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GEOLOGICAL SURVEY
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THE GEOLOGY OF THE WORCESTER AREA

by/deur

P. G. GRESSE, Ph.D. and J. N. THERON, D.Sc.

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THE GEOLOGY OF THE WORCESTER AREA

Abstract

The Worcester Sheet comprises most of the area known as the Cape Syntaxis, the area where the southern and western branches of the Cape Fold Beld meet and curve towards the south-southwest. The area is characterised by rugged mountain ranges and wide, fertile intermontane valleys, well known for fruit and grape cultivation.

The mountains are mostly formed of sandstones of the Palaeozoic Cape Supergroup, while the valleys are usually underlain by phyllite and greywacke of the Late Proterozoic Malmesbury Group. The shaly Karoo Sequence also tends to underlie areas of subdued relief, as in the northeastern part of the map bordering on the Karoo and in the southeast in the Caledon and Bredasdorp regions.

Metasediments of the Precambrian Malmesbury Group are exposed in fault-bounded valleys and erosional windows on the Worcester Sheet, and are correlated with similar rocks belonging to the Tygerberg and Boland terranes of the Saldania Subprovince. The metasediments are intruded by at least five major, composite granite plutons that are regarded as high-level diapiric intrusions. They range in age from 630 to 500 Ma and were intruded during the late- to post-tectonic phase, of the Saldania Orogeny.

The three groups of the Cape Supergroup are fully represented in the area. The lower Table Mountain Group overlies the Malmesbury metasediments and granites unconformably. It ranges in composition from conglomerate to sandstone and tillite. The Bokkeveld Group is exposed in its type areas on the Worcester Sheet – the Warm and Cold Bokkeveld around Ceres, and the Hex River Valley. Five upward-coarsening cycles representing several coalescing delta lobes can be recognised. The Bokkeveld Group is overlain conformably by the more arenaceous Witteberg Group which, like the Bokkeveld sediments, also contains a variety of Devonian fossils.

Only the lower part of the Karoo Sequence is found in the map area. Deposition was in a shallow, marginal, intracratonic marine basin. The glacial Dwyka Group at the base of the Sequence is followed by the predominantly argillaceous Ecca Group.

Rocks of the Middle Jurassic to Lower Cretaceous Uitenhage Group occur in remnant depositories along two westerly striking fault zones. The Worcester–Pletmos Basin line represents the onland extension of the offshore Pletmos Basin southeast of Plettenberg Bay, and the Bredasdorp Basin line in the Bredasdorp and Elim regions that of the offshore Bredasdorp Basin.

The most important of the Cenozoic deposits are those of the Bredasdorp Group, a sequence of marine to aeolian sediments of Pliocene to Late Pleistocene age. These highly calcareous deposits are found along the coastline in the south between Bot River and the eastern edge of the map. The Holocene Strandveld Formation is also regarded as part of the Bredasdorp Group.

A wide variety of terrace gravels, scree, silcrete and ferricrete, soils and alluvium cover the valley floors and mountain slopes throughout the area.

Apart from the granite intrusions in the Malmesbury metasediments, there are also a large number of dolerite dykes older than the Jurassic Karoo Dolerites in the area, as well as two olivine melilitite plugs that intrude the Mesozoic Enon Formation east of Robertson.

The basement sequence of Malmesbury Group rocks was deformed in late Precambrian to Cambrian times by the Saldania Orogeny, which culminated before and continued till after the intrusion of most of the Cape Granite Suite between 630 and 500 Ma ago. Cover rocks of the Cape and Karoo Sequences were subsequently deformed by the Permo-Triassic Cape Orogeny, which also produced strong overprinting in the basement in some areas. The Cape Fold Belt developed as two contemporaneous arcuate belts that merge in the syntaxis domain between Kleinmond and Ceres to produce northeasterly trending structures. Post-Jurassic normal and strike-slip faults traverse the area in easterly, northwesterly and southwesterly directions.

Dolomite and limestone of the Malmesbury and Bredasdorp Groups are the only mineral deposits mined in the map area. Notable deposits of kaolin and salt also occur, while good quality brick clay is found throughout the area, especially in areas underlain by Malmesbury, Bokkeveld, Witteberg and Ecca shales and phyllites.

Uittreksel

Die Worcesterblad beslaan die grootste gedeelte van die gebied wat bekend staan as die Kaapse Sintaksis, die gebied waar die suidelike en westelike arms van die Kaapse Plooigordel saamsmelt en suidsuidweswaarts buig. Die gebied word gekenmerk deur ruwe bergreekse en uitgestrekte, vrugbare valleie wat bekend is vir die kweek van vrugte en druiwe.

Die berge bestaan meestal uit sandstene van die Paleosoïese Kaap Supergroep terwyl die valleie gewoonlik onderlê word deur filliet en grouwak van die Laat-Proterosoïese Malmesbury Groep. Die skalieryke Karoo Opeenvolging neig ook om gebiede van lae reliëf te onderlê soos in die noordoostelike gedeelte van die kaartgebied aangrensend aan die Karoo en in die suidooste in die Caledon- en Bredasdorpomgewing.

Metasedimente van die Voorkambriese Malmesbury Groep is in die Worcesterblad blootgestel in verskuiwingsbegrensde valleie en erosievensters, en word gekorreleer met soortgelyke gesteentes wat hoort tot die Tygerberg- en Bolandterrein van die Saldania Subprovinsie. Ten minste vyf groot, saamgestelde granietplutone wat as hoëvlak diapiriese intrusies bestempel word, het die metasedimente ingedring. Die metasedimente, wat varieer in ouderdom van 630 tot 500 Ma, is relatief tot die Saldania Orogenese laat- tot na-tektonies ingedring.

Die drie groepe van die Kaap Supergroep is ten volle verteenwoordig in die gebied. Die onderste Tafelberg Groep rus diskordant op die Malmesbury-metasedimente en -graniete. Dit wissel in samestelling van konglomeraat tot sandsteen en tilliet. Die Bokkeveld Groep se tipegebied is blootgestel op die Worcesterblad — die Warm en Koue Bokkeveld rondom Ceres en die Hexriviervallei. Vyf opwaartsgrowwerwordende siklusse wat verskeie saamgesmelte deltalobbe verteenwoordig, kan herken word. Die Bokkeveld Groep word konkordant oorlê deur die meer arenitiese Witteberg Groep wat, net soos die Bokkeveldsedimente, ook 'n verskeidenheid van Devoonfossiele bevat.

Slegs die onderste gedeelte van die Karoo Opeenvolging word in die kaartgebied aangetref. Afsetting was in 'n vlak, marginale, intrakratoniese mariene kom. Aan die basis van die Opeenvolging is die glasiale Dwyka Groep wat gevolg word deur die oorwegend argillitiese Ecca Groep.

Gesteentes van die Uitenhage Groep van die ouderdom Middel-Jura tot Onder-Kryt kom in oorgeblewe afsettings langs twee weswaartsstrekkende verskuiwingsones voor. Die Worcester–Pletmos-komlyn verteenwoordig die aanlandige verlenging van die aflandige Pletmoskom suidoos van Plettenbergbaai, en die Bredasdorpkomlyn in die Bredasdorp- en Elimomgewing dié van die aflandige Bredasdorpkom.

Die belangrikste Senosoïese afsetting is die Bredasdorp Groep, 'n opeenvolging van mariene tot eoliese sedimente van Plioseen- tot Laat-Pleistoseenouderdom. Hierdie hoogs kalkryke afsettings word in die suide langs die kus tussen die Botrivier en die oostelike grens van die kaartgebied gevind. Die Strandveld Formasie van Holoseenouderdom word ook as deel van die Bredasdorp Groep beskou. 'n Wye verskeidenheid van terrasgruis, puin, silkreet en ferrikreet, grond en alluvium bedek valleivloere en berghange oor die hele gebied.

Afgesien van die granietintrusies in die Malmesbury-metasedimente word daar ook 'n hele aantal dolerietgange wat ouer as die Karoodoleriete van Jura-ouderdom is, asook twee olivienmelilitietproppe wat die Mesosoïese Enon Formasie oos van Robertson indring, aangetref.

Die opeenvolging van vloergesteentes van die Malmesbury Groep is in laat-Prekambriese tot Kambriese tye vervorm deur die Saldania Orogenese wat gekulmineer het voor, maar aangehou het tot na die intrusie van die grootste gedeelte van die Kaap Graniet Suite tussen 630 en 500 Ma gelede. Dekgesteentes van die Kaap en Karoo Opeenvolgings is sedertdien deur die Kaapse Orogenese van Perm–Triasouderdom vervorm. Dit het ook 'n sterk afdruk op die vloergesteentes in sommige gebiede gelaat. Die Kaapse Plooigordel het ontwikkel as twee gelyktydige, geboë gordels wat saamsmelt in die sintaksgebied tussen Kleinmond en Ceres en sodoende noordoosstrekkende strukture vorm. Af- en strekkingwaartse verskuiwings van Na-Jura-ouderdom sny deur die gebied in oostelike, noordwestelike en suidwestelike rigtings.

Dolomiet en kalksteen van die Malmesbury en Bredasdorp Groepe is die enigste delfstowwe wat in die kaartgebied gemyn word. Noemenswaardige afsettings van kaolien en sout kom ook voor terwyl goeie kwaliteit baksteenklei deurgaans gevind word, veral in gebiede wat onderlê word deur skalies en filliete van die Malmesbury, Bokkeveld, Witteberg en Ecca Groepe.

1. INTRODUCTION

Sheet 3319 Worcester covers the area from latitude 33°S in the north to the Atlantic coast between longitudes 19°E and 20°E, and includes portions of the magisterial districts of Ceres, Piketberg, Tulbagh, Wellington, Paarl, Worcester, Montagu, Robertson, Swellendam, Caledon, Hermanus and Bredasdorp. Geologically it comprises most of the area known as the Cape Syntaxis (De Villiers 1956; Söhnge and Hälbich 1983) where the western and southern branches of the Cape Fold Belt meet.

The geology of the area was first depicted on a 1:238 000-scale geological map of the Geological Commission of the Cape of Good Hope, compiled by Rogers, Schwarz and Du Toit, and published in 1906. Subsequently, the Geological Survey published a 1:125 000-scale map of part of the area (Sheet 3319 C Worcester/ 3419 A Caledon), compiled and described by De Villiers, Jansen and Mulder (1964). The present 1:250 000 Sheet 3319 Worcester is based on mapping by staff members of the Geological Survey (1959–1988), the University of Stellenbosch (1941–1943) and the University of Cape Town (1958–1976). The senior author revised many of these maps and their stratigraphic subdivisions, and also mapped small areas that were still outstanding.

Geological formations in the area range from the Late Proterozoic Malmesbury basement through Palaeozoic Cape and Karoo cover rocks, to isolated outliers of the Mesozoic Uitenhage Group, the Cenozoic Bredasdorp Group along the southern coast and various Quaternary surficial deposits.

The topography of the area is dominated by the very prominent mountain ranges of the Cape Fold Belt, separated by cultivated, wide intermontane valleys. The most prominent ranges are the Langeberg, Hex River, Witzenberg, Skurweberg, Du Toits, Drakenstein, Riviersonderend and Kleinriviers Mountains. The valleys of Ceres, the

Hex River, Tulbagh–Worcester–Robertson, Franschhoek and Grabouw, as well as the Rûens area, south of the Riviersonderend and Bredasdorp Mountains, are underlain mainly by Malmesbury phyllite and Bokkeveld shale. Northeast of Ceres, in the Ceres-Karoo, rocks of the Karoo Sequence are exposed in a relatively flat, semi-arid region resembling the greater Karoo.

The syntaxis, with its very high mountains, forms a prominent watershed between rivers flowing west (Berg River), north (Olifants and Doring Rivers), east (Breede and Riviersonderend Rivers), and south (Bot, Klein and Nuwejaars Rivers). Rivers draining to the south, notably the Bot and Klein Rivers, display characteristics of drowning, such as estuarine lagoons, at their mouths. The highest peaks occur in the northern mountains where the Matroosberg reaches an elevation of 2 249 m above sea level. In the southern mountains Akkedisberg is the highest at 847 m above sea level. The valleys and low-lying areas of Ceres, Tulbagh, Worcester, Robertson and Villiersdorp are generally more than 1 000 m lower than the mountain peaks.

The climate is predominantly Mediterranean, but temperatures and precipitation are largely influenced by relief. Mean temperatures range between 6 and 36 °C, but during winters the high mountains are capped with snow. Similarly, the rainfall – mainly during winter – varies from less than 200 mm in the northeast to more than 3 000 mm in the mountains. The most important water-storage dams of the southwestern Cape, like Voëlvlei, Brandvlei, Kwaggaskloof, Theewaterskloof and Wemmershoek, are situated in the area.

The natural vegetation of the area consists mainly of *Proteaceae*, *Restionaceae*, *Compositae* and Karoo-type plants such as the "renosterbos" (*Elytropappus rhynocerotis*), while intruder plants such as Rooikrans (*Acacia cyclops*), Port Jackson (*Acacia cyanophylla*) and Hakea (*Hakea tenuifolia*) are rapidly spreading.

2. GEOLOGICAL SEQUENCES

There are five main geological sequences exposed in the area (Table 2.1), namely (1) the late Precambrian Malmesbury Group and associated intrusive Cambrian to Namibian Cape Granite Suite that crop out in deeply incised valleys and on plains west of the mountains, (2) the earlier Palaeozoic Cape Supergroup which covers almost 80 per cent of the map area, (3) the later Palaeozoic Karoo Sequence in the northeast, (4) the Mesozoic Enon Formation in the Worcester–Robertson Valley and (5) the late Cenozoic Bredasdorp Formation in the south, and other surficial deposits.

3. MALMESBURY GROUP

The Precambrian Malmesbury Group, of which the main exposures are situated west of the Worcester Sheet, was defined as such by Hartnady *et al.* (1974). The Malmesbury metasediments form part of the Saldania Subprovince which has been divided into the Tygerberg, Swartland and Boland terranes separated by major northwest-trending fault and shear zones (Fig. 3.1). The latter seem to extend southeastwards onto the Worcester Sheet, underneath cover rocks of the Table Mountain Group, so that pre-Cape exposures in erosional windows and valleys of Sheet 3319 are provisionally correlated with these terranes.

3.1 TYGERBERG TERRANE

The pre-Cape exposures east of Stanford and Baardskeerdersbos are correlated

Table 2.1 – GEOLOGICAL UNITS ON THE WORCESTER SHEET

Quaternary to Tertiary		Surficial deposits Bredasdorp Group
Jurassic		Uitenhage Group
Permian to Carboniferous	KAROO SEQUENCE	Ecca Group Dwyka Group
Devonian to Ordovician	CAPE SUPERGROUP	Witteberg Group Bokkeveld Group Table Mountain Group
Cambrian to Namibian		Klipheuwel Group
	CAPE GRANITE SUITE	Wellington Pluton Stellenbosch Pluton Hermanus Pluton Robertson Pluton Greyton Pluton Worcester granite Fragment/Pluton
Namibian		Malmesbury Group

with the Tygerberg Formation because they appear to lie southwest of the extension of the Saldanha–Franschhoek terrane boundary. The rocks are very poorly exposed and completely overprinted by very intense deformation of the Cape Orogeny (see later), so that correlations on lithological or structural grounds are extremely difficult. In fact, the deformation is so intense that it is often not even possible to distinguish between pre-Cape phyllites and tectonised shales of the Devonian Bokkeveld Group. This problem is illustrated by the fact that phyllites south and southeast of Viljoenshof, close to the southern extremity of the map, which were previously mapped as Malmesbury (Spies *et al.* 1963), are now thought to be Bokkeveld on grounds of their apparently normal stratigraphic relationship to the Rietvlei Formation in the Buffelsjagsberg (Malan 1985).

Exposures northeast of Baardskeerdersbos and south of the Salmonsdam Nature Reserve are undoubtedly Malmesbury as they are intruded by granite, e.g. on Zondags Kloof 672 and Toekoms 244. Correlation of the triangular exposure of phyllite on Paapjes Valey 679, southwest of the Zondags Kloof occurrence, is still in question. It apparently follows normally on the Rietvlei Formation to the south, but there is clear evidence of faulting in this area. Consequently, the highly tectonised phyllites are thought to be related rather to the adjoining exposure of Malmesbury to the northeast.

The Malmesbury rocks northeast of Baardskeerdersbos occur mainly as highly weathered, brown, yellow or reddish, sericitic to chloritic phyllites, with minor fine-

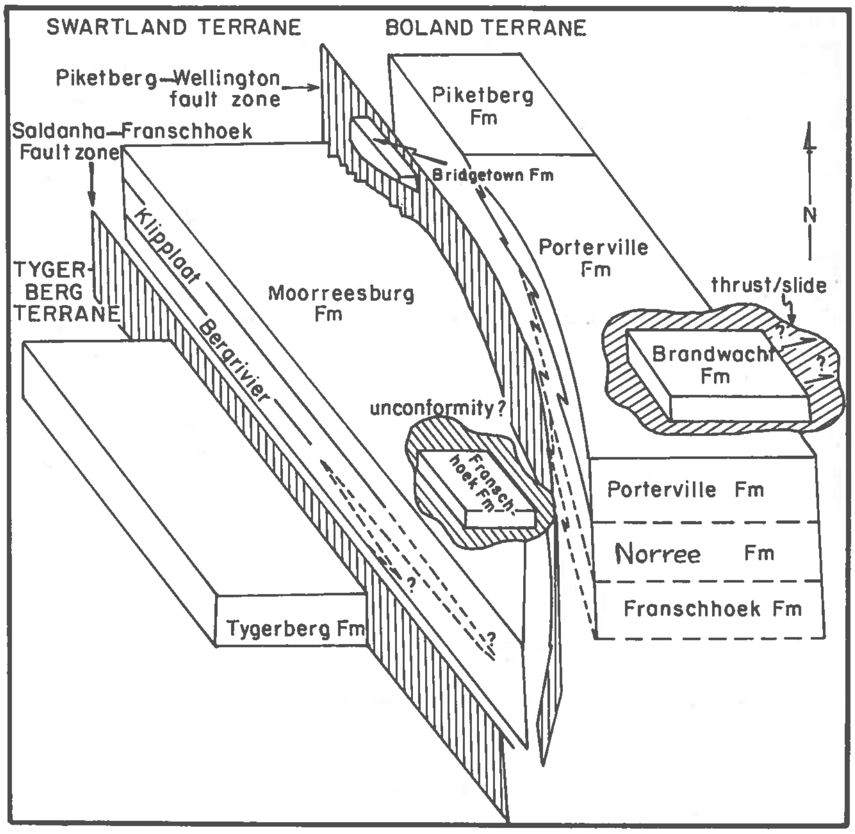

Fig. 3.1 - Schematic block diagram of probable spatial relationships between formations of the Malmesbury Group (adapted from Hartnady *et al.* 1974).

grained greywacke, in stream beds or road cuttings. The phyllites display at least two or three different cleavages, the two youngest of which appear to be related to the Cape Orogeny. Bedding is hardly ever preserved. In the contact aureole of granite intrusions the phyllites are hornfelsic and more resistant to weathering.

3.2 BOLAND TERRANE

The Saldanha–Franschhoek and Piketberg–Wellington Fault zones appear to converge towards the southeast (Fig. 3.1) and join somewhere in the region of Franschhoek (cf. Hartnady 1985, p. 11). This means that the Swartland terrane effectively wedges out in this direction and that the Boland and Tygerberg terranes should be juxtaposed farther southeast. This would further imply that the Franschhoek, Villiersdorp, Stettynskloof and Slanghoek areas also fall within the Boland terrane. De Villiers *et al.* (1964) apparently came to the same conclusion but they correlated all these pre-Cape exposures, including parts of the present-day Porterville Formation northeast of Wellington, with the "Klipheuvel Formation". These rocks do not resemble the Klipheuwel Group proper, which, to the west of the present map area, overlies the Porterville Formation unconformably at Heuningberg and southeast of De Hoek (Visser *et al.* 1981).

Five formations can be recognised in the Boland terrane, as defined here. They are the Porterville and Piketberg Formations in the Riebeek West–Piketberg region, the Franschhoek Formation in the Franschhoek–Villiersdorp–Riviersonderend region, the newly defined Norree Formation in the Robertson–Swellendam region and the Brandwacht Formation between Worcester and Robertson. The proposed relationships between the various formations in the Boland terrane are illustrated in Figure 3.2. One of the five formations mentioned, namely the Piketberg Formation, occurs to the northwest, beyond the limits of Sheet 3319.

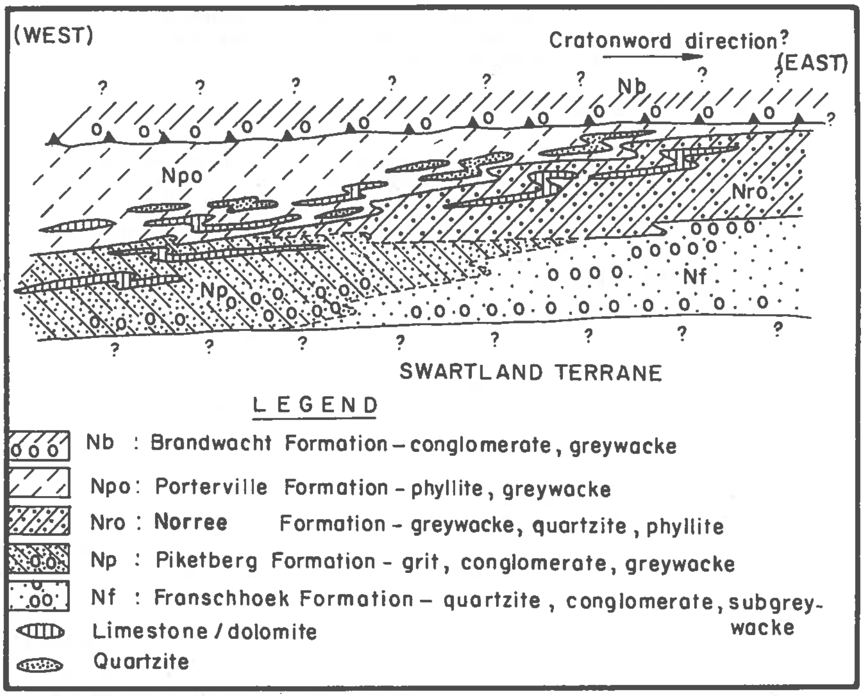

Fig. 3.2 - Proposed relationships between the formations of the Malmesbury Group in the Boland terrane.

Dunlevey (1984) provides evidence that the Robertson, Greyton–Riviersonderend and Swellendam Granite Plutons are diapiric intrusions in the Malmesbury metasediments. However, he incorrectly correlated the pre-Cape sediments, in the Worcester–Swellendam mountain foreland and at Greyton, with the Swartland terrane. It now transpires that it is in fact rocks of the Boland terrane into which granite plutons in these areas are intrusive – a fact hitherto not realised. Up until now the Boland terrane has been regarded as a "granite-free" metasedimentary sequence. The Franschhoek Formation itself is intruded by many quartz-porphyry dykes and bodies related to the late phase of Cape Granite intrusion (Dunlevey 1981). The Norree Formation is intruded by the Robertson and Swellendam Plutons (the latter to the east of the map area), and the Riviersonderend inlier by the Greyton Pluton. The age of these granites is of the same order as that of the Franschhoek and Saldanha quartz porphyries (Burger and Walraven 1976). There are no known granite intrusions in the Boland terrane west of Worcester, other than a quartz-porphyry dyke northeast of Botha Siding (De Villiers *et al.* 1964). However, there are unpublished reports – based on drilling results of mining companies – of granite intrusions in the western part of the Boland terrane, north of Piketberg, on Sheet 3218 Clanwilliam.

One notable unifying feature of the entire Boland terrane as defined here, is widely distributed greenstone dykes, sills and plugs, as well as slightly younger dolerite dykes (Chapter 3.2.5). Although there are also greenstones and lavas in the Swartland and Tygerberg terranes, they are much more localised in their distribution and, probably, also older than most of the Boland terrane greenstones.

3.2.1 Franschhoek Formation

The Franschhoek Formation was originally defined in the Franschhoek Valley, extending thence northwestwards into the Agter Paarl region, beyond the limits of the present map. There is, however, good reason for including certain other pre-Cape inliers, namely those at Kaaimansgat (Villiersdorp), Wemmershoek, Stettynskloof and Riviersonderend, in the Franschhoek Formation. These occurrences all comprise massive-looking quartzite, conglomerate, slate and phyllite. The quartzite is either grey or brown when fresh, weathering into lighter colour, whereas the conglomerate and slate tend to be either green, reddish or purplish when fresh. Some of the quartzites have been described as "subgreywacke" (De Villiers *et al.* 1964), consisting of angular, unsorted quartz grains in a fine-grained sericitic matrix. Other quartzites are white, coarse to very coarse feldspathic rocks. The conglomerate is polymictic and consists of pebbles, cobbles and boulders – up to 30 cm in diameter – of quartz, various metasedimentary rock types, quartz porphyry, lava and hornfels. Due to deformation these rocks are usually strongly folded and cleaved, and pebbles are distinctly oriented and elongated.

Some earlier investigators propagated a possible pre-Franschhoek basement in the Franschhoek Valley. Hartnady (1969) remarked on the sheared and brecciated nature of the gneissic granite underlying Franschhoek conglomerates south of Franschhoek. He suggested that this granite, like the sheared granite thrust over the Brandwacht Formation at Worcester and perhaps even the peripherally sheared "Robertson Granite", could represent pre-Malmesbury granitoids. Dunlevey (1983) also advocated a pre-Malmesbury basement at Franschhoek on grounds of a "sedimentary contact" recognised in a section of core. However, considering the intense deformation observed everywhere in the Franschhoek (Hartnady 1969) and also in the "sediments" in contact with the granite in the core section mentioned, it is very doubtful that it represents a normal, undisturbed sedimentary contact.

3.2.2 Norree Formation*

The Norree Formation is a newly defined stratigraphic unit in the Boland terrane. It occurs in the area between Nuy and Swellendam, between the Table Mountain Group outcrops in the north and the Worcester Fault in the south. Although the name is used here for the first time, rocks of this Formation have previously been mapped by various geologists including De Bruyn *et al.* (1974), Toogood (1976) and, partly, also Hartnady (1969).

The Norree Formation consists of phyllite, medium-grained to gritty greywacke, feldspathic and sericitic quartzite, limestone, dolomite, and felspathic and calcareous grit. With the exception of the calcareous rocks, it closely resembles the lithologies of the Franschhoek Formation. Furthermore, excluding the more massive quartzitic horizons, the Norree Formation also bears a certain resemblance to the Piketberg Formation, which occurs to the northwest of the present map area. It is therefore tentatively suggested that the three formations may have a facies relationship as depicted in Figure 3.2. There appears to be a transition zone, containing an intercalated quartzitic and calcareous facies, between the Porterville pelites and the underlying Norree and Piketberg Formations. The calcareous-quartzitic Norree Formation could represent a near-shore, littoral facies which grades into a calcareous-pelitic, deeper-water (shelf) facies towards the south.

In the region between the Hex River and Noree, west of Robertson, greywackes and phyllites underlying the Brandwacht Formation, formerly called the "Glen Heatlie Formation" by Hartnady (1969) and included in an undifferentiated Malmesbury sequence by Toogood (1976), are now regarded as forming part of the Norree Formation. Quartzitic and calcareous horizons appear to interfinger with the greywacke and phyllite in the Noree–Vink area (De Bruyn *et al.* 1974; Toogood 1976). Quartzites at Waaihoek, Mitchell's Pass, Botha Siding and in Slanghoek, between Worcester and Wolseley, seem to underlie the Porterville pelites and wackes and are also included in the Norree Formation. A sequence of rocks cropping out between Gouda and Wellington, west of the Elandskloof and Limiet Mountains, contain many quartzitic horizons resembling those at Waaihoek, and they are therefore also tentatively regarded as part of the Norree Formation. These rocks were previously named "Vogelvlei greywacke and quartzite" by Rabie (1974), but Visser *et al.* (1981) failed to distinguish them from the rest of the Porterville Formation. Also included in this succession is the concordant Voëlvlei greenstone body, a highly altered volcanic rock consisting of chlorite, quartz, calcite, saussuritised feldspar, actinolite, apatite and iron-oxides. These rocks, as well as all those mentioned in the Worcester–Wolseley area, were previously correlated with Franschhoek rocks by De Villiers *et al.* (1964), but under the name of the Klipheuwel Formation.

Clearly there are good reasons to distinguish these rocks from the rest of the Porterville Formation, but whether they can, in fact, be correlated with the Franschhoek Formation still needs to be ascertained. Once again, it appears highly likely that the Franschhoek, Piketberg and Norree Formations are facies of the same succession (Fig. 3.2).

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* Not yet approved by SACS

A problem was also encountered in classifying the Greyton–Riviersonderend inlier of pre-Cape rocks, which are presently included with the Franschhoek Formation because of the absence of calcareous rocks. However, the association of greywacke, quartzite and pelites, intruded by granite, is almost identical to the Robertson and Swellendam occurrences.

3.2.3 Porterville Formation

The Porterville Formation is only found in the northwestern corner of the map, north of Saron and northwest of Wellington, as well as in the Tulbagh Valley as far south as Botha Siding. It consists predominantly of phyllitic shale and fine- to medium-grained greywacke. The unit displays a rapid alteration of the two main lithologies, giving it a characteristic banded appearance. There is, however, no grading, but cross-lamination has been preserved in a number of places where cleavage development is less intense, as for example at Artois, between Tulbagh and Wolseley. The Porterville shales are generally bluish grey to black when fresh, but weather to brown and buff colours. Sericite is developed in the phyllitic shale. The greywackes consist of quartz, albite, muscovite and microcline with about 50 per cent clay matrix.

3.2.4 Brandwacht Formation*

The Brandwacht Formation, defined by Hartnady (1969) in the area immediately north of Worcester, had already been recognised as a distinctive lithological unit in the early 1940s (De Bruyn *et al.* 1974). The broad band of conglomerate occurring in a syncline northwest of Noree and Vink (Toogood 1976) is here regarded as part of the Brandwacht Formation, following the work of De Bruyn *et al.* (1974). Hartnady (1969) found that the Brandwacht Formation of Worcester was also preserved in a synclinal structure, resting on older rocks with a basal conglomerate. This basal unit is up to 100 m thick and possibly represents a type of tectonic mélange associated with a major slide or thrust surface.

The Brandwacht Formation comprises a very distinct lithological association consisting of greywacke and pelite, with interbedded conglomerate and volcanics. The greywackes are greenish grey to dark grey when fresh but weather to a drab brown. They usually consist of angular quartz grains in a quartz-sericite-chlorite matrix. Graded bedding is characteristic and the greywackes range from ruditic through arenaceous to fine-grained shale varieties. The conglomerates form poorly sorted, irregular lenses and contain quartz, greywacke and slate clasts.

The metamorphosed Brewelskloof "Andesite Member" (Hartnady 1985) consists of a concordant greenstone body in the upper part of the Brandwacht Formation. This rock has variously been described as diorite (De Bruyn *et al.* 1974), biotite-eucrite (De Villiers *et al.* 1964) and metabasalt (Hartnady *et al.* 1974). Hoal (1978) called it a meta-andesite, and described extrusive textures and deformed amygdales.

3.2.5 Greenstones of the Boland terrane

Greenstones in the Boland terrane consist either of large concordant bodies,

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* Not yet approved by SACS

deformed with the enveloping rocks during pre-Cape tectonism, or of younger intrusive dykes, sills or plugs that were only affected by the Cape Orogeny. The two main concordant bodies are the ones at Voëlvlei and at Brewelskloof.

The Voëlvlei greenstone is about 5 km long and crops out along the western shores of the Voëlvlei Dam where it is in sharp contact with Robertson shale and phyllite. This greenstone was compared with the Bridgetown-type volcanics, northwest of the present map area, by Visser *et al.* (1981). It exhibits extensive calcification (Fig. 3.3), chertification, manganisation and ferruginisation, and these alteration products penetrate the surrounding shale to a distance of about 6 m. Pyroclastic textures may be present, but are difficult to recognise as a result of alteration and tectonism. The fresh rock is dark green to grey, and fine grained. Its original mineralogy has been obliterated and it presently consists of chlorite, quartz, calcite, saussuritised albitic feldspar, actinolite, apatite and iron-oxide minerals. An ophitic texture can still be recognised in places.

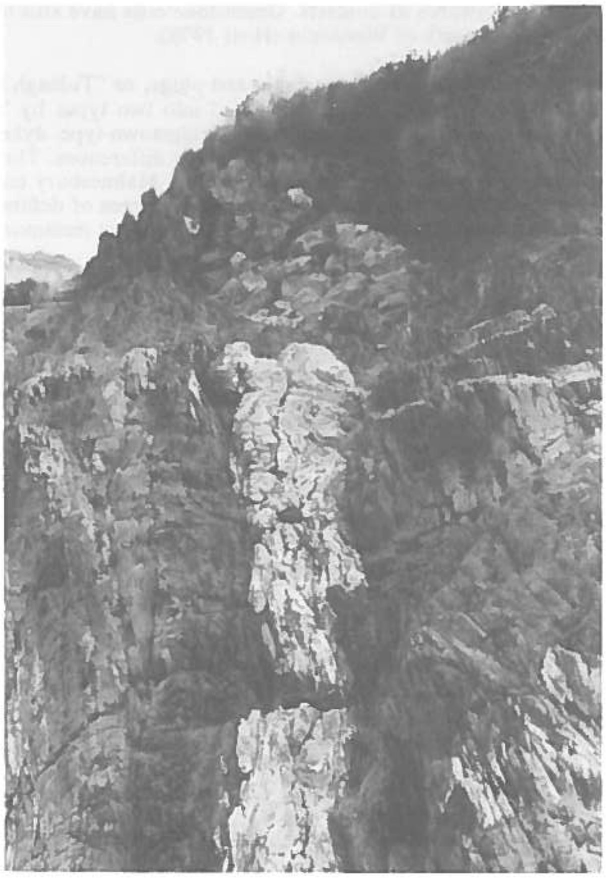

Fig. 3.3 - Pink, replacement carbonate lens in Voëlvlei greenstones.

The Brewelskloof greenstone is an early tectonic, intrusive or extrusive (Hoal 1978) concordant body in the upper Brandwacht Formation north of Worcester. The greenstone has been cleaved and deformed with the metasedimentary envelope and exhibits low-grade, greenschist-type metamorphism. Highly sheared rock consists mostly of chlorite, calcite, quartz and magnetite/ilmenite, but in porphyritic varieties biotite, plagioclase (An 70-96), altered pyroxene and apatite form the main constituents, with secondary minerals such as chlorite, magnetite/ilmenite, quartz, epidote, calcite, sericite and tremolite.

In the same vicinity the Brandwacht Formation contains many concordant dykes or sills related to the Brewelskloof "Andesite Member", as well as other rock types, regarded as quartz felsites by De Bruyn *et al.* (1974) and as possible dacitic tuff by Siegfried (1984). The latter consists of angular fragments of quartz and plagioclase in a sericitic matrix. Some of the altered fragments resemble shards. The rock weathers white and is obviously highly sheared. This prompted Hartnady (1969) to call it a mylonite, although Siegfried (1984) could still recognise a gradation from coarse to fine grained towards its contacts. Greenstone rafts have also been noted in the granitic thrust sheet north of Worcester (Hoal 1978).

The Tulbagh–Winterhoek greenstone dykes and plugs, or "Tulbagh Metadolerite Swarm" (Hartnady 1985), were originally divided into two types by Visser *et al.* (1981). They distinguished between deformed Bridgetown-type dykes and less-deformed Kleinvlei-type dykes, but there are no other differences. The dykes have concordant as well as cross-cutting relationships to the Malmesbury tectonic grain, but even the discordant ones have undergone varying degrees of deformation along strike. They also display chilled contacts, xenoliths and contact metamorphism of the host rock.

The greenstones are very similar to the ones already described and vary from fine- to coarse-grained and pyroclastic types. The fine-grained ones consist mostly of chlorite and altered feldspar. Coarser-grained, less-deformed varieties are composed of plagioclase, augite/pigeonite, hornblende, uralite, quartz, chlorite, apatite, calcite and iron-oxide minerals. Pipe-like bodies consist of tuff and lava with a prominent flow texture, and angular to rounded clasts of quartz and chert. Greenstone bodies between Robertson and Swellendam are correlated, by the present authors, with the Tulbagh–Winterhoek occurrence.

The Klapmuts–Franschhoek greenstones occur as dykes and plugs in the Franschhoek Formation and granites of the Stellenbosch Pluton (Siegfried 1985). Three dykes and two plugs occur on line between Klapmuts, Pniel and Keerwedernek, south of Franschhoek. One of these is 5 m wide and at least 200 m long. Their strike parallels the general northwesterly trend of major faults in the area. A single dyke occurs 7 km southeast of the Wemmershoek Dam and another plug is situated on Dwarsberg, 13 km south of Rawsonville. These rocks have been described as tuff, feldspathic rhyolite and amygdaloidal andesite by Truter (1949), while a gabbroic variety is also present. The greenstones are generally greenish grey and fine grained, and consist now mostly of chlorite, plagioclase, epidote and secondary silica.

3.3 DEPOSITIONAL ENVIRONMENT AND AGE

The stratigraphic relationships between the stratigraphic units of the three northwest-trending tectonic terranes of the Malmesbury Group (Fig. 3.1) are still unknown. It is not clear whether they represent the products of a single depositional system, or of separate depositional systems that were subsequently juxtaposed by lateral and/or vertical crustal movements.

The Tygerberg Formation is typified by regular alternations of shale, greywacke and impure quartzite with a few thin, impure limestone and conglomeratic beds. The flysch-type deposits are clearly of turbidite origin and accumulated either in a continent-rise/ocean-trench environment (Hartnady *et al.* 1974; Tankard *et al.* 1982), or as submarine fans at the foot of the continental slope in a tectonically active environment (Von Veh 1983).

Sediments of the Swartland terrane – not represented on the Worcester Sheet – have been likened to more proximal eugeosynclinal deposition by Tankard *et al.* (1982). Hartnady (1985) speculated on the possibility that sediment accretion and intense, localised polyphase deformation within a subduction complex was represented. In this scenario, the Swartland–Boland terrane boundary may represent a geosuture with the mafic volcanics of the Bridgetown Formation (Fig. 3.1) being disrupted relics of oceanic crust.

The highly variable succession of phyllite, greywacke, conglomerate, limestone, chert and arkosic sandstones of the Boland terrane has been compared to shallow marine-shelf deposition in a miogeoclinal setting (Hartnady 1985; Stump 1976) or submarine-fan sedimentation (Tankard *et al.* 1982). Tankard *et al.* (1982, p. 305) apparently considered the Franschhoek Formation, or part thereof, as belonging to the Boland terrane and thought that it had some similarities to braided fluvial sediments.

The general concept of Malmesbury sedimentation has always been one of a geosynclinal basin fringing the western and southern margins of the Kalahari Craton. The present correlation scheme (Fig. 3.2) is based on the possibility that the Franschhoek and Piketberg Formations are related and represent coarser, fluvio-marine sediments at the base of the Boland succession, deposited along a highly irregular, northeastward-transgressing coastline. The subarkosic to arkosic sandstones are thought to be derived from the crystalline basement to the northeast. The shelf- and shoreline-related sandstone–limestone gradational facies of the Piketberg and Norree Formations grade upwards into the deeper-water Porterville pelites and greywackes. The overlying Brandwacht Formation may represent deltaic sediments deposited during a subsequent regressive episode. Alternatively it could be an allochthonous, tectonically emplaced wedge of an adjoining terrane (Hartnady 1969, 1985). A better understanding of the age and nature of the Brewelskloof andesites will perhaps shed new light on the nature and origin of the Brandwacht Formation.

The age of the Malmesbury Group, or of the various terranes of the Saldania Subprovince, is still highly speculative. Likely it is related to the Gariep Sequence which overlies basement gneiss unconformably in southern Namaqualand. The age of the basement, 1 000–1 200 Ma (Burger and Coertze 1973; Clifford *et al.* 1975), places an upper limit on the age of the Malmesbury, while the age of the intrusive Cape Granite Suite, ±630–500 Ma (Schoch and Burger 1976; Burger and Walraven 1976), can be regarded as a lower limit.

4. KLIPHEUWEL GROUP

The name "Klipheuwel Beds" was first used by Haughton (1933), who assigned it to a succession of sedimentary rocks in the western Cape that is younger than the

Malmesbury Group and older than the Cape Supergroup. Although the Klipheuwel and Table Mountain successions are conformable in places, they are separated by an unconformity on a regional scale (Visser 1967). De Villiers *et al.* (1964) correlated most of the pre-Cape outcrops in the Worcester, Tulbagh and Slanghoek Valleys, and west of the Limiet Mountains, north of Wellington, with the "Klipheuwel Formation". Most of these exposures are now thought to belong to the Porterville and Norree Formations.

Only one small outcrop of reddish conglomerate at the northern end of the Slanghoek Valley, west of the road on Witte Else Boom 214, is now still regarded as proper Klipheuwel. The conglomerate is very poorly sorted and contains clasts of quartzite, vein quartz and purple shale. The quartzite clasts are rounded to subrounded and up to 15 cm in diameter, but the quartz and shale clasts are angular to flaky. It is a clast-supported conglomerate with only a small proportion of gritty matrix.

Similar outcrops of red to purple conglomerate, sandstone and shale are found at Riebeek West and Heuningberg, some 30 to 50 km northwest of Slanghoek on the Cape Town Sheet. The conglomerates at Slanghoek and Heuningberg are almost identical and are assigned to the Magrug Formation of the Klipheuwel Group.

The Klipheuwel Group is thought to have been deposited as alluvial-fan and lacustrine deposits during block faulting or rifting at the end of the pre-Cape (late Pan-African) orogenesis (Tankard *et al.* 1982).

5. CAPE SUPERGROUP

The three groups of the Cape Supergroup (Table 2.1) are fully represented. They cover large portions of the map area where, due to the generally rugged relief, good exposures are found. One exception is the basal contact of the Supergroup which is often covered beneath scree and/or soil. The best exposures of the marked unconformity between the Cape Supergroup and the highly deformed Malmesbury Group occur at Klein Winterhoek, Sneeugat and Bellevue Peak, north of Tulbagh, along the slopes of the Waaihoek Mountains and at the entrance to Hexrivierpoort on New Glen Heatlie 183. The unconformity between the Cape Supergroup and the Cape Granite is clearly visible at the foot of Witteberg near the hotel in the Du Toitskloof Pass, along the mountain slopes northeast of Wemmershoek Dam and in the Langeberg Range north of Robertson.

5.1 TABLE MOUNTAIN GROUP

5.1.1 Piekenierskloof Formation

In its type area to the northwest of the Worcester Sheet the Piekenierskloof Formation, which occurs at the base of the Table Mountain Group, is typically conglomeratic. Rocks that could be assigned to this unit are only sporadically developed in the northwesternmost portion of the present map area. In most instances these basal rocks consist of medium- to coarse-grained, thick orthosandstone beds with thin, intercalated, gritty (vein quartz) and purplish shale layers. Rudites do become more prominent in the Slanghoek area, west of Worcester, probably reflecting a local basement high. Here, on farms like De Hoek 399 and Slanghoeksberg 409, coarse polymictic conglomerate with rather angular clasts of quartzite, quartz porphyry, chert, and pelite fragments of Malmesbury derivation, is found. Although its thickness exceeds 50 m in places, it is not shown on the map because of its limited outcrop width, due to steep topography.

5.1.2 Graafwater Formation

This Formation has transitional boundaries with both the underlying Piekenierskloof Formation, where developed, and the overlying Peninsula Formation. It comprises purplish to reddish, thin-bedded sandstone, siltstone and mudstone, characterised by ripple marks, mud cracks, bioturbation and trace fossils (Fig. 5.1). At Porterville the Graafwater Formation just exceeds 100 m but there is an overall lateral facies change southwards. At the entrance to the Vier-en-twintigriviere ravine, on Drie Das Bosch 18, the lower mudstone–siltstone sequence has thinned markedly and farther south, along the Limiet Mountains on Palmiet Valley 54, the Graafwater Formation totals a mere 25 m. The unit is also recognisable in the Groot Winterhoek Mountains and just south of Mitchell's Pass on Ons Rus (Tul. Q. 3.37 294). The thinning of the Formation and its intermittent exposure constrain its accurate delineation – on this scale – along the slopes of the Witzenberg Range. At Waaihoek (Zeebas Bosch 192), northwest of Worcester, lenticular purple-red siltstone and mudstone units wedge out against pre-Graafwater topography (Rust 1967).

Fig. 5.1 - Desiccation cracks in the Graafwater Formation on Voorberg, Porterville.

Thin, lenticular reddish siltstone and mudstone, some with organic traces, mud cracks and ripple marks, occur intermittently within the lowermost white orthosandstone beds of the Peninsula Formation in the mountain ranges near Franschhoek, but not in the Du Toitskloof and Stettynskloof Mountains.

5.1.3 Peninsula Formation

The Peninsula Formation consists of predominantly planar-bedded, light-grey, coarse-grained quartzitic sandstone, with occasional thin layers or stringers of vein-quartz pebbles, particularly towards its base and top (Fig. 5.2). From Du Toitskloof northwards black and white chert pebbles become more frequent (Rust 1967).

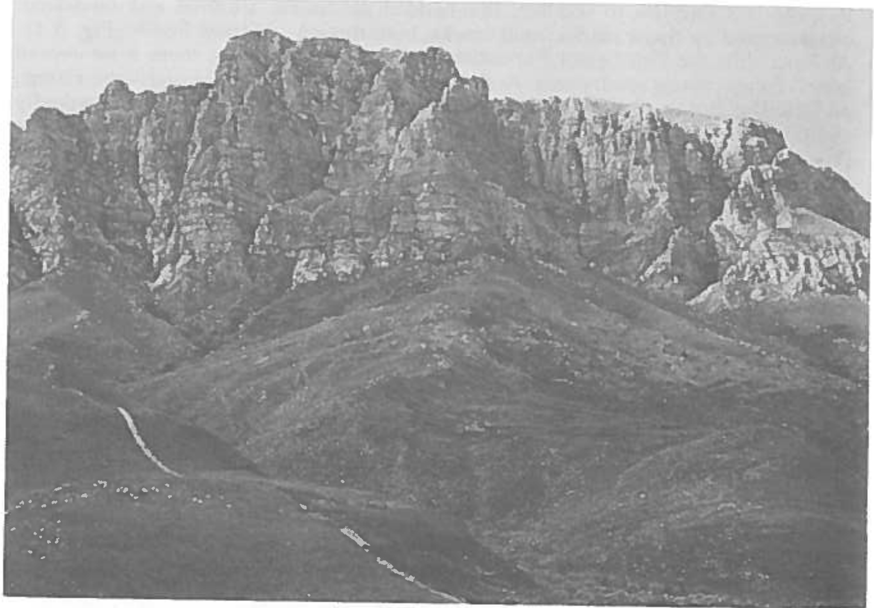

Fig. 5.2 - Thickly bedded, coarse-grained quartzitic sandstone of the Peninsula Formation in Du Toitskloof resting unconformably on granite.

Although feldspar occurs throughout, it is rather inconspicuous. The succession is generally thickly bedded with isolated bioturbated zones, biogenic trails and rare arthropod traces. Large-scale tabular cross-bedding becomes prominent in places, for example along the coast at Hermanus, especially near the New Harbour. Occasional shale and siltstone beds, up to 1 m thick, also occur. The Formation varies from a maximum thickness of approximately 2 000 m in the north to 900 m in the south.

The upper contact of the Peninsula Formation varies from a normal, sharp, concordant contact to a gradational one. Its uppermost beds occasionally display a zone of complex intraformational folds, the "Fold Zone", which may extend for more than 100 m into the Peninsula Formation.

5.1.4 Pakhuis Formation

The Pakhuis Formation in this area comprises three members which are not distinguished on the map. The close relationship between the underlying "Fold Zone" and the occurrence of the basal Sneeukop Member of the Pakhuis Formation necessitates its description here. In the map area the soft-sediment deformation associated with the "Fold Zone" seems to diminish gradually towards the southeast. Its morphology and origin have been extensively discussed by Haughton *et al.* (1925), Rust (1967, 1981) and Blignault (1981). Ubiquitous characteristics, well displayed at Gevonden 522 (Rawsonville), Slanghoek Peak, Franschhoek Pass and Groot Hoek 70 (De Doorns), are sharp, narrow, cuspate anticlinal folds alternating with broad-bottomed synclines with near-vertical or even overfolded flanks (Fig. 5.3). The resultant canoe-shaped structures attain maximum dimensions of 200 to 300 m across and have their long axes oriented mainly north–south.

Fig. 5.3 - Narrow, cuspate anticlinal folds separated by broad-bottomed synclines in the fold zone, Pakhuis Formation on Limietberge, Bainskloof.

Diamictite of the Sneeukop Member, a lithic quartz arenite with abundant faceted and striated erratics, is restricted to the synclines of the "Fold Zone"' and therefore has a most irregular distribution and thickness. The diamictite, which is rather structureless and weathers reddish brown, rarely exceeds 70 m in thickness. Erratics vary considerably in size and consist mainly of quartzite and other resistant sedimentary and metamorphic rock types such as chert, black siltstone, blue and white vein quartz, and rare jasper and chalcedony. Evidently these clasts underwent pre-glacial rounding. Accessible, well-exposed outcrops occur in Franschhoek Pass, Mitchell's Pass and on De Molen Rivier 294, some 25 km north of Ceres. Clastic dykes (Blignault 1981) and patterned ground (Daily and Cooper 1976; Hobday and Tankard 1978) have also been described from this unit.

Both the "Fold Zone" and the "enclosed" diamictite of the Sneeukop Member were very conspicuously truncated by a phase of intraformational erosion. This was followed by local redeposition of water-sorted sediments – the Oskop Member – at, amongst others, Wellington Sneeukop, Slanghoek Peak, Wemmershoek Forest Reserve and in the Franschhoek and Hex River Mountains. This orthosandstone unit is usually indistinctly or thickly bedded and lenticular in habit. It contains conglomerate lenses within upward-coarsening cycles. The upper surface of the sandstone of the Oskop Member is frequently marked by current ripples with variable flow directions and, north of the map area, by glacial striae (Rust 1967, 1981).

The Oskop Member is conformably overlain by a thin, dark bluish-green, poorly bedded quartzose diamictite, the Steenbras Member, seldomly more than a few metres thick. The latter also contains striated and faceted erratics, mostly of quartzite and vein quartz, but also some less-resistant types. The Steenbras diamictite differs from the Sneeukop diamictite in being darker coloured, and in having a greater percentage of clay matrix and a smaller proportion of erratics.

The rarely exposed upper contact of the Pakhuis Formation is probably gradational into the overlying Cedarberg Formation. However, at Wellington Sneeukop, the Kweekkraal Mountains – north of Villiersdorp – and in the Hex River Mountains – north of De Doorns – the contact is sharp.

5.1.5 Cedarberg Formation

The smoothly weathered slopes which characterise this Formation make it an outstanding marker horizon amidst the otherwise rugged-weathering Table Mountain Group (Fig. 5.4). However, good accessible outcrops of Cedarberg shale are rare. The Formation consists of two members – not distinguished on the map – namely the thinly laminated, micaceous Soom Shale Member at the base, overlain by the Disa Siltstone Member which constitutes the larger portion of the Formation. Pyrite occurs in both units.

The Soom Shale is well exposed at Langvlei in the Voorberg, just east of Porterville, where it attains a thickness of some 12 m. It thins southwards, as is evident in Michell's Pass, at Gevonden 522 (Rawsonville), Kweekkraal Mountains – north of Villiersdorp – and in the Hex River Range (Buffelshoek and Groothoek Peaks). The bluish-black shale weathers to ash-white, finely laminated, friable clay. Near Buffelshoek Peak it contains the trilobite *Mucronaspis olini* and incomplete mollusc specimens (Moore and Marchant 1981; Cocks and Fortey 1986). This mucronaspidine trilobite is generally considered characteristic of a late Ashgillian, uppermost Ordovician age. An orthosandstone bed, the "Hard Band", which occurs in the Soom Member in the Slanghoek and Limiet Mountains, is prominently displayed at Wellington Sneeukop, where it is 6 m thick.

Good exposures of the Disa Member occur more commonly than those of the underlying Soom Shale. The Disa Member evidently thickens eastwards (Rust 1967). In the Franschhoek Pass it attains 75 m and in the Voorberg, east of Porterville, 70 m. At the latter locality the Disa Member consists of a basal thin-bedded siltstone overlain by more massively bedded, bioturbated, fossiliferous siltstone and mudstone, followed by fine-grained, dark-grey sandstone in which the bed thickness increases upwards from 15 cm at the base to 30 cm at the top (Rust 1967). The fossiliferous zone contains a brachiopod assemblage of which the overall generic aspect is that of the Hirnantia fauna which is widespread in the latest Ordovician throughout the world

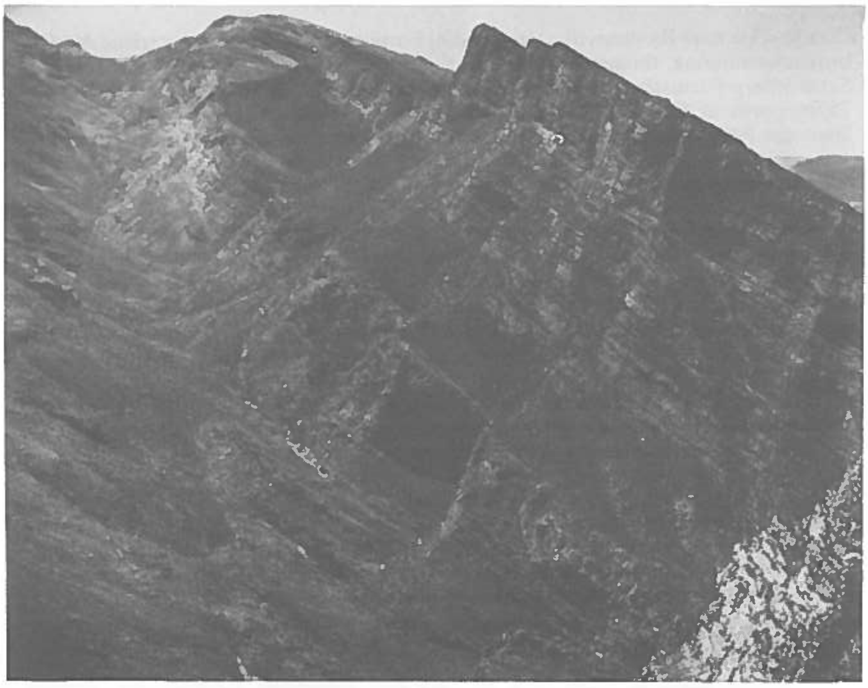

Fig. 5.4 - Smooth, grass-covered slope constituted by the Cedarberg Formation in the Hexrivier Mountains. The overlying cliff is built by the Goudini and Skurweberg Formations. Note the fold zone in the upper portion of the Peninsula Formation, just below the Cedarberg shales.

(Cocks and Fortey 1986). This zone has also been identified southwards in the Witzenberg Range and at Wellington Sneeukop.

The Disa Member frequently displays ripple marks, load casts, biogenic tubes and trails, and small-scale trough cross-bedding. It generally coarsens upwards and has a gradational contact with the overlying Goudini Formation. Roadside excavations in the Groenland Mountains, 2 km southeast of Mount Lebanon, display thin pyritic layers.

5.1.6 Goudini Formation

The basal contact of this Formation is usually taken at the first more-prominent, light-coloured, medium-grained quartzitic sandstones with bed thicknesses of 0,5 m or more. Thin reddish-weathering, micaceous siltstone beds are interbedded throughout. Conspicuous bluish-grey siltstones with biogenic trails are present near its top. Ripple marks occur sparingly and can be seen below the Nuweberg Dam in Viljoens Pass, north of Grabouw.

At its type section (Malan *et al.* 1989) on Kliphout Kloof 411, just south of

Goudini Spa near Rawsonville, the Goudini Formation displays characteristic reddish-brown weathering, thinner bedding and finer grain size compared with the overlying Skurweberg Formation. It varies in thickness from 115 m in the type area to about 75 m north of Ceres – at De Molen Rivier 294 and at Horingbekkloof east of Sneeugat Peak – and less than 30 m in Franschhoek Pass (Rust 1967).

5.1.7 Skurweberg Formation

Seen megascopically, this Formation is the culmination of an overall upward-coarsening cycle that progressed from Cedarberg, through Goudini, to Skurweberg deposition (Fig. 5.4). The thick-bedded, coarse-grained, light-grey quartzitic sandstone of the Skurweberg Formation is well displayed and easily accessible at its type section in Michell's Pass near Ceres (Theron *et al.* 1989). Bedding thickness is normally 0,5 to 0,8 m, but there is a gradual increase northwards. Both planar and trough cross-bedding occur profusely, the former variety predominating. Bedding surfaces are only infrequently rippled and biogenic trails occur sparingly as well. Thicker sandstone beds are often separated by erosive contacts and thin stringers or lenticles of white vein-quartz pebbles are occasionally found.

The Formation generally weathers positively and builds most of the major mountain peaks of the Skurweberg and Hex River Ranges (Fig. 5.5). It ranges in thickness from 206 m in its type area near Ceres to 400 m in the Soetmuis Mountains south of Napier. The upper boundary is drawn at the base of the first feldspathic, finer-grained, thinner-bedded quartzose sandstone bed of the Rietvlei Formation.

Fig. 5.5 - Grotesque weathering features of the Skurweberg Formation, north of Ceres.

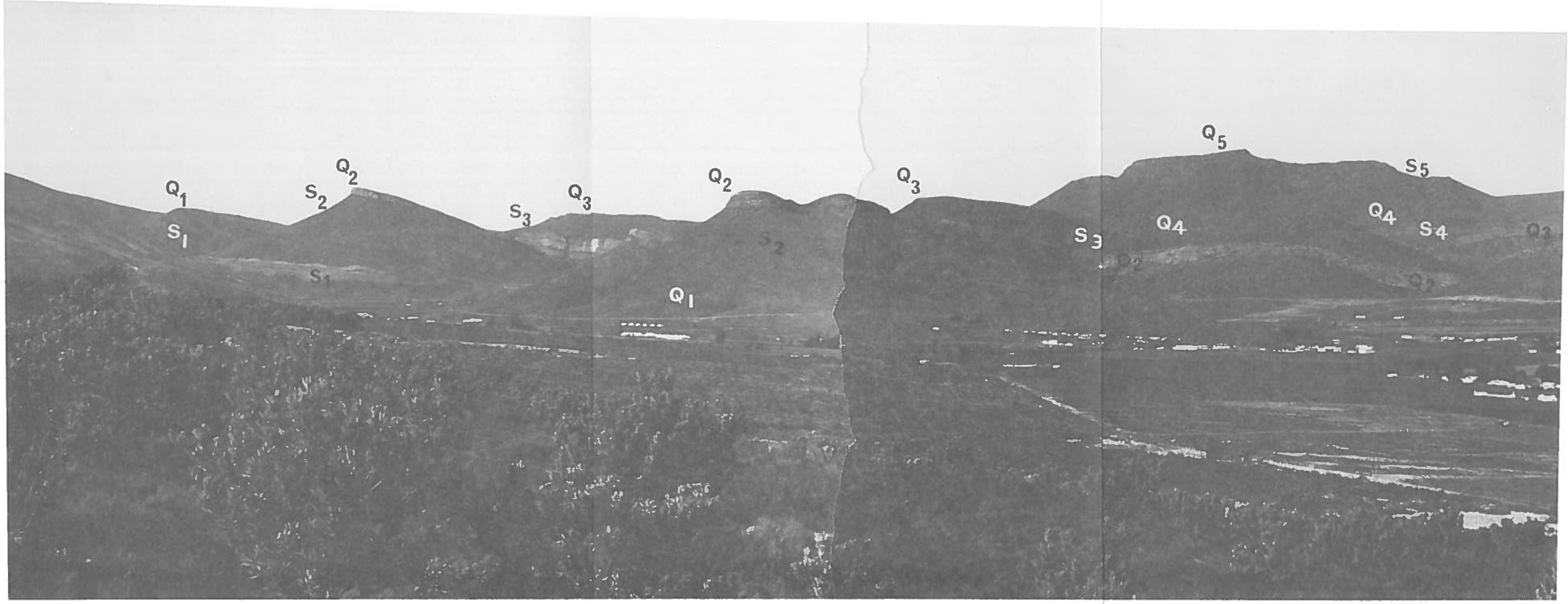

Fig. 5.6 - Typical megacycles of the Bokkeveld Group in the Hex River Valley consisting of five prominent weathering arenitic formations, alternating with pelitic formations. In the foreground the Rietvlei Formation is exposed. Gydo Formation - S1; Gamka Formation - Q1; Voorstehoek Formation - S2; Hex River Formation - Q2; Tra-Tra Formation - S3; Boplaas Formation - Q3; Waboomberg Formation - S4; Wuppertal Formation - Q4; Klipbokkop Formation - S5; Osberg Formation - Q5.

5.1.8 Rietvlei Formation

The Rietvlei Formation consists of alternating light-grey quartzose sandstone, feldspathic sandstone and some shale. Bedding thickness varies – ranging from 20–30 cm – but is generally considerably less than that of the Skurweberg Formation. It is topographically more subdued at outcrop as well. Although planar cross-bedding also occurs, this Formation is more typically trough cross-bedded. Current ripples occur sparingly throughout and thin pebbly lenses are occasionally present. The pebbles, from 5 to 10 mm in diameter, consist mainly of white or blue quartz, but black cherty shale is also present in places. At Mountain Lodge (Matroosberg 57) a 30-m-thick interbedded shale/siltstone zone occurs.

The boundary between the Rietvlei Formation and the Bokkeveld Group, as exposed in Gydo Pass (north of Ceres) and in the Hex River Pass, is transitional, comprising a 7-m alternation of dark- and light-grey sandstone, siltstone and shale beds. Elsewhere it is relatively sharp. The Formation averages 200 m in the Hex River Valley.

5.2 BOKKEVELD GROUP

The relatively subdued topography of the Bokkeveld Group, compared to the over- and underlying units, reflects its predominantly pelitic nature. Five arenitic formations, alternating with six pelitic formations, give rise to hogback topography. The Warm and Cold Bokkeveld, around Ceres and the Hex River Valley, are the classical areas where the Bokkeveld Group was first recognised (Fig. 5.6). In the area south of 34° its subdivision is not always feasible, due to the poor development of the arenitic units coupled with poor exposures and intense deformation.

5.2.1 Gydo Formation

This dark-grey to black shale, mudstone and siltstone unit, which forms the base of the Bokkeveld Group, is some 160 m thick in Gydo Pass, north of Ceres. It displays gradual upward coarsening, with siltstone and fine-grained sandstone layers progressively increasing in the upper half. Black, cherty mudstone nodules – often fossiliferous – and calcareous, yellow-brown-weathering nodules and lenses are scattered throughout. Fresh road cuts reveal scattered pyrite crystals, thin layers of pyrite and calcite, and a wide variety of invertebrate fossils (Reed 1925; Theron 1972; Oosthuizen 1984), especially in the lower carbonate-bearing shales (Fig. 5.7). Fossils occur either singly or in thin coquina-like lenses. Extensive bioturbation is present in places and micro cross-lamination often occurs in the more silty units.

5.2.2 Gamka Formation

The dark-grey, fine- to medium-grained, rather lithic to feldspathic sandstones and siltstones of the Gamka Formation follow conformably on the Gydo shale–siltstone sequence and, together with the latter, represent an overall upward-coarsening cycle. Thin subsidiary shale and intraformational conglomerate beds also occur in this unit. Bed thickness averages 25 cm, with some beds attaining as much as 1 m. Low-angle tabular cross-bedding is fairly common, and silty layers display micro cross-lamination. Current and wave ripple marks are usually common in the uppermost beds. A characteristic feature of these sandstones is the thin, reddish-brown crust which the rock acquires on weathering.

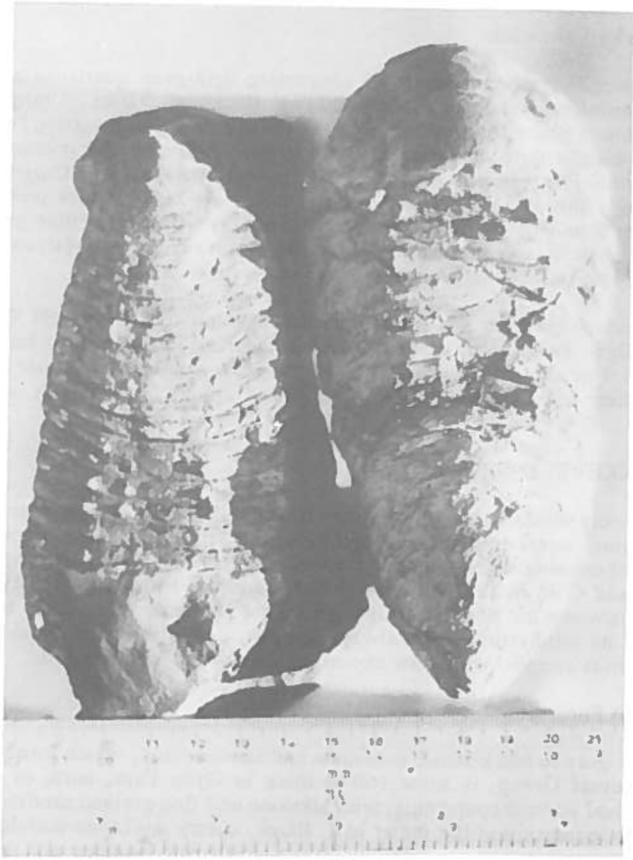

Fig. 5.7 - Internal moulds of *Burmeisteria herscheli* (Murchison) from the Gydo Formation, Buffelskraal (Hex River Valley) and Gydo Pass (Ceres).

Lenses rich in fossils or scattered individual impressions of fossils occur in this unit. Concentrations of prominently ribbed spiriferids, such as *Australospirifer antarcticus*, are typical for these sandstones (Fig. 5.8).

In the area around Ceres the Formation is 70 m thick, but in the Hex River Valley it barely attains 30 m. In the latter instance it is composed of two to three thick-bedded, dark-grey sandy units, sandwiched between an alternation of silty and sandy shale. The lower half tends to be more fossiliferous.

South of Matroosberg Siding, on the farms Helpmekaar 148 and Oudekraal 145, ball-and-pillow structures are present in the alternating beds of cherty mudstone, siltstone and sandstone. Whether this is the result of loading or slumping is uncertain.

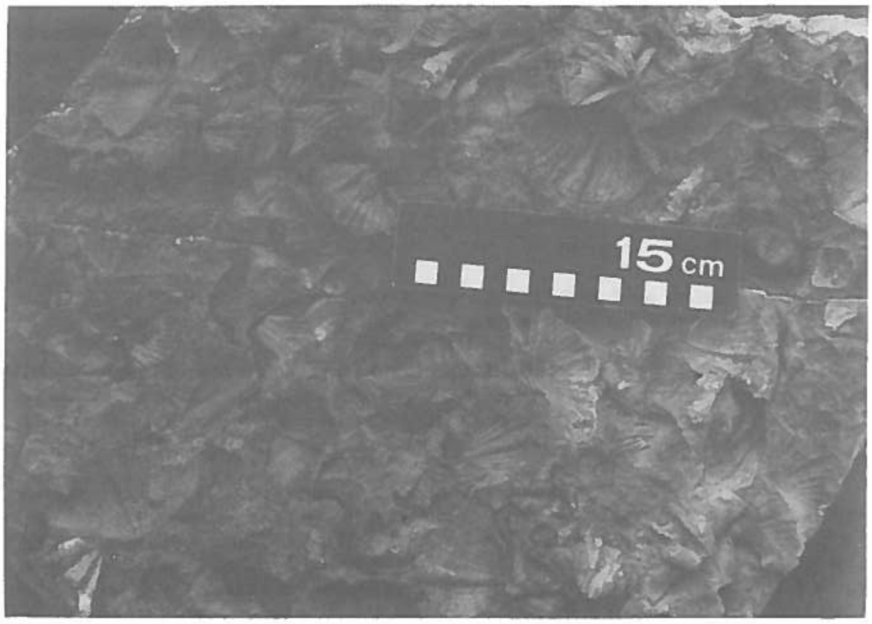

Fig. 5.8 - *Australospirifer antarcticus* (Morris and Sharpe) coquina layer from the Gamka Formation, typical of the Cold Bokkeveld and Hex River Valley.

There is a progressive attenuation of the Gamka Formation south- and eastwards, and a decrease in sandstone grain size. The unit is barely 20 m thick south of the Ouhangsberge (Worcester District), 15 m near McGregor, and even less south of Caledon. In addition to parallel and low-angle cross-bedding these southerly outcrops display graded bedding and slumping.

South of the Ouhangsberge the typical fossils, e.g. spiriferids and crinoid stems, are still recognisable in the Gamka Formation, but south of Caledon this is no longer the case -- the sequence as a whole seems to become less fossiliferous towards the south. There is also a marked intensification of cleavage in this direction.

5.2.3 Voorstehoek Formation

Following concordantly on the Gamka sandstone beds the lower half of the Voorstehoek Formation consists predominantly of dark-grey mudstone and shale with thin calcareous lenses, whereas siltstone and shale predominate in the upper portion. Thin, micaceous, fine-grained, cross-bedded sandstone horizons are also common in the Voorstehoek/Gamka transitional zone. A few persistent sandy horizons, less than a metre thick, also occur higher up in the sequence. These red-weathering sandstone horizons are characterised by wave, current and interference ripple marks, ripple cross-lamination, bioturbation and trace fossils.

A wide variety of fossils are present, particularly in the lower half of the Voorstehoek Formation. They occur singly or prolifically in lenses a few centimetre thick, as can be seen in the road cuttings of Hex River Pass and Gydo Pass. Often one or two Brachiopod varieties predominate, for example south of the Ouhangsberge (northeast of Villiersdorp), where a 1-cm-thick spirifer-rich lens 30 m from the upper contact of the Formation has a lateral extent of more than 100 m. Similar crinoid-rich lenses, in which stems and segments are scattered haphazardly, occur quite commonly, as on Loopende Rivier 33 in the Montagu District and Ezelsfontein 384, Zwaar Mond 387 and Leeuwen Fontein 361 in the Ceres District. The Formation varies in thickness from 200 m in the Cold Bokkeveld (Hex River Valley area) to approximately 300 m south of Caledon, towards Napier.

5.2.4 Hex River Formation

This Formation is 55 m thick at the type section on Kransfontein 610, 8 km east of De Doorns, and builds a prominent series of reddish-brown-weathering cliffs along the eastern margin of the Hex River Valley (Fig. 5.6). It consists mainly of light-grey, medium- to fine-grained, feldspathic and micaceous, medium- to thick-bedded proto-sandstones overlying a dark-grey fine-grained wacke up to 15 m in thickness. Tabular and trough cross-bedding occur as well as current and wave ripple marks. A fairly consistent transport direction towards the south-southeast is indicated.

Stringers of grit and matrix-supported conglomerate occur in places. Angular to subrounded pebbles, up to 14 mm across, consist mainly of vein quartz, feldspar, shale and quartzite on Loopende Rivier 33, Montagu District. Intraformational conglomerate lenses, found sporadically, have discoidal shale clasts, with dimensions up to 14 x 6 cm, in a sandy matrix. Occasional thin siltstone beds display wavy and flaser bedding. Fossils are scarce. On Karbonaatjies Kraal 38, about 4 km north of Matroosberg Siding, brachiopods are found in the uppermost beds of the Formation. Single specimens occur erratically at other localities. Bioturbation is present intermittently; 3 km south of Matroosberg Siding *Skolithos* occur in road cuts on Helpmekaar A.

There is a marked reduction in the maturity and extent of development of sandstone units southwards. South of the Riviersonderend Range the upper and lower limits of the Hex River Formation are indistinct. Interbedded sandy shale beds become prominent and southeast of Caledon, e.g. on Weltevrede 489, Witvoetkraal 492 and Lange Kuil 525, the Formation, which is approximately 30 m thick here, can only be recognised by occasional thin (20 cm), quartzose sandstone beds. Towards Napier sandy shale attains even more prominence.

5.2.5 Tra-Tra Formation

This Formation, with a thickness that varies from 250 to 300 m, has a conformable and generally sharp contact with the underlying Hex River Formation. Dark-grey shale, mudstone and siltstone attain prominence directly above the latter. This is followed by a sandy mudstone and siltstone sequence with a number of thin (c. 6 m), but conspicuous and continuous, sandstone horizons. Quite coarse-grained sandstone lenses are present in these beds, for instance about 12 km north of Ceres on Koele Fontein 323, just east of the Doringbos homestead. The sandy nature of the upper portion of the Tra-Tra Formation often precludes a clear delineation of its upper contact with the Boplaas Formation. These two units also define an upward-coarsening megacycle.

Poorly preserved lycopod stems (Plumstead 1967), intense bioturbation, calcareous mudstone lenses and nodules, and wave and current ripple marks are common. In the

Hex River Valley crinoid stem segments (ossicles) occur near the railway tunnel, just west of Tunnel Siding, while spiriferid impressions and crinoid fragments are present on Loopende Rivier 33 and south of the Ouhangsberge, southwest of Worcester.

5.2.6 Boplaas Formation

The Boplaas Formation consists of grey, fine- to medium-grained, micaceous, feldspathic protosandstone. Around Ceres, in the Warm and Cold Bokkeveld, and De Doorns – where the best exposures occur – sandstones in the upper part of the Formation are generally better sorted, more mature and well bedded. The lower part of the Formation consists of micaceous, massively bedded, mottled sandstone with interbedded thin siltstone and sandy shale with flaser bedding, which have a gradational contact with the underlying Tra-Tra shales. Bedding thickness in the lower portion usually exceeds 30 cm, but decreases in the upper part. The basal portion furthermore displays extensive bioturbation, whereas the overlying sequence is characterised by plant fragments (Plumstead 1967) and a wide variety of trace fossils. Both planar and trough cross-bedding occur, as well as load casting, channelling and thin, intraformational conglomerate beds. Diversely oriented oscillation and current ripple marks, as well as primary current lineation, are present in the upper mature portion. Overall transport direction is towards the south-southeast.

The Boplaas Formation also reflects the general southward decrease in sand content of the Bokkeveld Group. Along the northern flank of the Riviersonderend Mountains the upper, relatively mature part separates into 3 evenly spaced, prominent, light-grey protosandstone units, each aboute 10 m thick, alternating with siltstone and sandy shale. Towards Napier these sandstone horizons become more inconspicuous and on Brakke Fontein 517 only fine-grained sandstone and sandy shales occur.

A fairly consistent thickness of 35 m in the Ceres/Hex River area changes to between 60 and 100 m south of the Riviersonderend Mountains towards Napier. However, in view of the gradational lower contact of the Formation, the latter values are rather uncertain.

5.2.7 Waboomberg Formation

This Formation conformably succeeds the Boplaas Formation and is about 200 m thick at the type section along the eastern flank of Waboomberg on Leeuwen Fontein 361, northeast of Ceres. It consists of dark-grey siltstone with immature sandstone and thin shale intercalations in the lower half, overlain by dark-grey carbonate-bearing shale and mudstone. Thin siltstone beds are again present near the top of the Formation. The best exposures of the Formation are in road cuttings of Theronsberg Pass. Southwards the Formation thickens slightly.

The more silty units display bioturbation, small-scale cross-laminated scour-and-fill structures, oscillation ripple marks, and nodules and lenses of cherty mudstone. The upper mudstone/ shale portion is markedly fossiliferous. Although a wide variety of fossils occur, mollusc species predominate. The dominant trilobite species is *Metacryphaeus venustus* (Theron 1972; Cooper 1982).

5.2.8 Wuppertal Formation

This Formation, together with the underlying Waboomberg Formation, once again represents an upward-coarsening megacycle. The Wuppertal Formation is 26 m thick in the Cold Bokkeveld and consists of upper and basal sequences of well-indurated, grey, fine- to medium-grained protosandstone, separated by interbedded dark-grey siltstone, shale and immature micaceous sandstone. The best outcrops are on Koele Fontein 323 and Elandsrivier 366, northeast of Prince Alfred Hamlet. Southwards the lower sandy unit gradually becomes finer grained and thins towards the Hex River Valley, eventually losing its identity and becoming part of the underlying pelitic formation. Trace fossils, bioturbation, intraformational conglomerate lenses, interference, oscillation and current ripple marks, pit-and-mound structures, and planar and trough cross-bedding occur. At Tunnel Siding, 10 km northeast of De Doorns, the uppermost bedding plane of the Wuppertal Formation has extensive winding channels and other irregularities, probably caused by mutual interference of gully systems on tidal flats. The arenaceous units of the Wuppertal Formation thin gradually towards the south. From Villiersdorp to McGregor, where delineation of the unit becomes uncertain due to decrease in sand content, oscillation and interference ripple marks and channelling still typify the uppermost beds.

5.2.9 Klipbokkop Formation

From the Cold Bokkeveld southwards and eastwards towards Gydo, Karoopoort and Verkeerdevlei, the Klipbokkop Formation thickens to 300 m. It is a sequence of alternating reddish-grey-weathering, micaceous siltstone and mudstone, with argillaceous sandstone up to 1-m-thick and protosandstone interbeds. The uppermost 30 m or so of the succession is generally more arenaceous. Bioturbated lenses, rare brachiopod impressions and a wide variety of trace fossils, most conspicuously *Spirophyton*, occur. The more sandy units display oscillation and current ripple marks, micro cross-lamination and planar cross-bedding. On some of the thin, basal siltstone beds, as for instance near Tunnel Siding, swash-and-rill marks occur extensively. The best exposures are east of Op-die-Berg village on Vaalbokskloof and Sandberg Mountain.

South of the Langeberg Range the overlying Osberg and Karoopoort Formations of the Bokkeveld Group can no longer be distinguished unambiguously, so that, for mapping purposes, the upper boundary of the Klipbokkop Formation is taken below the first typical micaceous, light-grey siltstone and sandstone beds of the Witteberg Group. Therefore, in this particular instance, it exceeds 400 m in thickness.

5.2.10 Osberg Formation

This Formation, consisting of light-grey, medium- to thick-bedded, feldspathic protosandstone, follows conformably on the uppermost Klipbokkop siltstone beds north of the Langeberg Range – see Figure 5.9. In the Warm and Cold Bokkeveld, the 30-m-thick Osberg Formation can be subdivided into prominent, arenaceous basal and upper parts separated by a central shale, mudstone and siltstone sequence. The proportion of sandstone decreases southeastwards. The Formation thins from 30 m at Waboomshoek, just north of Verkeerdevlei, to 10 m at Swartberg in the Montagu District, i.e. over a distance of 32 km. At Swartberg itself the Formation thins further from 10 to 5 m over a distance of 0,5 km. The medium- to coarse-grained micaceous sandstone displays planar and trough cross-bedding, a wide variety of ripple marks and bioturbation. *Spirophyton* trace fossils, fragmentary plant material and thin intraformational conglomerate lenses occur. Some clasts of the last mentioned consist of blue-black cherty mudstone or ferruginous shale. At Swartberg the sandstone displays heavy-mineral stringers as well. South of the Langeberg Range the Osberg Formation cannot be distinguished as such.

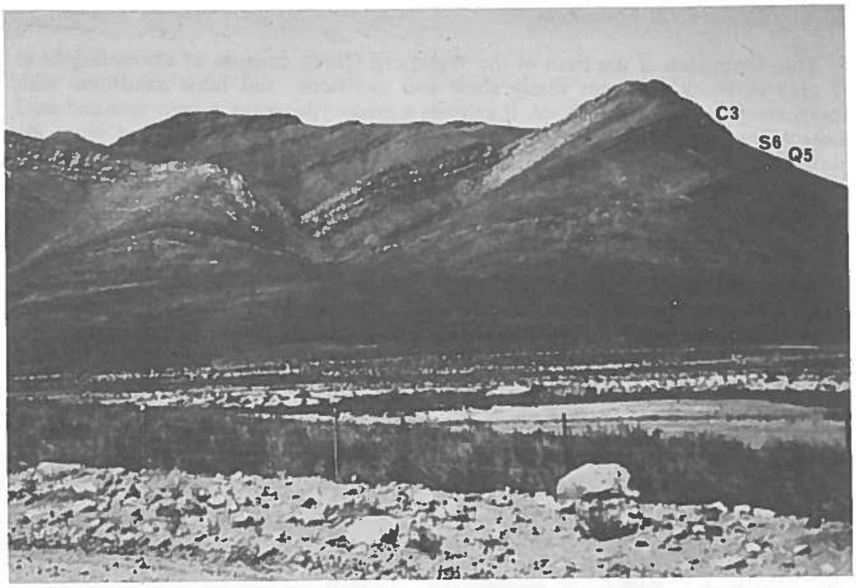

Fig. 5.9 - The Bokkeveld-Witteberg transition at Karoopoort. The Osberg Formation (Q5) in the foreground is overlain by both the Karoopoort Formation (S6) and the Wagen Drift Formation (C3). The Blinkberg Formation arenites form the prominent cliffs, which are in turn overlain by Swartruggens Formation shales and Witpoort Formation sandstones on the mountain crest.

5.2.11 Karoopoort Formation

The Karoopoort Formation, which measures 40 m at the type section at the southwestern entrance to Karoopoort in the Ceres District, retains its thickness over most of the map. It consists of dark-grey siltstone, sandy shale and minor mudstone beds. Plant fragments, trace fossils (especially *Spirophyton*), bioturbation, dessication cracks, small-scale scour-and-fill and erosional structures, ball-and-pillow and contorted bedding, as well as ripple lamination, occur. The Formation has a transitional upper and lower boundary, and can also only be delineated in the area north of the Langeberg Range. It usually forms a narrow but conspicuous grassy ledge below the more positively weathering arenaceous Witteberg outcrops. The best exposures occur at Karoopoort, the Vaalbokskloof, Gydo and Swartberg Mountains.

5.3 WITTEBERG GROUP

The predominantly arenaceous Witteberg Group follows conformably on the Bokkeveld Group (Fig. 5.9). Distinctive features of Witteberg sandstones compared to those of the Bokkeveld Group are: high sericite content, greater sandstone maturity and, correspondingly, lighter colours. Seven formations are recognised in the Witteberg succession.

5.3.1 Wagen Drift Formation

This Formation at the base of the Witteberg Group consists of alternating beds of grey to black siltstone, sandy shale and mudstone, and lithic sandstone with interspersed light-grey sandstone. It exhibits a gradual decrease in grain size and sand content southwards. Just east of the village Op-die-Berg, north of Ceres, the Formation has a total thickness of about 135 m. A lower, more sandy portion of the Formation is approximately 100 m thick here, with some of the thin-bedded sandstone units up to 15 m thick. At Swartberg and Keisieberg, in the Montagu District, the lower sandy part approximates only 50 m of a total thickness of 165 m.

Rocks of the Formation weather yellow to red brown or light grey. The sandstones are often tabular or trough cross-bedded and characteristically mica rich. Trace fossils, especially *Spirophyton* (Fig. 5.10), and a variety of ripple marks and other indicators of shallow water and subaerial conditions; such as mudcracks, runzel and rill marks and intraformational conglomerate lenses, are exceedingly abundant. Pit-and-mound structures and slumping features (flowage structures, ball-and-pillow structures, etc.) also occur frequently. Plant fragments consisting of psilophyte and

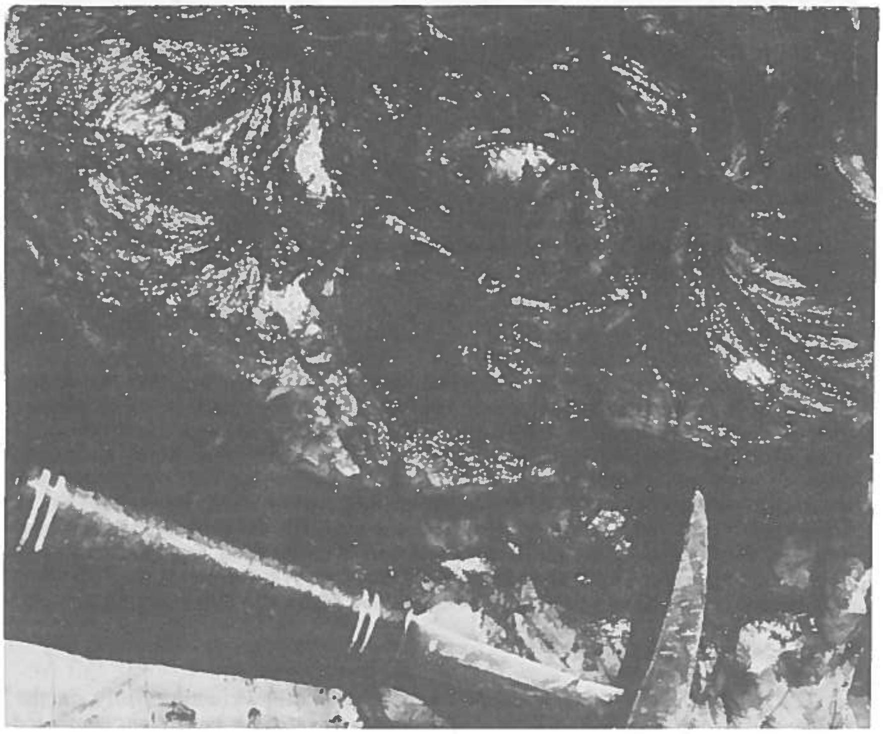

Fig. 5.10 - Typical *Spirophyton* trace fossils in the Wagen Drift Formation, Karoopoort.

lycopod stems, the latter of which have been tentatively classified as *Haplostigma irregulare* (Plumstead 1967), and a varied suite of marine mollusc and brachiopod species such as found at Gouwernments Leegte 17 (Elim), are also present. The genus *Tropidoleptus* sp., which has a characteristic Devonian (Givetian–Frasnian) age range and distribution pattern, has been identified in these beds (Boucot *et al.* 1983).

A distictive weathering feature of this Formation, well displayed in the Cold and Warm Bokkeveld, is that low-dipping siltstones weather to form scarps, similar to the overlying sandstones, thus giving a false impression of the thickness of the arenaceous units. However, where siltstone beds have high dips they tend to blend with the shales.

South of the Langeberg Range the otherwise well-defined and laterally continuous sandy beds are much thinner (2–3 m) and frequently all bedding has been destroyed by bioturbation. Along the Riviersonderend River two to three laterally continuous, white-weathering, micaceous, quartzose sandstone beds, 2 m thick, occur along the base of the Wagen Drift Formation, which locally exceeds 400 m in total thickness . Along the N2 route, from Lebanon Forestry Station to Houhoek, parallel and ripple cross-lamination, lenticular bedding, slumping, convolute bedding, bioturbation, ripple marks and climbing-ripple cross-lamination occur.

5.3.2 Blinkberg Formation

The Blinkberg Formation is a 90-m-thick sequence of medium-grained, thick-bedded, light-grey quartzitic sandstone which always shows up prominently throughout the area. It overlies the Wagen Drift Formation conformably with a fairly sharp contact. Thinner-bedded zones occur in places. Primary structures include prominent tabular cross-bedding, some trough cross-bedding, current-ripple lamination and rib-and-furrow structures. Heavy-mineral laminae, well displayed near Brandvlei Dam, often accentuate small-scale bedding features and occur fairly commonly throughout. *Spirophyton* is a prominent trace fossil, especially in thin-bedded intervals. Lycopod stems are poorly preserved and only the genus *Haplostigma irregulare* has been tentatively identified (Plumstead 1967) (Fig. 5.11).

The Blinkberg Formation thins southwards to 50 m in the Worcester–Robertson area, and it is only 15 m thick at its southernmost outcrop near Greyton–Genadendal. The sandstone generally becomes fine grained southwards with thin, intercalated, micaceous siltstone beds. The more mature sandstone beds weather yellowish white and the silty beds reddish brown.

5.3.3 Swartruggens Formation

The less-conspicuous Swartruggens Formation follows conformably on the uppermost thick-bedded, quartzose sandstone beds of the Blinkberg Formation. At the type area, just north of Karoopoort on Ossenkloof 268, the Formation is 300 m thick (De Beer 1989) and consists of siltstone and mudstone alternating with grey, thin-bedded, fine- to medium-grained sandstone. Locally there are two fairly persistent, prominently white-weathering sandstone horizons which are several metres thick. Rocks of this Formation generally weather yellow to reddish brown and are distinctly micaceous. Wavy bedding, ripple-drift lamination, current and wave ripple marks, rib-and-furrow structures, current lineation, dessication cracks, rill marks and

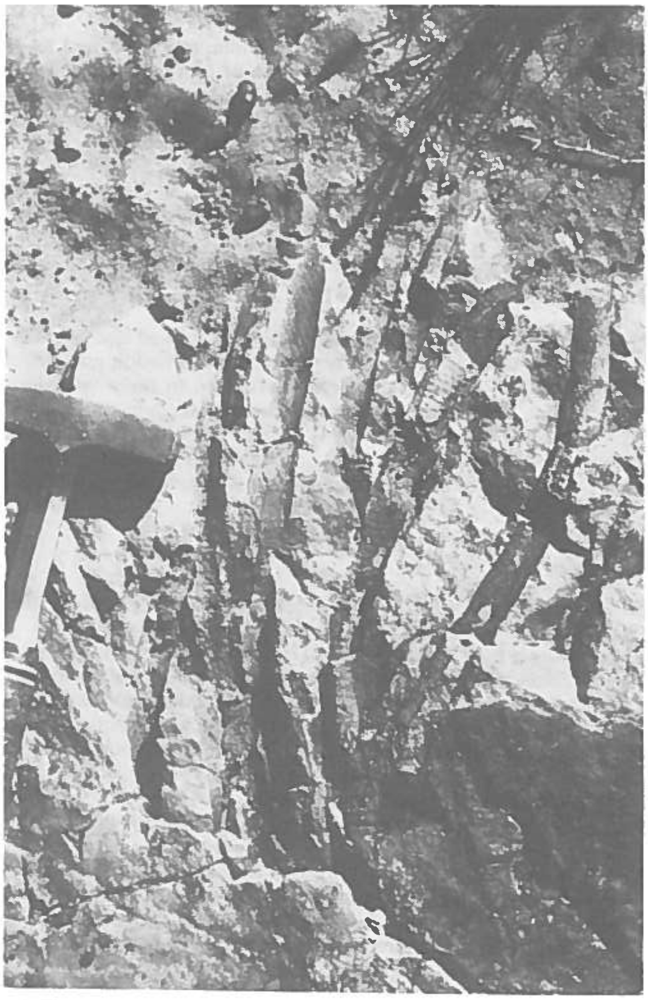

Fig. 5.11 - Lycopod stems in the Blinkberg Formation.

a variety of trace fossils, notably *Spirophyton*, occur. Thin intraformational conglomerate lenses are occasionally found. Most of the above-mentioned features are still present farther southwards, e.g. in the vicinity of Brandvlei Dam (south of Worcester) and around Greyton. However, as before, sandstone beds become fewer, thinner and less mature with a corresponding increase of shale and mudstone.

5.3.4 Witpoort Formation

The arenaceous Witpoort Formation is topographically the most prominent unit of the Witteberg Group. It attains a thickness of between 310 and 380 m near Karoopoort in the Ceres District, but thins westwards and southwards. Just north of the Brandvlei Dam, near Worcester, where the basal contact of the Witpoort Formation is well displayed in road cuttings, the unit is approximately 65 m thick. The Formation can be subdivided into the Rooirand, Perdepoort and Skitterykloof Members, which are not distinguished on the map.

The basal reddish-brown-weathering Rooirand Member, which follows with a sharp conformable contact on the Swartruggens Formation, consists of grey, medium- to thick-bedded, fine- to medium-grained quartzitic sandstone. The upper third locally consists of thinner-bedded sandstone and siltstone. Tabular cross-bedding, wavy and flaser bedding, micro cross-lamination, climbing-ripple cross-lamination, rib-and-furrow structures and small-scale upward-coarsening cycles occur. Some of the thinner-bedded and more silty layers display trace fossils and bioturbation. Channelling also occurs in places.

The overlying, more mature, white-weathering Perdepoort Sandstone Member (the "White Streak") is a prominent marker horizon. It consists of light-grey, well-sorted, medium- to fine-grained quartzitic sandstone. Individual beds vary in thickness from less than 0,5 to 2 m, and tabular cross-bedding is prominent. Dark heavy-mineral laminae often enhance the outlines of current bedding and subhorizontal stratification. Rarely, as on Groot Kloof 232 north of Karoopoort, do gritty horizons with larger (75 mm), angular quartzite clasts occur. Plant fragments (*Haplostigma*) are also occasionally present. South of the Breede River, on the Ouhangs-, Ganna- and Rooiberg, the Perdepoort Member is only 50 m thick compared to some 160 m at Karoo Poort.

The discontinuous Skitterykloof Member, consisting of coarse-grained pebbly sandstone and thin conglomerate layers, forms the upper part of the Witpoort Formation. It has not been identified south of Worcester and, even to the north, this unit is probably not more than a few metres thick. On Parys 317 and Vrystaat 331 in the Koue Bokkeveld, the Skitterykloof Member is represented by thin conglomerate layers, consisting mainly of rounded vein-quartz pebbles.

5.3.5 Kweekvlei Formation

This Formation, which follows concordantly on the uppermost sandstones of the Witpoort Formation, consists of dark-grey, micaceous shale and subordinate siltstone. The shales are thinly to thickly laminated, and the siltstones micro cross-laminated. Wavy and flaser bedding are present, as well as ripple lamination and flat-topped wave and interference ripple marks. Bioturbation is common but, except for plant fragments, no other fossils have as yet been found. The Formation weathers to a light-grey or reddish to brown colour. Good outcrops of the Kweekvlei Formation are rare. Borrow pits for road gravel occur in the Formation around Karoopoort on Karoo Poort 266, and in the Cold Bokkeveld on Driedrift 284 and Vrystaat 331. Outcrops are also present on Platte Klip 177 and Jurgens Fontein 263 in the Ceres Karoo, but to the south, in the Breede River Valley, Kweekvlei shales are only exposed at Gannaberg and Gemsbokkop. Excavations next to the Breede River on the Worcester–Rawsonville road have shown that fresh Kweekvlei shale is markedly graphitic (De Villiers *et al.* 1964). The Kweekvlei Formation thins from some 50 m at Karoopoort to about 30 m in the Cold Bokkeveld, and 37 m near Brandvlei Dam.

5.3.6 Floriskraal Formation

The Floriskraal Formation consists of several thick yellow-brown-weathering, medium- to coarse-grained, often feldspathic, quartzitic sandstone beds which alternate with, and lens out into, siltstone and sandy micaceous shale. Thin layers of grit and conglomerate also occur. The angular to subrounded clasts (< 4,0 cm) consist mostly of vein quartz, chert, granite, shale and feldspar. The sandstone horizons are extensively planar and trough cross-bedded. Channelling is also present, as well as climbing-ripple lamination, upward-coarsening cycles, intraformational conglomerate lenses and interference ripple marks. Plant fragments are sometimes found. The siltstone beds show cross-lamination and ripple marks.

The lower boundary of the Floriskraal Formation is transitional, but the upper boundary with the Waaipoort Formation may be sharp or transitional. However, in the Cold Bokkeveld, especially on Vrystaat 331 about 2 km west of Witklippies homestead, Dwyka tillite rests with a gradational contact on the Floriskraal Formation. The light-grey Floriskraal sandstones gradually, over several centimetres, become coarser, with an increase in angular quartz and lithic fragments. Simultaneously the rock gradually becomes darker grey-green in colour, the clay content increases and, eventually, it has all the appearances of a diamictite. The Floriskraal Formation thins from 70 m near Karoopoort to some 35 m in the Cold Bokkeveld, and 25 m near Brandvlei Dam.

5.3.7 Waaipoort Formation

The Waaipoort Formation, where present, consists of shale, mudstone, siltstone and thin, intermittent, immature sandstone beds. The micaceous and more sandy lower portion weathers reddish brown, with wave ripple marks fairly common. Bioturbation, trace fossils, rib-and-furrow, ripple lamination and micro cross-lamination are also present. The overlying more pelitic portion is conspicuously thinly laminated, sometimes also massive (mudstone), dark grey in colour and markedly less micaceous. It normally weathers to a greenish-grey colour. These uppermost mudstones have a gradational contact with the overlying Dwyka tillite and dropstones are found in them at various localities.

The transition between the lower and upper portions of the Waaipoort Formation, although not very obvious in the field, can often be clearly discerned on aerial photographs. The upper mudstones often contain thin, dark-brown to black, dolomitic and/or carbonaceous or cherty mudstone lenses which are markedly fossiliferous. Numerous imprints of plants – *Protolepidodendron* and *Archaeosigillaria* – have been described (Plumstead 1967) and a variety of palaeoniscoid fishes have also been identified from adjoining areas (Gardiner 1969). These fossils are probably widespread, but owing to poor outcrops only fragments have as yet been found in the map area. The best exposures are on Bloed Rivier 176, about 20 km north of Karoopoort, where the Formation is 25 to 30 m thick. It thickens southwards to about 37 m south of Worcester (De Villiers *et al.* 1964). The Formation is absent above the Floriskraal Formation in the Cold Bokkeveld (Visser *et al.* 1981).

5.4 DEPOSITIONAL ENVIRONMENT AND AGE

According to Rust (1967, 1973) and Tankard *et al.* (1982) the Piekenierskloof Formation was deposited in the Early Ordovician as a southeastward-directed fan-delta complex. Progressive subsidence relative to the adjoining fault-bounded "Atlantic Highlands" maintained a high relief along the northwestern margin of the early Cape Basin. The proximal Piekenierskloof rudites graded basinwards into predominantly coarse-grained sandstones of a braided alluvial complex. The overlying Graafwater

Formation is related to a sheltered tidal and shallow subtidal setting (Rust 1977), and the Peninsula Formation to high-energy longshore barrier-bar and shelf sedimentation (Hobday and Tankard 1978). This is, however, contested by Turner (1987) and Thamm (1989), who visualized that deposition of the Graafwater and Peninsula sediments took place within a major braid-plain system that prograded southwards into a marine depository. Interfingering fine-grained, bioturbated marine sediments attest to a series of transgressive marine interludes.

In the Late Ordovician an extensive Gondwana ice sheet, centered in central Africa, bordered the Cape Basin to the north. At least two major glacial advances, with an interglacial stage, are recorded in the Pakhuis Formation. Significant lowering of water level occurred in the Basin because of the extent of glaciation on the land, resulting in partial exposure and development of permafrost on the emergent sand banks. The Sneeukop ice sheet, carrying a large load of quartz sand and river-and beach-worn pebbles, first entered the Basin from the north. Rust (1981) envisaged the moving ice sheet, where it rested directly on unconsolidated Peninsula sand, to have caused soft-sediment deformation and the resultant Fold Zone. Where permafrost occurred, no folds developed. The southerly trend of the structures are ascribed to the movement of the ice sheet. During the ensuing interglacial and ablation of the ice load, terminal moraines and other glacial debris were fluvially reworked and redeposited as the Oskop sandstone. Only the surficial sediments were affected, most of the Sneeukop tillite being deposited as englacial till directly in the cores of the synclinal structures of the "Fold Zone". Under the harsh climatic conditions frost fissures and patterned ground were formed in the exposed areas, and shallow sand dykes developed when open fissures were filled from above by dry mass wasting. Recurrence of glacial conditions is reflected by the Kobe ice sheet. The Steenbras tillite, in the southern part of the map area, was deposited subaqueously from distal portions of the floating Kobe ice sheet. North of the map area, the Kobe tillite was deposited as a series of ground moraines and glacial pavements developed on the Oskop Sandstone Member.

With amelioration of climate and downwasting and retreat of the Kobe ice sheet at the expiry of the Ordovician (Hirnantian) mainly fine mud was initially washed into peripheral glacial lakes and the shallow marine embayment, producing the Soom Shale Member of the Cedarberg Formation. Progressive upward coarsening of the latter, as reflected by the Disa Siltstone Member, and the presence of a marine fauna at various levels, indicate the increased retreat of the ice sheets concomitant with a rise of sea level.

With northward transgression of the shoreline during the Early Silurian the Goudini and Skurweberg sediments, derived from a basement mainly composed of granitoids and gneisses, were deposited in a shallow open sea. A low mesotidal regime existed and the sediments were reworked by currents and wave activity (Rust 1967; Tankard *et al.* 1982). Thick, laterally continuous, tabular sand bodies accumulated on the shallow marine shelf. Northwards these sediments graded into extensive coastal plains, criss-crossed by braided river systems (Thamm 1987). The Early Devonian (Pragian) Rietvlei Formation was deposited in a wide, shallow embayment, open to the southeast and flanked by a mature low-gradient coastal plain.

An increased rate of subsidence, perhaps caused by more active basin-margin fault displacement in the Emsian, resulted in a marked northward advance of the shoreline and progression of the basal, muddy Bokkeveld shelf facies across the Rietvlei sand-shoal deposits. The pulsatory tectonic nature of the Bokkeveld Basin and provenance is reflected by the alternation of arenitic and pelitic entities. The five major upward-coarsening "packages" which evolved feather out downslope into a relatively more homogeneous mudstone–siltstone sequence in the south. The "packages" represent successive southward advances of several, laterally coalescing, arcuate deltas along a mixed tidal- and wave-dominated lobate coastline (Theron 1972; Tankard and Barwis 1982). Delta-platform sands successively encroached upon delta-slope and shelf sediments containing a typical Malvinokaffric marine fauna from the Lower (Emsian) to the end of the Middle Devonian (Givetian) (Hiller and Theron 1988). Variations in these upward-coarsening packages reflect differential preservation and marine reworking during transgressions. In the mapped area the Hex River and Boplaas Formations reflect a sudden marked rejuvenation of the western source area ("Atlantic Mountains") and mainly eastward-directed transport (Theron and Loock 1988).

Shallowing of the Cape Basin set in during the Frasnian, and delta-front and delta-plain silt, sand and mud of the basal Witteberg Group, the Wagen Drift Formation, accumulated. The overall sedimentary pattern displayed by the Witteberg lithofacies indicates a gradual return to more extensive reworking of the deltaic sediments in shallower water and the corresponding accrual of thicker, more continuous and mature arenitic units (Blinkberg and Witpoort Formations). These barrier-beach, tidal, shore-face and inter-bay sands gradually thin south- and eastwards, merging in that direction with delta-slope and shelf deposits.

The Swartruggens sediments display regular upward-coarsening cycles as the reworked delta-front and shore-face sands prograded basinwards with decreasing subsidence. The overlying quartz sands of the Wittepoort Formation were extensively reworked in the surf zone, in various tidal channels and by long-shore currents. By now the lobate Bokkeveld shoreline had reverted to a linear, clastic coastline, as had previously existed during the Silurian. The conspicuous, exceptionally homogeneous and laterally persistent Perdepoort Member, and the overlying, sporadic, gritty to conglomeratic Skitterykloof Member respectively represent an open-beach facies and reworked mouth-bar deposits accumulated towards the end of the Devonian (Famennian).

A sudden, rapid basin-wide subsidence introduced the pelitic Kweekvlei Formation. However, as the basin gradually shallowed again these shelf and delta-slope mud and silt deposits were encroached upon by the delta-front, mouth-bar, barrier-beach and shoreline sands of the Floriskraal Formation.

The easterly directed component of the Floriskraal drainage pattern in the mapped area (Loock 1967) may either reflect the recurrence of the marked east–west longshore drift which previously characterised the Witteberg Basin, or signify reactivation of the western Atlantic source area and notable contribution by a major western delta. These sediments accumulated in a considerably reduced, elongate, marginal intracratonic basin (Loock 1967; Rust 1973). The succeeding Waaipoort silt and mud evidently represent lagoonal to mud-flat deposition behind and adjoining the prograding Floriskraal deltas and shoreline. The large number of fish remains in this Formation suggests entrapment and asphyxiation in shallowing stagnant pools (Gardiner 1969).

The absence of Waaipoort sediments coupled with the distribution of the western perimeter of the Witteberg Basin, as well as the clear indication of a north- and eastward-directed palaeoslope during initial ice flow and deposition of the basal

Dwyka tillite in the mapped area (Visser and Loock 1982), seems to strengthen the above argument in favour of an Early Carboniferous reactivation of the old western (Atlantic) source area.

6. KAROO SEQUENCE

These rocks occur northeast of Karoo Poort in the Ceres-Karoo, in the Cold Bokkeveld north of Gydo Mountain, south of the Langeberg Range between Worcester and Robertson, and in a small outlier at Greyton. Only the lower part of the Sequence is present within the boundaries of the map.

6.1 DWYKA GROUP

The Dwyka Group consists mainly of hard, massive, dark grey-green tillite which weathers yellowish brown. Selective weathering of the near-vertical cleavage gives rise to characteristic "tombstone" structures. The tillite consists of angular to rounded erratics, varying from less than 1 cm to several metres in size, in a fine-grained matrix. The arenaceous content of the latter is variable. Some erratics display glacial striae and facetting. The following rock types occur: quartzite (various), vein quartz, chert, banded ironstone, jasper, hornfels, limestone, sandstone, conglomerate, granite, gneiss, basalt, amygdaloidal lava, diorite and quartz porphyry. About 2,5 km due west of Langvlei Siding a coarse, feldspathic sandstone erratic attains about 10 m in diameter.

In places the Dwyka Group displays crude stratification which is sometimes enhanced by pelitic layers of limited extent. Sheet-like, lenticular to shoestring-type, coarse, arenaceous bodies, 1 to 3 m thick and free from erratics, also form important marker horizons. Although they are discontinuous, they do persist regionally along approximately the same stratigraphic zone. These arenitic zones are well displayed in the Ceres-Karoo. On the farm Jurgens Fontein 263 a 4-m-thick, light-grey sandstone lens crops out for almost 700 m. Boulder beds also occur in the last-mentioned area and form regional marker horizons (Theron and Blignaut 1975). They consist of either a single layer or boulders embedded in massive diamictite, or layers of boulder rudite with a matrix of diamictite. Their significance is discussed in detail by Visser and Hall (1985).

Good outcrops of the Group in the Ceres-Karoo are generally confined to inselbergs such as Fonteinskop, next to the Sutherland road, northeast of Karoo Poort. In the Cold Bokkeveld outcrops are generally scarce and widely scattered; the best localities are towards the east on Hoop En Uitkomst 279. The Group is largely covered by younger alluvial deposits south and southwest of Worcester. A small outcrop occurs on the farm Aan de Doorns 369. Better exposures are present farther south, at Bruintjieskop on the farm Moddergat 541 and on Lemoenspoort 545, eastwards towards Robertson along the northern flank of Ouhangsberg, Gannaberg and Gemsbokkop, and on Aasvoëlberg at Eilandia. Just north of Gemsbokkop and Gannaberg several small inliers of tillite reveal good exposures of the otherwise rare basal contact between the Dwyka tillite and the Waaipoort Formation.

Other minor outcrops of tillite, generally deeply weathered, occur just west of Robertson and at Greyton. Better outcrops south of the Riviersonderend River, on Genadendal 39, expose typical dark grey-green diamictite which contains erratics and "dropstones" of varied size and composition within a very fine-grained matrix. These are the southernmost outcrops of the Dwyka known, and their contact relationship with the underlying Witteberg sediments has been discussed by Gouws (1961), De Villiers and Gouws (1961), and Loock (1967). The clearly paraconformable relationship here evidently represents a hiatus in deposition.

The upper gradational contact with the Prince Albert Formation is rarely seen, but in the Cold Bokkeveld and Ceres-Karoo alternating, thin, tillitic and shale lenses are evident; dropstones are present as well. According to De Villiers *et al.* (1964) the thickness of the Dwyka Group in the map area is approximately 485 m.

6.2 ECCA GROUP

6.2.1 Prince Albert Formation

Outcrops of this Formation are generally poor. It consists mainly of thinly laminated, dark bluish-grey shale which weathers to an olive or red-brown colour. In the Cold Bokkeveld and Ceres-Karoo thin (3–5 cm), silty to cherty layers occur intermittently. On exposure these disintegrate into small yellow-brown angular chips.

Between Worcester and Robertson the Formation is only intermittently exposed, with good, fairly accessible outcrops occurring along the flanks of Aasvoëlberg, north of Eilandia. In the same vicinity, on Scherpen Heuvel 481 and Kleigats Hoogte 483, varve-like laminites and arthropod tracks have been observed.

According to De Villiers *et al.* (1964) the Formation attains a thickness of approximately 200 m south of Worcester, but more recently 120 m was measured just north of Ribbokkop on Scherpen Heuvel 481. As elsewhere, a transitional contact exists between the Prince Albert Formation and the overlying Whitehill Formation.

6.2.2 Whitehill Formation

The Whitehill Formation consists of thinly laminated, pyritic, carbon-bearing black shale and measures about 30 m in thickness. The Formation weathers characteristically to a conspicuous greyish-white, gypsiferous to lime-rich zone. Thin, grey to yellow-coloured cherty lenses are often also apparent.

In the Worcester–Robertson area two small road-material quarries on Scherpen Heuvel 481 (north of Ribbokkop) and De Hex Rivier 50 (northwest of Onder Noree homestead) provide good exposures of the Whitehill Formation. In the two excavations the Formation consists of weathered, light-grey to grey, well-laminated shale containing numerous limonite-rich laminae and some dark-grey dolomitic concretions. Thin gypsiferous lenticles are sometimes present as well. A 1,5-m-thick unit, containing yellowish illite-rich claystone or K-bentonite laminae interpreted as altered air-fall tuffs (Martini 1974; Viljoen 1987), has also been exposed here. Fossils of the crustacean *Notocaris tapscotti* were found here and Oelofsen (1981) reports an insect wing and a large number of specimens of the aquatic reptile *Mesosaurus tenuidens* from the Worcester–Robertson outlier.

6.2.3 Collingham Formation

The Collingham Formation, which concordantly overlies the Whitehill shales, is poorly exposed in the Ceres-Karoo but in the Worcester–Robertson outlier it is exposed in the above-mentioned quarry sites as well as in road cuttings. Here it is about 45 m thick, compared to the generally accepted thickness of 30 m to the north.

The Collingham Formation consists here of a rhythmically interbedded sequence of thin tabular beds of dark-grey shale, yellowish-coloured soft claystone, siltstone and cherty mudstone. Bedding thickness varies from 20 to 40 mm, with some of the siltstone horizons somewhat thicker in places. Parallel lamination is dominant. No trace fossils have been found as yet.

A yellowish-weathering, illite-rich claystone (K-bentonite) typifies the Collingham Formation and has a wide distribution throughout the Karoo Basin. These claystones and chertified beds contain devitrified and replaced glass shards, and have been interpreted as air-fall tuffs (Lock and Wilson 1975). Analyses have shown the potassium content of these ash beds to vary from 4 to 10 per cent K_2O (Verwoerd *et al.* 1990).

6.2.4 Tierberg Formation

The conformably overlying Tierberg Formation consists of grey-black (fresh) to olive-green (weathered), well-laminated shale, mudstone and siltstone. The Formation is extensively weathered and poorly exposed in the Ceres-Karoo. Occasional thin, silty horizons are sometimes ripple marked and biogenic trails occur on Witte Wal 171, along the Groot River.

Outcrops are somewhat better in the Worcester–Robertson outlier, where the most complete section across the Tierberg Formation in this area occurs between Aasvoëlberge and Mowershoogte, just west of the Worcester–Robertson divisional boundary. From the Tierberg–Collingham contact up to Mowers Siding the sequence is mainly composed of mudstone, shale and siltstone. North of the railway line, however, there are a gradually increased number of arenaceous layers. This latter succession is tentatively correlated with the Waterford Formation, the uppermost unit of the Ecca Group.

6.2.5 Waterford Formation

In the low range of hills, Mowershoogte, between Worcester and Robertson, numerous fine- to medium-grained sandstone beds are intercalated with pelitic units. These arenaceous beds are generally massive or sometimes parallel laminated, and wave ripple marks, clay-pellet conglomerate and brownish lime-rich lenses occur (pers. commun. J.H.A. Viljoen).

Two small occurrences near Worcester are fairly well exposed. On De Mond Van Hartebeest Rivier 379, west of Worcester, dark-grey, fine- to medium-grained, micaceous sandstone and siltstone beds alternate with green to brownish shale and mudstone. Ball-and-pillow slump structures, wave ripple marks, lime-rich nodules, intraformational conglomerate clasts and numerous small plant fragments (including *Schizoneura*) occur. Similar beds just east of Worcester Station have yielded specimens of *Gangamopteris cyclopteroides*, *Glossopteris browniana* and *Cardiocarpus* (Rogers 1905). Grey sandstone beds are very prominent here, displaying cross-bedding and a bed thickness of up to a metre.

6.3 DEPOSITIONAL ENVIRONMENT AND AGE

At the end of Cape Supergroup sedimentation a shallow, marginal, intracratonic marine basin existed in this area (Loock 1967; Theron and Thamm 1990). With deterioration of the climate in the Namurian (Lower to Middle Carboniferous), glaciation developed on highlands to the west and south (Smellie 1981; Veevers and Powell 1987). Ice streams radiating from these distant alpine-type mountains flowed north and northeast into the basin (Visser and Loock 1982).

During the ensuing Westphalian ice-spreading centres towards the south and north of the Dwyka Basin grew extensively and ice lobes entered the Basin to form a coalesced ice cover (Visser 1989). The initial ice advance was grounded as indicated by deformation glacial bedforms and erosion of bedrock along the Basin edge (Visser 1990). During the complex sequence of advances and retreats of the ice front predominantly lodgement tills were laid down. The further deterioration of climate and corresponding increased build up of the ice mass caused isostatic depression of the basin floor to below sea level. From the Westphalian to the Sakmarian (310–280 Ma), therefore, rain-out and subaqueous debris-flow diamictons, subaqueous and subglacial meltwater sands, suspended mud and turbidity current sands and silts accumulated (Visser 1989). Rapid sea-level rise in the late Sakmarian (275 Ma) was accompanied by rapid disintegration of the ice sheet over the platform and by extensive debris rain and suspension settling of mud (Prince Albert Formation).

Isostatic uplift along the basin margins caused shrinking of the Basin and shallowing to within the limits of the photic zone, therefore implying a maximum depth of about 80 m (Cole *et al.* 1990). The Basin was probably linked southwards with the palaeo-Pacific Ocean and the waters may have been brackish (Oelofsen 1981; Cole *et al.* 1990). The black organic-rich shales of the Whitehill Formation probably accumulated by suspension settling of mud under reducing conditions. Numerous thin air-fall tuffs thereafter periodically interrupted the suspension settling and the Collingham Formation was deposited. The more cherty units evidently represent redeposited volcanic ash emplaced by turbidity currents. The tuffs can probably be related to subaerial eruption centres located in southern South America, near the palaeo-Pacific margin (Viljoen 1987). Downwarping of the Karoo Trough was accompanied by deposition of shales of the Tierberg Formation in a deepwater-basin plain, predominantly by suspension settling. The upward-coarsening sequence south of the Langeberg Range represents shallowing of the depositional basin as a result of uplift of a southern provenance and progressive northward migration of deltas.

7. MESOZOIC DEPOSITS

Rocks of the Middle Jurassic to Lower Cretaceous Uitenhage Group occur in disconnected remnant depositories along two westerly striking fault zones on Sheet 3319 (Fig. 7.1). To the north the first and most prominent of these is the Worcester–Pletmos Basin line (Dingle *et al.* 1983), which joins the Worcester Fault between Worcester and Heidelberg. The half-grabens along this line represent the onland extension of the offshore Pletmos Basin southeast of Plettenberg Bay. The second, southerly occurrence is of very limited extent and belongs to the onland extension of the Bredasdorp Basin southeast of Cape Agulhas.

7.1 WORCESTER–PLETMOS BASIN LINE

The onshore Uitenhage Group in the southern Cape has been subdivided into four basic units, namely from top to bottom the Sundays River, Kirkwood, Enon and Robberg Formations. This succession reveals downwards an increasing average grain size and variation in depositional environments from distal to proximal (Dingle *et al.* 1983; Tankard *et al.* 1982). Only the basal, conglomeratic Enon Formation has

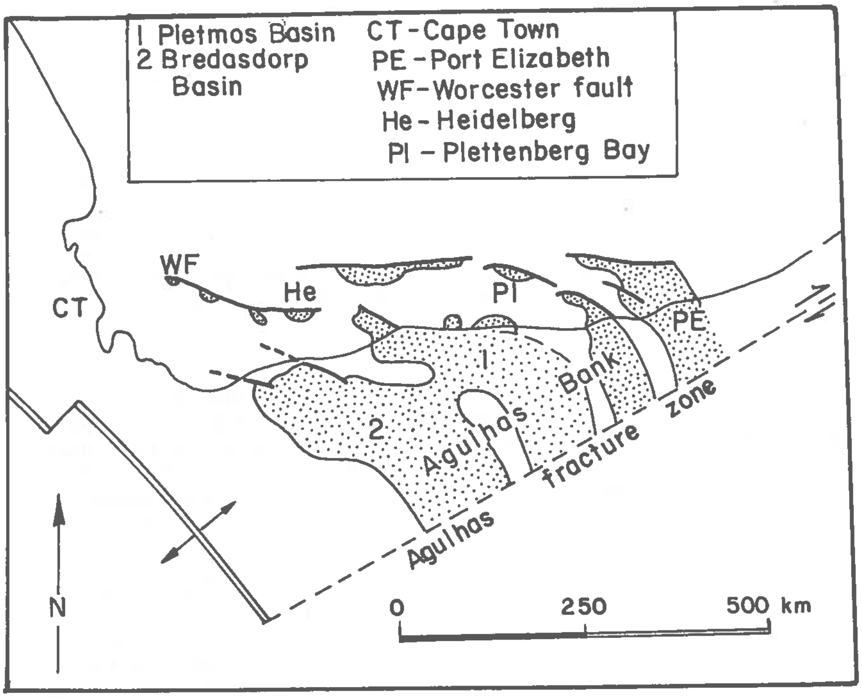

Fig. 7.1 - Distribution of Mesozoic sedimentary basins in the southern Cape Province. (After Tankard *et al.* 1982).

been defined between Worcester and Robertson, although Kirkwood sandstones are probably also present between Robertson and Ashton. In the map area there are three separate occurrences, namely at Worcester, between Nuy and Vink, and east of Robertson.

At Worcester, the Enon conglomerate consists of well-rounded to sub-angular clasts of Witteberg sandstone and grit – exceptionally up to 3 m in diameter – in bedded reddish, argillaceous sandstone. Fragments of vein quartz and silicified wood are also present. The beds dip south and fracturing of conglomerate clasts proves post-Enon movement on the Worcester Fault (Söhnge 1934). The unconformable relationship between the Enon and the Ecca Group can be seen at this locality (De Villiers *et al.* 1964).

Between Nuy and Vink the Enon rests on Ecca and Dwyka rocks. It consists of greenish shale clasts (Ecca) and sandstone clasts (Witteberg) in a whitish, greenish or reddish mudstone matrix which is highly calcareous in places (Söhnge 1934).

East of Robertson, and as far as Ashton (on the adjacent sheet), Enon conglomerate rests on Witteberg rocks. Quartzitic and micaceous sandstone clasts were mostly derived from the Witteberg Group, but Dwyka tillite and fine-grained greenish sandstone and shale pebbles occur on the adjoining sheet. Unfossiliferous, fine-grained, grey sandstones exposed near Klaas Voogdsrivier Siding may belong to the Kirkwood Formation. Fracturing of the Enon in the vicinity of the Worcester Fault once again indicates fault activity after the Enon deposition.

The lithology of Enon clasts in the Worcester–Swellendam area reflects the progressive denudation of adjacent geological formations excluding Table Mountain and Malmesbury Group rocks at the present level of Enon exposure (Söhnge 1934). The latter author therefore concluded that none of these formations had been exposed during deposition of the Enon. De Villiers *et al.* (1964) mention Table Mountain sandstone and Malmesbury clasts in the Enon at Worcester, immediately adjacent to the Worcester Fault, but it is not certain whether these are perhaps more recent deposits. Interbedded tuff layers in the Enon conglomerates, correlated with the Suurberg Group of the Algoa Basin (Hill 1975), have been reported from Robertson (Lock *et al.* 1975) and Worcester (Marsh *et al.* 1979; unconfirmed).

7.2 BREDASDORP BASIN LINE

Onland deposits of the Bredasdorp Basin were only recently discovered. Apart from an occurrence beyond the present map, some 20 km northeast of Bredasdorp (Malan and Theron 1987), exposures were also found southeast of Elim, near the southern tip of Soetendalsvlei along the shores of Waskraalsvlei and Voëlvlei (Waskraal Basin) (Andreoli *et al.* 1989). An exposure of Enon conglomerate at Byeneskranskop on Uylen Kraal 695, east of Gansbaai (Malan 1985) is too small to be shown on the map.

South of Soetendalsvlei the road cuts through a coarse, quartzite-clast conglomerate at Jubelee Hill which is capped by surface-cemented Tertiary gravels of similar composition. A borehole just east of the map area revealed interbedded white, grey and red conglomerate, sandstone and mudrock with some tuffaceous material. These rocks apparently occur along a narrow trough with a faulted boundary in the north and resting unconformably on the Table Mountain Group in the south. Gravimetrick work confirms a half-graben or graben-type fault trough extending eastwards into the sea (Andreoli *et al.* 1989).

The Uitenhage Group rocks in the "Waskraal Basin" are known from a few small outcrops only, as well as from a 44-m borehole which did not reach the base of the succession. Lithologically the succession comprises mainly fine-grained to gritty, cross-bedded sandstone and grey shale, with subordinate conglomerate which consists of Bokkeveld phyllite clasts. Both the sandstone and shale are commonly carbonaceous and pyritic, and appear to be of lagoonal origin. Hence this occurrence is correlated with the Kirkwood Formation (Andreoli *et al.* 1989), although it is not differentiated as such on the map.

7.3 DEPOSITIONAL ENVIRONMENT AND AGE

The taphrogenic Uitenhage basins of the southern Cape were initiated during Middle Jurassic times as a consequence of the first stages of Gondwanaland break-up (Tankard *et al.* 1982). Large tensional displacements on southward-dipping normal faults – up to 6 km in the case of the Worcester Fault – caused Newark-type basins to develop along synclinal axes of the Cape Fold Belt (Lock *et al.* 1975). (Newark-type basins are half-grabens characterised by synsedimentary faulting and contemporaneous alkaline volcanism (Potter and Pettijohn 1963)). The isolated depocentres along the Worcester–Pletmos line are probably remnants of an originally much larger, continuous deposit. Sedimentation in the northward-tilting basins was partially controlled by active boundary faulting. The Enon conglomerates were deposited as northward-building alluvial fans, grading downslope into alluvial-plain sandstones and, ultimately, playa-lake sandstones and mudstones (Lock 1978; Rust and Winter 1979). Locally, very coarse debris-flow wedges are related to synsedimentary fault movements.

8. CENOZOIC DEPOSITS

Some Cenozoic deposits along the southern African coastline can be closely linked to marine transgressions and regressions caused by uplift, episodic sea-floor spreading which changed the volumes of ocean basins in the Tertiary (Rona 1973), and by the Pleistocene ice ages. Many other surficial deposits are found farther inland, notably along large intermontane valleys and the main courses of the Breë, Riviersonderend and Hex Rivers.

8.1 BREDASDORP GROUP

The calcareous, marine or marine-related Bredasdorp deposits have been described by Wybergh (1919, 1920), Maasdorp and Murray (1948), Spies *et al.* (1963), Siesser (1971, 1972), Ruddock (1973), Tankard (1975) and, more recently, Malan (1985, 1988). Malan (1989a) proposed a new lithostratigraphic subdivision of the Bredasdorp Group into five formations, in addition to unnamed beach and raised-beach deposits (Fig. 8.1). He distinguished between the De Hoopvlei and Wankoe Formations of Pliocene age, the Klein Brak and Waenhuiskrans Formations of Middle to Late Pleistocene age, and the Holocene Strandveld Formation. All these units were deposited on a marine-cut platform, up to 25 km wide, in the southern Cape which gently slopes seaward from an elevation of some 90 m above sea level. The oldest deposits occur farthest inland with a progressive younging towards the coast. The type area of the Bredasdorp Group is to the east of the present sheet (cf. Malan and Viljoen 1990) and only the westernmost occurrences of this Group are found in this area.

8.1.1 De Hoopvlei Formation

Small outcrops of this basal Formation of the Bredasdorp Group are found east of Elim on farm 343 and on Miere Kraal 190 (not shown on map). The Formation consists of a thin layer of coquinite and calcirudite at the base, overlain by calcarenite with low-angle cross-bedding and stringers of pebbles, shells and conglomerate lenses. Most other sedimentary structures have been destroyed by secondary calcification. Its maximum thickness is less than 10 m. The marine Pliocene index fossils *Echinodiscus* sp. *Glycymeris borgesi*, *Tivela baini*, *Cardium* edgari, *Scissodesma spengleri* and *Notocallista shcwarzi* occur in these rocks (Malan 1988).

8.1.2 Wankoe Formation

This aeolian, cross-bedded calcarenite unit with calcrete lenses is up to 130 m thick and is described in detail by Malan (1989b). It overlies the De Hoopvlei Formation on Heuningrug, east of Elim. Its westernmost occurrence – too small to be shown on the map – is in an old quarry on Welgesind 648, 3 km southeast of Stanford (Malan 1988). The calcarenite is porous and consists of well-rounded sand and shell grains. Terrestrial fossils like *Dorcasia* are occasionally present.

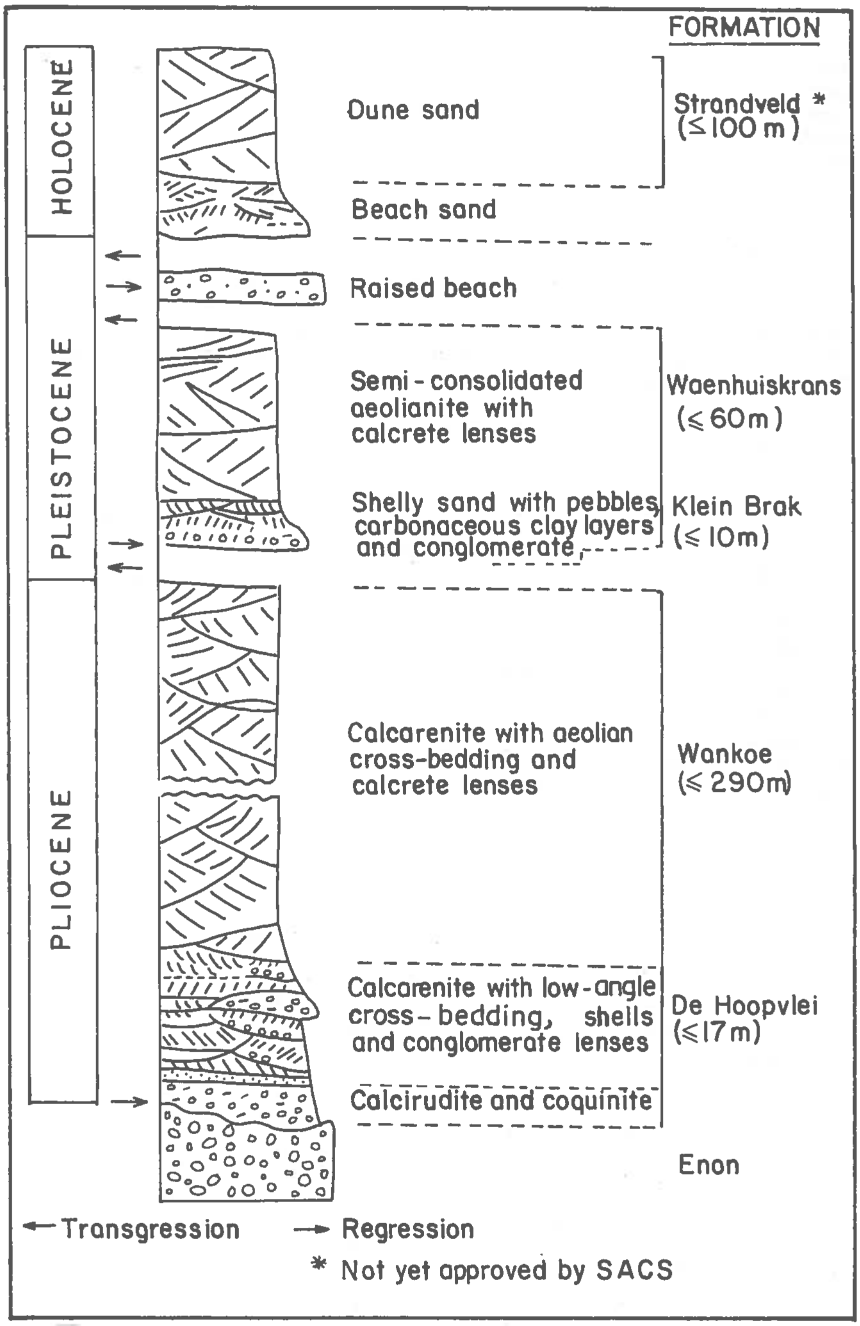

Fig. 8.1 - Generalised stratigraphic column of the Bredasdorp Group. (From Malan 1989a).

8.1.3 Klein Brak Formation

This basal unit of the Pleistocene Bredasdorp rests on a transgression surface at about 6 to 8 m above sea level (Fig. 8.2). It is a marine/estuarine succession, 2 to 11 m thick, consisting of shelly sand with pebble stringers and, locally, carbonaceous clay layers. The Formation occurs intermittently along the coast between the Kleinriviersvlei, near Hermanus, and Cape Agulhas. Gypsum lenses and estuarine fossil shells are found near Die Kelders. Conglomeratic intervals, which are up to 7,6 m thick at Klipgat se Plaat, north of Die Kelders, consist of mainly subrounded pebbles and cobbles of limestone and quartzite which are mostly subrounded.

Fig. 8.2 - Rocks of the Bredasdorp Group overlying a marine platform planed on Table Mountain sandstone at Klipgat, north of Die Kelders.

Exceptionally, boulders up to 300 mm in diameter occur. Sandy horizons display bioturbation, trough cross-bedding, low-angle cross-bedding, as well as some aeolian cross-bedding. The carbonaceous clay contains reeds and other plant matter in places, and also Pleistocene-age pollen. A few terrestrial shells, as well as many marine-estuarine species of the "Swartkops Fauna", have been identified in these sediments (Malan 1988).

8.1.4 Waenhuiskrans Formation

Like the Wankoe Formation, this unit is a semi-consolidated aeolianite (Fig. 8.3) which is described in detail by Malan (1989c). It generally overlies the Klein Brak Formation conformably, but at Die Plaat, north of Gansbaai, the boundary is locally unconformable. The cream-coloured, porous, cross-bedded dune sands consist of well-rounded sand and shell grains with calcrete lenses and attain a thickness of about

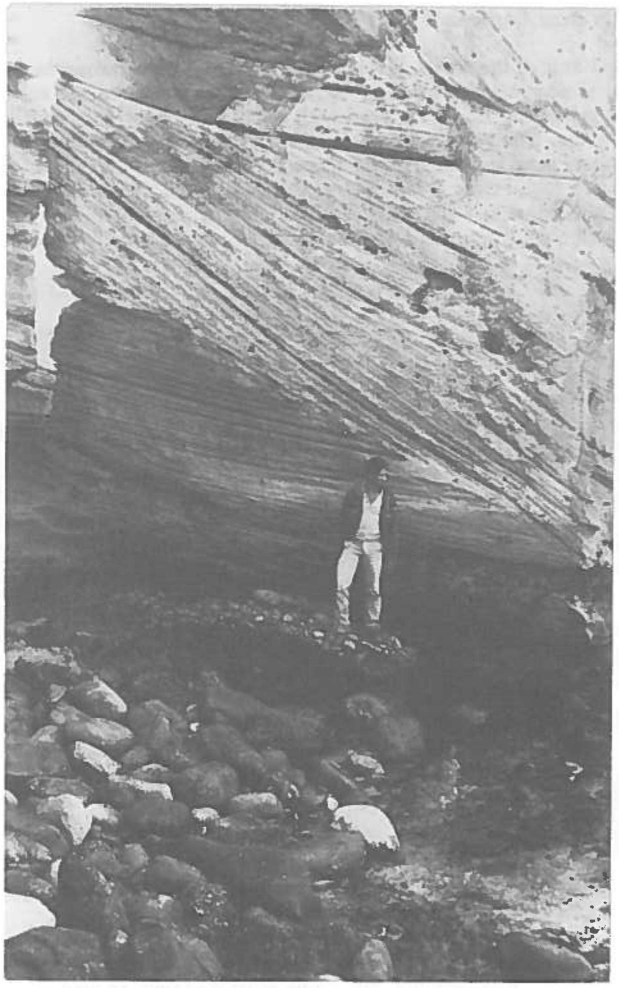

Fig. 8.3 - Aeolian cross-bedding in the Waenhuiskrans Formation along the coast at Die Plaat, north of Die Kelders.

170 m on Woest Arabie 722, south-southeast of Stanford. The Formation is found over large areas along the coast from less than 30 to 380 m above sea level on Helderfontein 688, south-southeast of Stanford. Evidently the sand was blown beyond the limits of marine transgression and inundated the adjoining coastal land surface.

8.1.5 Strandveld Formation

Long stretches of coastline between Kleinmond and Cape Agulhas are covered by Holocene shell-bearing dune sand of the Strandveld Formation. Areally the largest deposit occurs as northeasterly trending, transverse dunes of the Strandveld along the 15-km Walker Bay coast, east of Hermanus. The dune ridges are generally 30 m apart and wet sand with scattered shells occurs in the floors (sabkhas) between dunes. The main dune-forming winds are northwesterly. More complex dune forms are also present. Landward of the unconsolidated dunes semi-stabilised (vegetated) dunes, on older consolidated Bredasdorp aeolianite, reach heights of up to 126 m above sea level. Between Hawston and Kleinmond, west of Hermanus, the formation of barrier dunes and back-barrier marshes has been described in detail by Rogers (1981).

8.2 SILCRETE AND FERRICRETE (Ts/Tf on map)

On the Worcester Sheet most duricrust exposures are found south of the Riviersonderend Mountains, and west of the mountain chain between Saron and Wellington. In these areas ferricrete and silcrete cap low hillocks, which are remnants of the early Tertiary, African erosion surface of Partridge and Maud (1987). This surface slopes seaward, with the result that the duricrust cappings occur at progressively lower elevations towards the south and west.

The silcrete normally forms a very hard, cream-coloured crust with a glassy matrix and conchoidal fracture, but may become softer and more friable lower down. Ferricretes vary from hard, brown, ferruginous layers to nodular or conglomeratic deposits and may grade laterally into silcrete. The duricrust layers are normally less than 2 m thick and developed preferentially in areas underlain by pelitic Bokkeveld and Malmesbury rocks.

The largest deposits are present south of the Bredasdorp Mountains on granite, Malmesbury and Bokkeveld bedrock, where erosion of post-African surface was apparently not as extensive as farther north. Many of them appear to be related to breccia along major faults. Brecciated quartzite and phyllite have been recemented into hard, ferruginous crusts. This type of deposit is also evident in the Bokkeveld terrain between Napier and Riviersonderend. Ferricrete and lateritic soils are found, amongst others, along the Bot River Valley where they often cement terrace gravels. Smaller occurrences are found north of Wellington and in the Theewaterskloof, Grabouw and Caledon regions. In many of the latter instances the bedrock geology, rather than the surficial deposits, is shown on the map.

8.3 SCREE (T-Qt on map)

Scree and scree fans are found mainly in the western and northern parts of the map area, e.g. the slopes of the Drakenstein, Du Toits, Wemmershoek, Elandskloof, Winterhoek, Hex River, Witzenberg, Gydo and Swartruggens Mountains. Often extensive scree cover conceals the underlying geology and merges downslope with pediment gravel and sand. In places it is difficult to distinguish between scree, pediment and high-level gravels, as for example in the Tulbagh–Wolseley and

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* Not yet approved by SACS

Saron–Voëlvlei areas. Southeast of Wolseley semi-consolidated scree and pediment gravel overlie an older erosion surface at the foot of the mountains – probably the "African Surface" of Partridge and Maud (1987) – which slopes towards the main drainages. Scree fans are found along the eastern slopes of the Stettyns Mountains, between Worcester and Villiersdorp, while remnants of an older, scree-covered land surface are found at about 580 m above sea level along the southern shoulder of the Langeberg Range, east of Robertson. According to Partridge and Maud (1987) these deposits are younger than the Late Jurassic to Early Miocene "African Surface", and they are attributed to structurally controlled dissection of variable age. In the high mountainous areas the scree consists of angular blocks of sandstone and quartzite varying in size from several centimetres to several metres, with fine grit, gravel and sand in between. In areas underlain by Bokkeveld rocks between De Doorns and Touws River, scree slopes are mostly covered by gritty sand with scattered rock fragments.

8.4 LOAM AND SANDY LOAM (T-Ql on map)

Loamy soil forms as weathering product of shale bedrock, such as the Bokkeveld, Malmesbury, Dwyka and Enon. Light-brown to red-brown loam and sandy loam soils are widely distributed south of the Breë River between Brandvlei Dam, south of Worcester, and Langvlei, where they overlie the Dwyka Formation. Soils overlying Dwyka sediments are usually also slightly calcareous. Between Worcester and Robertson, and also east of Robertson, areas underlain by the Enon Formation are also covered by loam. Smaller patches of these soils are found along the course of the Nuwejaars River, between Elim and Soetendalsvlei, overlying Bokkeveld shales. The large area with Bokkeveld bedrock, between Bot River and Riviersonderend and Napier, is almost entirely covered by a thin layer of loamy soil, but the underlying geology is mostly shown on the map.

8.5 RIVER TERRACE GRAVELS

These deposits are found at different elevations along the main drainage systems in the area, such as the following rivers: Riviersonderend, Breë, Berg, Klein Berg and Vier-en-twintigriviere. They consist mostly of rounded to well-rounded cobbles and boulders of the most resistant rock types in the catchment areas, usually sandstone and quartzite. Some of the older gravels are partly cemented with a calcareous, ferruginous or siliceous matrix.

Remnants of a terrace, about 15 m above the bed of the Breë River, are found west of Worcester. South and east of the town the terrace deposits merge with younger gravels of the Hex River piedmont fan. A similar terrace is present along the west bank of the Hex River at De Doorns.

Wide-spread terrace-gravel deposits are found at 2- to 5-m elevation above river bed along the Klein Berg River in the Tulbagh Valley and west of Nuwekloof Pass. Similar gravels line the Vier-en-twintigriviere streams at Saron, and farther southwards along the foot of the Elandskloof and Limiet Mountains towards Wellington. Gravels, in which palaeolithic artefacts of the "Stellenbosch Culture" have been discovered, are found at 15 and 30 m above the bed of the Berg River, east of Paarl. Other remnants of old erosion surfaces – without gravel cover – are found at 122 and 196 m above present river level, along the western slopes of the Klein-Drakenstein and Limiet Mountains and Groenberg (De Villiers *et al.* 1964).

Terrace gravel, up to several metres thick, is found at 6 to 8 m above river bed in the Ceres–Prince Alfred Hamlet area. Gravel terraces line the Riviersonderend River from south of Villiersdorp to Riviersonderend and farther east. They lie at elevations ranging from 6 to 5 m above the present river bed and display various degrees of calcareous or ferruginous cementation. The higher ones may be related to the middle Pliocene river terraces of Deacon *et al.* (1983). More-restricted terrace deposits are also present along the Klein and Nuwejaars Rivers, between Stanford and Agulhas, at elevations ranging from 6 to 20 m above the river beds. Krige (1927) related these gravels to +6- and +20-m marine transgressional events along the coast.

8.6 LIGHT-GREY TO PALE-RED SANDY SOIL (Qg on map)

Light-grey, sandy soils are by far the most extensive surface deposits in the map area. They are mostly the weathering product of Table Mountain sandstone and cover many of the major intermontane basin floors and valleys. These soils usually occur between slope scree and river alluvium, and therefore merge laterally into both these types of deposits.

The largest deposits of sandy soil occur along the Breë River Valley between Worcester and Wolseley, south of Brandvlei Dam, in the Franschhoek Valley, east of Kleinmond, and between Hermanus and Cape Agulhas. Similar deposits are found south and southwest of Verkeerdevlei, north of De Doorns. In the Hermanus–Agulhas area, these soils are often the weathering product of the Bredasdorp Group. They become darker, depending on the amount of organic matter present, and near the Botriviersvlei and Kleinriviersvlei, peat layers are interbedded with the sandy soil. On the other hand, clean white sands east of Kleinmond have been exploited as glass sand in the past.

Sand from the shores of Brandvlei Dam, and the banks of the Breë River southwest of Robertson, is blown upslope by prevailing westerly winds and has become quite a hazard, especially in the Brandvlei and Kwaggaskloof Dam areas south of Worcester. In places, as on the slopes of Sandberg, southwest of Robertson, sand has been blown over mountains and hills, and now also covers the leeward slopes.

8.7 BRACKISH, CALCAREOUS SOIL (Qb on map)

Brackish soils are mainly found in the southern coastal region, in marshes and pans situated on the calcareous Bredasdorp Group. Marshy areas along the tributaries of the Nuwejaars River east of Elim and the areas surrounding Waskraalsvlei, Voëlvlei, Soetendalsvlei and Soutpan, as well as along the Ratel River north of Quoin Point, are also included in this category. An area along the northern shore of the Theewaterskloof Dam, west of Villiersdorp, displays similar characteristics. These soils are generally clayey and grey to black, depending on the amount of organic material, and are overgrown by grass and reeds. During winter they may become completely submerged.

8.8 ALLUVIUM

The main alluvium deposits are found along the Riviersonderend, Breë, Hex and Doring Rivers, and their tributaries, as well as in the upper reaches of the Klein Berg and Vier-en-twintigriviere north and south of Saron. The boundary between alluvium, terrace gravel, pediment gravel and scree is not always clear and is therefore probably somewhat arbitrary in places. East and west of Worcester, and west of Franschhoek, a distinction was made between gravelly alluvium and sandy alluvium, but usually it consists of a mixture of sand, silt and gravel. Old alluvium-filled channels of the Breë and Vier-en-twintigriviere Rivers, overlain by younger alluvium and pediment, have been intersected in boreholes near the mountains. The composition of the alluvium varies from quartzose sand in Table Mountain sandstone terranes to silty in areas underlain by Malmesbury, Bokkeveld and Karoo rocks. Pebbles and cobbles usually consist of angular to well-rounded vein quartz and quartzite.

A geophysical study, by Van Zijl *et al.* (1981), of the Breede River Valley between Wolseley and Worcester showed that thick alluvium is mainly associated with the main tributaries such as the Holsloot, Molenaars, Jan du Toit and Waboom Rivers, and, to a lesser extent, with the Breede River itself east of Wolseley. They concluded that most of the alluvium was transported from the surrounding mountains by the tributaries. The thickness of the deposits varies from 20 to 40 m. The deposits consist of boulder deposits, which increase in thickness upslope away from the Breede River itself, and sandy alluvium. The total thickness of alluvium, as well as that of the boulder deposits, attains a maximum west and southeast of Rawsonville in the Molenaars and Holsloot Rivers.

9. INTRUSIVE ROCKS

The greenstones and the "Brewelskloof meta-andesite", which are closely associated with the Malmesbury Group, have already been described in the chapter dealing with the latter, since at least some of these rocks may be extrusive rather than intrusive.

9.1. CAPE GRANITE SUITE

There are six separate granite occurrences on the Worcester Sheet. Perhaps with the exclusion of the Worcester Granite Fragment all of them form part of Scholtz's (1946) "Southwestern plutons", which intruded Malmesbury sediments towards the end of the latter's main deformation phase. Consequently the granite plutons exhibit elongation parallel to regional anticlinal axes of the Malmesbury Group. Schoch *et al.* (1977) conclude that the Cape Granite plutons are high-level diapiric intrusions that crystallised from magmas produced by anatexis at progressively higher levels in the crust. They have been dated at between 630 and 500 Ma (Burger and Coertze 1973, 1976). Within each pluton several different granite types have been recognised on grounds of petrographical and petrochemical properties.

9.1.1 Wellington Pluton

This is perhaps the occurrence of Cape Granite about which least is known, because of its very poor exposure and deep weathering. The Pluton has a strike length of about 35 km and a width of about 12 km, if the isolated exposures in the Du Toitskloof Pass and at Wemmershoek Dam are included with the main outcrop around Wellington. The exposure in Stettynskloof, south of Rawsonville, is also regarded as part of the Wellington Pluton. Exposures of the Wellington Pluton, the Stellenbosch Pluton, and also the Paarlberg Pluton beyond the western boundary of the map, are spatially so close together in the Wemmershoek–Franschhoek region that they seem to belong to the same intrusion.

The only available information on the Wellington Pluton is by Siegfried (1984). According to him the best exposures occur in the Daljosaphat Forest Reserve 582, in Du Toitskloof Pass and on the farms Bloukommetjieskloof, Dagklip and Twyfeling around Wellington. A contact-metamorphic aureole of between 800 and 1 400 m wide is present in Malmesbury rocks around Wellington. Siegfried (1984) recognised three different types of granite in the Wellington Pluton – not distinguished on the map – but, because of poor exposure, could not always determine their contact relationships.

The main body of the Wellington Pluton consists of a coarse-porphyritic to coarse-grained granite which Siegfried informally named the Groenberg Granite. It also includes the exposures in the Du Toitskloof Pass and at Wemmershoek Dam. The granite is light grey and contains K-feldspar phenocrysts with a bimodal size distribution of 30 and 10 to 15 mm respectively. The phenocrysts are rounded and randomly oriented. Biotite crystals appear to be peripherally altered to chlorite. A few elongated xenoliths, up to 20 mm in diameter, were observed.

A medium-grained porphyritic granite, that occurs mainly in the southern part of the Pluton in Du Toitskloof Pass and in the Daljosaphat Forest Reserve, was informally named the Daljosaphat Granite by Siegfried. The matrix of this granite is generally finer grained than that of the "Groenberg Granite", and phenocrysts – some 20 mm in diameter – are also fewer. This granite is highly weathered in all of the outcrops.

Isolated boulders and a few dykes of a fine-grained granite, informally named the Kleinbosch Granite by Siegfried, are intrusive in both the "Daljosaphat" and "Groenberg Granites". The granite is even grained with a matrix grain size of 3 to 5 mm. Muscovite is the dominant mica. The "Kleinbosch Granite" occurs on the slopes of Groenberg, 5,5 km north of Wellington in the Daljosaphat Forest Reserve, and 5 km south of Wellington on the farms Leeurivier, Welbedacht, Olyvenbosch and Klein Olyvenbosch. One of the dykes can be seen in the road cutting near the summit of Du Toitskloof Pass.

Quartz-porphyry dykes in the Wellington Pluton are discussed later.

9.1.2 Stellenbosch Pluton

All granite exposures in the Berg River Valley between Lategan Siding and Franschhoek, as well as those on Elands Kloof 5 north of Villiersdorp, have been grouped with this Pluton. These granites are mainly granite porphyries, according to De Villiers *et al.* (1964), and also include their pre- and post-Klipheuwel Formation (i.e. Franschhoek Formation) intrusions. More recent information is provided by Dunlevey (1983, 1984) and Siegfried (1985).

Siegfried (1985) recognised a coarse-grained granite in the vicinity of Lategan Siding, as well as south and west of Middenberg, west of Franschhoek. The best outcrop is on the farm Rosalind, northwest of Lategan Siding, and this granite contains K-feldspar phenocrysts, quartz, plagioclase and biotite. In the same vicinity coarse-grained granite with fine-grained granite dykes are present on Lormarins 1166. At the waterfall on this farm, deep fractures in the granite have been infilled with purple mudstone from the overlying Table Mountain Group.

De Villiers *et al.* (1964) differentiated between two granite porphyries north and south of Franschhoek. The northern one was regarded as younger than the

Franschhoek Formation and the other as forming the "basement" for the Franschhoek Formation. A similar distinction was subsequently made by Hartnady (1969) and Dunlevey (1983). In the southwestern end of the Franschhoek Valley, the latter author distinguished between an older (pre-Malmesbury), grey-green non-porphyritic "Keerwedernek Granite" and a reddish, porphyritic "Assegaaibosch Granite", which he regarded as belonging to the Cape Granite Suite. The Keerwedernek Granite, which also contains xenoliths of the Assegaaibosch Granite, has a more basic composition than the average Cape Granite (Dunlevey 1983). These granites are often brecciated by faulting in the Assegaaibos region and are also altered and highly weathered. They have not been distinguished on the map.

De Villiers *et al.* (1964) considered most of the granite on Elands Kloof 5 as post-Franschhoek granite porphyry, but Hartnady (1969) mapped it as a sheared granitoid with one younger granite-porphyry boss in Perdekloof, situated in the southwestern part of the valley.

9.1.3 Hermanus Pluton

In the southern part of the Worcester Sheet, six separate granite occurrences are exposed as fault-bounded inliers in eroded anticlinal crests of Table Mountain Group rocks. These are the exposures: (1) on Hemel En Aarde 587 (Onrus River Valley) north of Hermanus, (2) along the southern edge of the Kleinriviers Mountains east of Hermanus, (3) on and in the vicinity of the farms Zondags Kloof 672 and Paapjes Valey 679, 15 km east of Stanford, (4) along the Koue River on Platte Rug 203 and on Toekoms 244, respectively northwest and northeast of Elim, (5) in the Uilkraals River Valley on Avoca (The Hell 737), northeast of Franskraalstrand, and (6) along the beach and Haelkraal River, east of Pearly Beach. Some of these occurrences have been named and given "pluton status", namely the Onrus (1), Avoca (5) and Haelkraal (6) Plutons (SACS 1980). However, when the mega-anticlinal structure, of which the northern limb is defined by the Kleinriviers and Bredasdorp Mountains, is restored to its original shape, prior to Mesozoic tensional faulting, all these exposures occupy the axial region of a single structure and it seems unnecessary to regard each exposure as a separate pluton. It is proposed here that all these occurrences form part of a single intrusive body, the Hermanus Pluton.

Although various types of granite have been described from this area, the general composition of the Hermanus Pluton is that of a coarse-grained to porphyritic granite. All exposures have been subjected to kaolinisation.

On Hemel En Aarde 587 along the Onrus River, an older, sheared, porphyritic biotite granite is intruded by a younger unsheared granite (De Villiers *et al.* 1964). Good exposures occur at the Attakwaskloof Dam where a number of quartz-porphyry dykes are also visible.

The Avoca Granite is also coarse porphyritic, with feldspar phenocrysts up to 60 by 30 mm on Zondags Kloof 672 and Paapjes Valey 679. Other minerals include quartz, muscovite, microperthite, plagioclase and apatite. The granite is usually highly sheared, due to the boundary faults. Fresh outcrops can be seen only along the Uilkraals River. The lithologically similar Paapjes Valey/Zondags Kloof Granite exposure exhibits flow orientation of phenocrysts and a fine-grained chill phase adjacent to Malmesbury contacts. This granite is highly sheared at the base of the Table Mountain Group and has been transformed into a greenish quartz-feldspar-chlorite gneiss. The exposure of similar granite north of the Kleinriviersvlei, east of Hermanus, is cut by aplite veins.

The coarse porphyritic, muscovite-biotite granite which crops out over a distance of 1,5 km along the coast southeast of Pearly Beach, as well as along the Haelkraal River farther inland, extends for about 20 km offshore (Gentle 1977). The eastern half of the exposure is characterised by tourmaline nodules, 20 to 30 cm across (Fig. 9.1), while the northwestern part has the composition of a microadamellite. The tourmaline nodules are ascribed to a late phase of boron somatism and consist of bluish quartz, black tourmaline (schorl) and creamy-coloured plagioclase. The "Haelkraal Granite" exhibits a certain degree of cataclasis which can be ascribed to deformation during the Cape Orogeny (Gentle *et al.* 1978). The latter authors obtained a K-Ar biotite age of 248 ± 1,5 Ma for this granite, which is in agreement with the second episode of the multiphase Cape Orogeny (Hälbich *et al.* 1983).

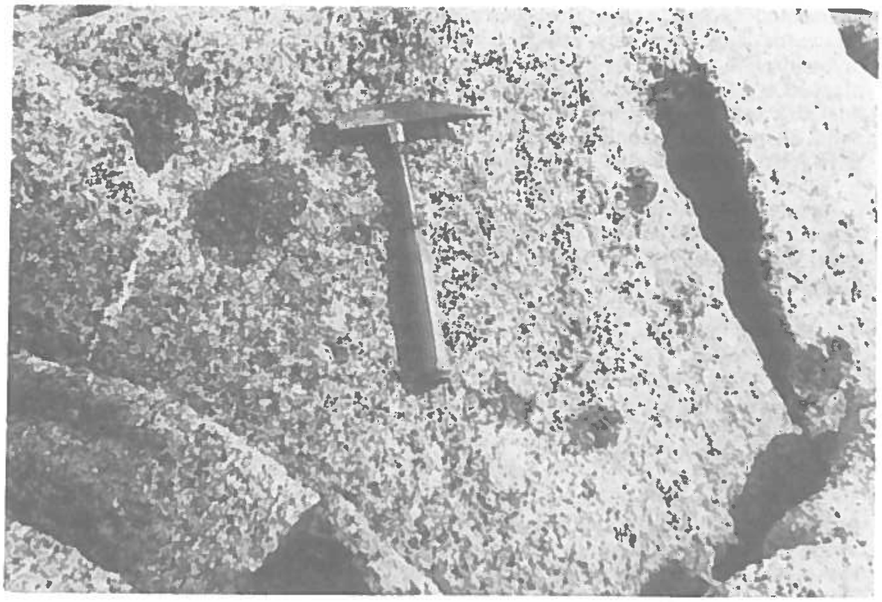

Fig. 9.1 - Tourmaline nodules in the "Haelkraal granite" east of Pearly Beach.

A coarse- to medium-grained granite is found on the farm Toekoms 244, northeast of Elim, and fresh outcrops occur along the road between Boskloof and Kersgat on Bos-Kloof 138. The main constituents of this granite are quartz, oligoclase and micropherthite. A 10-m-wide, fine-grained, biotite-granite dyke occurs in the Koue River on Platte Rug 203, northwest of Elim.

9.1.4 Worcester Granite Fragment/Pluton?

Isolated remnants of this controversial granite are found in small patches north of the Worcester Fault, between Worcester and Robertson. Texturally this granite is atypical of the Cape Granite in that it is an intensely tectonised, gneissic rock, which, according to De Villiers *et al.* (1964), exhibits all gradations from a crushed granite to mylonite. Rogers and Schwarz (1900) referred to it as a "phyllite-gneiss", Toogood (1976) called it an augen schist, while De Bruyn *et al.* (1974) mapped it as equigranular granite and quartz porphyry. Also, other than typical granite plutons of the Cape Granite Suite, this granite does not show intrusive contact relationships with the Malmesbury, but was emplaced tectonically as an allochthonous, south-dipping thrust sheet (Hartnady 1969). It may therefore belong either to a pre-Malmesbury basement, or to one of the Cape granite plutons farther south. In the Brewelskloof area, north of Worcester, the granite gradually becomes more sheared northwards as the contact with Malmesbury rocks is approached. In the process the rock changes from gneiss with a porphyroblastic texture to a fine-grained quartz-sericite rock or mylonite.

Towards the east, in the direction of Robertson, the rock apparently becomes more schistose. Toogood (1976) describes it as a light-grey, well-foliated schist with quartz and feldspar augen in a quartz and chlorite matrix. The texture is clearly cataclastic and dark-grey, siliceous zones may represent zones of advanced mylonitisation. A coarser-grained variety, with augen up to 80 cm in length, was mapped as conglomerate by De Bruyn *et al.* (1974). Toogood (1976) suggested that this rock could represent a pseudoconglomerate formed by severe deformation of aplite dykes in the granite. Good exposures occur in an irrigation canal north of the farm Bellevue (De Nonna 341), between Worcester and Nuy.

Hoal (1978) reported the presence of possible acid volcanics (rhyodacite or quartz andesite) in the granite north of Worcester. This has yet to be confirmed. De Villiers *et al.* (1964) also reported a dolerite intrusion in the granite which Siegfried (1984) thought to be a dyke of biotite eucrite related to the Brewelskloof intrusion.

Two fractions of a sample of the granite of Worcester yielded concordant U/Pb zircon ages of 557 $\pm$ 13 Ma and 575 $\pm$ 13 Ma (Walraven *et al.* 1987). This seems to suggest that it belongs to the Cape Granite Suite, but it could also be an upthrusted fragment of basement granite, reset during the Saldanian Orogeny.

9.1.5 Robertson Pluton

The Robertston Pluton is an eliptical intrusion into the Norree Formation of the Malmesbury Group, located between the Langeberg Range in the north and the Worcester Fault in the south, and comprising an exposed area of about 31 km². It has been discribed by Rastall (1911), Scholtz (1946) and, more recently, by Dunlevey (1984). The last-mentioned author distinguished four different granites, as well as a later diabase intrusion and three different sets of quartz veins. These distinctions are not shown on the map.

Most of the Pluton is composed of a medium- to fine-grained granite, the "Willem Nelsrivier Granite" (Dunlevey 1984), containing feldspar phenocrysts up to 17 mm in length. Other primary minerals include quartz, biotite, apatite, zircon and ilmenite. Biotite shows alteration to chlorite, and plagioclase to saussurite. The "Willem Nelsrivier Granite" is marginally sheared to produce a microgranite-like material, previously referred to as a marginal zone or hood facies by Scholtz (1946) and De Bruyn *et al.* (1974). Rare xenoliths occur in the form of biotite nodules which are up to 15 cm in diameter.

The wedge-shaped "Koenieboskraal Granite Porphyry" is intrusive into the former granite, east of the Tierberg ridge. The two granites are interleaved over a distance of 50 to 150 m along a north-northeast-trending zone that dips westwards. Creamy white feldspar phenocrysts in the rock are up to 5 cm long and display preferred orientation parallel to a distinct foliation in the matrix. The age relationship between the granite porhyry and the other granite types is unknown.

The marginal zone of the Robertson Pluton, especially the northeastern segment, contains aplogranite dykes, up to 1 m wide, named the Dassieshoek Aplogranite by Dunlevey (1984). The aplogranite is a white-weathering, fine- to medium-grained, quartzo-feldspathic rock and traverses the marginally sheared "Willem Nelsrivier Granite" and adjacent Malmesbury sediments.

The "Norree Pseudo Quartz Porphyry" dykes (Dunlevey 1984) transect the northwestern segment of the Pluton in a north-northwesterly direction. This rock type is fine grained with a dark blue-green colour and contains quartz grains up to 7 mm in diameter. These dykes or sheets are foliated parallel to their rather diffuse contacts and usually contain a median shear or fracture. Similar sh-.rs are present in the adjoining host rock. Dunlevey (1984) suggested that the porpnyry sheets might have been formed by fluids reacting with the "Willem Nelsrivier Granite" during mylonitisation and brecciation.

Various ages of quartz and quartz–tourmaline veins and shears, related to both pre-Cape and Cape orogenic events, were recognised by Dunlevey (1984). He also mentioned reports of small-scale scheelite (tungsten), gold and cobalt enrichment in the Malmesbury host rock adjoining the Robertson Pluton. A single U/Pb age determination on this Pluton yields a minimum age of 479 $\pm$ 10 Ma (Burger and Walraven 1976).

9.1.6 Greyton Pluton

This granite occurs in the pre-Cape inliers about 7 km northwest and 1,5 km north (not shown on map) of Riviersonderend. The Pluton, which is elongated parallel to the east–west strike of the Malmesbury rocks, has a strike length of about 8 km and is 1 km wide, although it disappears northwards underneath the Cape unconformity. The intrusive contact with the Malmesbury rocks is fairly clear but there is hardly any evidence of contact metamorphism. The granite has been described by Beyers (1935), Scholtz (1946) and, more recently, by Dunlevey (1984). The latter recognised three types of granite – not indicated on the map.

A medium- to coarse-grained biotite granite, the Jongenskloof Granite, forms the main mass of the Pluton. Scattered feldspar phenocrysts occasionally exceed 15 mm in length. Very rare xenoliths, in the form of biotite nodules, are less than 50 mm in diameter.

This granite is intruded by the Vlermuisboskloof Granite Porphyry (Dunlevey 1984) along the southern edge of the Pluton. The two granites are interleaved along their contact over a distance of 50 m. The quartz–feldspar–biotite matrix of the porphyry, characterised by K-feldspar phenocrysts (up to 30 mm), is sheared parallel to the contact zone, suggesting syntectonic intrusion.

Aplogranite dykes, less than 25 cm wide, penetrate the two afore-mentioned granites at the western and eastern extremities of the Pluton. Dunlevey (1984) named this leucocratic rock, composed of very small grains of creamy white feldspar and glassy quartz, the Soetmelksvleirivier Aplogranite. In addition to a few quartz veins, one diabase dyke intrudes the granite on The Oaks 145.

9.1.7 Quartz-porphyry dykes (єkp on map)

Quartz-porphyry dykes intruded the Wellington, Stellenbosch and Hermanus Plutons, as well as the Malmesbury Group in the Worcester and Franschhoek Valleys. These dykes are particularly common in the Wellington–Paarl–Franschhoek region where they are known as the Franschhoek Quartz Porphyry Dykes (Dunlevey 1981), but similar rocks have been described by Schoch and Burger (1976) for an area near Saldanha on the West Coast. Geochemical and geochronological evidence indicate that the quartz-porphyry intrusions belong to the final stages of the emplacement of the Cape Granite Suite (Dunlevey 1981).

In the Franschhoek region the quartz porphyries are intrusive in the Franschhoek Formation, formerly regarded as "Klipheuwel Formation" by De Villiers *et al.* (1964). The recognition of the dykes as part of the Cape Granite Suite proves that the Franschhoek Formation belongs to the Malmesbury Group, and refutes the "pre- and post-Klipheuwel intrusive events" shown on the 1:125 000 Worcester/Caledon Sheet of 1966.

The quartz porphyries consist of a cryptocrystalline matrix with phenocrysts of euhedral, fractured or rounded microcline microperthite, plagioclase and embayed quartz phenocrysts. A distinguishing feature is the red colour of some of the feldspars. Other minerals include biotite, chlorite, hypersthene and zircon, while spherulites are common in the matrix. The name rhyolite porphyry may also be applicable to the rock (Schoch and Burger 1976), and in larger bodies it grades into granite porphyry with a microcrystalline texture.

Quartz-porphyry intrusions occur on the eastern flank of Kleinberg between Worcester and Wolseley, in the Stettyns and Wemmershoek Valleys, in the Franschhoek Valley between Lategan Siding and Assegaaibos Dam, in the Elandsrivier Valley north of Villiersdorp, as well as in some exposures of the Hermanus Pluton. Five quartz-porphyry dykes, one containing a Malmesbury xenolith, are exposed in the Du Toitskloof Pass east of Paarl. A dyke swarm, probably corresponding to those mapped by Dunlevey (1981) in the Franschhoekberg tunnel, occurs on the slopes of Middenberg, southwest of Franschhoek.

Petrographic evidence suggests that the quartz-porphyry dykes intruded rapidly under a very steep pressure gradient causing mechanical fracturing and resorption of crystals. The Franschhoek quartz porphyries have been dated at 536 $\pm$ 35 Ma (Dunlevey 1983).

9.2 DOLERITE (єd on map)

A large number of dolerite dykes are intrusive into Malmesbury rocks and granites throughout the area. They tend to occur in swarms, often with either northwesterly or northeasterly strikes. Although they clearly post-date pre-Cape rocks, intrusive relationships with younger units are seldomly exposed. It is highly probable that most of them belong to the so-called Western Province dolerites (Nell and Brink 1944), which pre-date the Jurassic Karoo dolerites. According to Visser *et al.* (1981) the greenstone dykes – or epidiorites – of the Tulbagh region exhibit a higher degree of alteration and shearing than the afore-mentioned dolerites. Some dolerites are also greenish in colour and have undergone various degrees of low-grade regional metamorphism and deformation – probably related to the Permo-Triassic Cape Orogeny -- but they, unlike the greenstone dykes, seem to post-date the Late Proterozoic Saldanian Orogeny in all instances.

Northeast-trending dykes cut across the stratigraphy of the Malmesbury metasediments at Voëlvlei and north of Worcester, while strike-oriented dykes occur in the Tulbagh Valley and north, east and south of Wellington, especially along the Bainskloof Pass. Many of the dykes are also intrusive in granites, as for example in the Wemmershoek Valley and south of Lategan Siding in the Franschhoek Valley. Other dykes have been mapped south of Franschhoek, west of Middenberg, and on Elands Pad 586 south of the Du Toitskloof Pass. Dunlevey (1984) also reported "diabase" dykes in the Robertson and Greyton Plutons. The dolerite dykes are generally in the order of 3 to 20 m wide and can only in exceptional cases be followed for more than 10 to 15 km along strike, usually much less.

The dolerite is typically dark grey or greenish grey and fine to medium grained. The main constituents are plagioclase and augite, and the texture is generally subophitic. Accessory minerals include serpentine (after olivine), quartz, apatite, biotite, pyrite, magnetite and ilmenite. Hornblende and pyroxene are usually altered to uralite, and plagioclase to saussurite, epidote, calcite and chlorite. De Villiers *et al.* (1964) report porphyritic and amygdaloidal dolerites from Wemmershoek which are composed of pigeonitic augite (20%), labradorite (68%), andesine (8%) and epidote, ilmenite, pyrrhotite and quartz (4%). Some dykes in the Bainskloof Pass also contain spessartite and pargasite. South of Lategan Siding a dolerite dyke which had intruded granite, reacted with it to form quartz-diorite or diorite porphyry, which, in turn, intruded the granitic host rock as veins. The quartz-diorite is composed of quartz (15%), pigeonitic augite partly altered to amphibole, clinozoisite (14%), hornblende altered to chlorite, epidote (11%), plagioclase (50%) and accessories such as biotite, epidote, clinozoisite, chlorite, sericite, apatite and iron oxides.

9.3 OLIVINE MELILITITES (Tm on map)

The olivine melilitites of the southern Cape belong to a period of alkaline igneous activity which occurred on the Southern African subcontinent during the Early Cretaceous to Paleogene (Dingle *et al.* 1983). Two plugs of olivine melilitite occur on the Worcester Sheet, east of Robertson (Verwoerd *et al.* 1990).

One of these is intrusive in the Mesozoic Enon Formation on the farm Goedvertrou 45, 8 km east of Robertson. The weathered plug is situated on a ploughed hilltop west of the Klaas Voogds River, where it was apparently first discovered by A.W. Rogers (Rogers and Schwarz 1900). Söhnge (1934) regarded it as an explosion breccia, about 60 m long, consisting of angular fragments of white quartzite in a dark-green to black matrix. According to Taljaard (1936) the fine-grained, pitted rock consists of serpentinised olivine, augite, melilite (2,3%), magnetite, volcanic glass and zeolite minerals.

The other, better-known occurrence, the "Goedemoed" plug (Verwoerd *et al.* 1990), intrudes Witteberg Group rocks on the farm Wolvendrift Annex 126, 13 km southwest of Robertson. It has been described by Taljaard (1936), Mathias (1949), Gerrard (1958) and Duncan *et al.* (1978), who gave a whole-rock K-Ar date of 63,7 ± 1,3 Ma for the plug. The intrusion forms massive outcrops, 150 m across, with columnar jointing and an inconspicuous contact-metamorphic aureole, on the northern flank of Elandsberg, immediately south of the Breë River. The rock is fresh and consists of olivine (32,5%), augite (30,5%), melilite (14,6%) and magnetite (15,2%), with subordinate perofskite and biotite (Taljaard 1936). Other workers also reported nepheline, leucite, analcime, apatite and spinel.

10. STRUCTURE

10.1 INTRODUCTION

Two major orogenic events affected the map area. The basement sequence of Malmesbury Group rocks was deformed in late Precambrian to Cambrian times by the Saldanian Orogeny (Hartnady *et al.* 1974) which culminated before, and continued till after, the intrusion of the Cape Granite Suite between 630 and 500 Ma ago (Allsopp and Kolbe 1965; Burger and Coertze 1973, 1976; Schoch and Burger 1976). The basement sequence west of longitude 19°E is divided into three tectonic terranes (Fig. 3.1) (Hartnady *et al.* 1974) that need not necessarily be of exactly the same age.

Cover rocks of the Cape and Karoo Sequences, following upon a major post-Saldanian unconformity, were deformed by the Permo-Triassic Cape Orogeny (Söhnge and Hälbich 1983). This deformation episode, to a limited degree, reactivated some structures in the basement, but produced a strong overprinting of structures in areas of intense Cape-age orogenic activity.

Most of the Syntaxis Domain (Söhnge and Hälbich 1983), the area in which the easterly striking Southern Cape Fold Belt and the north-northwesterly striking Western or Cedarberg Fold Belt merge and curve towards the southwest, is situated within the map area. The result is that the Syntaxis Domain contains a series of relatively tight synclinal and anticlinal structures related to both the western and southern arcuate fold belts. Although it was previously believed that the Cedarberg Fold Belt is older than the southern one (De Villiers 1944), recent studies on the syntaxis seems to favour contemporaneous development of the two trends (De Beer 1989).

Post-Jurassic normal and strike-slip faults traverse the area in easterly, northwesterly and southwesterly directions, and resulted in considerable fragmentation and displacement of structures of both orogenies.

10.2 SALDANIAN OROGENY

10.2.1 Tygerberg terrane

Only a few small outcrops between Stanford and Elim, in the southern part of the area, are correlated with the Tygerberg terrane of the southwestern Cape. All these occurrences are intruded and locally metamorphosed by granite, but the exposure is so poor that little can be said about their structural features. They display up to two cleavages that transect the bedding. The younger cleavage was overprinted during the Cape Orogeny.

10.2.2 Boland terrane

Because of the apparent southeastwards wedging out of the Swartland terrane, (Hartnady 1985) all other pre-Cape exposures on the Worcester Sheet are included in the Boland terrane. The only modern structural investigations of these rocks are those of Hartnady (1969) and Toogood (1976). Hartnady investigated the pre-Cape rocks north of Worcester between Waaihoek and the Hex River, at Franschhoek and at Kaaimansgat, near Villiersdorp, while Toogood studied the area between the Hex River and the Robertson Pluton.

North of Worcester, Hartnady (1969) recognised four phases of deformation of which at least the first three were related to pre-Cape (Saldanian) tectonism. He postulated a first "phase O," which produced large north-facing folds and which determined the variable attitude and geometry of smaller "phase-M" folds (Fig. 10.1). Phase M represents the main folding event, with northwesterly trending folds, during which a penetrative slaty cleavage (S1) developed. The observed inhomogeneity of the phase-M folds is the result of the control exerted by the pre-existing phase-O structural geometry. A lineation on S1, which takes the form of both an intersection lineation and a stretching lineation (elongated pebbles in conglomerate), plunges variably towards the south. A later "phase X" folded the S1 cleavage conjugately into northeast and north-northwest-striking folds with axial-planar crenulation cleavages. The two trends may also occur in isolation. The youngest event, "phase K", is represented by weak, open crenulations with subhorizontal axial planes.

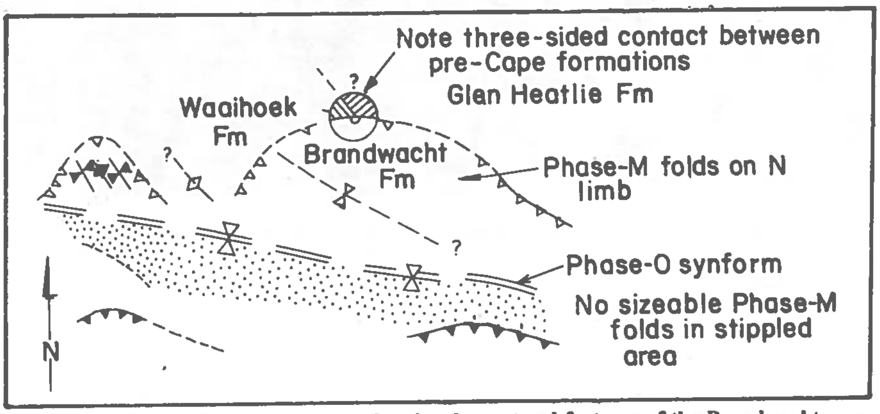

Fig. 10.1 - Schematic-plan view of regional structural features of the Brandwacht Formation between two confining thrust planes. (From Hartnady 1969).

Hartnady (1969) proposed a close relationship between phases M and X, in which constriction during phase X occurred in domains of greater mechanical anisotropy, during phase-M flattening. He did, however, leave the option open that phases X and K could be imprints of the Cape Orogeny. The tectonic dislocation at the base of the Brandwacht Formation was described as a phase-O tectonic slide, while the granite in the south was emplaced and foliated as a phase-M thrust sheet.

Phase-M structures are also present in the Porterville and the Norree Formations, which underlie the Brandwacht Formation to the west and east respectively. Isoclinal folds in the Norree Formation that are truncated by the Cape unconformity on Vredehoek 602, southeast of Wolseley (Fig 10.2), as well as south of Ceres at the entrance to Mitchell's Pass, are probably examples of this event. Between Wellington and Gouda, at the Voëlvlei Dam and on Limiet River northeast of Groenberg, the Porterville and Norree Formations display excellent examples of north-northwesterly folds and an upright cleavage, which can probably be correlated with Hartnady's phase M at Worcester.

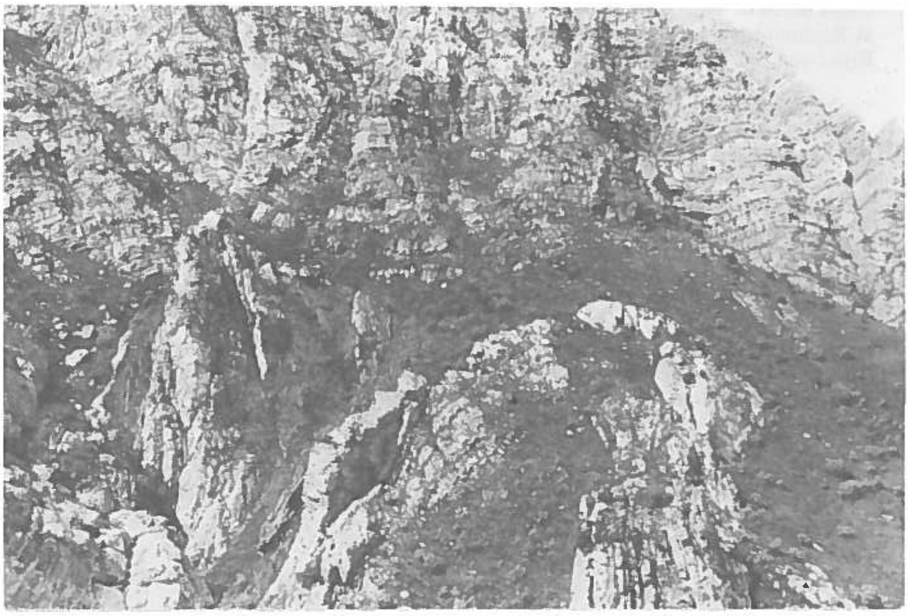

Fig. 10.2 - Unconformity between folded Norree Formation (Malmesbury Group) and shallowly inclined Peninsula Formation at Waaihoek, between Worcester and Wolseley.

East of Worcester, similar structures have been described by Toogood (1976). He recognised "phase-M" structures as isoclinal, reclined folds with a southerly dipping, penetrative, axial-planar cleavage and down-dip stretching lineation, parallel to the fold axes. Measurements on pebbles showed constrictive strain during this main folding event (Fig. 10.3). Toogood, however, maintained that the foliation in the sheared granitoids occurring sporadically along the Worcester Fault pre-dates the main deformational event (phase M), as it is cut by the latter cleavage on the farm Bellevue, east of Worcester. The Robertson Pluton intruded towards the end of phase-M folding, causing a local deflection in the regional tectonic grain, and was itself marginally sheared in the process (Toogood 1976; Dunlevey 1984). Late-phase crenulation structures probably correspond to Hartnady's phase X.

Hartnady (1969) also conducted structural analyses farther south at Franschhoek and Kaaimansgat in rocks now correlated with the Franschhoek Formation. These were, however, less successful, because of very poor exposures and the deeply weathered nature of the rocks. He concluded that the main deformation at Kaaimansgat could probably be correlated with phase M at Worcester, but that the Franschhoek deformation differed from it. He attributed this to the fact that different zones in the Malmesbury Group reacted differently to applied stresses during the Saldanian Orogeny.

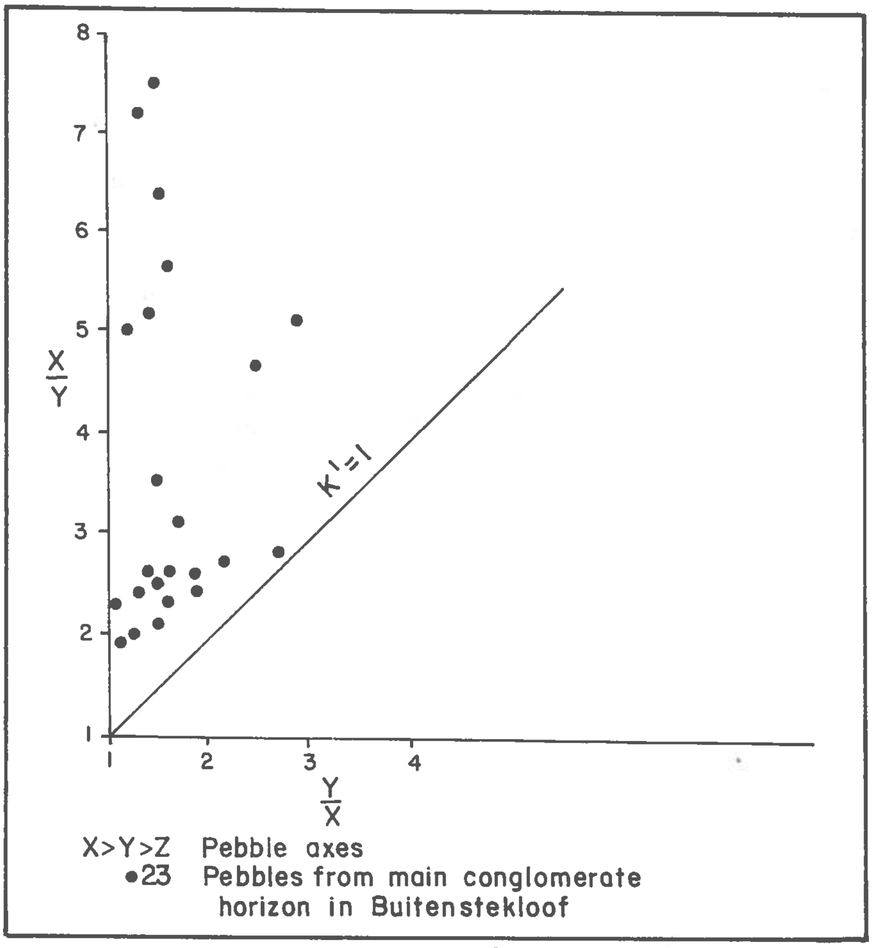

Fig. 10.3 - Axial-ratio plot for deformed conglomerate pebbles, Brandwacht Formation. (From Toogood 1976).

10.2.3 Metamorphism

Regional metamorphic conditions in the Brandwacht Formation attained a maximum during phase-M deformation and reached conditions of about 400 °C (± 50 °) at c. 3 kb (Hoal 1978). The presence of biotite in the Brewelskloof meta-andesite suggests that biotite-grade greenschist-facies conditions were reached. Biotite grew both syn- and post-tectonically and this implies that the peak of metamorphism outlasted phase-M deformation. Elsewhere in the area, pre-Cape metamorphic conditions apparently never exceeded lower low-grade (chlorite-grade) or even very low-grade conditions.

Limited contact-metamorphic effects associated with granite intrusions have been reported from the area. Mostly the Malmesbury rocks are hornfelsic only in the immediate vicinity of granite bodies, and are characteristically spotted, owing to the growth of biotite and/or andalusite, especially around the Wellington Pluton. Dunlevey (1984) reported the presence of diopside and grossular garnet in dolomite and limestone in the contact-metamorphic aureole of the Robertson Pluton, conforming to the hornblende-hornfels facies of medium-grade metamorphism. Chloritoid is ubiquitously present in Malmesbury rocks within a distance of 10 to 50 m from the contact with the overlying Table Mountain Group, but this is related to dynamothermal metamorphism during the Cape Orogeny.

10.3 CAPE OROGENY

The outcrop pattern of the Cape Supergroup on the Worcester Sheet reflects the main structural features of the Cape Orogen, namely a series of parallel mega-anticlinal mountain ranges separated by synclinal, intermontane valleys. The main features are the continuous Witzenberg–Waaihoek–Langeberg and the semi-continuous Landskloof–Du Toits–Stettyns–Riviersonderend Ranges, separated by the Worcester–Robertson Valley, and followed by other similar structures farther south. These major structures curve from a northerly strike in the west (Cedarberg Belt) to easterly in the east (Southern Cape Belt), with subordinate northeasterly folds in the central Syntaxis Domain (Fig. 10.4). Generally, only the northern limbs of mega-anticlines are preserved, the southern halves having been down-faulted in Mesozoic times by major easterly trending normal faults, such as the Worcester and Riviersonderend Faults that tend to follow the major structures.

Very little is known about the style and age of the western Cedarberg Fold Belt. From the map it is evident that, in the area concerned, it consists of a series of rather simplistic parallel synclines and anticlines that die out towards the east, north of Ceres, and apparently also to the west. This is the reason why De Villiers (1956) felt that these folds were mainly monoclinal in character. The fold belt as a whole is convex towards the east.

The Southern Cape Fold Belt has been studied in detail by Hälbich and co-workers (Söhnge and Hälbich 1983). This Belt is also arcuate and convex towards the north. Hälbich (1983) concluded that the deformational history of the Southern Belt was sequential and affected by northerly directed compression. The orogenesis consists of four paroxysms that produced coaxial, easterly trending structures over a period of 48 Ma from Early Permian to Middle Triassic. The structures consist of northward-vergent folds, overfolds and thrusts that include gravity-induced collapse folds and bedding décollement along some northward-inclined megalimbs.

The Worcester Sheet covers mainly the Syntaxis Domain of the Cape Fold Belt (Fig. 10.4). In the east and southeast structures conform to Hälbich's (1983) thin-skinned, thrust tectonic model. Folds are north and northwest vergent, and ample evidence of northwesterly directed thrusting and imbrication is visible in the mountains between Quoin Point and Gansbaai (Fig. 10.5), as well as in coastal outcrops. Stretching lineations and slickensides trend northwest. On Waterval 671, east of Stanford, granite below the Cape unconformity is intensely sheared, foliated and refoliated over a distance of 20 to 30 m below the contact, suggesting large-scale thrusting along this contact. Evidence of thrusting, or reverse faulting, was also observed southeast of Villiersdorp, on Bosch Kloof 65, and north of Grabouw in the Nuweberg Forest Reserve, where the Cedarberg and Pakhuis Formations are

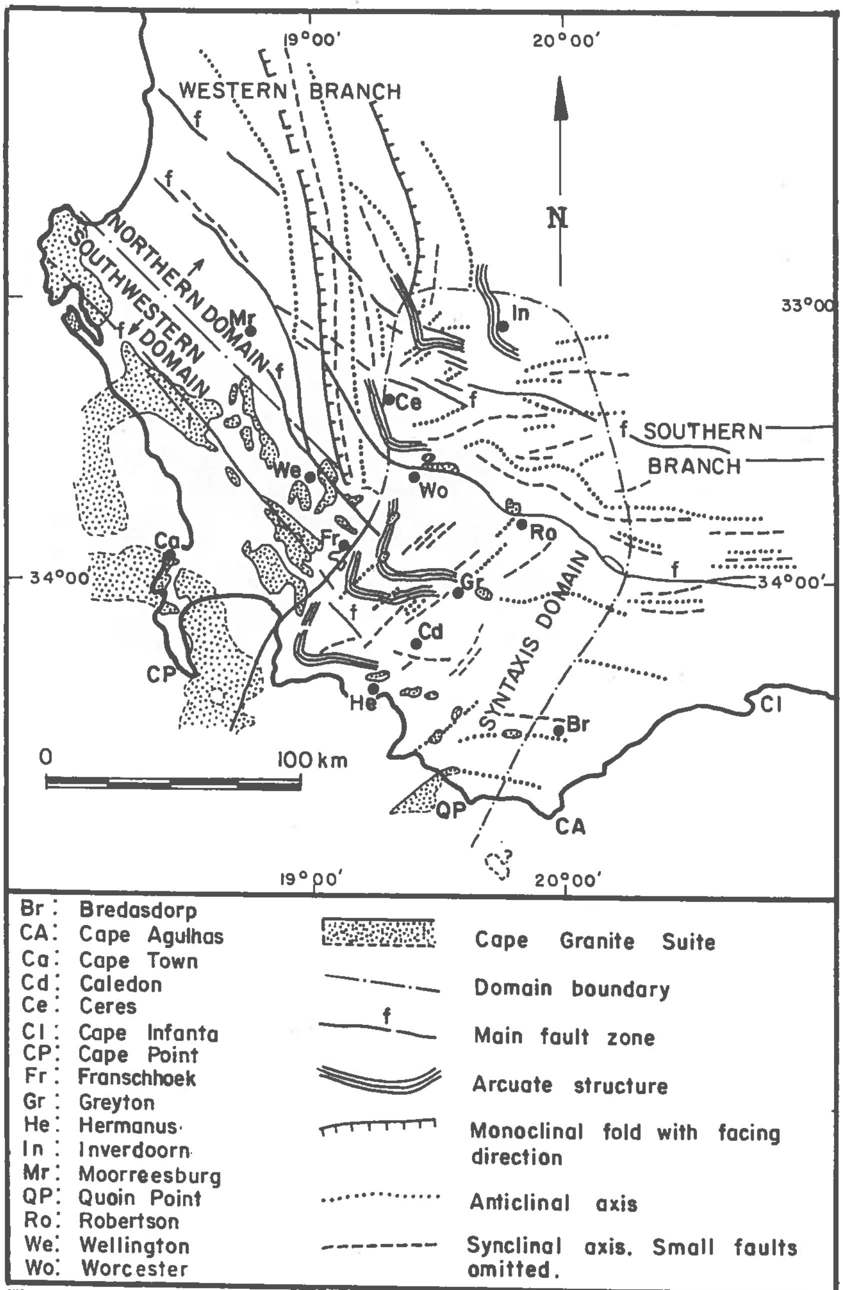

Fig. 10.4 - Tectonic domains of the Cape Fold Belt in the southwestern Cape Province. The western branch comprises a northern domain, with folded formations on metapelite basement, and a southwestern domain, with almost undisturbed cover on granite-invaded basement. The southern branch comprises east-trending folds. The syntaxis domain, with isolated plutons in the basement, is characterised by a complex interplay of box folds and buckles formed by compressive stress. (From Söhnge and Hälbich 1983).

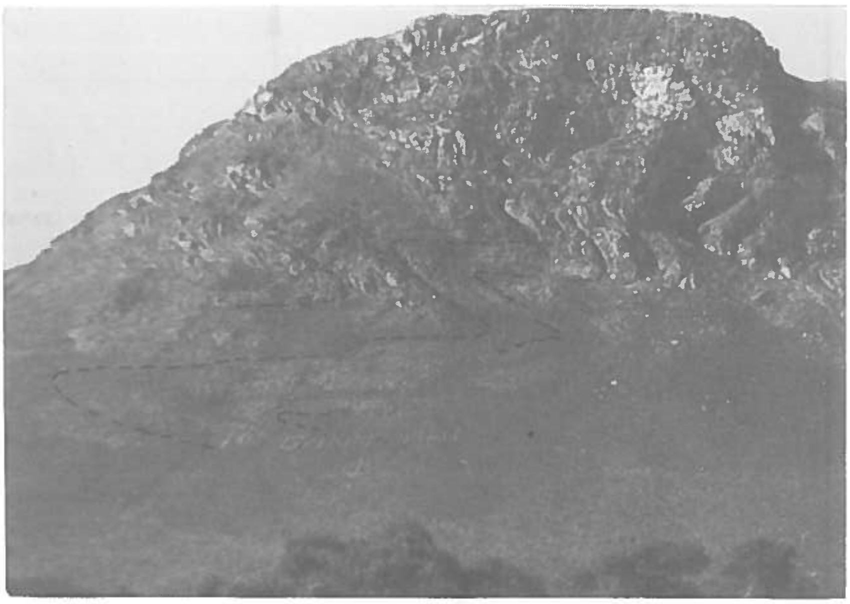

Fig. 10.5 - North-vergent and recumbent folds in the Table Mountain Group overlying a possible thrust in the Franskraal Mountains, east of Gansbaai.

duplicated as a result of thrust imbrication. Gresse (1988) also proved thrusting of the Brandwacht Formation over the Peninsula Formation, along the Langeberg Mountains between Worcester and Nuy, as opposed to Toogood's (1976) overfold model (Fig. 10.6).

De Beer (1989) studied the syntaxis in the Witteberg Group northeast of Ceres. He found limited evidence of cross-folding and interference folding in the area. Northeast- and north- to northwest-trending structures in the well-layered Witteberg succession take the form of zonal, monoclinal flexures or kink folds (Fig. 10.7) that exhibit conjugate or box-fold geometry in places. The interference patterns that developed at the intersections of the two trends do not consistently favour one of the fold directions as being older than the other. De Beer (1989) concluded that the northwest trend in the Ceres syntaxis represents the Cedarberg folds and the northeast trend, the westernmost part of the Southern Fold Belt, and that both directions developed simultaneously. He felt that structures in the basement influenced the development of the syntaxis significantly.

South and east of Ceres, and down to Kleinmond, the syntaxis displays a number of large northeasterly trending folds such as the Hex River anticline, the synclines through Villiersdorp and Bot River, and the Klipberg anticline south of Robertson. The present authors feel that these structures do not represent true cross-folds, but that they developed as a consequence of continued northward shortening in the east, a change in strike in the basement and the oblique trend of the depositional axis of the cover rocks across the Kleinmond–Franschhoek–Worcester–Ceres axis. Isopach maps for the Table Mountain Group (Rust 1967) show that the basin edge and trough in the southwestern Cape trend northwesterly through the Worcester area. This oblique strike, relative to the easterly trend of the southern Cape folds, was indirectly

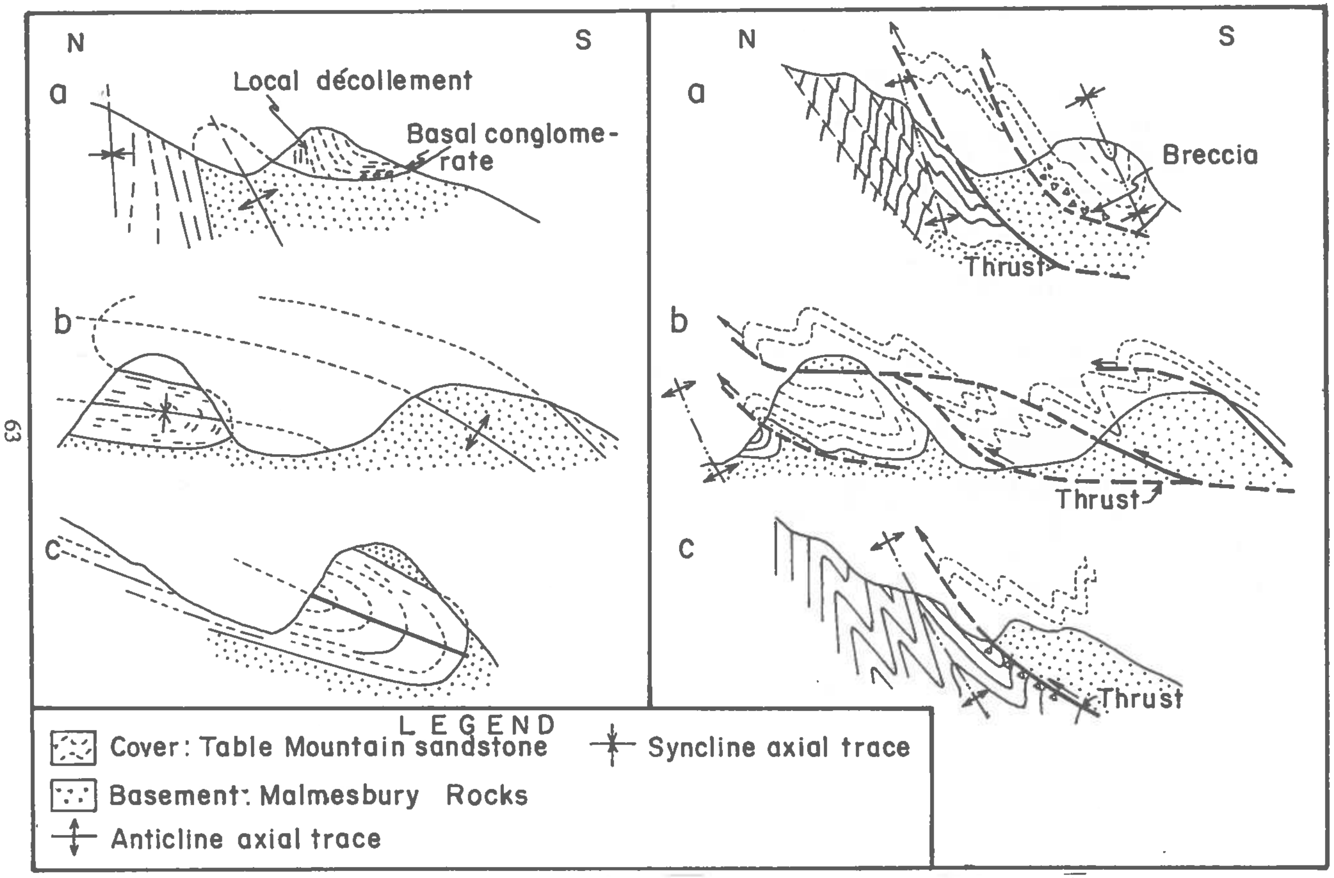

Fig. 10.6 - Contrasted styles of deformation at Nuy, near Worcester, after Toogood (1976) (left) and Gresse (1988) (right).

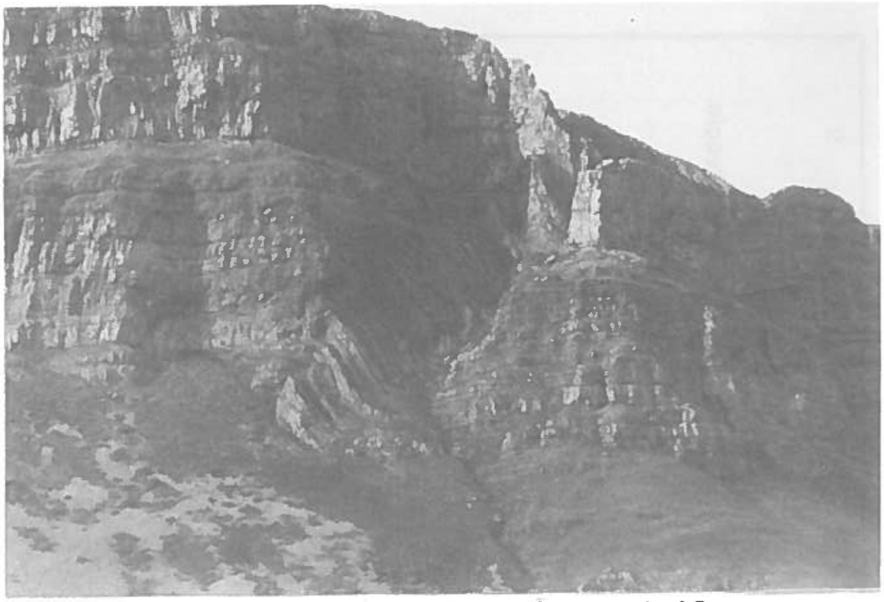

Fig. 10.7 - Kink-folding in the Witteberg Group, north of Ceres.

responsible for the development of northeasterly oriented folds in this region. The initial megafolds, such as represented by the Tulbagh–Worcester–Robertson synclinal valley, were probably still able to accommodate the curvature of the trough axis through the syntaxis, but, with continued northward shortening, overfolding and thrusting carried the southern fold belt farther north, and the fold axes in the west lagged further behind as northward and westward movement was inhibited by the northwesterly depositional strike in this region and, possibly, by rigid basement buttresses such as the Stettyns Rise (Rust 1967). The effect of this process is illustrated by the southern flank of the Langeberg which steepens and becomes inverted abruptly, east of the Hex River gorge, as opposed to normal dips in the west between Tulbagh and Worcester. The syntaxial zone was further tightened by continued northward pressure in the east and, perhaps, by compression from the southwest or strike-slip movement in the basement underneath the Cedarberg Belt. The relatively rigid, granite-intruded Tygerberg and Swartland terranes probably also served as a buttress in the south, preventing significant westward propagation of folds and thrusts in the cover.

10.4 POST-JURASSIC FAULTING

Between 135 and 130 Ma ago South America separated from Southern Africa along the Agulhas–Falkland Fracture Zone in the south (Tankard *et al.* 1982). Right-lateral transform movement along this zone caused tensional displacements on southward-dipping normal faults in the south and western Cape (Fig. 7.1). The largest of these are the Worcester Fault, which runs from Nuwekloof Pass west of Tulbagh to Robertson and farther east, and the Riviersonderend Fault, extending from south of Grabouw to Riviersonderend and beyond. Smaller faults occur in the south between Hermanus and Quoin Point, and elsewhere. These faults have down-faulted the southern limbs of the mega-anticlinal mountain ranges (Fig. 10.8), with the result that

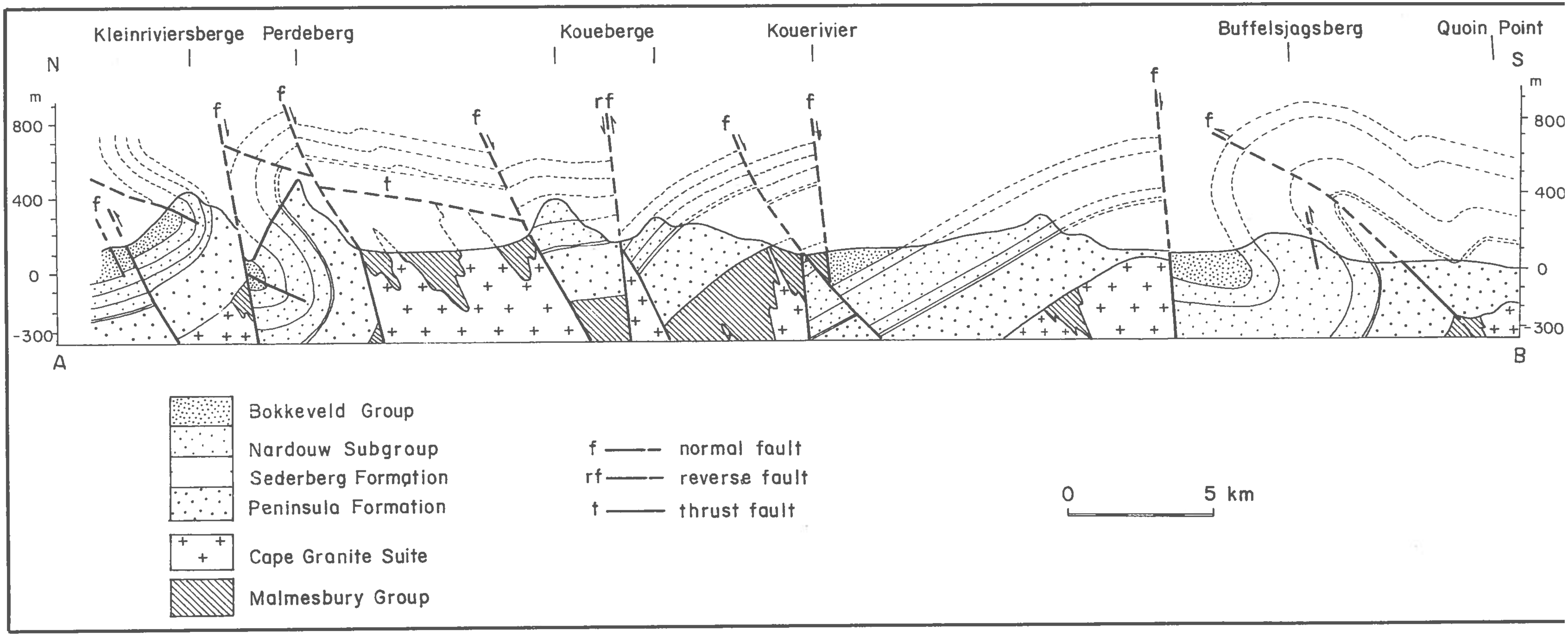

Fig. 10.8 - North–south section from Quoin Point to the Kleinriviers Mountains, east of Hermanus.

synclines now occupy the position of pre-existing anticlines. Remnants of pre-Cape rocks in anticline crests are preserved north of the fault lines in almost every instance. It has been suggested in the past, by Hartnady (1969) and Hälbich (1983), that some of these faults may coincide with earlier thrust faults. This could account for remnants of zones of breccia that overlie basement rocks immediately north of the normal faults, as for example east of Robertson along the Worcester Fault.

Dunlevey (1976) reinterpreted the position of the Worcester Fault east of Robertson. He moved the fault line about 1 km north along the Klaas Voogds River to a position north of the two hills Aasvoëlnes and Kranskop. He correlated the crudely layered quartzite breccia in these hills, regarded as Witteberg quartzite by Söhnge (1934), with the "White Enon" of the Oudtshoorn area. However, the present authors, after reinvestigating the area east of Robertson, found more of the breccia on Witberg, 2 km northwest of Aasvoëlnes, concluding that the breccia represents *in situ* brecciated Table Mountain quartzite – or possibly Witteberg – overlying a post-Cape thrust that runs north of Witberg and coincides with the upper surface of a highly sheared limestone horizon. No evidence could be found of the breccia having been redeposited in any way. The trace of the Worcester Fault was reinstated in its old position south of Aasvoëlnes and Kranskop (cf. Söhnge 1934).

The displacement along these faults varies from a few metres to more than 6 000 m in the case of the Worcester Fault at Worcester (De Villiers *et al.* 1964). Large variations in displacement occur along strike. This variation in throw is accompanied by a strong curvature of the fault line, as well as offsets, such as shown by the Riviersonderend Fault northwest of Riviersonderend, and by the Worcester Fault west of Robertson. This is a very characteristic feature of listric faults associated with rifting (Bossworth 1985), and leads to the development of subbasins such as exhibited by the Enon Formation (Fig. 10.9).

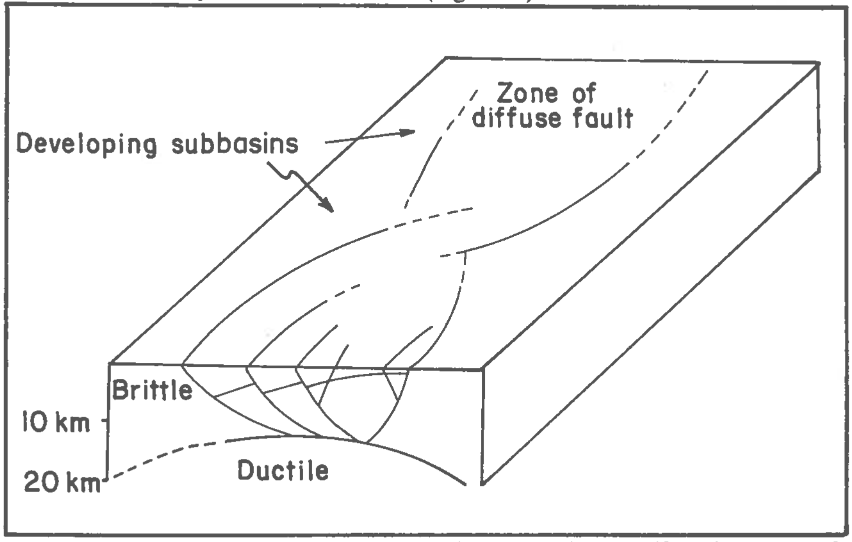

Fig. 10.9 - Proposed model for the propagation of continental rifts. Upper crustal extension may initiate as a broad zone of diffuse faulting, but evolves to a system composed of a few main listric faults (and perhaps in some cases planar fault-bounded blocks) above two opposite-directed detachments. (From Bosworth 1985).

Apart from the easterly trending normal faults, there are also a large number of northwesterly and northeasterly striking faults. The northwesterly faults have a tendency to merge with the main easterly trending faults, but the northeasterly faults appear to be younger than the rest. They displace the main faults at a number of places, as for instance south of the Riviersonderend Mountains, west of Genadendal, and in the Baardskeerdersbos and Viljoenshof areas. These faults display appreciable dextral displacements, as can be seen particularly well in the Kleinriviers Mountains between Hermanus and Napier. They are probably oblique slip faults, involving dextral downthrow on their southeastern sides. The northwesterly and northeasterly striking wrench faults can be related to the normal easterly trending faults in a single north–south extensional regime (rifting), or they could have developed slightly later in a dextral shear regime during similar movement along the Agulhas–Falkland Fracture Zone in the South Atlantic.

11. MINERAL DEPOSITS

With the exception of quarries for construction materials and limestone in the vicinity of Robertson, there are no working mines on Sheet 3319. Manganese has been mined on a small scale in the past. Smaller uneconomic deposits of a variety of other minerals occur.

11.1 MANGANESE

Manganese, mostly in the form of pyrolusite and psilomelane, is found as surficial enrichment along joints and fault breccias in sandstone of the Table Mountain Group. These deposits do no persist in depth. The richest concentrations were apparently deposited in open veins, while low-grade deposits occur in the surrounding rock.

The largest occurrence in the area is probably the one in Du Toitskloof Pass, above the old road tunnel. The mineralisation occurs along a fault zone that is about 200 m wide. The ore body is only about 3 m wide and between 100 and 300 m long. Most of the high-grade ore, assaying between 36–45 per cent Mn, 14–23 per cent Fe and 0,5 per cent P_2O_5, was mined out before 1917 (Boardman *et al.* 1960). Similar small deposits have been described by De Villiers *et al.* (1964) from, amongst others, northeast of Franschhoek near Adolfskop on Eenzamheid, and east-northeast of Kleinmond (Hermanus River 542). Small-scale manganese enrichment of similar nature is widely distributed in the Grootwinterhoek and Skurweberg Mountains north of Tulbagh. The mode of occurrence and the manganese minerals are the same as described above, but lithiophorite has also been reported from the Franschhoek occurrence (Boardman *et al.* 1960).

A somewhat different type of deposit, found on a major fault at the Caledon Spa, is described by Boardman *et al.* (1960). Chalcedonic and opaline silica, as well as oxides of iron and manganese, have built a deposit of significant size – some 100 m in diameter – around the springs. High-grade manganese ore is interlayered with softer, ferruginous and siliceous layers, and De Villers *et al.* (1964) estimated that, with selective mining, there could be up to 250 000 t of ore at an average grade of 40 per cent Mn.

On Bosjesmans Valley 218 northeast of Botha Siding, between Worcester and Wolseley, manganese mineralisation occurs along a fault in the Norree Formation of the Malmesbury Group. This was mined on a small scale during the previous century. The mineralisation peters out at a depth of about 5 m. According to

Boardman *et al.* (1960), the ore assayed 22–43 per cent Mn, 5,6–37 per cent Fe and 0,5–2 per cent P_2O_5, and consisted mainly of psilomelane and goethite.

11.2 LIMESTONE AND DOLOMITE

Two types of limestone deposits are found in the area. Steeply dipping, dolomitic limestone lenses are found in the Precambrian Norree Formation at Robertson and Voëlvlei, while horizontally bedded limestone, calcareous sandstone and calcrete are present in the Cenozoic Bredasdorp Group between Hermanus and Cape Agulhas.

11.2.1 Precambrian limestone and dolomite

Reasonably pure limestone and dolomite lenses occur in the Norree Formation west, north and east of Robertson (Martini 1987).

A near-vertical dolomite lens, measuring about 150 by 1 500 m, is being exploited on Kruispad 12 near Langvlei Siding. The grade of the light-grey, massive dolomite varies from 82 to 98 per cent RCO_3. The estimated total reserves on the farm amount to some 5 million m^3.

A 14-million-m^3 limestone deposit, consisting of four impure limestone lenses interbedded with phyllite, is being quarried at Dassieshoek (Langevalley 15), 5 km north of Robertson. The SiO_2 and Al_2O_3 content of these limestones are quite high in some cases (Table 11.1).

Table 11.1 - PARTIAL ANALYSES OF LIMESTONE AND DOLOMITE IN THE ROBERTSON FORMATION

Sample No.	1.	2.	3.	4.
SiO_2	34,43	23,37	9,14	11,02
Al_2O_3	6,62	7,42	2,41	4,20
Fe_2O_3	1,62	1,26	0,21	0,83
MgO	0,74	2,16	1,55	1,71
CaO	30,00	60,81	84,11	78,41

1. **Road quarry on Wolwe Kloof 49 (from Martini 1987).**
2–4. **Dassieshoek quarry, analyst G.S.O., Pretoria.**

Numerous other limestone and dolomite lenses in the vicinity of Robertson on the farms Noree, De Hex Rivier 50, Zand Rivier 106, Wolwe Kloof 49, Klein Klaas Voogds Rivier 28 and Klaas Voogds Rivier 37 together contain another $20X10^6$ m^3 of potentially mineable rock. A few small road quarries are already exploiting some of these deposits, as for example at Orrelkop on the farm Wolwe Kloof 49.

Limestone in Malmesbury rocks was also exploited many years ago near the western margin of the Voëlvlei Dam, north of Wellington (Visser *et al.* 1981), and immediately north of Worcester (De Villiers *et al.* 1964). Very little is known about these deposits.

11.2.2 Cenozoic limestone

A discontinuous belt of soft, sandy or hardpan limestone, belonging to the Bredasdorp Group, extends from Hawston along the coast to beyond the eastern boundary of the map area (Martini 1987). These limestones account for a few hundred million m^3 of low- to high-grade material. The latter is usually a very hard, well-cemented, white or cream-coloured rock, or a softer, shelly limestone which may contain anything from 69 to 91 per cent $CaCO_3$. Generally, however, the limestone, calcrete and calcareous sands are of a poor quality, mainly because of the high silica content (Table 11.2). The only working quarry in Bredasdorp limestone is situated 1 km northeast of Bredasdorp on the adjoining 3420 Riversdale map.

Table 11.2 - PARTIAL ANALYSES OF LIMESTONE IN THE BREDASDORP GROUP. (From earlier sources quoted in Martini 1987).

Sample No.	1.	2.	3.	4.	5.
SiO_2	26,0	34,08	7,0	-	25,84
Al_2O_3	4,0	0,07	1,5	-	0,07
Fe_2O_3	-	0,16	-	-	0,08
CaO	-	35,47	-	-	39,82
MgO	tr.	0,46	tr.	1,91	0,56
CaCO	68,0	63,3	91,0	80,4	71,2
L.O.I.	-	28,79	-	-	32,96

1. Soft sandy limestone, Linkerhands Gat 655, southeast of Stanford.
2. Dune sand, 10 km south-southwest of Stanford.
3. Indurated limestone, Kleyn Hagel Kraal 321.
4. Beach sand, Walker Bay State Forest.
5. Dune sand, Afsaal on Kleyn Hagel Kraal 321.

11.3 KAOLIN

Kaolinitic clays are mainly found in the southern part of the area, where they developed from the *in situ* weathering of granite and pelitic rocks of the Malmesbury and Bokkeveld Groups. The deposits are generally small and not of a high quality, because of the high quartz content and also undesirable iron oxides in some instances.

White to reddish kaolin is found north of Hermanus on Hemel En Aarde 587, where the granite is particularly deeply weathered along a fault. Small deposits are also present east of Gansbaai along the Uilkraals River on Uylen Kraal 695 and Avoca (The Hell 737), and also on Hagelkraal 318 farther to the southeast. All these deposits were investigated by the Geological Survey between 1983 and 1985, including several boreholes, but proved to be very small and of poor quality (Malan 1985).

In the same vicinity, on Dirk Uys Kraal 298, Spies *et al.* (1963) mention a large deposit of white kaolinitic clay derived from weathered Malmesbury (now regarded as Bokkeveld) shale. Tests at the time indicated that it was not suitable for ceramic purposes. Near Wolseley, on Waverley 273, very small quantities of a kaolinitic clay are sporadically mined for use in insecticides.

De Villiers *et al.* (1964) mention kaolinitisation of granite in Kaaimansgat (Elands Kloof 5) north of Villiersdorp, and, to a lesser extent, northeast of Wellington. The same authors also report a small occurrence of sericitic kaolin in weathered shale of the Table Mountain Group, east of Franschhoek.

11.4 GRAPHITE

Graphitic shales are present in the Cedarberg Formation of the Table Mountain Group, in the lower part of the Bokkeveld Group, and in the Prince Albert Formation of the Karoo Sequence. Carbonaceous shale in the latter was found to be graphitic near Langvlei Siding, west of Robertson (Whiteside 1976). Known occurrences in the Bokkeveld Group are found in a road quarry east of Baardskeerdersbos and, farther south, a borehole on Dirk Uys Kraal 298.

A graphitic shale in the Table Mountain Group on Wolven Gat 297, southwest of Elim, is radioactive and contains 0,004 per cent U_3O_8. Graphitic Cedarberg shale, which also contains pyrite, has been prospected in the past about 2 km northwest of Kleinmond. The deposit was found to be very small and of inferior quality (De Villiers *et al.* 1964).

11.5 GYPSUM

Gypsum, found in association with the Whitehill Formation, has been exploited on a small scale for agricultural purposes on Kolkies Kraal 234, east-northeast of Ceres. Reserves are estimated at some 250 000 t (Visser *et al.* 1963).

11.6 GLASS SAND, SILICA

Glass sand, previously mined on a small scale, occurs on The Draay 563, northeast of Kleinmond. The deposit, more than 4 m thick in places, is relatively small but of good quality. It originated from weathering of Table Mountain sandstone.

Spies *et al.* (1963) report the presence of fairly thick vein quartz in the Gansbaai–Bredasdorp area. The best occurrence is on the farm Grashoek (Berg Hoek 197), southeast of Napier.

11.7 SALT

Several smaller pans in the southern part of the map area, south of Elim, produced small quantities of salt in the past (Spies *et al.* 1963). These include Vispan, Melkbospan, Soutpan and pans on Rhenoster Kop 285, Rooi Wal 251 (Rondepan) and

Melkbosch 97, 7 km northeast of Napier. Their production is mainly dependent on low rainfall. The only pan still in production at present is Soutpan, on Farm 287 (Springfield). The present water surface covers about 180 ha and is 9 m above sea level. Several weirs and retaining walls have been built in and around the pan. The pan produces between 2 000 and 4 000 t of salt per year, but only about 5 per cent of the pan surface is being used at present (Malan 1985).

11.8 PYROPHYLLITE

Small deposits of this mineral occur in the Norree Formation along the eastern flank of Kleinberg, between Worcester and Wolseley. The pyrophyllite occurs in association with andalusite, kyanite, diaspore and ottrelite. According to Potgieter (1950) the pyrophyllite is pure enough for commercial use, although reserves available do not appear to exceed 10 000 t.

11.9 GOLD

A shaft was sunk into a 10-m-wide quartz vein on Kwartelfontein 231, 12 km south of Greyton, but no gold was found. Similar old prospects are reported from several farms in the vicinity of Napier, notably Hansiesriver (Farm 34), where quartz veins along faults in the Bokkeveld Group were investigated (Malan 1985). Gold has been reported from a quartz vein on the farm Dassieshoek north of Robertson, near the contact of the Robertson Pluton (Dunlevey 1984).

11.10 LIGNITE AND PEAT

Thin layers of lignite, a few centimetres thick, have been reported from the farm Tierfontein (Nieuwe Post 204), northeast of Baardskeerdersbos (Van Vuuren 1976). Small peat deposits are also present in the vicinity of Stanford.

11.11 CONSTRUCTION MATERIALS

11.11.1 Clay

Fine-grained sediments of the Malmesbury, Bokkeveld, Witteberg and Ecca Groups are converted to good-quality brick clay under certain conditions of weathering. These conditions existed along large faults or under old land surfaces which are today marked by silcrete or ferricrete cappings. Brick-making concerns are found throughout the area, mostly in the vicinity of larger towns.

Several brick-clay quarries, situated on weathered Malmesbury phyllite, occur just off the western edge of the map in the Wellington and Paarl regions. Good-quality clay, derived from Ecca shales, has been found underneath 6 m of alluvium on Wysersdrift 386, west of Worcester, while another large deposit in the Wagendrift Formation is being worked south of the Brandvlei Dam wall. Yellow to reddish clay, derived from *in situ* weathering of Bokkeveld shale, is found west (Klipheuvel 410) and south of Caledon, and also south of Botrivier. Another large deposit east of Napier, on Kleine Zanddrift 146, is being exploited at present.

11.11.2 Stone aggregate

Various rock types are used for aggregate for construction purposes, namely Malmesbury hornfels and dolomitic limestone, granite, basic dykes and intrusions, and quartzite. Quarries in hornfels and granite are found in the Paarl and Wellington regions. Granite on Pietercielies Kloof 202, between Napier and Elim, has also been prospected with a view to using it for concrete aggregate. Dolomitic limestone is quarried near Robertson. Two large quarries are situated in the Brewelskloof andesite north of Worcester. This aggregate is used for road construction and railway ballast, but the high biotite content makes it unsuitable for use in concrete.

Aggregate quarries situated in quartzite of the Table Mountain and Witteberg Groups are found throughout the area, as for example at the foot of Voorsorgberg, south-southwest of the Brandvlei Dam, and north of Caledon. They are usually not exploited continuously, but construction companies make use of the local product whenever the need arises for dam or road construction. Malmesbury quartzite along the western shore of Voëlvlei has also been used for the same purpose.

11.11.3 Building sand

Good-quality building sand is found along all the rivers draining the quartzite mountains, especially along the Breede River between Rawsonville and Robertson.

11.11.4 Dimension stone

Although there are no operative dimension-stone quarries in the area at present, quartzitic sandstone – mainly from the Table Mountain Group – and Bredasdorp limestone have in the past been used as building stone. Examples of the latter can be seen in church and school buildings at Stanford. Fine examples of buildings constructed from locally derived quartzitic sandstone are found at Hermanus and many other towns in the area.

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Appendix A – FOSSIL DISTRIBUTION IN THE BOKKEVELD GROUP

STRATIGRAPHY	SPECIES	LOCALITY
1. TRILOBITA		
Waboomberg Formation	*Metacryphaeus caffer* (Salter) *Metacryphaeus venustus* Wolfart *Metacryphaeus* sp. *Typhloniscus baini* Salter	De Doorns, Tunnel/Triangle Siding, Lopenderivier Bronaar/Boplaas De Doorns Lopenderivier/ Perdefontein
Tra-Tra Formation	*Burmeisteria herscheli* (Murchison) *Metacryphaeus caffer* (Salter)	Theronsberg Pass Theronsberg Pass
Voorstehoek Formation	*Bainella cristagalli* (Woodward) *Burmeisteria herscheli* (Murchison) *Gamonedaspis boehmi* (Knod) *Metacryphaeus caffer* (Salter) *Phacopina lakei* (Reed)	Matroosberg Siding Matroosberg Siding Swaarmoed De Doorns, Matroosberg Siding, Lopenderivier Hottentotskloof
Gydo Formation	*Bainella africana* (Salter) *Burmeisteria herscheli* (Murchison) *Burmeisteria fontinalis* (Reed) *Burmeisteria notica* (Clarke) *Francovichia clarkei* (Ulrich) *Malimanaspis? dereimsi* (Kozlowski) *Oosthuizenella ocellus* (Lake) *Pennaia pupillus* (Lake)	Gydo Pass Gydo, Eselfontein, Leeufontein, Bokkerivier Eselfontein De Doorns/Buffelskraal De Doorns/Buffelskraal Eselfontein, Lakenvlei, Hottentotskloof, Buffelskraal/De Doorns Gydo, Osplaas/De Doorns Gydo, Vadersgawe

Gydo Formation cont.	*Phacopina hexensis* (Reed) *Phacopina lakei* (Reed) *Renniella rossouwi* Cooper *Typhloniscus baini* Salter	Uitkoms, De Doorns Eselfontein, Buffelskraal/De Doorns Buffelsberg/De Doorns Gydo, Stettyn
2. BRACHIOPODA		
Wagendrift Formation	*Australospirifer antarcticus* (Morris and Sharpe) *Chonetes* sp. *Lingula lepta* Clarke *Tropidoleptus* sp.	Elim/Hartebeestekraal Elim/Hartebeestekraal Elim/Hartebeestekraal Elim/Hartebeestekraal
Waboomberg Formation	*Australocoelia* sp. *Chonetes rucki* (Ulrich) *Schellwienella* sp. *Tropidoleptus* sp.	Lopenderivier/Perdefontein Bronaar/Boplaas, De Doorns/Tunnel Siding Bronaar/Boplaas, Lopenderivier/Perdefontein Bronaar/Boplaas
Tra-Tra Formation	*Australocoelia* sp. *Australospirifer* sp. *Lingula lepta* Clarke *Notiochonetes* sp. *Stropheodonta* sp.	Theronsberg/Leeuwenfontein Lopenderivier/Perdefontein, Ouhangsberge Theronsberg/Leeuwenfontein Theronsberg/Leeuwenfontein Theronsberg/Leeuwenfontein
Hexrivier Formation	*Australocoelia palmata* (Morris and Sharpe)	Karbonaatjeskraal
Voorstehoek Formation	*Acrospirifer iheringi* (Kayser)	Swaarmoed, Matroosberg Siding, Lopenderivier/Perdefontein

Voorstehoek Formation cont.	*Australospirifer antarcticus* (Morris and Sharpe)	Swaarmoed, Matroosberg Siding
	Australospirifer sp.	Matroosberg Siding
	Chonetes cf. *falklandicus* Morris and Sharpe	Lopenderivier
	Chonetes (Notiochonetes) hallei (Clarke)	Matroosberg Siding
	Chonetes rücki Ulrich	De Doorns
	Lingula keideli Clarke	Wuppertal, Matroosberg Siding, Swaarmoed
	Lingula lepta Clarke	Wuppertal, Matroosberg Siding, Swaarmoed
	Lingula scalprum Clarke	Swaarmoed
	Lingula sp.	Matroosberg Siding
	Orbiculoidea baini (Sharpe)	Matroosberg Siding
	Schellwienella agassizi (Hartt and Rathbun)	Matroosberg Siding
	Schellwienella sulivani (Morris and Sharpe)	Gydo, Uitkomst
Gamka Formation	*Australocoelia palmata* (Morris and Sharpe)	Gydo, Hottentotskloof, Stinkfontein
	Australocoelia tourteloti Boucot	Kleinstraat Siding, Lopenderivier/Perdefontein
	Australospirifer antarcticus (Morris and Sharpe)	Zandrivier/Keurfontein, McGregor, Buffelsberg/Hex River Pass
	Australospirifer iheringi (Kayser)	Kleinstraat Siding
	Chonetes cf. *falklandicus* (Morris and Sharpe)	Lopenderivier/Perdefontein
	Cryptonella baini (Sharpe)	Lopenderivier/Perdefontein
	Mutationella sp.	Matroosberg Siding, Hottentotskraal/Eselfontein, Kleinstraat Siding

Gamka Formation cont.	Stropheodonta? *arcei* Ulrich	Kleinstraat Siding
Gydo Formation	*Acrospirifer iheringi* (Kayser)	Lopenderivier/Perdefontein
	Ambocoelia pseumdoumbonata Kozlowski	Gydo, Vadersgawe, Matroosberg Siding
	Australocoelia palmata (Morris and Sharpe)	Lopenderivier/Perdefontein
	Australocoelia tourteloti Boucot	Gydo, Vadersgawe
	Australocoelia sp.	Lopenderivier/Perdefontein
	Australospirifer antarcticus (Morris and Sharpe)	Wuppertal, Grootrivier, Gydo/Vadersgawe, Buffelsberg/Hex River Pass, Lopenderivier/Perdefontein, Montagu, Warmwaterberg, Bosluiskloof, Gamkapoort, Weltevrede, Klaarstroom, Keurboomstrand, Noaga
	Australospirifer sp.	Gydo
	Centronella sp.	Gydo/Vadersgawe, Vredelus (Stinkfontein)
	Chonetes cf. *falklandicus* (Morris and Sharpe)	Gydo
	Chonetes (Notiochonetes) hallei (Clarke)	Gydo/Vadersgawe
	Chonetes sp.	Hottentotskraal/Grootvlakte, Witzenbergvallei
	Cryptonella baini (Sharpe)	Gydo, Hottentotskraal/Lakenvlei
	Cryptonella sp.	Lopenderivier
	Derbyina sp.	Gydo
	Eodevonaria arcuatus (Hall)	Gydo/Vadersgawe
	Lingula lepta Clarke	Uitvlugt
	Meristella sp.	De Doorns, Gydo/Vadersgawe
	Mutationella whitiorum (Clarke)	Gydo
	Orbiculoidea baini (Sharpe)	Osplaas
	Orbiculoidea collis Clarke	Driefontein

Gydo Formation cont.	*Orthis* sp.	Gydo, Eselfontein
	Pleurothyrella simplex (Schwarz)	Gydo
	Rensselaeria sp.	Gydo, Stinkfontein/Vredelus
	Rhynchonella bodenbenderi (Kayser)	Eselfontein
	Schellwienella sulivani (Morris and Sharpe)	Gydo, Lakenvlei
	Schellwienella sp.	De Doorns
	Stropheodonta sp.	Ceres
3. MOLLUSCA = PELECYPODA		
Waboomberg Formation	*Modiomorpha* sp.	Tunnel Siding, Lopenderivier/ Perdefontein
	Nuculana inornata (Sharpe)	Tunnel Siding
	Nuculites sp.	Boplaas/Bronaar, Lopenderivier
	Palaeoneilo orbignyi Clarke	Boplaas/Bronaar
Tra-Tra Formation	*Grammysia* sp.	Wageboomberg/Theronsberg Pass
	Janeia sp.	Wageboomberg/Theronsberg Pass
	Myalina sp.	Wageboomberg/Theronsberg Pass
	Nuculites sp.	Wageboomberg/Theronsberg Pass
	Palaeoneilo orbignyi Clarke	Wageboomberg
	Palaeoneilo sp.	Wageboomberg
Voorstehoek Formation	*Actinopteria eschwegii* Clarke	Swaarmoed
	Grammysia campestris (Reed)	Matroosberg Siding
	Grammysia scaphuloides Reed	Swaarmoed, Matroosberg Siding
	Janeia bokkeveldensis (Reed)	Swaarmoed

Voorstehoek Formation cont.	*Janeia* sp.	Swaarmoed, De Doorns, Lopenderivier
	Modiomorpha sp.	Hottentotskloof, Lopenderivier/Perdefontein
	Nuculana sp.	Swaarmoed, Hottentotskloof
	Nuculites abbreviatus (Sharpe)	Swaarmoed
	Nuculites colonicus Reed	Swaarmoed, Lopenderivier/Perdefontein
	Nuculites obtusus Reed	Swaarmoed
	Nuculites sharpei Reed	Swaarmoed
	Palaeoneilo antiqua (Sharpe)	Swaarmoed, Hottentotskloof, Matroosberg Siding, Stinkfontein/Vredelus
	Palaeoneilo sp.	Hottentotskloof, Gamkapoort
	Pleurodapis multicincta Clarke	Swaarmoed, Matroosberg Siding
Gydo Formation	*Actinopteria eschwegii* (Clarke)	Gydo
	Ctenodonta stowi (Reed)	Gydo, Bosluiskloof
	Goniophora gydoensis (Reed)	Gydo
	Grammysia campestris (Reed)	Eselfontein
	Grammysia corrugata (Sharpe)	De Doorns
	Grammysia fontinalis (Reed)	Eselfontein
	Janeia baini (Sharpe)	Gydo
	Janeia bokkeveldensis (Reed)	Ceres
	Janeia braziliensis (Clarke)	Eselfontein
	Modiomorpha hexensis (Reed)	De Doorns, Keurbosch
	Modiomorpha montaguensis (Reed)	Stinkfontein/Vredelus, Matroosberg Siding
	Modiomorpha nigra (Reed)	De Doorns, Stinkfontein/Vredelus
	Nuculana inornata (Sharpe)	Gydo, De Doorns
	Nuculites abbreviatus (Sharpe)	Gydo
	Nuculites africanus (Sharpe)	Gydo
	Nuculites colonicus Reed	Eselfontein

Gydo Formation cont.	*Nuculites oblongatus* Conrad	Eselfontein
	Nuculites pacatus Reed	Eselfontein
	Nuculites sharpei Reed	Gydo, Eselfontein
	Palaeoneilo antiqua (Sharpe)	Tafelberg, Gydo, De Doorns
	Palaeoneilo arcuata (Schwarz)	Gydo
	Palaeoneilo orbignyi Clarke	Eselfontein
	Palaeoneilo rudis (Sharpe)	Eselfontein
	Palaeoneilo subantiqua Reed	Eselfontein
	Sanguinolites sp.	Ceres
	Sphenotomorpha bodenbenderi (Clarke)	De Doorns
GASTROPODA		
Waboomberg Formation	*Bellerophon* sp.	Bronaar/Boplaas, Tunnel Siding, Lopenderivier
	Diaphorostoma sp.	Bronaar/Boplaas, Tunnel Siding
	Tentaculites desuetes Reed	Tunnel Siding
	Tentaculites sp.	Bronaar/Boplaas, Perdefontein/Lopenderivier
Tra-Tra Formation	*Bellerophon africanoides* Reed	Theronsberg Pass
	Tentaculites crotalinus Salter	Theronsberg Pass
Voorstehoek Formation	*Bellerophon laticarinatus* (Knod)	Swaarmoed
	Bellerophon sp.	De Doorns
	Hyolithes orbignyi Kozlowski	Swaarmoed
	Hyolithes sp.	Swaarmoed
	Tentaculites crotalinus Salter	Swaarmoed
	Tentaculites desuetes Reed	Swaarmoed, Matroosberg
	Tentaculites sp.	Gydo, De Doorns, Matroosberg

Gamka Formation	*Bellerophon* sp. *Tentaculites* sp.	Kleinstraat Siding De Doorns
Gydo Formation	*Bellerophon* cf. *dereimsi* (Knod) *Bellerophon* cf. *laticarinatus* (Knod) *Bellerophon quadrilobatus* Salter *Diaphorostoma baini* (Sharpe) *Loxonema capense* Reed *Loxonema zwartbergense* Reed *Pleurotomaria* cf. *kayseri* Ulrich *Hyolithes subaequalis* (Salter) *Orthotheca steinmanni* (Knod) *Tentaculites baini* Reed *Tentaculites crotalinus* Salter *Tentaculites desuetes* Reed	Gydo Lakenvlei Eselfontein, Ceres Gydo Gydo, Matroosberg Siding Swaarmoed Hottentotskloof Gydo, Ceres Gydo, Swaarmoed Gydo Lakenvlei, Ceres, Hottentotskloof Keurbosch
CEPHALOPODA		
Waboomberg Formation	*Orthoceras* sp.	Bronaar/Boplaas
Voorstehoek Formation	*Orthoceras bokkeveldense* Reed *Orthoceras* sp.	Swaarmoed Matroosberg Siding
Gydo Formation	*Orthoceras* sp.	Gydo, Ceres
4. ECHINODERMATA = CYSTOIDEA		
Voorstehoek Formation	*Placocystella capensis* Rennie	Swaarmoed, De Doorns, Matroosberg Siding, Stinkfontein, Lopenderivier/Perdefontein
Gydo Formation	*Placocystella capensis* Rennie	Gydo, De Doorns

BLASTOIDEA		
Voorstehoek Formation	*Pachyblastus dicki* Breimer and Macurda	Matroosberg Siding, Stinkfontein
Gydo Formation	*Pachyblastus dicki* Breimer and Macurda	De Doorns
CRINOIDEA		
Waboomberg Formation	Stem segments	Lopenderivier/Perdefontein
Tra-Tra Formation	Stem segments	Tunnel Siding, Lopenderivier/Perdefontein, Ouhangsberge
Voorstehoek Formation	*Ophiocrinus stangeri* Salter Crinoid calyx, arms & segments?	Lopenderivier/Perdefontein Swaarmoed, Hottentotskloof, Matroosberg Siding, Stinkfontein, Lopenderivier
Gydo Formation	*Ophiocrinus stangeri* Salter Crinoid calyx, arms & segments?	Gydo, De Doorns De Doorns, Lopenderivier/ Perdefontein
STELLEROIDEA (Ophiuroidea)		
Waboomberg Formation	*Drepanaster* sp. *Taeniaster* sp. *Ophiuroid* arms & ossicles (indet.)	Bronaar/Boplaas Waboomberg/Theronsberg Pass Lopenderivier/Perdefontein
Voorstehoek Formation	*Drepanaster* sp. *Encrinaster (Hexura) weitzi* (Owen)	Matroosberg Siding Swaarmoed, Hottentotskloof, Matroosberg Siding, Lopenderivier/Perdefontein

5. COELENTERATA: SCYPHOZOA (Conularioidea)		
Waboomberg Formation	*Conularia* sp.	Lopenderivier/Perdefontein
Tra-Tra Formation	*Conularia baini* Ulrich	Theronsberg Pass
Voorstehoek Formation	*Conularia* sp.	Matroosberg Siding, Lopenderivier
Gydo Formation	*Conularia africana* Sharpe *Conularia quichua* Steinmann & Döderlein *Conularia* cf. *undulata* Conrad *Conularia ulrichana* Clarke	Gydo, Ceres Gydo Uitkomst, Ceres Eselfontein
ANTHOZOA		
Tra-Tra Formation	*Favosites* sp.	Theronsberg Pass
Gydo Formation	*Pleurodictyum bokkeveldense* Gevers *Zaphrentis zebra* Schwarz	Gydo Gydo
6. BRYOZOA		
Waboomberg Formation	"*Fenestella*" sp.	Bronaar/Boplaas
Tra-Tra Formation	"*Fenestella*" sp.	Theronsberg Pass