A. INTRODUCTION

Field Note A3. The Study Area – Geology

Geological setting

Rocks and sediments of four main groups characterise the Study Area, between Cape Agulhas and Cape Infanta. They are (from old to young, name of era in brackets): A. Table Mountain Group (Silurian); B. Bokkeveld Group (Devonian); C. Uitenhage Group (Late Jurassic / Early Cretaceous); and D. Bredasdorp Group (Tertiary), as shown in Figure 1.

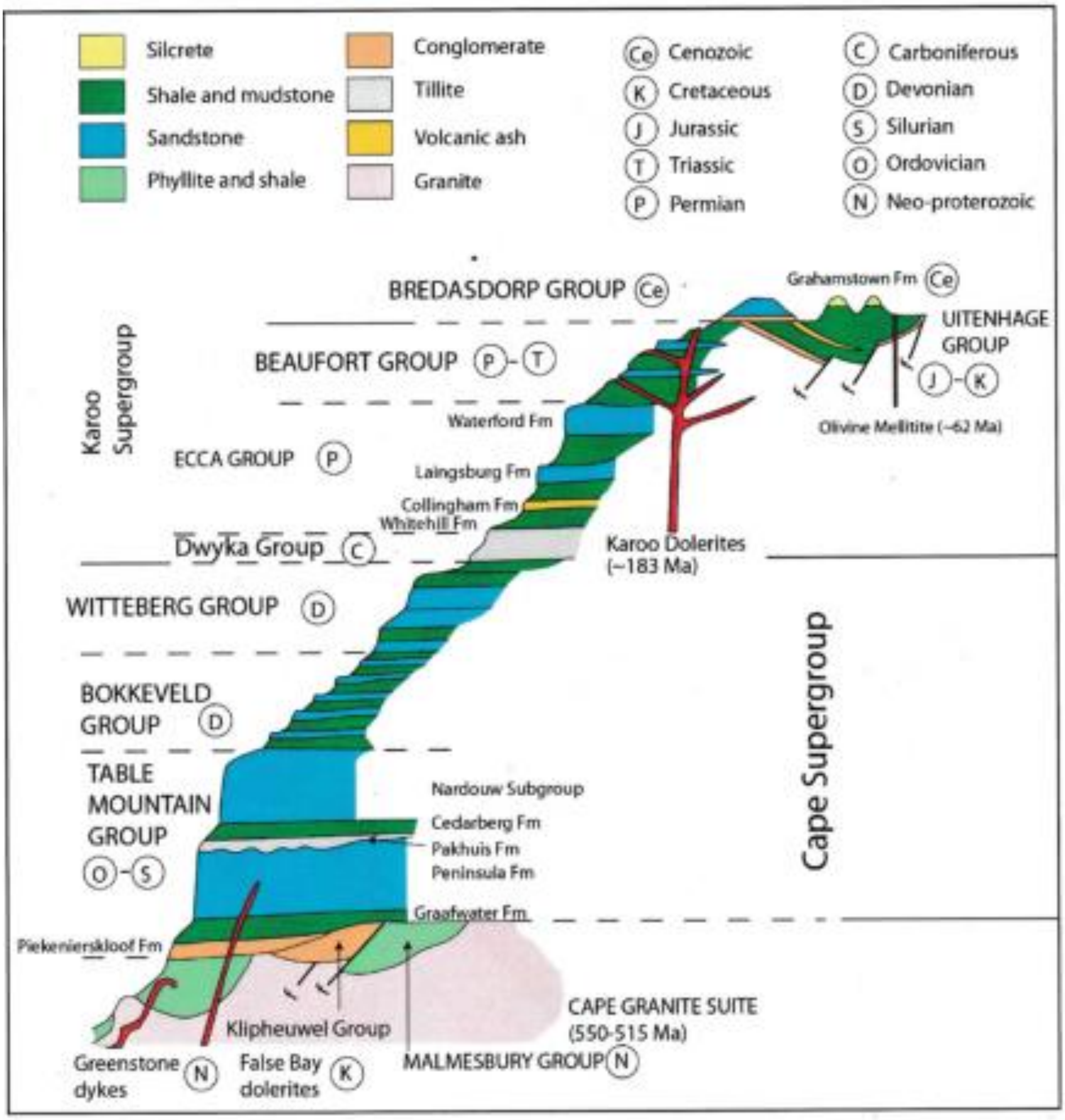


Figure 1. Schematic stratigraphic profile of the Western Cape, showing the formations mentioned above.
(Source: J Malan and J Viljoen: Field Trip Guide, 2016).

Geological history

A brief summary of the geological history and the main geological formations of the region are given in the table below (Figure 2).

AGE (Ma)	ERA	PERIOD/EPOCH		REGIONAL TECTONICS	SEDIMENTARY & VOLCANIC UNITS	
0.012	CENOZOIC	Quaternary	Holocene Pleistocene		Sandveld Formation Waenhuiskrans Formation Kleinbrak Formation Wankoe Formation De Hoopvlei Formation	Bredasdorp Group
2.6 5.3		Neogene	Pliocene Miocene	200 metre uplift event 200m epeirogenic uplift along SAA		
23 66		Paleogene	Eocene		Quoin Point volcanic complex	
145	MESOZOIC	Cretaceous		Gondwana extension, rifting and break-up Agulhas - Falklands Fracture Zone development Cape Orogeny thrust fault reactivation Listric normal faults and half grabens	Enon Formation	Uitenhage Group
201		Jurassic				
252		Triassic		Cape Orogeny Northward directed compression E-W trending folds Bedding parallel thrust faults		
299 359	PALEOZOIC	↑ Permian Carboniferous			Witteberg Group	Cape Supergroup
419		Devonian			Bokkeveld Group	
443 485		Silurian Ordovician			Table Mountain Group	
541		Cambrian				
635	NEO-PROTEROZOIC	↑ Ediacaran		Gondwana Formed Saldanian belt development, Pan-African Orogenic event	Tygerberg Formation	Malmesbury Group
850		Cryogenian				

Figure 2. Summary of the stratigraphy and geological history of the south-western part of Southern Africa. Note that the time scale (age) is not linear.
(Modified from: Hodge, M: MSc thesis, 2013).

Four other units, of different nature (as will be explained later) are present in the Study Area namely: A. Red sand, B. Calcrete (limestone crust), C. Soils and D. Alluvium (erosional materials transported by water).

The following sectionsl briefly describe the geological formations in the Study Area, from old to young. Detailed descriptions and discussions can be found in Chapters C and D of this website.

This study follows the conventional names and symbols of the various formations, as they appear on the geological maps. A very general geological map of the Study Area is given below (Figures 3, 4 and 5).

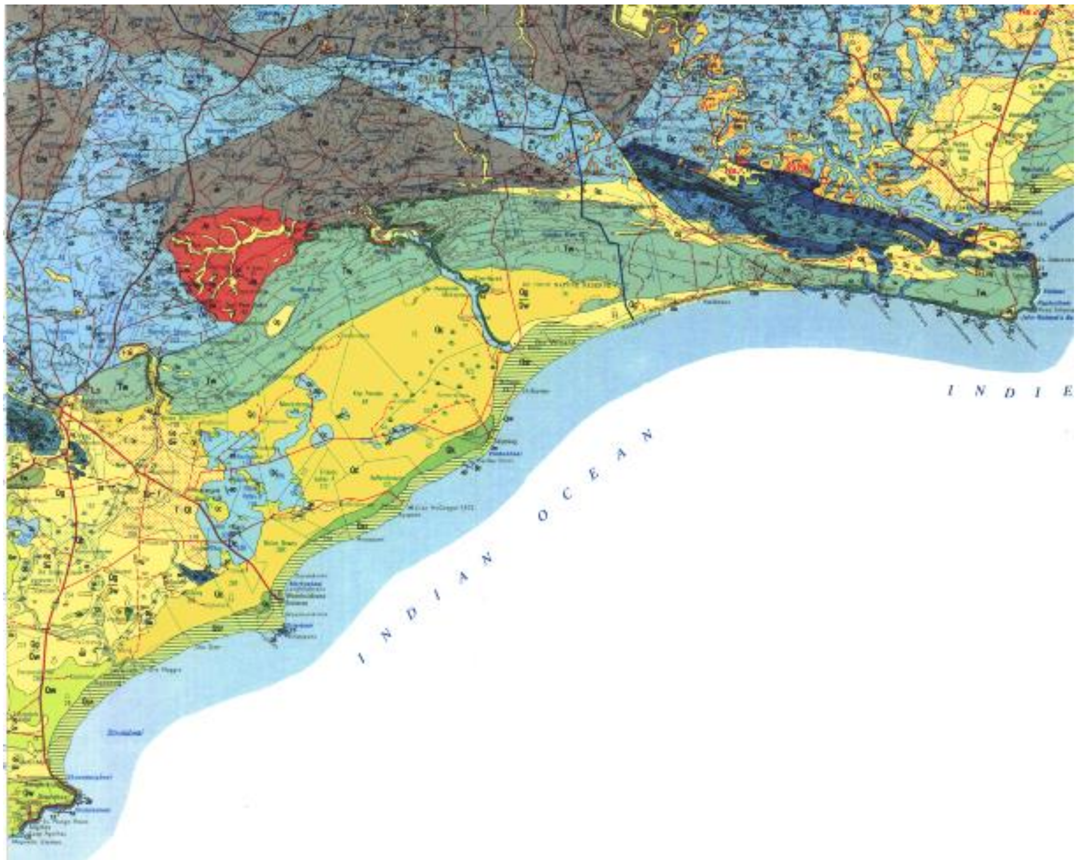


Figure 3. Geological map of the Study Area. See legend in Figure 5.
Source: 3420 Riversdale sheet, 1:250,000, 1993.

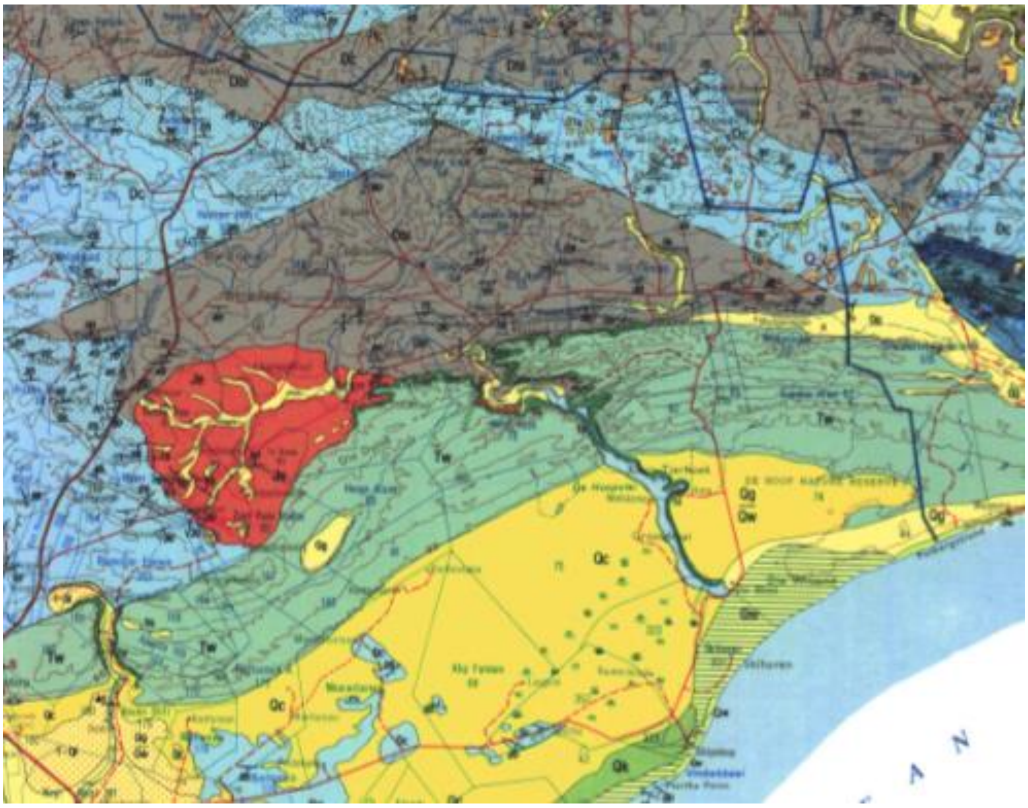


Figure 4. Enlargement of the middle section of the geology map shown in Figure 3, where all the formations, which characterise the Study Area, are present.

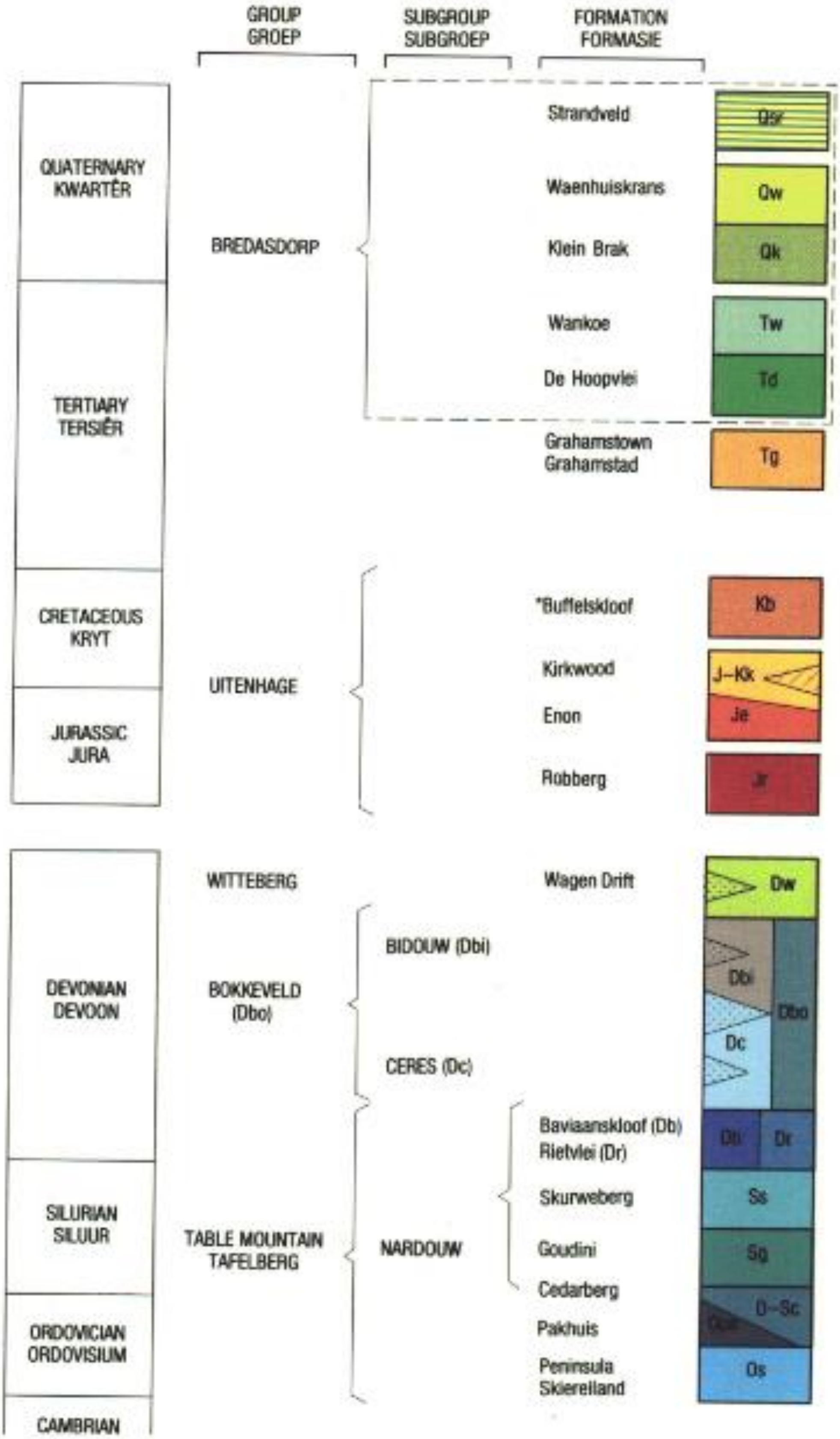


Figure 5. Legend for the Riversdale geological map.

Cainozoic Formations

The Bokkeveld Group

The Bokkeveld Group (the middle part of the Cape Supergroup, of Devonian age) is composed of sedimentary rocks of predominantly regressive sequence, with a maximum total thickness of over 3000 m. Typical Bokkeveld rocks are mudstones and sub-feldspathic to feldspathic sandstones, laid down with an obvious periodicity and regularity. They may be created by annual processes such as seasonally varying deposits reflecting variations in the runoff cycle, by shorter term processes such as tides, or by longer term processes such as periodic floods. These deposition cycles form thin layers, or laminae (Figure 6). In places the shales turn into clay (Figure 7) (read below, kaolin). All the hills (Ruëns) north of the Hard Dunes comprise Bokkeveld shales (grey and light-blue on the geology map shown above).

Figure 6. Bokkeveld shales outcrop in a river cut.

Figure 7. Bokkeveld shales turn into colourful clays via weathering and mineral alteration.

Quartz veins

Quartz veins are very common within the Bokkeveld shales. There is a multitude of veins on the Bokkeveld Shale Hills north of the Hard Dunes. These veins are the result of fluid movement along joints, fractures, cleavage and fault plains. The width of quartz veins in the shales varies from a few millimetres to a few metres. (Figures 8 and 9).

Figure 8. Thin quartz veins (arrows) within folded shales.

Figure 9. Boulders of very a thick milky quartz vein protrude the top of a Bokkeveld shale hill.

The Enon Formation

The Enon Formation (of the Uitenhage Group) was formed along the southern section of South Africa during the break up of Gondwana when there was widespread erosion of the rocks comprising the Cape Fold Belt. It is considered to be Late Jurassic to Early Cretaceous in age, some 145 ma ago.

Conglomerates are the most diagnostic feature of the Enon, so much so that in the past the formation was referred to as the Enon Conglomerate Formation. The conglomerates consist of large, sub-rounded to rounded clasts of sheared or unsheared quartzite and sometimes slate, shale and charcoal. Quartzite clasts are generally more rounded whereas the slate and shale clasts are angular. These are interbedded with subordinate sandstone lenses ranging from white, yellow, red and green in colour, claystones and rare mudstone units. These were deposited in a high-energy alluvial environment where debris flows were common (Figures 10 and 11).

Figure 10. Enon Formation conglomerate with a high content of angular shale fragments.

Figure 11. Heap of small and huge clasts of the Enon Formation.

The Grahamstown Formation

The Grahamstown Formation in the Study Area is mostly found on hill tops (Figure 12) or as isolated boulders. The age of this formation is Miocene (older than the Bokkeveld and Enon Formations and younger than the Bredasdorp Group). It is regarded a palaeo (ancient) land surface. The silcrete can attain thicknesses of up to several metres. Silcrete formed by iron oxides is called ferricrete; some silcretes are rich in manganese.

Figure 12. Silcrete caps a Bokkeveld Formation shale hill north of the Hard Dunes.

Modified from Roberts, Memoir 95. 1993:

In 1902, the term "silcrete" was coined for what has been defined as "an indurated product of surficial and near-surface silicification, formed by the cementation and/or replacement of host material of various origins and type by low temperature physiochemical processes" (slightly modified after Summerfield, 1981).

Silcretes have attracted broad interest scientists since the turn of the century, because they:

1. Demarcate and preserve ancient land surfaces;
2. Provide an indication of erosion rates since their formation;
3. Record specific climatic conditions;
4. Preserve sedimentary strata that would have been eroded in an unsilicified state;
5. Occasionally contain fossils and trace fossils, providing information on old environments;
6. Have, in the past, been utilised as an economic source of silica, for example for refractory brick making and aggregate (Viljoen and Malan, 1993);
7. Are probably the most widely used lithology for Stone Age artefact manufacture in the south-western and southern Cape.

Silcrete is generally grey (Figure 13) although cream, red, brown or yellow tinges have been noted. It is extremely hard, generally having the hardness of quartz, shattering into angular fragments with conchoidal fracture. Very fine-grained to coarse-grained and pebbly types may occur in the same profile. Vugs - empty or containing secondary silica and ferruginous material - are plentiful. Silcrete breccias (Figure 14) are ubiquitous, comprising angular fragments of silcrete recemented by secondary silica.

Figure 13. Typical appearance of pebbly silcrete. The red and green colourations are caused by lichens.

Figure 14. Block of silcrete breccia.

Kaolin

Kaolinite is a clay mineral, formed by weathering or hydrothermal alteration of aluminosilicate minerals. Thus, rocks rich in feldspar commonly weather to kaolinite. In order to form ions like Na, K, Ca, Mg, and Fe must first be leached away by the weathering or alteration process.

In the Study Area (as well as in the rest of the Ruèns) the feldspatic Bokkeveld shales, as a result of weathering, were altered into Kaolin. Kaolin can be found in wide swathes of land in red, pink, brown, white, ochre and other colours, and can be easily identified on hill slopes and along road and river cuttings (Figures 15 and 16). The Kaoline was mined in many locations in the Study Area. See Chapter S.

Figure 15. Kaolin on the slope of a hill is eroded by rain and runoff.

Figure 16. Abandoned kaolin quarry.

Regional erosion

A period of about 140 Million years, between the deposition of the Enon Formation and the deposition of the Breadasdorp Group Formations, was characterised by events of erosion, planation and deep weathering, as well as tilting and uplifts of the African sub-continent.

These geological processes resulted in the Cainozoic Formations being unconformly lain over the Bokkeveld Formations (Figures 17) and the Enon Formation (Figure 18).

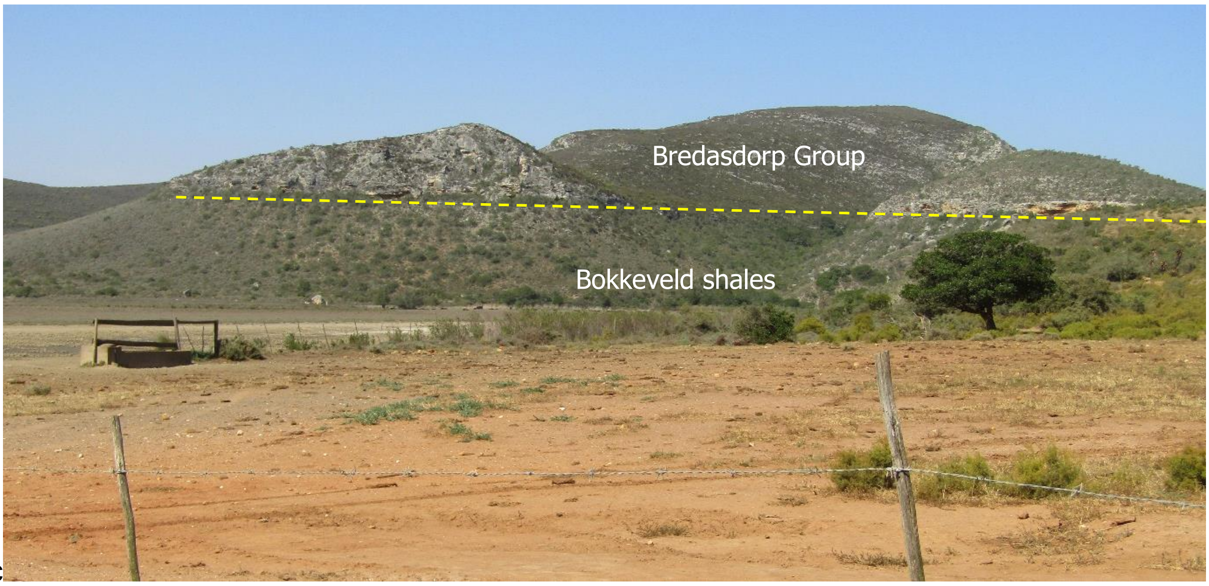
c 

Figure 17. The contact (yellow dashed line) between the Bokkeveld shales and the overlain Bredasdorp Group. View to the north across the Salt River Gorge.

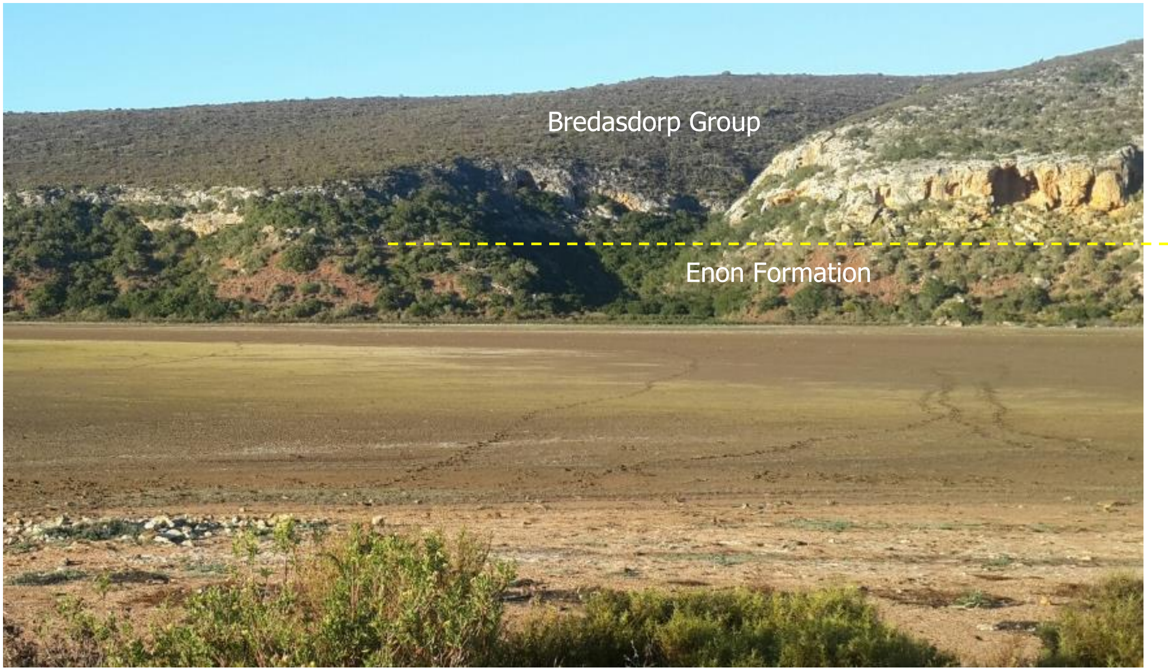


Figure 18. The contact (yellow dashed line) between the Enon Formation and the overlain Bredasdorp Group. View to the south across the Salt River Gorge.

Cainozoic Formations

The Bredasdorp Group

The Bredasdorp Group is the most recent lithological unit present along the SA south-western coast. It unconformly covers the underlying geology from Hermanus to Plettenberg Bay (Figure 19).

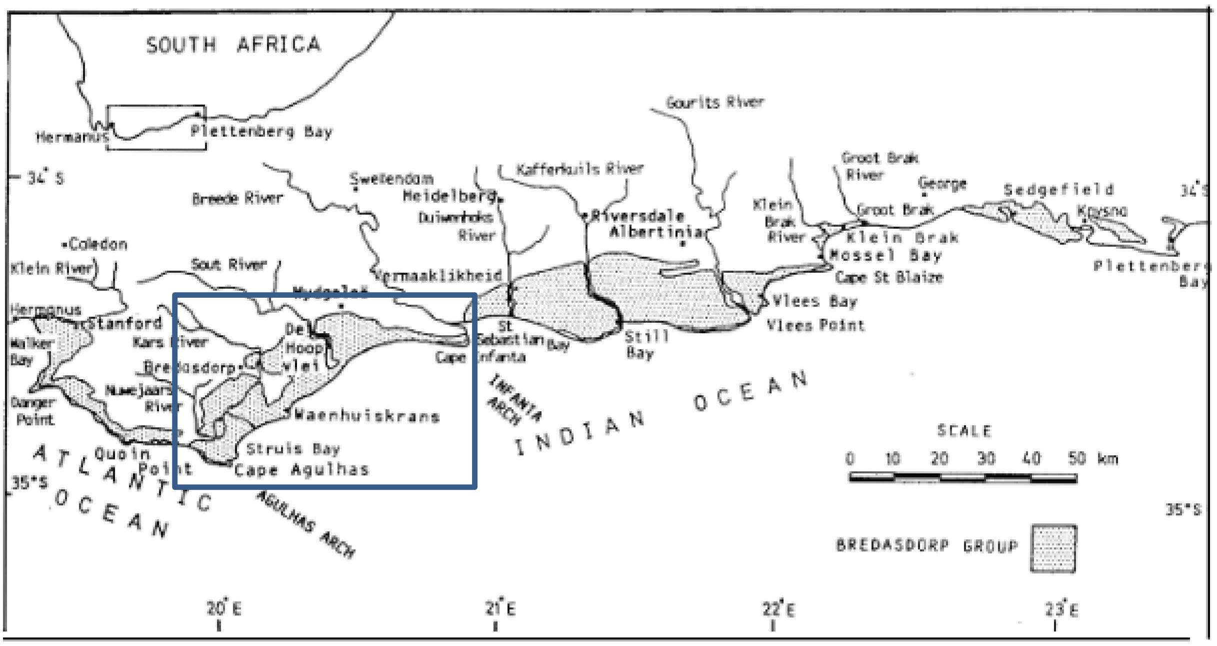


Figure 19. The distribution of the Bredasdorp Group along the south coast of South Africa. The Study Area is within the box.
Source: J Malan's MSc thesis, 1990.

From J Malan MSc thesis 1990:

The Bredasdorp Group consists of typically marginal-marine coastal deposits with interstitial marine sediments, deposited during marine regressions. The succession is characterised by aeolianites, calcarenites, calcareous sandstones, pebbly limestones, beach gravels and calcrete.

The Bredasdorp Group was deposited and consolidated during interglacial periods throughout the Pliocene and Pleistocene. Sea-level fluctuations and climate changes were the main controlling factors for the formation and preservation of the successions. The atmospheric conditions during glacial low-stand periods are commonly cooler and windier on average, with sediment predominately mobile; however during interglacial high-stand periods, the warmer and wetter conditions aided in the consolidation and carbonate cementation of the various Bredasdorp Group rock units.

The succession has a variable width ranging between 0.2 and 7 km and attains a maximum thickness of ~500 m. In the area between Cape Agulhas and Cape Infanta the group attains a height of 273 m (south of Potberg) and 189 m west of the Salt River Gorge.

The table below (Figure 20) is a summary of the Bredasdorp Group stratigraphy with ages of deposition, depositional environments and petrographic characteristics. A generalised geological section is given in Figure 21.

Age (Ma)	Period/Epoch	Lithostratigraphic Unit	Depositional Environment	Lithological Characteristics
0.012	Holocene	Strandveld Formation	Fluvial Colluvial Marine (beach and shoreface) Near-marine Aeolian dune fields Interdune environments	Unconsolidated beach, river, scree, aeolian dune sands Stabilised dune deposits Beach rock Quartz -feldsparthic sands Significant shell fragment content
0.088	Upper Pleistocene	Waenhuiskrans Formation	Coastal (near-marine) Backshore dune fields Aeolian dune corridors Interdune environments	Unconsolidated, semi-consolidated, consolidated, calcified dune rock Well sorted - very well sorted Medium grained Calcarenite, calcerous sands Calcrete layers Large-scale aeolian crossbedded Thickly bedded (3 metres) Terristrial gastropods Well rounded marine shells, foraminifera fragments Maximum thickness 200 metres
0.125 0.126	Upper Pleistocene Middle Pleistocene	Kleinbrak Formation	Shallow marine Estuarine Beach Lagoonal environments	Consolidated sand, calcarenite, marine gravel, conglomerate, significant shell content. Poorly sorted to well sorted. Pebbly limestone
1.8 2.6	Lower Pleistocene Late Pliocene	Wankoe Formation	Coastal (near-marine) Backshore dune fields Aeolian dune corridors Interdune environments	Calcified dune rock Well sorted - very well sorted Fine - medium grained Calcarenite, calcaerous sandstone Pebble lenses, calcrete layers Massive, large-scale cross bedded Weathered Terrestrial shells Positive erosive landscape feature, forms prominent ridges Maximum thickness 300 metres
	Late Pliocene	De Hoopvlei Formation	Shallow marine (beach, shoreface, backshore, foreshore) Estuarine, lagoonal environments Deposited on Tertiary marine terrace.	Cemented Beach gravel Poorly sorted Basal pebbly conglomerate, calcarenite, calcerous sandstone Marine shells Average thickness 8 metres

Figure 20. Summary table for the Bredasdorp Group.
Source: M Hodges's MSc thesis, 2013.

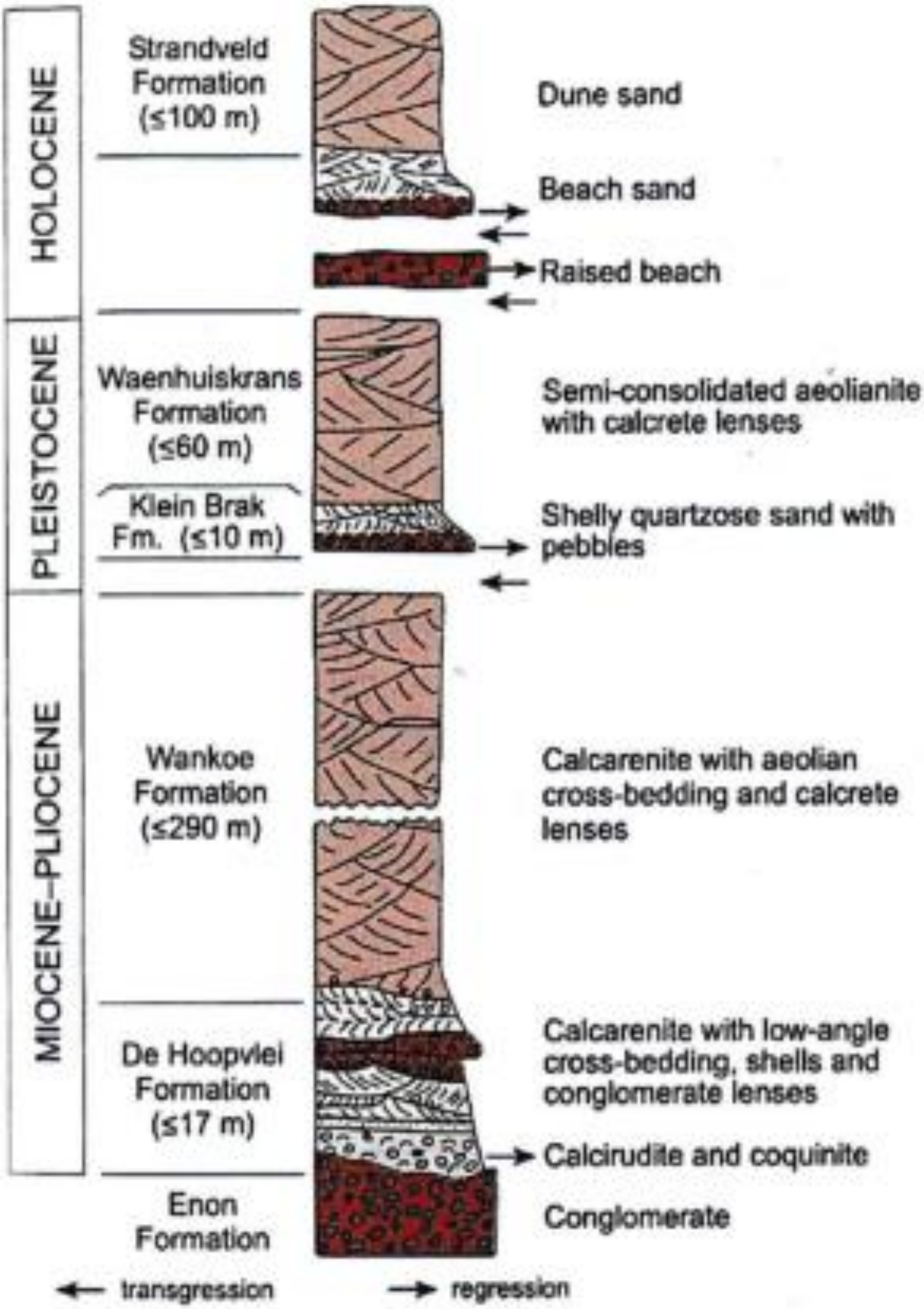


Figure 21. Generalised geological section of the Bredasdorp Group.
Source: J Malan's and J Viljoen's Field Trip Guide, 2016.

The De Hoop Vlei Formation

The De Hoop Vlei Formation is the basal, marine unit of the Bredasdorp Group. It unconformly overlies the eroded Cape Supergroup rocks and forms a thin veneer on a wave-cut, seaward-sloping platform (Figures 17 and 18 above). It underlies the Wankoe Formation. The age of this formation is early to mid-Pliocene (3 million years ago) (Figures 22 and 23).

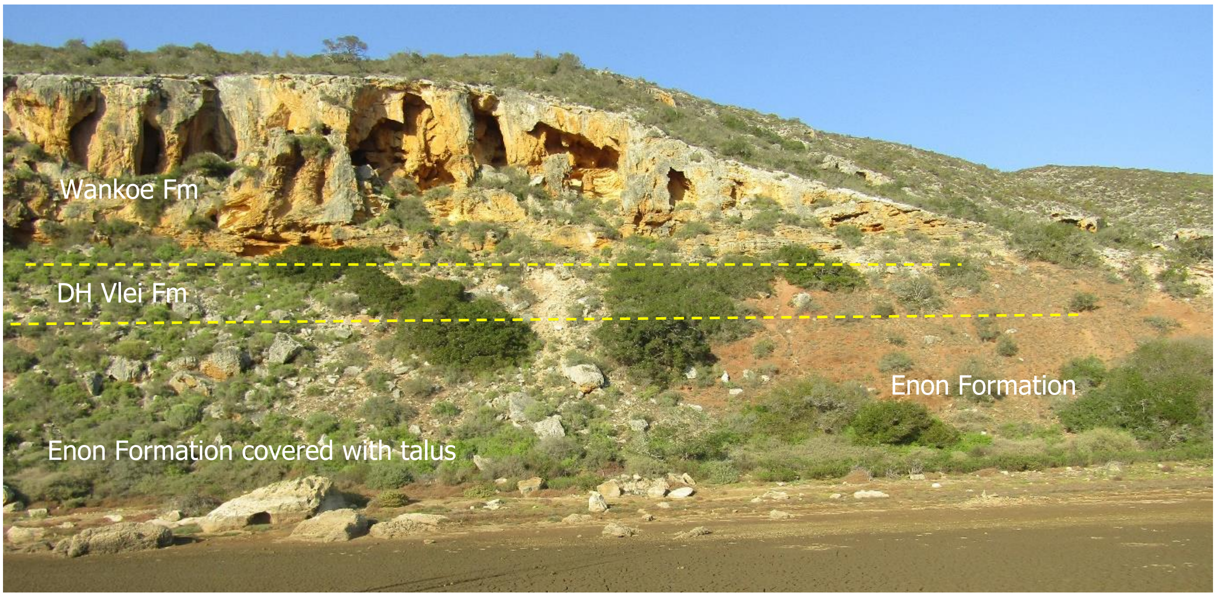


Figure 22. One of the stratotypes (the sites where typical sections of a formation are exposed) of the De Hoop Vlei Formation (between the two dashed yellow lines) at Rooikrans, in the south side of the Salt River Gorge.

Figure 23. Shells comprise one of the layers of the De Hoop Vlei Formation.

The Wankoe Formation

The Wankoe Formation constitutes the bulk of the Bredasdorp Group. It is aeolian in nature (deposited and shaped by winds). It was deposited probably during the Late Pliocene regression as shifting dunes, which were calcified later, to form the aeolianites (or calcarenite ridges, locally called Hard Dunes (Figure 24).

Figure 24. Steep slopes are typical of the Hard Dunes. The dashed yellow line indicates the obscured contact between the Voorstehoek Fm (shales) and the Bredasdorp Group Formations.

The Wankoe Formation consists of massive and large scale, cross bedded, grey weathering calcarenite and calcareous sandstone. Scattered pebbles, pebble lenses and calcrete (limestone crust) layers are present in places (J Malan, 1990). In many places the contact is obscured by talus and debris (resulting from the disintegration of the Wankoe Formation and the capping calcrete), as well as by thick vegetation. The Wankoe Formation is the main host of the karst features, namely dry valleys, caves, overhangs (Figure 25) and dolines.

Figure 25. Typical planar cross-bedding (arrows) of the Wankoe Formation.

The Klein Brak Formation

The Klein Brak Formation was deposited on a wave-cut platform cut into the Uitenhage Group and Cape Supergroup starta, of Late Pliestocene age (the Interglacial high of ~125,000 years ago). It consists of sand and calcarenite with shelly / conglomerate / gravel layers. The maximum thickness of this formation is 7 m [From Malan, 1991]. Cemented and loose pebbles, forming the lowest layer of this formation, are shown in Figures 26 and 27.

Figure 26. Pebble conglomerate of the Klein Brak Formation near Cape Agulhas.

Figure 27. Loose pebbles of the Klein Brak Formation on the shores of De Hoop Nature Reserve.

The Waenhuiskrans Formation

The Waenhuiskrans Formation (named so after the village Waenhuiskrans, next to which good exposures of this formation are found, and where the Waehnuiskrans Cave is located. Its age is Late Pleistocene. It consists of consolidated to semi consolidated calcarenite and calcareous sandstone ridges with scattered calcrete and soil horizons. It is characterised by large scale aeolian cross-bedding (Figures 28 and 29). It attains a maximum thickness of 60 m (outside the Study Area).

Figure 28. Consolidated Waenhuiskrans Formation ridge, disintegrating by wave action.

Figure 29. Semi-consolidated Waenhuiskrans Formation ridge partly covered by dune sand.

The Strandveld Formation

The Strandveld Formation is the youngest formation of the Bredasdorp Group and of the coastal area. It consists of dune fields, attaining heights of up to 100 m (Figures 30 and 31). There are several dune fields in the Study Area.

Figure 30. Typical dune landscape.

Figure 31. Long swathes of dunes are being stabilised by vegetation (naturally and artificially).

Other formations

Four other formations present in the Study Area are: A. Red sand, B. Calcrete (limestone crust), C. Soils and D. Alluvium (erosional materials transported by water).

a. Red sand

The red, fine grain sand is abundant in the area between Bredasdorp and Potberg. This study has found that this sand is not only confined to valleys or topographic lows, but forms hills as high as 100 m above sealevel; it is also found in confined areas as high as 183 m above sealevel (Figures 32 to 35).

Figure 32. Satellite image of red sand in a valley (yellow arrow), and at the top of a plateau (black arrow). The surface rock (the greyareas) is calcrete (read below).

Figure 33. Road climbing a red sand hill.

Figure 34. Red sand in a valley.

Figure 35. Yellowish sand at the top of a Hard Dune plateau.

The fine, red sand is very similar to the fine, white sand which forms the present day coastal shifting dunes. This study suggests that the red sand is the unconsolidated sand (dunes) of the Wankoe Formation. Like other formations in the area, it is partially covered with calcrete (read below).

The above proposed geological scenario is to be further investigated (laboratory analyses of the grain size, mineralogical content etc and discussions with other geoscientists are required). See Chapter W.

b. Calcrete

Definition

Calcrete is a rock which was formed 'in situ' (on site) from the local materials, i.e. it was not transported and / or deposited by an agent (wind or water) like other sedimentary formations.

The following definitions of calcrete are from four separate sources; together they explain the formation of this sediment:

1. Calcrete, also called Hardpan, calcium-rich duricrust, a hardened layer in or on a soil. It is formed on calcareous materials as a result of climatic fluctuations in arid and semiarid regions. Calcite is dissolved in groundwater and, under drying conditions, is precipitated as the water evaporates at the surface. Rainwater saturated with carbon dioxide acts as an acid and also dissolves calcite and then redeposits it as a precipitate on the surfaces of the soil particles; as the interstitial soil spaces are filled, an impermeable crust is formed.

2. A limestone formed by the cementation of soil, sand, gravel, shells, by calcium carbonate deposited by evaporation, or by the escape of carbon dioxide from ground water. It is also called caliche.

3. A crust or layer of hard mineral or subsoil encrusted with calcium-carbonate occurring in arid or semiarid regions.

4. A sedimentary rock; a hardened deposit of calcium carbonate. This calcium carbonate cements together other materials, including gravel, sand, clay, and silt. It's found in aridisols (desert soils) and mollisols (grassland soils and dark fertile surface horizons).

Calcrete on the South Coast

Calcrete is abundant along the coast between Cape Town and Knysna. It was formed through a process of laterisation, whereby the top layers were weathered into soil which, with time, turned into case-hardening of the topography. Calcrete forms a capping layer on the limestone formations of the Bredasdorp Group, as well as (but to a much lesser extent) on earlier formations such as the Enon Formation. The calcrete layer is being eroded and disintegrated. It can be observed as sheets (Figures 36 and 37) and as low lumps (Figure 38).

It has been assumed that the formation of the calcrete in the area took place from mid-Tertiary to early-Pleistocene, but the evidence is rarely preserved and complete (intact laterised profiles did not survive in the area). Calcrete can attain several meters in thickness.

Figure 36. Calcrete crust on a road.

Figure 37. Calcrete sheets on red sand.

Figure 38. Calcrete lumps on red sand.

c. Soils

There are many pockets of soils on the Calcrete capping (Figure 39) as well as in valleys and depressions (Figure 40). There are many other types of soils in the Study Area.

Figure 39. Soil on the disintegrated calcrete capping.

Figure 40. Soil on the floor of a valley.

d. *Alluvium*

Alluvium is carried by rivers and deposited along their courses (Figures 41 and 42).

Figure 41. Alluvium is deposited along the Salt River course.

Figure 42. Satellite image of the Salt River Gorge. Alluvium is deposited on the floor of the vlei.