and inflorescence growth increased with increasing root temperature. A root-temperature of 30°C resulted in vegetative growth for the full eight weeks of the experiment, while at 20°C growth slowed dramatically after flowering and at 11°C almost no growth occurred. The highest shoot: root ratio was obtained with a root temperature of 30°C. The percentage fruit set at 30°C was found to be more than twice that at 20°C. At 11°C poor set or bunch necrosis occurred. Skene & Kerridge (1967) found that at 30°C, the roots formed were longer and thinner in diameter than those at 20°C. Van Zyl & Van Huyssteen (1979) suggested that a high soil temperature hinders the storage of carbohydrates in roots.

Root temperature has also been found to affect the qualitative pattern of cytokinins in Sultanina vines (Skene & Kerridge, 1967). It was not clear whether this was as a result of a temperature effect on cytokinin production or interconversion, or due to own use by the roots. The authors did not want to suggest that this change in the qualitative pattern of cytokinin could explain the morphological differences resulting at different root temperatures but they did suggest that the cytokinins may be responsible for the improved fruit set of Sultana vines at a root temperature of 30°C. The root exudate of grapevines also contained gibberellin-like substances, which could be associated with the effects of root temperature on shoot elongation.

2.5.4 Soil texture and structure

Sand and pebbles on the soil surface reflect radiation from the sun and are good heat accumulators; this is then released at night. Surface shale also acts as a buffer against soil water evaporation and, therefore, reduces the resulting cooling effect that follows. Stony and sandy soils have the highest conductivity and therefore heat up the most rapidly, benefiting growth and root absorption (Fregoni, 1977). This affects quality positively *via* its effect on vine physiology in the Northern Hemisphere. However, in summer this heating effect could result in scorching of the berries. It is also important to remember that, although these factors are favourable for quality in cooler regions, in warmer winegrowing areas the increase in temperature results in degradation of the acid, aroma components and polyphenols of the grapes with a corresponding reduction in quality. As these modifying effects of the soil surface condition are restricted to the zone near the ground, in cooler areas trellis systems should be low, while in warmer areas higher trellises with foliage covering will result in a higher quality product (Fregoni, 1977).

Texture has a number of long recognised relationships with most other soil characteristics, for example, nutrient status, structural development, soil compaction, drainage etc. (Van Zyl & Van Huyssteen, 1979). These authors, therefore, suggest that it plays an important role in determining soil potential for wine grapes. Soil texture influences the vertical root distribution in the root zone (Nagarajah, 1987). Coarse textured soil provided a uniform root distribution while moderately coarse and fine textured soils resulted in a concentration of roots in the surface layers and a sharp reduction in root growth in the deeper horizons of the profile. This did not appear to be related to bulk density. Vertical root growth reduction was associated with increasing silt and clay content in the soil profile. Other factors that were suggested to play a role were soil strength, soil porosity and soil aeration. Nagarajah (1987) did not find any correlation between lateral root growth and soil texture. Rooting patterns are important for quality through influencing the availability of nutrients and soil water, and thus determining the buffer capacity of the soil against unfavourable climatic conditions.

The texture and structure of soils, both in the Northern and Southern Hemispheres, appear to have an effect on the grapevine *via* their effect on the water supply to the vine, and concomitantly, drainage. Sandy soils are well aerated, have a low water retention capacity and are excessively drained. Clay soils have characteristics opposite to these. There must therefore be a clay content at which the soil has an optimum water retention capacity (Van Zyl & Van Huyssteen, 1979). Seguin (1983, 1986), however, found that in Bordeaux and Burgundy, wine quality does not appear to be linked to soil texture as there is considerable variation in the gravel and pebble (0-50%) and clay (negligible-60%) content of the soil. The author stated that soil structure appeared to play a more important role. The best terrains have predominantly a high degree of macroporosity with concomitant superior drainage and prevention of frequent water logging and water stagnation at root level. Coarse soils and clay soils with sufficient humus and abundant calcium to flocculate the clay-humus complex are permeable (Seguin, 1986). These soils will have better aeration as well as being more easily penetrated by vine roots.

2.5.5 Soil depth

The effective depth of a soil determines, to a great extent, its ability to provide the vine with nutrients and moisture (Saayman, 1981). This is due to its effect on root growth. A soil that allows a deep, well-developed root system will provide a buffer against unfavourable conditions such as drought and malnutrition (Van Zyl & Van Huyssteen, 1979). Deep soils also have a cooler, more regular temperature that results in even root growth. Seguin (1986) stated that this constancy of soil environment determines a quality terroir.

The effective depth of the soil is determined by various constraints such as a dense clay subsoil, a fluctuating free water table, solid or weathering bedrock, alternating textured layers, a low pH (pH (KCl) below 5,1) with resulting aluminium toxicity and natural subsoil compaction (Van Zyl & Van Huyssteen, 1979). These authors found that the effective depth of the soil had an important interaction with climate in determining production levels.

In an investigation to determine the optimum depth of soil preparation for dry land viticulture on a Glenrosa soil, Conradie & Myburgh (1995) determined that the soil should be loosened to between 600 mm and 1000 mm. The cultivar used for the investigation was Pinot noir (phenologically early). Soil preparation deeper than 1000 mm resulted in excessive vigour due to increased nitrogen absorbtion by the larger root system and a reduction in wine quality. For later ripening cultivars the optimum soil depth would, however, probably be deeper than 600 mm in order to buffer the late season water stress.

Effective depth can be modified by means of various management practices. Soil preparation can effectively break compacted layers in order to allow root penetration. Liming can be used to raise the soil pH but must be placed in the subsoil during soil preparation in order to be effective. Ridging can be used in order to increase effective soil depth of waterlogged soils. Rootstocks differ in their adaptation to soil depth and can be used judiciously in order to attenuate the depth limiting characteristics.

2.5.6 Soil water status

In Mediterranean climates, which are characterised by a dry summer period, the agronomic potential of a soil can often be directly related to its potential to supply the vine's water requirements; water availability being the result of both the quantity of water present as well as the force with which this water is retained by the soil (Champagnol, 1997). Soil depth, texture and composition influence the soil water holding capacity of the soil and the available water for the vine. Those soils in which the vines can develop deep roots provide a relatively constant hydric pattern (Seguin, 1986). Soil type and soil water regime both influence rooting patterns (Van Zyl, 1988). Cultivars also differ in their response to soil water-holding capacity (Reynolds & Naylor, 1994).

Grapevine physiology is affected extensively by the soil moisture regime. Stomatal conductance and transpiration decreased with decreasing soil water-holding capacity while vines were not under conditions of water stress, but soil water holding capacity (directly related to texture of the soil) did not necessarily provide an additional significant limitation to vine growth once grapevines were already experiencing water stress (Reynolds & Naylor, 1994). In a field trial on Sauvignon blanc in South Africa, Conradie (1998) found that aroma profiles of wines from the same locality, but different soils, were different. This effect was, however, season dependant and appeared to be most closely related to the soil water status.

Soil factors must be considered in conjunction with the prevailing rainfall and evaporative demand (influenced by temperature, wind, cultural practices and cultivar differences). In temperate areas with high rainfall, good internal drainage is vital (Saayman, 1992). The author suggested that this is also an important characteristic in South Africa. Badly drained soils (characterised by blue or white horizon colours) must be avoided while moderately drained soils (red to yellowish brown colours) are preferred for dry land conditions. These soils should be deep with a good soil water-holding capacity and without root growth limiting layers. Naturally occurring lime (associated with soils with good drainage properties) is probably less important in relatively dry climates such as South Africa (Saayman, 1992). Duplex soils, generally considered inferior to deep red apedal and/or neocutanic soils due to their lower induced vine vigour and yield, induced a more consistent wine quality over different seasons (Saayman & Kleynhans, 1978). The subsoil with a high clay content ensured that the soil water reserve is sufficient for constant ripening of phenologically late cultivars.

2.5.7 Summary

That soil does have an effect on wine character and quality is certain, but whether this effect is direct or indirect is not clear. Although there appear to be a number of contributing factors such as soil colour, temperature and chemical composition, the most convincing indications are that the effect of soil type is through its physical properties and, more specifically, through the water supply to the grapevine. This must be considered in conjunction with the meso- and seasonal climate.

Deep soils without chemical or physical restraints for root development promote a well-developed root system with a high degree of buffering against climatic extremes and contribute to constancy of the product across vintages, irrespective of the seasonal climate.

3. Characterisation of the Bottelaryberg-Simonsberg-Helderberg winegrowing area using existing information

The following sections will concentrate on the environmental features of the Bottelaryberg-Simonsberg-Helderberg winegrowing area. Existing digital information will be discussed with reference to its applicability for identification of natural terroir units on a mesoclimatic scale. Certain cultivation and management practices that temper the natural factors and that are commonly practised in the Stellenbosch wine-growing region must, however, be kept in mind.

3.1 Viticultural practices

Viticultural management practices are not standard between vineyards but are usually adapted by the wine grower in order to best suite their conditions. Many of the vineyards are cultivated under dry land conditions, while supplementary irrigation is being increasingly practised in order to prevent excessive water stress during the dry summer months. Deep soil preparation practices (up to 1200 mm) result in deep rooting of vines even under what would otherwise have been unfavourable conditions. Drainage and, possibly, ridging increase the effective depth of soils. Liming during soil preparation alleviates the acidity of the sub-soils and phosphorous applications are invariably necessary. Vines are mostly spur pruned but the bud load per vine may differ. A number of different training and trellising methods are used, *inter alia* goblet vines, Perold trellis, 3,4 and 5 wire vertical trellises. Cordon height can vary between vineyards, with resulting temperature differences in the bunch zone. Summer canopy management practices are increasingly practised in order to obtain optimal sunlight penetration in the canopy. The emphasis of the O.I.V. Resolution VITI 2/93 (Anon, 1993) is that the delimited homogenous viticultural zones must be capable of yielding original vitivinicultural products of quality without major human intervention. Due to the dry and warm ripening period in the Bottelaryberg-Simonsberg-Helderberg winegrowing area (see section 3.2), a soil buffer is required to temper the climate-induced stresses. This buffer is provided by deep soil preparation with chemical additions and supplementary irrigation is frequently provided to alleviate moisture stress. Conversely, drainage and ridging may be used to reclaim soils in landscape positions that are unsuitable for viticulture. Certain long-term management decisions, therefore, have positive implications for viticulture, while others are not necessarily conducive to production of quality wines. Gladstones (1992) points out that although winemaking technology, plant material and vineyard management (within limits) can be changed, the static environmental factors of the vineyard are not amenable to control. The knowledge of the terroir, therefore, remains one of the most important aspects for long-term management decisions to create balanced vines for the production of wines of a high quality.

3.2 Topography

A narrow coastal plain is bordered by the NW-SE mountain ranges of Stellenboschberg (1175 m) and Simonsberg (1390 m) and the SW-NE Helderberg (1137 m). It is indented by the SW-NE Bottelaryberg (520 m). The Eerste River valley bisects the study area. This topography results in a large variation in aspect and altitude and affects the airflow in the region. According to the description of terrain morphology described by Schultz (1997; after Kruger), the study area has the following terrain morphology:

Key	**Description**
1	Plains with straight slopes, low relief (0-30 m) and more than 80% of the surface with slopes less than 5%.
9	Moderately undulating plains with concave or convex slope forms, moderate relief (30-210 m) and more than 80% of the surface with slopes less than 5%.
23	Free standing hills with concave or straight slope forms, moderately high relief (130-450 m) and less than 20% of the surface has slopes less than 5%.
26	Undulating hills with concave or convex slope forms, moderately high relief (130-450 m) and less than 20% of the surface has slopes less than 5%.

3.2 Climate

Kendrew (1961) describes the climate as being Mediterranean, although cooler than similar latitudes and altitudes in the Northern Hemisphere.

3.2.1 Temperature

Along the coast, the increase in temperature northwards is much smaller than the increase inland and monthly mean temperatures do not vary greatly from the annual mean due to the moderating influence of the sea (South African Weather Bureau, 1996).

De Villiers *et al.* (1996) digitised the GDD and MFT indices for the South Western Cape using the spatial distribution data of Schultz, Department of Agricultural Engineering, University of Natal. This mean monthly maximum and minimum temperature data has been adapted for altitude and landscape position on a grid of 1 minute of a degree (ca. 1.7 km). The broader, cool coastal area in the South Western Cape that was observed with the MFT index in comparison with the GDD index seems to agree more closely with what is found in reality, but this formula has been applied without taking continentality into account and the classification has not yet been tested. The digitised temperature distribution, quantified by the MFT and GDD indices, for the Bottelaryberg-Simonsberg-Helderberg study area is shown in Fig. 3.1 and 3.2. Ninety-five percent of the study area falls into Region III of the classification used by Le Roux (1974), with growing degree-days between 1666 and 1943. The remaining 5%, the south eastern part of the study area including the midslopes of the Helderberg with predominantly northern and western slopes, belong to Region II (with growing degree days between 1389 and 1666) (Fig. 3.1). The MFT index (Fig. 3.2) shows a similar picture with approximately 93% of the study area falling into the moderate category (21-22.9°C). The remaining cooler 7% also includes the midslopes of the Helderberg, as well as a small part of the south western portion of the study area. This index appears to make a greater allowance for the effect of the proximity to the sea on the temperature of the ripening month.

3.2.2 Rainfall and relative humidity

Due to the complex topography of the South Western Cape, the rainfall in this area is highly variable with the tendency being to decrease from west to east. Mountains receive the most rainfall with sheltered lowlands and enclosed valleys recording lower values (Kendrew, 1961). Mean annual precipitation ranges from 400-800 mm (Schultz, 1997). De Villiers *et al.* (1995) used evaporation figures, crop factors and rainfall for the growth season to determine rainfall classes for the Bottelaryberg-Simonsberg-Helderberg area. He concluded that rainfall during the growth season of below 200 mm would result in high levels of water stress for the grapevine, while more than 350 mm would result in vigorous growth. This data was captured on a grid of 1 minute of a degree (ca. 1.7 km). According to this study, summer rainfall higher than 350 mm was associated with mountains, 200-350 mm with the midslopes of Simonsberg, Stellenboschberg and Helderberg and below 200 mm with the greatest proportion of the study area.

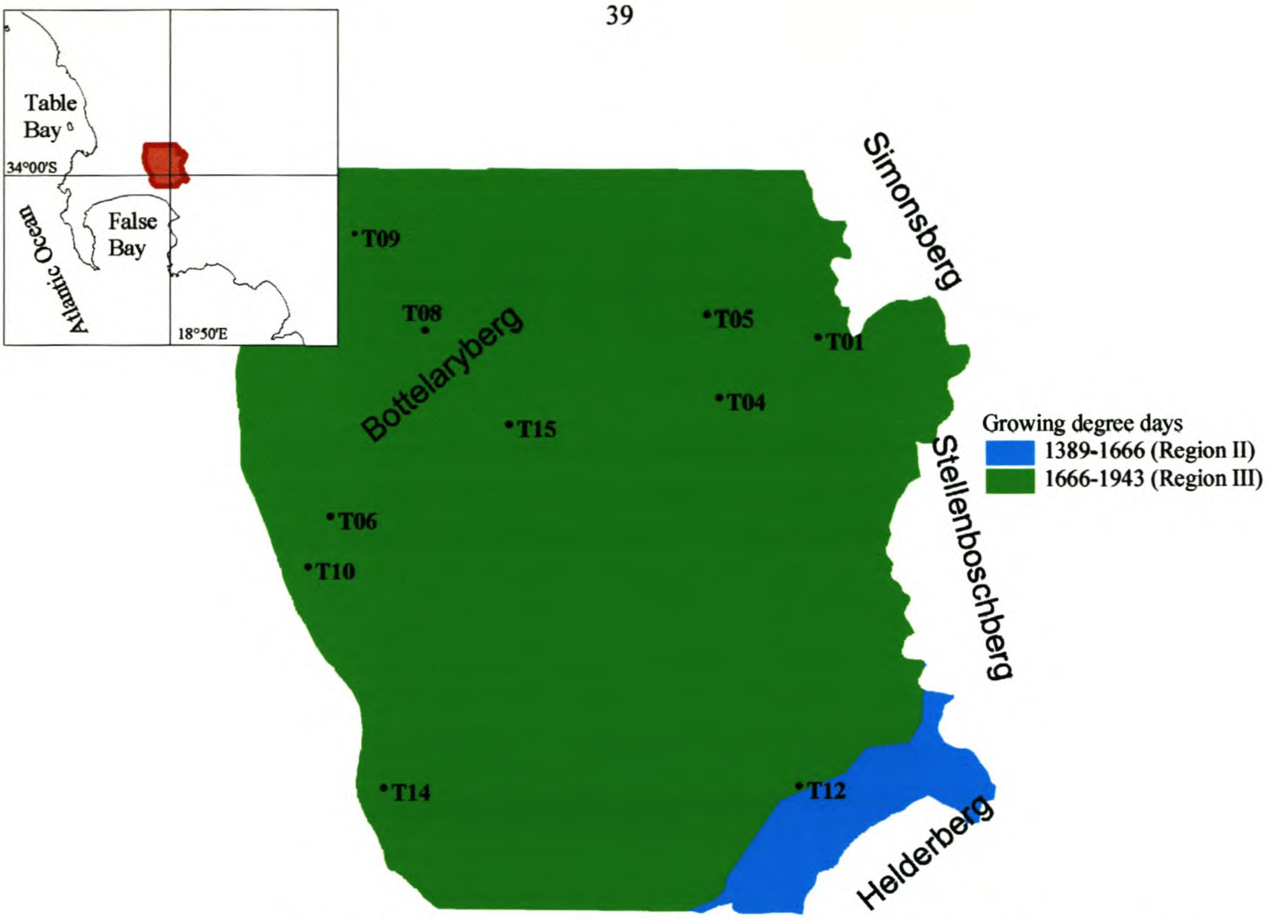


Fig. 3.1. Spatial variation of the Winkler Growing Degree Day Index in the Bottelaryberg-Simonsberg-Helderberg study area, as adapted by Le Roux (1974) and digitised by De Villiers *et al.* (1996).
Insert shows position of study area in relation to False Bay and Table Bay. T01-T15 are automatic weather stations.

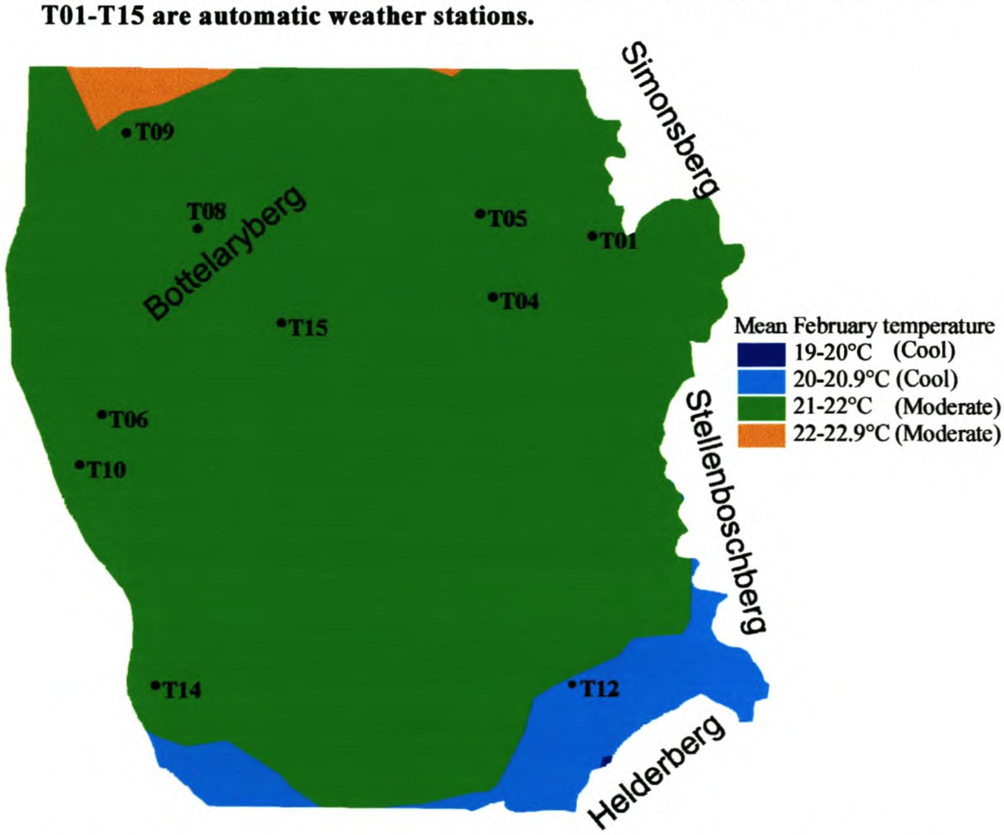


Fig. 3.2. Spatial variation of the mean February temperature index in the Bottelaryberg-Simonsberg-Helderberg study area, as adapted and digitised by De Villiers (1996).
T01-T15 are automatic weather stations.

Daily mean relative humidity for February is in the region of 66-72%, while the daily minimum relative humidity for February is approximately 48-52% (Schultz, 1997).

3.2.3 Wind

3.2.3.1 Synoptic scale

Kendrew (1961) and the South African Weather Bureau (1996) describe the summer winds as being strong southerly or south easterly while strong northerly and north westerly winds occur in winter. The mountain ranges in the South Western Cape cause the winds to blow along rather than across the coast, increasing their velocity. The proximity to the sea results in an interplay between land and sea breezes (Kendrew, 1961). Hot northerly and north easterly berg winds can also occur, usually in the morning as the sea breeze neutralises them in the afternoon (Kendrew, 1961).

3.2.3.2 Local scale

A study of the sea-breeze occurrence and its influence on temperature during February was initiated in the Stellenbosch-Klein Drakenstein area (Bonnardot, 1997). There were sufficient temperature differences between land and sea for the sea breeze to have occurred for approximately 80% of the days in February. The wind speed was higher at stations closest to the sea and decreased further inland. This also depended on slope aspect. Stations open to the sea also experienced a higher frequency of sea breezes during the study period. The sea breeze penetrated inland and was recorded at stations up to 45 km from Table Bay and 30 km from False Bay. In doing a temperature analysis, Bonnardot (1997) found that stations close to the sea and inland but open to the sea, or at high altitude, had the lowest maximum and minimum temperatures.

A Regional Atmospheric Modelling System (RAMS) using a 5 km grid was applied at two times for 4 February 2000 (climatic records close to average) to determine the penetration and effect of the sea breeze in the Western Cape (Planchon, Bonnardot & Cautenet, 2000) with the following results. In the morning (09:00 local time), a weak land wind (1-3 $m.s^{-1}$) rotated in the direction of False Bay. This opposed the synoptic wind from the south. The mountainous relief of the area surrounding Stellenbosch resulted in varied local circulations (slope breezes). At 17:00 local time, the sea breeze was in the same direction as the synoptic wind and, aided by the topography, penetrated inland from the direction of False Bay. These winds were strong (7-8 $m.s^{-1}$). For the Stellenbosch area, humid air only penetrated from the direction of False Bay as the sea breeze originating from the Atlantic Ocean (from the direction of Table Bay) only penetrated inland further north than Table Bay. The surface temperature already approached 25°C (optimum for photosynthesis, Kriedemann, 1977) at about 15 km from False Bay and 30°C (photosynthetic activity declines, Kriedemann, 1977) at approximately 37 km. The thermal threshold is situated in the environs of the Bottelaryberg hills. Even though the sea breeze penetrated further north from the direction of False Bay, according to the model and verified by data from weather stations in the vineyards, the associated temperature effect was not experienced beyond the Bottelaryberg. Even low relief results in upwelling of air and moisture loss, resulting in a reduced temperature effect. Western slopes, in spite of receiving the sea breeze (deviated from the direction of False Bay), do not show the typical effects of the sea breeze for this date (see east-west vertical transect in Planchon *et al.*, 2000).

3.3 Geology

The geology of the Bottelaryberg-Simonsberg-Helderberg study area is shown in Fig. 3.3 (Theron, 1990). The underlying rocks of the coastal plain belong to the Malmesbury group (830-980 Ma – of the Namibian Epoch, pre-Cambrian), which includes shales, schist, phyllite and greywacke (Theron *et al.*, 1992). In the study area this group is mainly represented by rocks of the Tygerberg formation, which is only found to the west of the Saldanha-Franschoek Fault Zone, while on the higher slopes of the Simonsberg, the Franschoek formation is found (composed of conglomerate with subordinate grit and shale) (Theron *et. al.*, 1992). The pile of sediments belonging to the Malmesbury group was compressed into tight folds during orogeny (mountain building - mainly through westward directed pressure, Theron *et. al.*, 1992) and the rocks are therefore susceptible to weathering and erosion (Anon., undated). Granite intrusions occurred during the Cambrian period (630 –500 Ma). The Cape Granite Suite in the study area is represented by two plutons, namely, the Kuils River-Helderberg pluton and the Stellenbosch pluton. The Kuils River pluton consists predominantly of coarse-grained, porphyrytic granite (containing K-feldspar, quartz, plagioclase and muscovite). The Stellenbosch pluton has been fragmented in the north by a number of faults and in the south and east is hidden by sandstones of the Table Mountain group. Most of the pluton consists of coarse-grained biotite granite with large, conspicuous alkali-feldspar crystals (Theron *et al.*, 1992). 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-

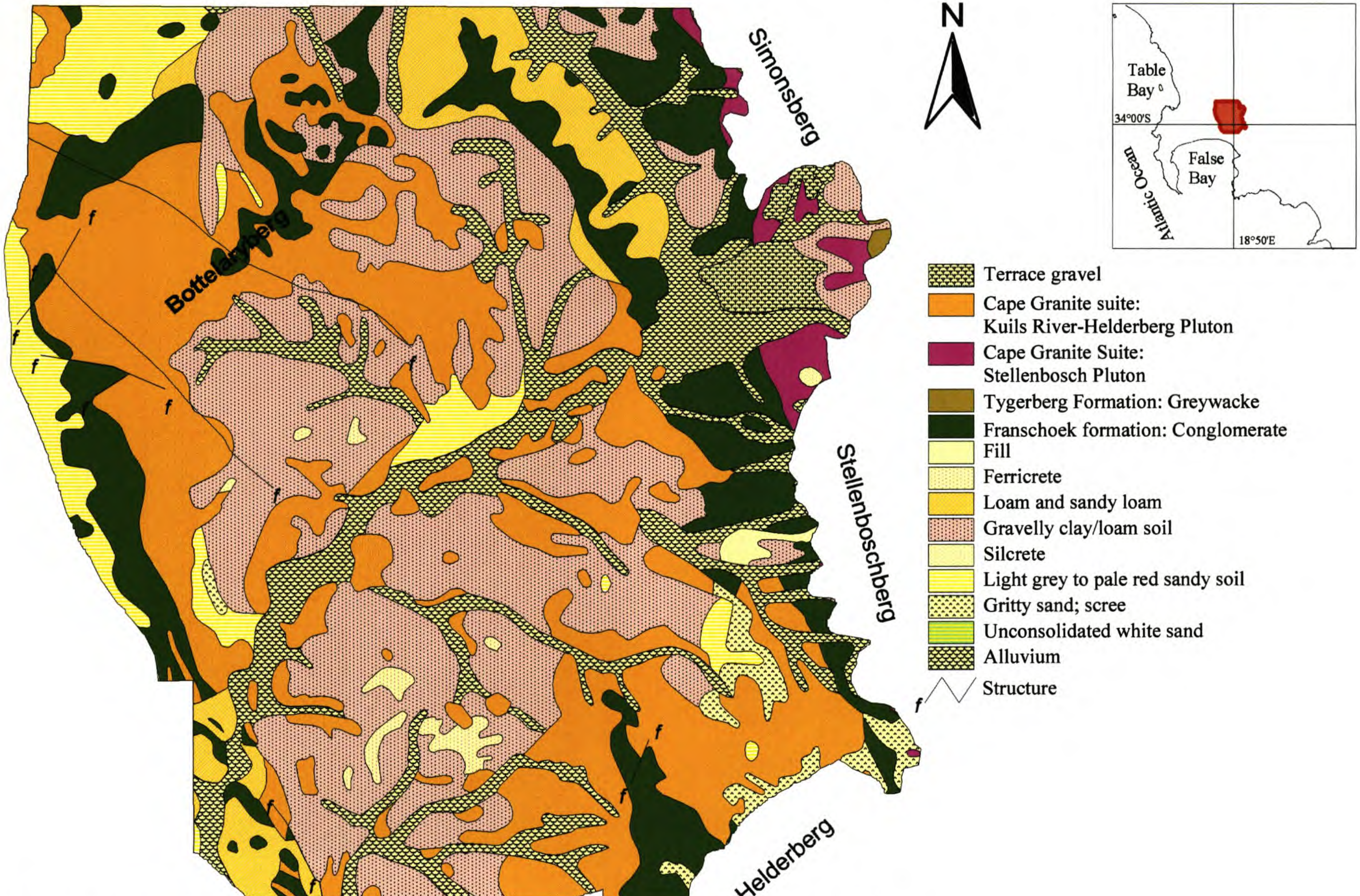


Fig. 3.3. The geology of the Bottelaryberg-Simonsberg-Helderberg study area (after Theron, 1990). Insert shows position of study area in relation to False Bay and Table Bay.

metamorphic effect of the Cape granite intrusion (Theron *et. al.*, 1992). Erosion levelled the resulting mountain land to sea level and further subsiding of the land allowed the deposition of the Cape Supergroup sediments (600 – 425 Ma) (Anon., undated). The Peninsula Formation is the most significant in the topography of the study area (Theron *et al.*, 1992) and was deposited in the Silurian and Ordovician epochs (SACS, 1999). This was followed by Permian to Triassic Cape Orogeny (Theron *et al.*, 1992). Subsequently the sandstones and shales of this Cape Supergroup, which originally covered the coastal plain, have mostly eroded away leaving remnants such as the Cape Peninsula and Simonsberg (Anon., undated). Quartenary sediments and soils are also present throughout this region. The Springfonteyn and Witzand Formations consist mainly of aeolian sand. Other unnamed deposits include silcrete, ferricrete, flood-plain deposits, varied soils, terrace-gravel layers and scree on mountain slopes (Theron *et al.*, 1992). The soils formed *in situ* on Malmesbury rocks (Qg) are usually yellow, red or brown. They have a high clay content and often contain small nodules of ferricrete and quartz (Theron *et al.*, 1992). Weathered granitic soils (Qgg) are generally reddish to light brown, sandy to gritty and clayey. They sometimes contain thin layers of grit and pebbles (Theron *et al.*, 1992). Alluvium is found in the river and stream courses, much of which would have a Table Mountain sandstone origin, and therefore, a sandy texture. The more clayey alluvium probably has Malmesbury rocks as a source (Theron *et al.*, 1992). The geology of the Bottelaryberg-Simonsberg-Helderberg study area is, therefore, complex.

It is particularly difficult to associate geology with derived soils in the Stellenbosch wine growing 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, 1998). Often the material from which the soil has developed has a very different geological origin to that of the underlying "parent" material. Transported granitic soils can overlie Malmesbury bedrock (Theron *et al.*, 1992). The only soil group for which the geology of the parent material is of obvious importance will be the residual soils with Mispah, Glenrosa and Swartland soil forms as examples.

3.4 Soil distribution

3.4.1 Land types

A land type can be described as a class of land for which the macroclimate, terrain morphological form and soil pattern are reasonably homogenous (Soil Classification Working Group, 1991). A land type inventory gives the predominant slope inclination and slope shape for each terrain morphological unit. The different soil forms, soil depth, clay percentage for A, E and B-horizons and mechanical limitations per terrain morphological unit are also given. For certain of the terrain units in the study area, up to 12 different soil forms are present. Although the soils were originally mapped on a scale of 1:50 000, the land types have been mapped on a scale of 1:250 000. Broad soil patterns have been used to describe the individual land types in order to create a general legend for land type maps. These broad soil patterns provide the reader with an indication of the soils in the area. Once the land type has been allocated a broad soil pattern, it is given the first available number for the respective soil pattern resulting in a key e.g. Ac17, Db52, Fa144 etc. The land types present in the Bottelaryberg-Simonsberg-Helderberg study area are shown in Fig. 3.4. A brief description of their characteristics is given in Appendix I.

From Fig. 3.4 and the above descriptions it can be seen that the red-yellow apedal soils (Ac) can be found on the footslopes of the Simonsberg, Helderberg and Stellenboschberg and a small area in the centre of the study area. Plinthic and duplex soils (Ba and Ca) are found on the lower crests and slopes of the Bottelary hills and the lower footslopes and plains associated with the Helderberg and Stellenboschberg. Duplex soils (Db) are situated to the south of the Bottelaryberg hills and on the west bank of the Eerste River. Residual soils (Fa) are found in the southwest of the study area. Sands (Hb) are situated to the north of the Bottelaryberg while the deep, unconsolidated material (Ia) is found in the environs of Stellenbosch.

Although the dominant soil types per terrain morphological type are given in the memoirs associated with the maps, their spatial distribution within the land type is not indicated and this data can, therefore, not be used for an in-depth study of soils in the area.

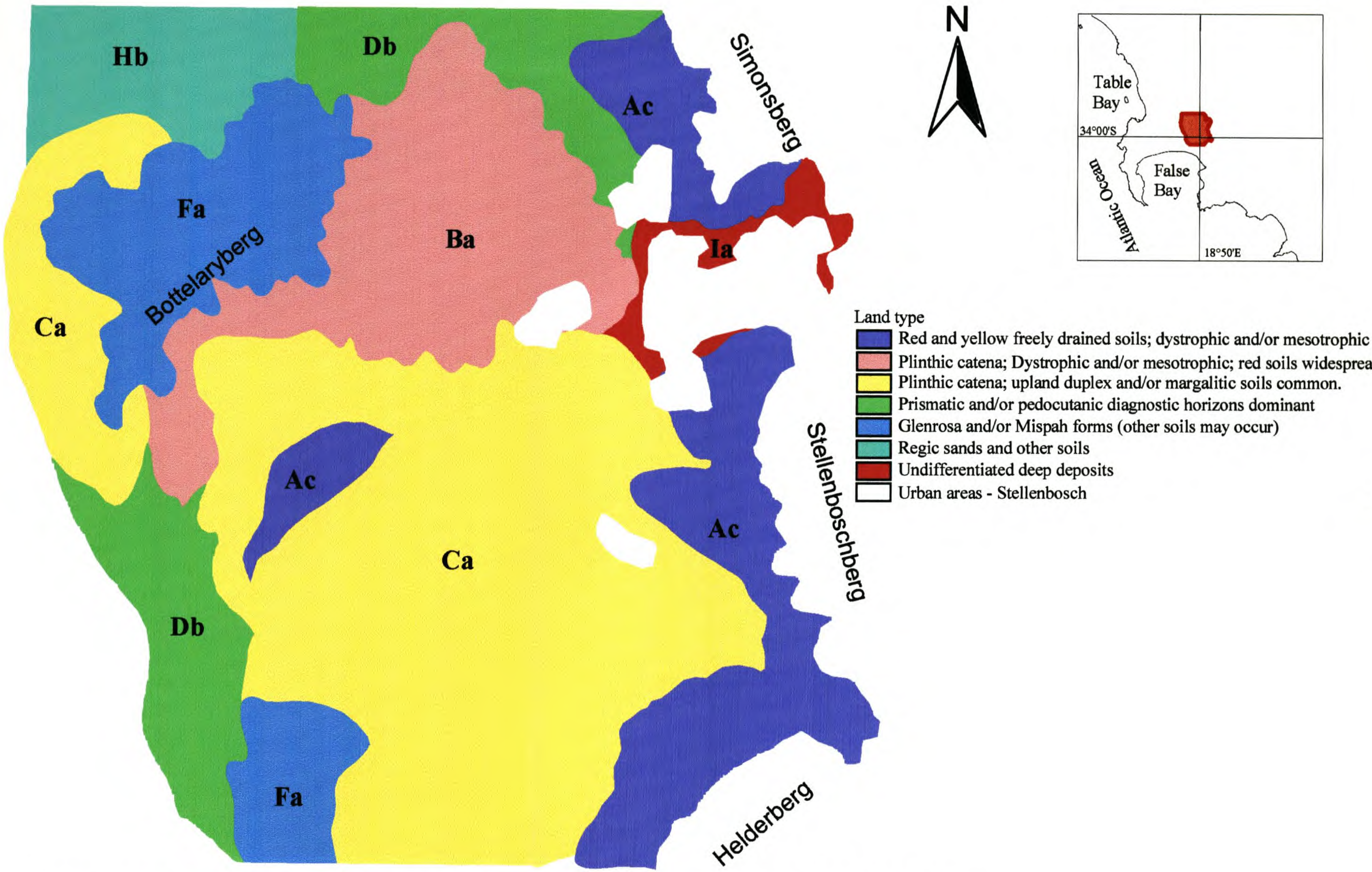


Fig. 3.4. Land types in the Bottelaryberg-Simonsberg-Helderberg study area. Digital data obtained from ARC-Institute for Soil, Climate and Water.
Insert shows position of study area in relation to False Bay and Table Bay.

3.4.2 Soil associations

Peri-urban soil survey

The most detailed soil data available for the Bottelaryberg-Simonsberg-Helderberg study area is that of the Peri-Urban Soil Survey mapped on a scale of 1:25 000 and 1:50 000 by Ellis *et al.* (1975), Ellis *et al.* (1976) respectively (Fig. 3.5). The soil groups were mapped on 1:10 000 orthophotos and then transferred to 1:50 000 topo-cadastral maps. The alluvial soils follow the valleys closely. A distinction is made between poorly drained alluvial sands and deep, well drained alluvial sands. Duplex soils are grouped according to degree of wetness as well as relative depth. Red and yellow apedal soils are grouped according to their relative depth and stone content. The less dominant soil types present in the soil associations are also indicated in the descriptive code. The texture of the soils is, however, not given (other than that implicit in the soil form).

Residual soils are found in the environs of the Bottelaryberg hills, slopes of the Helderberg and the south of the study area. The Bottelaryberg hills, Simonsberg, Stellenboschberg, Helderberg and the south of the study area have red and yellow apedal soils on their slopes. Dry duplex soils are found in higher lying positions than shallow wet duplex soils, which are found mostly in the southern portion of the study area. Medium deep wet duplex soils are common in the lower lying regions of the study area. Alluvial soils (dry and wet) mostly follow valley floors. A combination of saline duplex soils and deep sands are found in the most north west part of the study area. This map shows a widespread distribution of residual soils.

Soil associations

The soil associations of the Western Cape were mapped on a scale of 1:250 000 by Ellis *et al.* (1980). The dominant soil forms (MacVicar *et al.*, 1977) were grouped and described by associated soil forms, soil depth (<250 cm, <350 cm, <450 cm and >450 cm), clay content (4%, <10%, <15%, >15%) and general description of the association. This map gives a general indication of the soils found in the Bottelaryberg-Simonsberg-Helderberg study area (Fig. 3.6), but can not be used for any in-depth analysis due to its small scale. Alluvial soils are present along the courses of the Eerste River and its tributaries, to the north west of Stellenbosch and above 400 m on the WNW slopes of the Helderberg. Red and yellow mesotrophic to distrophic neocutanic and apedal soils (such as Oakleaf, Clovelly and Hutton) are found mainly on the footslopes of the Bottelaryberg, Simonsberg, Helderberg and

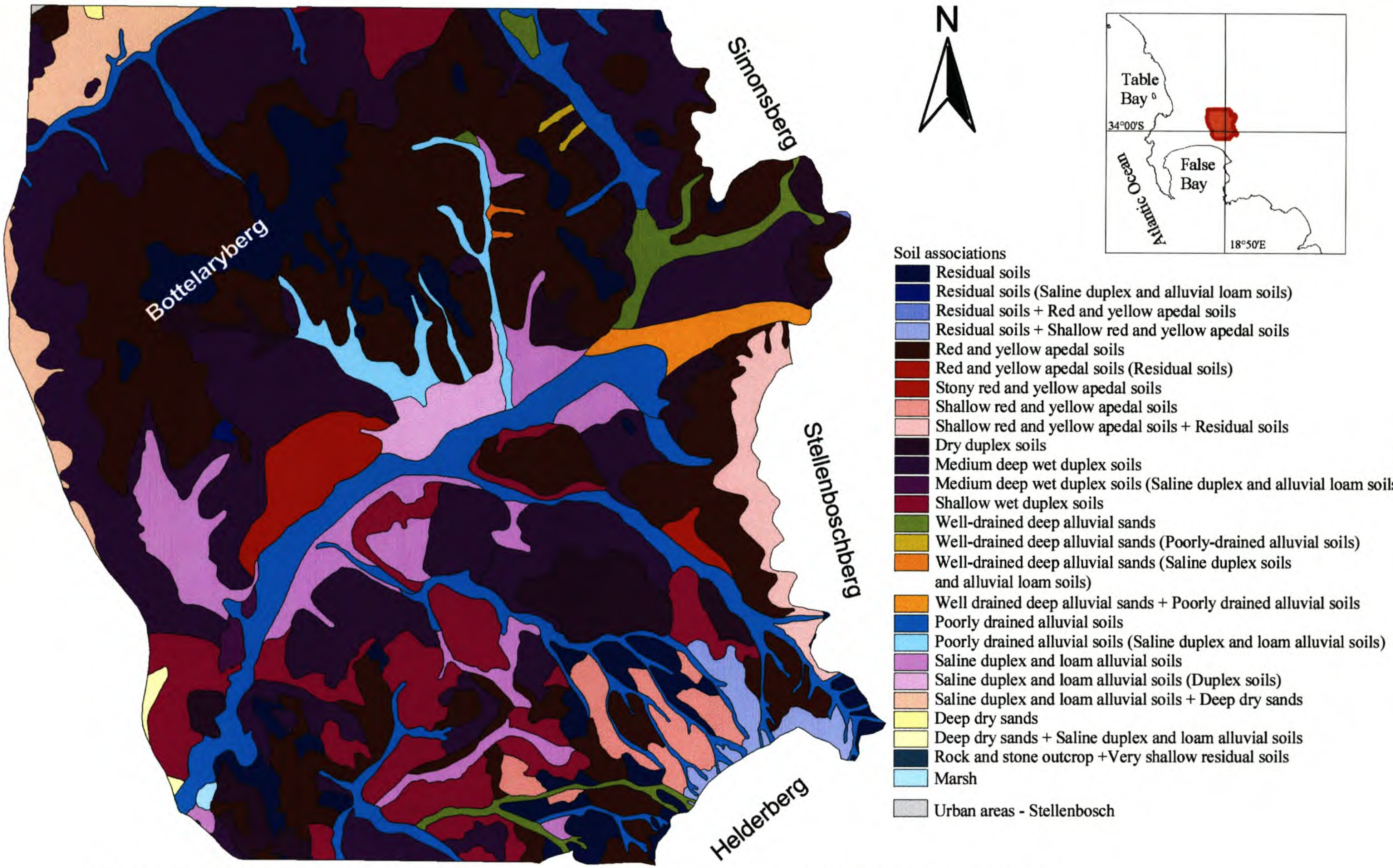


Fig. 3.5. Soil associations in the Bottelaryberg-Simonsberg-Helderberg study area (after Ellis *et al.*, 1975, 1976). Scale of base data is 1:25 000 and 1:50 000. Insert shows position of study area in relation to False Bay and Table Bay.

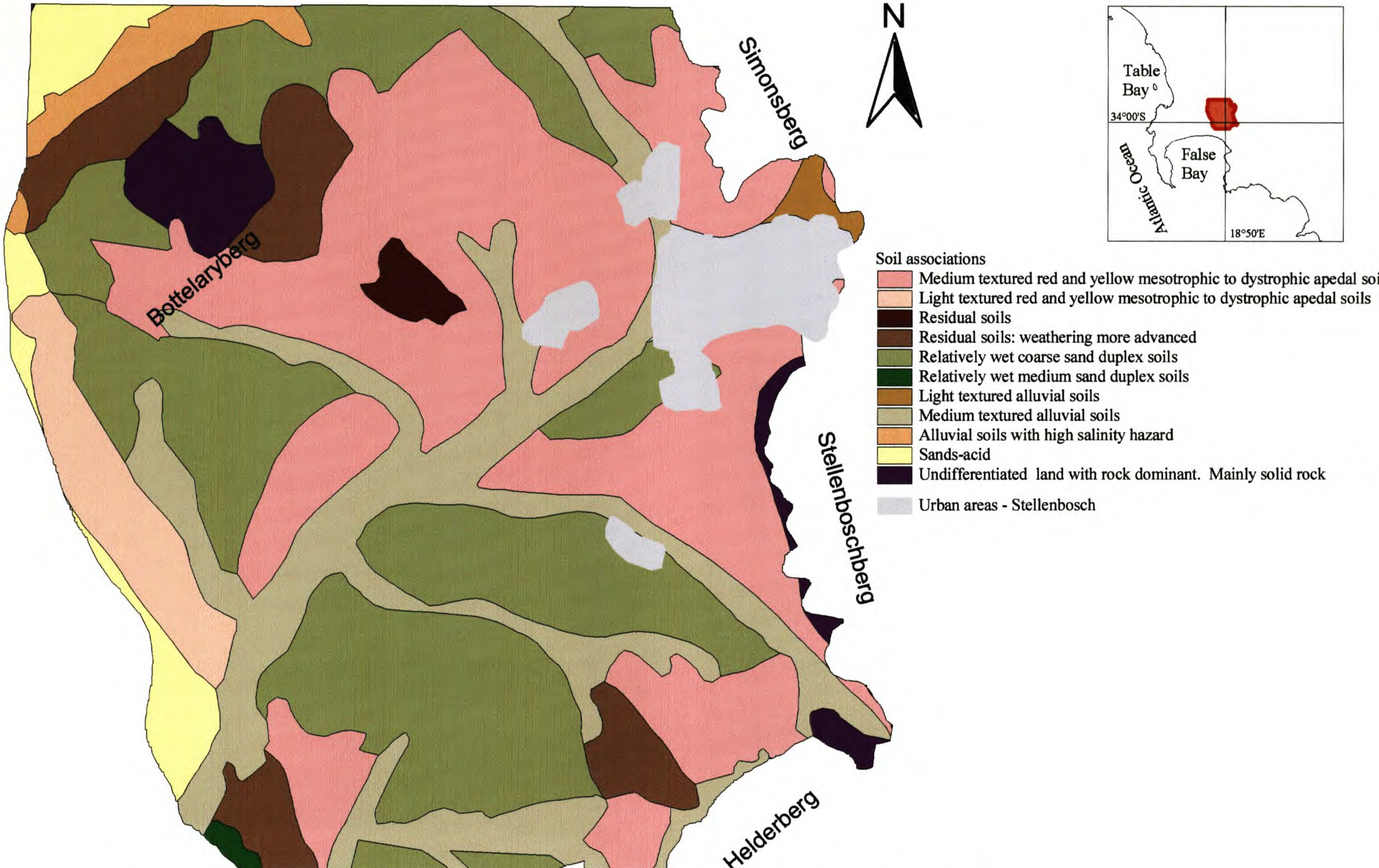


Fig. 3.6. Soil associations in the Bottelaryberg-Simonsberg-Helderberg study area (after Ellis *et al.*, 1980). Scale of base data is 1:250 000. Insert shows position of study area in relation to False Bay and Table Bay.

Stellenboschberg. Small areas of residual soils are present on Bottelaryberg hills, WNW slope of Helderberg, in the south of the study area and to the northwest of the Bottelaryberg hills. Undifferentiated soils are situated on the NE slope of the Helderberg and on the upper slopes of the Stellenboschberg. Duplex soils are generally found in lower lying areas. Sandy soils are found to the extreme northwest and west of the study area.

4. Materials and methods

4.1 Identification of study area

The study area (Fig. 4.1) includes the footslopes of the Simonsberg, midslopes and footslopes of Stellenboschberg and Helderberg, the Eerste river valley and the Bottelaryberg hills (henceforth to be referred to as the Bottelaryberg-Simonsberg-Helderberg wine-growing area or study area). This study area falls within the Stellenbosch wine-producing district, to the west and south west of the town of Stellenbosch. It covers an area of approximately 25 000 ha and contains diverse topographic features. The proximity to the ocean and the presence of two predominant currents, the cold Benguela current along the west coast and in Table Bay and the warm Agulhas current along the south coast and in False Bay, play an important role in the climatic patterns of the area.

Vineyards in this coastal area are found predominately between 60 m and 300 m above sea level, on granite foothills and protuberances associated with the mountains of the Table Mountain sandstone group with mainly duplex and apedal and neocutanic red and yellow, intensively weathered granite soils (Saayman, 1981). The soils are generally acidic and have a low cation exchange capacity and organic material content (Saayman, 1981)

This study area was chosen for a number of reasons:

i). It is situated in one of the most important areas for quality wine production in the Western Cape,

ii). Its proximity to ARC Infruitec-Nietvoorbij allows easy and regular access to the experimental sites,

iii). It represents a complex area containing coastal plain, river valley, free standing hills, mountain slopes and a wide variety of altitude and aspects,

iv). It has already been the subject of a number of studies and there is, therefore, already much existing data,

v). There are complex climatic patterns resulting from the topography and proximity to the sea.

Land types (explained in section 3.4.1), and imaginary lines in the north and south, were used to delimit the boundaries of the study area.

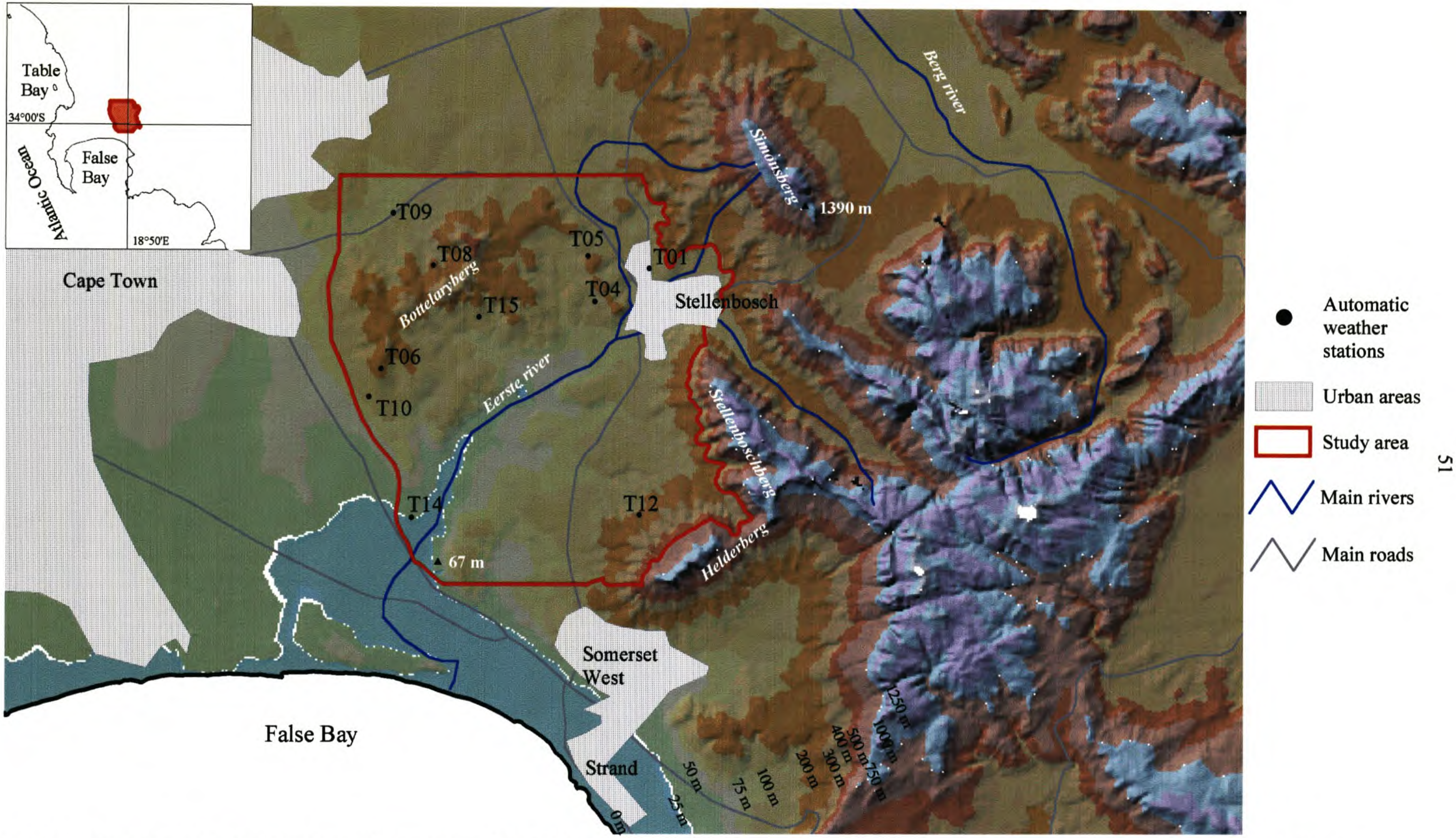


Fig. 4.1. Position of Bottelaryberg-Simonsberg-Helderberg study area in relation to the coastline and other geographical features. Insert shows position of study area in relation to False Bay and Table Bay.

4.2 Climatic data

A network of automatic weather stations has been established in the Bottelaryberg-Simonsberg-Helderberg study area since 1994 (Table 4.1). These weather stations are either situated in the vine row (in the case of T04, T05 and T06) or on open ground, representing various landscape positions. The parameters of temperature, dry and wet bulb temperature, rainfall, radiation, sun duration, wind speed and wind direction are recorded every 6 min. These values are averaged or summed, depending on whether or not the parameter is cumulative in nature, for the period of an hour. The temperature sensors are housed in a Stevenson screen 1.2 m above ground level. ARC Institute for Soil, Climate and Water, AgroMet, manages the climatic databank.

Data generated by the automatic weather station network for the period 1995 to 2000 was used to calculate a number of climatic variables and indices relevant to viticulture in the South Western Cape. For the theory behind the relevant indices, refer to section 2.3.1.

Table 4.1. Attributes of the automatic weather station (AWS) network in the Bottelaryberg-Simonsberg-Helderberg study area (adapted from Bonnardot, 1997).

AWS Code	Area represented	Altitude (m)	Aspect	Slope (%)	Distance from False Bay (km)	Distance from Table Bay (km)
T01	Stellenbosch	148	SW	3	20	35
T04	Papegaaiberg	148	NW	10	18	33
T05	Devon Valley	210	WNW	12	20	32
T06	Kuils River	250	ESE	15	13	24
T08	Bottelary	235	N	9	19	27
T09	Bottelary	110	N	6	20	24
T10	Kuils River	130	SW	9	12	24
T12	Helderberg	225	NNW	14	12	36
T14	Faure	27	S	5	7	28
T15	Stellenboschkloof	153	S	15	16	28

4.3 Topographic data

Terrain morphological units

It was shown in Fig. 2.1 that terrain morphological units describe certain landscape attributes such as slope inclination and slope type. These terrain morphological units are used as a basis for the description of attributes of land types and have an important implication for agriculture. A map of terrain morphological units (compiled by M. Wallace, Department of Agriculture: Western Cape, with the aid of Spatial Analyst in ArcView®) for the Bottelaryberg-Simonsberg-Helderberg study area was obtained (Appendix II). A digital elevation model (DEM) of 50 m, obtained from the Chief Director of Surveys and Mapping, was used to identify these units. In short, the definitions of the crests and valley-bottoms were based on the movement of water and further refined by excluding slopes above a certain threshold. The distinction between midslope and footslope was based on distances from crests and valley bottoms. This method has since been further refined and it is possible to adjust the ratio of the various terrain morphological units to approximate the proportion described in the Land type Memoirs (Macvicar, 1984, as an example). The data used for this study was the initial, unrefined method but probably does not differ much in appearance from the newer model (M. Wallace, Department of Agriculture: Western Cape, 2000. Personal communication). These terrain morphological units were used as a basis to create landscape units.

Aspect

The importance of aspect for the determination of mesoclimate, as well as its significance for viticulture, has been discussed in detail in section 2.2.2. The 50 m DEM data, mentioned above, was used to identify the four chief compass directions of north, south, east and west (Fig. 4.2) using the Triangulation Network of ArcInfo® (Department of Agriculture: Western Cape) to create aspect maps for the Bottelaryberg-Simonsberg-Helderberg study area (Appendix III).

The "intersect theme" function of ArcView® 3.0a x-tools extension was used to divide the terrain morphological units with the aid of both aspect maps. This resulted in oriented terrain morphological units with the following aspects: north (315° to 45°), north west (270°to 315°), south west (225° to 270°), south (135° to 225°), south east (90° to 135°) and north east (45° to 90°).

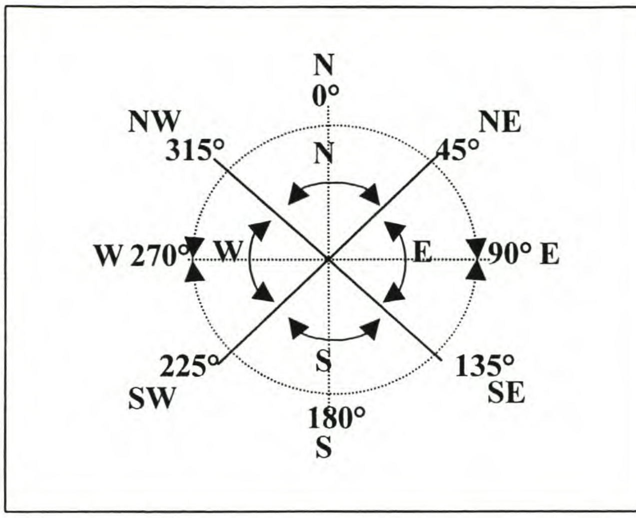


Fig. 4.2. Compass directions used for the determination of aspect for the Bottelaryberg-Simonsberg-Helderberg study area.

Altitude

As discussed in section 2.2.1, altitude has an important effect on spatial temperature variability and is therefore one of the primary determinants of mesoclimate. The altitude map created from the 50 m DEM data by Department of Agriculture (Appendix IV) was used to create polygons of approximately 100 m intervals (0-100 m, 100-200 m, 200-300 m, 300-400 m, >400 m). The "intersect theme" function of ArcView® 3.0a x-tools extension was used to divide the orientated terrain morphological units into altitude categories, resulting in landscape units described by means of their position in the landscape, aspect and altitude (Appendix V).

4.4 Soils

The digital soil data from the combined Peri-Urban soil surveys of Ellis *et al.* (1975, 1976), being the most detailed digital soil data available for the Bottelaryberg-Simonsberg-Helderberg study area, was used to further refine the landscape units with the "intersect theme" function of ArcView® 3.0a. Secondary soil types were ignored and only the main soil types were included. This resulted in units with terrain morphological type, aspect, altitude and general soil description attributes (soil-landscape units).

Soil profile studies using the South African binomial soil classification system (Soil Classification Working Group, 1991) were performed at sites in the study area (D. Saayman, Distillers, 2000. Personal communication) in order to verify the digital soil data. The position of each of these sites was digitised and overlayed on the soil association data from Ellis *et al.* (1980) and the more detailed data of Ellis *et al.* (1975 & 1976) with the aid of ArcView 3.0a®.

4.5 Geology

Geological digital data was obtained from the Council for Geoscience, Pretoria. Due to the high degree of tectonic movement and mixing of geological material in the South Western Cape, geological attributes were only given to landscape units containing residual soils (*in situ* soil weathering). The geological origin of the other soil types is uncertain. Due to the small scale of the geological data (originally mapped at 1:250 000), it was not used to intersect the soil-landscape units. The two maps were overlaid and the "select by theme" function of Arc View® 3.0a was used to identify the associated geology for each residual soil-landscape unit. Where the soil-landscape unit contained more than one geological parent material it was divided if the proportion of the two geological formations was similar. If there was a definite dominant geological formation for that soil-landscape unit, the unit was given the attributes of the said geological formation. Five categories were used for this classification.

1.) **GR** No distinction was drawn between the granites belonging to the different plutons. The reddish to light brown, sandy to gritty, clayey soils are products of weathered granite (Qgg) and were therefore included in this category.

2.) **SH** The greywacke of the Tygerberg formation (Malmesbury group) formed a second class with the *in situ* weathered material formed on Malmesbury rocks (Qg). This is usually yellow, red or brown with a high clay content.

3.) **QS** Cenozoic deposits of sedimentary rocks and sand.

4.) **F** Ferricrete. Loose nodules or iron cemented zones.

5.) **CG** The Franschoek formation consists of conglomerate and grit horizons (Theron *et al.*, 1992).

4.6 Natural terroir units

The soil landscape units obtained from the various overlays of digital data were grouped as follows:

a) All land unsuitable for viticulture was grouped, irrespective of landscape position, aspect or altitude. This included valley bottoms (terrain morphological unit 5), poorly drained alluvial soils, rocky outcrops and urban areas.

b) Units that were homogenous with respect to the following factors were grouped:

i) Three categories of aspect were used: north west (north and north west i.e. 270° to 45°, passing through 0°), south-west (south and south west i.e. 135° to 270°) and east (45° to 135°).

ii) The altitude categories remained as follows: 0-100 m, 100-200 m, 200-300 m, 300-400 m and 400-550 m.

iii) Although there are many different soil forms, they can be grouped into four main categories. The soil associations were grouped as follows:

Residual soils (A). This group includes the shallow soils of Mispah, Glenrosa and Cartref forms. The limit to root growth in this category will be parent material in various stages of weathering (lithocutanic or saprolite horizons) and a leached E horizon. Weathered granite has a high percentage of quarts particles, resulting in a higher proportion of sand and/or grit together with the clay, while weathered shale generally has a higher clay content. Weathered sandstone is sandy in texture and is poor in mineral elements. The potential of the soil for viticulture will depend on the nature of the decayed parent material with shales being considered excellent for quality (D. Saayman, Distillers, 2000. Personal communication).

Red and yellow apedal soils (B). This group includes the medium deep, shallow and stony phases of the red and yellow apedal soils of Hutton, Clovelly, Avalon, Bainsvlei and Pinedene forms and neocutanic soils of Oakleaf and Tukulu soil forms. These soils can have limits to root growth due to a high bulk density in the subsoil and/or a low pH. They have excellent drainage as well as generally good water retention properties.

Duplex soils (D). This group includes the medium deep dry and medium deep wet, shallow wet duplex and medium deep duplex soils of the Swartland (high salinity hazard), Sterkspruit, Glenrosa, Kroonstad, Longlands, Estcourt, Wasbank and Valsrivier forms. These soils have a relatively sandy topsoil above a subsoil with a markedly higher clay content. The change in texture results in a limit to root growth and often in a perched water table resulting in an E-horison. These soils have excellent drainage in the topsoil and good soil water retention in the subsoil, a combination resulting in restricted but sustained growing conditions.

Sandy soils (S). This group includes the deep alluvial sands and deep dry sands of the Dundee, Oakleaf and Fernwood forms. The limits to root growth are stratification, if present, and low levels of organic material and nutrients. These soils have a low water retention capability and require irrigation.

5. Results and discussion

5.1 Climate

5.1.1 General climatic description of the Bottelaryberg-Simonsberg-Helderberg study area.

Using the mean data from the weather station network and the description of Peguy (referred to in Tonietto, 1999), the climate of the area can be described as Mediterranean. It has a predominant winter rainfall with the summer rainfall for the period of December, January, and February being less than one sixth of the annual rainfall. The coldest month has a mean temperature lower than 15°C and at least eight of the monthly mean temperatures are higher than 10°C (Fig. 5.1).

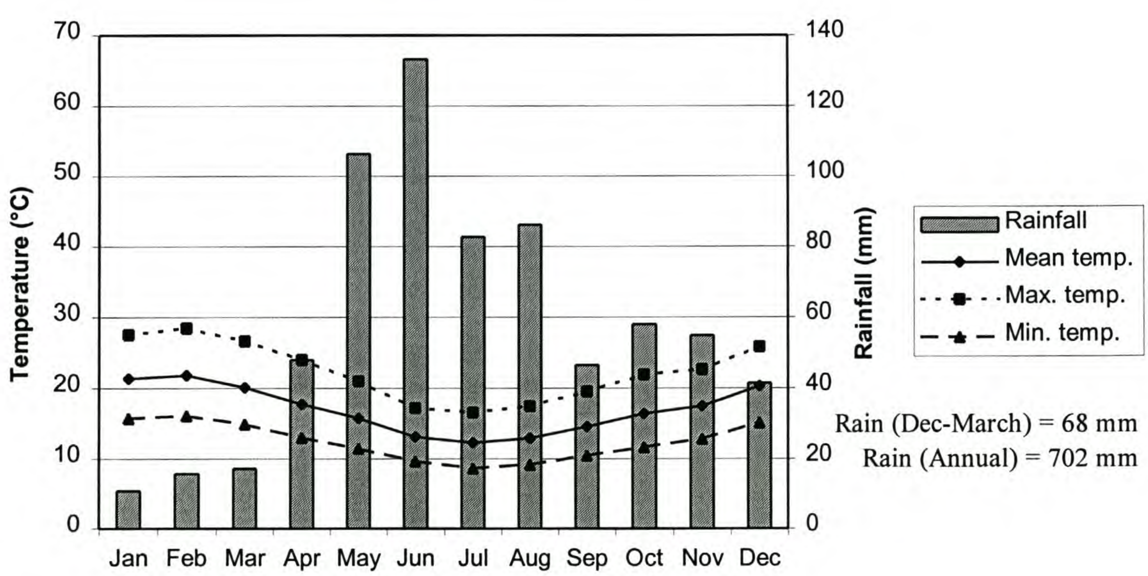


Fig. 5.1. Mean monthly temperature and rainfall values averaged for 11 weather stations in the Bottelaryberg-Simonsberg-Helderberg study area for the period 1995 to 1999. Compiled from data supplied by ARC-ISCW AgroMet.

According to the global climatic classification of Tonietto (1999) and Table 5.1, the average climatic values for the study area show that it has a warm temperate climate with no heliothermic constraints for the ripening of cultivars (IH4). The temperate nights (IF2) can be expected to cause later ripening cultivars to ripen under cooler night conditions than earlier cultivars. The pronounced drought period (January to February, according to the index of Bagnouls & Gaussen, in Galet 1993) generally requires irrigation of the vineyards (IS2). This classification places the study area in the same group as Madrid (Spain) and Lisbon and Evora (Portugal).

Calculation of the average growing degree-days for the Bottelaryberg-Simonsberg-Helderberg study area (1995-2000) according to the method of Le Roux, places the study area in category III (Table 5.1). The average for the MFT index places the study area in the moderate category. This suggests that the Bottelaryberg-Simonsberg-Helderberg wine growing area is suitable for the production of red and white table wine, especially red wine, and port.

These global climatic indices were also applied at the scale of individual weather stations and compared to available digital data. According to Fig. 3.1 and 3.2, all the automatic weather stations fall into Region III (1667-1943°C) and only T12 falls into the cool category (19-20.9°C) of the MFT index. On the contrary, Table 5.1 shows that for the five-year period of 1995-2000, stations T04, T12, T14 and T15 fall into Region IV (1944-2220°C) of the Winkler index, while the remaining stations can be classified as Region III. For this same period, T06 and T10 fell into the cool category of the MFT index, while the remainder of the stations, including T12, were moderate (21-22.9°C).

All the automatic weather stations for which there is data belong to category IH3 (1800-2100) of Huglin's heliothermic index (Table 5.1).

The IF index (mean minimum March temperature) (Table 5.1) shows that there is no discrimination between automatic weather stations in the Bottelaryberg-Simonsberg-Helderberg study area with respect to the cool nights index as all the automatic weather stations fall into category IF2 (14-18°C).

The Temperature variability index for the period 1995 to 2000 was obtained for the months of January, February and March (Table 5.1). This data represents the final ripening months of early, middle and late ripening cultivars respectively. Temperature variability decreased from January to March. The station with consistently one of the lowest values for temperature variability was T08. This could be due to a number of factors, such as its position on the midslope of a hill and relatively high altitude (probably above thermal inversion layer that could develop at night – see sections 2.2.1 and 5.1.2.2), proximity to the Atlantic Ocean and proximity to a stream. Other stations with little temperature variability are those close to the

Table 5.1. Mean values for some climatic parameters and indices for the period 08/1995-03/2000 for the automatic weather station (AWS) network in the Bottelaryberg-Simonsberg-Helderberg study area. Compiled from data supplied by ARC-ISCW AgroMet.

AWS	GDD[1] (Sep-March) (°C)	MFT[2] (°C)	Max temp. (Feb.) (°C)	IH[3] (Oct-March) (°C)	IF[4] (March) (°C)	IS[5] (Oct-Match) (mm)	TVI[6] (Jan) (°C)	TVI[6] (Feb.) (°C)	TVI[6] (March) (°C)	Rainfall (Apr-Aug) (mm)	Rainfall (Dec-Feb) (mm)	RH[7] (15:00) (Feb) %	Wind from S/SW/W[8] (Feb) (%)	Wind $>4 m.s^{-1}$ [9] (Dec-Mar) (%)
T01	1886	21.82	27.96	2308	16.5	-215	39.8	37.7	37.1	423.45	58.8	48.26	79.5	52.07
T04	1947	22.12	29.56	2350	15.6	-196	42.8	41.4	40.5	490.55	59.2	53.68	13.9	3.86
T05	1844	21.58	28.64	2301	15.7	-184	40.7	39	38.2	379.40	56.6	57.48	52.4	25.77
T06	*[10]	20.90	27.34	*	15.8	-160	36.7	34.5	32.1	458.25	67.8	57.7	78.6	18.52
T08	1805	21.12	27.02	2169	16.4	-148	34.4	33.9	32.7	418.90	60.2	55.2	72.2	68.5
T09[11]	*	21.63	28.56	*	15.8	*	40.8	39.5	38.7	472.00	60.6	51.8	*	*
T10	1791	20.94	26.92	2171	16	-194	38.3	35	34	338.75	44.4	55.28	84.3	61.67
T12	1975	22.34	28.98	2377	17	-140	37.7	36.6	34.5	492.40	84.6	56.4	64.8	17.92
T14	1968	22.10	28.04	2338	16.4	-207	38.4	37	37.6	361.70	60.2	55.42	76.7	43.61
T15	1954	22.02	28.16	2321	16.8	-193	37.6	35.4	34.1	582.40	66.4	54.62	66.2	42.36
AVG[12]	1896	21.66	28.07	2292	16.2	-182	38.5	36.7	35.6	438.42	62.0	54.89	65.4	37.14

[1] GDD=Summation of temperatures above 10°C for the growth season (Le Roux, 1974).
[2] Mean February Temperature (De Villiers, 1996).
[3] Heliothermic index (Huglin, 1978).
[4] Cool Nights Index (Tonietto, 1999).
[5] Aridity Index (Riou *et al,* as reported in Tonietto, 1999)).
[6] Temperature variability index (Gladstones, 1992).
[7] Average percentage Relative Humidity at 15:00.
[8] Percentage of wind occurring from the south, southwest and west during February.
[9] Percentage of recorded winds with a speed greater than $4 m.s^{-1}$ for the period December to February.
[10] * denotes missing value.
[11] Average for period 08/1995 to 08/1998.
[12] Average of 9 stations, excludes data from automatic weather station T09.

sea on slopes greater than 10% and/or on convex positions (stations T06, T10, T12, T15). Automatic weather station T04, on a footslope, recorded the highest temperature variability.

Riou's aridity index (see section 2.3.2) shows that most of the stations fall into the category with severe drought (Table 2.5 and Table 5.1), while T01 and T14 are classified as having very severe drought conditions requiring irrigation (classification according to Tonietto, 1999). The initial soil water reserve (Wo) used by Tonietto (1999) for his global viticultural study has been used in these calculations. It is important to stress that no soil information has been taken into account in this calculation and using a true value for Wo may well change the existing classification. As was suggested in section 2.5, the spatial variation of soils can be associated with the variation in landscape. Also, as mentioned in section 2.2.4, lower positions on especially concave slopes have an accumulation of soil water. Position in the landscape should, therefore, also affect this index if true Wo values (at present unavailable) were to be used.

It must be emphasised that five years of climatic data is insufficient to draw conclusions, but, because each of the seasons has been very different climatically, these averages provide an idea of expected trends. It is clear from the global indices used and the available digital climatic data that, though invaluable for regional planning and the evaluation of macroclimates for viticulture, they do not provide sufficiently detailed information for the identification of natural terroir units on a mesoclimatic scale. A number of other factors that have already been mentioned, such as aspect, altitude, slope inclination, slope shape, degree of openness of the site, soil colour, nature of the soil surface etc. must be taken into account for such an identification. Tonietto (1999) states that although the global climatic indices are very informative, it is necessary to analyse the interaction of the climate with natural and anthropological factors in a region if we wish to examine the climate of the said region in greater depth.

5.1.2 Spatial climatic variation in the Bottelaryberg-Simonsberg-Helderberg study area

In order to examine the effects of some of the factors affecting meso (or topo) climate, pertinent weather stations were compared. The positions of the automatic weather stations mentioned in the following sections in relation to the topography of the study area can be seen in Fig. 4.1.

5.1.2.1 Effect of proximity to the sea on climate in the Bottelaryberg-Simonsberg-Helderberg study area

Wind direction and velocity

As has been previously discussed, the proximity of the study area to the ocean results in a sea breeze effect. As the presence of a sea breeze is characterised by a change in wind direction and an increase in wind speed in the afternoon, mean data for two stations with the same aspect (SW), namely, T10 (12 km from False Bay) and T01 (20 km from False Bay) were compared (Fig. 5.2 & 5.3) to determine whether the sea breeze reached as far as T01 – one of the stations situated the furthest away from False Bay. Both T01 and T10 recorded a mean increase in wind speed during the afternoon, with T01 recording a slightly delayed affect.

Another station (T14) was compared to the above-mentioned two stations in order to show the effect of a closed position in the landscape on air movement. Station T14 is placed behind an avenue of palm trees and near an historical graveyard with white-painted walls. Both these obstacles to air movement are situated to the south-southwest of the weather station. As a result, despite being situated even closer to False Bay than T10, the wind speed in the afternoon (Fig. 5.2) is attenuated.

All stations also recorded a change in wind direction from predominantly north and north east (land origin) at 05:00 to predominantly west and south west (sea origin) at 15:00. Both changes in wind speed and wind direction would suggest that the sea breeze reached as far as T01 (20 km from False Bay).

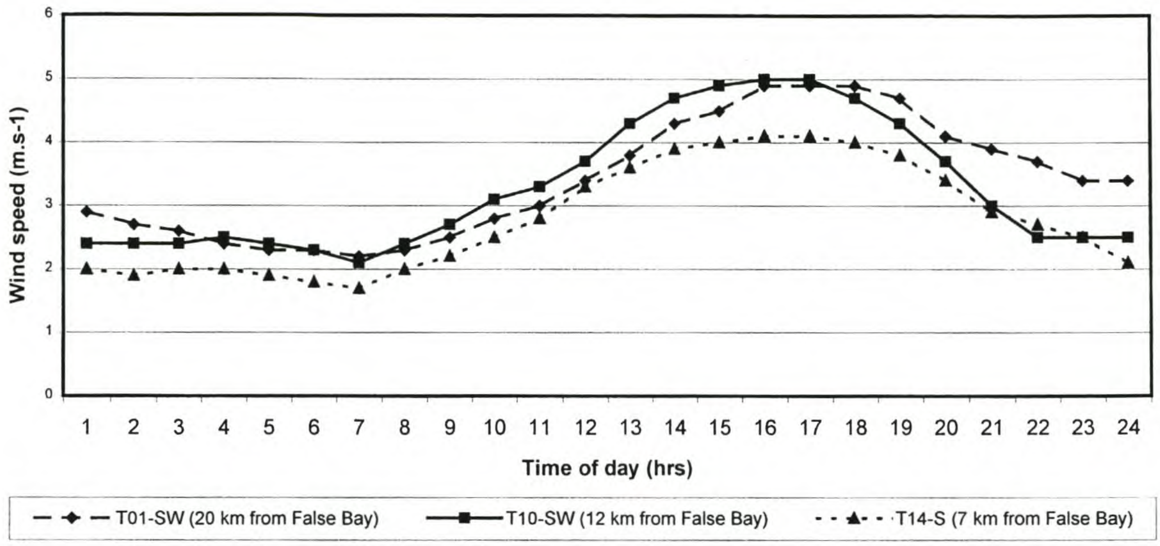


Fig. 5.2. Effect of distance from the sea and position of the weather station on wind speed as recorded at weather stations in the Bottelaryberg-Simonsberg-Helderberg study area. Hourly values are means for February 1998. Compiled from data supplied by ARC-ISCW AgroMet.
T01, T10 & T14 are automatic weather stations.
SW & S are the aspects of automatic weather station sites.

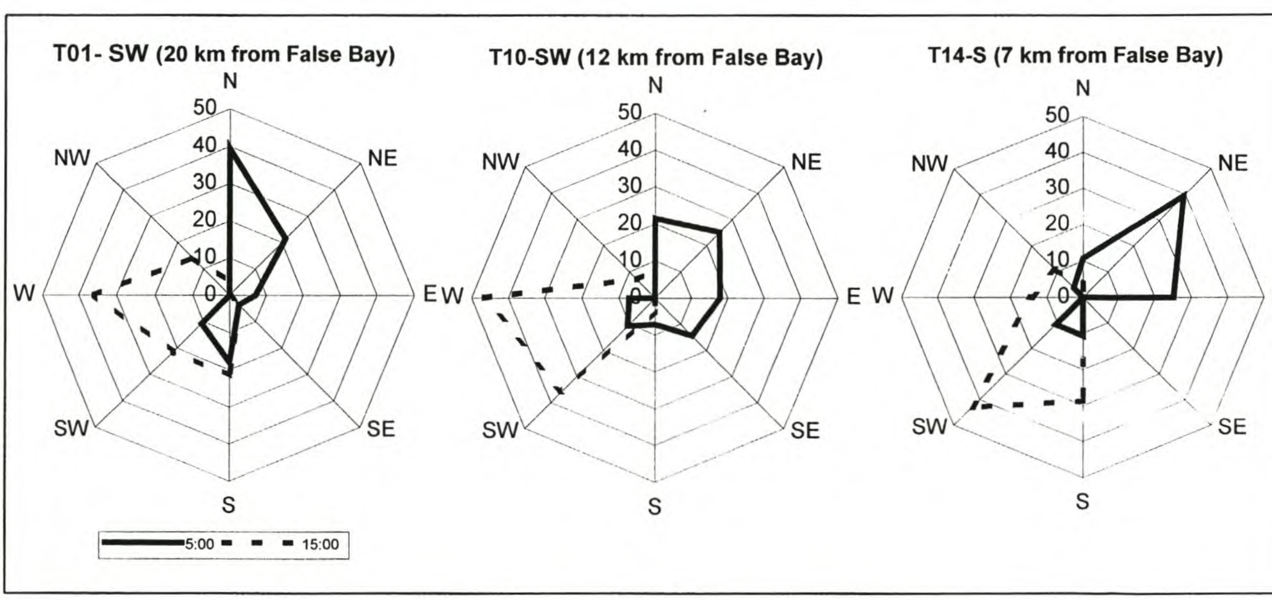


Fig. 5.3. Effect of distance from the sea and position of the weather station on wind direction as recorded at weather stations in the Bottelaryberg-Simonsberg-Helderberg study area in the early morning (05:00) and afternoon (15:00). Hourly values are means for February 1998. Compiled from data supplied by ARC-ISCW AgroMet.
T01, T10 & T14 are automatic weather stations.
SW & S are the aspects of automatic weather station sites.

Relative humidity

Examination of three stations from the Bottelaryberg-Simonsberg-Helderberg study area (Fig. 5.4) shows that relative humidity decreases with distance from the sea. This effect appears to be stronger than the effect of aspect as both stations T01 (SW) and T04 (NW) recorded lower relative humidity values than station T10 (closer to the sea). The interaction between relative humidity and the sea breeze was discussed in section 2.3.3. Station T01 (SW) did record slightly higher values of relative humidity than T04 (NW but at similar distance from False Bay) between 14:00 and 20:00, February 1998, suggesting that the moist sea breeze managed to penetrate to this site to a certain extent. Although higher contrasts in relative humidity between aspects facing towards and away from False Bay could be recorded at weather stations situated closer to False Bay, the effect on relative humidity was negligible at 20 km from False Bay.

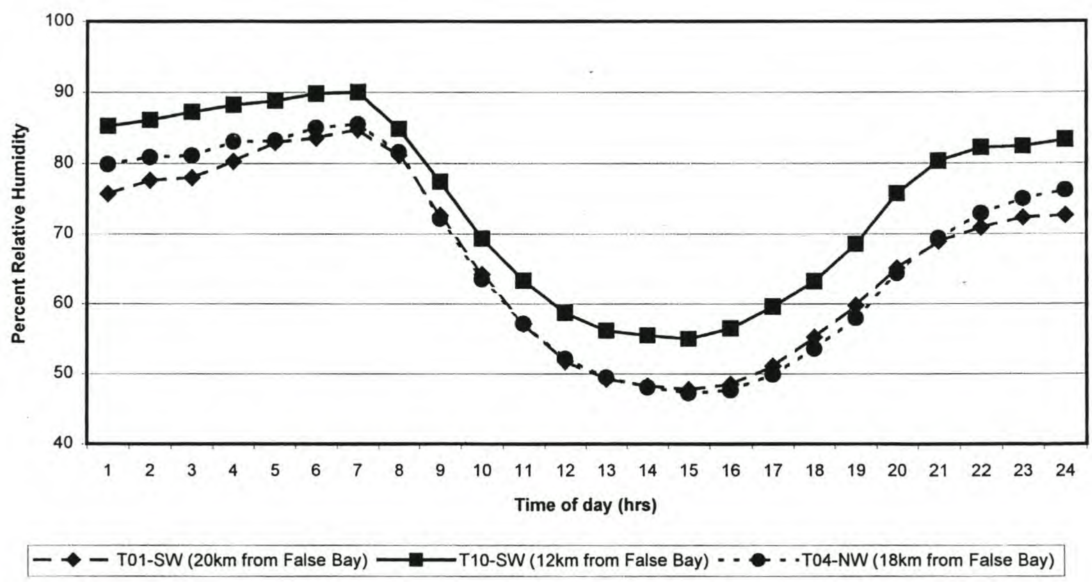


Fig. 5.4. The effect of aspect and distance from the sea on relative humidity values as recorded at three stations in the Bottelaryberg-Simonsberg-Helderberg study area. Hourly values are means for February 1998. Compiled from data supplied by ARC-ISCW AgroMet.
T10, T04, T01 are automatic weather stations.
SW and NW are the aspects of the respective weather station sites.

An average of the percentage relative humidity at 15:00 during February for the period 1995-2000 (Table 5.1) showed that station T01 recorded the lowest value. The higher values recorded at automatic weather stations T04 and T05 may be due to their position in the vineyard row (effect of irrigation, transpiration, less air movement etc.). A station close to and open to the sea (T10), recorded a comparatively high value for this parameter, as would be expected.

Temperature

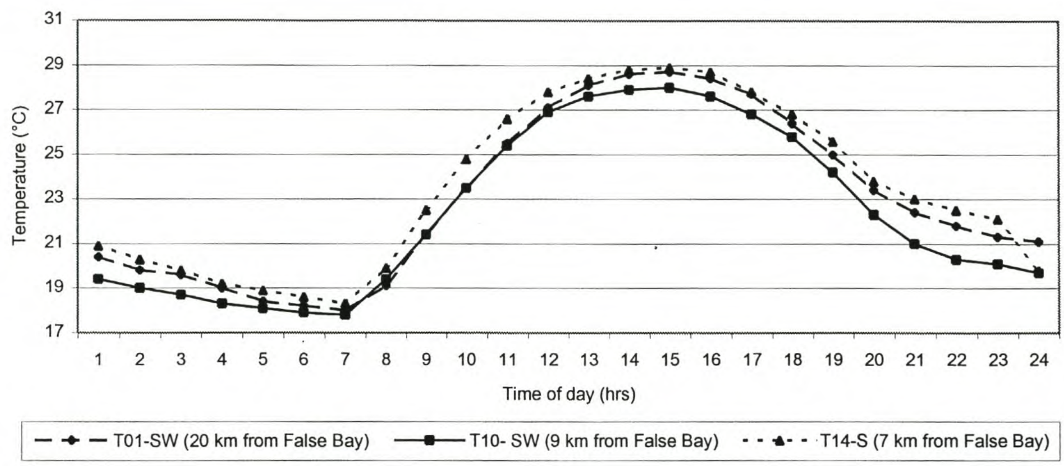
An example of February and July diurnal temperatures for two weather stations with comparable aspect (SW) and slope inclination (Table 4.1), but at different distances from False Bay is given in Fig. 5.5. During February (Fig. 5.5 a), the station further away from False Bay (T01) recorded a higher maximum temperature than station T10 (close to False Bay). The two stations recorded the maximum temperature at the same time, but station T01 recorded warmer temperatures in the late afternoon and night. This suggests that proximity to the ocean has a strong effect on afternoon temperature, due to the degree of penetration by the sea breeze (see section 3.2.3).

Station T14 was compared to these two stations as it had recorded the sea breeze (increase in speed and change of direction of wind in the afternoon) (Fig 5.2 & 5.3), is close to False Bay, but is situated near the white walls of an historical graveyard. The high albedo of the walls resulted in higher than expected temperatures being recorded at this station (Fig. 5.5a), annulling any moderating effect of the ocean in its immediate vicinity. The mean afternoon temperatures recorded during February 1998 were almost as warm as station T01, situated the furthest away from False Bay.

During July, the sea had a strong effect on temperature variability, and especially on minimum temperature (Fig. 5.5b). The station closer to the sea (T10) recorded a lower maximum temperature than station T01, but also recorded a significantly higher minimum temperature.

Both T01 and T10 recorded an increase in wind speed in the afternoon (Fig. 5.2), with T10 recording stronger winds due to being closer to False Bay, as well as a change in wind direction (Fig. 5.3). This suggests that the sea breeze reaches as far as T01. Station T10, however, recorded higher relative humidity values and this resulted in the pronounced cooling effect during summer as shown in Fig. 5.5a. The importance of the position of the weather station is emphasised by the data recorded at station T14. The immediate surroundings of a weather station must always be taken into account when interpreting climatic data.

(a)



(b)

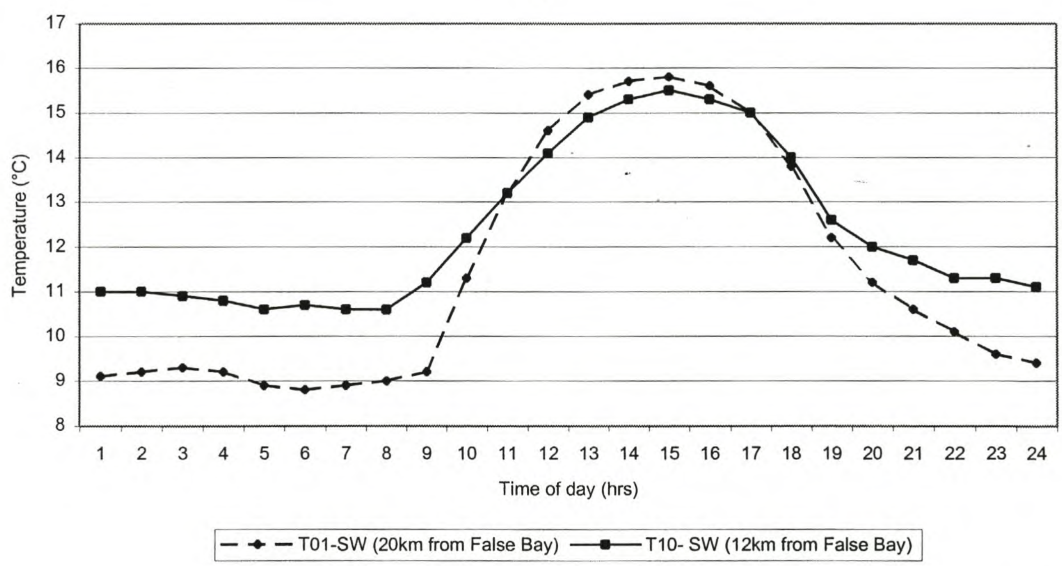


Fig. 5.5. Effect of distance from the sea and position of the weather station on diurnal temperature variation for the months of (a) February 1998 and (b) July 1998 as recorded at automatic weather stations in the Bottelaryberg-Simonsberg-Helderberg study area. Hourly values are means for the respective months. Compiled from data supplied by ARC-ISCW AgroMet.
T01, T10 & T14 are automatic weather stations.
SW is aspect of automatic weather station sites.

5.1.2.2 Effect of topography on climate in the Bottelaryberg-Simonsberg-Helderberg study area

Effect of altitude

Temperature: The effect of altitude on temperature on northern slopes in the Bottelaryberg-Simonsberg-Helderberg study area can be seen by comparing two weather stations with similar slope aspect (north) and inclination (<5%) (Fig. 5.6), in this case the automatic weather stations T08 and T09. In summer (Fig. 5.6a), the two stations recorded a similar minimum temperature. The maximum temperature was recorded earlier at the higher station (14:00 at T08 and 15:00 at T09) and there was a difference of 1.8°C between the two maximum temperatures recorded. The picture in winter (Fig. 5.6b) differs from the above. The plot situated at 235 m had smaller temperature fluctuations than that at 110 m. Between 11:00 and 19:00 the higher site was cooler than the lower site (a difference of 1.3°C between the maximum temperatures, recorded at 15:00). The effect of the thermal zone mentioned by Gladstones (1992) can be seen when the minimum temperatures are examined. The temperature reduction at night time for the higher plot was less than that for the lower plot, probably due to the gravitation of cold air downwards and the creation of a layer of warmer night air above it.

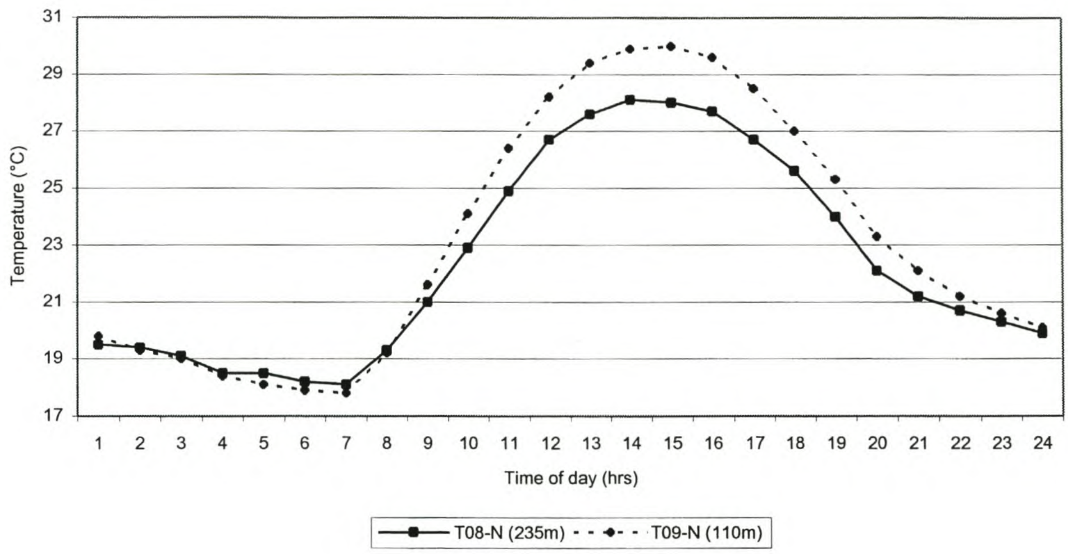
Relative humidity: A comparison between weather stations T08 and T09 shows that although the higher situated station (T08) recorded lower relative humidity at night and in the morning, it recorded slightly higher values in the late morning and afternoon (10:00 – 21:00) (data not shown). Although this station is north facing it is situated close to the top of a hill and could be affected by a deviated sea breeze.

Effect of aspect

Radiation and sun duration: The effect of aspect on sun duration and radiation is shown in Fig.5.7. This comparison emphasises that slopes with a northern exposure recorded higher radiation and longer sun duration values than slopes with a southern exposure (Fig. 5.7 a, b). Slopes with an eastern exposure showed higher values for radiation and sun duration than westerly exposures in the morning, but lower from 17:00 onwards (Fig. 5.7 c, d).

Temperature : The northwest slopes of the Helderberg (represented by T12) and Papegaaiberg (represented by T04), the Stellenboschkloof (represented by T15) and the

(a)



(b)

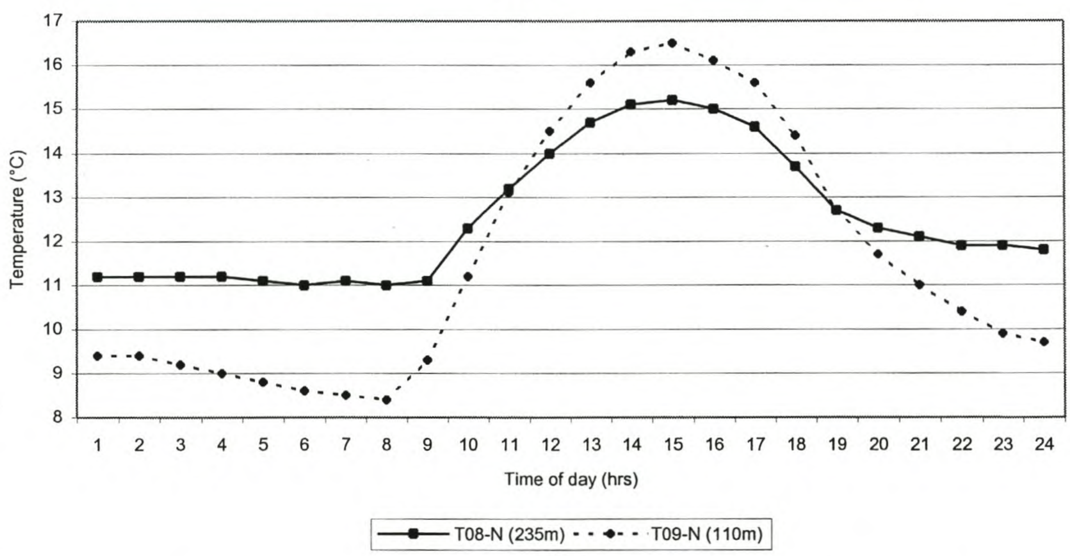


Fig. 5.6. Effect of altitude on diurnal temperature variation for the months of (a) February 1998 and (b) July 1998 as recorded at automatic weather stations in the Bottelaryberg-Simonsberg-Helderberg study area. Hourly values are means for the respective months. Compiled from data supplied by ARC-ISCW AgroMet.
T08, T09 are weather stations.
N is aspect of weather station sites.
110 m, 235 m are altitudes of respective weather station sites.

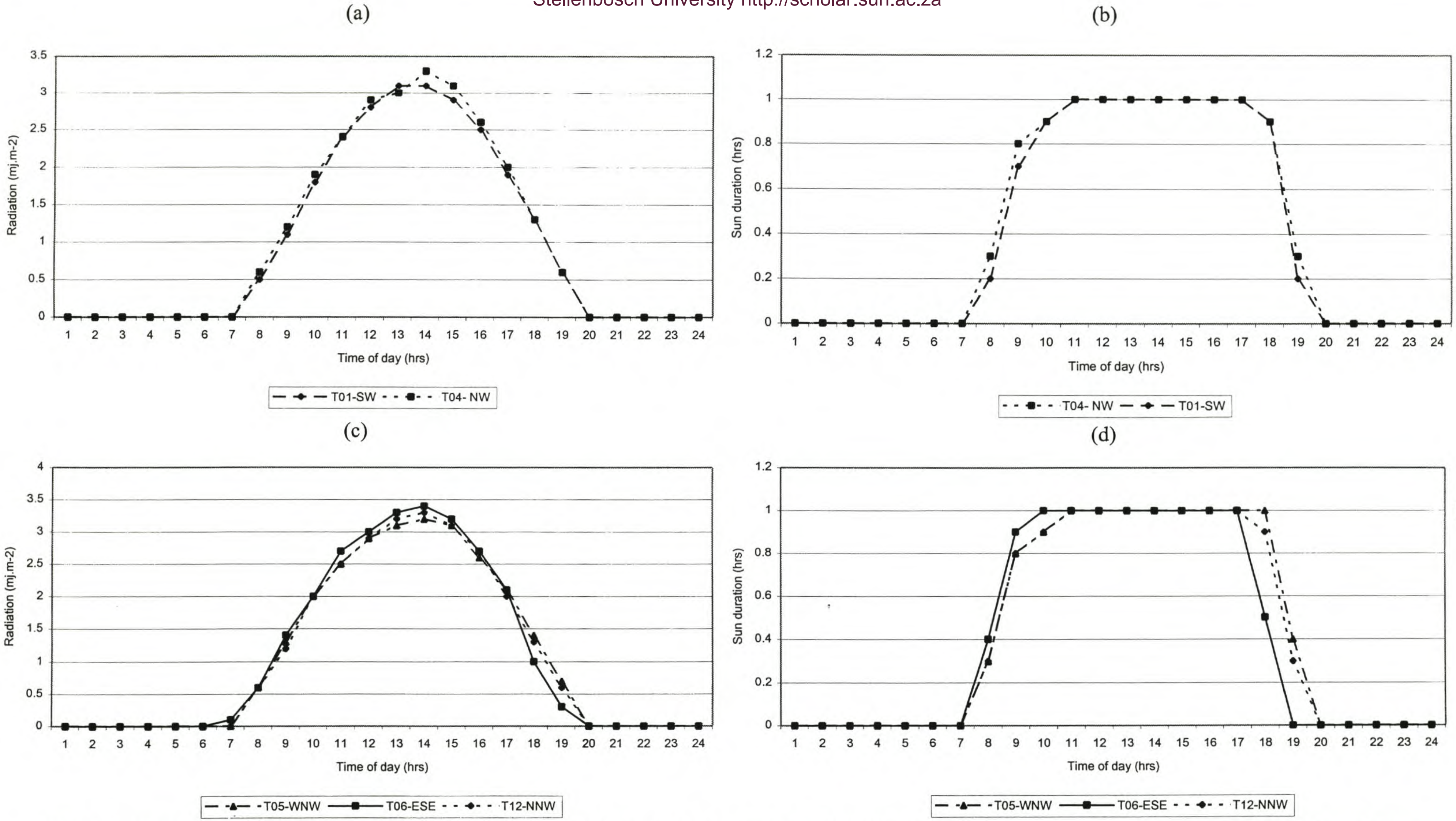


Fig. 5.7. Effect of aspect on radiation (a, c) and sun duration (b, d) as recorded at automatic weather stations in the Bottelaryberg-Simonsberg-Helderberg study area. Hourly values are means for February 1998. Compiled from data supplied by ARC-ISCW AgroMet.
T01, T04, T05, T06, T12 are automatic weather stations.
SW, NW, WNW, ESE, NNW are aspects of respective weather station sites.

coastal plain (represented by T14, probably due to its closed position) were the warmest sites with recorded mean February temperature values higher than 22°C (Table 5.1). Stations T04 (NW) and T12 (NNW) also recorded the highest maximum temperatures in February (Table 5.1). Therefore, despite the proximity to False Bay, the north west slopes of the Helderberg can be considered to be relatively warm.

A station with a more northerly aspect recorded higher temperatures than a southerly facing station for most of the day in summer (Fig. 5.8 a). Both the minimum and maximum temperatures are reached at the same time. Station T04, although at a similar altitude to station T01, is situated on the footslopes of a valley on Papegaaiberg while station T01 is situated on the foot slopes of the Simonsberg. The resulting difference in relief and a possible thermal inversion layer resulting from cold air collecting in the aforementioned valley could explain the higher night time temperatures recorded at station T04. It must be kept in mind, however, that other factors, such as soil colour, can also affect the temperature measured at a site due to the radiation of stored heat. During winter (Fig. 5.8 b), the more northern slope was consistently warmer than the southern slope. The differences are, however, reduced compared to summer due to the larger angle between the earth and sun during winter.

Another example (Fig. 5.8 c, d) shows the differences in temperature between slopes with western and eastern components. During summer (Fig. 5.8 c), the ESE facing site started warming up before the other two sites, between 06:00 and 07:00. It reached values as high as, or higher than the more northerly sites in the morning, after which the temperature increased more slowly to reach a maximum at 14:00. This is due to its better sunlight interception in the morning (Fig. 5.7 d). While the temperature at station T06 (ESE) started decreasing, the temperature recorded at stations T12 (NNW) and T05 (WNW) continued to increase, reaching higher maximum temperatures at 15:00. Station T12, with the more northerly component, recorded a higher maximum temperature than T05. It also had a higher minimum temperature, possibly due to radiation of heat from large, light-coloured rock surfaces close to the weather station. During winter (Fig. 5.8 d), station T06 (ESE) recorded lower temperatures than stations T12 (NNW) and T05 (WNW). The north/south components of the aspect appears to play a greater role than the east/west components during winter, as early warming of the ESE slope could only be noted between 08:00 and 09:00. Station T06, however, still recorded a lower maximum temperature than the north west facing stations, as well as earlier in the afternoon.

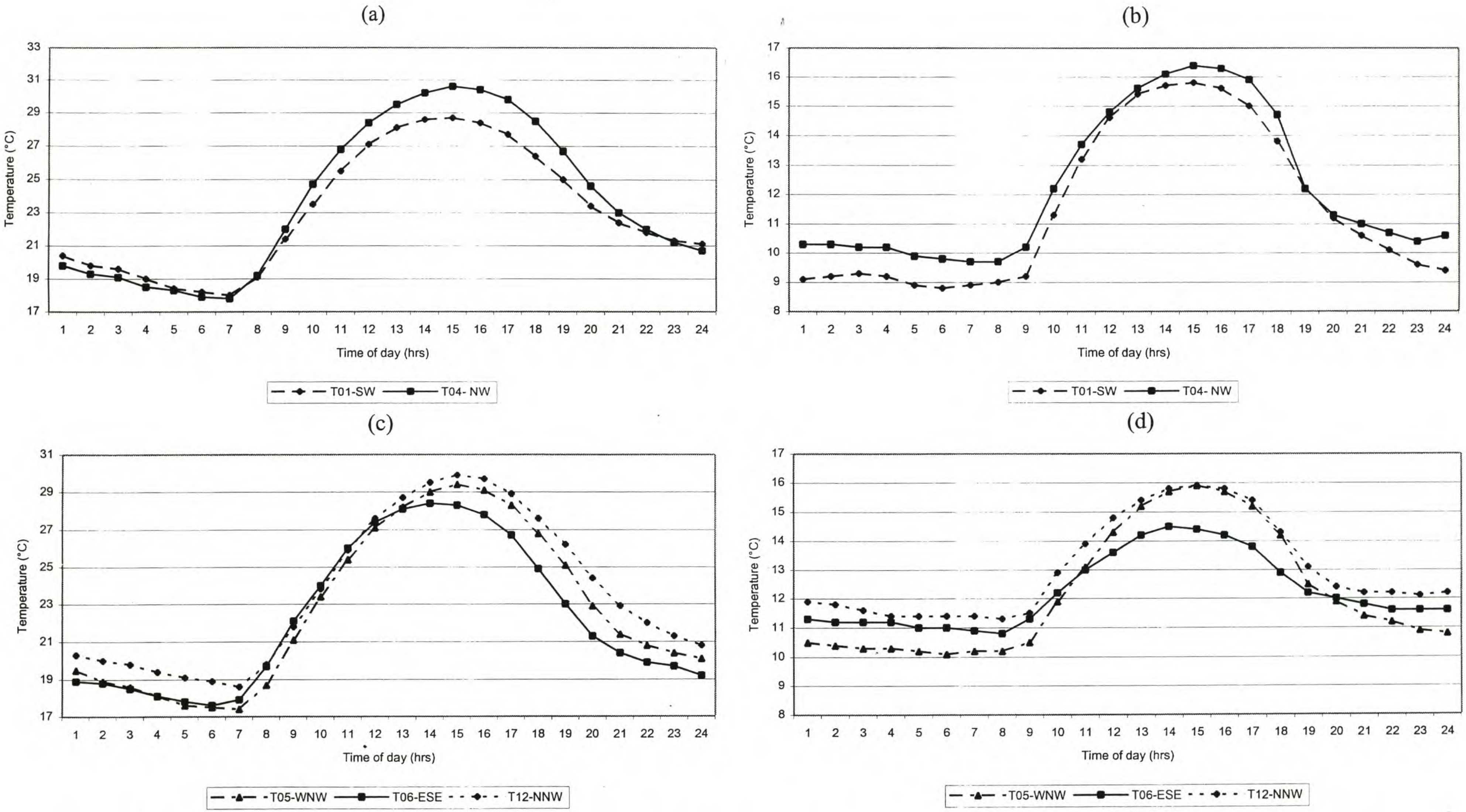


Fig. 5.8. Effect of aspect on diurnal temperature variation for (a, c) February 1998 and (b, d) July 1998 as recorded at automatic weather stations in the Bottelaryberg-Simonsberg-Helderberg study area. Hourly values are means for the respective months. Compiled from data supplied by ARC-ISCW AgroMet.
T01, T04, T05, T06 & T12 are automatic weather stations.
SW, NW, WNW, ESE & NNW are the aspects of the respective weather station sites.

It appears, therefore, that under the conditions in the Bottelaryberg-Simonsberg-Helderberg study area, altitude and aspect have a similar degree of effect on temperature. Gladstones (1992) suggests that such effects are additive. The time at which the maximum temperature is reached appears to be a function of the E/W aspect component and the associated differences in sunlight interception, although the exposure of the ESE facing station to the sea breeze may also have had an effect on the temperatures recorded here.

Wind: February 2000 (09:00 to 18:00) was used as an example to plot the dominant summer wind directions for each of the automatic weather stations in the Bottelaryberg-Simonsberg-Helderberg study area from frequency data obtained from ARC-ISCW AgroMet (Fig.5.9). The direction varied between south and west directions (probable sea breeze), depending on the position of the weather station in the landscape. It is important to remember that the wind direction mapped is that which was recorded with the highest frequency during February 2000. These dominant winds may not have all occurred on the same day. The hourly wind speed data for the same month is plotted per direction in Fig. 5.10. The strongest winds came from the compass directions of S, SSE and SW, depending on the landscape position of the weather station. All the stations recorded the gentle night breezes from northerly directions as well as the stronger mountain winds from E, NE and NNE. From Fig. 5.10 it can be noted that the lowest wind speeds (<6 $m.s^{-1}$) were recorded when the weather stations were situated in the vineyard row (T04, T06, T05), and protected positions (T14). Stations facing the dominant winds recorded high frequencies (and velocities) of winds from the SW and SSW. T01 also recorded strong SSE winds. Surprisingly, the highest wind speeds were recorded at station T08, facing away from the dominant winds. T12, although facing NNW, recorded a high frequency of winds from the SSW and W. As most of the more southerly winds at this station were recorded before 08:00 in the morning and after 17:00, they could be up and down-slope winds.

Wind speed and direction are, therefore, the result of a complex interaction between topography and relief resulting in interplay between the synoptic wind, up- and down-slope winds and the sea breeze. Although the temperature effect of the sea breeze can be considered a positive factor for wine grape production, the wind speeds that were recorded could be disadvantageous for grapevine physiology and could even result in mechanical damage to grapevines.

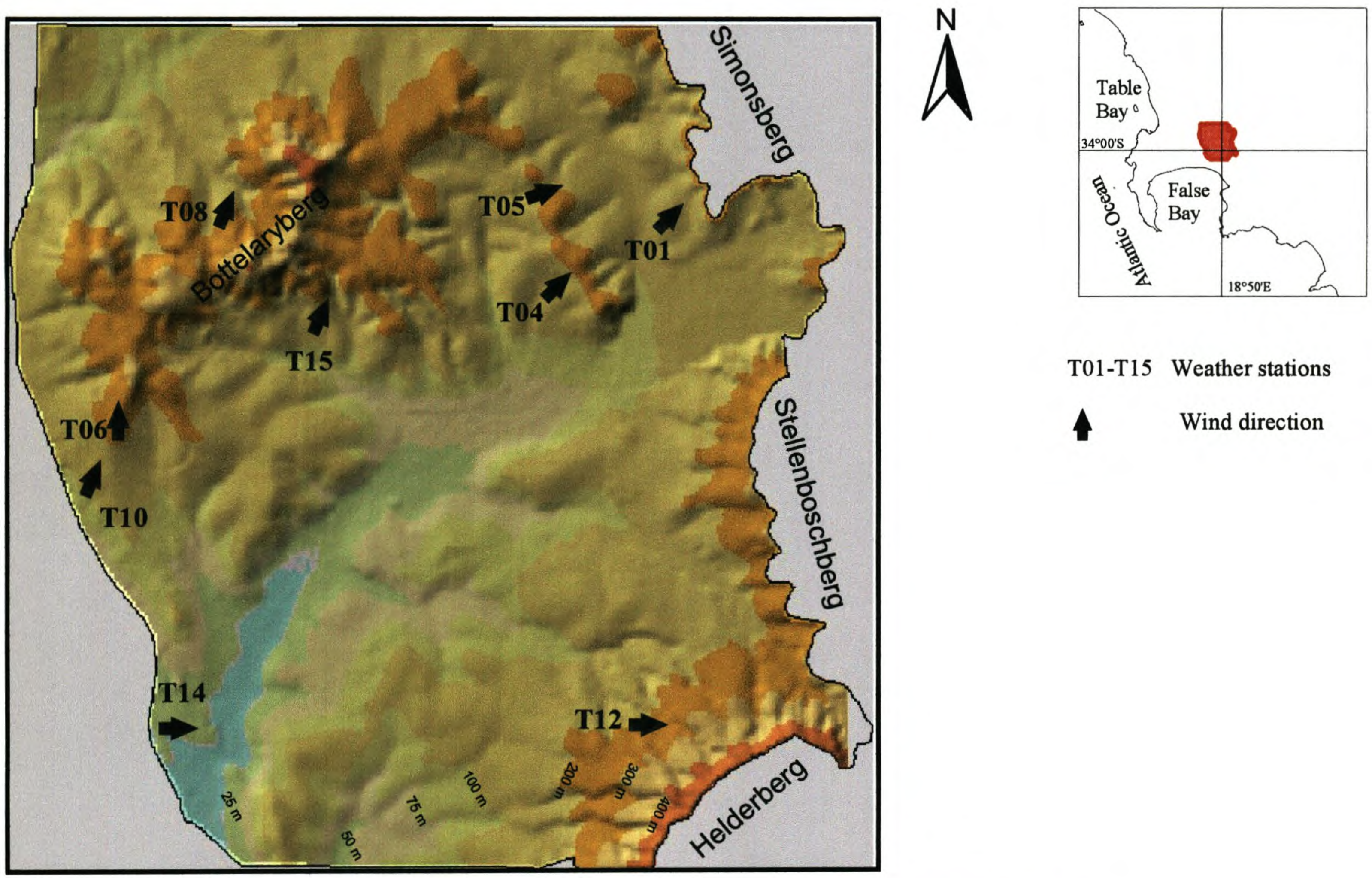


Fig. 5.9. Spatial variation of dominant wind direction for February 2000 (09:00-18:00) recorded in the Bottelaryberg-Simonsberg-Helderberg study area. Compiled from data supplied by ARC-ISCW AgroMet. Insert shows position of study area in relation to Table Bay and False Bay.

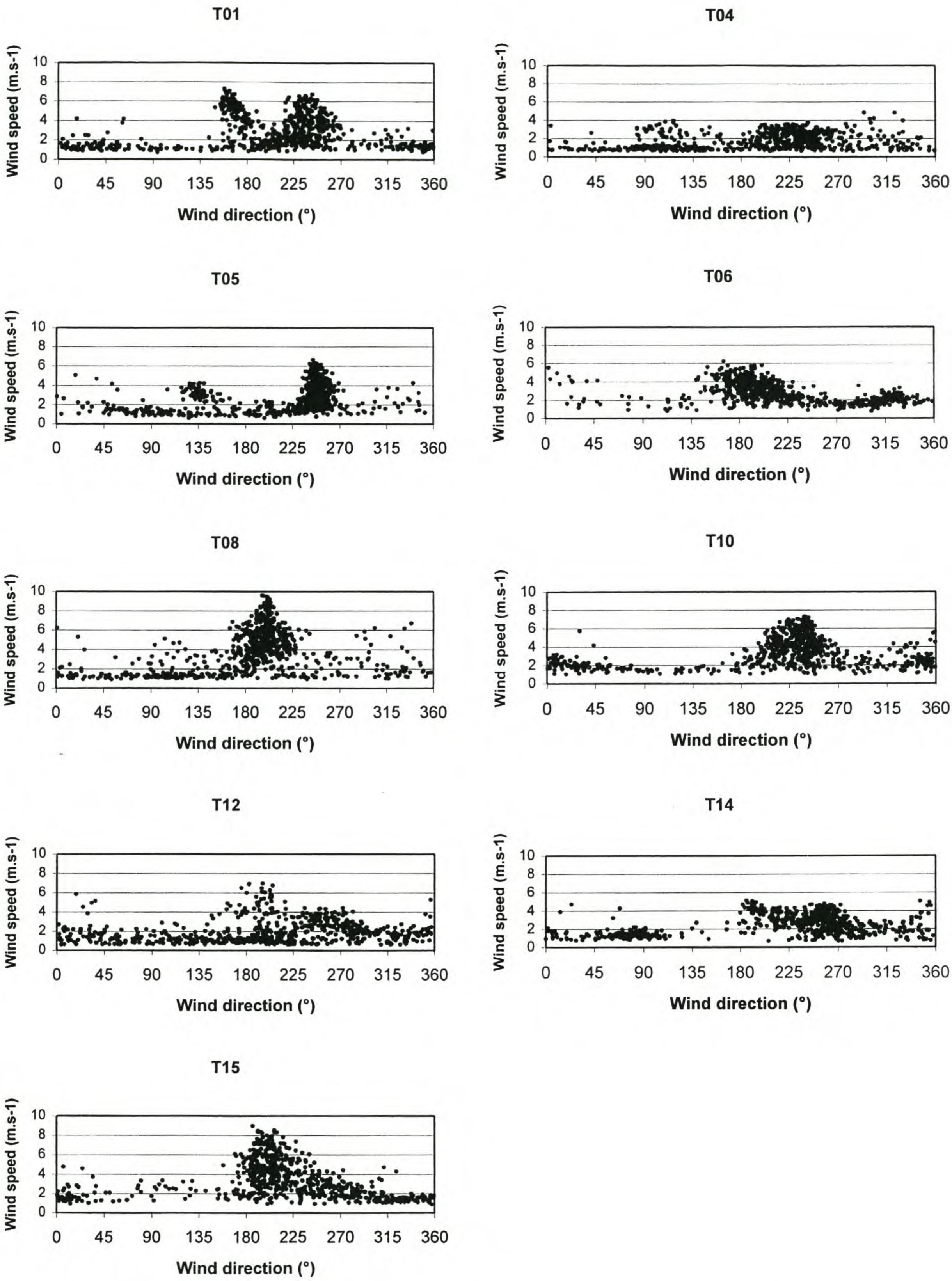


Fig. 5.10. Wind speed per wind direction recorded at automatic weather stations in the Bottelaryberg-Simonsberg-Helderberg study area during February 2000. Compiled from data obtained from ARC-ISCW AgroMet. Each point represents hourly wind speed.

Relative humidity: Stations T01 (SW) and T04 (NW, but at same distance from False Bay) recorded similar values of relative humidity during February 1998 despite T04 facing away from the sea (Fig. 5.4). As mentioned previously, however, the contrast could be higher for stations closer to False Bay.

Rainfall: Table 5.1 shows differences of up to 28 mm in rainfall between stations (example of T05 and T12) for the period December to February (post-véraison period). Although it is difficult to establish a clear explanation for this rainfall distribution in relation to the topography, some suggestions can be made. A "black south easter" is a rain bearing summer wind and the ESE (T06) and S (T15) facing stations recorded relatively high rainfall figures. The high lying NW station of T12 recorded the highest rainfall for the period December to January, probably due to the upwelling of moist air from the rain-bearing north westerly winds, although these winds rarely occur in the summer months. Greater variation was observed for the winter rainfall (April – August) with the highest values being recorded in the Stellenboschkloof (represented by T15) and at stations on sites facing north or north west i.e. towards the winter rain bearing winds.

Comparison between data obtained from the automatic weather station network, the position of each weather station and the existing digital temperature data suggests that the latter is not applicable on a mesoclimatic scale and that topographical units could, to large extent, be representative of climatic variability.

5.2 Soil variation in the Bottelaryberg-Simonsberg-Helderberg study area

The descriptions of soil profiles from sites within the Bottelaryberg-Simonsberg-Helderberg study area are given in Appendix VI. Comparison of the digital soil association data (Ellis *et al.*, 1975, 1976, 1980) (Fig. 3.5 and 3.6) with the data obtained from the profile studies (Appendix VI) yielded the results shown in Appendix VII.

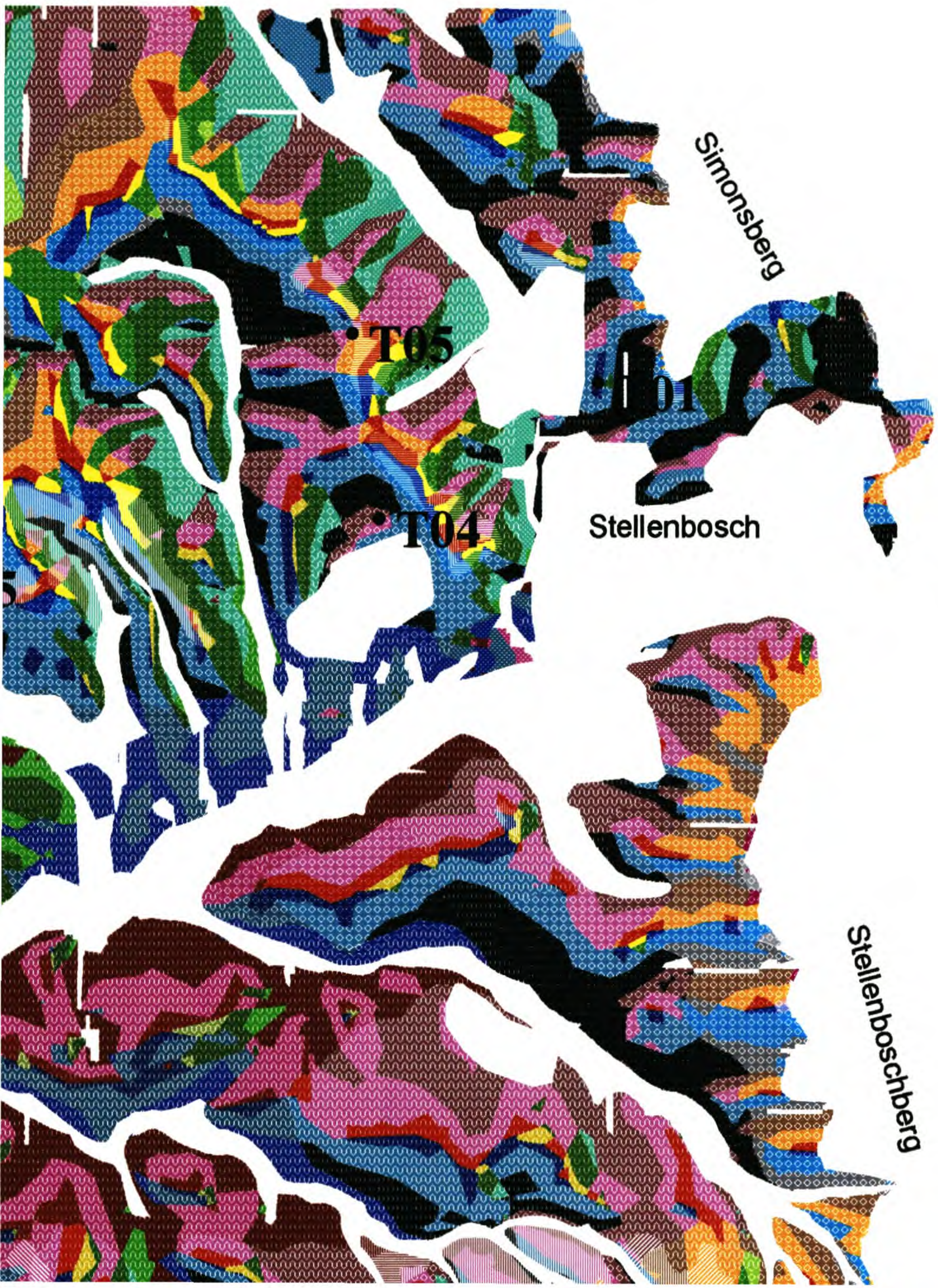
These results emphasise the extreme variability of soils in the Bottelaryberg-Simonsberg-Helderberg study area and the difficulty in using soil association data for a terroir study in this area. In some instances (e.g. T06CS) the less detailed data (Ellis *et al.*, 1980) was correct, in other cases (e.g. T08CS) the more detailed data (Ellis *et al.*, 1975, 1976) was correct, while for other sites neither digital data set correctly described the profile (T06CS). Only 65% of the profiles were correctly described by each digital data set. There will always be discrepancies within a soil association but the landscape variation may account for some of this variation. Detailed soil studies will, however, always be necessary for any farm management planning in an area as complex as the Bottelaryberg-Simonsberg-Helderberg study area.

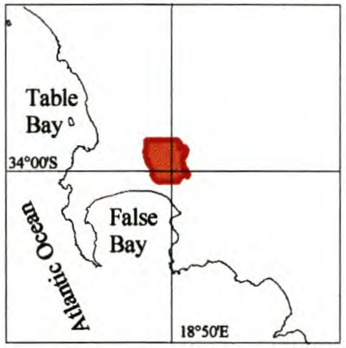
5.3 Natural terroir units

The natural terroir units for the Bottelaryberg-Simonsberg-Helderberg study area are presented in Fig. 5.11 and Appendix VIII. A total of 195 units were identified. In order to make the various groupings of factors included in the delimitation identifiable on the map, a combination of colours and fills have been used. A range of colours represents the landscape units. Shades of yellow and green represent east; blue, turquoise and grey represent south and red, mustard, brown and lilac represent north and west aspects. A patterned fill in white on the coloured background represents the broad soil groups. A four-part key is used to represent each unit (Appendix VIII). The first number represents the terrain morphological unit, the following letter(s) represent(s) the aspect, followed by a number representing the altitude category, and finally letters representing the soil group and, in the case of residual soils, the associated geology.

Within the broader soil groups there will be differences in drainage and soil water retention properties, as well as in chemical composition and, importantly, soil depth. However, due to the nature of variation in soil characteristics over very short distances in the South Western Cape (see section 5.3), and the general need for deep soil preparation, intense soil surveys will be needed on a farm level before vineyard establishment.

For a similar study in the Rhone valley on a scale of 1:25 000, an average of 10 to 20 homogenous terroir units were delimited for a viticultural area of 1000 ha. This study was based on topography, climate and a combination of geology and soils (effective depth, amount of rocks, soil description) (Fabre *et al.*, 1998). The number of natural terroir units delimited in the Bottelaryberg-Simonsberg-Helderberg study area is approximately 8 per 1000 ha. If soil depth and degree of drainage are included, the total number of natural terroir units increases to approximately 12 per 1000 ha of study area. However, in view of the scale of the data (1:50 000 soil map and 50 m DEM), and the general practices of deep soil preparation





Code

Terrain units

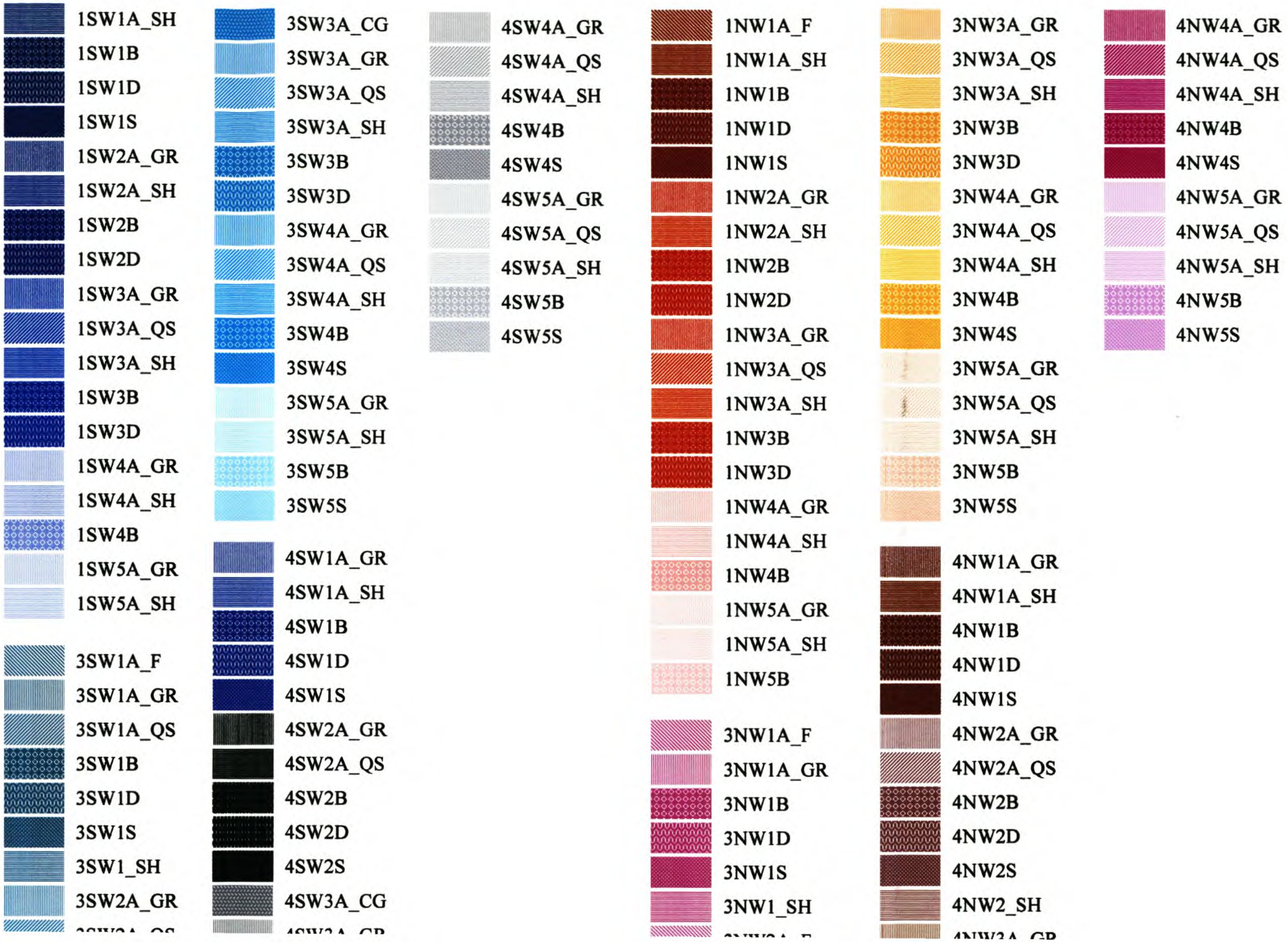
1	Crest
3	Midslope
4	Footslope
5	Valley bottom

Aspect

E	East (45° - 135°)
SW	South west (135° - 270°)
NW	North west (270° - 45°, passing through 0°)

Altitude

1	0-100 m
2	100-200 m


1SW1A_SH
1SW1B
1SW1D
1SW1S
1SW2A_GR
1SW2A_SH
1SW2B
1SW2D
1SW3A_GR
1SW3A_QS
1SW3A_SH
1SW3B
1SW3D
1SW4A_GR
1SW4A_SH
1SW4B
1SW5A_GR
1SW5A_SH
3SW1A_F
3SW1A_GR
3SW1A_QS
3SW1B
3SW1D
3SW1S
3SW1_SH
3SW2A_GR
3SW3A_CG
3SW3A_GR
3SW3A_QS
3SW3A_SH
3SW3B
3SW3D
3SW4A_GR
3SW4A_QS
3SW4A_SH
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4SW1B
4SW1D
4SW1S
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4SW2D
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4SW4A_QS
4SW4A_SH
4SW4B
4SW4S
4SW5A_GR
4SW5A_QS
4SW5A_SH
4SW5B
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4NW5A_SH
4NW5B
4NW5S

and supplementary irrigation in the region, the broad soil categories should be sufficient for a medium scale identification of natural terroir units. More detailed studies would be needed per production unit (estate or cooperative) at a later stage.

From Appendix VIII it can be seen that a dominant soil type, which appears to be most closely related to altitude, can be associated with most of the landscape units. In some cases two dominant soil types are present and only in rare cases (3NW5 - it contains similar amounts of residual soils of various origin) is there no dominant soil type. Duplex soils are found mostly below 200 m. Between 100 m and 200 m, the position on the landscape unit is shared with red and yellow apedal (and neocutanic) soils. Between 200 m and 300 m, red and yellow apedal (and neocutanic) soils dominate while above 300 m residual soils are dominant. The only exceptions being the warm north western midslopes where the position between 300 m and 400 m is shared between residual soils and red and yellow apedal (and neocutanic) soils on high lying footslopes i.e. terrain morphological unit 4, altitude 300-400 m.

In order to evaluate the grouping, the actual positions of the weather stations in the landscape (Table 4.1) were compared to the determined natural terroir units. Their potential representation of the surrounding area was also examined.

T01 (1SW2B) — The altitude and aspect are well represented by the natural terroir unit. It has a relatively flat slope, which falls within the limits for the terrain morphological position of crest.

The red and yellow apedal soils and south western slopes are common to the lower slopes of the Simonsberg.

T04 (4NW2B/3NW3B) — The altitude and aspect are well represented. The slope percentage correlates with the footslope position.

This area is dominated by north western and southern slopes with red and yellow apedal soils.

T05 (3NW2B/3NW3B) — The altitude and aspect are well represented. Although the slope is less steep than definition for a midslope, it represents one of the steeper slopes.

This area is characterised by predominantly northern and western slopes. Although red and yellow apedal soils are dominant, some residual soils (predominantly greywacke origin) are present.

T06 (1E3B)	The altitude and aspect are well represented. The steepness of the slope would suggest that the terrain morphological position of crest is not correct. The higher lying area represented by this weather station has predominantly south and east facing slopes with a combination of red and yellow apedal soils and duplex soils.
T08 (1NW3B)	The altitude and aspect are well represented. The slope is on the borderline of the definition for crest, which would suggest a correct placement. The aspects in this area are predominantly north west. The higher lying areas have predominantly red and yellow apedal soils.
T09 (1NW2D)	The altitude and aspect are well represented. The slope correlates with the terrain morphological position of crest. Similarly to the higher lying slopes the aspects are predominantly north and west. Duplex soils are dominant.
T10 (3SW2D)	The altitude and aspect are well represented. The slope is too gentle for placement as midslope (according to definition). The surrounding area has predominantly southern slopes and duplex soils in lower lying positions.
T12 (3NW3B)	The altitude and aspect of this site are well represented. The slope approaches that of the midslope category. The dominant north and west facing slopes have predominantly red and yellow apedal soils.
T14 (3SW1D)	The altitude and aspect are well represented. The terrain morphological position appears to be misrepresented as the slope is too flat for a midslope position. This area is characterised by lower lying south and east slopes with some north and west slopes. The western portion has predominantly duplex soils while the higher lying eastern portion is characterised by residual and red and yellow apedal soils.
T15 (1S2B/3S2B)	The altitude and aspect are well represented. The steep slope would suggest a transition from crest to midslope. The surrounding area has predominantly southern and eastern slopes. There is no dominant soil type.

6. Conclusions and recommendations

This study was initiated in order to meet the growing demands of the consumer with respect to knowledge of the origin of the product. Although the Wine of Origin category of "Wards" meets this demand to a large extent, a scientific basis for the identification and characterisation of viticultural terroirs, on a more detailed level, must be established. This will enable the identification of regions according to their potential for certain cultivars and the expected wine character. The first step in achieving this aim is the identification of relatively homogenous natural terroir units and the characterisation of the viticultural environment.

As was highlighted in preceding chapters, the Bottelaryberg-Simonsberg-Helderberg study area is complex with many factors affecting the mesoclimate and root environment, compounded by management practices that affect the vigour and microclimate of the vine. This should result in diverse wines of different characters, each representative of their own unique environment.

The aim of the study was to use existing digital information to identify these natural terroir units with application to viticulture. From the previous chapters it is clear that landscape characteristics (aspect, altitude, terrain morphological units) are the most significant components affecting the spatial variation of mesoclimate and soil distribution in a complex area such as the Bottelaryberg-Simonsberg-Helderberg study area and, as such, should be used as primary keys for the identification of natural terroir units.

It is important to remember the scale of the original data and not to apply the results at a level more detailed than the said data. In this case, the natural terroir units can only be applied at a scale of 1:50 000 (geological data excluded), remembering also that the DEM data was based on a 50 m grid.

This study identifies certain deficiencies in the public domain with respect to environmental data as well as indicating related potential study fields, which are further discussed below.

The terrain morphological units provided an obvious starting point for the identification of natural terroir units due to their combination of different landscape factors (slope and slope shape) and relationship with temperature variability and air and soil water movement. There were some discrepancies between observed and modelled data, but the model has since been further refined and must be re-evaluated for use as a base for the identification of natural terroir units.

Although the importance of soil in the terroir concept is indisputable, the lack of detailed data for the Bottelaryberg-Simonsberg-Helderberg study area was found to be one of the greatest deficiencies in this intensively studied region. The complex geology and soils and high degree of spatial variation makes it difficult to use these parameters as primary keys for the identification of natural terroir units in the Bottelaryberg-Simonsberg-Helderberg study area. The scale of the soil and geological data is also limiting. There is a myriad of soil information available from detailed farm studies and a study to compile these individual assays into a detailed comprehensive soil map for the study region will be invaluable for future terroir studies.

Relief, as well as topography, plays an important role in sunlight interception and air movement, in turn affecting mesoclimate. It is, however, difficult to quantify. Two methods of quantification are the degree of openness of the landscape or the landscape closing up index. These methods determine the "openness" of the landscape with the aid of a clinometer or theodolyte in eight or more compass directions. The direction and nature of the masking feature is noted. Although these measurements are usually performed in the field, it is theoretically possible to use stereoscopy in order to determine the indices.

Temperature in the study area is not only affected by sunlight interception and radiation from the soil, but also by the occurrence and efficacy of the sea breeze. The RAMS is a powerful tool for modelling the movement of sea breeze as well as the occurrence and interplay of slope and land breezes. Further numerical simulations of the sea breeze on a detailed grid (±200 m) must be performed with average data to determine the spatial limit of the effectiveness of the sea breeze. This "front" would form an important basis for further division of the study area as well as being a tool for extrapolation of temperature and relative humidity data from the automatic weather station network within the Bottelaryberg-Simonsberg-Helderberg study area.

The combination of environmental factors encapsulated by the natural terroir units provides an important starting point for characterisation of climatic factors, ecophysiological reactions of the grapevine under different environmental conditions and the resulting wine character. From Fig. 5.11, it is possible to identify areas suitable for production of different wine styles, based on their period of ripening. For example late ripening cultivars require a good soil water reserve coupled with the less vigorous growth provided by duplex soils.

The definition of viticultural terroirs emphasizes the need for ecophysiological studies of cultivars in order to determine the interaction between the vine and terroir. The next phase in a terroir study, therefore, entails the grouping of natural terroir units with respect to their ecophysiological potential as expressed in, for example, growth vigour and wine character. Representative natural terroir units must be used to determine their viticultural and oenological expression so as to group them into viticultural terroirs. This second phase has been running simultaneously with the present study at ARC Infruitec-Nietvoorbij and a data bank of viticultural and oenological data already exists. However, before analysing the data and applying it to the natural terroir units, the degree of representation of the natural terroir units must be investigated.

The use of terroirs to understand and manage vineyards requires diverse information, which this topographically based method organises into homogenous units. Such a study can be performed at various scales, depending on the end use of the product, to identify natural terroir units. It is an invaluable decision-making tool from farm to regional level. The complex nature of the terroir concept, as well as the complex environmental framework of the South Western Cape emphasizes the need for a dedicated multidisciplinary team and continued research on all levels of the environment and vine to identify and characterise viticultural terroirs to meet the future marketing challenges.

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Appendix I

Legend to Land type maps (Macvicar, C.N., 1984)

Ac Red-yellow, apedal, well drained soils.

Predominantly red and yellow distrophic and/or mesotrophic soils without water tables are present.

Ba Plinthic catena, high-lying duplex and margalitic soils scarce.

In its perfect form, this catena is represented by (from top to bottom on high lying landscapes) Hutton, Bainsvlei, Avalon and Longlands forms. The valley bottom is covered by a gleyed soil (e.g. Katspruit). The soil forms of Glencoe, Wasbank, Westleigh, Kroonstad and Pinedene are present. Plinthic soils must cover more than 10% of the surface of the land type before it qualifies. High lying duplex soils include Estcourt, Sterkspruit, Swartland, Valsrivier and Kroonstad but constitute less than 10% of the surface. Red and/or yellow distrophic and/or mesotrophic apedal soils are dominant over the eutrophic red and/or yellow apedal soils and red soils cover more than a third of the surface.

Ca Plinthic catena, high lying duplex and/or margalitic soils are wide spread.

This unit refers to land that qualifies as a plinthic catena (see description for Ba), but where duplex soils cover more than 10% of the surface in high lying positions.

Db Prismacutanic and/or pedocutanic diagnostic horizons are dominant.

Duplex soils are dominant. High lying soils include Estcourt, Sterkspruit, Swartland, Valsrivier and Kroonstad. These soil forms must constitute more than half of the soil surface. Most of the duplex soils have non-red B horizons.

Fa Glenrosa and/or Mispah forms (other soils may be present).

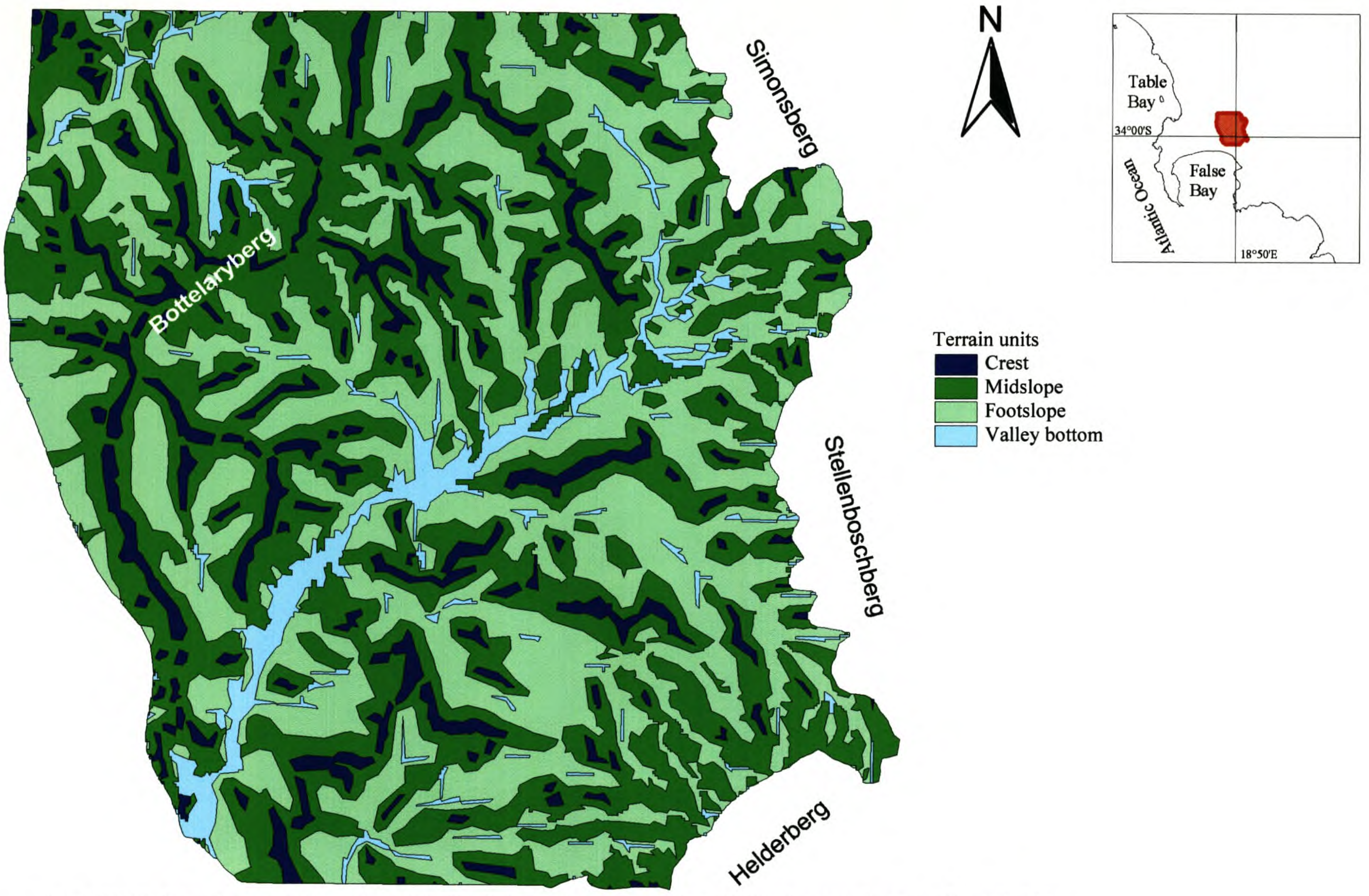
The landscape is pedologically young and is not overwhelmingly rocky, alluvial or aeolian. The dominant soil forming processes were weathering of rock, the forming of an orthic A horizon and clay illuviation to form lithocutanic horizons (e.g. Glenrosa and Mispah). Oakleaf soils formed by weathering of rocks are included (shallow and deep, usually in high lying positions). Free lime is usually not found in any part of the landscape

Hb Grey regic sands

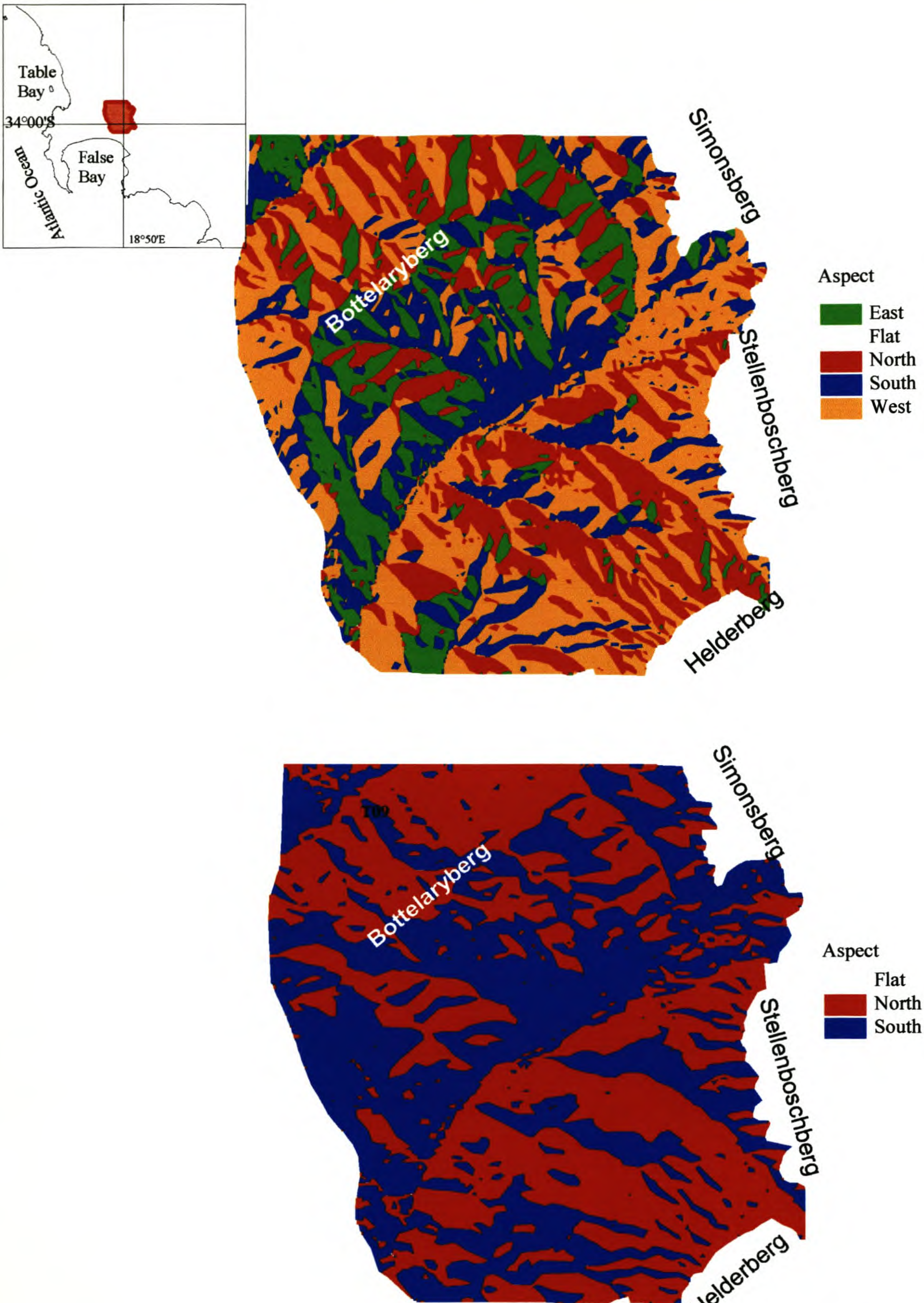
Deep grey sands of the Fernwood form are included. Less than 80 percent but more than 20 percent of the surface is constituted by the above.

Ia Diverse land classes

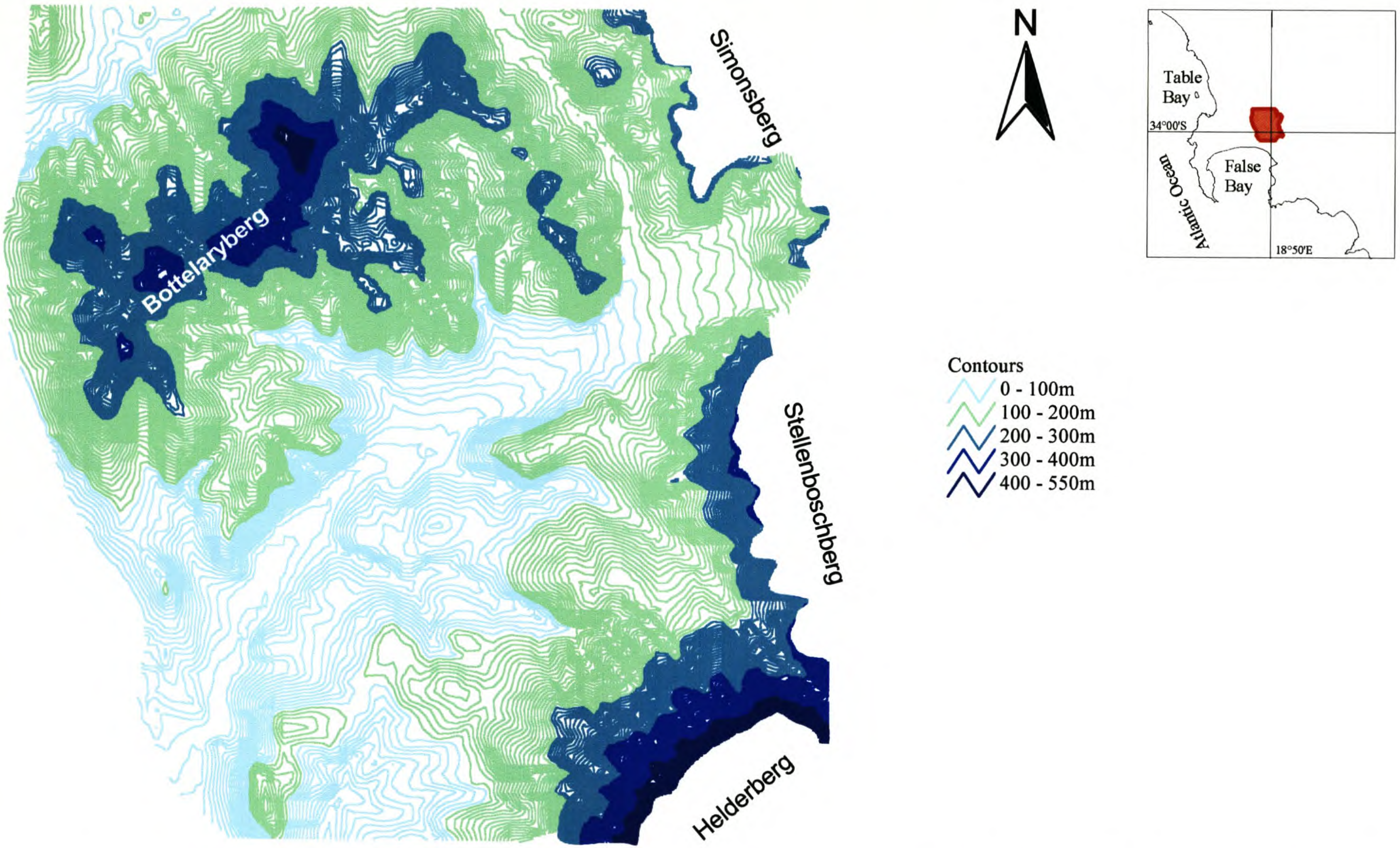
At least 60% of the surface is made up of deep (deeper than 1m to underlying rock) unconsolidated material that is pedologically young (often Oakleaf and Dundee).



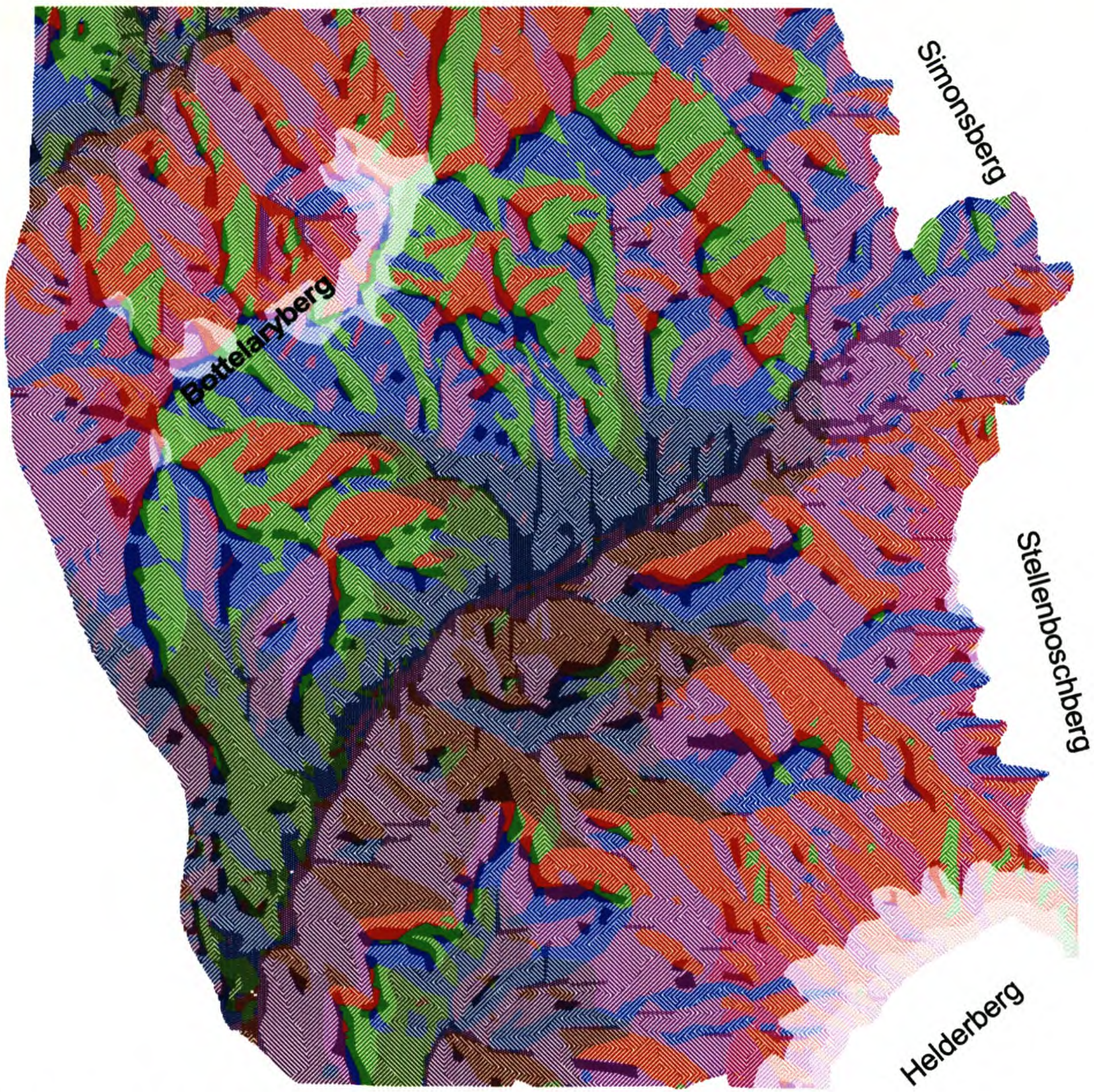
Appendix II. Terrain morphological units in the Bottelaryberg-Simonsberg-Helderberg study area. Compiled by M. Wallace, Department of Agriculture: Western Cape (1999).
Insert shows position of study area in relation to False Bay and Table Bay.

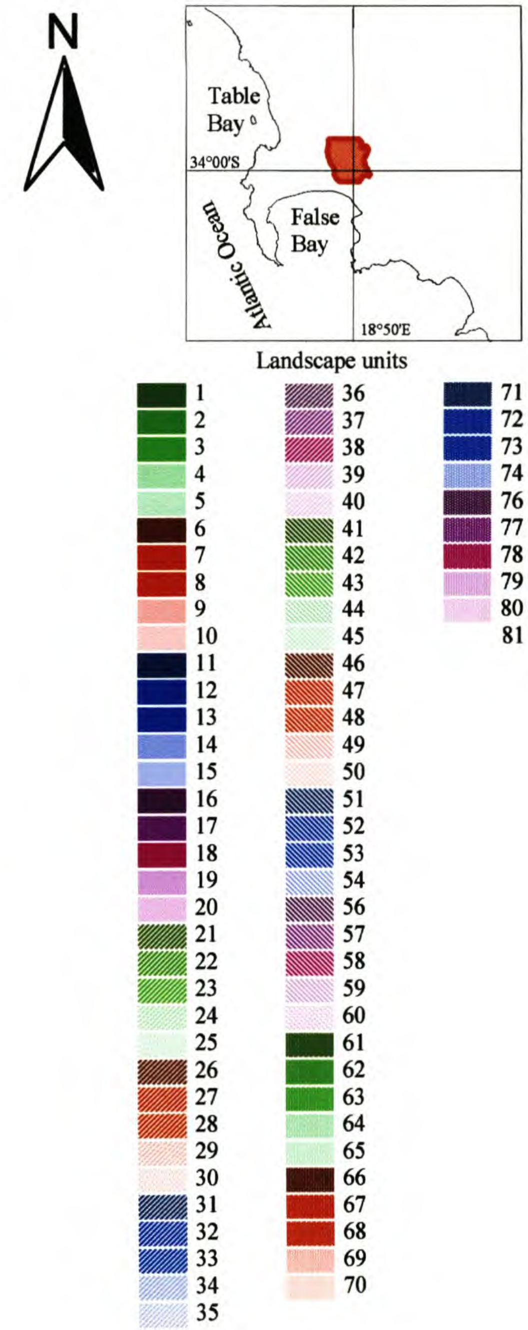


Appendix III. Slope aspects in the Bottelaryberg-Simonsberg-Helderberg study area. Compiled by Department of Agriculture: Western Cape. Insert shows position of study area in relation to False Bay and Table Bay.



Appendix IV. Altitude variation in the Bottelaryberg-Simonsberg-Helderberg study area. Compiled by Department of Agriculture: Western Cape from 50m DEM data. Insert shows position of study area in relation to False Bay and Table Bay.





Appendix V. Landscape units in the Bottelaryberg-Simonsberg-Helderberg study area. Insert shows position of study area in relation to False Bay and Table Bay.

Appendix V. A key to the landscape units in the Bottelatyberg-Simonsberg-Helderberg study area

Landscape units	Terrain unit	Aspect	Altitude	Hectares
1	1	East	0-100 m	72.43
2	1	East	100-200 m	273.61
3	1	East	200-300 m	147.83
4	1	East	300-400 m	24.94
5	1	East	400-550 m	2.45
6	1	North	0-100 m	78.38
7	1	North	100-200 m	265.99
8	1	North	200-300 m	179.11
9	1	North	300-400 m	32.60
10	1	North	400-550 m	5.21
11	1	South	0-100 m	90.96
12	1	South	100-200 m	250.85
13	1	South	200-300 m	121.62
14	1	South	300-400 m	19.15
15	1	South	400-550 m	3.32
16	1	West	0-100 m	89.11
17	1	West	100-200 m	251.21
18	1	West	200-300 m	159.87
19	1	West	300-400 m	35.10
20	1	West	400-550 m	5.63
21	3	East	0-100 m	517.72
22	3	East	100-200 m	1007.94
23	3	East	200-300 m	445.14
24	3	East	300-400 m	114.45
25	3	East	400-550 m	14.98
26	3	North	0-100 m	482.32
27	3	North	100-200 m	1269.29
28	3	North	200-300 m	662.45
29	3	North	300-400 m	249.28
30	3	North	400-550 m	102.53
31	3	South	0-100 m	735.84
32	3	South	100-200 m	1177.71
33	3	South	200-300 m	504.73
34	3	South	300-400 m	94.57
35	3	South	400-550 m	6.45
36	3	West	0-100 m	799.29
37	3	West	100-200 m	1935.92
38	3	West	200-300 m	797.21
39	3	West	300-400 m	240.35
40	3	West	400-550 m	76.52
41	4	East	0-100 m	500.21
42	4	East	100-200 m	928.69

Landscape units	Terrain unit	Aspect	Altitude	Hectares
43	4	East	200-300 m	112.09
44	4	East	300-400 m	9.67
45	4	East	400-550 m	6.36
46	4	North	0-100 m	859.52
47	4	North	100-200 m	1596.76
48	4	North	200-300 m	312.99
49	4	North	300-400 m	83.75
50	4	North	400-550 m	27.41
51	4	South	0-100 m	969.51
52	4	South	100-200 m	1004.23
53	4	South	200-300 m	163.60
54	4	South	300-400 m	15.45
56	4	West	0-100 m	989.69
57	4	West	100-200 m	2497.42
58	4	West	200-300 m	439.66
59	4	West	300-400 m	70.42
60	4	West	400-550 m	20.99
61	5	East	0-100 m	126.85
62	5	East	100-200 m	26.39
63	5	East	200-300 m	0.64
64	5	East	300-400 m	0.11
65	5	East	400-550 m	0.82
66	5	North	0-100 m	89.84
67	5	North	100-200 m	59.47
68	5	North	200-300 m	9.94
69	5	North	300-400 m	3.88
70	5	North	400-550 m	1.99
71	5	South	0-100 m	354.94
72	5	South	100-200 m	25.85
73	5	South	200-300 m	3.09
74	5	South	300-400 m	0.15
76	5	West	0-100 m	360.55
77	5	West	100-200 m	146.28
78	5	West	200-300 m	36.07
79	5	West	300-400 m	3.94
80	5	West	400-550 m	3.18
81	5	Flat	0-100 m	0.75

Appendix VI

Profile No:	T01SB	**Soil Form:**	Swartland 2111
Latitude/Longitude:	33 54 43/18 51 49	**Terrain unit:**	Lower footslope
Elevation (m):	167	**Slope (%):**	9
Described by:	D. Saayman & V.A. Carey	**Slope shape:**	Concave
Date:	23/10/2000	**Aspect:**	SW

Horison	Depth (mm)	Description[1]	Diagnostic horizons
A	0-300	Dark yellowish brown 10YR4/4; fine sand, 15-20% clay, 20% fine gravel	Orthic
B	300-800	Strong brown 7.5YR5/6, sub-angular fine blocky;>30% clay	Pedocutanic
C	800+	Partially weathered shale, brownish yellow 10YR6/8; dark red mottles 2.5YR3/6; blocky; >30% clay	Saprolite

Profile No:	T01CS	**Soil Form:**	Klapmuts 2110
Latitude/Longitude:	33 54 40/18 51 45	**Terrain unit:**	Lower footslope
Elevation (m):	164	**Slope (%):**	7
Described by:	D. Saayman & V.A. Carey	**Slope shape:**	Concave
Date:	23/10/2000	**Aspect:**	WSW

Horison	Depth (mm)	Description	Diagnostic horizons
A	0-300	Yellowish brown 10YR5/4; fine sand; 10-15% clay, 20% fine gravel	Orthic
E	300-500	Fine sand; apedal; 25% clay, mottles	E
B	500-800	Yellowish brown 10YR5/8 and dark yellowish brown 10YR 4/4; medium blocky, >30% clay	Pedocutanic
C	800+	Partly weathered shale; brownish yellow 10YR6/8; very pale brown 10YR7/4 and red 2.5YR4/6 mottles, medium to strong blocky, >30% clay.	Saprolite

[1] Soil colours evaluated in moist condition.

Profile No:	T04CS	**Soil Form:**	Oakleaf 221/20
Latitude/Longitude:	33 55 48/18 50 18	**Terrain unit:**	Upper midslope
Elevation (m):	178	**Slope (%):**	7
Described by:	D. Saayman & V.A. Carey	**Slope shape:**	Convex
Date:	25/10/2000	**Aspect:**	WSW

Horison	Depth (mm)	Description	Diagnostic horizons
A	0-300	Dark reddish brown 5YR3/3; fine sand, 20% clay	Orthic
B1	300-900	Dark red 2.5YR 3/6; signs of aggregation; fine sand, 20-25% clay	Neocutanic
B2	900+	Red 2.5YR4/6; signs of aggregation; fine sand, 20-25% clay; 20% fine gravel; relict plinthic character, quasi-concretions	Neocutanic

Profile No:	T04CY	**Soil Form:**	Oakleaf 2210
Latitude/Longitude:	33 55 24/18 49 43	**Terrain unit:**	Crest
Elevation (m):	172	**Slope (%):**	5
Described by:	D. Saayman & V.A. Carey	**Slope shape:**	Convex
Date:	25/10/2000	**Aspect:**	W

Horison	Depth (mm)	Description	Diagnostic horizons
A	0-300	dark brown 7.5YR4/4; fine sand, 15-20% clay	Orthic
B1	300-900	yellowish red 5YR4/6; slight aggregation; fine sand, 20% clay	Neocutanic
B2	900+	yellowish red 5YR4/6; red 2.5YR5/5 mottles; slight aggregation; fine to coarse sand, 20-25% clay; relict plinthic character	Neocutanic

Profile No:	T05CS	**Soil Form:**	Oakleaf 2220
Latitude/Longitude:	33 55 44/18 49 54	**Terrain unit:**	Upper midslope
Elevation (m):	198	**Slope (%):**	11
Described by:	D. Saayman & V.A. Carey	**Slope shape:**	Straight
Date:	06/11/2000	**Aspect:**	NW

Horison	**Depth (mm)**	**Description**	**Diagnostic horizons**
A	0-300	Dark reddish brown 5YR 3/4; fine sand, 15% clay	Orthic
B	300-800	Yellowish red 5YR4/6-8; slight aggregation; fine sand, 20-25% clay	Neocutanic
B2/C	800+	Yellowish red 5YR4/6-8; slight aggregation; fine sand, 20-25% clay; 30% fine quasi-concretions; relict plinthic character	Neocutanic

Profile No:	T05CY	**Soil Form:**	Oakleaf 2110
Latitude/Longitude:	33 54 32/18 48 27	**Terrain unit:**	Midslope
Elevation (m):	177	**Slope (%):**	11
Described by:	D. Saayman & V.A. Carey	**Slope shape:**	Convex
Date:	06/11/2000	**Aspect:**	NE

Horison	**Depth (mm)**	**Description**	**Diagnostic horizons**
A	0-300	Dark brown 7.5YR4/4; fine to coarse sand, 10-15% clay	Orthic
B	300-800	Strong brown 7.5YR5/8; slight aggregation; fine to coarse sand 15% clay	Neocutanic
B2/C	800+	Reddish yellow 7.5YR6/8; dark red 2.5YR3/6 mottles; slight aggregation; fine to coarse sand, 15-20% clay; 20% fine gravel; relict plinthic character.	Neocutanic

Profile No:	T06CY	**Soil Form:**	Sepane 2110
Latitude/Longitude:	33 57 22/18 44 00	**Terrain unit:**	Upper midslope
Elevation (m):	222	**Slope (%):**	15
Described by:	D. Saayman & V.A. Carey	**Slope shape:**	Convex
Date:	26/10/2000	**Aspect:**	WSW

Horison	**Depth (mm)**	**Description**	**Diagnostic horizons**
A	0-400	Dark brown 10YR3/3; fine sand; 10% clay	Orthic
A3	400-500	Dark brown 10YR3/3; apedal; fine sand; 10% clay; 70% fine gravel	Orthic/apedal
B	500-800	Reddish yellow 7.5 YR 6/8; weak blocky; 25 % clay	Pedocutanic
C1	800-900	Brownish yellow 10YR6/6; red 2.5YR4/8 mottles; apedal; 10% clay; 40% fine gravel	Unconsolidated material with signs of wetness
C2	900+	Brown 7.5YR5/4; strong blocky; >30% clay	Unconsolidated material with signs of wetness

Profile No:	T06CS	**Soil Form:**	Swartland 2111
Latitude/Longitude:	33 57 24/18 43 32	**Terrain unit:**	Upper midslope
Elevation (m):	213	**Slope (%):**	13
Described by:	D. Saayman & V.A. Carey	**Slope shape:**	Convex
Date:	26/10/2000	**Aspect:**	WSW

Horison	**Depth (mm)**	**Description**	**Diagnostic horizons**
A	0-300	Dark yellowish brown 10YR4/4; fine sand, 10% clay; 40% fine and coarse gravel	Orthic
B	300-900	Strong brown 7.5YR5/8; weak blocky; 25-30% clay	Pedocutanic
C	900+	Partly weathered shale; yellowish brown 10YR 5/8; lithocutanic character with signs of wetness; 30% clay	Saprolite

Profile No:	T08SB	**Soil Form:**	Oakleaf 2120
Latitude/Longitude:	33 54 44/18 45 28	**Terrain unit:**	Upper midslope
Elevation (m):	185	**Slope (%):**	13
Described by:	D. Saayman & V.A. Carey	**Slope shape:**	Convex
Date:	28/10/2000	**Aspect:**	NW

Horison	**Depth (mm)**	**Description**	**Diagnostic horizons**
A	0-300	Dark brown 10YR4/3; coarse sand, 10% clay; 30% fine gravel	Orthic
B	300-800	Strong brown 7.5YR5/6; slight aggregation; coarse sand, 20-25% clay	Neocutanic
C	800+	Yellowish brown 10YR5/6; moderate to strong blocky; >30% clay; lithocutanic character	Unspecified, without signs of wetness

Profile No:	T08CY	**Soil Form:**	Swartland 2211
Latitude/Longitude:	33 54 43/18 45 31	**Terrain unit:**	Upper midslope
Elevation (m):	235	**Slope (%):**	17
Described by:	D. Saayman & V.A. Carey	**Slope shape:**	Convex
Date:	28/10/2000	**Aspect:**	WNW

Horison	**Depth (mm)**	**Description**	**Diagnostic horizons**
A	0-300	Dark brown 10YR3/3; coarse sand, 5-10% clay; 30% fine gravel	Orthic
B	300-600	Yellowish red 5YR4/8; weak blocky; coarse sand, 20-25% clay; 30% fine gravel	Pedocutanic
C	600+	Partly weathered granite, reddish brown 5YR4/4; blocky; >30% clay, signs of wetness	Saprolite

Profile No:	T08CS	**Soil Form:**	Vilafontes 2/1120
Latitude/Longitude:	33 54 37/18 45 06	**Terrain unit:**	Upper midslope
Elevation (m):	183	**Slope (%):**	13
Described by:	D. Saayman & V.A. Carey	**Slope shape:**	Convex
Date:	28/10/2000	**Aspect:**	NE

Horison	**Depth (mm)**	**Description**	**Diagnostic horizons**
A	0-300	Dark brown 10YR4/3; coarse sand; 5% clay	Orthic
E	300-600	Light yellowish brown; coarse sand, 5% clay	E
B	600+	Yellowish brown 10YR 5/8; slight aggregation; coarse sand, 20-25% clay; 20% fine gravel	Neocutanic

Profile No:	T09SB	**Soil Form:**	Klapmuts 2210
Latitude/Longitude:	33 53 55/18 44 45	**Terrain unit:**	Lower midslope
Elevation (m):	90	**Slope (%):**	11
Described by:	D. Saayman & V.A. Carey	**Slope shape:**	Convex/straight
Date:	06/11/2000	**Aspect:**	NW

Horison	**Depth (mm)**	**Description**	**Diagnostic horizons**
A	0-300	Dark brown 10YR4/3; fine to medium sand, 10-15% clay; 30% fine gravel	Orthic
E	300-400	Yellowish brown 10YR5/4; fine to medium sand, 15-20% clay, 80% fine gravel, gleyed character	E
B	400-700	Yellowish brown 10YR5/8; moderate blocky; 25-30% clay	Pedocutanic
C	700+	Yellowish brown 10YR5/8 and brownish yellow 10YR 6/6; weathered shale, moderate to strong blocky; >30% clay.	

Profile No:	T09CS	**Soil Form:**	Klapmuts 2220
Latitude/Longitude:	33 53 53/18 44 08	**Terrain unit:**	Midslope
Elevation (m):	97	**Slope (%):**	9
Described by:	D. Saayman & V.A. Carey	**Slope shape:**	Convex
Date:	Midslope	**Aspect:**	N

Horison	**Depth (mm)**	**Description**	**Diagnostic horizons**
A	0-300	Brown 7.5YR5/4; fine sand; 15% clay; 40% fine gravel	Orthic
E	300-500	Fine sand 10% clay; 80% fine gravel; gleyed characteristics	E
B	500-800	Strong brown 7.5YR5/8; strong blocky; fine sand, 25% clay.	Pedocutanic
C	800+	Partly weathered shale, strong brown 7.5YR5/6 and dark brown 7.5YR4/4; red and white mottles; coarse, well developed blocky; fine sand; 25% clay; signs of wetness.	Saprolite

Profile No:	T10SB	**Soil Form:**	Klapmuts 2110
Latitude/Longitude:	33 57 40/18 43 36	**Terrain unit:**	Lower midslope
Elevation (m):	142	**Slope (%):**	8
Described by:	D. Saayman & V.A. Carey	**Slope shape:**	Concave
Date:	28/10/2000	**Aspect:**	SW

Horison	**Depth (mm)**	**Description**	**Diagnostic horizons**
A	0-200	Dark brown 10YR3/3; medium sand, 5% clay	Orthic
E	200-400	Yellowish brown 10YR5/4; medium sand, 5% clay; 50% fine gravel; plinthic and gleyed character	E
B	400+	Yellowish brown 10YR5/6; strong, fine angular structure; >30% clay	Pedocutanic

Profile No:	T10CY	**Soil Form:**	Clovelly 2100
Latitude/Longitude:	33 58 05/18 44 07	**Terrain unit:**	Lower midslope
Elevation (m):	122	**Slope (%):**	5
Described by:	D. Saayman & V.A. Carey	**Slope shape:**	Straight
Date:	28/10/2000	**Aspect:**	SSE

Horison	**Depth (mm)**	**Description**	**Diagnostic horizons**
A	0-300	Yellowish brown 10YR5/4; medium to fine sand, 0-5% clay	Orthic
B	300+	Strong brown 5/6; apedal; medium to fine sand; 0-5% clay	Yellow-brown apedal

Profile No:	T10CS	**Soil Form:**	Klapmuts 2110
Latitude/Longitude:	33 57 53/ 18 43 57	**Terrain unit:**	Upper midslope
Elevation (m):	161	**Slope (%):**	8
Described by:	D. Saayman & V.A. Carey	**Slope shape:**	Convex
Date:	28/10/2000	**Aspect:**	SSW

Horison	**Depth (mm)**	**Description**	**Diagnostic horizons**
A	0-300	Dark brown 10YR4/3; medium to fine sand; 10% clay; 40% fine and coarse gravel and stones.	Orthic
E	300-500	Yellowish brown 10YR5/8; fine sand; gleyed character	E
B	500-800	Strong brown 7.5YR5/8; fine blocky; >30% clay	Pedocutanic
C	800+	Partly weathered shale; strong brown 7.5YR5/6; dark red 10R3/6 mottles; fine angular; >30% clay	Saprolite

Profile No:	T12CS	**Soil Form:**	Tukulu 21/220
Latitude/Longitude:	34 00 38/18 51 25	**Terrain unit:**	Lower midslope
Elevation (m):	218	**Slope (%):**	6
Described by:	D. Saayman & V.A. Carey	**Slope shape:**	Convex
Date:	26/10/2000	**Aspect:**	NW

Horison	**Depth (mm)**	**Description**	**Diagnostic horizons**
A	0-400	Dark reddish brown 5YR3/3; coarse sand, 15-20% clay; 20% fine gravel	Orthic
B	400-700	Yellowish red 5YR4/8 and dark reddish brown 3/4, slight aggregation and earthworm activity; coarse sand, 20-25% clay.	Neocutanic
C	700+	Yellowish brown 10YR5/8; medium to weak blocky; lithocutanic character; >30% clay.	Unspecified with signs of wetness

Profile No:	T14CS	**Soil Form:**	Estcourt 2100
Latitude/Longitude:	34 01 17/18 44 52	**Terrain unit:**	Lower footslope
Elevation (m):	25	**Slope (%):**	Flat
Described by:	D. Saayman & V.A. Carey	**Slope shape:**	Straight
Date:	28/10/2000	**Aspect:**	Flat

Horison	**Depth (mm)**	**Description**	**Diagnostic horizons**
A	0-300	Yellowish brown 10YR 5/4; medium to coarse sand, 10-15% clay; 40 % fine gravel	Orthic
E	300-500	Brown 10YR5/3; gleyed character; medium to coarse sand, 10-15% clay; 80% fine gravel	E
B	500-700	Yellowish brown 10YR5/6; prismatic; >30% clay	Prismacutanic
C	700+	Yellowish brown 10YR5/8 with grey 10YR6/1 and red 2.5YR4/6 mottles; prismatic structure; >30% clay	Prismacutanic

Profile No:	T14CY	**Soil Form:**	Dundee 1210
Latitude/Longitude:	34 00 28/18 45 35	**Terrain unit:**	Valley floor
Elevation (m):	16	**Slope (%):**	1
Described by:	D. Saayman & V.A. Carey	**Slope shape:**	Straight
Date:	28/10/2000	**Aspect:**	SE

Horison	**Depth (mm)**	**Description**	**Diagnostic horizons**
A	0-200	Brown 10YR5/3; medium sand, 5% clay.	Orthic
C1	200-700	Dark brown 10YR3/3; apedal; alternating sand and silt; medium sand, 0-5% clay; plinthic character	Stratified alluvium
C2	700+	Dark grey 10YR4/1 and dark greyish brown 10YR4/2; weak blocky; 15 % clay	Stratified alluvium

Profile No:	T14SB	**Soil Form:**	Dundee 1210
Latitude/Longitude:	34 00 29/18 45 35	**Terrain unit:**	Valley floor
Elevation (m):	16	**Slope (%):**	1
Described by:	D. Saayman & V.A. Carey	**Slope shape:**	Straight
Date:	28/10/2000	**Aspect:**	SE

Horison	**Depth (mm)**	**Description**	**Diagnostic horizons**
A	0-200	Brown 10YR5/3; medium sand, 5% clay.	Orthic
C1	200-700	Dark brown 10YR3/3; apedal; alternating sand and silt; medium sand, 0-5% clay; plinthic character	Stratified alluvium
C2	700+	Dark grey 10YR4/1 and dark greyish brown 10YR4/2; weak blocky; 15 % clay	Stratified alluvium

Profile No:	T15SB	**Soil Form:**	Oakleaf 1/21/210
Latitude/Longitude:	33 56 12/18 46 42	**Terrain unit:**	Upper midslope
Elevation (m):	128	**Slope (%):**	14
Described by:	D. Saayman & V.A. Carey	**Slope shape:**	Convex
Date:	06/11/2000	**Aspect:**	SSW

Horison	**Depth (mm)**	**Description**	**Diagnostic horizons**
A	0-500	Dark brown 7.5YR3/2; coarse sand, 10% clay	Orthic
B	500-1000	Reddish brown 5YR 4/4; slight aggregation; fine to coarse sand, 10-15% clay	Neocutanic
C	1000+	Yellowish red 5YR4-5/8; slight aggregation, fine to coarse sand, 15% clay; relict plinthic character	Unspecified

Profile No:	T15CY	**Soil Form:**	Oakleaf 2110
Latitude/Longitude:	33 56 06/18 46 50	**Terrain unit:**	Upper midslope
Elevation (m):	155	**Slope (%):**	14
Described by:	D. Saayman & V.A. Carey	**Slope shape:**	Convex to straight
Date:	06/11/2000	**Aspect:**	SSW

Horison	**Depth (mm)**	**Description**	**Diagnostic horizons**
A	0-300	Dark yellowish brown 10YR 4/4; medium to coarse sand, 5-10% clay	Orthic
B	300-800	Yellowish brown 10YR5/8; slight aggregation; fine to coarse sand, 10-15% clay	Neocutanic
C	800+	Yellowish red 7.5YR5/6 with red 5YR4/6 mottles; slight aggregation; fine to coarse sand, 15-20% clay; relict plinthic character	Unspecified

Profile No:	T15CS	**Soil Form:**	Oakleaf 2110
Latitude/Longitude:	33 56 13/18 46 53	**Terrain unit:**	Lower midslope
Elevation (m):	132	**Slope (%):**	8
Described by:	D. Saayman & V.A. Carey	**Slope shape:**	Straight
Date:	06/11/2000	**Aspect:**	SSW

Horison	Depth (mm)	Description	Diagnostic horizons
A	0-300	Dark brown 7.5YR4/4; fine to coarse sand, 5-10% clay.	Orthic
B	300-600	Strong brown 7.5YR5/6; very slight aggregation; fine to medium sand, 10-15% clay.	Neocutanic
C	600+	Strong brown 7.5YR5/8 with red mottles 2.5YR4/8; slight aggregation; fine to medium sand, 15% clay; relict plinthic character	Unspecified

Profile No:	T25CS	**Soil Form:**	Klapmuts
Latitude/Longitude:	33 57 40/18 50 27	**Terrain unit:**	Upper midslope
Elevation (m):	130	**Slope (%):**	7
Described by:	D. Saayman & V.A. Carey	**Slope shape:**	Straight
Date:	26/10/2000	**Aspect:**	NNW

Horison	Depth (mm)	Description	Diagnostic horizons
A	0-300	Dark brown 10YR4.3; coarse sand, 5-10% clay; 10% fine gravel	Orthic
E	300-500	Yellowish brown 10YR5/4; apedal; coarse sand, 5-10% clay	E
B	500-800	Reddish yellow 7.5YR6/8 with red 2.5YR4/8 mottles; weak blocky; >30% clay	Pedocutanic
C	800+	Yellowish brown 10YR5/8 with very pale brown 10YR7/4 and dark red 2.5YR3/6 mottles; weak blocky; >30% clay	

Profile No:	T25CY	**Soil Form:**	Kroonstad 1000
Latitude/Longitude:	33 57 04/18 50 43	**Terrain unit:**	Lower footslope
Elevation (m):	193	**Slope (%):**	5
Described by:	D. Saayman & V.A. Carey	**Slope shape:**	Convex
Date:	26/10/2000	**Aspect:**	N

Horison	**Depth (mm)**	**Description**	**Diagnostic horizons**
A	0-300	Dark brown 7.5YR4/4; coarse sand, 5-10% clay; 50 % fine gravel	Orthic
E	300-600	Dark brown 10YR4/3; apedal; coarse sand; 5-10% clay; 60% fine gravel	E
G	600+	Greyish brown 10YR5/2 and strong brown 7.5YR5/8 with dark red mottles 2.5YR3/6; prismatic; gleyed ped faces, >35% clay	G

Profile No:	T26CY	**Soil Form:**	Oakleaf 21/220
Latitude/Longitude:	34 01 44/18 51 06	**Terrain unit:**	Lower midslope
Elevation (m):	320	**Slope (%):**	20
Described by:	D. Saayman & V.A. Carey	**Slope shape:**	Convex
Date:	26/10/2000	**Aspect:**	WNW

Horison	**Depth (mm)**	**Description**	**Diagnostic horizons**
A	0-500	Dark reddish brown 5YR3/4; fine sand; 10-15% clay	Orthic
B	500-900	Yellowish red 5YR4/6; slight aggregation; fine sand, 20-25% clay	Neocutanic
C	900+	Yellowish red 7.5YR5/6; slight aggregation; fine sand, 20-25% clay; 40% fine gravel; relict plinthic character	Unspecified

Profile No:	T26SB	**Soil Form:**	Klapmuts 2120
Latitude/Longitude:	34 01 30/18 50 29	**Terrain unit:**	Upper midslope
Elevation (m):	247	**Slope (%):**	18
Described by:	D. Saayman & V.A. Carey	**Slope shape:**	Convex
Date:	26/10/2000	**Aspect:**	SW

Horison	**Depth (mm)**	**Description**	**Diagnostic horizons**
A	0-200	Dark brown 7.5YR3/2; fine to coarse sand, 15% clay	Orthic
E	200-600	Brown 7.5YR5/4; apedal; fine to coarse sand, 15% clay, 80% fine gravel	E
B	600-800	Strong brown 7.5YR5/6; blocky to weak prismatic; >30% clay	Pedocutanic
C	800+	Reddish yellow 7.5YR6/8; blocky to weak prismatic; lithocutanic character with signs of wetness	

Appendix VII. Comparison of soil types obtained from digital soil association data (Ellis *et al.* 1975, 1976 and 1980) and soil profile studies (see Appendix VI) for sites in the Bottelaryberg-Simonsberg-Helderberg study area.

Site ID no.	Soil associations (Ellis *et al.*, 1975, 1976)	Soil associations (Ellis *et al.*, 1980)	Soil profile studies (based on Appendix VI)
T01SB	Red & yellow apedal & neocutanic soils	Medium textured red and yellow apedal & neocutanic soils	Dry duplex soil
T01CS	Red & yellow apedal & neocutanic soils	Medium textured red and yellow apedal & neocutanic soils	Medium deep wet duplex soil
T04CS	Red & yellow apedal & neocutanic soils	Medium textured red and yellow apedal & neocutanic soils	Medium textured red neocutanic soils
T04CY	Red & yellow apedal & neocutanic soils	Medium textured red and yellow apedal & neocutanic soils	Medium textured red neocutanic soil
T05CS	Red & yellow apedal & neocutanic soils	Medium textured red and yellow apedal & neocutanic soils	Medium textured red neocutanic soil
T05CY	Red & yellow apedal & neocutanic soils	Medium textured red and yellow apedal & neocutanic soils	Medium textured yellow neocutanic soil
T06CY	Red & yellow apedal & neocutanic soils	Relatively wet coarse sand duplex soils	Medium deep wet duplex soil
T06CS	Medium deep wet duplex soils	Light textured red & yellow apedal & neocutanic soils	Dry duplex soil/ residual soil: advanced weathering
T08SB	Medium deep wet duplex soils	Undifferentiated	Medium textured yellow neocutanic soil
T08CY	Medium deep wet duplex soils	Undifferentiated	Residual soil: advanced weathering/ Dry duplex soil
T08CS	Red & yellow apedal & neocutanic soils	Undifferentiated	Medium textured yellow neocutanic soil
T09SB	Medium deep wet duplex soils	Residual soils. Weathering more advanced	Residual soil: advanced weathering/ shallow wet duplex soils/
T09CS	Medium deep wet duplex soils	Residual soils. Weathering more advanced	Residual soil: advanced weathering/ medium deep wet duplex soil/
T10SB	Medium deep wet duplex soils	Light textured red & yellow apedal & neocutanic soils	Shallow wet medium sand duplex soil
T10CY	Red & yellow apedal & neocutanic soils	Light textured red & yellow apedal & neocutanic soils	Light textured yellow apedal soil
T10CS	Red & yellow apedal & neocutanic soils	Light textured red & yellow apedal & neocutanic soils	Medium deep wet duplex soil
T12CS	Shallow red & yellow apedal & neocutanic soils	Medium textured red and yellow apedal & neocutanic soils	Red neocutanic soil
T14CS	Shallow wet duplex soils	Sands-Acid	Medium deep wet duplex soil

Site ID no.	Soil associations (Ellis *et al.*, 1975, 1976)	Soil associations (Ellis *et al.*, 1980)	Soil profile studies (based on Appendix VI)
T14SB	Shallow wet duplex soils/poorly drained alluvial soils	Medium textured alluvial soils	Alluvial soil
T15SB	Red & yellow apedal & neocutanic soils	Medium textured red and yellow apedal & neocutanic soils	Red neocutanic soil
T15CY	Red & yellow apedal & neocutanic soils	Medium textured red and yellow apedal & neocutanic soils	Yellow neocutanic soil
T15CS	Red & yellow apedal & neocutanic soils	Medium textured red and yellow apedal & neocutanic soils	Yellow neocutanic soil
T25CS	Medium deep wet duplex soils	Medium textured red and yellow apedal & neocutanic soils	Medium deep wet duplex soil
T25CY	Saline duplex and loam alluvial soils	Relatively wet coarse sand duplex soils	Medium deep wet coarse sand duplex soil
T26CY	Red & yellow apedal & neocutanic soils	Medium textured red and yellow apedal & neocutanic soils	Medium textured red neocutanic soil
T26SB	Residual soils	Relatively wet coarse sand duplex soils/ Residual soils	Medium deep wet duplex soil

Appendix VIII. A key to the natural terroir units in the Bottelaryberg-Simonsberg-Helderberg study area.

Natural "terroir" unit	Terrain unit	Aspect	Altitude	Soil type	Soil type	Hectares	% Landscape unit
1E1B	1	East	0-100 m	B	Red and yellow apedal or neocutanic soils	7.57	10.63
1E1D	1	East	0-100 m	D	Duplex soils	62.80	88.11
1E1SW	1	East	0-100 m	H	Sandy soils	0.90	1.26
1E2A_GR	1	East	100-200 m	A	Residual soils (Granite origin)	11.92	4.43
1E2A_SH	1	East	100-200 m	A	Residual soils (Grewacke origin)	14.50	5.39
1E2B	1	East	100-200 m	B	Red and yellow apedal or neocutanic soils	116.41	43.32
1E2D	1	East	100-200 m	D	Duplex soils	125.91	46.85
1E3A_GR	1	East	200-300 m	A	Residual soils (Granite origin)	15.78	10.67
1E3A_SH	1	East	200-300 m	A	Residual soils (Grewacke origin)	19.37	13.10
1E3B	1	East	200-300 m	B	Red and yellow apedal or neocutanic soils	108.82	73.61
1E3D	1	East	200-300 m	D	Duplex soils	3.87	2.62
1E4A_GR	1	East	300-400 m	A	Residual soils (Granite origin)	20.21	81.06
1E4A_SH	1	East	300-400 m	A	Residual soils (Grewacke origin)	0.54	2.17
1E4B	1	East	300-400 m	B	Red and yellow apedal or neocutanic soils	4.18	16.78
1E5A_GR	1	East	400-550 m	A	Residual soils (Granite origin)	1.17	47.79
1E5A_SH	1	East	400-550 m	A	Residual soils (Grewacke origin)	1.28	52.21
1NW1A_F	1	Northwest	0-100 m	A	Residual soils (Ferricrete)	0.15	0.13
1NW1A_SH	1	Northwest	0-100 m	A	Residual soils (Grewacke origin)	4.37	3.67
1NW1B	1	Northwest	0-100 m	B	Red and yellow apedal or neocutanic soils	1.18	0.99
1NW1D	1	Northwest	0-100 m	D	Duplex soils	111.69	93.94
1NW1SW	1	Northwest	0-100 m	H	Sandy soils	1.51	1.27
1NW2A_GR	1	Northwest	100-200 m	A	Residual soils (Granite origin)	21.24	5.53
1NW2A_SH	1	Northwest	100-200 m	A	Residual soils (Grewacke origin)	10.98	2.86
1NW2B	1	Northwest	100-200 m	B	Red and yellow apedal or neocutanic soils	105.48	27.48
1NW2D	1	Northwest	100-200 m	C	Duplex soils	246.10	64.12
1NW3A_GR	1	Northwest	200-300 m	A	Residual soils (Granite origin)	19.62	7.51
1NW3A_QS	1	Northwest	200-300 m	A	Residual soils (Alluvium and scree - probably sandstone origin)	0.94	0.36
1NW3A_SH	1	Northwest	200-300 m	A	Residual soils (Grewacke origin)	24.15	9.25
1NW3B	1	Northwest	200-300 m	B	Red and yellow apedal or neocutanic soils	189.21	72.45
1NW3D	1	Northwest	200-300 m	D	Duplex soils	27.24	10.43
1NW4A_GR	1	Northwest	300-400 m	A	Residual soils (Granite origin)	33.88	62.31
1NW4A_SH	1	Northwest	300-400 m	A	Residual soils (Grewacke origin)	3.17	5.82
1NW4B	1	Northwest	300-400 m	B	Red and yellow apedal or neocutanic soils	17.33	31.87
1NW5A_GR	1	Northwest	400-550 m	A	Residual soils (Granite origin)	4.83	58.74
1NW5A_SH	1	Northwest	400-550 m	A	Residual soils (Grewacke origin)	1.93	23.45
1NW5B	1	Northwest	400-550 m	B	Red and yellow apedal or neocutanic soils	1.47	17.81
1SW1B	1	Southwest	0-100 m	B	Red and yellow apedal or neocutanic soils	0.14	0.11
1SW1D	1	Southwest	0-100 m	D	Duplex soils	4.66	3.47
1SW1S	1	Southwest	0-100 m	H	Sandy soils	129.46	96.42
1SW2A_GR	1	Southwest	100-200 m	A	Residual soils (Granite origin)	4.72	2.53
1SW2A_SH	1	Southwest	100-200 m	A	Residual soils (Grewacke origin)	9.61	5.14
1SW2B	1	Southwest	100-200 m	B	Red and yellow apedal or neocutanic soils	6.81	3.65
1SW2D	1	Southwest	100-200 m	D	Duplex soils	165.72	88.68
1SW3A_GR	1	Southwest	200-300 m	A	Residual soils (Granite origin)	189.04	83.01
1SW3A_SH	1	Southwest	200-300 m	A	Residual soils (Grewacke origin)	20.71	9.10
1SW3B	1	Southwest	200-300 m	B	Red and yellow apedal or neocutanic soils	0.70	0.31
1SW3D	1	Southwest	200-300 m	D	Duplex soils	17.27	7.58
1SW4A_GR	1	Southwest	300-400 m	A	Residual soils (Granite origin)	145.49	84.39
1SW4A_SH	1	Southwest	300-400 m	A	Residual soils (Grewacke origin)	6.74	3.91
1SW4B	1	Southwest	300-400 m	B	Red and yellow apedal or neocutanic soils	20.17	11.70
1SW5A_GR	1	Southwest	400-550 m	A	Residual soils (Granite origin)	1.21	9.91
1SW5A_SH	1	Southwest	400-550 m	A	Residual soils (Grewacke origin)	11.03	90.09
3E1A_GR	3	East	0-100 m	A	Residual soils (Granite origin)	2.72	2.17
3E1B	3	East	0-100 m	B	Red and yellow apedal or neocutanic soils	3.21	2.56
3E1D	3	East	0-100 m	D	Duplex soils	14.59	11.65
3E1S	3	East	0-100 m	E	Sandy soils	104.64	83.61
3E2A_GR	3	East	100-200 m	A	Residual soils (Granite origin)	370.19	37.39
3E2A_SH	3	East	100-200 m	A	Residual soils (Grewacke origin)	3.35	0.34
3E2B	3	East	100-200 m	B	Red and yellow apedal or neocutanic soils	39.27	3.97
3E2D	3	East	100-200 m	D	Duplex soils	11.79	1.19
3E2S	3	East	100-200 m	E	Sandy soils	565.59	57.12
3E3A_GR	3	East	200-300 m	A	Residual soils (Granite origin)	365.82	78.63
3E3A_QS	3	East	200-300 m	A	Residual soils (Alluvium and scree - probably sandstone origin)	7.13	1.53
3E3A_SH	3	East	200-300 m	A	Residual soils (Grewacke origin)	81.06	17.42
3E3B	3	East	200-300 m	B	Red and yellow apedal or neocutanic soils	0.02	0.00
3E3D	3	East	200-300 m	D	Duplex soils	11.21	2.41

Natural "terroir" unit	Terrain unit	Aspect	Altitude	Soil type	Soil type	Hectares	% Landscape unit
3E4A_GR	3	East	300-400 m	A	Residual soils (Granite origin)	322.01	74.26
3E4A_QS	3	East	300-400 m	A	Residual soils (Alluvium and scree - probably sandstone origin)	30.37	7.00
3E4A_SH	3	East	300-400 m	A	Residual soils (Grewacke origin)	81.08	18.70
3E4B	3	East	300-400 m	B	Red and yellow apedal or neocutanic soils	0.17	0.04
3E5A_GR	3	East	400-550 m	A	Residual soils (Granite origin)	21.66	56.14
3E5A_QS	3	East	400-550 m	A	Residual soils (Alluvium and scree - probably sandstone origin)	11.54	29.92
3E5A_SH	3	East	400-550 m	A	Residual soils (Grewacke origin)	3.05	7.90
3E5B	3	East	400-550 m	B	Red and yellow apedal or neocutanic soils	2.33	6.03
3NW1_SH	3	Northwest	0-100 m	A	Residual soils (Grewacke origin)	8.81	8.08
3NW1A_F	3	Northwest	0-100 m	A	Residual soils (Ferricrete origin)	0.79	0.72
3NW1A_GR	3	Northwest	0-100 m	A	Residual soils (Granite origin)	18.27	16.76
3NW1B	3	Northwest	0-100 m	B	Red and yellow apedal or neocutanic soils	6.78	6.22
3NW1D	3	Northwest	0-100 m	D	Duplex soils	32.68	29.97
3NW1S	3	Northwest	0-100 m	E	Sandy soils	41.71	38.26
3NW2A_F	3	Northwest	100-200 m	A	Residual soils (Ferricrete origin)	742.53	50.16
3NW2A_GR	3	Northwest	100-200 m	A	Residual soils (Granite origin)	11.27	0.76
3NW2A_QS	3	Northwest	100-200 m	A	Residual soils (Alluvium and scree - probably sandstone origin)	6.09	0.41
3NW2A_SH	3	Northwest	100-200 m	A	Residual soils (Grewacke origin)	108.23	7.31
3NW2B	3	Northwest	100-200 m	B	Red and yellow apedal or neocutanic soils	1.22	0.08
3NW2D	3	Northwest	100-200 m	D	Duplex soils	16.45	1.11
3NW2S	3	Northwest	100-200 m	E	Sandy soils	594.57	40.16
3NW3A_GR	3	Northwest	200-300 m	A	Residual soils (Granite origin)	1181.09	87.78
3NW3A_QS	3	Northwest	200-300 m	A	Residual soils (Alluvium and scree - probably sandstone origin)	10.58	0.79
3NW3A_SH	3	Northwest	200-300 m	A	Residual soils (Grewacke origin)	90.06	6.69
3NW3B	3	Northwest	200-300 m	B	Red and yellow apedal or neocutanic soils	45.45	3.38
3NW3D	3	Northwest	200-300 m	D	Duplex soils	18.30	1.36
3NW4A_GR	3	Northwest	300-400 m	A	Residual soils (Granite origin)	839.01	75.88
3NW4A_QS	3	Northwest	300-400 m	A	Residual soils (Alluvium and scree - probably sandstone origin)	85.15	7.70
3NW4A_SH	3	Northwest	300-400 m	A	Residual soils (Grewacke origin)	105.77	9.57
3NW4B	3	Northwest	300-400 m	B	Red and yellow apedal or neocutanic soils	1.48	0.13
3NW4S	3	Northwest	300-400 m	E	Sandy soils	74.24	6.71
3NW5A_GR	3	Northwest	400-550 m	A	Residual soils (Granite origin)	193.76	66.02
3NW5A_QS	3	Northwest	400-550 m	A	Residual soils (Alluvium and scree - probably sandstone origin)	1.67	0.57
3NW5A_SH	3	Northwest	400-550 m	A	Residual soils (Grewacke origin)	32.53	11.08
3NW5B	3	Northwest	400-550 m	B	Red and yellow apedal or neocutanic soils	40.08	13.66
3NW5S	3	Northwest	400-550 m	E	Sandy soils	25.44	8.67
3SW1A_GR	3	Southwest	0-100 m	A	Residual soils (Granite origin)	40.49	76.28
3SW1A_QS	3	Southwest	0-100 m	A	Residual soils (Alluvium and scree - probably sandstone origin)	4.83	9.10
3SW1B	3	Southwest	0-100 m	B	Red and yellow apedal or neocutanic soils	1.64	3.10
3SW1D	3	Southwest	0-100 m	D	Duplex soils	1.19	2.25
3SW1S	3	Southwest	0-100 m	E	Sandy soils	4.93	9.28
3SW2A_GR	3	Southwest	100-200 m	A	Residual soils (Granite origin)	0.68	0.06
3SW2A_QS	3	Southwest	100-200 m	A	Residual soils (Alluvium and scree - probably sandstone origin)	138.43	12.95
3SW2A_SH	3	Southwest	100-200 m	A	Residual soils (Grewacke origin)	815.19	76.29
3SW2B	3	Southwest	100-200 m	B	Red and yellow apedal or neocutanic soils	27.56	2.58
3SW2D	3	Southwest	100-200 m	D	Duplex soils	72.46	6.78
3SW2S	3	Southwest	100-200 m	E	Sandy soils	14.25	1.33
3SW3A_CG	3	Southwest	200-300 m	A	Residual soils (Franschoek conglomerate origin)	12.19	0.63
3SW3A_GR	3	Southwest	200-300 m	A	Residual soils (Granite origin)	881.64	45.37
3SW3A_QS	3	Southwest	200-300 m	A	Residual soils (Alluvium and scree - probably sandstone origin)	871.71	44.86
3SW3A_SH	3	Southwest	200-300 m	A	Residual soils (Grewacke origin)	50.40	2.59
3SW3B	3	Southwest	200-300 m	B	Red and yellow apedal or neocutanic soils	0.75	0.04
3SW3D	3	Southwest	200-300 m	D	Duplex soils	126.56	6.51
3SW4A_GR	3	Southwest	300-400 m	A	Residual soils (Granite origin)	0.36	0.05
3SW4A_QS	3	Southwest	300-400 m	A	Residual soils (Alluvium and scree - probably sandstone origin)	21.30	2.67
3SW4A_SH	3	Southwest	300-400 m	A	Residual soils (Grewacke origin)	635.31	79.57
3SW4B	3	Southwest	300-400 m	B	Red and yellow apedal or neocutanic soils	52.00	6.51
3SW4SW	3	Southwest	300-400 m	E	Sandy soils	89.42	11.20
3SW5A_GR	3	Southwest	400-550 m	A	Residual soils (Granite origin)	5.20	6.82
3SW5A_SH	3	Southwest	400-550 m	A	Residual soils (Grewacke origin)	21.00	27.53
3SW5S	3	Southwest	400-550 m	E	Sandy soils	50.06	65.65
4E1A_GR	4	East	0-100 m	A	Residual soils (Granite origin)	8.82	25.18
4E1A_QS	4	East	0-100 m	A	Residual soils (Alluvium and scree - probably sandstone origin)	5.30	15.12
4E1B	4	East	0-100 m	B	Red and yellow apedal or neocutanic soils	12.35	35.23
4E1D	4	East	0-100 m	D	Duplex soils	4.98	14.21
4E1S	4	East	0-100 m	E	Sandy soils	3.59	10.25
4E2A_GR	4	East	100-200 m	A	Residual soils (Granite origin)	0.53	0.13
4E2B	4	East	100-200 m	B	Red and yellow apedal or neocutanic soils	1.14	0.27

Natural "terroir" unit	Terrain unit	Aspect	Altitude	Soil type	Soil type	Hectares	% Landscape unit
4E2D	4	East	100-200 m	D	Duplex soils	84.69	19.96
4E2S	4	East	100-200 m	E	Sandy soils	337.95	79.65
4E3A_GR	4	East	200-300 m	A	Residual soils (Granite origin)	5.33	0.74
4E3A_SH	4	East	200-300 m	A	Residual soils (Grewacke origin)	15.60	2.16
4E3B	4	East	200-300 m	B	Red and yellow apedal or neocutanic soils	316.64	43.94
4E3D	4	East	200-300 m	D	Duplex soils	382.98	53.15
4E4A_GR	4	East	300-400 m	A	Residual soils (Granite origin)	55.61	85.50
4E4A_SH	4	East	300-400 m	A	Residual soils (Grewacke origin)	9.11	14.01
4E4B	4	East	300-400 m	B	Red and yellow apedal or neocutanic soils	0.32	0.49
4E5A_QS	4	East	400-550 m	A	Residual soils (Alluvium and scree - probably sandstone origin)	76.24	71.48
4E5A_SH	4	East	400-550 m	A	Residual soils (Grewacke origin)	26.75	25.07
4E5B	4	East	400-550 m	B	Red and yellow apedal or neocutanic soils	3.68	3.45
4NW1A_GR	4	Northwest	0-100 m	A	Residual soils (Granite origin)	0.68	6.90
4NW1A_SH	4	Northwest	0-100 m	A	Residual soils (Grewacke origin)	3.41	34.77
4NW1B	4	Northwest	0-100 m	B	Red and yellow apedal or neocutanic soils	1.34	13.67
4NW1D	4	Northwest	0-100 m	D	Duplex soils	4.21	42.96
4NW1S	4	Northwest	0-100 m	E	Sandy soils	0.17	1.71
4NW2_SH	4	Northwest	100-200 m	A	Residual soils (Grewacke origin)	19.74	1.74
4NW2A_GR	4	Northwest	100-200 m	A	Residual soils (Granite origin)	2.96	0.26
4NW2A_QS	4	Northwest	100-200 m	A	Residual soils (Alluvium and scree - probably sandstone origin)	53.91	4.74
4NW2B	4	Northwest	100-200 m	B	Red and yellow apedal or neocutanic soils	1033.23	90.90
4NW2D	4	Northwest	100-200 m	D	Duplex soils	11.43	1.01
4NW2S	4	Northwest	100-200 m	E	Sandy soils	15.34	1.35
4NW3A_GR	4	Northwest	200-300 m	A	Residual soils (Granite origin)	59.55	2.77
4NW3A_QS	4	Northwest	200-300 m	A	Residual soils (Alluvium and scree - probably sandstone origin)	7.35	0.34
4NW3A_SH	4	Northwest	200-300 m	A	Residual soils (Grewacke origin)	503.50	23.42
4NW3B	4	Northwest	200-300 m	B	Red and yellow apedal or neocutanic soils	1459.87	67.90
4NW3D	4	Northwest	200-300 m	D	Duplex soils	48.10	2.24
4NW3S	4	Northwest	200-300 m	E	Sandy soils	71.60	3.33
4NW4A_GR	4	Northwest	300-400 m	A	Residual soils (Granite origin)	7.44	1.53
4NW4A_QS	4	Northwest	300-400 m	A	Residual soils (Alluvium and scree - probably sandstone origin)	390.92	80.40
4NW4A_SH	4	Northwest	300-400 m	A	Residual soils (Grewacke origin)	85.00	17.48
4NW4B	4	Northwest	300-400 m	B	Red and yellow apedal or neocutanic soils	2.83	0.58
4NW5A_GR	4	Northwest	400-550 m	A	Residual soils (Granite origin)	11.00	12.15
4NW5A_QS	4	Northwest	400-550 m	A	Residual soils (Alluvium and scree - probably sandstone origin)	1.98	2.18
4NW5A_SH	4	Northwest	400-550 m	A	Residual soils (Grewacke origin)	6.45	7.11
4NW5B	4	Northwest	400-550 m	B	Red and yellow apedal or neocutanic soils	70.33	77.63
4NW5S	4	Northwest	400-550 m	E	Sandy soils	0.84	0.93
4SW1B	4	Southwest	0-100 m	B	Red and yellow apedal or neocutanic soils	6.84	25.08
4SW1D	4	Southwest	0-100 m	D	Duplex soils	15.05	55.20
4SW1S	4	Southwest	0-100 m	E	Sandy soils	5.38	19.72
4SW2A_GR	4	Southwest	100-200 m	A	Residual soils (Granite origin)	2.37	1.58
4SW2A_QS	4	Southwest	100-200 m	A	Residual soils (Alluvium and scree - probably sandstone origin)	2.57	1.72
4SW2B	4	Southwest	100-200 m	B	Red and yellow apedal or neocutanic soils	0.12	0.08
4SW2D	4	Southwest	100-200 m	D	Duplex soils	1.04	0.69
4SW2S	4	Southwest	100-200 m	E	Sandy soils	143.61	95.93
4SW3A_CG	4	Southwest	200-300 m	A	Residual soils (Franschoek conglomerate origin)	802.07	29.21
4SW3A_GR	4	Southwest	200-300 m	A	Residual soils (Granite origin)	41.67	1.52
4SW3A_QS	4	Southwest	200-300 m	A	Residual soils (Alluvium and scree - probably sandstone origin)	44.14	1.61
4SW3A_SH	4	Southwest	200-300 m	A	Residual soils (Grewacke origin)	2.68	0.10
4SW3B	4	Southwest	200-300 m	B	Red and yellow apedal or neocutanic soils	704.09	25.64
4SW3D	4	Southwest	200-300 m	D	Duplex soils	1034.17	37.67
4SW3S	4	Southwest	200-300 m	E	Sandy soils	116.73	4.25
4SW4A_QS	4	Southwest	300-400 m	A	Residual soils (Alluvium and scree - probably sandstone origin)	0.02	0.12
4SW4B	4	Southwest	300-400 m	B	Red and yellow apedal or neocutanic soils	17.89	98.01
4SW4S	4	Southwest	300-400 m	E	Sandy soils	0.34	1.87
HARD ROCK						2.83	
MARSH						242.19	
URBAN						17.02	
VALLEY BOTTOM	5					8.02	
WET ALLUVIAL						4.24	