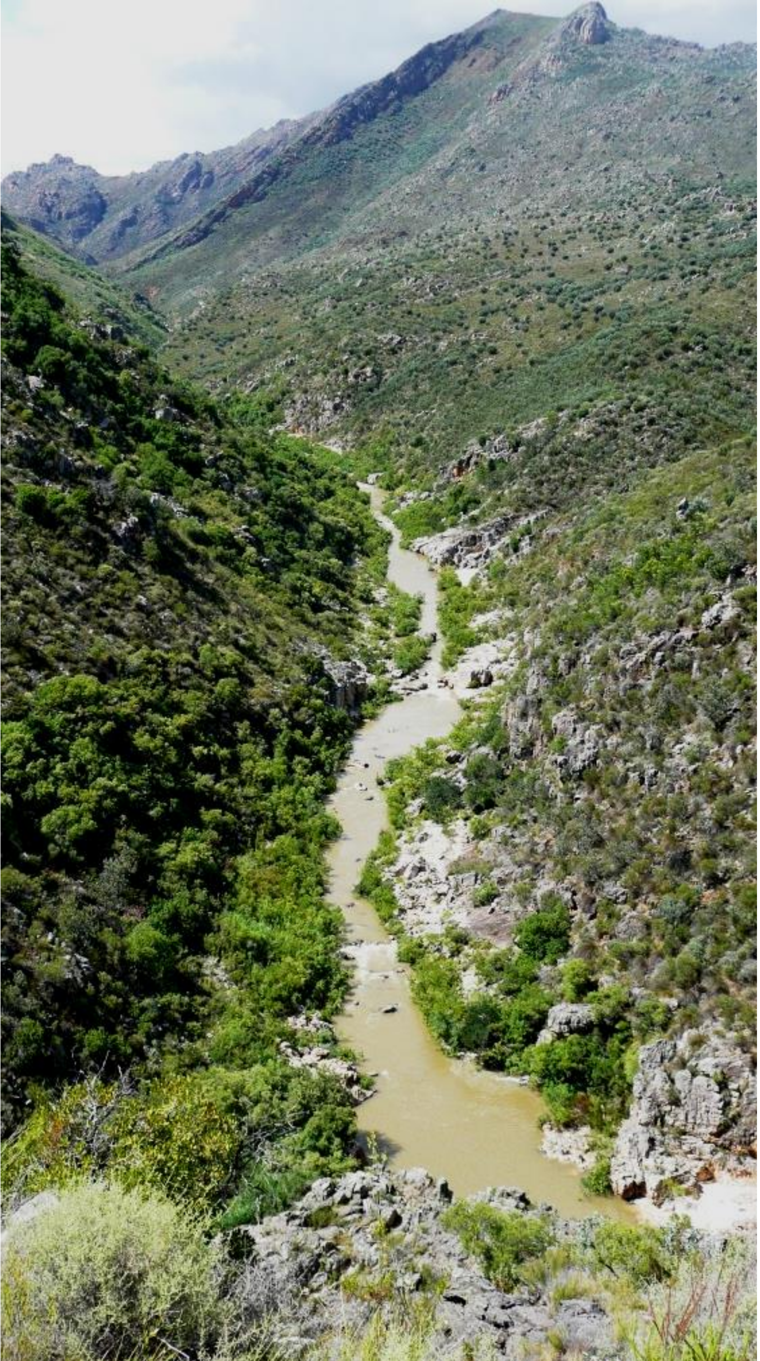

STORIES IN STONE

A GUIDE TO THE GEOLOGY OF THE WESTERN CAPE, SOUTH AFRICA

Duncan Miller

Previous page: Onderboskloof – the headwaters of the Olifants River, eroding the Cedarberg

CONTENTS

ACKNOWLEDGEMENTS

Parts of the text have been reworked from the following articles published previously, in either *Village Life* or the *South African Lapidary Magazine*; and individual chapters are available on the Cape Town Gem & Mineral Club website http://ctminsoc.org.za/field-guides.php.

Miller, D. 2005. The Sutherland and Robertson olivine melilitites. *South African Lapidary Magazine* 37(3): 21–25.
Miller, D. 2006. The history of the mountains that shape the Cape. *Village Life* 19: 38–41.
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Miller, D. 2007. The geology of Robben Island, Table Bay, Cape Town. *South African Lapidary Magazine* 39(2): 23–27.
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Miller, D. 2007. A brief history of the Malmesbury Group and the intrusive Cape Granite Suite. *South African Lapidary Magazine* 39(3): 24–30.
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Few of the geological interpretations in this guide originate with me. Most of them are taken from the various publications listed in the Bibliography. I am entirely responsible for any errors of interpretation.

Photographs are all by Duncan Miller, except where indicated by Amour Venter, Jo Wicht and Gregor Borg.

Safety

Some locations can be dangerous because of opportunistic criminals. Preferably travel in a group with at least two vehicles. When inspecting a road-cut, park well off the road, your vehicle clearly visible, with hazard lights switched on. Be aware of passing traffic, particularly if you step back towards the road to photograph a cutting. Keep children under control and out of the road.

Fossils

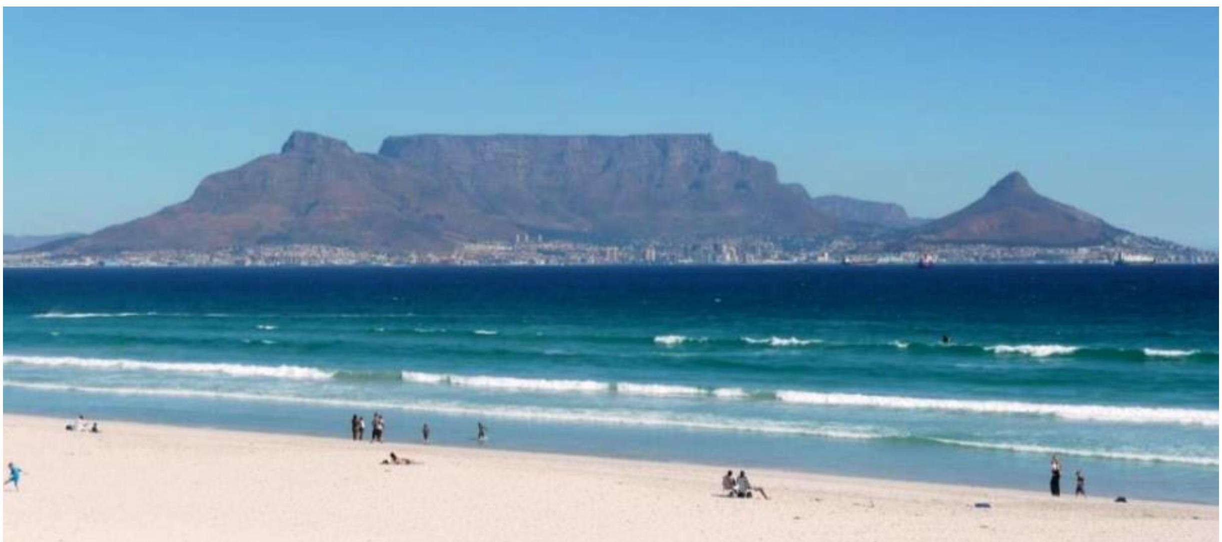
It is illegal to collect fossils in South Africa without a permit from the South African Heritage Resources Agency. Descriptions of fossil occurrences in this book do not encourage illegal collection.

INTRODUCTION

Cape Town's Table Mountain is a geological wonder. Carved by erosion, its sandstone cliffs rest on a base of granite. It is one of the most famous landmarks in the world. The Cape Peninsula's sandstone hosts a shrinking remnant of *fynbos*, the uniquely rich flora that has evolved on the nutrient poor sandy soils. But how many people know that Table Mountain's flat top marks the passage of a long vanished glacier, or that the black rocks at its base once were mud at the bottom of an even more ancient sea?

How many people know that the granites at Sea Point were visited in 1836 by Charles Darwin during the homeward voyage of the Beagle, and that it helped to resolve a long-standing debate about the origin of granites world-wide? These various rocks have diverse origins. Their stories can be read by those who have the curiosity and the patience to learn the language of geology.

Devil's Peak, Table Mountain and Lion's Head, seen across Table Bay



The rocks of the Western Cape are the remnants of two distinct mountain building episodes, both of them associated with the assembly of the latest supercontinent, Gondwana. In order to follow the historical sequence of deposition, collisions, and mountain building you need to be able to recognise three different packages of rocks. The oldest package consists of the Malmesbury Group metamorphic sedimentary and volcanic rocks, about 550 million years old. (All geological dates are approximate because they are associated with a statistical error. This usually is around plus minus one percent of the quoted age.) The igneous Cape Granite Suite, consisting of various rock bodies ranging in age from about 550 to 520 million years, is intrusive into the Malmesbury Group rocks. Uplift in a mountain building event and then rapid erosion of these two groups of rocks was followed by deposition of the Cape Supergroup sedimentary rocks. Folded and eroded remnants of these form the prominent Cape Fold Belt mountains.

This guide describes accessible exposures of these three packages of rocks. It is an up-to-date account, intended for readers who want to know something about the geological history of the Western Cape, but who have no formal training in geology.

The geological record may be read like a book, but it is a book from which many pages, and indeed whole chapters, are missing. Geologists spend a great deal of time describing rocks in detail, but because the geological record of past events is incomplete the evidence can be ambiguous. Consequently, it is difficult to construct a single coherent story. Many reconstructions of past geological events must be tentative. This is necessary, to avoid giving the impression of false certainty. It also means that often there is not only one story that can explain the available evidence. Where geologists' opinions differ fundamentally in their interpretation of the rocks, there is more than one story to tell.

Geological explanations can change from time to time, and so the reconstructed stories of the past also change to accommodate new evidence. As a result, there may be some discrepancies between the explanations in this book and those in earlier geological publications. Because this is not an academic text book, I do not debate the merits of any particular version of the past, but try to present the most coherent story based on the published evidence currently available. Any errors are mine alone.

There is a bibliography at the end of the book, listing the sources consulted.

The reconstructions of events in the distant past require a great deal of imagination to picture what southern Africa may have been like at various times over the past thousand million years. Because not everyone is going to read through the whole guide, there will be some repetition in different sections. The text is as free of technical jargon as possible, but there are some fundamental geological concepts you need to comprehend in order to understand geological history.

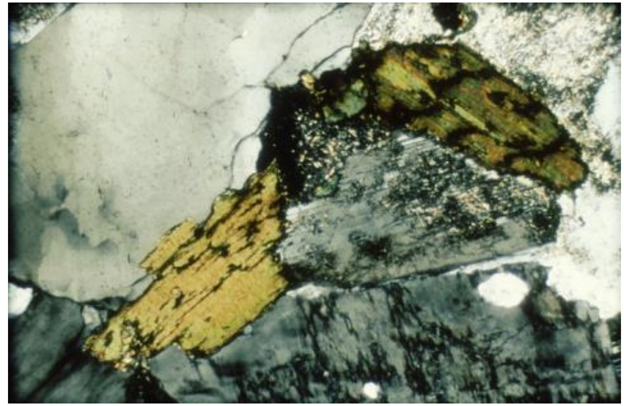
A group of amateur geologists visiting an outcrop on the Langebaan Peninsula (photograph by Amour Venter)

These include the rock cycle processes of weathering, deposition, metamorphism, igneous intrusion, melting and volcanic eruption. The mechanism underlying these is plate tectonics, the ongoing, heat-driven cycle of continental rupture and collision that creates most volcanoes, ocean basins, mountain chains and continents. More detailed descriptions of these processes and their effects on the rocks of the Western Cape can be found in these locally published books: *The Rocks and Mountains of Cape Town* by John Compton (2004); *The Story of Earth and Life* by Terence McCarthy and Bruce Rubidge (2005); *50 Must-see Geological Sites in South Africa* by Gavin Whitfield (2015); and *Geological Adventures in the Fairest Cape: Unlocking the Secrets of its Scenery* by John Rogers (2018). Even more detailed information about the local geology is available in the published explanations to the 1:250 000 geological map sheets 3318 (Theron, Gresse, Siegfried and Rogers 1992) and 3319 (Gresse and Theron 1992), and the explanation to the 1:250 000 metallogenic map sheet 3318 (Cole 2003). These may be available from the South African Council for Geoscience, Private Bag X112, Pretoria, 0001 and some regional offices.

SOME ROCKS AND MINERALS OF THE WESTERN CAPE

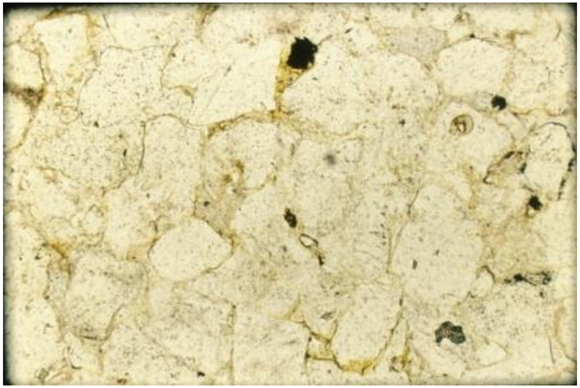
Rocks are collections of mineral grains, sometimes embedded in natural glass. Minerals are simply naturally occurring chemicals, usually compounds made up of various chemical elements. Most rocks can be classified as one of three types, based on how they formed. Igneous rocks solidify from a complete or partial melt. The coarser varieties, like granite, consist of interlocking mineral grains that grew while solidifying from a melt.

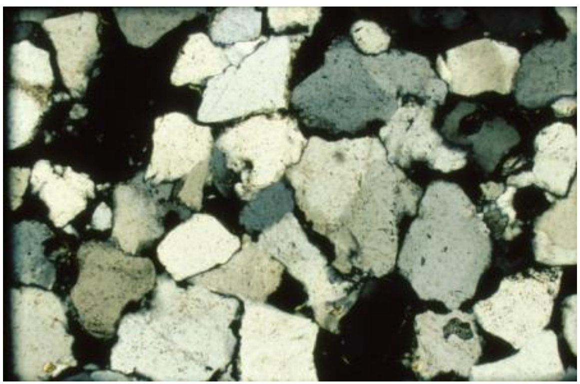
Coarse-grained Cape granite, consisting of large orthoclase feldspar crystals, smaller crystals of plagioclase feldspar, quartz and various dark minerals including mica



A petrographic thin section of Cape granite under crossed polarised light, showing the three major constituents – light grey quartz, partly altered and included dark grey feldspar, and two greenish-brown crystals of biotite mica. The width of the field of view is 1,75 mm.

Sedimentary rocks consist of particles, often derived from erosion, deposited by water, wind, ice or gravity. In the coarser varieties, like sandstone and conglomerate, the individual particles may be cemented together by some secondary matrix.





Two photographs of a petrographic thin section of sandstone from Table Mountain, under plane polarised light (above) and crossed polarised light (below), showing the partly interlocking individual sand grains with interstitial cement The width of the field of view of each photograph is 1,75 mm.

Metamorphic rocks have undergone chemical and physical changes due to heat and/or pressure. Their original constituents have been changed into other minerals and their physical relationships with each other altered.

A water-worn cobble of metamorphic Malmesbury hornfels with two generations of cross-cutting quartz veins

Many people are familiar with quartz, one of the most common minerals in the crust of the Earth, and will be confident that they can recognise it on sight. The other really common minerals making up most of the crust of the Earth are the feldspars, actually a group of minerals sharing similar crystal structures.

A quartz crystal cluster from Vredendal. The geometric points and flat faces of the quartz reflect its regular, internal crystallographic structure.

Like quartz, the feldspars are silicates, meaning they have crystallographic frameworks made up of atoms of silicon and oxygen. In the silicates, four oxygen atoms are arranged symmetrically around a central silicon atom in a tetrahedron. This is like a small pyramid with a triangular base and sides. In the feldspars these tetrahedra are linked together in a three-dimensional network, with adjacent silicon atoms sharing oxygen atoms at the corners.

To make things more complicated, in the feldspars some of the silicon atoms are replaced by aluminium atoms, in a regular way; and the whole framework is stuffed with additional atoms, which commonly are potassium, sodium, and calcium in varying proportions. It is these additional atoms, as well as the cooling rate during crystallisation, which give rise to the differences between the various feldspar minerals. The potassium-rich feldspars include high temperature sanidine, which one can find as tiny clear crystals in pumice, a frothy volcanic rock, sometimes washed up on the Cape beaches.

Rectangular, clear sanidine feldspar crystals in pumice from Yzerfontein beach

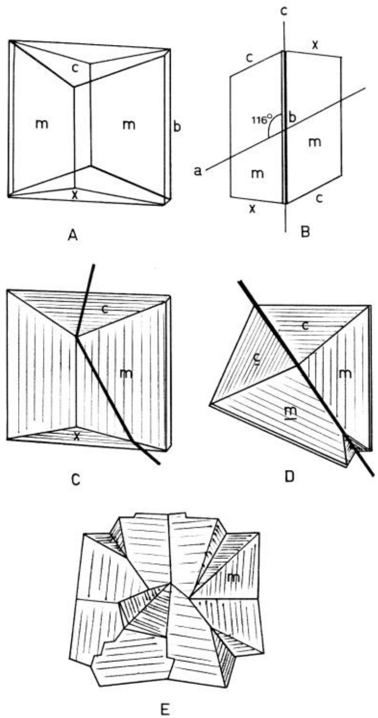
A common potassium feldspar is microcline, often, but not always, green. The green gem variety is called amazonite. By now, anyone who has looked closely at the Cape granites should be very familiar with another common potassium feldspar, orthoclase. This forms the big blocky crystals in slowly cooled granitic rocks, and in gem quality it is familiar as blue, pink, or grey moonstone.

Coarse-grained Seeberg granite near Langebaan with a twinned orthoclase feldspar crystal in the centre. The width of the field of view is about 15 cm.

More spectacular are complex twinned crystals of adularia, a particular wedge-shaped habit of orthoclase feldspar, that occur in a dolomite quarry near Vredendal.

Complex, twinned adularia crystal from Vredendal

The sodium and calcium feldspars form a continuous series in terms of composition, between sodium-rich albite, and calcium-rich anorthite, called the plagioclase series. Various intermediate compositions have names of their own. One of these is labradorite, which has a beautiful blue sheen, and is popular in jewellery. It is easy to be overwhelmed by the numerous names for feldspars, and some can be distinguished only through chemical analysis. Nevertheless, the characteristic blocky and wedge-shaped crystal habits, as well as twinning and cleavage, often help to distinguish the various types.



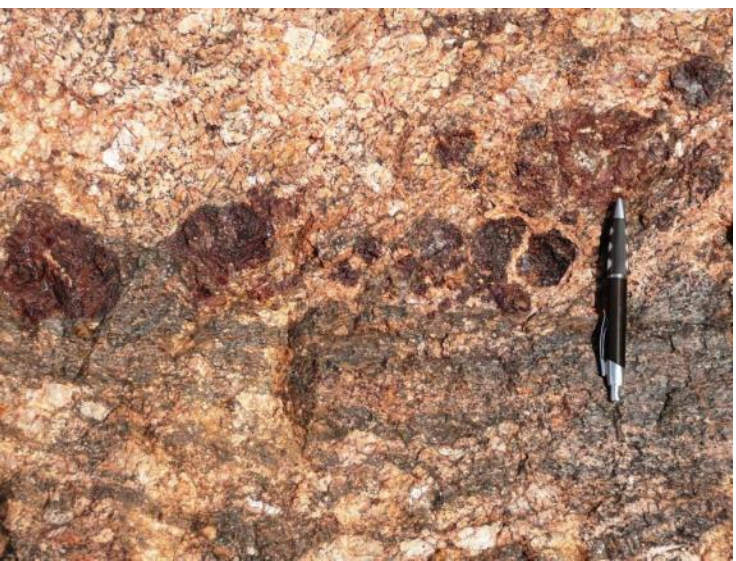
Explanatory diagrams of adularia feldspar twins from Vredendal, published previously in: Miller, D. 2006. Minerals from the Vredendal dolomite quarry, Western Cape. *South African Lapidary Magazine* 38(1):6-11. A copy of the article is available on the Friends of Minerals Forum.

A: Diagram of an idealised monoclinic adularia single crystal viewed obliquely from the right, showing the narrow side pinacoid b, the broad prism faces m, the basal pinacoid c, and the second-order pinacoid x.
B: Diagram of the adularia crystal viewed from the side, showing the crystallographic axes. The c-axis is vertical, the b-axis emerges perpendicularly from the page, while the a-axis is inclined by 116° to the vertical plane bearing the b and c-axes. The basal pinacoid c is parallel to the inclined a-axis, and the prism faces m and side pinacoid b are parallel to the vertical c-axis.
C: Drawing of the adularia single crystal viewed obliquely from the right, showing the approximate trace of the {021} Baveno twin plane, as a thick line, on the crystal faces.
D: The right-hand portion of the crystal is mirror reflected through the twin plane to produce the pyramidal twin, viewed from above in this drawing.
E: Polycyclic twinning, involving four twin pairs like those in D, can be visualised as four-fold rotation of the Baveno twin around the shared a-axis, separated by the line joining the upper two c faces. This produces the complex cyclic twins sketched in E, viewed from above, from a real example found by Lesley Bust. The corner fish tail grooves can be on either the upper or lower surface, depending on the relative development of the basal pinacoid c and the second-order pinacoid x faces. This particular example also has some evidence of reflection twinning across the {100} plane, parallel to the vertical plane containing both the b- and c-axes of the untwinned crystals, so three different twin laws are involved here.

A GEOLOGICAL HISTORY OF THE SOUTHWESTERN CAPE

The history of the rocks of the southwestern Cape starts over a thousand million (or a billion) years ago, when a huge chain of mountains spanned what is now South Africa. Remnants of the eroded roots of these mountains are now exposed in Namaqualand and KwaZulu-Natal. How do such mountains form? The crust of the Earth consists of a number of discrete plates, which continually move relative to each other. This is because of convection in the mantle, driven by heat generated by radioactivity in the interior of the Earth.

Red garnet crystals in a Namaqualand rock transformed by heat during deep burial



Consequently, continental masses are subjected to endlessly changing squeezing and stretching, as crustal plates collide with each other or split apart. Major continental masses, or supercontinents, do not seem to last long in geological time, but break apart, perhaps because of the heat that accumulates beneath them.

Oceanic crust is thinner than continental crust, and conducts heat more easily, so a supercontinent acts as a kind of pressure-cooker lid on the escape of Earth's internal heat. This build-up of heat leads to rifting and break-up of the supercontinent. The fragments then drift away from each other, with new ocean basins forming between them. The global convection cells in the mantle that drive continental drift form linear chains of volcanoes running around the Earth in the middle of these ocean basins. New oceanic crust is formed here, and the sea floor spreads out towards the continental margins. Here, under many of them, oceanic crust plunges back down into the Earth's mantle. This process is called subduction. Because the Earth is a closed sphere, the moving continental masses eventually override and close the older ocean basins. When oceans close completely, collision of the adjacent continental masses squeezes, deforms and metamorphoses the ocean floor rocks.

These rocks often are plastered onto the continental margins and are involved in building mountain chains. This mountain building process is called orogeny. The deep roots of these mountains are intruded by buoyant molten masses of rock. These can solidify slowly at depth to form granites and related rocks, or erupt on the surface to form volcanoes, like those surrounding the modern Pacific Ocean.

About 1 100 million years ago these processes created a huge mountain chain, stretching across what is now southern Africa. They formed part of the ancient supercontinent geologists call Rodinia. These mountains were like the modern Andes in South America and were near the edge of a continental mass. Off the coast there was a deep trench. Here the relatively thin but dense oceanic crust underwent subduction, plunging beneath the margin of thicker but less dense continental crust. As the wet slab of oceanic crust descended into the hot mantle of the Earth it heated up, and started to melt some of the surrounding rock. The buoyant molten rock rose up through the lower crust and intruded into the overlying rocks. These were baked and metamorphosed by the heat of the intrusive igneous rock, as well as by the pressure of their being buried deep underneath the mountain range. With the final closure of the ocean, the two opposing continental masses collided and welded together, and the descent of the ocean slab stopped. The mountains no longer were growing through the addition of new continental crust, so they wore down through erosion. This loss of material created a gravitational imbalance, which caused the continental mass to rise. The lighter continental rocks literally floated up on the denser mantle. This led to further erosion, eventually exposing the deep roots of the former mountain chain. Today, the intensely folded and thermally metamorphosed rocks of the former mountain roots are exposed in Namaqualand and in northern KwaZulu-Natal. Together they form the Namaqua-Natal Belt.

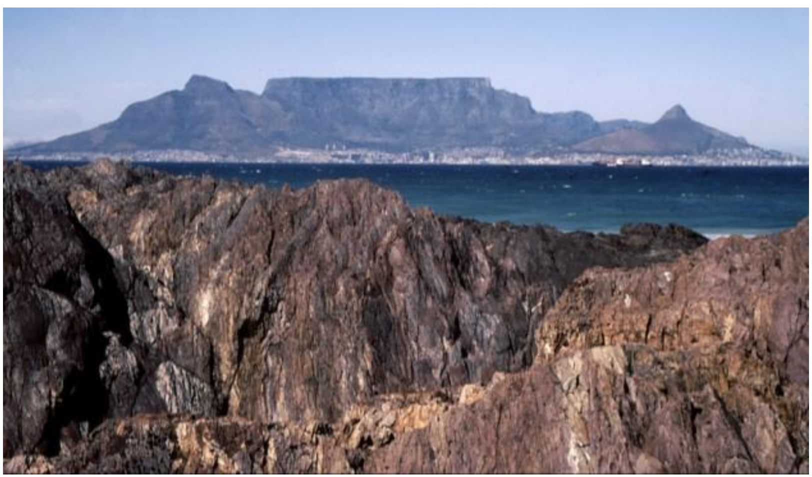
Spektakel Suite Granite, Kliprand in Namaqualand

A piece of the sunken oceanic slab still may be hung up in the continental collision zone, now buried beneath much younger rocks. The evidence for this is a linear magnetic anomaly running from around Sutherland to Port St Johns on the east coast. In this narrow strip, the local magnetic field of the Earth is stronger than on either side. It is known as the Beattie Anomaly, after the scientist who discovered it in 1909. Some geologists interpret this to be due to an approximately ten kilometre thick slab of dense ocean floor rock stuck in the crust at a depth of between ten and twenty kilometres. The Beattie Anomaly largely coincides with a broader band that represents a zone of electrically conductive material in the crust. This is known as the Southern Cape Conductive Belt and lies underneath the southern margin of the present Karoo basin and the northern edge of the Cape Fold Belt mountains. It has been assumed that the Beattie Anomaly and the Southern Cape Conductive Belt are caused by the same buried slab of oceanic crust, but the Southern Cape Conductive Belt can be traced further west than the Beattie Anomaly. The Southern Cape Conductive Belt was once thought to define the southern margin of the Namaqua-Natal Belt and represent a now buried, 1 000 million year old geological collision zone or continental suture. The highly deformed rocks in the core of this collision zone give rise to a band of crust with abnormal properties. This band of crust is probably weaker than the surrounding crust. This is similar to a welded joint in steel, which is weaker than the surrounding metal. If this interpretation of the Southern Cape Conductive Belt is correct, then we can expect the buried basement rocks both north and south of the suture to be something like the highly metamorphosed sediments and granites presently exposed in Namaqualand. They should have similarly variable compositions, and similar geological ages, varying from about 1 100 to 2 000 million years old.

A copper prospecting shaft dating from 1685, near Springbok in Namaqualand

More recent research has involved reading signals reflected off deep layers in the crust. The results have prompted a revised interpretation, typical of the uncertainty of geological reconstruction of what cannot be seen directly. In this version of the story, the Beattie Anomaly may not be the trace of a remnant of subducted ocean floor, but rather an extensive zone of dense and electrically conductive metal-bearing mineralisation within deeply buried Namaqua metamorphic rocks underlying the Cape Fold Bet. Unfortunately it is beyond the reach of current technology to sample it directly, so we have to contend with two competing and unresolved explanations.

The supercontinent of Rodinia started to break up shortly after its formation about 1 000 years ago. Around 780 million years ago, an ocean basin started to develop between what is now Africa and South America, tearing obliquely across the Namaqua-Natal Belt. This ocean, known by geologists as the Adamastor Ocean, was open until about 550 million years ago. Sandy and clay-rich sediments accumulated on the continental slopes and on the deep ocean floor. Some of these sediments consisted of mud slides down the edge of the continental shelf, as well as chemically precipitated calcareous sediments. There were also volcanic extrusions onto the sea floor. These included flows of pillow lavas and possibly one or more seamounts.



The rocks in the foreground are metamorphosed and steeply folded Malmesbury Group rocks, originally deposited as sediments on the floor of the former Adamastor Ocean.

The Adamastor Ocean closed up progressively from the north, part of the formation of the next supercontinent – Gondwana. The dating of the closure is uncertain, but between 575 and 550 million years ago ocean floor sediments and some contemporaneous volcanic rocks were plastered onto the south-western edge of the African continental mass. These metamorphosed sediments and lavas form the Malmesbury Group rocks. These are the oldest intact rocks actually found in the Western Cape, and their basement is not exposed. Nevertheless, old zircon grains included in rocks within the Malmesbury Group sedimentary rocks have dates of 1 100 to 1 900 million years. These were inherited by erosion of exposed rocks pre-dating the Adamastor Ocean. This indicates that the present basement consists of older rocks, like those of Namaqualand, which pre-date the breakup of Rodinia.

The Malmesbury Group rocks are poorly exposed on land. Their visible outcrops make up less than two percent of the area of the Western Cape. They consist of a largely monotonous sequence of shale, dirty sandstone, limestone and dolomite, with no clear regional marker horizons, and with intense deformation in parts. This makes it virtually impossible to correlate different horizons across the exposures. Consequently, it is no surprise that there are conflicting interpretations of the sequence of these rocks.

Steeply dipping, thermally metamorphosed Malmesbury Group rock was quarried in the past on Devil's Peak.

For the past 45 years, most geologists have described the Malmesbury Group rocks in terms of three northwest trending wedges or terranes; a southern Tygerberg Terrane, a central Swartland Terrane, and a north-eastern Boland Terrane, all separated by major fault zones. These terranes were thought to differ in terms of degree of deformation, variation in composition, and possible geographic origin. It has been suggested that they may have been three widely spaced pieces of ocean floor, sandwiched together along two north-easterly trending fault zones. These are the Colenso Fault zone to the south, and the Piketberg-Wellington Fault zone to the north.

More recent views of the Malmesbury Group introduced a horizontal division – same rocks, slightly different story. A lower Swartland complex is characterised by extreme deformation, and is exposed in the central Swartland region in two south-east trending domes, the Swartland dome and the Spitzkop dome. Most of the Swartland complex consists of intensely sheared, fine-grained sedimentary rocks. These include the commercially exploited limestones of the De Hoek Member, quarried at Piketberg. Metamorphosed volcanic rock occurs in the Bridgetown Formation along the Berg River, perhaps representing fragments of basaltic oceanic crust or the remains of a basaltic seamount capped with now dolomitised limestone.

The rocks of the Swartland complex were subjected to intense deformation with low-angle thrusting and shearing around 560 million years ago, as they were crumpled against the existing continental margin. Separated from the Swartland complex by a suspected but unexposed regional unconformity is the overlying (revised) Malmesbury Group. These rocks have suffered less intense deformation. In the Western Cape the (revised) Malmesbury Group consists of the metamorphosed sedimentary rocks of the Piketberg, Porterville and Tygerberg Formations, and the volcanic Bloubergstrand member of the Tygerberg Formation. This is a 50 metre thick layer of fine red tuffs and dark brown to greenish amygdaloidal andesitic lava that crops out on the coast near Bloubergstrand.

Boulder of amygdaloidal lava at Bloubergstrand

All these rocks were plastered onto the continental margin around 545 million years ago as the Adamstor Ocean basin closed and continental collision took place. These rocks now form the so-called Saldania Belt. The sediments and volcanic rocks were not only deformed by compression but also thermally metamorphosed to regional greenschist facies. Initially, compression was oblique from the northwest, giving rise to left-hand slip along major fault zones like the Colenso Fault.

The collision gave rise to a chain of mountains. Subduction of the sea floor caused deep-seated melting in the older basement rocks, and produced pods of buoyant granitic magma which intruded the deformed sediments. Geologists have reached no consensus about the direction of subduction. Some portray the oceanic crust plunging west underneath rocks now forming part of South America. Others imagine it plunging towards the east, beneath the continental margin of the stable crustal core of what would become Gondwana.

Granite boulders at Oudekraal. The lower slopes of Lion’s Head in the background are composed of the same granite, originally solidified many kilometres below the surface, and exposed by erosion.

The subduction-related granitic magmas, of variable composition, partially incorporated the country rocks as they rose. As they cooled they solidified, mostly never reaching the surface and erupting as lava. In some places, the cooling magma also introduced mineralised fluids that formed veins and stockworks containing metals like gold, copper, tin, tungsten and molybdenum, mostly in small sub-economic amounts.

The currently exposed granitic rocks make up the Cape Granite Suite, which formed in four phases of magmatism during the Saldanian Orogeny. The oldest of these granitic rocks dates from 555 to 540 million years ago. They form large batholiths, with local migmatite and contact metamorphism at their margins. The famous granite/slate contact at Sea Point is a good example of such a margin.

In 1836 Charles Darwin visited the Sea Point contact, between lighter intrusive Cape granite and the darker host Malmesbury rocks of the Tygerberg Formation.

Paarl Rock, seen from Nantes Dam, is part of the weathered crest of the Paarl Granite Pluton. The rounded weathering is typical of even-grained granite. (Photograph by Amour Venter)

The Darling Batholith, intruded south of the Colenso Fault while undergoing left-hand shear, is another example. This phase of magmatism was deep seated, and coeval with at least the later stages of compressional deformation of the Malmesbury sediments. A second phase of granites, with somewhat different composition inherited from a possibly deeper source rock, intruded between about 540 and 520 million years ago. The Paarl Granite is an example of this.

Several small intrusions of rocks darker than granite date to this phase; such as the 535 million-year-old gabbro and granodiorite exposed at Yzerfontein. The third phase of intrusion, sometimes into pre-existing granites and at relatively shallow depths, took place around 520 million years ago. Some granitic magma also reached the surface to erupt as lava. Rhyolitic ignimbrites (silica-rich welded tuffs) on the Saldanha Peninsula and Postberg have been dated to 542 and 515 million years respectively, for now.

As the Adamastor Ocean closed, the former compression from the northeast swung around towards the south. This presumably was due to other continental fragments colliding with the growing margins of Gondwana. This reversed the movement on some of the large faults in the Western Cape and coincided with the main phase of intrusion of the largest granite plutons.

By about 540 million years ago, at the time of the intrusion of the Peninsula Granite to the south, the slip on the Colenso Fault had changed from left-hand to right-hand. Orogenies, or mountain building events, involve not only compressive but also tensional forces.

The 515 million-year-old volcanic rocks on Postberg, viewed from Langebaan lagoon

Many of the granite intrusions took place in a tensional setting, after relaxation of the main collisional phase. Late orogenic uplift and erosion of the Saldania Belt must have been rapid. This enabled the rhyolitic volcanism to take place onto and immediately adjacent to exposed coarse-grained granite that only a few million years previously had cooled and solidified at depths of 7 to 10 kilometres. The Saldanian mountain building episode, with its associated volcanism, forms part of a ramified belt of sutures that welded together the various continental fragments to make up the former supercontinent of Gondwana.

Ongoing tensional faulting then produced narrow sedimentary basins, with their long axes following the regional northwest-southeast structural trend. Gritty sediments of the Franschhoek Formation, containing pebbles derived from the Cape granites, were deposited in one of these fault troughs. This is also the depositional setting of the slightly younger conglomerates and sandstones of the Klipheuwel Group. In the latest revision of the Malmesbury Group rocks, the Franschhoek Formation is included in the Malmesbury Group, although previously it was included in the Klipheuwel Group. These rocks lack fossils and have not been dated directly. Nevertheless, they are sandwiched in time between the end of the Saldanian magmatism at 515 million years ago, and the onset of deposition around 510 million years ago of the lowermost sedimentary units of the Cape Supergroup. The original thickness of the Klipheuwel Group is unknown, but by the onset of deposition of the Cape Supergroup the entire landscape had been planed off nearly flat by erosion. There were only a few granite hills and local geographic highs providing at most a few hundred metres of geographic relief.

The erosional contact between the top of the Cape granite below and the nearly horizontal layers of the sedimentary rocks of the Cape Supergroup above, near Hout Bay

At the end of the Saldanian Orogeny, ongoing tension led to crustal thinning, particularly along the Southern Cape Conductive Belt, the old weak weld zone running east-west at the southern edge of the Namaqua continental crust. This caused the southern edge of the continent to sag, forming the so-called Cape Trough. The Cape Supergroup was deposited in this deepening trough, which possibly was an aborted rift valley.

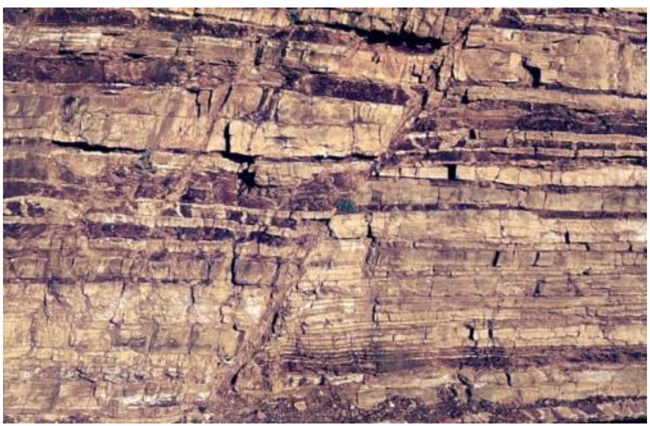
On a hot day a group of geologists inspects the Piekenierskloof Formation at the base of the Table Mountain Group, Piekenierskloof Pass

The oldest sediments in this trough are conglomerates, beds of gritty sandstone with pebbles and cobbles eroded from the immediate margins of the rift. These filled local hollows and now form the patchy Piekenierskloof Formation at the base of the Table Mountain Group. The Piekenierskloof Formation is exposed in the Piekenierskloof Pass, and at Kasteelberg and Heuningberg further south, where it lies above an unconformity on Malmesbury Group and Klipheuvel Group rocks.

The coarse, pebbly, sedimentary rock of the Piekenierskloof Formation, Piekenierskloof Pass

On the Cape Peninsula, the basal layers of the Table Mountain Group are the reddish and purple sandstones and shales of the Graafwater Formation. These used to be exposed best on Chapman's Peak, but still can be seen along Tafelberg Road. These rocks lie directly on Cape granite, with the basal sedimentary layers draped over former humps in the pre-Cape land surface. The Graafwater Formation rocks show well-preserved wave ripple marks as well as desiccation cracks. These indicate intermittent exposure of shallow water muddy sediments. They contain many trace fossils, including the feeding tracks of arthropods like trilobites.

The Graafwater Formation, formerly exposed on Chapman's Peak road. Note the fault cutting obliquely across the sedimentary layers.



Closer view of the Graafwater Formation on Chapman's Peak, showing the lighter sandy layers and darker muddy layers, some with sand-filled drying cracks

As the Cape Trough continued to deepen, it was filled with very well-sorted, coarse sandy sediments, which now make up the bulk of the Peninsula Formation, with a basal date of around 488 million years. These are the white and yellowish sandstones that form the conspicuous cliffs of Table Mountain and the surrounding Hottentots Holland mountains. There is no clear agreement among geologists about the original sedimentary environment of these rocks. These sands could have been laid down by braided rivers on a broad plain, or else on beaches and offshore bars on the coast of a shallow sea, the Agulhas Sea.

The thickness of the Peninsula Formation varies. It is about 500 metres thick on Table Mountain and 1 200 metres thick in the Hottentots Holland Mountains. Some layers contain trace fossils similar to those in the underlying Graafwater Formation, but no shelly fossils have been found.

Between about 440 million and 420 million years ago what is now central Africa had drifted over the South Pole, and huge glaciers formed on large parts of Gondwana. In places these glaciers, entering the area from the north, deformed the topmost layers of the Peninsula Formation to form a folded zone, on top of which the glacial tillites of the Pakhuis Formation were deposited. These rocks contain numerous pebbles, with flat-faceted and scored surfaces indicating their transport by ice, embedded in a sandy matrix.

This formation occurs on the very top of Table Mountain at Maclear's Beacon, and also is accessible at the top of Sir Lowry's Pass and in the Franschhoek Pass. At Maclear's Beacon the glacial rock is about two metres thick, with a polygonal weathering pattern that might be inherited from frost wedging. At Sir Lowry's Pass and Franschhoek Pass there are two glacial layers, separated by a sandy horizon that records the temporary retreat of the glaciers. With the final melting of the glaciers, fine mud was deposited, forming the Soom Shale and Disa Member of the overlying Cedarberg Formation. In places these fine sediments are highly fossiliferous, containing some of the best preserved fossils of their time in the world.

Tilted rocks of the Table Mountain Group near Villiersdorp. The Peninsula Formation forms the lighter rocks below, with the narrow green band of the Pakhuis and Cedarberg Formations between it and the darker, reddish Nardouw Subgroup above it.

On top of the Cedarberg Formation, the sandstones of the Nardouw Subgroup were deposited. These sandstones originated in a shallow sea, inter-fingering with a river flood plain towards the north. In the Western Cape area these rocks occur only east of Gordon's Bay. The valleys of the Palmiet and Steenbras Rivers also contain rocks of the lowermost Gydo Formation of the overlying Bokkeveld Group. These are greenish-grey shales and thin dark sandstone beds. They represent muds that were deposited in the deepening Agulhas Sea about 400 million years ago. Typically they contain fragments of marine invertebrate fossils, but locally these fossils generally have been destroyed by the strong cleavage of these intensely folded rocks.

Folded sedimentary rocks of the Witteberg Group exposed near Worcester on the downthrown side of the Worcester Fault. These rocks display fossil ripple marks, indicating their deposition in shallow water (left).

The Western Cape has undergone significant erosion, so most of the succeeding Witteberg Group rocks of the Cape Supergroup are not represented in the area, except near Worcester. The Witteberg Group rocks were deposited 370 to 330 million years ago and they mark the end of deposition in the Agulhas Sea, which began to experience compression, folding of the sediments, and uplift.

This incipient mountain building created a continental basin, initially open to the sea. This area was situated near the South Pole at the time, and the first sediments to fill this basin were the glacial deposits of the Karoo Dwyka Group. As these glaciers waned, and the continent drifted further north, muddy sediments that were eroded from the rising mountain belt formed the Ecca Group deposits in a progressively shallower sea. In the Western Cape these fossiliferous Karoo Supergroup rocks are preserved north of Ceres and in a small outlier south of Worcester.

A hill of Dwyka tillite, one of two at Karoopoort north of Ceres, showing the typical 'tombstone' weathering

While the Karoo rocks were being deposited, the mountains to the south continued to grow. This phase of mountain building is called the Cape Orogeny. This was the result of a subduction ocean trench that developed about 1 500 km away, on the southern margin of Gondwana. It is analogous to the modern trench off the west coast of South America. The compressive forces from this subduction zone caused the weak crust beneath the Cape Trough to buckle. The granite-reinforced rocks to the south acted as a ram, squeezing the softer Cape Supergroup sedimentary rocks against the old Namaqua metamorphic belt to the north. This crumpled the Cape Supergroup rocks, in a series of 'paroxysms' lasting from about 278 to 230 million years ago, thrusting the rock layers over each other and forming the Cape Fold Belt. This runs mostly east-west, following the ancient line of crustal weakness defined by the Southern Cape Conductive Belt. In the extreme west, the Cape Fold Belt mountains lie north-south, forming the Cedarberg Mountains. In this western belt the deformation is less severe than in the southern belt. Geologists are uncertain how this came about, but it probably has to do with the asymmetric geometry of the compressive forces causing the folding in the first place.

These events had little effect on the rocks of the southwestern Cape, possibly because they were protected by the reinforcement of the relatively rigid homogenous granite beneath them. Nevertheless, it is puzzling that in the southern Cape the basement granites show intense northward shearing and deformation associated with the Cape Orogeny, while in the southwestern Cape the Table Mountain Group rocks are largely undeformed. From south of Gordon’s Bay to Franschhoek the Cape Fold Belt does form a steep, east-facing monocline, sharply truncated on the western side facing False Bay. The intervening rocks between the Hottentots Holland Mountains and Table Mountain have eroded away, exposing the Cape granites and Malmesbury rocks that make up the Kuilsrivier and Durbanville Hills, and that underlie the sands of the Cape Flats.

View looking east from Swartklip on False Bay, towards the Steenbras mountains above Gordon’s Bay

The Cape Peninsula is crossed by numerous faults with a north-easterly orientation, following the general fabric of the basement rocks of the Western Cape as a whole. Erosion along these faults, some with vertical throws of hundreds of metres, is responsible for the major cross-cutting valleys and embayments, like the Fishhoek Valley and Smitswinkel Bay. These faults, mostly extensional normal faults, probably are related to the opening of the Atlantic Ocean. They are in the same orientation as numerous intrusive dolerite dykes of the so-called False Bay Swarm. These intrude the Malmesbury Group rocks, the Cape granite, and some even the basal layers of the Peninsula Formation. They date to around 132 million years ago and are younger than the Karoo dolerites further north.

Dolerite dyke in Malmesbury rocks at Bloubergstrand

There is some evidence that an earlier generation of dolerite dykes exists. These are cross-cut by some of the later dykes, and are more intensely deformed and altered by weathering. They appear to be similar in composition to the matrix of an igneous breccia plug at Cape Point, which intrudes the granite but not the overlying sandstone. The matrix of this plug is a basic igneous rock containing olivine phenocrysts, largely altered to serpentine. It contains fragments of a wide variety of rocks including granite. These fragments all must pre-date the deposition of the Table Mountain Group, and may be fragments of the much older, buried Namaqua-age rocks.

The breakup of Gondwana created new oceans around southern Africa. One of the major results was the development of large faults, like the Worcester Fault, with downthrows of many kilometres on their southern sides. The outlier of Witteberg and Karoo Supergroup rocks south of Worcester owes its preservation to the down throw of the Worcester Fault. These faults formed steep south-facing escarpments, the eroded remnants of which can be seen in the Hex River mountains and the Langeberg further east.

The southern escarpment of the Langeberg in the Cape Fold Belt mountains between Swellendam and Montagu

Over the past 120 million years these escarpments have eroded back and down, depositing vast accumulations of sediment in faulted basins in the surrounding sea floors and in the shallower basins on land. Around Cape Town, lower sea-levels in the past allowed deep incision of rivers flowing into False Bay and Table Bay. These valleys are now drowned by sandy sediment, which also forms the sand dunes covering the Cape Flats. Ground water level fluctuations have given rise to cemented soil horizons, creating surface rocks like silcrete and ferricrete. These are cemented by silica or hydrous iron oxide precipitates respectively. In places, like in the Durbanville Hills and on the more arid west coast, these can form sheets of surface rock relatively resistant to erosion.

In some locations these relatively recently cemented rocks can contain abundant fossils. Wave erosion of an outcrop of fossiliferous phosphatic rock just below the low water line at Milnerton beach produces a wide variety of fossils, including elephant molars and giant sharks' teeth, which wash up on the beach after storms. Fossils of a roughly similar age, some five million years old, are found in great numbers in a former phosphate quarry, now the West Coast Fossil Park at Langebaan. Here the rich geological history of the west coast is well displayed in a museum and excavation areas open to the public.

Fossilised teeth of an extinct giant shark, found on Milnerton Beach. These are about 10 cm long.

Fossilised portion of an elephant molar, found on Milnerton Beach. This is about 15 cm long.
These fossils, and others found in the 1970s, are at Iziko Museums, in Cape Town.

CAPE TOWN'S TIN MINES

In the vicinity of Cape Town there are some six tin-bearing deposits, associated with the Cape Granite Suite. The geology of the various tin occurrences in the Cape has been described most recently by Theron et al. (1992) and Cole (2003). Three of these occurrences were mined for cassiterite (SnO_2) in the early 20th century (Jones 2010). The deposit first mined at the turn of the century was on the farm Annex Langverwacht 245 near Kuils River. Most of the production was from alluvial deposits, producing over 700 tonnes of cassiterite concentrate until the working ceased in 1956. The visible remains of mining include various trenches and shafts, sunk into or near the ore bodies, as well as the remains of a boiler and hoisting machinery (Ingram 2003, Miller 2006).

Remains of a boiler and hoist at Zevenwacht (photograph by Amour Venter)

The abandoned hoist at Zevenwacht (photograph by Amour Venter)

The primary tin-bearing lodes, from which the alluvial cassiterite weathered, consist of quartz veins and fine-grained granite dykes, in a zone about 500 metres wide. The quartz veins reportedly contain molybdenite, wolframite, cassiterite, arsenopyrite, tourmaline, mica, and quartz. These veins are similar to others located in granites in the Helderberg area, and in metamorphosed sediments of the Malmesbury Group around Durbanville. The latter were prospected between 1904 and 1906, producing about 0,5 tonnes of concentrate. The tin mineralisation is related directly to the waning phases of the intrusion of the Cape Granites, dated to around 510 million years ago.

There are still several open horizontal adits at the former Zevenwacht tin mines (photograph by Amour Venter)

Inspecting one of the abandoned adits at the Zevenwacht tin mine (photograph by Amour Venter)

There are also some hazardous, partly-filled open shafts at Zevenwacht (photograph by Amour Venter)

At Kuils River black cassiterite (SnO_2) grains mostly 1 to 2 millimetres in diameter occur in quartz veins and fine-grained granitic (aplite) dykes in the granite host rock. These veins and dykes form ‘lodes’ between 1 and 3 metres wide, trending in a north-westerly direction across the boundary area of the farms Annex Langverwacht, Rosendal and Haasendal. On Annex Langverwacht and Rosendal various shafts and trenches were dug to intersect the ore bearing lodes. In addition to cassiterite the quartz veins also carry the tungsten mineral wolframite ($FeWO_4$), as well as molybdenite, pyrite, arsenopyrite, chalcopyrite, and tourmaline.

Erosion of the primary ore bodies produced alluvial deposits in the streams draining the hilly area. The stream bed on Annex Langverwacht was mined for its cassiterite-bearing quartz gravel. In fact, the alluvial deposits were the main source of the estimated 778 tonnes of cassiterite recovered during sporadic mining between 1902 and 1956. Only 28 tonnes of cassiterite concentrate and 5 tonnes of tungsten ore were mined from the hard rock lodes.

At Durbanville, cassiterite occurs along with small amounts of gold in quartz veins in the shales and impure quartzites of the Malmesbury Group rocks. This mineralisation has been identified geochemically as magmatic, that is, derived from a molten igneous source, presumably a nearby granitic intrusion. Various excavations exist on the farms Welbeloond, Hoogekraal 157 and Kuipers Kraal 133. A total production of 0,5 tonnes of concentrate at 70 percent tin has been reported from this area.

Cassiterite (SnO_2) crystals up to 2 cm across in vein white quartz from Zevenwacht, in the historical Wagner Collection, University of Cape Town

In 1909 cassiterite was discovered in a stream above Vredehoek on Devil's Peak (Nellmapius 1912). Mining here started in 1911 but had ceased by 1916 after producing an estimated total of about 4 tonnes of concentrate (Spargo 1991). The visible remains include the concrete flumes for concentrating the dense cassiterite, as well as beautifully constructed retaining walls, a blocked vertical shaft some 55 metres deep, and an accessible horizontal adit penetrating the Malmesbury Group rocks about 100 metres.

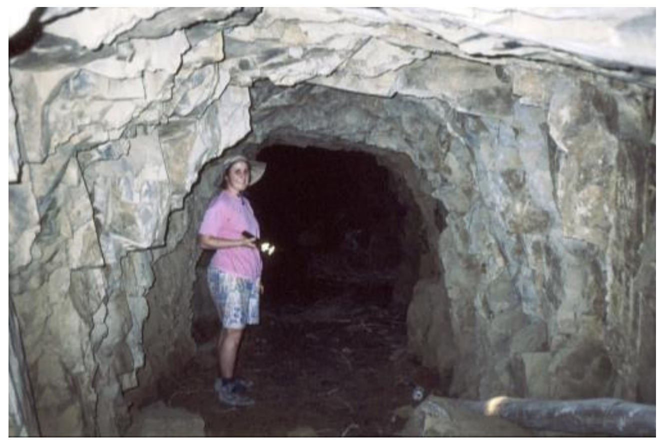
View towards Vredehoek from the former Devil’s Peak tin mine, with the concrete washing flumes in the foreground

The Vredehoek tin mine on the slopes of Devil's Peak is some distance from the nearest granite-Malmesbury contact, but the style of mineralisation is very similar to that reported from Durbanville. No doubt the mineralisation also owes its existence to fluids expelled during the solidification of the intrusive Cape Granite.

The carefully constructed, abandoned walling at the Devil’s Peak tin mine above Vredehoek

The cassiterite occurs in nearly horizontal quartz veinlets, in a zone about 8 metres wide with a north-south orientation, in Malmesbury Group shales. The veins consist of coarsely crystallised quartz with dark reddish-brown, cassiterite crystals, mostly near the margins of the veins. Accessory minerals are tourmaline, pyrite, arsenopyrite and rutile. No more than about 4 tonnes of tin concentrate were produced between 1911 and 1912. The short history of this mine has been documented in detail by Spargo (1991). Unfortunately, the visible remains are disintegrating rapidly, and despite being approached several times with plans to conserve them, the Cape Town City Council has remained indifferent to their preservation.

Adrian Frith at the obscure, collapsed entrance to the adit at the former Vredehoek tin mine on Devil's Peak. Subsequently it has been fenced off with a notice not to enter.



Vera Frith exploring the horizontal adit in the former Vredehoek tin mine on Devil's Peak

Dark brown cassiterite (SnO_2) crystal in white vein quartz, from the Vredehoek mine on Devil's Peak. The specimen is 8 cm wide.

To gain some insight into the origin of these tin deposits, one must turn to the history of the Malmesbury Group rocks and the Cape Granites which intruded them. Between about 1 000 and 600 million ago, an ocean lay to the west of present-day southern Africa. Regular alternations of muddy and sandy sediments accumulated on this ocean floor, probably as submarine fans on the deep ocean floor. Sometime around 600 million years ago this ocean closed up in a mountain building event (or orogeny). Wedges of metamorphosed sediments in the form of shale and impure quartzites were plastered onto the continental margin to make up the rocks of the so-called Tygerberg Terrane.

The dating of this event is uncertain but the older Cape Granites, intrusive into the rocks of the Tygerberg Terrane and associated with the collisional phase of the orogeny, have been dated to about 585 million years. The Tygerberg Terrane is the southernmost of three wedges of Malmesbury Group rocks (the other two are the Swartland Terrane and the Boland Terrane), separated from each other by major northwest trending faults.

Various episodes of granite intrusion took place into these rocks, extending over a long period of time from about 585 to 516 million years ago, and resulting in a large mountain chain.

So, how does all this happen? Why do oceans open and close? How do mountains and granite intrusions form? And what does this have to do with tin? Until about forty years ago geologists did not have good answers to these questions. Now we know that the semi-rigid crust of the Earth is covered with discrete plates, like the back of a tortoise. But unlike a tortoise, they are all different shapes and sizes, some carry continents and some carry only much thinner oceanic crust. These crustal plates are continuously on the move relative to one another, driven by heat convected through the mantle rocks below them.

The metamorphosed Malmesbury Group rocks in the foreground were deposited originally on the sea floor, then were subducted, deformed, and eventually exposed by erosion.

At volcanic mid-ocean ridges new crust is created, and the ocean floor widens, in places plunging back into the mantle below continental margins or shunting continents along until they collide. In both cases associated mountains form by a combination of mechanisms. Simplistically, continental collision may form mountains by crumpling, plastering any intervening ocean floor rocks onto the join, and by thickening the crust. The formation of the Himalayas through the collision of India with Asia is a modern example.

When ocean floor plunges under a continental margin (the process known as subduction), wet ocean sediments are driven into the hot mantle and may partially melt. This molten mass is buoyant and can rise, intruding, metamorphosing, and often partly melting the crustal rocks above it, and forming volcanoes where any molten rock reaches the surface. Much of the melt cools and solidifies at depths of 10 kilometres or more, to form coarse-grained igneous rocks like granite. The Andes are a good modern example of such mountains, associated with the subduction of Pacific Ocean crust. These mountain-building processes are known as ‘orogeny’.

Obviously, both orogenic mechanisms can be involved in building any particular mountain chain. An ocean floor can be subducted until the ocean closes completely and the continental masses on each side collide, creating a complex geological record consisting of a variety of rocks – volcanic lavas, metamorphosed sediments, and intrusive igneous rocks of various kinds including granites. Erosion of the mountain chain will expose these various rocks, eventually revealing the originally very deep roots of the mountain chain.

These granite domes on Paarl Mountain originally crystallised from molten magma tens of kilometres below the surface of the Earth. They have been exposed by subsequent erosion of the rocks above them. (photograph by Amour Venter)

Typically, these exposed roots will include metamorphosed sediments, altered chemically and physically by the intense heat and pressure of their burial and deformation. Depending on the level of erosional exposure, they may also include masses of intrusive igneous rocks, originally formed in the roots of developing mountains by partial or total melting of deeply buried rocks. This is precisely the situation we have with the Malmesbury Group rocks and the intrusive Cape Granite.

A world-famous example of the contact between the metamorphosed, partly digested, Malmesbury slate and the intrusive, formerly molten Cape Granite is exposed at the southern end of the Sea Point beach front.

Dark Malmesbury Group rocks intruded by lighter Cape Granite at the Sea Point beach front.

These are the exposed remnants of the roots of a former mountain chain the size of the Alps, subsequently eroded down to modern sea-level. The rocks now exposed on the surface were buried at least 10 kilometres deep when the Cape Granite actually solidified more than 500 million years ago. This formed part of the early assembly of the Gondwana supercontinent and preceded the deposition of the Table Mountain sandstones and formation of the Cape Fold Belt.

A molten body of granitic composition, intruding into metamorphosed sedimentary rocks at a depth of many kilometres in the roots of a growing mountain chain has a profound effect on the surrounding rocks. Apart from the thermal metamorphism caused by the heat conducted away from the cooling molten mass as it crystallises and solidifies, it expels fluids. These hydrothermal fluids under pressure penetrate the surrounding rocks, including the metamorphosed sediments and any pre-existing granite. Hydrothermal fluids carry with them various dissolved elements, including some that can precipitate on cooling to form metallic ores, depending on the composition of the source rocks and those they travel through.

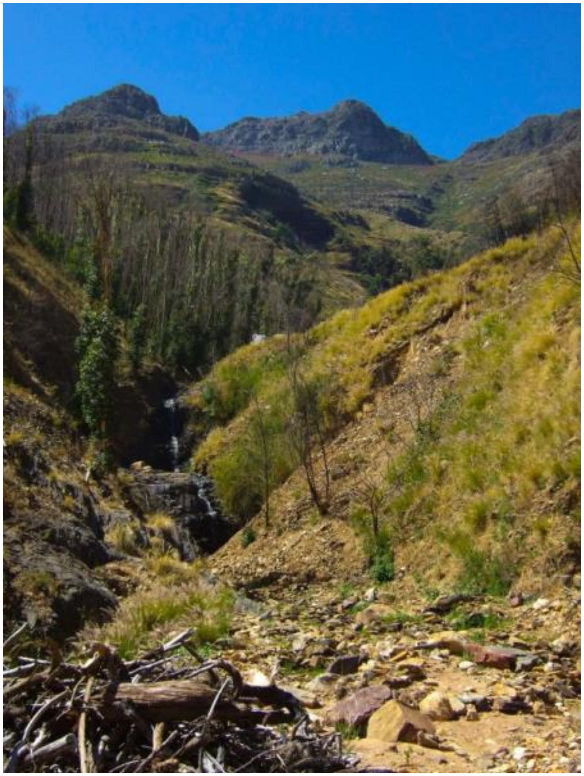
These dissolved elements may crystallise in cracks in the cooler surrounding rocks, forming veins or more dispersed impregnations at sufficient concentrations to be of potential interest to us. One of the mobile elements that can be transported in hydrothermal fluids is tin. In the case of the Cape tin mines, ore bodies are found in both the metamorphic Malmesbury Group rocks and in late stage veins in the Cape Granite. In a recent review, ‘The Metallotects of Southwestern Gondwana’, this occurrence is described as ‘classical granitic-intrusion-related origin of the cassiterite-bearing quartz veins’ (Borg & Gauert 2018: 658).

These colourful intrusive igneous rocks at Yzerfontein have veins of iron sulphides containing small amounts of copper and gold. (photograph by Amour Venter)

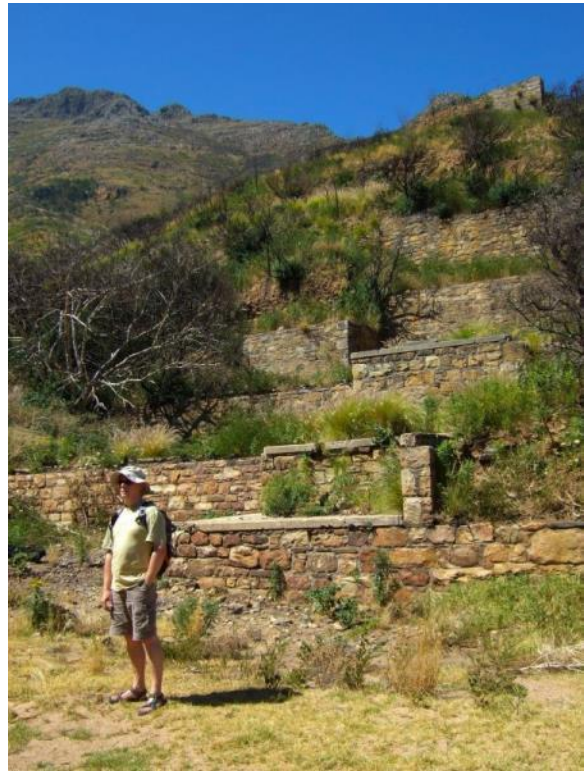
The three historic tin mines described here exploited ores forming a subset of about 20 distinct reported deposits of hydrothermal mineralisation associated with emplacement of the Cape Granites. These are described in detail by Rozendaal & Scheepers (1995). Other examples include the relatively well-known gold-bearing copper/iron sulphide veins on the coast at Yzerfontein; veinlets containing pyrite, chalcopyrite, magnetite, molybdenite; arsenopyrite in the Boterberg Granodiorite southwest of Philadelphia near Malmesbury; and other less well-known occurrences of tin, tungsten, copper, gold, and molybdenum mineralisation (Cole 2003, Jones 2010).

VIRTUAL TOUR OF THE DEVIL'S PEAK TIN MINE

PHOTOGRAPHS BY GREGOR BORG



Tin Mine Stream runs down the northern slopes of Devil's Peak to the Cape Town suburb of Vredehoek.



The only externally visible remains of the mine are some disintegrating concrete washing flumes and this rather elaborate walling on the southern side of Tin Mine Stream.

The interior of the mine is wet. The horizontal adit is ankle deep in water, even in summer. There are unprotected, water-filled vertical shafts in the floor of the main mining chamber.

Some of the rubble-filled shafts are timbered, with the original timbers preventing collapse.

The tin ore, cassiterite, occurs in nearly horizontal quartz veins, some of which are still visible in the mine. The width of the field of view is 1,6 metres.

It is quartz veins like these cutting the Malmesbury hornfels outside the mine that must have lead prospectors in the early 1900s to explore here for exploitable tin ore.

ROBBEN ISLAND

Although private tours are not allowed on Robben Island, many of the features described here are visible on Google Earth (north to the right).

Based on: Theron, J. N. & Hill, R. S. 1990. *Geologiese beskrywing van Robbeneiland*. Guidebook for the excursion of the South Western Cape Branch of the Geological Society of South Africa 16 November 1991. Geological Society of South Africa. (Translated from the original Afrikaans and updated by Dr J. Rogers 2001).

Robben Island lies about 7,5 kilometres from Bloubergstrand and 9,5 kilometres from Moullie Point. It is roughly oval in shape with a north/south axis of about 3,4 kilometres and a width of just over 2 kilometres. The maximum height above sea level is about 30 metres. The coastline is predominantly rocky, with the only sandy beach south of the harbour in Murray's Bay. The coastline consists of outcrops of rock of the Tygerberg Formation, a subdivision of the Malmesbury Group. Rocks of the Tygerberg Formation are exposed at Tygerberg, Bloubergstrand, Robben Island, Signal Hill, and from Granger Bay to the famous contact with the granite at Sea Point. These rocks consist of greywacke (gritty), phyllite (shaley), and quartzitic sandstone, with the volcanic layers of the Bloubergstrand Member exposed on the coast at Bloubergstrand. They are Late Precambrian, about 850 to 550 million years old, and were formed by sedimentary deposition and volcanic activity on a growing submarine delta. The surface of the island is covered with sandy limestone and calcrete of the Langebaan Formation, and shelly sand dunes of the Witzand Formation. The Langebaan Formation is Pleistocene, less than 1,6 million years old. It is exposed generally along the West Coast and represents cemented calcareous dunes of various ages. The Witzand Formation is Holocene, less than 10 000 years old, and consists of recent and modern coastal dunes.

The metamorphosed sedimentary rocks of the Tygerberg Formation on Robben Island are similar to the exposures between Green Point and Sea Point, but are less intensely thermally metamorphosed (baked) than the latter, which are closer to the contact with the intrusive granite.

Metamorphosed and highly tilted Malmesbury Group rocks of the Tygerberg Formation near the southern end of Robben Island

The Robben Island rocks consist of alternations of dark grey to greenish greywacke (gritty), siltstone, and phyllitic (micaceous) shale. The layers vary from about 0,5 to 2 metres thick. These rocks contain mainly mica and scattered quartz and feldspar grains.

Between Ladies' Rock and Long Bay the rocks show cross-bedding, ripple marks, graded bedding, loading deformation, and other signs of soft-sediment deformation. There are also a few more massive layers of quartzitic sandstone up to 3 metres thick.

Gently folded surface of Malmesbury slate in Van Riebeeck's Quarry with well-preserved current ripples

Between Minto Hill and the coast at the southern end of the island there is a quarry known locally as Van Riebeeck's quarry. Rock from this quarry was used for some construction at the Castle in Cape Town, including the front portal. Most of the rocks of the island have been folded tightly and generally have a strong cleavage along which they fracture easily.

The cleavage direction tends to be parallel to the axial plane (through the crest) of the folds. This quarry, and another further north at Rangatira Bay, is situated at the crest of a fairly broad anticlinal (up-arching) fold where the rocks are less deformed. This arch is clearly visible at the southwestern end of Van Riebeeck's quarry, where the curved floor displays well-preserved ripple marks and small cross-cutting faults. In both quarries one particular layer, a hard blue slate approximately 1 to 2 metres thick, is more massive and appears to have resisted deformation more strongly. This has been quarried selectively down to the ripple-marked floor.

Drill holes in the Malmesbury slate at Rangatira Bay

The quarrying operations involved drilling lines of holes parallel to the jointing, plugging the holes with an expanding material like wooden pegs that swell when wet, and splitting the rock into large blocks bounded by the bedding planes top and bottom, and by the joint planes at the sides. Some of the split blocks with plugged holes are still visible in situ in Van Riebeeck's quarry. At the Rangatira Bay quarry rows of holes on exposed cleavage surfaces rounded by wave action are visible in the smoothly polished rocks in the intertidal zone outside the protective sea-wall. Evidently quarrying started in the intertidal and moved inland, following the desirable, hard, blue slate.

The distinctive white bands in the slate at Van Riebeeck's Quarry allow this material to be identified in several historical buildings in Cape Town.

At both quarries this horizon contains a distinctive white band showing characteristic contortions and cross-sections of ripples. A similar white band can be seen in the rocks originally forming the uprights of both sides of the entrance to the Castle of Good Hope, and in floor tiles of several old buildings in Cape Town, including the Castle. Microscopic examination of petrographic thin sections to determine the mineralogy has shown that this distinctive material originated from Robben Island.

On a large scale the Malmesbury rocks on Robben Island form a broad open synclinal (trough-like) fold with a N 30° W trend, following the regional structural trend in these rocks in the Western Cape.

Locally the rocks tend to be tightly folded with dips up to 65°, with the exception of the resistant rocks exposed in the two slate quarries. There are a number of north to northwest trending faults with associated brecciated fault zones exposed at various places, between Edmond's Pool and Long Bay, north of Long Bay, at Rangatira Bay, and at the northern-most point of the island.

Long Bay owes its existence to the presence of an eroded dolerite dyke with an approximately east/west trend. Typical spheroidal weathering has created rounded boulders in the intertidal zone. The dolerite, a dark, medium-grained, igneous rock, contains the pyroxene augite and plagioclase feldspar, as well as minor amounts of biotite, olivine, quartz, ilmenite, and magnetite. There are similar dolerite dykes exposed on the Cape Peninsula, possibly Carboniferous to Jurassic (345 to 135 million years ago) in age, but representing at least two intrusive episodes of differing age. Their possible relationship to the well-known Karoo dolerites is unresolved.

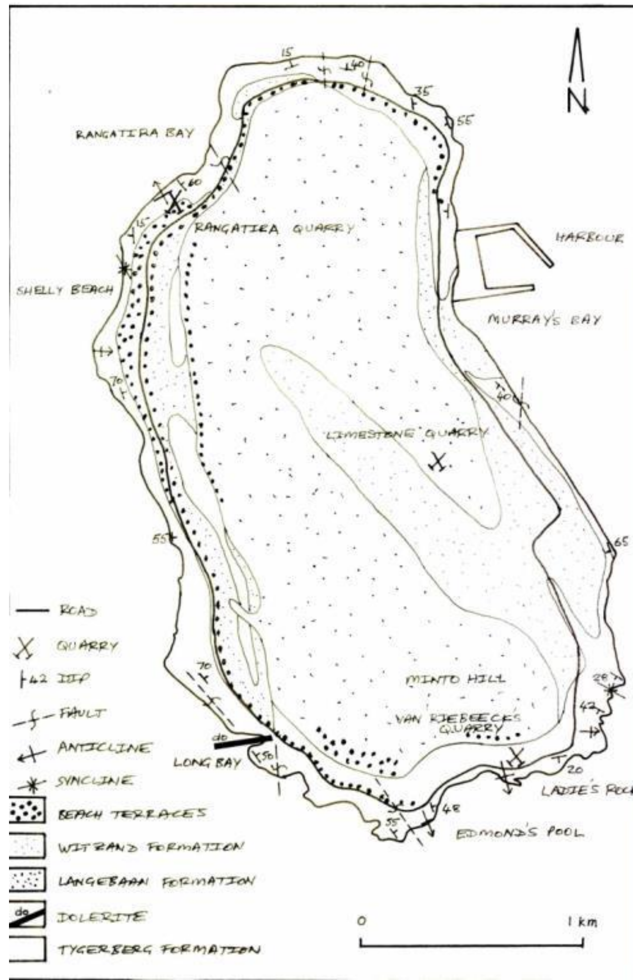
The dark boulders of a weathered dolerite dyke, forming the inlet of Long Bay on the western shore of Robben Island

The interior of the island is blanketed by calcareous sandstone and limestone of the Langebaan Formation, in places overlain by sand. The Langebaan Formation limestone is light grey to cream coloured, is varied in grain size, and contains fragmented shell and visible quartz grains. The degree of consolidation is also variable as can be seen in the old lime quarry near the centre of the island. This quarry is in a consolidated calcareous dune deposited by primarily southerly palaeo-winds. During the Pleistocene, the last 1,6 million years, sea-level varied greatly in response to fluctuations in ice volume at the poles and in mountain glaciers. For instance, at the height of the last glacial period around 17 000 years ago the sea-level around Cape Town was about 130 metres vertically lower than at present and the coast was many tens of kilometres further west. Robben Island was then a low hill, connected to the Blouberg by a ridge (now about 15 metres below sea level), with the Salt and Diep Rivers flowing down a wide valley north of Cape Town. At such times of low sea-level huge amounts of calcareous sand were exposed on the former sea floor and available for wind erosion and redeposition.

The light-coloured, calcareous, but unconsolidated coastal dune sands belong to the Witzand Formation. On the West Coast strong southerly summer winds are responsible for the formation of long tongues of sand moving inland in a north westerly direction where the coast is not protected by cliffs. The dunes at Hout Bay are a familiar example. On Robben Island there is an example north of the sandy beaches of Murray's Bay.

At times during the Pleistocene and Holocene relative sea-level was higher than at present. These relative high stands of the sea left wave-cut platforms and elevated beach terraces at numerous places along the Cape Peninsula and the West Coast. Old beach deposits of indeterminate age occur on Robben Island on wave-cut platforms at about 6 to 9 metres above present mean sea-level between Ladies' Rock and Long Bay, and at Shelly Beach. These terraces are associated with rounded cobbles and gravel, as well as shell deposits, some of which are partially cemented by calcrete. A lower, presumably more recent, terrace occurs at about 3 to 4 metres above present mean sea-level between Edmond's Pool and Rangatira Bay.

The shell deposits exposed at the seaward edge of this terrace were probably deposited by storm waves about 5 000 years ago when relative sea-level was about 2 to 3 metres higher around southern Africa. They were quarried historically to be burned for lime to make cement and whitewash.



Sketch map of Robben Island showing places mentioned in the text

CAPE TOWN TO CAPE COLUMBINE

This route starts with a look at the intrusive contact between Cape granite and Malmesbury hornfels at Sea Point. A visit to a special outcrop of Malmesbury Group rocks at Bloubergstrand then takes you on a tour along the West Coast to various exposures of rocks of the Cape Granite Suite.

Anyone driving around the Cape Peninsula is familiar with granite, perhaps without even knowing it. It forms the rounded boulders exposed along the shoreline from Sea Point to Chapman's Peak on the western seaboard; and from Simon's Town, past Boulder's Beach with its comical penguins, to Miller's Point on the False Bay coast. Above these granites lie the horizontal beds of the yellowish Table Mountain sandstone, which is younger than the granite.

So, how did it get there? Geologists now know that when continents collide and ancient seas are squeezed between them, it gives rise to huge mountain chains, like the Himalayas or the Alps. In their roots partly molten rock intrudes the deeply buried and heated sediments, eventually cooling to form pods of granite. Such a mountain chain wrapped itself around what is now southern Africa, but it wore down through erosion very rapidly, and in a couple of million years was reduced to an undulating plain at sea-level. This plain, made up of an exposed patchwork of Malmesbury Group rocks and intervening humps of Cape granite, eventually was drowned by the sea. Sandy shoreline sediments were deposited, solidifying with progressively deeper burial, to form the Table Mountain sandstone. Subsequent uplift and erosion has stripped off most of the sandstone, leaving steep cliffs rising above the granite lower storey.

The granite of the Cape Peninsula is a typical granite, with coarse mineral grains which crystallised slowly out of the deeply buried molten mass as it cooled. If you look at it closely, the most conspicuous mineral is a feldspar, which forms blocky, light coloured crystals, sometimes up to the size of a matchbox.

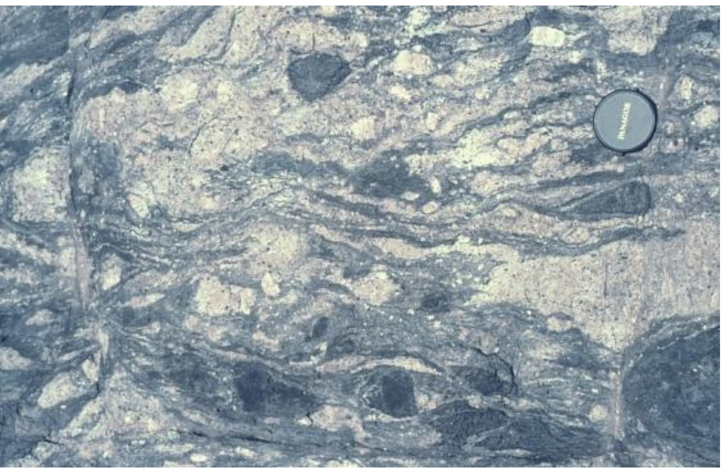
The Peninsula Granite cropping out along the shoreline south of Sea Point (photograph by Amour Venter)

In between these feldspars there are greyish, glassy-looking patches of quartz, as well as smaller amounts of black minerals, like mica and tourmaline. The Peninsula Granite is part of a widespread family of granitic exposures of similar age, stretching from George in the east to the Richtersveld in the west, with some patches exposed near Worcester and Robertson. Near Cape Town, the towns situated on or near granite include Stellenbosch, Paarl with its famous landmark Paarl Rock, Darling, and Langebaan.

The weathered granite makes fertile soils, which in the past supported renosterveld, and now is prime agricultural land for growing wheat and increasingly for grape vines; although in some areas, like the Darling hills, the high potassium levels in the soils derived from the weathered feldspars in the granite can cause problems for wine farmers.

Getting up close to Cape granite (photograph by Jo Wicht)

At the well-known contact between intrusive granite and metamorphosed Malmesbury sediments at the southern end of the Sea Point promenade you can see coarse feldspar crystals, which are cream or grey coloured blocks, several centimetres in size. These are surrounded by a finer-grained material, made up mostly of quartz and smaller feldspar crystals. The dark, streaky looking patches in the granite are inclusions of Malmesbury slate, into which the molten granite originally intruded.



The migmatite, or mixed rock, at the Sea Point contact between lighter granite and darker metamorphosed Malmesbury sediments.

A loose boulder of migmatite at Sea Point, with granite at the bottom and bands of contaminated, formerly partially molten Malmesbury sedimentary rock above. Fluids expelled from the crystallising granite enabled large feldspar crystals to form in the metamorphosed sedimentary rock. (photograph by Jo Wicht)

These dark rocks originally formed the walls of the chamber holding the molten granite, called magma. As the magma forced its way into the surrounding rock, pieces of the wall rocks broke off. Some melted and dissolved in the granite magma but some were baked and included in the solidifying mass. These elongated inclusions of metamorphosed Malmesbury rocks tend to be orientated northwest-southeast in the granite.

This shows that while the deeply buried magma mass was solidifying it was subjected to direction pressure, which caused the elongated feldspar crystals and dark inclusions to line up as they have. We'll see this again later, in the Darling Granite.

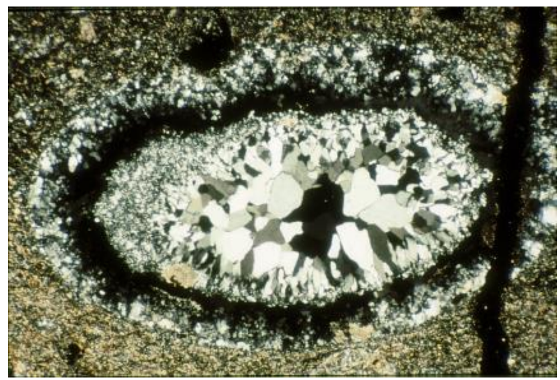
The Bloubergstrand Formation of the Malmesbury Group is exposed along the beach front and on the tombolo at the northern end of Big Bay. The tombolo is accessible at low tide.

The tombolo at Big Bay, Bloubergstrand

The rocks here are the remains of an undersea volcano associated with Malmesbury Group sedimentary rocks. The molten lava had numerous gas bubbles that were distorted into typical almond-shapes as they rose in the flow. The fresh lava blocks tumbled down the sides of the erupting mound to form irregularly orientated jumbles, confusing the original lava flow directions. Eventually the empty gas bubbles filled with quartz and calcite, to form white amygdales embedded in the finer-grained, dark blue, altered lava rock.

Michael Schoeman pointing to the amygdaloidal lava on the Bloubergstrand volcanic outcrop

The almond-shaped amygdales, now filled with calcite and quartz, originally flowed upwards in the molten lava, like air bubbles in honey.

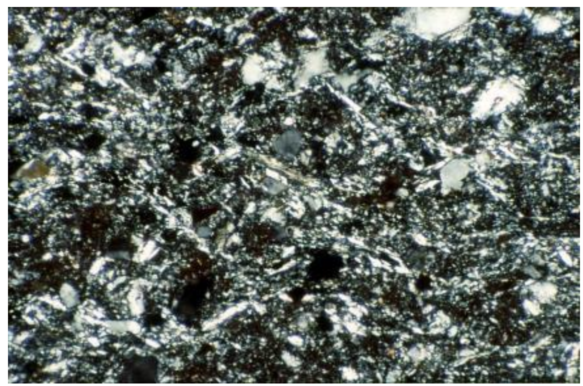


A petrographic thin section through a single amygdale 30 mm long shows its later filling with quartz grains

A bit further south, along the rocky beachfront there are more exposures of this amygdaloidal lava, as well as reddish sub-aqueous tuff. This is a fine-grained rock consisting of volcanic ash deposited under water. Volcanic ash is composed of very fine mineral grains, really a sort of volcanic grit. If it is hot enough when it settles on the sea floor the individual grains can weld together to form a hard, structureless rock.

This volcanic rock was erupted on the floor of the Adamastor Ocean before it closed and its sediments were intruded and metamorphosed by rocks of the Cape Granite Suite during the Saldanian Orogeny. Recently, the tiny zircon crystals erupted in the Bloubergstrand lava were dated by uranium-lead isotope dating, and shown to be 554,5 ± 5,4 million years old (Kisters, Agenbach & Frei 2015). This date is identical to that of the earliest Cape granites, implying that both volcanism and sedimentation were taking place in a closing marine basin, with these sub-marine rocks being plastered onto the growing margin of Gondwana as the former Adamastor Ocean closed.

The contact between the lighter, fine-grained, welded tuff and the darker sedimentary rocks on which it was deposited, at Bloubergstrand



Seen in a petrographic thin section under the microscope the tuff consists of very fine mineral grains. Width of field of view is 0,5 mm.

The Darling Granite pluton has a width of about 15 kilometres and a length of 55 kilometres, and is itself stretched and elongated in the northwest-southeast orientation. It is one of a number of similar granite bodies exposed in the Western Cape. Other well-known examples are the granites on the Cape Peninsula, Paarl Mountain, and the granites around Langebaan and Saldanha. The rock in between these granite plutons is mostly buried under sand and soil, but consists of intensely folded and baked Malmesbury Group rocks. These started out as sediments deposited on the floor of an ancient sea. This sea closed up, with collision of the continental masses on each side. This collision buried, squeezed, and baked the former ocean floor sediments. Molten material intruding from below this pile of baked and deformed sediments eventually cooled and solidified at depth. Subsequently, several cycles of erosion exposed the granites we see today.

As you near the Darling hills on the R27, you can see a conspicuous quarry on the right-hand side of the road. This provided the strong granite needed for the aggregate used in the concrete for the containment building of the nearby Koeberg nuclear power station. The rocks exposed on the hilltop at !Khwa ttu San Cultural Centre, some 40 kilometres north of Cape Town on the R27 near Yzerfontein also are granites belonging to the Darling pluton.

This is a mass of rock which originally solidified at depth, and which forms part of the Cape Granite Suite of rocks. Geologists estimate that the Darling Granite formed about 545 million years ago, at a depth of 7 to 10 kilometres below the surface. What we see now has been exposed by erosion of the formerly overlying rocks.

The Darling Granite exposed at !Khwa ttu (photograph by Amour Venter)

The Darling Granite can be visited easily at !Khwa ttu. Here it has the usual constituents of granite, but has been squeezed by geological forces while it was still soft. The matchbox-shaped feldspar crystals have been forced to line up, with their lengths roughly north-south, as have the elongated inclusions of partly digested Malmesbury slates.

A xenolith, a fragment of dark Malmesbury slate, embedded in the Darling Granite at !Khwa ttu (photograph by Amour Venter)

The whole mass of the Darling Granite has been stretched northwest-southeast. The cause of this is the Colenso fault, which runs from Saldanha to Stellenbosch, past the landward side of the Darling Granite pluton. Geologists think this fault must have been active when the Darling Granite was intruded into the surrounding Malmesbury rocks 540 million years ago. It may well have been active on several occasions since, and some geologists think it may still pose a potentially hazardous line of weakness in the crust of the Earth, cutting right across the Western Cape.

From the R27–Yzerfontein intersection to Darling you could take a detour. The Darling hills are underlain by the multi-component Darling Pluton. One of its youngest components, the Klipberg Granite, is exposed in the prominent hill to your left shortly before you reach Darling town itself. It is a relatively fine-grained granite, producing rock-strewn slopes, very different from the more deeply weathered soils that cover most of the fertile hilly terrain.

The coastal town of Yzerfontein has several rocky exposures along the shoreline, none of which consist of granite, although they are part of the Cape Granite Suite. The northern-most one, at the northern end of Yzerfontein beach is gabbro, a coarse-grained igneous rock containing no quartz, and hence not a granite.

A group of members of the Cape Town Gem & Mineral Club visit the outcrop of gabbro at the northern end of Yzerfontein beach. The rock here is a coarse-grained igneous rock consisting of dark green magnesium- and iron-rich minerals and light-coloured feldspar. (photograph by Amour Venter)

A boulder of gabbro at Yzerfontein beach with magmatic layering, formerly horizontal layers with varying concentrations of lighter-coloured feldspar and darker-coloured pyroxene and amphibole minerals. (photograph by Amour Venter)

The gabbro displays clear banding, with darker and lighter bands alternating on a ten centimetre scale. The lighter bands contain a greater proportion of feldspar compared to the darker ones. This is ‘magmatic banding’, formed by crystals of different density settling out of molten rock in a magma chamber at different rates, under the influence of gravity.

At the southern end of the Yzerfontein main beach, and most of the way around the coastal outcrop towards the south, there is a different rock type – diorite. This is finer-grained and contains less of the dark green minerals than gabbro. In places, like in the artificial cliffs at the harbour, there are gabbro xenoliths in the diorite, showing that the diorite solidified later.

Further south still, at Schaapen Island, the diorite is intruded by a dyke of light-coloured rock called syenite, which is crammed with darker xenolithic inclusions of gabbro and diorite. These obviously solidified before their incorporation in the intrusive syenite.

Intrusive syenite containing xenolithic fragments of dark gabbro and diorite, on Schaapen Island, Yzerfontein

There are also numerous veins containing red jasper and yellow pyrite crystals cutting the diorite on Schaapeneiland. (photograph by Amour Venter)

Plan your visit for low tide when you can walk dry shod to the ‘island’. (photograph by Amour Venter)

The origin of these dark ‘mafic’ rocks at Yzerfontein is somewhat obscure, but there are smaller outcrops of similar rocks scattered throughout the Tygerberg Terrane. They are part of the intrusive phase of the Saldanian Orogeny, when Malmesbury Group sediments were deeply buried and magma formed by partial melting intruded the rocks at higher levels. These darker, denser rocks could be the residues after separation of the lighter components that formed granites, possibly also intermingling with them to some extent to form the hybrid granodiorite rocks of intermediate composition. A recent interpretation is that they may be the ‘smoking gun’ of deeply sourced magma from the Earth’s mantle, that provided the necessary heat source for the production of the large volumes of Cape granite intruded during the Saldanian Orogeny (Clemens et al. 2017).

In the last road cutting south of the turnoff to Langebaan, the R27 crosses granitic rocks directly affected by the Colenso Fault zone. This is one of the numerous NW-SE trending faults that follow the ‘grain’ of the southwestern Cape. Here the associations between a wide variety of granitic rocks is complicated by a series of faults and joints. The rock ranges from coarse-grained granite to fine-grained aplite, in which it is difficult to make out the individual grains by eye.

The granite rocks in the road cutting on the R27 immediately south of the Langebaan turnoff, show a dramatic variation in texture and grain size over short distances. This may be due to the proximity of the Colenso Fault. (photograph by Amour Venter)

At Langebaan itself the Olifantskop granite quarry is hollowed out of the hill northeast of the town. This granite was used for building the breakwater and harbour of Saldanha.

The Olifantskop granite quarry at Langebaan, showing the curved jointing typical of large granite bodies. This exfoliation eventually produces rounded domes like those of Paarl mountain. (photograph by Amour Venter)

Across the lagoon, the rocky tip of Langebaan Peninsula has harboured a geological secret for over a hundred years. It was only about twenty years ago that geologists from the University of Stellenbosch discovered that these rocks are in fact the remains of a volcano, and not granite that cooled at depth at all.

The volcanic rocks of Postberg, seen across the lagoon from Langebaan

An eroded pinnacle of Postberg ignimbrite, a rock that looks superficially like granite but in fact erupted on the surface as a lava

Several of these molten masses managed to reach the surface. They erupted in a sequence of explosive, high-temperature lava flows, so hot that the volcanic dust, small quartz and feldspar crystals, and shards of volcanic glass were welded together to form the rock geologists call ‘tuff’. The crystal inclusions made these rocks look superficially like granite, but when studied closely using paper-thin slices under the microscope, their volcanic origin was revealed. These volcanic rocks are the subject of ongoing research that has identified the ‘granite’ rocks on the northern side of Saldanha Bay to be volcanic too.

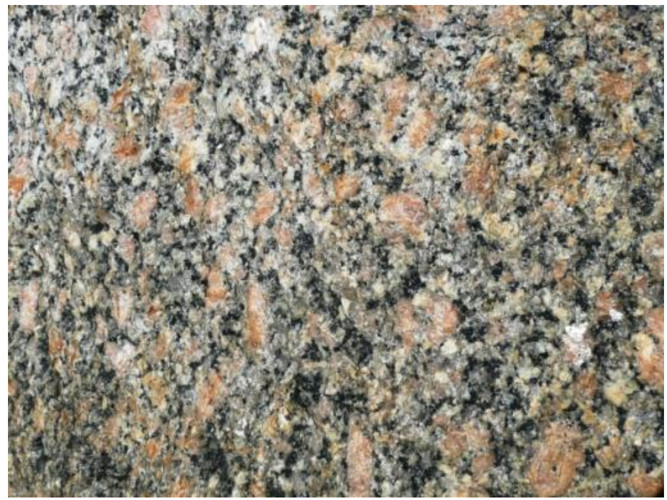
The granular appearance and insets of other rocks make the Postberg ignimbrite look like a granite, when in fact it is a welded tuff.

Outcrops of the Postberg ignimbrite are easily accessible by car at Tsaarsbank in the West Coast National Park.

Cape Columbine juts into the icy Atlantic ocean, just south of the picturesque and rapidly expanding village of Paternoster on the West Coast. It is justifiably famous for its vernacular architecture, abundant crayfish, unpredictable weather, and its lighthouse. This is a solidly handsome building, and was the last manned lighthouse built on the South African coast. It was inaugurated on 1 October 1936 and still operates, although it has been automated. A visit allows you get to grips with the granitic rocks cropping out on the shoreline at Paternoster and at Cape Columbine itself.

Outcrop of Vredenburg Granite on the beach at Paternoster. The rounded weathering is typical of a fairly homogeneous granite.

The older of the two granitic rocks is the Vredenburg Granite also referred to as the Vredenburg quartz monzonite in some older publications. It is a rock with both potassium feldspar and plagioclase feldspar and a high quartz content of 30–40% (Bailie et al. 2020). It forms the major outcrop of granite on the Vredenburg Peninsula, and weathers into massive blocks, creating castellated tops to the hills.



The Vredenburg Granite is a coarse-grained granite, with conspicuous pink potassium feldspar crystals, in a fairly coarse matrix of other feldspar, quartz and mica.

One of these, Kasteelberg just outside the village of Paternoster, is an important archaeological site with a long history of human habitation, including the remains of Khoikhoi encampments. These pre-colonial herders had both cattle and sheep, which they grazed on a seasonal round in the Swartland and coastal strandveld. They would congregate at Kasteelberg to harvest seals at the coast, and render their fat in earthenware pots.

The granite slabs at Kasteelberg contain numerous elongated grooves made by these itinerant herders, perhaps to grind grass seeds to make porridge.

Down at the coast, the Vredenburg Granite crops out around Paternoster and as far south as Cape Columbine itself. Just south of Paternoster it forms big boulders, some of them like giant monoliths tossed into the sea. These rounded boulders are the result of sustained weathering, first by ground water percolating down joint cracks in the massive granite, and eventually through ‘onion skin’ weathering as successive layers exfoliate, taking off the sharp corners first and rounding the boulders in place. They are far too large to have been tumbled round in the sea.

All the granitic rocks in the Western Cape are thought to have intruded during and shortly after a continental collision, which took place over half a billion years ago, part of the assembly of the former Gondwana supercontinent. The Vredenburg Granite dates to about 560–540 million years, and is related in time to the Paarl and Robertson granite intrusions. It is relatively undeformed, although cut by some aplite (fine-grained granite) veins and narrow shear zones. What xenoliths there are, appear to be pieces of other igneous rocks, quite unlike the metamorphosed Malmesbury sedimentary rocks which form the conspicuous black xenoliths in the well known Peninsula Granite and the Darling Granite.

Shortly after its emplacement the Vredenburg Granite was intruded by small bodies of mafic (dark) rock, which are exposed in a small bay on the northern side of Cape Columbine. These rocks contain feldspar and quartz crystals in a very dark, fine grained matrix, and may be related in origin to the similar mafic intrusive rocks exposed on the coast further south at Yzerfontein.

Aplite dyke of fine-grained granite, running through a boulder of Vredenburg Granite, and a xenolith of igneous rock (below)

The dark rocks on the right in the photograph above are an igneous intrusion into the lighter Vredenburg Granite, just south of Paternoster.

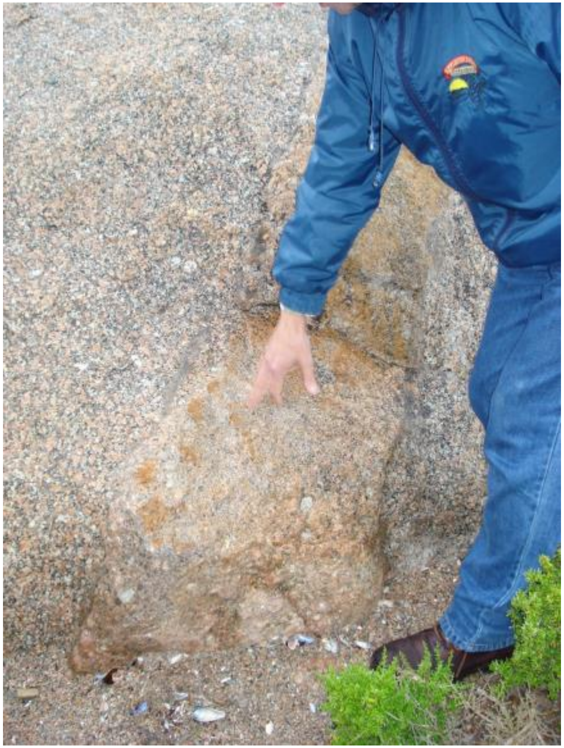
The next magmatic event was the intrusion of the Cape Columbine Granite, which is exposed from Cape Columbine itself, just west of the lighthouse, southwards for a few kilometres, until it disappears under the sand of Northwest Bay.

Cape Columbine itself, viewed from the lighthouse

The next rocky outcrop to the south is the Trekoskraal Granite, older than both the Vredenburg Granite and the Cape Columbine Granite. This is explained partly by the presence of the Colenso Fault zone, which runs NW-SE all the way from Northwest Bay to Stellenbosch.

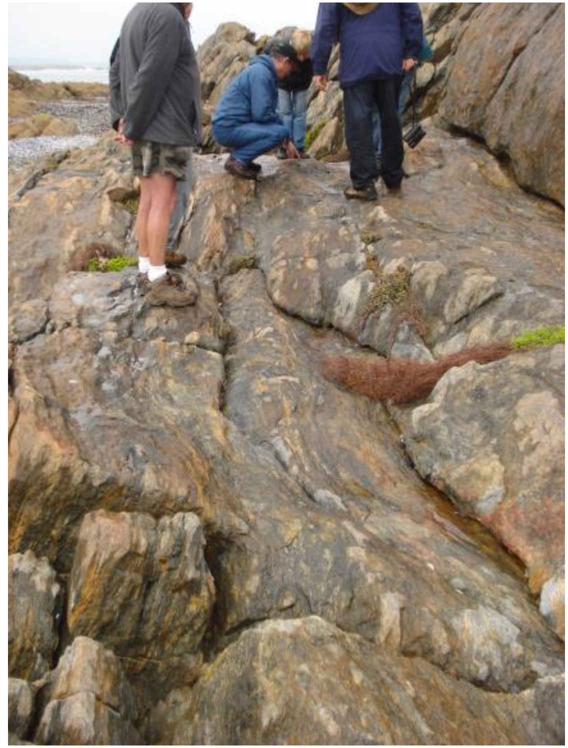
The Colenso Fault is an important feature of the geology of the Western Cape and may be a major crustal suture line. There is evidence that it was active from the time of the first intrusion of the Cape granites. The early Darling Granite, which lies right up against the fault and dates to about 550 million years ago, is sheared and stretched parallel to it in a NW-SE direction, with indications that the fault then allowed slip to the left. The younger Trekoskraal Granite, cropping out just south of the fault at Northwest Bay, has signs that by about 540 million years ago the fault slip had changed direction to the right, presumably because of a change in the direction of maximum pressure in the ongoing continental collision. The Cape Columbine Granite, dating from about 520 million years ago, was also affected by right-hand slip on the Colenso Fault, which obviously was active for tens of millions of years.

The Cape Columbine Granite is finer grained than most of the Vredenburg granite, but looks superficially similar. Closer inspection shows that it is littered with large granitic xenoliths, mainly angular chunks of Vredenburg Granite, into which it is intrusive. The Cape Columbine Granite contains very dramatic shear zones, mostly trending north-northwest, more or less parallel to the Colenso Fault lying just to the south.



A large granite xenolith of Vredenburg Granite in the Cape Columbine Granite (photograph by Jo Wicht)

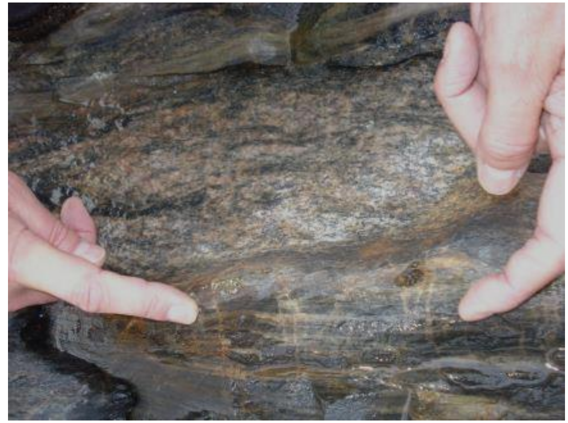
These shear zones are typically very dark, fine grained, and usually not very wide, up to about 10 centimetres. Nevertheless, there is at least one very dramatic example up to 25 metres wide and over 1,5 kilometres long.



Highly deformed shear zone in the Cape Columbine Granite (photograph by Jo Wicht)

This looks nothing like a granite, but more like a highly metamorphosed sedimentary rock. In fact it is a ‘cataclasite’ or zone of completely crushed granite, or mylonite, in which the quartz has been largely recrystallised.

Another view of the dramatic shear zone in the Cape Columbine Granite. This line of intense deformation of the granite is visible from space as the dark NW-SE diagonal line in the Google Earth photograph below.



Within the shear zone, individual crystals and granite xenoliths have been stretched to many times their original lengths. (photograph by Jo Wicht)

These zones formed presumably in response to regional collisional pressures causing right hand slip on the Colenso Fault and also the localised shearing in the Cape Columbine Granite. This cataclasite is exposed in the rocks just below Cape Columbine lighthouse itself and is a spectacular geological feature. It is well worth the visit to this windswept promontory.

THE CAPE FOLD BELT

The Western Cape owes its scenic splendour to its mountains. From the Cedarberg to the Langeberg, from Du Toits Kloof to Devil's Peak, sandstone cliffs tower over the intervening valleys, trapping moisture to form the rivers that irrigate the picturesque Cape farmlands. Without our mountains there would be no winelands, no snowy peaks in winter, no mountain fynbos, and no spectacular gorges. We take our mountains for granted, assuming they were always there, and always will be. We couldn't be more wrong. The lifetimes of humans are measured in tens of years, so we think of mountains as eternal. But the lifetimes of mountains are measured in tens of millions of years. They emerge, wear away, and disappear in majestic cycles that geologists have begun to understand only recently. We have only a tiny glimpse of the complex and incomprehensibly long history of the rocks that we see on the surface of the Earth today.

Anyone with a passing interest in rocks can recognise that the mountain peaks of the Cape are all made up of the same yellowish gritty sandstone, and that the fertile valleys tend to have low hills of very different rocks – fine-grained dark shales and coarse grey granite. For a long time, geologists have known that sandstones such as these originally were laid down as sandy sediments on beaches which flanked a shallow sea; that the dark shales were originally mud; and that granite is the frozen relic of once molten rock that cooled very slowly at great depths in the Earth. But how did all three of them land up together in the Western Cape?

The lush valleys below the sandstone mountains of the Cape receive their water from the numerous gorges carved by erosion. This is the southern side of the Langeberg, near Swellendam.

Why are some of the sandstone layers neatly horizontal, like on Cape Town's Table Mountain, and others are shockingly distorted, like in Montagu's Cogman's Kloof? What cataclysm could have caused the seabed to turn to stone, vault onto land, and perch end-up like an open book lying on its spine?

Originally flat-lying sandstones of the Table Mountain Group tilted vertically in Kogman's Kloof, cut through the Cape Fold Belt near Montagu

If you know what to look for, you can read the silent history written in these pages of stone. The story is written in three dimensions, on pages jumbled by time, so it takes great persistence and even greater imagination to piece together the remnants. The story is incomplete, necessarily so, because many of the pages are missing.

Indeed, whole chapters may be missing, but generations of geologists have worked at piecing together a story that is consistent with what remains there are, and how we currently understand the subterranean workings of the Earth. The Earth is not static or immutable, as those who live near volcanoes or who suffer earthquakes and tsunamis are well aware. Powerful internal forces tear away at the continents, heave up mountains, and shunt huge slabs of Earth's crust around like toffee.

In cross-section the Earth is like an apple cut in half. The thin skin is the crust on which we live, on which the oceans lie, and on which mountain ranges sit like wrinkles. Beneath, the flesh of the apple is represented by Earth's mantle, which over time can creep like tar, responding slowly to the Earth's internal heat. In the centre is the nickel-iron core, part molten, part solid. Like a very slowly simmering pot of porridge, the mantle carries heat from the core to the crust, causing the cold and rigid crust to crumple, tear, and slide about, colliding with itself, keeping the surface of the Earth in a stately dance in which crustal 'plates' grow and shrink, causing the continental masses on them to join up, rotate, separate, and move off to join other partners. These collisions and ruptures form and destroy the ocean floors, endlessly changing the surface of the Earth over hundreds of millions of years.

It is probably impossible to comprehend a time span of a million years - even geologists just get used to bandying about huge numbers without really thinking about them – but to get some idea imagine shaving just a millimetre off the top of Table Mountain each year. At that rate, it would take a million years to erode it down to sea-level. And forty thousand human generations would have passed during that time! So a lot can happen in a million years; but geology works in tens, hundreds and thousands of millions of years. To understand the origin of the Cape mountains we have to travel back in time over a thousand million years, to a time when a huge mountain chain, similar to the modern South American Andes, straddled southern Africa. Its deeply eroded roots stretch from Namaqualand to KwaZulu-Natal but a thousand million years ago it formed the southern margin of the now vanished supercontinent known to geologists as Rodinia.

Around 1000 million years ago, Rodinia started to crack up, undermined by hot material welling up through the mantle. An ocean (known as the Adamastor Ocean by us time travellers) formed more or less where the present Atlantic Ocean is. Sediments brought down by rivers poured into this ocean, joining the lavas erupted by undersea volcanoes to form the new floor of this widening ocean basin.

Fossil current ripples in the Van Riebeeck's Quarry on Robben Island, formed in sediments on the floor of the former Adamastor Ocean.

About 100 million years later, the Earth's internal engine shunted the continents in the opposite direction again, and the Adamastor Ocean was forced to close up, squashing and baking the ocean sediments and lavas, finally plastering some of this stew onto the southern and western margins of what would become the African continent. Fragments of these rocks now underlie some of the Western Cape valleys, forming fertile dark soils derived from these so-called Malmesbury Group rocks.

The rocks in the foreground belong to the Malmesbury Group. They originally were deposited on the floor of the Adamastor Ocean, which closed up during the formation of the Gondwana supercontinent.

They once formed the roots of yet another mountain chain stretching around the coast of southern Africa, caused by the continental collision that closed the Adamastor Ocean. Buried to a depth of over 10 kilometres in this crumpled heap, some of the Malmesbury Group rocks were intruded by molten rock that cooled slowly to form granite, now exposed by erosion as the grey granite of Paarl Mountain and the familiar rounded boulders seen on many of the beaches of the Atlantic seaboard of the southern Cape Peninsula.

The granite domes of Paarl mountain in the middle distance are remnants of the erosional surface of Gondwana, before the deposition of the Table Mountain Group sandstones.

These granites are about 540 million years old, but very quickly were exposed by erosion of the mountain chain to result in a nearly flat, only slightly undulating landscape forming part of the supercontinent called Gondwana.

At this time, southern Africa and South America were joined, with the now submerged Falkland Plateau wrapped around the southern tip of Africa, and the present Falkland Islands just off Port Elizabeth. This didn't last long, in geological terms.

The Table Mountain Group sandstones were laid down in the Agulhas Sea, on top of the eroded surface of Malmesbury Group rocks and the intrusive Cape Granite Suite.

The shales and sandstones of the Graafwater Formation at the base of the Cape Supergroup on the Cape Peninsula, on Chapman's Peak

The area occupied now by the Western Cape started to sag and an ocean called the Agulhas Sea invaded, depositing coarse sandy sediments on the exposed granite and Malmesbury Group rocks basement. The new ocean sediments were laid down horizontally on the bottom of this shallow sea, and were followed by more muddy sediments above them, and in turn another layer of sandy ones.

This three-fold package, the yellowish lower sandstones of the Table Mountain Group, the dark blue shales of the Bokkeveld Group, and the white sandstones of the Witteberg Group can be recognised throughout the Western Cape, except of course where they have been removed by erosion.

Typical scenery in the Bokkeveld shales near Ceres

On the Cape Peninsula only the lowermost sandstones are preserved, resting on the granite/Malmesbury basement. Further north and east, the Cedarberg and Langeberg ranges consist of the Table Mountain Group, and their intervening valleys tend to be filled with the blue shales of the Bokkeveld Group.

Characteristic brachiopod fossils in shales of the Bokkeveld Group, near Ceres

The Witteberg Group sandstones form the southern edge of the Karoo, and are well exposed on the inland side of the Langeberg and their continuations into the southern Cape.

The Witteberg, consisting of Witteberg Group sandstone, south of Laingsburg on the edge of the Great Karoo Basin

A characteristic trace fossil in the Witteberg sandstone, perhaps caused by a feeding trilobite

So why do these rocks not form a uniform layered cake, with neatly horizontal layers, perhaps just cut by a few river valleys? Instead, they form spectacular, contorted mountains, with narrow gorges cut through rocks crumpled like soft cloth thrown into huge folds by some enormous force. Well, they have been thrown into huge folds by some enormous force.

Far to the south, at the outer margin of what now is the Falkland Plateau, compression was taking place, due to the sea floor plunging back into the mantle by the inexorable power of Earth's heat engine. This compression was transmitted to the area of weakness where sagging of the crust had formed the Agulhas Sea, and the sediments there were wedged up against the cold, hard, edge of the former supercontinent of Rodinia. (Remember Rodinia?) The so-called Cape Fold Belt mountains were formed during this period of compression about 400 million years ago, much like a thick cloth being rumpled up as you push it from one side of a table to a heavy pot in the middle. This accounts for the vertical folding in gorges like Cogman's Kloof.

Geologists have identified four episodes, or ‘paroxysms’ of compression and folding in the Cape Fold Belt. The sandstones on Table Mountain were spared this fate, probably because they rest on a particularly resistant block of granite.

The contorted sandstones in Kogman’s Kloof near Montagu, due to compressive forces from far to the south

On the southern Cape coast a beautiful granite is exposed on the beach at Haelkraal, just east of Pearly Beach. This granite contains rounded crystals of blue quartz, which glint in the sun like little fish eyes.

This rock has also been deformed by Earth movements, but in this case the deformation was associated with the north-south squeezing that took place with the formation of the Cape Fold Belt mountains. This was also the result of compression due to the continental collision that took place around 400 million years ago about 1 000 kilometres south of present South Africa.

The sheared and jointed Haelkraal granite near Pearly Beach

The black tourmaline-rich nodules in the Haelkraal granite are up to the size of tennis balls.

The Haelkraal granite, itself originating in a previous mountain building episode, was squeezed towards the north, and now has a layered and fractured look due to shearing. It also has an unusual concentration of tourmaline, which originally crystallised in spherical lumps up to tennis ball size. These black nodules add to the visual appeal of this rock.

The story doesn't stop there though, because on the inland side of the Cape Fold Belt mountains another crustal sag developed, onto which a huge thickness of Karoo rocks was deposited, capped by the Drakensberg lavas which were erupted as Gondwana itself started to crack up, as supercontinents do. The Falkland Plateau tore away, sliding south and west as the present Atlantic Ocean started to open up from the south, and the coastline of southern Africa took on more of its familiar shape.

With this tearing way, huge cracks developed in the rocks of the western and southern Cape, the Worcester Fault being the most famous of these. Subsequent erosion has exposed the Table Mountain Group rocks in long linear mountains with their steepest faces just on the northern side of these cracks. Rivers draining the Karoo cut through them to form spectacular gorges like Cogman's Kloof, Seweweekspoort, and Meiringspoort.

Seweweekspoort follows a river valley that cut through the Langeberg Mountains of the Cape Fold Belt.

This erosion also exposed an interesting and geologically relatively recent phase of igneous intrusion in the Western Cape. As you leave Robertson you can take the turnoff to the right to Bonnievale and visit Van Loveren Private Cellar. The Goedemoed olivine melilitite pipe is exposed on the hillside on the southern side of the Breede River on the wine farm. It forms a dark triangle of rocks on the yellow quartzite hill. This outcrop was a failed volcano. The molten rock tunnelled its way up through the crust of the Earth, until at a fairly high and cool level, it hit a thick layer of sandstone, and ran out of steam.

Where roads cross over the crests of the Cape Fold Belt mountains, like the Swartberg Pass between Prince Albert and Oudtshoorn, they are among the most spectacular in the country.

The Goedemoed intrusive pipe crops out as the dark patch on the hillside, below the sandstone capping.

Here it solidified, waiting until erosion of the sandstone by the waters of the Breede River cut through the hillside, exposing the dense, dark rock on its slopes. In places, this dark rock cracked while cooling to form hexagonal columns, reminiscent of the famous ones at Giant's Causeway in Northern Ireland.

The Goedemoed outcrop has columnar jointing, due to contraction of the cooling magma as it crystallised.

This intrusion has been dated to 63,7 ± 1,3 million years (Duncan et al. 1978). It is part of an arc of co-called olivine melilitite intrusions located at Heidelberg, Robertson, Lambert's Bay, Sutherland, and in Bushmanland and Namaqualand. They are all arranged around the margin of the Kalahari Craton, which is a very ancient and relatively stable piece of Earth's crust.

These rocks are the result of partial melting of upper mantle peridotite, and have their origins below the base of the crust. Because of their similarity to kimberlite, they have been prospected quite intensively, but no diamonds have been found. These intrusions all have Late Cretaceous to Early Tertiary ages, spanning about 26 million years, and postdating the intrusion of the 80 to 90 million year old diamond-bearing kimberlites further to the north east (Verwoerd et al. 1990).

The Goedemoed intrusion did not reach the palaeo-surface to erupt as lava. This small intrusion literally ran out of steam before reaching the surface. Having lost heat by contact with the relatively cold country rocks, it was stopped in its ascent by layers of Witteberg sandstone. It has been exposed by erosion by the Breede River, which runs between Van Loveren Private Cellar and the hillside.

The erosion of the Cape Fold Belt mountains will continue unabated for several millions of years. Eventually they will have been eroded down to a coastal plain, probably invaded by the sea, to form a new sequence of sedimentary rocks. These in turn will be welded onto the resistant core of southern Africa, in the next round of supercontinent formation. Enjoy the mountains while you can!

A view of the snow-capped Matroosberg in the Cape Fold Belt mountains between DeDoorns and Ceres, seen from the N1 travelling south

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