SERIES

Geology and Wine 7. Geology and Wine Production in the Coastal Region, Western Cape Province, South Africa

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SUMMARY

South Africa's wine industry, founded in 1659, ranks 16th in the world in terms of vineyard acreage and 7th in terms of wine production, making the country a significant player in the world wine industry. The industry saw early success with the wines of Constantia in the 18th century and is currently recovering from the influence of legislative controls that restricted the industry over much of the 20th century.

The Coastal Region, which includes the important Stellenbosch and Paarl Districts, forms the heartland of the industry and accounts for approximately 45% of the country's wine production. Geologically this important region is underlain by argillaceous sediments of the Malmesbury Group (late Proterozoic); granitic intrusives of the Cape Granite Suite (Late Proterozoic–Cambrian); conglomerates and mudstones of the Klipheuwel Group (Ordovician); and arenaceous sediments of the Table Mountain Group (Middle Ordovician–Early Devonian). In addition, Cenozoic deposits – soils, river gravels, aeolian sands and bedrock weathering products including saprolites and kaolin – are important factors. Soils consisting of loam or containing clay layers are important owing to their ability to retain moisture that can be utilized by vines during the dry summer months.

The two main subdivisions of the Coastal Region, the Stellenbosch and Paarl districts, are discussed below in more detail. Their geological, topographic and general climatic characteristics illustrate the wide range of terroirs present in districts and are features to be considered as the country ponders over changes to its Wine of Origin legislation.

SOMMAIRE

Fondée en 1659, l'industrie vinicole d'Afrique du Sud est aujourd'hui la 16e en importance au monde quant à la superficie cultivée et la 7e quant au volume de vin produit, ce qui en fait un producteur significatif de l'industrie vinicole planétaire. L'industrie a connu ses premiers succès avec les vins de Constance au 18e siècle, et de nos jours, elle se remet progressivement des effets législatifs contraignants qui ont été en vigueur au cours d'une grande partie du 20e siècle.

La région Côtière, en particulier les importants districts de Stellenbosch et de Paarl, constituent le coeur de l'industrie avec 45 % de la production de vin du pays. Le substratum géologique de cette importante région est constitué des sédiments argileux du Groupe de Malmesbury (fin du Protérozoïque); des masses intrusives de la suite granitique du Cap (fin du Protérozoïque-début du Cambrien); des conglomérats et des lutites du Groupe de Klipheuwel (Ordovicien), et; des sédiments arénacés du Groupe de Table Mountain (Ordovicien moyen-début Dévonien). Les couches cénozoïques de sols, graviers fluviatiles, sables éoliens ainsi que les produits d'altération comme les saprolites et les kaolins sont également des facteurs importants. Les sols constitués de loam ou qui renferment des couches d'argiles sont importants pour la survie de la vigne durant les mois secs de l'été, à cause de leur capacité à retenir l'eau.

Les deux principales zones de la région Côtière, soit les districts de Stellenbosch, et celui de Paarl, font l'objet d'une discussion détaillée ci-dessous. Leurs caractéristiques géologiques, topographiques et climatiques générales permettent de comprendre le large éventail de terroirs de ces districts et constituent autant de facteurs à considérer au moment oj le pays considère la possibilité d'apporter des changements à sa législation sur les vins d'origine.

INTRODUCTION

South Africa's wine industry, based mainly around the towns of Stellenbosch and Paarl, some 40–50 km east of Cape Town, has a long tradition dating back to 1659. The country's wine production is a relatively small but significant contributor to the world wine scene. Since the return to democracy in 1994 the country has experienced booming wine exports, new cellars coming into production, and impressive increases in the value of historic vineyard properties in the heart of the winelands. Today the wine industry is poised to compete alongside other new world producers such as the Californians, Chileans, Argentines and Australians. Three hundred years of winemaking history also provides an important component to Cape Town's tourist industry, particularly through the presence of historic estates such as Groot Constantia (Fig. 1), and stunning geological scenery (Fig. 2). As Canadian wine writer Tony Aspler (1998, p. 226) stated: "Without doubt, the Cape is the world's most spectacular wine region in terms of its scenery".

For a country rich in geological heritage, surprisingly little has been written specifically on the geology of South Africa's winelands, a fact that this paper seeks to address. The aim of this paper is to introduce the reader to the geology of the Coastal

Figure 1 Groot Constantia Estate, established in 1680 by Simon van der Stel. Photo C. Bargmann.

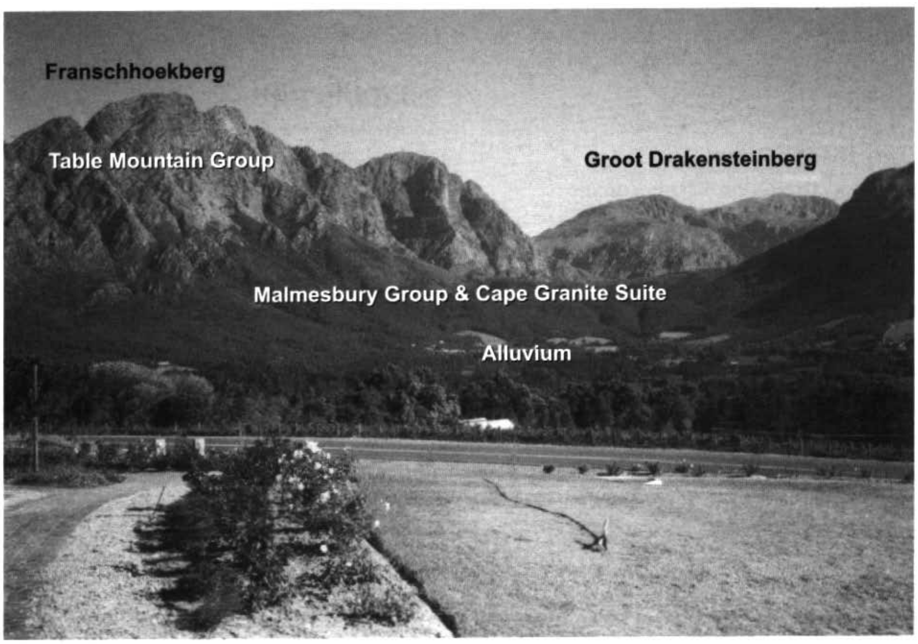

Figure 2 Mountains at the southern end of Franschhoek Ward, Paarl District of the Coastal Region. Photo C. Bargmann.

Region and highlight some of the geological components that make the wine growing conditions of the area unique.

Two noteworthy previous publications are field trip excursions organised by Lawrie Minter from the University of Cape Town as part of the 6th International Conference on Fluvial Sedimentology, 1997, and the International Volcanological Congress, 1998 (Joubert et al., 1997; Minter, 1998). Additionally, Wooldridge (2000) detailed some aspects of geology affecting vineyards in South Africa, and Saayman (1977) discussed the influence of soil and climate on wine quality. The following M.Sc. theses also detail aspects of geology in South African vineyards. Carey (2001) described the definition of natural terroir units in the Stellenbosch District, and a summary of the principles involved is given in Carey et al. (2002). Various aspects of vineyard soils were described by van Schoor (2001) while Wooldridge (1988) demonstrated how the geological origins of soils affect clay mineralogy and potassium content.

The Infrutec-Nietvoorbij Institute of the Agricultural Research Council (ARC) in Stellenbosch is currently conducting a research project on terroir in the wine regions of South Africa. According to John Wooldridge of ARC, "the South African wine industry is committed to the process of terroir identification and demarcation, and is making every effort to do so on the basis of sound scientific principles including geology, which was previously thought by many to be irrelevant" (e-mail of 24 March 2003). This relatively new project is ongoing and only limited results have been published to date. These include the effects of soil and climate on Sauvignon Blanc grapes (Conradie et al., 2002), and the possible influence of soil types on Cabernet Sauvignon grapes (Conradie, 2002). Bonnardot et al. (2002) detailed the influence and effects of sea breezes, while the effects of the mountains around Stellenbosch on topography are discussed by Wooldridge and Beukes (2003a, b).

Early History

The first European settlement in Southern Africa was established by the Dutch East India Company as a re-supply point for their fleet on the sea journey between Holland and the Dutch colonies in the East Indies (modern Indonesia). This settlement was established on 6th April, 1652, and grew to become the bustling modern city of Cape Town.

One of the earliest decisions made by settlement commander Jan van Riebeeck was to cultivate vines for fruit and wine production. Van Riebeeck sought to supply wine to the ships as a means of reducing the death rate of sailors owing to scurvy. Observing that the climate was similar to that of France and Spain, he reasoned correctly that vines would survive on the southern tip of Africa. The first vine cuttings arrived from Europe in 1655; the first South African wine was made in February, 1659.

The appointment of Simon van der Stel as governor in 1679 resulted in expansion of the fledgling wine industry. The town of Stellenbosch was founded some 40 km east of Cape Town and a model wine and fruit farm established on 770 hectares of land at Constantia to the south of Cape Town. By 1761 the Constantia estate was exporting its red and white wine to Europe and in due course these Muscat based wines were widely acclaimed, possibly the earliest success for wines from the "new world" (Hughes et al., 1992; Hands and Hughes, 1997).

Unfortunately this early success did not continue into the 19th century, as outlined by the wine writer Hugh Johnson (1989). By 1814 the British had taken possession of the Cape, and the industry initially benefited from secure exports to Britain. Unfortunately the wines produced had declined from the former high quality to a greatly inferior standard and the industry suffered when protective duties in Britain were removed in the mid 19th century. Further misfortune struck in the late 19th century when epidemics of powdery mildew as well as the aphid-like insect Phylloxera attacked the vineyards.

Modern Wine Industry

By the early 1900s the wine industry was suffering from overproduction and low prices and in response farmers began to establish co-operative wineries. The structure of the modern South African wine industry owes much to the largest of these, the De Ko-operative Wijnbouwers Vereniging van Zuid Afrika (KWV), which was formed in January, 1918. KWV was given powers to sell the products of members' grape production in hopes of stabilizing farm revenues. Subsequently these powers were strengthened by act of parliament, giving KWV a controlling position over South Africa's wine industry. This situation lasted until the mid 1980s when KWV's controls were progressively relaxed. Over the last twenty years the industry has developed considerably, resulting in new producers, grape cultivars and expansion into new areas. The controlling influence of KWV finally ended in 1997 when the organization converted to a public company (Hughes et al., 1992; Hands and Hughes, 1997; du Plessis, 1999).

SOUTH AFRICAN WINE PRODUCTION

Conditions suitable for the growth of vines and grapes for wine production occur in the hinterland of Cape Town, an area that extends north to Vredendal, and east to Bonnievale and Calitzdorp (Fig. 3). A separate region of vineyards is located along the Orange River in the north of the country, in the Northern Cape Province (Fig. 3).

According to official figures published by the South African Wine Industry Information and Systems organization (SAWIS), the surface area occupied by vineyards totaled 105,566 hectares in year 2000. The Paarl, Stellenbosch and Malmesbury districts, as defined by the KWV and used by SAWIS (Fig. 3), account for 45% of South Africa's vineyard area (Fig. 4). This area corresponds approximately to the Coastal Region Wine of Origin area (see below). These three districts also contain a significant proportion of the country's red grape varietals (Fig. 5). The remaining districts are generally hotter, lower rainfall areas that traditionally have supplied grapes for brandy and port production, dried fruit and table grapes.

On a world scale South Africa ranked 16th in terms of hectares planted and

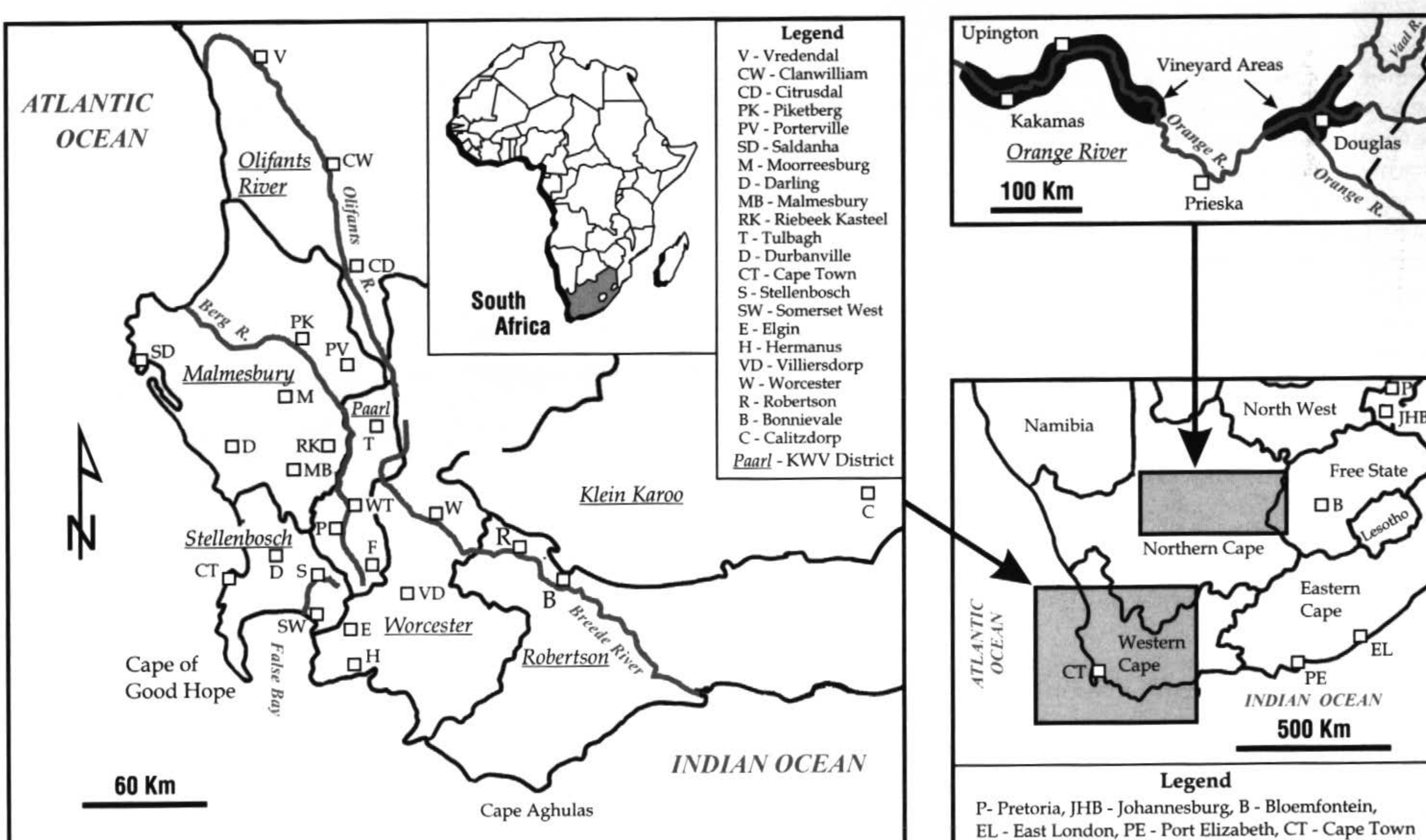

Figure 3 Wine-producing regions of the Western Cape and Northern Cape Provinces, South Africa. KWV regions labelled in underlined italics; cities and towns shown as solid squares with symbols. Modified from KWV (1997).

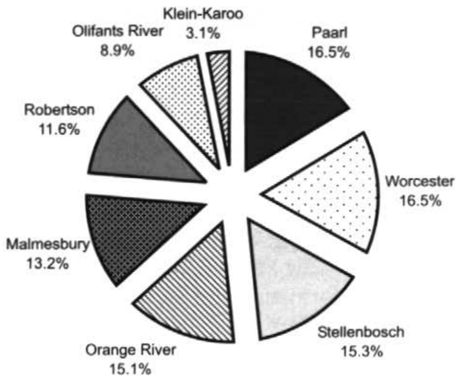

Figure 4 Distribution of South African Vineyards in year 2000; data from SAWIS (2001).

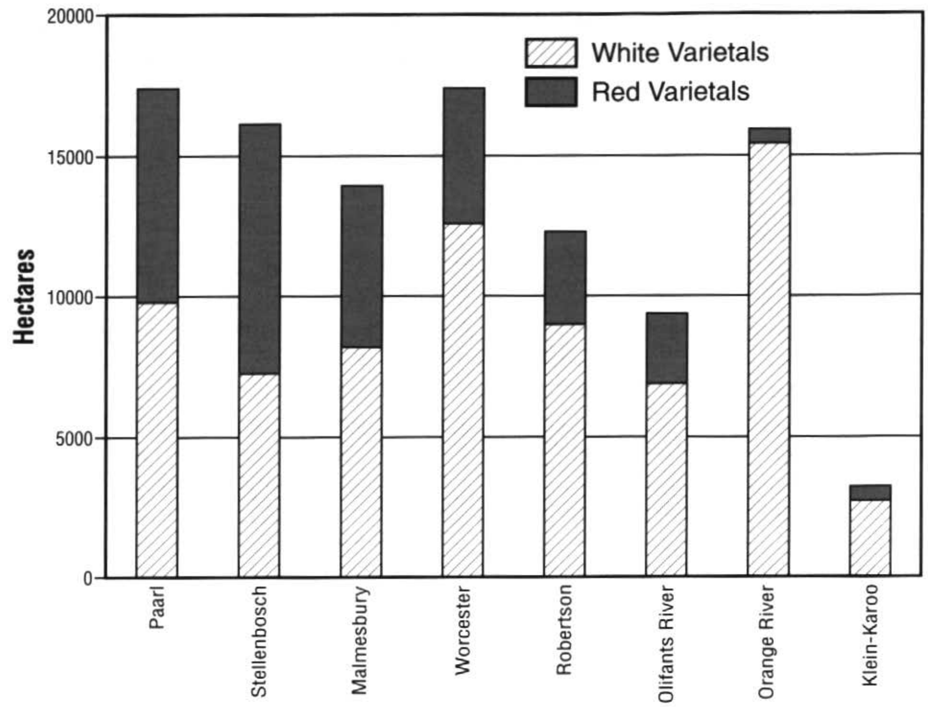

Figure 5 Distribution of red and white grape varietals in South Africa in year 2000. Data from SAWIS (2001).

7th in terms of production in 1998, accounting for 1.4% of global vineyards and 3.2% of global wine production (Table 1). In comparison, France, Italy and Spain dominate the wine industry in terms of both surface area planted and production, with the USA and Argentina being the largest players amongst new world producers. For a relatively warm country, South Africa has a curious distribution of vine cultivars, 67.7% being white and 32.3% red in 2000 (Fig. 6). As discussed below, in terms of degree days South Africa's winelands compare with areas such as the Napa Valley, California, and Tuscany, Italy, both of which are noted for their red wine production. Present varietal composition in South Africa reflects the recent history of the wine industry, which encouraged quantity rather than quality, and the production of the country's favorite spirit, brandy. The presence of the table grape white varietals Sultana and Hanepoot shows the importance of the table grape and dried fruit industries.

These varietal percentages (Fig. 6) do not reflect the dramatic changes in South Africa's vineyards in recent years, however. Between 1985 and 2000 the surface area planted increased from 92,142 to 105,566 Ha, and there has also been a significant change in the cultivar composition. Chardonnay and Merlot plantings have increased from virtually zero in 1985 to 5.7% (6017 Ha) and 4.6% (4856 Ha) respectively in 2000 (Fig. 7). Over the same time period, Cabernet Sauvignon, Sauvignon Blanc, Shiraz and Pinotage, South Africa's own varietal, have all shown increases in plantings as the industry moves towards the production of quality cultivars. Colombar has also increased, and has proved

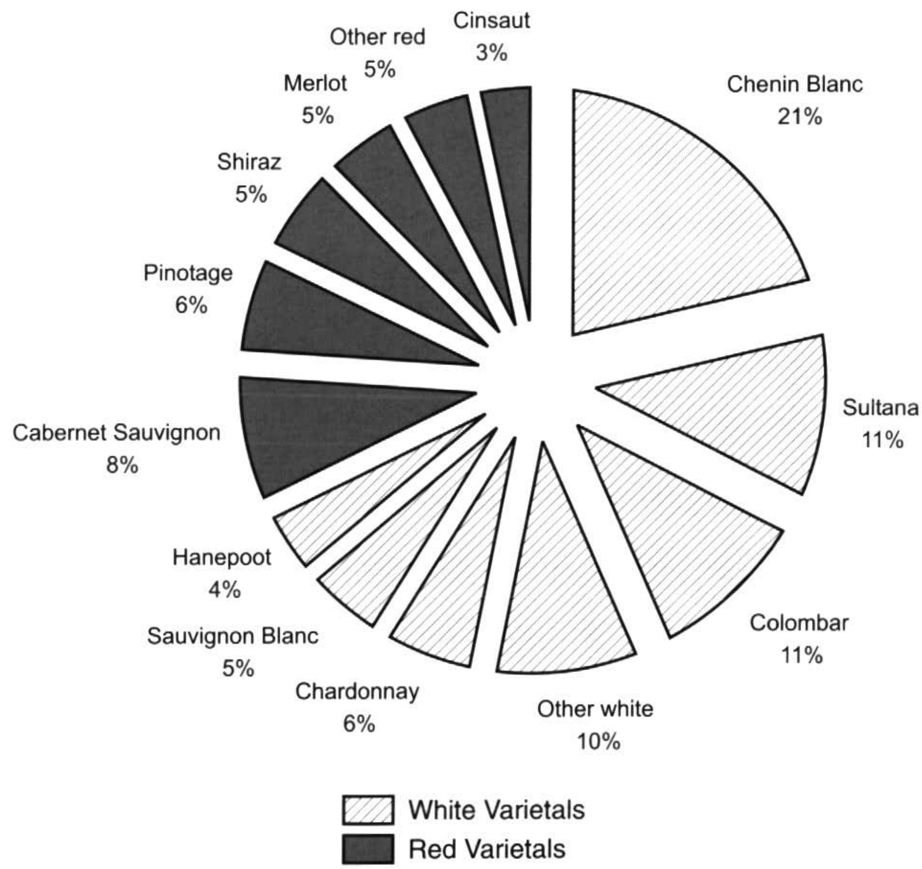

Figure 6 Grape varietal percentage composition of South African vineyards in year 2000. Data from SAWIS (2001).

Table 1 International comparison of areas under vines and wine production (data from KWV 1996, 1997; du Plessis 2000; SAWIS)

Country	Hectares planted with vines 1994	1995	1996	1997	1998	Percentage of world total vineyard area	Ranks (1998)
Spain	1280000	1235000	1224000	1155000	1180000	15.1	1
France	929000	926000	917000	914000	914000	11.7	2
Italy	956000	927000	922000	914000	899000	11.5	3
Turkey	567000	570000	567000	602000	602000	7.7	4
USA	310000	305000	311000	315000	364000	4.7	5
Argentina	-	-	211000	209000	210000	2.7	8
Chile	-	-	116000	132000	144000	1.8	11
South Africa*	103000	103000	106000	108000	111000	1.4	16
Australia	67000	73000	81000	90000	98000	1.3	19

* All vineyards including wine grapes, table grapes, currents and rootstock vineyards.

Country	Wine production (million litres) 1994	1995	1996	1997	1998	Percentage of world total vineyard area	Ranks (1998)
Italy	5927.6	5629.4	5965.0	5084.7	5416.8	20.9	1
France	5464.0	5561.0	5877.3	5361.2	5267.1	20.4	2
Spain	1895.4	1964.0	3267.5	3388.7	3032.0	11.7	3
USA	1617.5	1580.0	1864.3	2500.0	2045.0	7.9	4
Argentina	1817.3	1644.3	1268.1	1350.0	1267.3	4.9	5
South Africa	866.4	754.6	833.3	870.2	815.6	3.2	7
Australia	587.4	502.8	678.4	617.4	741.5	2.9	8
Chile	-	-	382.4	454.9	547.5	2.1	9

capable of making respectable white wines in addition to its role in brandy production. These increases have been largely at the expense of the country's traditional "workhorse" varieties of Chenin Blanc and Cinsault and the "other white" category which includes Palomino, Clairette Blanche and Cape Riesling.

WINE OF ORIGIN LEGISLATION IN SOUTH AFRICA

South Africa's wine regions are defined under the country's *Wine of Origin* legislation passed in 1972. This legislation stipulates that any indication of origin is prohibited unless the area has been officially demarcated (Saayman, 1999). The largest of the demarcated areas are *regions*, followed by smaller *districts* and finally *wards*. Region and district boundaries are based largely on administrative and magisterial divisions, whilst wards, in theory, take into account soil, geographical and climatic factors, although in practice wards commonly are based on the existing farm boundaries. Wine farms may also register as estates and label their wines as *Estate* wine. This requires that the estate wine producer uses grapes sourced solely from his/her property and the wine is made on site. Many wine farms choose not to register as estates, enabling them to use grapes from other vineyards – these wines may be labeled according to the applicable wine of origin rules but cannot claim estate status. The current (2001) demarcated Wine of Origin areas are listed in Table 2 along with the corresponding KWV regions used in the SAWIS information noted above.

In 1993 the Wine of Origin legislation was amended to allow for the creation of "super regions" forming geographical units. As a result, the Western Cape geographical unit has been defined to cover the entire wine producing area of the Western Cape Province (Table 2).

The focus of this paper is the Coastal Region, and in particular the Stellenbosch and Paarl districts shown in Figure 8. The Coastal Region covers a large area and includes the city of Cape Town and the towns of Durbanville, Stellenbosch, Paarl, Wellington and Malmesbury. Six districts are located in the Coastal Region: Paarl, Stellenbosch, Swartland, Tulbagh, Cape Point and Tygerberg. With the exception of the Tulbagh District, these are situated within a broad coastal plain between the Atlantic Ocean in the west and the mountains to the east of the towns of Stellenbosch, Paarl and Malmesbury. The Tulbagh district is an anomaly, as this area lies within an enclosed inland valley that is geographically an extension of the Breede River Region situated to the east of the Coastal Region (Fig. 8). As shown below, the Tulbagh District also is climatically warmer than the rest of the Coastal Region, and for these reasons will not be discussed in this paper.

CLIMATIC CONDITIONS

The Coastal Region benefits from a Mediterranean-style climate with warm to hot, relatively dry summers and cool, wet

Table 2 South Africa wine of origin classification for natural and sparkling wines in 2001 (data from SAWIS, KWV 1997)

Geographical Unit	Region	District	Ward	KWV Region
Western Cape	Coastal Region	Paarl	Franschhoek Wellington	Paarl
		Tulbagh	-	
		Stellenbosch	Bottelary Devon Valley Jonkershoek Valley Papegaaiberg Simonsberg-Stellenbosch	Stellenbosch
		Tygerberg	Durbanville	
		Cape Point	-	
		No District	Constantia	
		Swartland	Groenekloof Riebeekberg	Malmesbury
	No Region (Swartland area)	Piketberg	-	
	No Region (Overberg area)	Overberg	Elgin Walker Bay	Worcester
	No Region (Ceres area)	*No District*	Ceres	
	Breede River	Worcester	Aan-de-Doorns Goudini Nuy Scherpenheuwel Slanghoek	
		Robertson	Agterkliphoogte Boesmans River Bonnievale Eilandia Hoops River Klaasvoogds Le Chasseur McGregor Vink River	Robertson
		Swellendam	Buffeljags Stormsvlei	
	No Region (Bredasdorp District)	*No District*	Elim	
	Klein Karoo	Calitzdorp	-	Klein Karoo
		No District	Montagu Tradouw	
	No Region (Klein Karoo area)	*No District*	Herbertsdale Ruiterbosch Swartberg	
	Olifants River	Lutzville Valley	Koekenaap	Olifants River
		No District	Spruitdrift Vredendal Piekenierskloof	
	No Region (Olifants River area)	*No District*	Cederberg	
	No Region (Northern Cape & Free State are	Douglas	-	Orange River
		No District	Hartswater Lower Orange Riet River	

Boberg Region is introduced for fortified wines produced in the Paarl and Tulbagh districts.

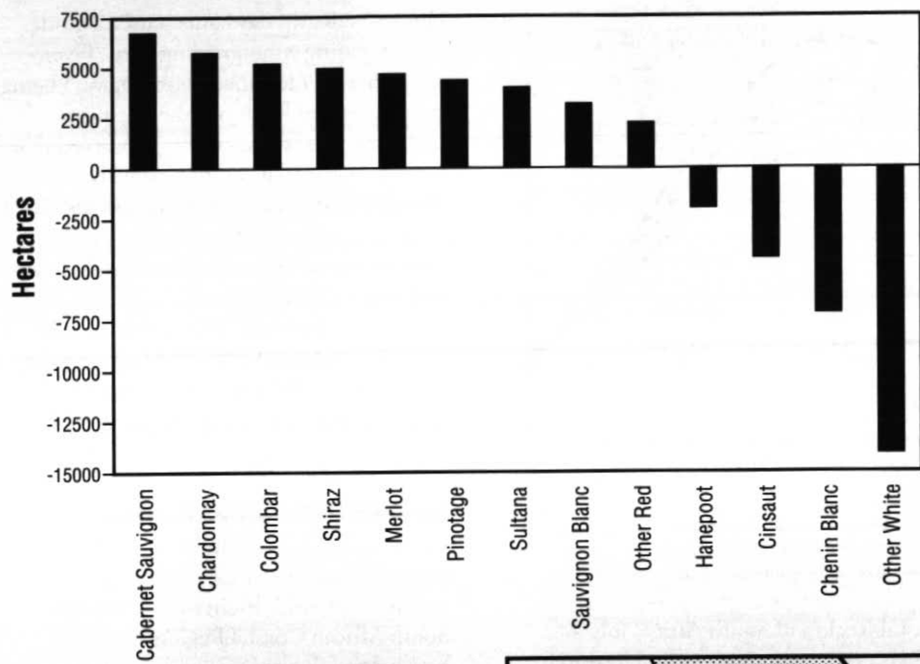

Figure 7 Change in cultivar composition of South African vineyards between 1985 and 2000. Based on data from SAWIS (2001).

winters, conditions that traditionally favour the production of wine grapes. General climatic characteristics will be described using data from the Cape Town, Stellenbosch, Franschhoek and Wellington areas, the locations of which are shown in Figure 8. Conditions become progressively warmer inland with average growing season temperatures (September–March) ranging from 18°C at Kirstenbosch (near Cape Town) to 20.9°C in Wellington, the most inland location. Winter temperatures (April–August) are fairly consistent across the Coastal Region at approximately 14°C (Fig. 9, 10).

Rainfall is concentrated in the southern hemisphere winter months of April–August (Fig. 11). The highest overall rainfall occurs in the Franschhoek area. Here the Groot Drakenstein weather station and Boschendal wine estate receive an average of 932 and 1355 mm/year, respectively (Fig. 12). The influence of the mountainous topography of the Franschhoek area is a significant factor in rainfall distribution. Cape Town, Stellenbosch and Wellington record annual average rainfalls that range between 500 and 700 mm/year (Fig. 12).

Degree Day System

One of the best known systems for international comparison of vine-growing regions used is that of degree days. This system operates by calculation of the heat summation over the growing season. Only days with average temperatures above 10°C are considered and the degree day figure is obtained by multiplying the average daily temperature by the number of days. The methodology used is described by Meinert and Busacca (2000) in an earlier paper in this series.

The system does have its limits. For example, it fails to account for total daylight hours, a factor in high-latitude wine regions.

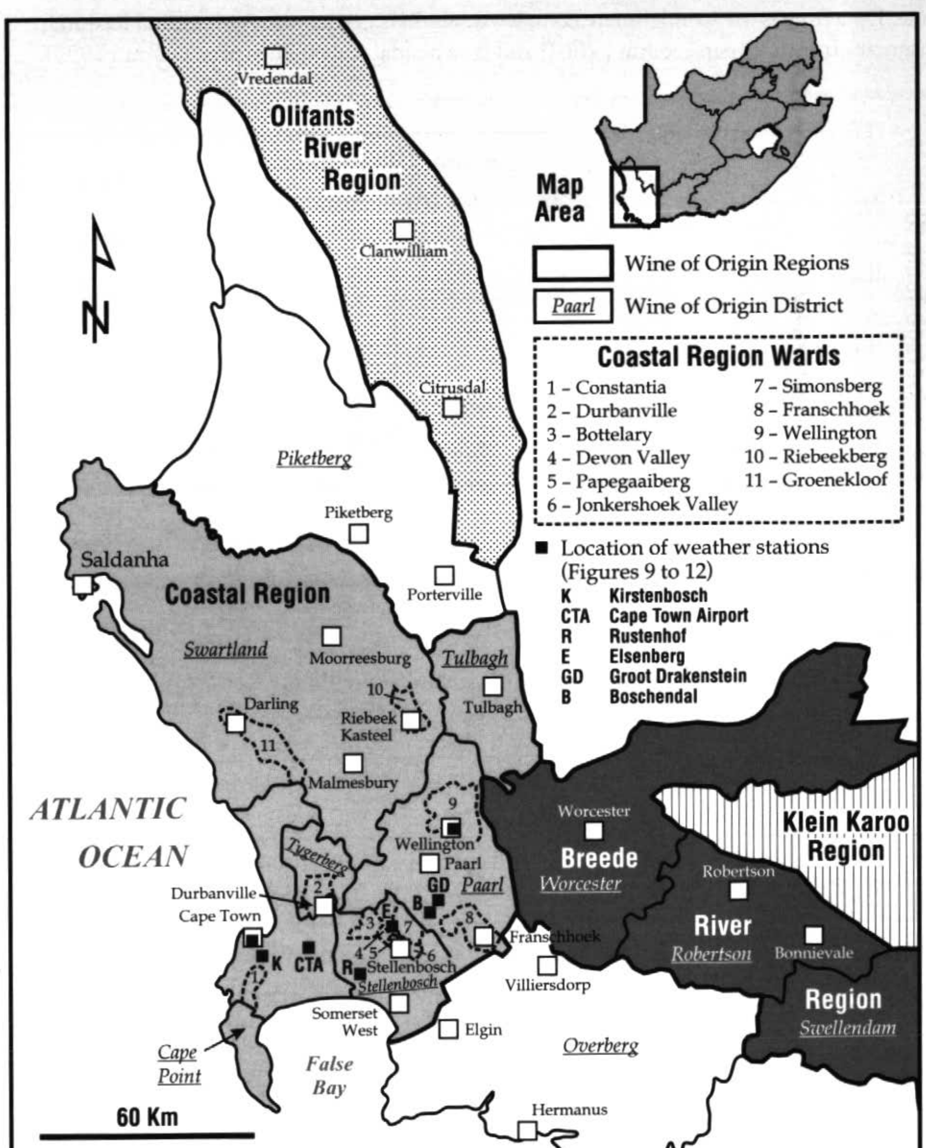

Figure 8 Wine of Origin subdivisions, Western Cape Province, South Africa. Coastal Region contains the Paarl, Tulbagh, Stellenbosch, Tygerberg, Cape Point and Swartland districts; Table 4 contains additional information. Based on data from SAWIS (2001).

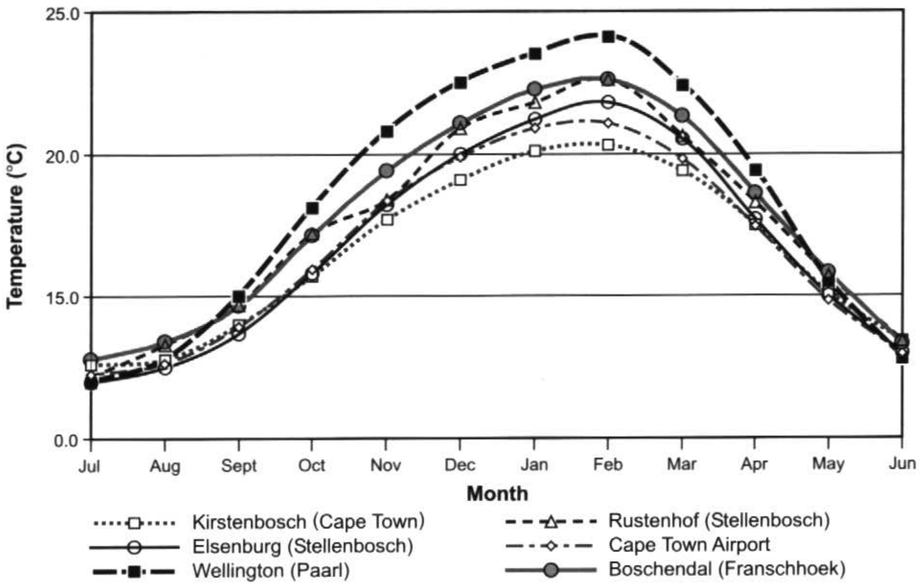

Figure 9 Average monthly temperatures in the Coastal Region of South Africa, July – June. Data from www.worldclimate.com; www.weathersa.co.za; also Agricultural Research Council - Infruitec (pers. comm., 2001; and Boschendal wine estate (pers. comm., 1995).

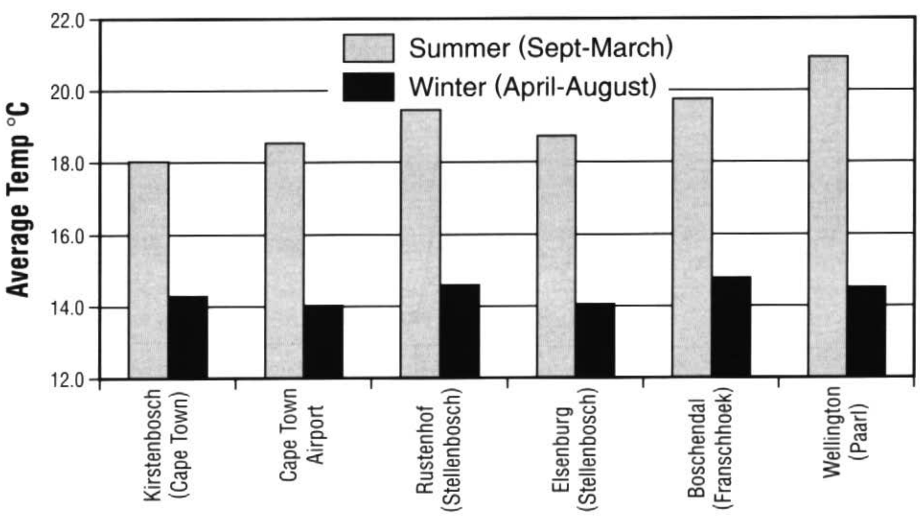

Figure 10 Average growing season and winter temperatures in the Coastal Region of South Africa. Data from www.worldclimate.com; www.weathersa.co.za; also Agricultural Research Council - Infruitec (pers. comm., 2001), and Boschendal wine estate (pers. comm., 1995).

Table 3 Regions defined by the Winkler degree-day classification (data from Gladstones 1994a, Knox 1982)

Region	Degree days (above 50°F)	Degree days (above 10°C)
1	<2500	<1389
2	2501-3000	1389-1667
3	3001-3500	1668-1944
4	3501-4000	1945-2222
5	>4000	>2222

However, degree days offer a useful guide for comparing wine-growing areas. Five categories are identified, with Region I being the coolest and Region V the warmest (Table 3). Gladstones (1994) observed that when this research was published by Amerine and Winkler (1944), the best dry wines were produced in Regions I and II, whilst Region III produced full-bodied dry and sweet wines. Region IV was identified as best for fortified wine production as table wine was usually of inferior quality; whilst Region V, usually irrigated, produced table grapes, dried fruit and poor quality table wines.

DEGREE DAY COMPARISONS

Table 4 presents a compilation of degree day information from various wine regions around the world. Eight locations in the South African Coastal Region are highlighted in bold face and show a degree day range of 1720–2230 using °C. Constantia, Durbanville (to the south and east of Cape Town, respectively), Firgrove and Koelenhof (both in the Stellenbosch District) are the coolest areas, falling within Region III, with degree days ranging from 1720–1906. Durbanville is widely regarded as a colder wine growing area than Koelenhof and the degree day figure of 1906 may not be representative of the Durbanville area as a whole. The two Franschhoek locations, Groot Drakenstein and Franschhoek itself, are warmer, 1967–2014 degree days, thus falling within Region IV. Wolseley and Tulbagh, within the Tulbagh District, in the northeast of the Coastal Region, are noticeably warmer areas with degree day figures of 2104 and 2230, thus falling within Region IV and V, respectively. As would be expected from the more inland location, the Tulbagh district records the warmest conditions. As shown in Table 4 the Stellenbosch and Paarl Districts are comparable in degree day terms to locations in the Napa and Sonoma valleys in California, and Tuscany in Italy.

GEOLOGICAL FRAMEWORK OF THE COASTAL REGION

Western Cape Province has been sculpted by almost continuous ice-free erosion since the breakup of Gondwanaland began ~200 million years ago; as a result the landscape closely reflects the underlying geology. Although weathering is deep and soils are widely developed, bedrock units are

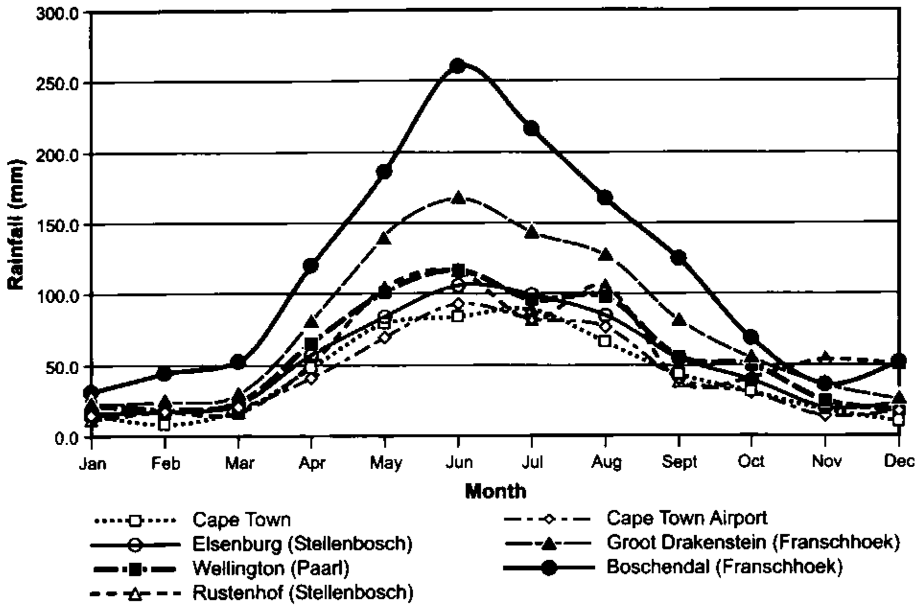

Figure 11 Monthly rainfall in the Coastal Region of South Africa. Data from www.atlasweather.com; www.weathersa.co.za; www.worldclimate.com; also Agricultural Research Council - Infruitec (pers. comm., 2001), and Boschendal wine estate (pers. comm., 1995).

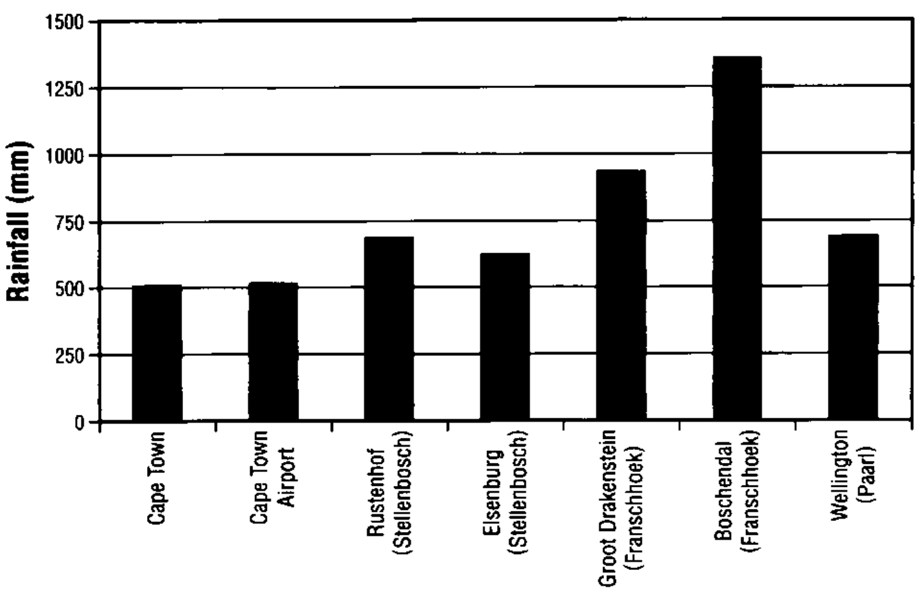

Figure 12 Average annual rainfall in the Coastal Region of South Africa. Data from www.atlasweather.com; www.weathersa.co.za; www.worldclimate.com; also Agricultural Research Council - Infruitec (pers. comm., 2001), and Boschendal wine estate (pers. comm., 1995).

reasonably well known through geological mapping. The Coastal Region includes geological units ranging from Late Proterozoic to Cretaceous in age, capped by more recent Cenozoic deposits. Geology, including the main rock types, is summarized in Tables 5, 6, 7, and a simplified geological map of the Coastal Region is provided in Figure 13. South Africa's vineyards have developed over time in areas where water supply is sufficient for vine growth rather than by specifically matching vines to geology, soils and climate. In terms of the distribution of vineyards the argillaceous sediments of the Malmesbury group and the granites of the Cape Granite Suite are the most important in the Coastal Region. These rocks have an extensive outcrop area and form clay rich soils, which are important for their water retention capabilities. In hotter areas, such as the Breede River and Olifants River regions (Fig. 8), where irrigation using water supplied by the rivers is more widely practiced, alluvial vineyard soils are significant for vineyards.

Malmesbury Group

The Malmesbury Group (Late Proterozoic) is the oldest geological unit of the Coastal Region. The Group formed as part of a pan-African mobile belt system that fringed a stable cratonic area, the Kalahari Craton, which occupied a large portion of Southern Africa in Late Proterozoic time. Sedimentation is considered to have begun at +/-950 Ma and terminated at approximately 570 Ma. The Malmesbury Group is believed to be have been deposited in a geosynclinal basin flanking the western and southern margin of the Kalahari Craton. As the top and base of the Malmesbury Group have not been identified, the stratigraphic thickness has only been estimated as being in excess of 6000 m (Theron et al., 1992; Gresse and Theron, 1992; Rozendaal et al., 1994; Gresse and Scheepers, 1993).

During deposition the Malmesbury Group was deformed by the Saldanian Orogeny, an event which started at +/-700 Ma and continued to +/-500 Ma. Based on the characteristics of the facies, lithology and tectonic character preserved, three distinct terranes – Tygerberg, Swartland and Boland – are identified. These are separated by two major northwest–southeast-trending fault structures known as the Saldanha/Franschhoek and the Wellington/Piketberg faults (Fig. 13).

The Tygerberg Terrane consists of medium- to fine-grained greywacke, phyllitic shales, siltstones and immature quartzites of the Tygerberg Formation. Hornfels, produced as a result of contact metamorphism owing to the later intrusion of the Cape Granite Suite, is also a feature (Theron et al., 1992; Gresse and Theron, 1992).

The Swartland Terrane lies between the Saldanha/Franschhoek and Wellington/Piketberg faults and contains the Berg River, Klipplaat, Moorreesburg and Franschhoek formations. The Berg River, Klipplaat and

Table 4 Degree-day totals for international wine regions (data from Knox, 1999; Meinert and Busacca, 2000; Stevenson, 1991; Paul Cluver Wines, Hamilton Russell Vineyards)

Location	Country/area	Degree days	Winkler Region
Algiers	Algeria	2880	V
Frenso	California	2590	V
Hunter Valley	Australia	2340	V
Calitzdorp	Klein Karoo, SA	2232	V
Tulbagh	**Coastal Region, SA**	**2230**	**V**
Naples	Italy	2220	V
Robertson	Breede River Region, SA	2164	IV
Wolseley	**Coastal Region, SA**	**2104**	**IV**
Lodi	California	2061	IV
Rawsonville	Breede River Region, SA	2032	IV
Franschhoek	**Coastal Region, SA**	**2014**	**IV**
Davis	California	2000	IV
Russian River	California	2000	IV
Ashton	Breede River Region, SA	1995	IV
Groot Drakenstein	**Coastal Region, SA**	**1967**	**IV**
Florence	Tuscany, Italy	1950	IV
Durbanville	**Coastal Region, SA**	**1906**	**III**
Koelenhof	**Coastal Region, SA**	**1898**	**III**
Healdsburg	Sonoma, USA	1767	III
Firgrove	**Coastal Region, SA**	**1756**	**III**
Calistoga	Napa Valley, USA	1745	III
Constantia	**Coastal Region, SA**	**1720**	**III**
Oakville	Napa Valley, USA	1717	III
Barossa Valley	Australia	1710	III
Asti	Piedmonte, Italy	1650	II
Santa Rosa	Sonoma, USA	1634	II
Hamel en Aarde Valley	Walker Bay, SA	1620	II
Walla Walla	Washington, USA	1616	II
Napa	Napa Valley, USA	1595	II
San Luis Obispo	California	1451	II
Coonawarra	Australia	1450	II
Niagara	Canada	1440	II
Bordeaux	France	1400	II
Elgin	Overberg, SA	1387	I
Mclaren Vale	Australia	1350	I
Burgundy	France	1330	I
Hawkes Bay	New Zealand	1300	I
Santa Cruz	California	1285	I
Reims	Champagne, France	1011	I
Otago	New Zealand	1000	I
Geisenheim	Germany	950	I
Trier	Germany	945	I

Moorreesburg formations consist of mica schist, greywacke, minor limestone, and quartz schist. The uppermost Franschhoek Formation consists of conglomerates, grits and quartzites with intermittent shales. The relative age of the Franschhoek Formation is subject to debate, but it is believed to be significantly younger and unconformable upon the rest of the Swartland Terrane (Theron et al., 1992; Gresse and Theron, 1992).

The final component of the Malmesbury Group is the Boland Terrane, which lies to the east of the Wellington/Piketberg Fault. Gresse and Theron (1992) proposed that the Franschhoek Formation preserved in the Swartland Terrane represents only the basal remnant of a younger sequence now preserved as the Boland Terrane. The grits, conglomerates and greywackes of the Piketberg Formation occur to the north of the Coastal Region, in the vicinity of the town of Piketberg (Fig. 13), and are regarded as a facies variation of the Franschhoek Formation. Gresse and Theron (1992) further proposed that the Franschhoek Formation is overlain by the Norree and Porterville formations. The Norree Formation contains medium-grained to gritty greywacke and quartzites, and occurs in the Breede River valley to the east of the Coastal Region. The Porterville Formation contains predominantly phyllitic shale, schist and fine- to medium-grained greywacke, and occurs in the Wellington area.

Of the successions present in the Malmesbury Group it is the Tygerberg, Moorreesburg, Franschhoek, and Porterville formations that are most significant in vineyard terms in the Coastal Region.

Cape Granite Suite

Plutons of the Cape Granite Suite intrude the sedimentary rocks of the Malmesbury Group: the main plutons are detailed in Table 6 and shown in Figure 13. Various ages of intrusion have been recorded, ranging between 632 and 502 Ma (Kent, 1980; Theron et al., 1992; Rozendaal et al., 1994). These intrusive events are Late Proterozoic to Early Cambrian in age, and partly contemporaneous with the deposition of the Malmesbury Group. The Cape Granite Suite also shows folding and structures related to the Saldanian Orogeny.

Scheepers (1995) interpreted the Cape Granite Suite as being subduction related and intruded in three phases. Phase I, between 600–540 Ma, includes mafic and intermediate intrusives and S-type granites. The granites occur west of the Saldanha/Franschhoek Fault and include the Stellenbosch, Kuils River/Helderberg, Darling and Cape Peninsula plutons, whilst gabbro - diorite bodies occur to the east of the fault in the vicinity of the town of Malmesbury. Phase II occurred between 560–520 Ma and consists of I-type granites situated east of the Saldanha/Franschhoek Fault. These include the Wellington, Perdeberg and Paarl plutons. Phase III, 520–500 Ma, consists of small A-type granites, gabbros and granodiorites, the principal ones being the Klipberg and Boterberg plutons.

Minor intrusive events are also observed in some areas. These range in age from Cape Granite Suite (522 +/-15 Ma) for quartz porphyry dykes to Early Cretaceous (132 +/-6 Ma) for the

Table 5 Pre-Cenozoic stratigraphy of the Coastal Region (based on Reid et al., 1991; Theron et al., 1992; Gresse and Theron, 1992; Gresse and Scheepers, 1993; Scheepers, 1995; Rozendaal and Scheepers 1995)

Age	Group	Formation	Main rocktypes
Early Cretaceous (132 Ma)			Dolerite
Ordovician - Early Devonian (450 - 409 Ma)	Table Mountain Group	Rietvlei	Sandstone, siltstone, shale
		Skurweberg	Sandstone
		Goudini	Sandstone, siltstone, shale
		Cederberg	Shale
		Pakhuis	Diamictite, sandstone
		Peninsula	Sandstone
		Graafwater	Sandstone, siltstone, shale
		Piekenierskloof	Sandstone, conglomerate
Early -Mid Ordovician? (500-450Ma)	Kilpheuwel Group	Populierbos	Mudstone, shale
		Magrug	Conglomerate, sandstone
Late Proterozoic - Early Cambrian (600-500Ma)	Cape Granite Suite		Granite, mafic, granodiorite and alkali granite intrusives
Late Proterozoic (~950-570Ma)	Malmesbury Group	Porterville	Shale, greywacke
		Norree	Greywacke, quartzite
		Piketberg	Grit, conglomerate, greywacke
		Franschhoek	Conglomerate, quartzite
		Moorreesberg	Greywacke
		Klipplaat	Quartz schist
		Berg River	Mica schist, greywacke
		Tygerberg	Greywacke, shale, siltstone, quartzite

Table 6 Cape Granite Suite plutons in the Coastal Region (based on Theron et al., 1992; Gresse and Theron, 1992; Rozendaal et al., 1994; Scheepers 1995; Rozendaal and Scheepers 1995)

Pluton	Plutonic phase and association	Age range	Principle rock types
Boterberg	A Type	520 - 500Ma	Granodiorite
Klipberg			Quartz syenite - alkali granite
Paarl	I Type	560 - 520Ma	Porphyritic granite
Perdeberg			Coarse porphyritic granite
Wellington			Coarse porphyritic to coarse granite
Cape Peninsula	S Type	600 - 540Ma	Porphyritic biotite granite
Darling			Porphyritic and even-grained biotite granites
Kuils River/Helderberg			Coarse porphyritic granite
Stellenbosch			Porphyritic biotite granite, medium- and coarse-grained granite
Mafic Intrusives	Theolitic		Olivine gabbro, gabbro, diorite, granodiorite

northwest–southeast trending dykes known as the False Bay Dolerites (Theron et al., 1992; Reid et al., 1991).

Klipheuwel Group

Clastics of the Klipheuwel Group (Early-Mid Ordovician; Table 5) have limited aerial extent and are generally found in northwest-trending outcrops commonly flanked by similarly trending faults (Fig. 13). An unconformable relationship exists between the Klipheuwel Group and underlying Cape Granite Suite and Malmesbury Formation rocks. The Group is divided into two formations: the Magrug Formation, a lower conglomerate, grit and sandstone unit; and the Populierbos Formation, an upper unit of red shale and mudstone. The Klipheuwel Group postdates the Cape Granite Suite and is overlain by Cape Supergroup rocks, giving an age range of 500–450 Ma for Klipheuwel deposition (Gresse and Scheepers, 1993). The depositional environment is envisaged as an alluvial fan system for the basal conglomerates, overlain by lacustrine sediments. The Klipheuwel Group attains a maximum thickness of approximately 2000 m. The very limited extent of these sediments is the controlling factor in their use for vineyards.

Table Mountain Group

The Table Mountain Group (Mid-Ordovician – Early Devonian; Table 5) provides the most significant contribution to the scenery of the Coastal Region as it makes up most of the majestic mountains of the area (e.g., Fig. 2). The base of the group is marked by a classic unconformity that is exceptionally well-exposed on the Atlantic coast of the Cape Peninsula (Fig. 14). Here the sandstones, siltstones and mudstones of the Graafwater Formation overlie granites of the Cape Peninsula Pluton.

The Table Mountain Group is the basal group within the Cape Supergroup, a 6000–10,000 m thick sedimentary succession that accumulated from Middle Ordovician to Early Carboniferous as deltaic and shallow-marine sediments on a passive continental margin. The Table Mountain Group itself attains a maximum thickness of about 4000 m (Cotter, 2000; Theron et al., 1992; Kent, 1980). Overlying the Table Mountain Group are the Bokkeveld and Witteberg groups, which outcrop predominantly to the east of the Coastal Region.

The Table Mountain Group is subdivided into eight formations composed mainly of quartzitic sandstones as shown in Table 5. The following formations are the exceptions: the basal Piekenierskloof Formation is a conglomerate package that grades into quartzitic sandstones and is developed in the northeast of the Coastal Region; the Graafwater Formation is typically developed as interbedded reddish sandstone, siltstone and shale bands that are best developed on the Cape Peninsula to the south of Cape Town (Fig. 14). Glacial deposits consisting of diamictite and sandstone form the Pakhuis Formation, which is overlain by the Cederberg Formation, containing the only significant shales and siltstones within the Table Mountain Group. The Ordovician-Silurian boundary is placed within the shales of the Cederberg Formation based on the fossils preserved (Visser and Theron, 1973; Theron et al., 1992; Gresse and Theron, 1992).

The predominance of sandstone is a limiting factor in terms of vineyard development. Poor soils and steep topography result in a negligible number of vineyards being planted on Table Mountain Group sandstones. Few vineyards are located on the Piekenierskloof, Graafwater, Pakhuis and Cederberg formations owing to limited aerial extent and poor accessibility in the Coastal Region. These formations do, however, have potential for vineyards, as the Piekenierskloof and Cederberg formations have planted successfully in the Olifants River Region.

Cenozoic Deposits

Cenozoic-aged deposits in the form of soils, and fluvial and aeolian sediments all have an influence on Coastal Region winelands. These units are summarized in Table 7 using information from Söhnge (1991) and Theron et al. (1992).

Table 7 Cenozoic stratigraphy of the Coastal Region (based on Sohnge 1991; Theron et al., 1992)

Era	Period/Age	Stratigraphy	Lithology	Soils/river gravels/palaeosurface	Alteration	Marine, tectonic and river history
Quaternary	Holocene (0.01Ma)	Witzand Formation	Aeolian sand	Reworked alluvium	Weathering of granites and potential for saprolite and kaolin formation	Stone Age artefacts. Palaeosurfaces modified by headward watercourse incision
	Late Pleistocene (0.1-0.01 Ma)	Langebaan Formation Velddrif Formation	Aeolian calcareous sand Calcrete	Reworked alluvium		Stone Age artefacts. Palaeosurfaces modified by headward watercourse incision
	Early-Mid Pleistocene (1.65-0.1Ma)	Milnerton Formation Springfontein Formation	Fluvial gravel, sand and clay Aeolian sand	Reworked younger gravel and sand Younger gravels		Sea level restored. First Stone Age artefacts (Acheulian Man)
	Late Pliocene (3.8-1.65Ma)			Duplex soils (50-100masl), Older gravels (12-37marb)		Marine regression
Tertiary	Middle Pliocene (4.2-3.8Ma)			Duplex soils (50-100masl), Older gravels (55marb)		Marine regression
	Early Pliocene (5.3-4.2Ma)	Varswater Formation	Sand and shelly gravel	Residual soil (80-140 masl) Pools surface (150masl)		Marine transgression, deepening of Eerste River palaeovalley
	Middle - Late Miocene (14.5-5.3Ma)	Saldana Formation	Conglomeratic sand phosphorite			Marine regression and uplift, deepening of Eerste River palaeovalley
		Elandsfontein Formation	Sandy soils and peaty clay			
	Early - Middle Miocene (23.5-14.5Ma)			Residual soils (150-200masl), Chilton surface (180-280masl)		Marine transgression
	Oligocene (34-23.5Ma)			Red apedal soils (200-300masl)		Eerste River captures Jonkeshoek River. Major regression, continental shelf exposed
	Eocene - Palaeocene (65-34Ma)			Red apedal soils (200-300masl). Schoongezicht surface (415-500masl)		Jonkershoek River flows north. Major marine transgression, current coastal plane submerged

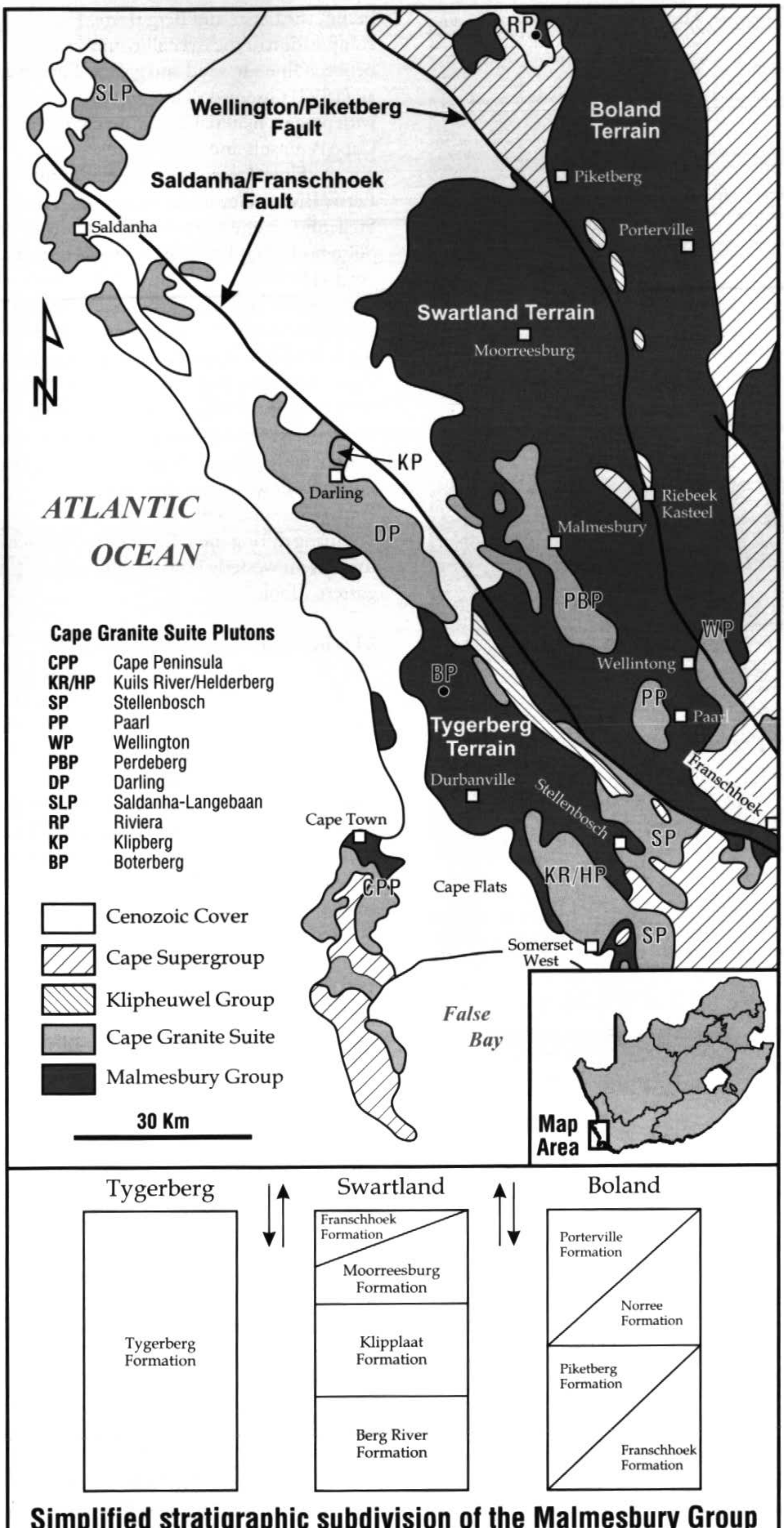

Figure 13 Generalized geology of the Coastal Region of South Africa. Modified from Rozendal and Scheepers (1995); Theron et al. (1992); and Gresse and Theron (1992).

Soils

Soil types are commonly represented by duplex soils (sand rich or loamy topsoils over clay), structureless apedal soils, structured soils, shallow soils over bedrock, and wet, dark-coloured soils (Toombs and Archer, 1999). Theron et al., (1992) distinguished between loam and sandy loam soils formed as in-situ weathering products of Malmesbury Group rocks, and gravelly clay/loam soils derived from weathering of the Cape Granite Suite.

Soils derived from the Malmesbury Group are yellow, red or brown, clay rich, and commonly contain ferricrete nodules and vein quartz pebbles. The sand content is variable; these soils tend to become sandier near modern rivers. Cape Granite Suite soils are light brown to reddish in colour, commonly sandy to gritty, with pebble layers present locally. Proximity to outcrops of the Table Mountain Group is a significant factor in soil formation in the Coastal Region, resulting in increased sand content. Colluvial soils and scree are also developed. (Gresse and Theron, 1992; Theron et al., 1992; Hughes et al., 1992). The most sought-after soils for vineyards in the Coastal Region are clay-rich loams, as these have the capacity to retain water that can be utilized by vines during the dry summer months. Such clay layers are a feature that is regularly mentioned in wine literature.

Soil classification in South Africa is based on a series of soil forms and families. The type and colour of the soil layers present and the properties of these layers are specific to particular soil forms and families, and each is given a name based on the type location. The names of certain soil forms, for example reddish brown Hutton loams, have become entrenched in South African wine literature. It is beyond the scope of this study to provide a detailed review of South African soil classification: interested readers are referred to the Soil Classification Working Group (1991) for more detailed information.

Saprolites and Kaolin

An additional feature in areas of granite bedrock is the presence of saprolites and kaolin. Saprolites were described by Joubert

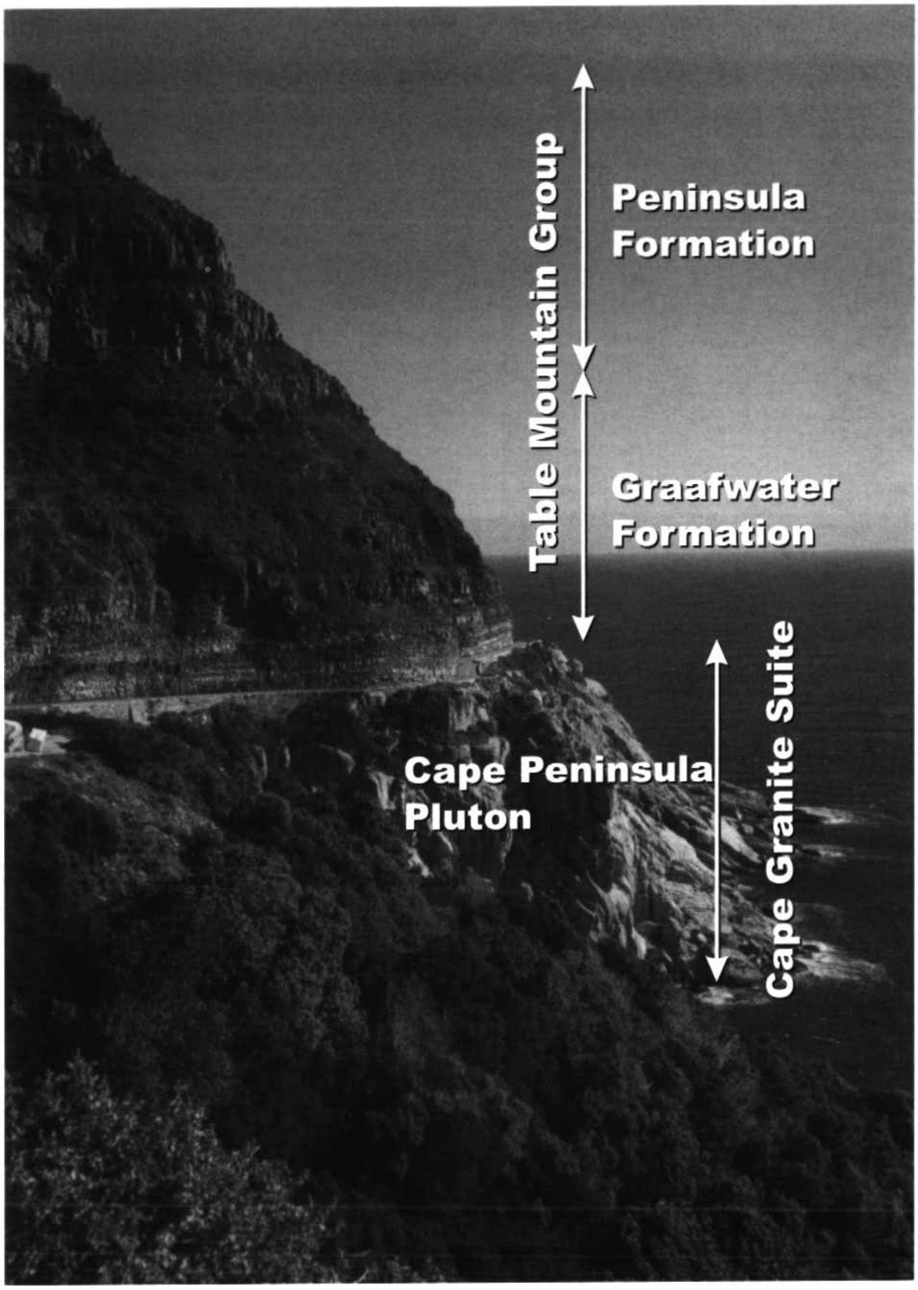

Figure 14 Basal contact of Graafwater Formation sandstones, siltstones and shales, Table Mountain Group (Mid-Ordovician to Early Devonian) overlying granite of the Cape Peninsula Pluton (Late Proterozoic). Photo C. Bargmann.

et al. (1997) in the soils of Groot Constantia and a Shiraz vineyard on the farm Langkloof near Wellington. According to Lambrechts (1982), saprolite horizons may reach depths in excess of 50 m. Kaolin has been identified at several important wine-producing locations in the Coastal Region, and is locally called "pot clay". Granite of the Kuils River/ Helderberg Pluton hosts the most extensive deposits of kaolin associated with vineyards. Commercially exploited kaolin deposits are located in the Cape Point District on the Cape Peninsula, where rehabilitation of the kaolin workings has included the planting of vineyards. Kaolin is also noted in the Stellenbosch pluton (Heckroodt, 1992; Theron et al., 1992; Söhnge, 1991; Knox, 1982).

Alluvium and Terrace Gravels

River alluvium and gravels are present in the Coastal Region's two main river drainage basins, the Eerste and Berg rivers. The composition of the river alluvium varies between fine silt, sand and gravel. Theron et al. (1992) observed that sandy alluvium, with organic material, is prominent in the Cape Peninsula and Stellenbosch areas.

Fluvial terraces are present in the Eerste River valley in the vicinity of Stellenbosch and were described in detail by Söhnge (1991). The best preserved terraces are divided into two groups: older gravels which range between 12–55 marb (metres above river bed), and younger gravels at 5–9 marb. Middle to Late Pliocene and Early Pleistocene ages were proposed by Söhnge (1991) for the older and younger gravels, respectively. The original river system is considerably older and may have started as a northerly flowing river during Late Cretaceous time, with river capture occurring during the Oligocene to produce the present westerly flowing drainage pattern (Table 7).

Marine and Aeolian Sediments

The Sandveld group is the proposed name for the Miocene to Holocene age marine and aeolian sediments deposited in the Cape Town hinterland (Theron et al., 1992). Deposition is concentrated in coastal areas and the Cape Flats, a broad low-lying area between Cape Town and Stellenbosch (Fig. 13). Aeolian sands regarded as Springfontein Formation occur as far inland as the Berg River in the vicinity of Paarl and are a feature of some vineyard areas.

TERROIR: STELLENBOSCH AND PAARL DISTRICTS

The Stellenbosch and Paarl districts are bounded on the east by mountains composed of Table Mountain Group sandstones; to the south is the coast of False Bay. To the west of these districts lie the Cenozoic sands of the Cape Flats and the towns of Brackenfell, Eerste River, Kuils River and Durbanville. The northern and western boundary of the Paarl District is based on the municipal boundary of the town of Paarl (Fig. 15).

Other features of the two districts include Bottelary hills; the Paarlberg, Stellenboschberg, Simonsberg, and Helderberg mountains; and two river drainages. Eerste River drainage basin covers much of the Stellenbosch District, flowing through the town of Stellenbosch in a southwesterly direction and eventually reaching the coast of False Bay. The Berg River valley is situated in the Paarl Distict; Berg River flows north from its source near Franschhoek, passing through the towns of Paarl and Wellington.

Role of Geology in Terroir

The French term "terroir" encompasses the whole natural environment of the vine: the climate, topography, soil, and bedrock geology, and includes viticultural practices such as cultivar selection and trellising systems, as described by Haynes (1999) and Wilson (2001) in earlier papers in this series. Traditionally in South Africa, research was limited to established wine areas because historical controls placed on the wine industry by the KWV prevented experimentation and expansion until the mid 1980s. Since then the country's winemakers have developed new wine growing areas, introduced additional grape varietals and become less dependent on the co-operative wineries. As a result of this process an understanding of the best combinations of grape varietal, climate, soils and bedrock geology, the fundamentals of terroir in South Africa and elsewhere, has begun to develop. Thus the concept of terroir is only beginning to be understood in Coastal Region settings.

Geology is a significant component of the local terroir. Perhaps most basically, geology plays an important part in the origin of the topography of the region as illustrated in Figure 16, which shows a section through the Eerste River basin to the south of the town of Stellenbosch. It is immediately clear from this diagram that river valleys are underlain by recessive-weathering granites of the Cape Granite Suite, whereas mountain peaks are composed of resistant-weathering sandstones of the Table Mountain Group, responsible, as noted above, for much of the spectacular scenery of the Cape. Faulted outcrops of Stellenbosch Pluton granites and Tygerberg Formation greywackes occur in the Jonkershoek Valley, which is flanked by the Stellenboschberg and Jonkershoek mountains composed of the resistant sandstones of the Table Mountain Group. Tygerberg Formation greywackes, intermediate in weathering character, form the slopes of the mountains. In the extreme west, the topographically more subdued Bottelary Hills mark the contact between Kuils River/Helderberg granites and Tygerberg Formation greywackes, which locally have been hornfelsed.

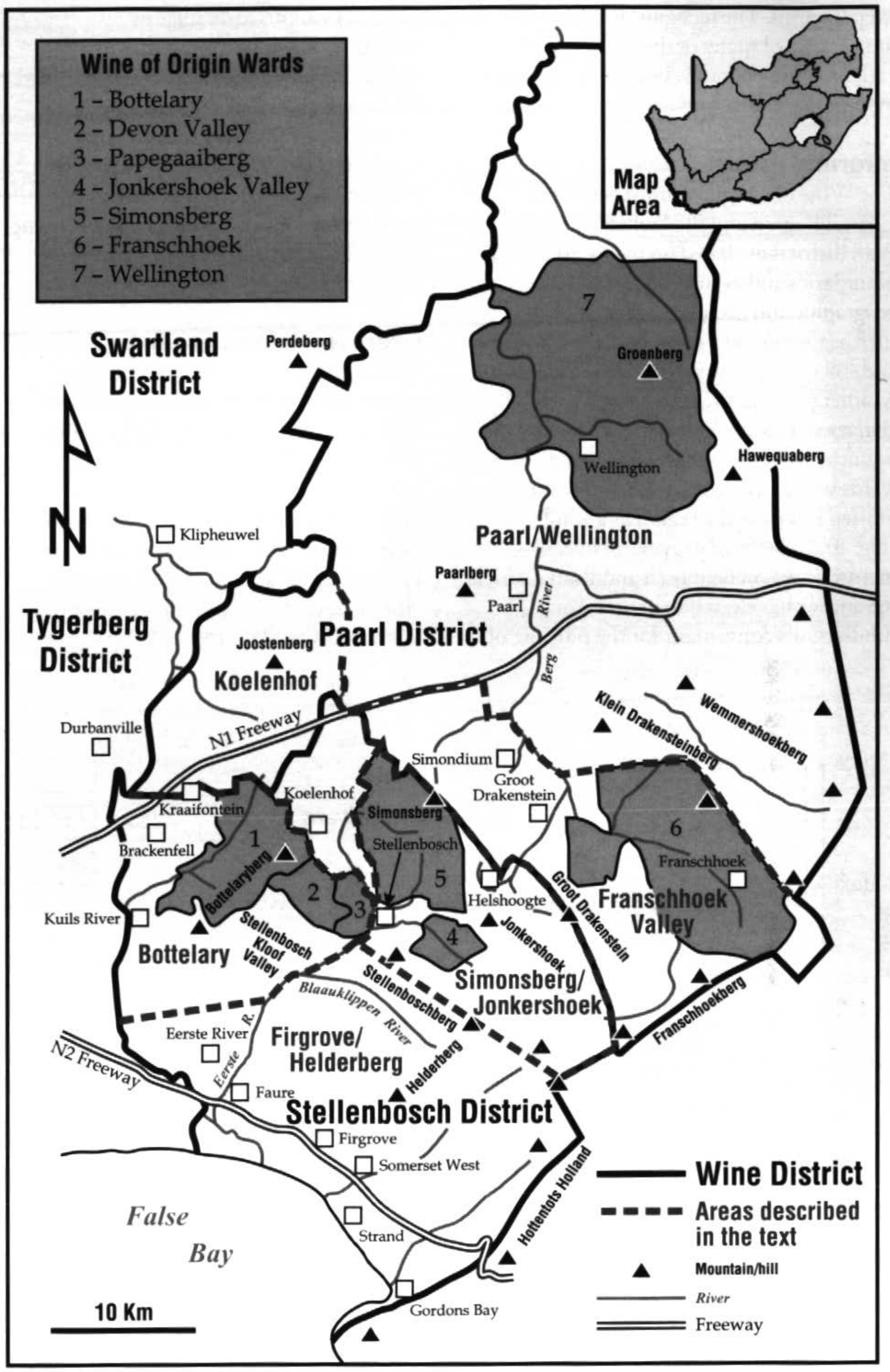

Figure 15 Stellenbosch and Paarl Wine of Origin Districts, Coastal Region of South Africa. Towns, e.g. Brackenfell, are shown as solid squares; mountains are shown as solid triangles with prominent mountains named in bold face, e.g. **Groenberg**. Modified from Domine (2001).

Clearly the differing slope orientations that occur are expressions of topography, and this is governed by bedrock geology. Topography is a key influence on grape vine growth and grape ripening through factors such as higher rainfall, exposure to morning or afternoon sunlight, and sea breezes. Additional geological influences on terroir include the site-specific influence of bedrock and associated colluvial and residual soils. Aspects such as weathering products, soil structure, texture, pH and retention of moisture, among others, are important considerations in the overall terroir. The recognition and importance of many of these site-specific variations are only now becoming apparent in the Coastal Region.

Informal Areas

The Wine of Origin boundaries of the Coastal Region and the Stellenbosch and Paarl districts are based on magisterial boundaries and as such do not reflect geographic and geological characteristics such as topography, river drainages, geology and soil type, or the varied local climates and weather patterns present. These "natural" characteristics are, in theory, defined by the boundaries of the wards. Unfortunately the wards within the Coastal Region cover a limited extent of the region as a whole (Fig. 8). In order to provide an overall picture of the Stellenbosch and Paarl districts the author has elected to use informal subdivisions convenient for the purpose of discussion at this early stage of understanding of terroir of the Coastal Region. These informal areas are described below and shown in Figure 15. Within these informal areas there are many vineyard-scale variations that reflect such components of terroir as altitude, slope orientation, bedrock geology and overlying soil type, which will become better understood with time.

Firgrove/Helderberg Area

This informal area covers the southern coastal portion of the Stellenbosch District (Fig. 15). The topography varies between the slopes and foothills of the Helderberg (1137 m) and Stellenboschberg (1167 m) mountains, and the lower-lying Eerste River valley (Fig. 17). To the east of the Helderberg Mountain ridge there are vineyards in the vicinity of the town of Somerset West (Fig. 15).

The village of Firgrove (Fig. 15) records a degree day total of 1756, which places this area in Winkler Region III (Tables 3, 4). Dew, totaling 100 mm, is noted as an important component of the local climate of the Meerlust Estate near the town of Faure (Fig. 15), and can remain on the vine leaves until late in the morning (Knox, 1982). The influence of the coast is strong, and sea breezes have a significant effect on the climate of the area. Vineyards are actively being planted on the foothills and slopes of Helderberg Mountain where cooler conditions result from both altitude and the effects of the sea breezes.

In terms of geology, Firgrove/ Helderberg area is underlain by the Kuils River/Helderberg Pluton granite, which is fringed by sediments of the Tygerberg Formation (Fig. 18). The Somerset West vineyards show distinctive geology with both Tygerberg Formation sedimentary

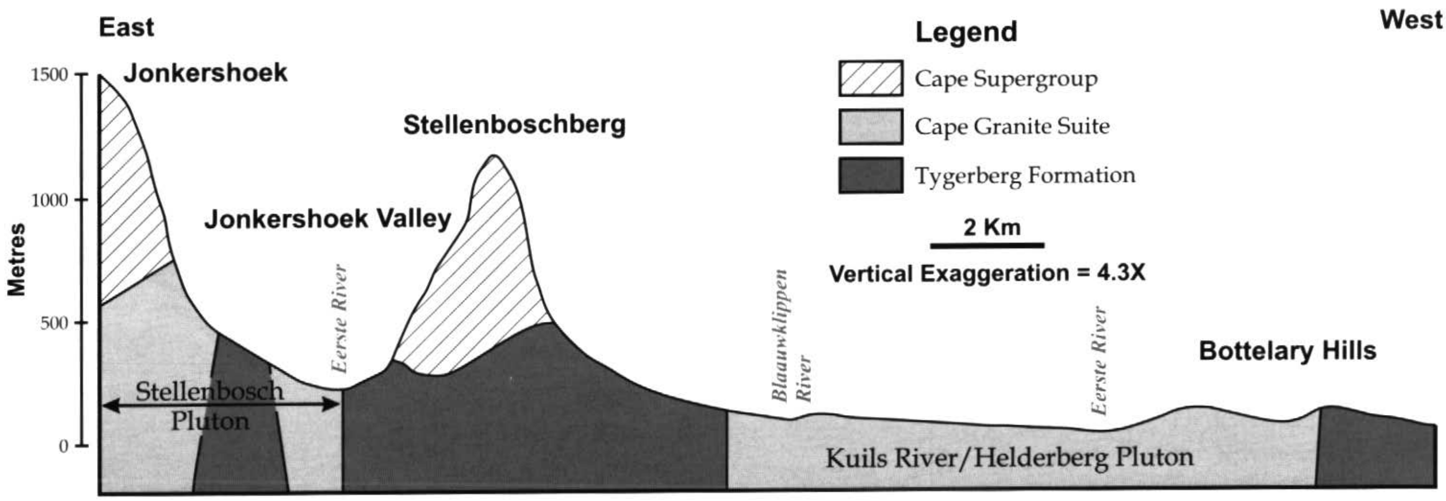

Figure 16 Schematic geological section through southern part of Stellenbosch District; Figure 18 shows location of east-west cross-section.

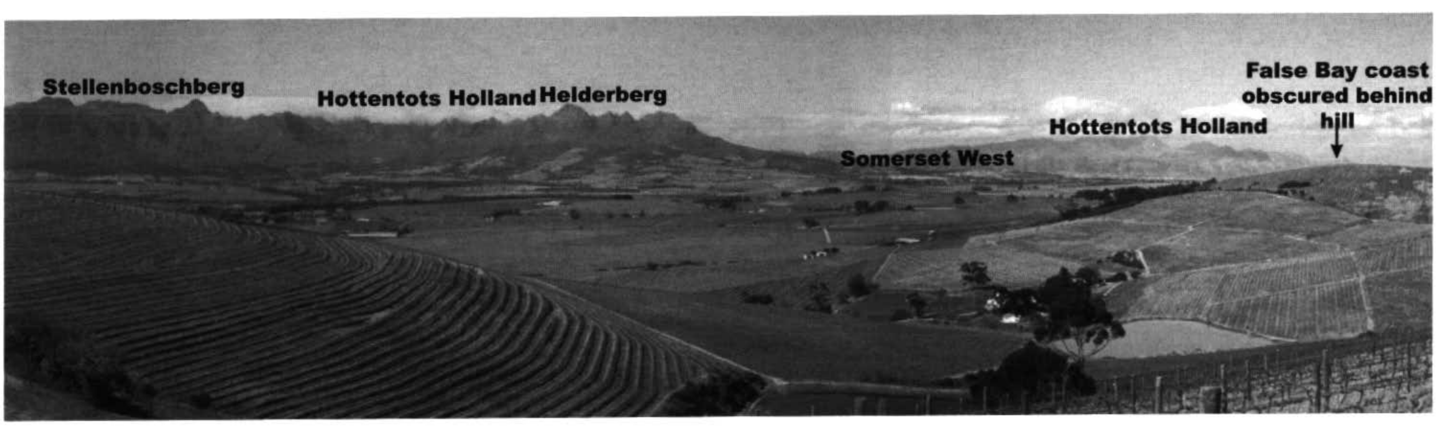

Figure 17 Firgrove/Helderberg informal area viewed from the Bottelary Hills, looking southeast from the Jordan Winery at the head of the Stellenboschkloof Valley. Eerste River basin is seen in the middle distance; Helderberg Mountain the far distance. Photo C. Bargmann.

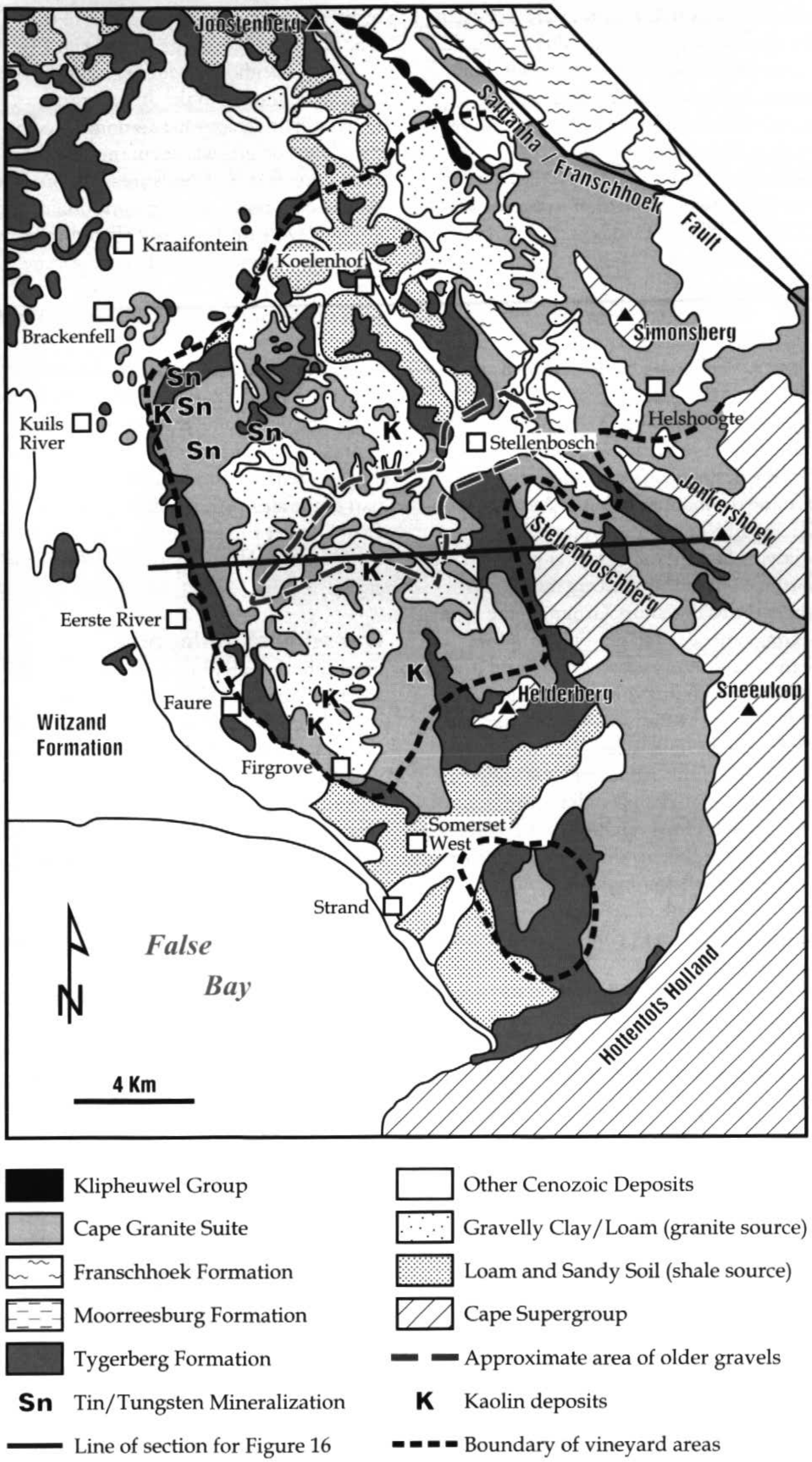

Figure 18 Generalized geology of the Stellenbosch District and the Joostenberg area, Coastal Region of South Africa. Line in centre of figure indicates location of schematic east-west cross-section seen in Figure 16. Modified from Geological Survey of South Africa (1990).

rocks and Stellenbosch Pluton granite present. Loamy soils are developed on the more mountainous areas near the Helderberg and Stellenboschberg mountains. In contrast, flatter areas in the Eerste River basin have a distinct sandy soil over a kaolin-rich sublayer. Heckroodt (1992) described the presence of kaolin over a wide area between the towns of Stellenbosch and Firgrove (Fig. 18). In areas with the Tygerberg Formation forming the bedrock, clay layers are present in overlying soils. Alluvial soils are present in areas close to the rivers, and deposits of the older gravels are present in the north of the area. In the vicinity of Somerset West there is significant alluvium, scree and sandy loam soils.

Surprisingly for an area with distinct local climates and geology, at present there are no wards defined in the Firgrove/ Helderberg informal area. Based on topography, climate and geology, sub-areas can be identified covering Somerset West, Firgrove/Faure and the foothills of the Helderberg, which could all be considered for ward status.

Bottelary Area

This informal area covers the northwest part of the Stellenbosch District (Fig. 15). The hilly topography and associated valleys on the flanks of the Bottelary and Papegaaiberg Hills provide numerous slopes and aspects suitable for vineyards.

No degree day figures are available for the Bottelary area, however the village of Koelenhof, to the east, has a degree day total of 1898 and the Durbanville, to the west, has a degree day figure of 1906. This indicates that the Bottelary area would have a degree day figure of approximately 1900 and a warmer overall climate than Firgrove/ Helderberg at 1756 (Table 4). The effects of sea breezes from both False Bay and the Atlantic are felt in the Bottelary area, although the coastal influence is lower than that felt by the Firgrove/Helderberg area discussed above.

The bulk of the Bottelary area is underlain by granites of the Kuils River/ Helderberg Pluton (Fig. 18). Soils here commonly are loams, although sandy loams and some sandy soils occur. Alluvial soils and some local occurrences of older river gravel exist along the Eerste River. Clay layers were noted and kaolin deposits were described by Heckroodt (1992) in the Devon valley and the Kuils River area. In contrast, near the towns of Brackenfell and Kuils River in the north and west of the district (Fig. 15), the geology comprises Tygerberg Formation greywackes in contact with granites of the Kuils River/Helderberg Pluton. Tin and tungsten mineralization is present in this area, and vein deposits are located on the Hazendal and Zevenwacht wine farms (Theron et al., 1992). The soils here are variable, ranging from loams and sandy loams on higher areas to aeolian sands and alluvial soils in the lower-lying areas. Soils can be gravelly and clay sublayers, important in providing moisture during the dry summer months, are present.

Three wards are currently demarcated within the Bottelary area as shown in Figure 15. The Bottelary Ward covers the northern slopes of the Bottelary Hills; Devon Valley Ward lies to the southeast and covers a distinct valley of the same name; whilst Papegaaiberg Ward is centered on the Papegaaiberg Hills in the east of the Bottelary area, just west of Stellenbosch town. There is scope for further subdivision of the Bottelary area. The most significant undemarcated area is the Stellenboschkloof valley located on the southern flanks of the Bottelary Hills, to the south of the current Bottelary Ward (Fig. 15).

Simonsberg/Jonkershoek Area

This informal area is situated to the northeast and southeast of the town of Stellenbosch (Fig. 15). The area covers the western slopes and foothills of the Simonsberg and Jonkershoek mountains, including the Jonkershoek valley shown in Figure 16. The area also covers the high altitude vineyards of Helshoogte (Fig. 15) in the neck between the Simonsberg and Jonkershoek mountains.

In terms of climate, the effects of altitude are again noticed here, with rainfall, particularly, being higher. This increase in rainfall is illustrated in Figure 12, which shows high totals recorded from the eastern side of the mountains at the Boschendal estate. The effects of altitude, slope orientation and exposure to sea breezes all play an important role in providing cooler growing conditions: this is particularly true of the Helshoogte area where vineyards are at elevations above 300 m. The slopes of the Simonsberg mountains provide a good example of the effects of slope orientation on vineyards. West-facing slopes of the Simonsberg vineyards are exposed to full afternoon sunshine, in contrast to east-facing slopes such as those on the other side of the Simonsberg mountains in the Simondium/ Groot Drakenstein area (Fig. 15) (see below), where cooler afternoon conditions result as the sun passes behind the mountains. The Simonsberg/Jonkershoek area lies between Koelenhof – degree days 1898 – and Groot Drakenstein – degree days 1967 (Table 4) – and similar degree day figures can be anticipated for the area.

The geology of the Simonsberg/ Jonkershoek area is the most complex of all of the Stellenbosch District informal areas (Fig. 18). The area in the vicinity of the Simonsberg mountains is underlain by granites of the Stellenbosch Pluton, with Table Mountain Group clastic sediments forming the mountain slopes. A small outcrop of Klipheuwel Group clastics overlying Stellenbosch granites occurs to the northwest of the Simonsberg mountains whilst the Malmesbury Group, in the form of conglomerates and sandstones of the Franschhoek Formation, is developed in a northwest-trending zone beginning near Stellenbosch. Loamy soils are common and sandy soils occur in valleys.

The Jonkershoek valley is underlain by fault-bounded units of both the Stellenbosch Pluton granites and Tygerberg Formation sediments (Fig. 16). Soils range from loams and decomposed granite to sandy alluvial soils. Scree is present in the valley, which gives a pebbly texture to the soils.

Two wards are defined in this area. The Simonsberg-Stellenbosch Ward covers the western slopes and foothills of the Simonsberg mountains, and the Jonkershoek Valley Ward covers the vineyards of the valley of the same name to the southeast of Stellenbosch (Fig. 15).

Koelenhof Area

The Koelenhof informal area covers a low-lying area to the north of the town of Stellenbosch between the Bottelary hills in the west and the Simonsberg mountains to the east (Fig. 15). Geographically and geologically this area extends north into the Paarl District in the vicinity of the 291 m high hill called Joostenberg.

The village of Koelenhof has a degree day total of 1898, showing that the overall climate is warmer than Firgrove/ Helderberg to the south. In climatic terms, breezes are important here: Van Zyl (2000) described the area as being "air conditioned" by breezes from both the Atlantic to the west and False Bay to the south (Fig. 13).

Koelenhof provides a geological contrast to the rest of the Stellenbosch District. The geology here is dominated by the shales and greywackes of the Tygerberg Formation (Fig. 18). Soils are sandy, may be aeolian or of transported granitic origin, and clay sublayers are developed. Tygerberg Formation greywackes and minor granite form the bedrock in the vicinity of Joostenberg, with much of this area covered by aeolian sands.

No wards are currently defined in this area. The distinctive nature, particularly of the geology, makes the area important enough to warrant an official classification. The Joostenberg portion in the northern part of the area currently falls within the Paarl District and highlights the problems of using municipal boundaries to define wine areas.

Franschhoek Valley area

Franschhoek Valley informal area forms the southern portion of Paarl District and is enclosed on three sides by mountains (Fig. 2). Between the Simonsberg and the Groot Drakenstein mountains is the northeast–southwest trending Groot Drakenstein valley with the Helshoogte vineyards (mentioned above) at its head (Fig. 15). Based on differing topography, the valley can be divided into two sub-areas: the Simondium/Groot Drakenstein sub-area and the Franschhoek sub-area. The Simondium/Groot Drakenstein sub-area covers the east-facing slopes of the Simonsberg mountains, and the Franschhoek sub-area occupies the more enclosed southern end of the Berg River Valley around the town of Franschhoek itself (Fig. 19). Topography in the Franschhoek valley creates a wide variety of slope orientations, ranging from the valley floor to west- and east-facing mountain slopes.

Climatic conditions are as follows. Average growing season temperatures at the Boschendal wine estate are slightly warmer than the Stellenbosch locations to the west, and cooler than the Wellington area to the north (Fig. 10). Degree day values for the Franschhoek Valley show a variation between 1967 and 2014 for Groot Drakenstein and Franschhoek, respectively. Both fall into Region IV, and again indicate that the Franschhoek Valley is a warmer wine region than Stellenbosch to the west

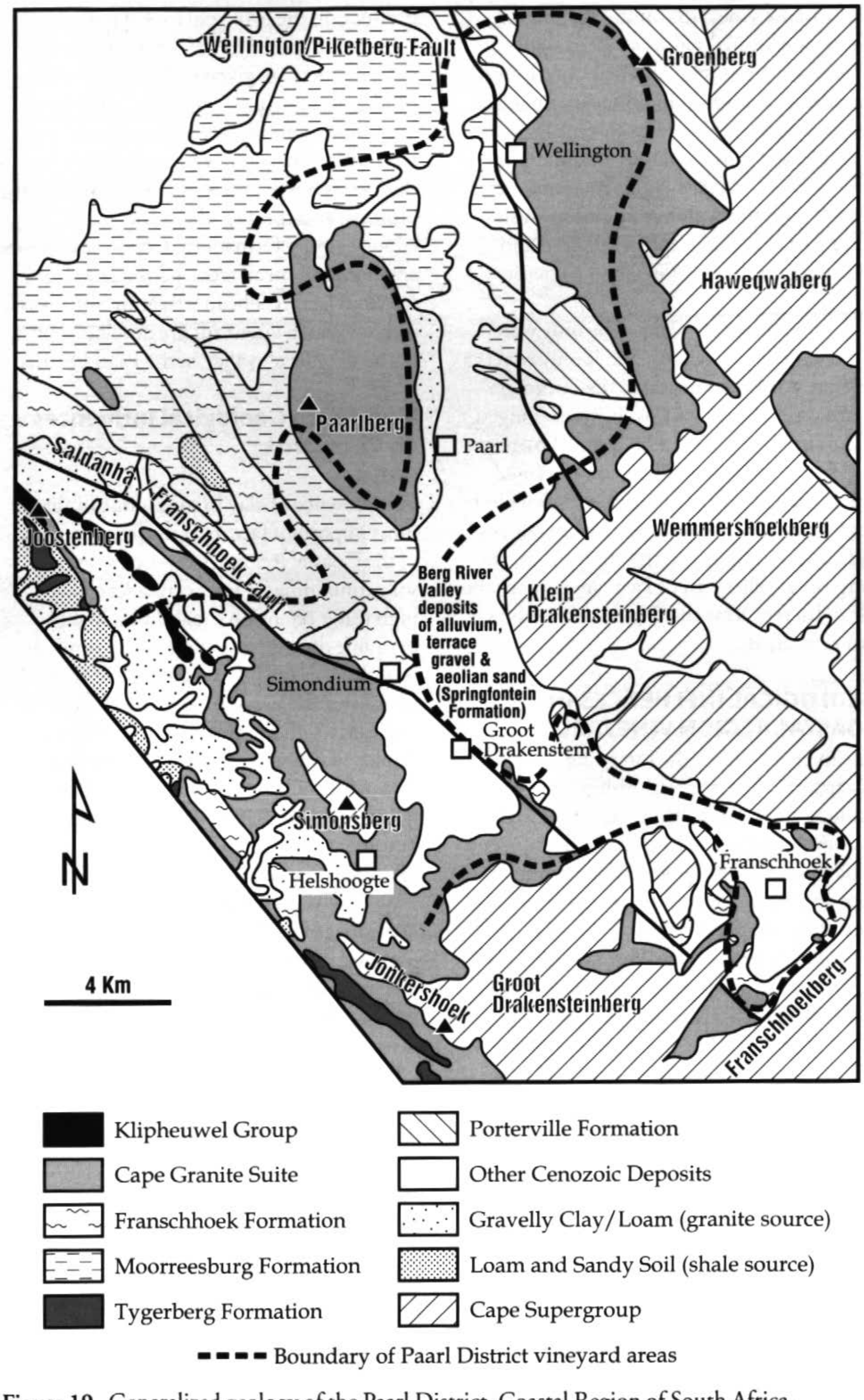

Figure 19 Generalized geology of the Paarl District, Coastal Region of South Africa. Modified from Geological Survey of South Africa (1990, 1997).

(Table 4). Average rainfall for the Franschhoek Valley is the highest of the areas described in this paper: the Boschendal wine estate and Groot Drakenstein weather station record 1355 and 931 mm of rainfall respectively (Fig. 12). These figures also indicate that there is considerable variation in rainfall dependent on location within the valley. Such variation in rainfall and temperature is to be expected in an area with varied topography that strongly influences weather and climate.

Bedrock geology consists of granites of the Stellenbosch Pluton and sediments of the Franschhoek Formation, both of which are faulted. The Simondium/Groot Drakenstein sub-area is mainly underlain by granites of the Stellenbosch Pluton and is bounded to the northeast by Franschhoek Formation conglomerates and quartzites. Loam and sandy loam soils occur on higher slopes with sandy and alluvial soils in the valleys (Fig. 19). The Franschhoek portion of the valley is dominated by alluvium along the valley floor and scree on mountain slopes. Sandy and alluvial soils sometimes gravelly are common, whilst loams and sandy loam occur in areas close to bedrock outcrop. The bedrock of the Franschhoek valley consists of a mixture of Stellenbosch Pluton granites and Franschhoek Formation clastics preserved below Cape Supergroup rocks.

Although two distinct sub-areas exist as described herein, only Franschhoek Ward is defined as a ward in terms of the Wine of Origin legislation in 2001 (Table 2). The eastern slopes of the Simonsberg mountains in the Simondium/Groot Drakenstein sub-area is a good example of an area with distinct topography and geology suitable for ward status. The variety of slope orientations in the Franschhoek Valley lends itself to the possibility of defining several discrete, small subdivisions with particular characteristics based on slope orientation, sunlight exposure, geology and rainfall.

Paarl/Wellington area

The final informal area covers the northern portion of the Paarl District (Fig. 15). Geographically this area is dominated by Paarlberg Mountain (729 m) to the east of Paarl, and the valley of the Berg River. Farther north near Wellington the slopes of the Groenberg (942 m) and Hawequaberg (1597 m) mountains are important vineyard areas.

As would be expected of the most inland location of the areas described, the maximum temperature over the growing season is the warmest, reaching 20.9°C at Wellington (Fig. 10). The presence of sea breezes from the Atlantic, approximately 60 km to the west, is noted as a factor in the local climate around Paarl (Hughes et al., 1992; Pienaar, undated). As a result relatively cooler conditions can be expected on the western slopes of Paarlberg Mountain, which are oriented favorably to benefit from these breezes. The Paarl/Wellington area probably falls within Region

IV in terms of degree day classification. This is based on Wellington being warmer than Franschhoek and Stellenbosch over the growing season, and the more inland locations of Wolseley and Tulbagh returning degree day figures falling between Regions IV and V (Table 4; Fig. 10).

Geologically this area is varied, and once again distinct sub-areas can be observed. Possibly the best known area of vineyards is located on the southwestern slopes of Paarlberg Mountain. This area also has distinctive geology, consisting of Paarl Pluton granites and Moorreesburg Formation sediments (Theron et al., 1992) (Fig. 19). The latter are locally cut by quartz porphyry dykes. The geology of this area is well represented at the Fairview wine farm. Here the highest altitude soils are derived from granitic and shaly bedrock. On midslopes the soils are colluvial, of granite origin, and cover a clay layer above the Moorreesburg Formation. At lower levels, sandy alluvial soils occur above a clay sublayer. In the extreme southwest of Fairview the land rises slightly and contains clay-based soils above the Moorreesburg Formation (Fairview, pers. comm.).

In contrast, the Berg River valley in the vicinity of the town of Paarl contains sandy alluvial soils that overlie Malmesbury Group sediments (Fig. 19). To the north near Wellington, vineyards are located on I-type granites of both the Paarl and Wellington plutons, and on sediments of the Moorreesburg and Porterville formations. Many of the vineyards on the Wellington Pluton are located on the western slopes of Groenberg Mountain and will benefit from the effects of altitude and slope orientation. Decomposed granite, Hutton-type loams and colluvial soils containing Malmesbury clasts were noted in this area by Joubert et al. (1997), and the Wellington Pluton was described as being deeply weathered and forming saprolites by Gresse and Theron (1992).

Wellington Ward is the only ward defined in this large area, and it only covers a discrete northern portion of the informal Paarl/Wellington area. Possibly the strongest terroir influence here is the warm climate, and further wards are likely to be defined where local conditions mitigate to provide a cooler climate. The southwest-facing slopes of Paarl Mountain and the vineyards of the Berg River valley east of Paarl are perhaps the most discrete areas that have not already been classified.

GEOLOGICAL INFLUENCES ON COASTAL REGION VINEYARDS

As can be seen from the foregoing discussion, the interrelationship between geology and climate is a key element in the terroir of the Coastal Region. Bedrock geology commonly governs topography, and topography in turn influences climate, including temperature, sunshine and rainfall. The bedrock geology also has a role in the type of soil present in areas of residual and colluvial soil. In terms of wine production the principal rock types and Cenozoic deposits in the Stellenbosch and Paarl districts are given in Table 8. For wine production the most important rock types are granites and greywacke dominated sediments. These rocks are particularly from the Stellenbosch and Kuils River/Helderberg plutons; and the Tygerberg and Moorreesburg formations. Cenozoic deposits are important in all areas, particularly loam soils and kaolin. The most significant alluvial soils on which vineyards are developed occur in the Berg River valley of the Paarl District.

Significant Geological Influences on Vineyards

Clays

The presence of clay in soils is one of the most important factors of the overall terroir of the Coastal Region. Clay-rich soils, and soils containing distinct clay layers, have high water retention capabilities, highly desirable during the generally dry summer months: this feature is regularly mentioned in South African wine literature. Successful vineyards with sandy soils commonly are duplex in character, with a clay sub-layer that assists in supporting the vine. The negative side of clay soils is their potential to become waterlogged, an undesirable feature for vines (Saayman, 1977).

The presence of significant quantities of kaolin has also been noted, particularly in the vineyards near Stellenbosch, although little has been written on its possible effects on vines and

Table 8 Principal rock types and Cenozoic deposits in wine producing areas of the Coastal Region

District	Informal area described in this paper	Wine of Origin Ward	Non classified subarea mentioned in this paper	Principal vineyard rocktype	Important Cenozoic deposits
Stellenbosch	Bottelary	Bottelary		Granite, greywacke	Loam soils, kaolin
		Devon Valley		Granite	Loam soils, kaolin
		Papegaaiberg		Granite	Loam soils
			Stellenboschkloof	Granite	
	Simonsberg/Jonkershoek	Simonsberg-Stellenbosch		Granite, conglomerate	Loam soils
		Jonkershoek Valley		Granite, greywacke	Alluvial gravel, scree
	Firgrove/Helderberg		Firgrove	Granite	Sandy soils, clay, kaolin
			Helderberg	Granite, greywacke	Loam soils
			Somerset West	Greywacke, granite	Alluvial gravels, scree
	Koelenhof			Greywacke	Sand, loam and clay soils
Paarl	Franshhoek Valley	Franschhoek		Conglomerate, granite	Alluvial gravels
			Simondium/Groot Drakenstein	Granite, conglomerate	
	Paarl/Wellington	Wellington		Granite	
			SW Paarlberg	Greywacke, granite	Colluvial soil
			Berg River Valley (Paarl)	Greywacke?	Alluvial gravels, sand

wine. Kaolin-rich soils may be less fertile and poor water sources – compared to soils containing clays such as montmorillonite and vermiculite – because kaolin has a low cation exchange capacity and a poor ability to absorb water molecules (Wilson, 1998; Dubbin, 2001).

Potassium-rich Settings

An important chemical characteristic of many shale- and granite-derived soils in the Coastal Region is the presence of potassium. Wooldridge (2000) noted that soils on the flanks of Paarlberg Mountain contain potassium released from granites, and that these soils have little capacity to buffer the uptake of potassium by vines. When potassium in the soil is transferred to the vine and grape, an increase in the pH of the grape results. In red wines produced from these settings the excess potassium can result in poor colour, and lower acidity wines with a "flabby" character (Saayman, 1992).

Soil Acidity

Acidity is another important chemical characteristic of many Coastal Region soils, and particularly the sub-soil. Acidic sub-soils can generate toxic aluminium levels which in turn restrict vine root growth. Deep soils, and potentially saprolite horizons, can be affected by this chemical restriction on vine growth. The addition of lime during soil preparation prior to planting a new vineyard is widely practiced in South Africa and elsewhere to counter the effects of low soil pH (Saayman, 1992).

CONCLUDING COMMENTS

My hope is that this paper introduces the reader to some of the history and geology of one of the most scenic wine regions of the world, the Coastal Region of South Africa. I particularly hope that my fellow Cape Wine Masters, and future students for the qualification, will benefit from the information provided herein.

At first glance Cape geology appears to be relatively simple, consisting as it does of four main geological units: the Malmesbury Group, Cape Granite Suite, Klipheuwel Group and Table Mountain Group. On further investigation a more complex scenario develops, with factors such as soil type, the presence of alluvium and sand, saprolite weathering, and kaolin formation all playing a role in the development of the geological and soil environment of Coastal Region vineyards.

In the Stellenbosch and Paarl districts the influence of climate and topography must not be understated, as both of these factors are critical in providing cooler conditions and rainfall in a wine-growing area that falls within the relatively warm degree day Regions III and IV. Geologically these districts are marked by strong influence from granites and, in the case of the Stellenbosch District, the unusual presence (in wine terms) of kaolin. Potassium, which has negative impacts on wine quality, is an unfortunate factor in the overall terroir resulting from the granite- and greywacke-based geology.

Owing to the legal restrictions and the co-operative dominated wine industry, experimentation with new areas and different grape cultivars was limited prior to the 1980s. It is only in the last two decades that South Africa's winemakers have been given the freedom to expand into new areas and experiment with matching cultivars and vineyard sites, which will ultimately define the unique elements of terroir in South Africa. The ongoing terroir study at the Agricultural Research Council in Stellenbosch will undoubtedly add considerably to this goal. As the industry develops, particularly into new viticultural areas, it is clear that further understanding of the role of geological factors in the local terroir will be established, to the continuing benefit of growers and consumers of wines from this historic area.

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EDITOR'S NOTE

Christopher Bargmann (B.Sc., Geology, Leicester University, England, 1983; M.Sc., Mineral Reserouces, Cardiff University, Wales, 1999) has spent much of his working career in gold and diamond exploration with JCI and De Beers in South Africa. Currently he is a geological consultant based in Wales. While living in Johannesburg, South Africa, he developed an interest in wine and began to study the subject through the Cape Wine Academy, the main wine education body in South Africa. In 2000 he became a Cape Wine Master (CWM). This qualification is similar to the U.K. Master of Wine (MW) qualification and requires the passing of written theory and tasting exams, and the completion of a thesis. Christopher Bargmann is one of only 48 CWMs at present.

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