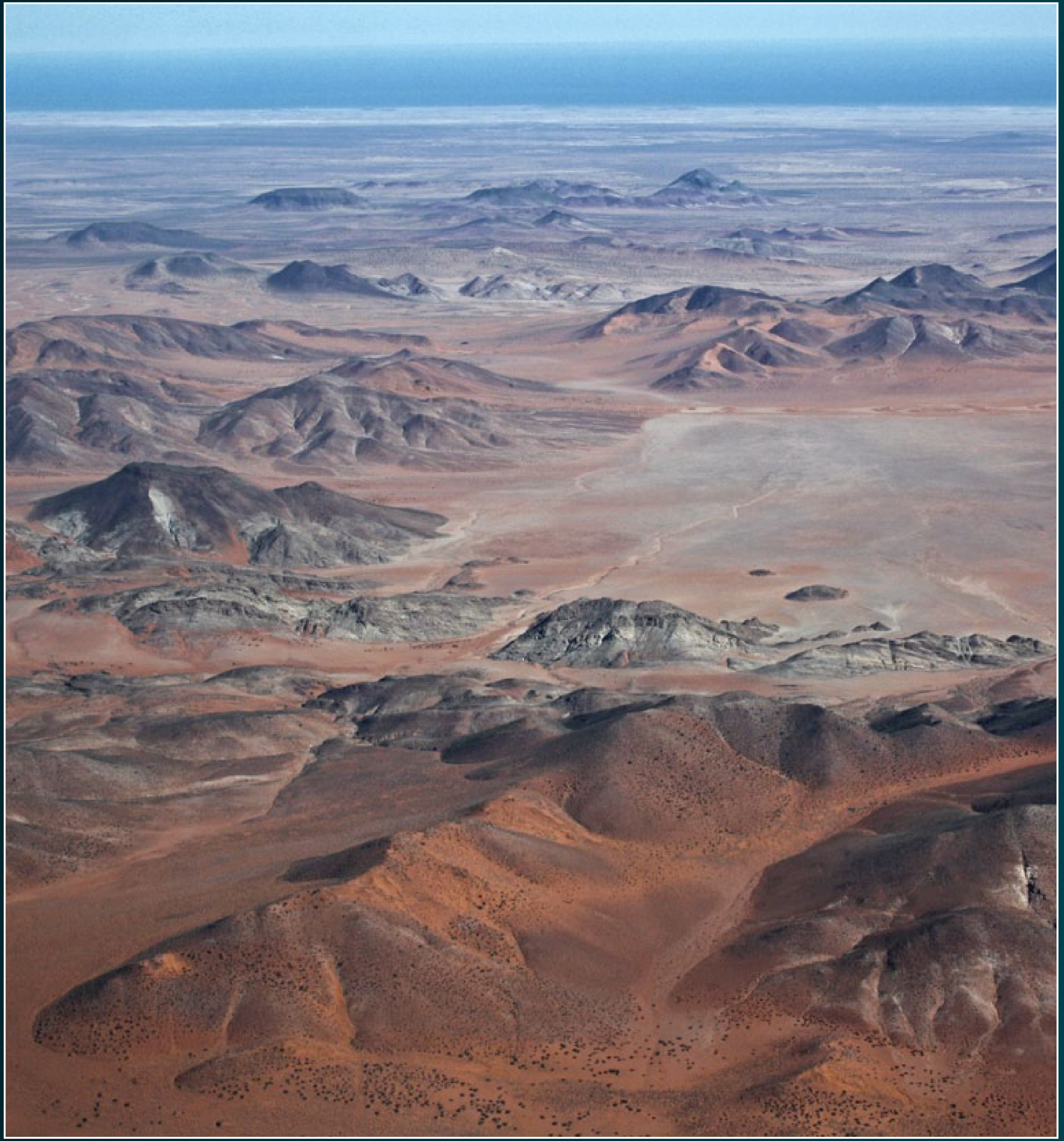


3 Foundations and Landshapes

The powerful combination of salt and wind has dramatic weathering impacts on rocks and buildings.

Coastlines are amongst the most dynamic landforms on earth. Located at the interface between the ocean and the land, the coast is constantly buffeted by wind, tides and waves, all of which have major influences on the coastline itself as well as the immediate hinterland. Attacked relentlessly by the swells rolling in from the South Atlantic, the Namibian coastline is one of the most energetic in the world. Sediment on the coast is moved on a daily basis, while sea levels are constantly changing over longer and shorter terms as a result of several factors. These include changes in atmospheric pressure, changes in the volume of the oceans, warming and expansion of the sea, and the physical uplift or subsidence of the continent. Nowadays, there appears to be little uplift or subsidence of the continental land area of Namibia, so sea level changes appear largely to be due to atmospheric pressure and other climatic changes. Records show that sea levels off Namibia have risen 5.5 centimetres over the past three decades.[1] Despite this, the coast is also advancing outwards in some places (see page 57).

Rivers flowing from the interior bring down sediment and nutrients that are then redistributed along the coast. This happens rapidly and forcefully on the Namibian coast as a result of the strong winds, swells and the Benguela Current, as described in the previous chapter. An additional process operating along the coast is the

regular occurrence of fog. Although not nearly as intense as the other processes, over extended periods of time fog can have profound effects on the rocks and landscapes in the coastal zone. Sulphates brought inland by the fog can slowly change calcretes into gypcretes, crystallise with sand particles into intricate gypsum desert roses, and turn the thin soils that cover gravel plains into gypsisols.[2] These gypsum-rich soils form the basis of so-called biological crusts which are home to a variety of localised organisms including lichens, cyanobacteria and algae which in turn slowly help weather rocky and stony substrates (see page 83). The biologically rich crusts are particularly fragile and subject to mechanical damage caused by vehicles driving over them.

One of the most obvious of the sea's varied effects on the land is its enormous corrosive and erosive powers. In addition to soil changes brought on by airborne sulphates, the salts within the fog also quickly cause metals to rust as well as crystallising into salt granules. Salt weathering on rocks, particularly granites, can produce unusual hollows. The terrestrial world is replete with scars and shapes moulded by wind, most clearly in the varied forms of dunes (see page 58), and sculptured rocks and valleys that have been scoured over the aeons by persistent, driving air which is loaded with sand.

Above: The popular desert roses are crystals of gypsum that have formed in sand, often close to the coast, and which include sand grains that give the characteristic rough, brown appearance.

Below: Beaches with abundant cobbles and pebbles are common on the Namib coast. These beaches are generally steep and the pebbles protect the beach from erosion by the waves.

A brief geological history

The oldest rocks on the Namibian coast are found in the Lüderitz area. These are gneisses of the Namaqua Metamorphic Complex and were formed some 1,200 million years ago. However, much of the coastline is underlain by rocks that were formed when at least three landmasses amalgamated some 550 to 600 million years ago to form the Gondwana super-continent. These rocks, today largely schists and quartzites of the Damara, Gariep and Kaoko Groups, were formed from sediments deposited in an ancient sea that lay between the land masses and later merged to form Gondwana. In addition, granites that intruded in the centre of the zone of amalgamation are now exposed along parts of the Namibian coast.

The origins of the present shape of the Namibian coastline lie in the subsequent break-up of Gondwana. Africa and South America began to separate around 132 million years ago along lines of weakness created hundreds of millions of years earlier when Gondwana originally formed. The break-up of Gondwana was heralded by the eruption of volcanoes and the emergence of dykes and granites that rose to the surface. Volcanic lavas that spewed out of such craters as Doros and Messum now make up much of the Etendeka Mountains in north-western Namibia, while outcrops of dykes are abundant along the coast. The most impressive granites that intruded include the Brandberg, Spitzkoppe and Erongo Mountains.

When Gondwana split 132 million years ago basaltic magma forced its way into the cracks that opened in the earth's crust. This magma hardened to form dolerite dykes that are now visible as prominent dark ridges.

Since the original break-up of the coastline some 132 million years before this book was written, the coast has undergone many changes caused by uplift, subsidence and climate change. Sea levels have varied from at least 400 metres below present levels to more than 400 metres above.[3] During the Last Glacial Maximum some 18,000 years ago the sea level was about 120 metres below today's levels, which would have extended Namibia's land surface about 10-50 kilometres westwards. Only 5,500 years ago sea level was about 1.5 metres above what we see today, which explains the cobble and boulder accumulations which can be seen above some of the present day beaches. Today the physical processes on the coast are largely dominated by the southerly winds, Benguela current and associated longshore drift. This can be seen from the northerly directed sand spits at Sandwich Harbour, Walvis Bay (see page 56) and Baia dos Tigres north of the Kunene River mouth in Angola which have developed from the strong longshore drift. The same processes have had a more unusual and economically significant impact on the coast, namely in sorting and depositing diamonds.

The Orange River mouth is the major source of diamonds which the river carried down to the sea from the interior of southern Africa. Longshore drift then transported diamonds northwards up the coast sorting them on the way as the larger, heavier stones were deposited first and the smaller, lighter stones were carried further northwards. As a result, the size and quantity of the gems decreases as one moves north away from the Orange River (see Figure 42, page 140).

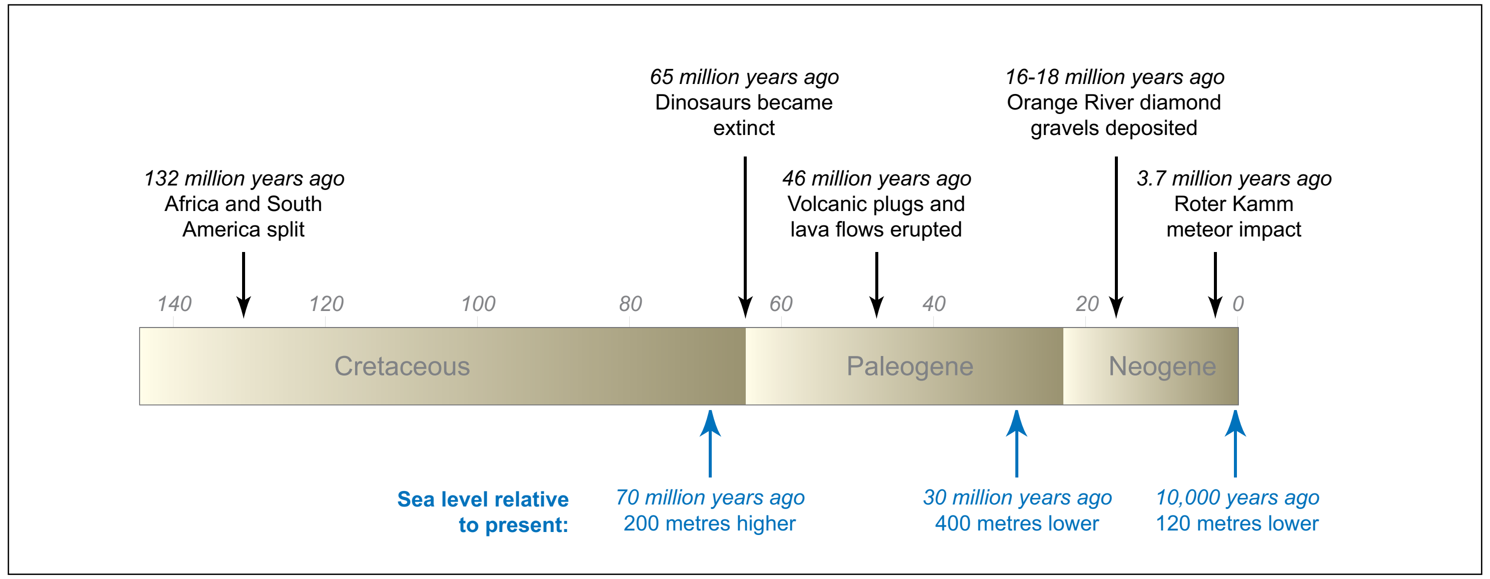


Figure 20. Some of the major events since Namibia's coast formed 132 million years ago.

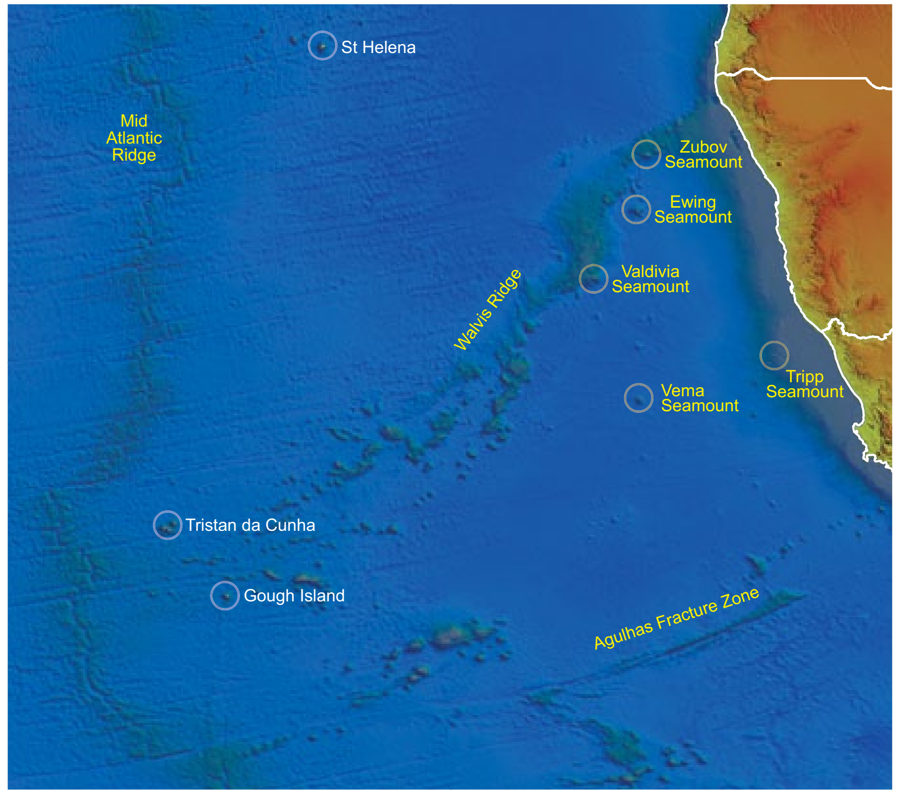
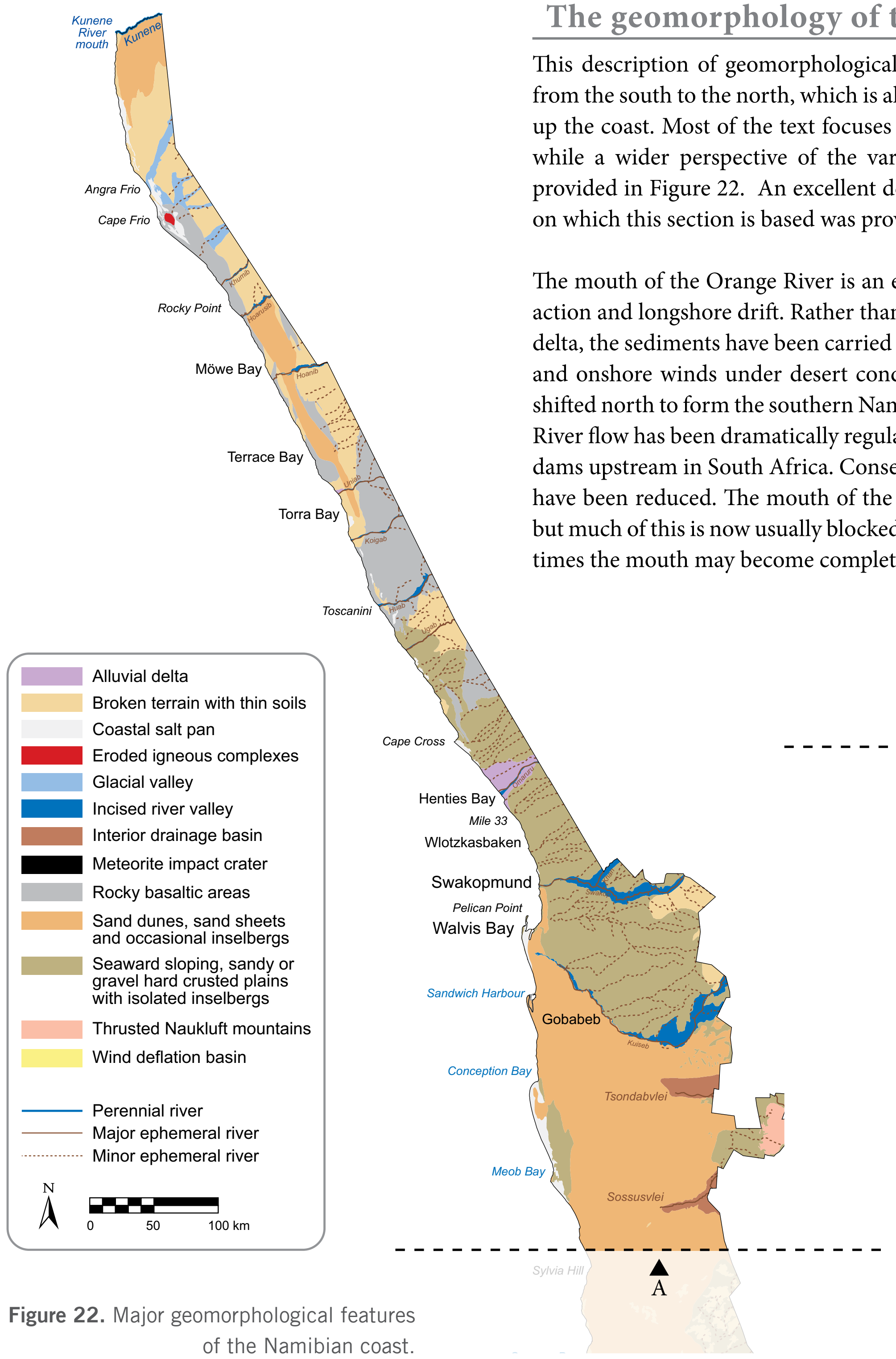


Figure 21. The floor of the south-east Atlantic Ocean bears scars from the break-up of Gondwana and separation of the Namibian and Brazilian coasts. The Walvis Ridge is a zone of extinct volcanic activity caused by the shifting continental plates, while the mid-Atlantic ridge marks the line along which the drifting continental plates continue to part ways.

The geomorphology of the coast

This description of geomorphological features of the coastal environment moves from the south to the north, which is also the path taken by the sediments that move up the coast. Most of the text focuses on features along and close to the shoreline, while a wider perspective of the varied geological and structural formations is provided in Figure 22. An excellent description of the coastal geomorphology and on which this section is based was provided by Mike Bremner in 1985.[4]

The mouth of the Orange River is an example of a delta that is dominated by wave action and longshore drift. Rather than accumulating at the river mouth as a visible delta, the sediments have been carried up the coast and onshore by the strong swells and onshore winds under desert conditions. In effect, the delta has actually been shifted north to form the southern Namib Desert sand sea. In modern times, Orange River flow has been dramatically regulated and subdued by the construction of large dams upstream in South Africa. Consequently, the previously heavy sediment loads have been reduced. The mouth of the river today is just over four kilometres wide but much of this is now usually blocked by a sandbar with a wetland behind it. In dry times the mouth may become completely blocked.



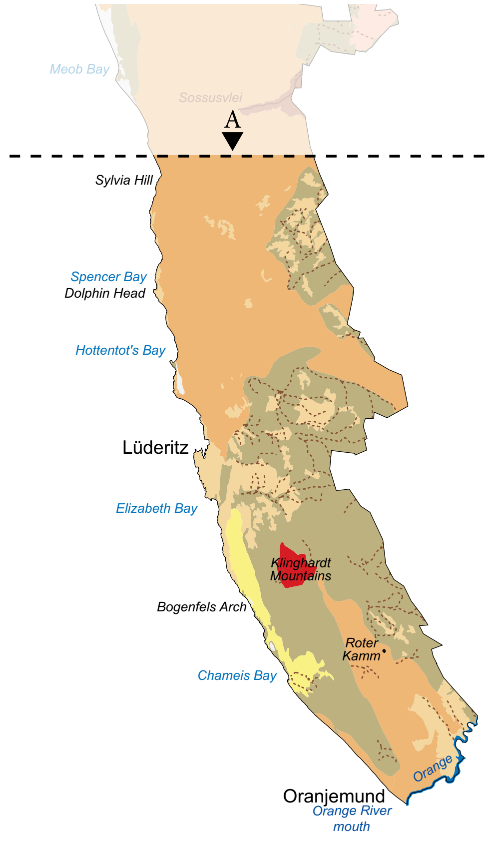


Figure 22. Major geomorphological features of the Namibian coast.

The Orange River mouth is some 4 kilometres wide although most of this is normally blocked by a sand bar that only opens during times of high water flow.

So called "J-bays" form on the downdrift, or northern, side of prominent rock promontories. Diamonds are often trapped in the bays.

From Oranjemund to Chameis Bay, the linear coastline is dominated by sand with old marine terraces occurring at varying heights up to 110 metres above sea level. The terraces have been extensively mined for diamonds. North of Chameis Bay the coastline is still roughly linear but is rockier with many headlands and small, north-facing sandy bays, which are locally known as 'J-bays' because of their shape. The rocks that form these J-bays and other south-facing re-entrant bays, belong to the Gariep Group.

Several small islands and rocks which are important breeding sites for seabirds and numerous Cape Fur Seals occur along this stretch of coastline. In historical times the vast deposits of guano which had built up on the islands were exploited (see pages 115 and 116).

The Bogenfels Arch which formed in dolomites of the Gariep Group is 54 metres high.

In the Bogenfels area there are spectacular sea arches and cliffs. Bogenfels arch itself has also been sculpted in dolomites of the Gariep Group. Just inland of this area the major valleys in the Gariep Group schists are aligned roughly north-south, funnelling the southerly wind which picks up in intensity along the valleys. As a result, the valley bottoms have been so scoured that some of them are now below sea level. The fierce winds have also eroded the hard, crystalline rock in the valleys to form fluted and polished forms known as yardangs (see photos on page 48).

The valleys (which are the wind deflation basins in Figure 22) also help channel the transport of sand from the shore northwards into the main Namib Sand Sea which begins east of Lüderitz. This is the windiest area along the entire coast (see page 30), and the energy of the winds is well illustrated by the rapid rate of decay of old diamond mining settlements.

Thirty kilometres south of Lüderitz, near Elizabeth Bay, the bedrock changes from meta-sediments of the Gariep Group to older and harder gneisses and quartzites of the Namaqua Metamorphic Complex. The structural orientation of these rocks is different and although many rocky headlands are present, they do not have the same north-facing sandy J-bays associated with them. These rocks extend as far north as Hottentot's Bay. Further north Damara age rocks are exposed intermittently along the coast.

Roter Kamm is inland of the coastal area amongst the dunes. This is a well preserved crater formed by the impact of a meteorite. The meteorite is believed to have had a diameter of roughly 100 metres when it crashed down some 3.7 million years ago. Today the crater is about 2.5 kilometres in diameter. Although erosion has lowered the crater walls by 200-300 metres, features that are characteristic of impact craters can still be recognised. Nothing now remains of the meteorite, which was probably vaporised when it crashed into the ground.

Gravel mounds in this valley near Lüderitz are reminders that this area was once mined for diamonds.

Left: The nearly perfectly circular ridge that rises from the dunes at Roter Kamm is a meteorite crater which is well preserved.

North of Lüderitz the shoreline starts becoming sandy with occasional rocky headlands and bays. These rocky headlands themselves may well have been islands during the recent periods of higher sea level. Salt pans are found behind rocky headlands where they are somewhat protected from wind. Good examples of these salt pans are found at Hottentot's Bay and Spencer Bay.

Below: Pans have developed inboard of Dolphin Head which lies at the southern end of Spencer Bay. Mercury Island is visible in the centre of the bay.

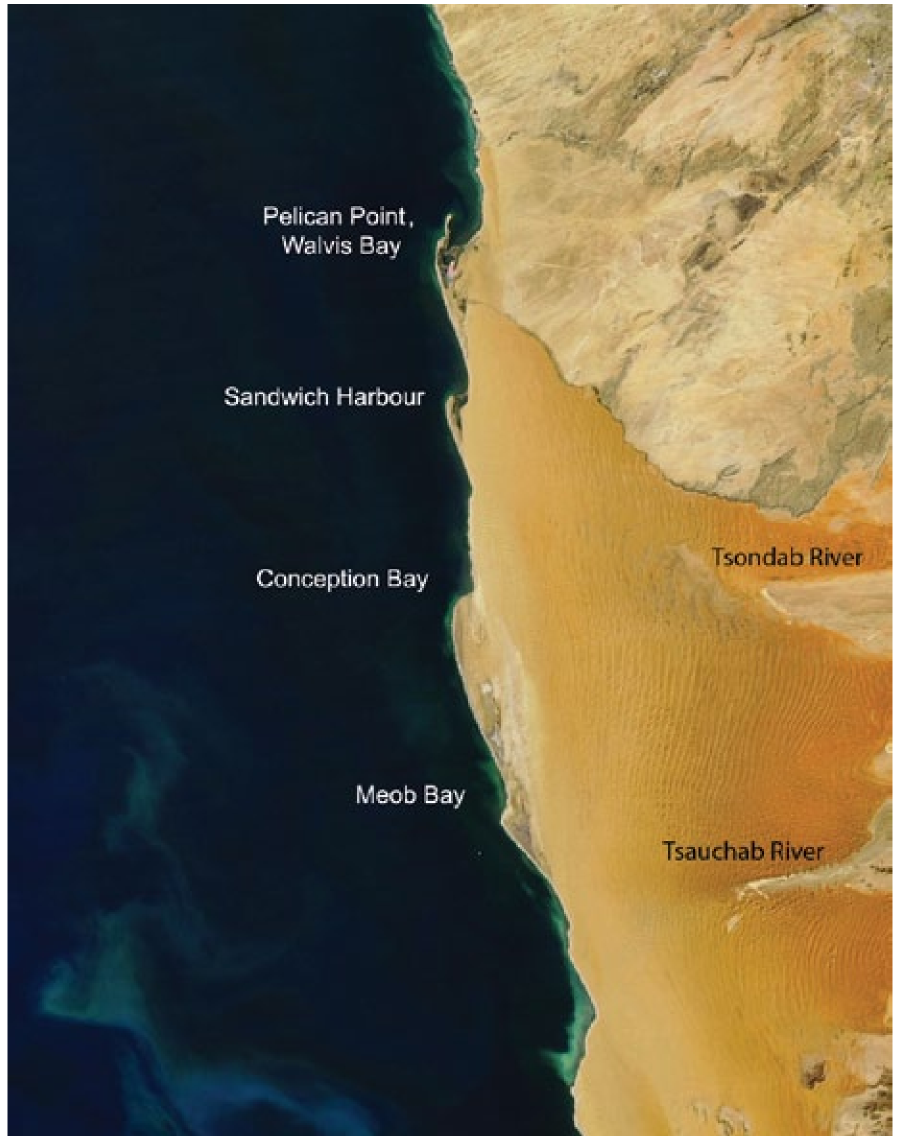
Pelican Point, Walvis Bay

Sandwich Harbour

Conception Bay

Meob Bay

Four major coastal sand spits occur along this stretch of coast. These are the Meob Bay, Conception Bay, Sandwich Harbour and Walvis Bay spits, recognised as low ridges of sand that have grown outwards from the mainland over time. Formed by the northward migration of sand by longshore drift, these spits may have developed near the mouths of ancient rivers. Supporting evidence comes from the fact that the Tsauchab and Tsondab Rivers are directly inland of Meob Bay and Conception Bay, respectively. Additionally, the dunes lying between the bays and the two pans, namely Sossusvlei and Tsondabvlei, that mark the ends of these rivers, appear to be more geomorphologically complex than those to the north and south, possibly as a result of wind blown sand filling in old river valleys.



The southern spits appear to have formed earlier than the northern ones, a feature illustrated by the decreasing number of associated salt pans and increasing areas of open water inland of each spit as one moves northwards. The coast in this section is also clearly growing out to sea, both in a northerly and westerly direction. The *Eduard Bohlen* was wrecked in 1909 (see page 122). She ran aground just offshore in thick fog, but now lies some 370 metres inland of the shore. Old maps, aerial and satellite images confirm that the coast has advanced considerably elsewhere, even in the last 30 years.

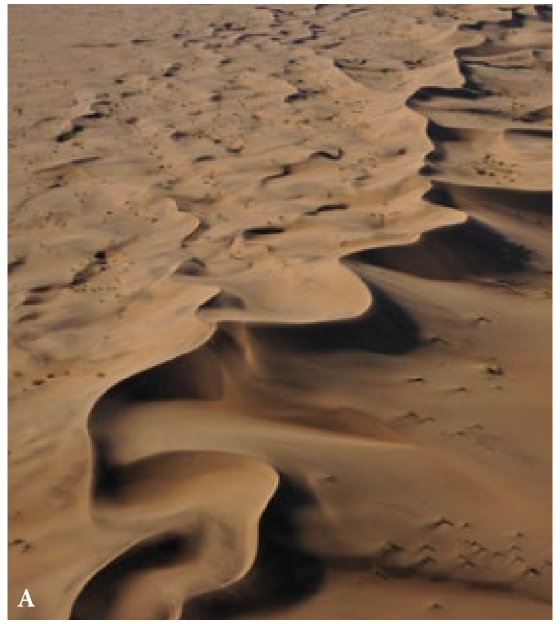
The Walvis Bay spit extended northwards by some 760 metres between 1973 and 2010 (Figure 23). The lagoon at Walvis Bay has the form of a major tidal delta, where more sediment seems to be moved into the lagoon on the rising tide than is removed on a falling tide. Sediment is also possibly blown into the lagoon from the south and the lagoon is therefore being steadily filled in. There have also been substantial changes at Sandwich Harbour since the 1980s which have affected the wetland areas that support so many birds (see page 91).

Above: The wreck of the *Eduard Bohlen* is now isolated amongst sand just south of Conception Bay, far from the sea that she originally sailed.

Below: Walls of dune sands such as the Lange Wand between Sandwich Harbour and Conception Bay provide forbidding obstacles to penetration of the interior by humans and animals. These walls also mark the seaward edge of the massive sand sea between Lüderitz and Walvis Bay.

Figure 23. Changes in the position and shape of the Walvis Bay spit and Pelican Point between 1973 and 2010. The background image is an aerial photograph taken in 2005, while the outlines were traced from aerial photographs and satellite images taken in the different years.[5]

The intermittent floods of the normally dry Kuiseb River are enough to prevent the northward advance of the Namib Sand Sea. An extended period of aridity with no river flow would allow the dunes to move northwards.



A - Long, complex linear dunes are the dominant dune form in the interior of the Namib Sand Sea. These form as a result of the interaction between two different wind systems.

B - The highest types of dunes are star dunes. In this photograph there are three arms visible which have developed as a result of multiple wind directions.

North of Walvis Bay the coast is rocky, dominated by Damara meta-sediments with occasional granite outcrops. A ridge of granite that juts out nearly five kilometres into the sea at Cape Cross forms the most prominent feature along this stretch. Dolerite dykes that lie transverse to the coastline form small bays and offshore shoals, such as at Rock Bay, south of Wlotzkasbaken. In general the coast here is flat and low, often with salt pans just inland of the shore. There are, however, some substantial coastal cliffs near the mouth of the Omaruru River.

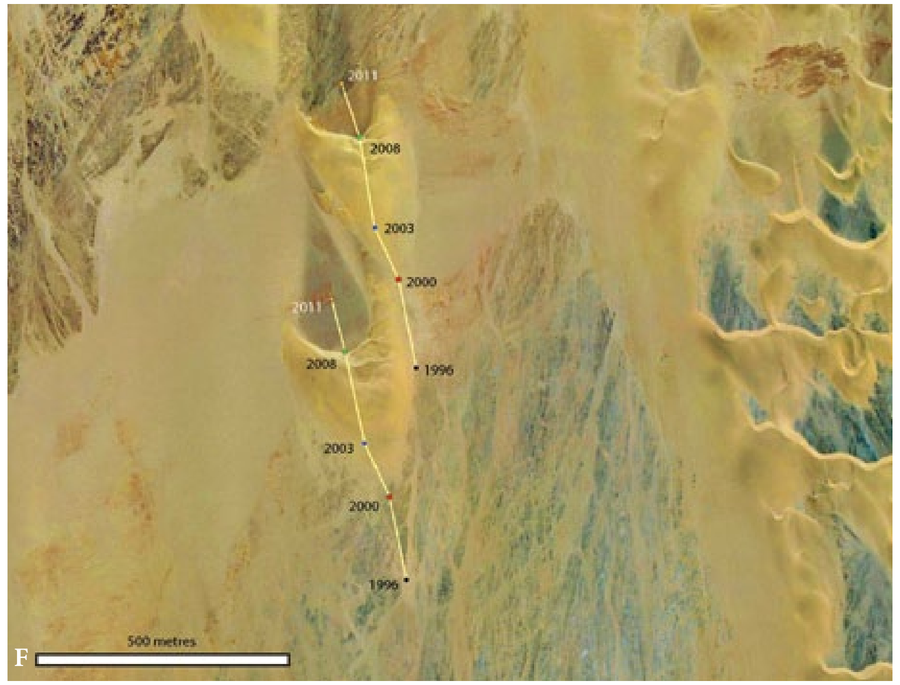
North of the Ugab River, basalts of the Etendeka Group and Damara granites alternate along the shore line. Low sand cliffs are found, most prominently near the Uniab River mouths, demarcating former deltas formed from sediments deposited by these rivers when sea levels were lower. Along the shore in places there are well developed cobble beaches indicating that the shoreline is pounded by substantial wave energy. The cobbles are made up almost exclusively of basalt washed down from the Etendeka Mountains.

Inland of the shore, dunes start appearing 60 kilometres north of the Huab River. These dunes are probably derived from sand which has been carried to the coast by rivers to the south and which has then been driven back onshore by the southerly wind and currents. Initially the dunes are isolated barchans but soon merge to become transverse and ultimately isolated linear dunes. These dunes block the Uniab and Hoanib Rivers during all but the biggest floods but are finally halted by the Hoarusib River which prevents them from spreading further north.

Prior to one large flood in 1982, a 10-metre high dune had blocked the Uniab River, which had not flowed for six years. Heavy rains caused a large volume of water to dam up behind the dune. When the dune was eventually breached, the flood of water washed away gemsbok and the pump station that supplied water to Terrace Bay.[6]

Many of the ephemeral river systems of the northern Namib have fan systems developed near their mouths. The Uniab River fan is the most noticeable of these, having a 30 metre high sea cliff and nine separate distributary channels that cut deep canyons into sediments. Permanent flows of water through parts of the fan form an important wetland, and a waterfall near the head of an incised canyon is a refreshing sight in this arid environment.

North of the Hoarusib River, dunes start developing again and these eventually amalgamate to form the Skeleton Coast dune field which is halted by the permanent flow of the Kunene River. Similar dune fields develop again north of the Kunene River until they finally stop at the Curoca River, inland of Tombua on the Angolan coast.



C - Hummock dunes are known from all along the coast, particularly close to the beach. These are small dunes that form on the leeside of an obstruction, often a bush, which causes wind-blown sand to be deposited. Often these small dunes provide shelter from high winds to small mammals and reptiles.

D - Barchan dunes form where the supply of sand is low. They can move rapidly across the desert floor. The "horns" develop on the downwind side of the barchan.

E - Transverse dunes form perpendicular to the wind direction.

F - How far do mobile dunes move in a year? Using satellite images and aerial photographs for the period between 1996 and 2011, the movement of barchan dunes in the Skeleton Coast dune field was measured. During this 15 year period the two dunes indicated moved approximately 600 metres to the North West. The speed of movement is related to the strength and persistence of the prevailing wind. The underlying image was taken in 2008.

Many valleys carved and shaped originally by ancient glaciers cut across the landscapes of the northern coast. Within the Skeleton Coast Park, the best developed glacial valley is that of the Engo, but glaciers also sculpted the middle reaches of the Kunene River. The glaciers cut down through these valleys westwards into what is now Brazil. This happened about 300 million years ago when Africa was the core of the Gondwana super-continent, and the area was much closer to the South Pole.

Numerous raised terraces occur in the area between Swakopmund and the Kunene River mouth. These gravel and sand terraces lie at various altitudes above today's sea level and were formed in periods of higher sea level some two to three million years ago. Terrace Bay earns its name from the well developed terraces that occur there. In the past they have been explored and mined for diamonds. While some have been found, they are few and small, probably because the ultimate source of all the diamonds on the Namibian coast is the Orange River lying over 1,000 kilometres to the south (see page 139).

Inland of Cape Frio there is a prominent landmark called Agate Mountain that may be an onshore extension of the Walvis Ridge (see pages 51 and 61). The "agate" after which the mountain is named is, however, not agate, but is actually made up of a similar looking mineral called aragonite.

An exceptional geomorphological event occurred in 1995 after a large storm dumped at least 60 millimetres of rain on the catchment of the Hunkab River on the 2nd April.[7] This downpour followed several weeks of rain which had saturated the ground. People driving south between Möwe Bay and Terrace Bay the following morning discovered that the road along the coast had been washed away by the Hunkab. This is not uncommon after heavy rain in the Namib, but what made this so unusual is that the river had breached 15 kilometres of dunes to reach the sea. The huge amounts of sand carried in the river and out to sea soon formed a small delta, but this was removed by wave action and wind within a week. Subsequent floods down the Hunkab, such as the one in 2000, have had an easier route through to the sea. With time, however, the dunes will probably block the river course again.

The Kunene River mouth is about three kilometres wide. A sand bar often lies across its mouth, but water continues to flow through several channels in the bar. The bar develops when flows from the Angolan highlands weaken because of low rainfall and small releases of water from the Gove and Calueque dams in Angola. The wetlands just upstream of the mouth are important feeding grounds for aquatic birds, and have been proposed as a Ramsar wetland site (see page 102).

Beneath the waves

Below the waves of the South Atlantic is an area with topography that is much more complex than most of what we can see on land. However, this submarine landscape is hidden without special equipment such as submersibles and seismic sensors. Much less is therefore known of Namibia's submarine geology and geomorphology, and it is often said that we now know more about the surface of Mars than we do about floors of our oceans.

Immediately offshore is the continental shelf which is 100-140 kilometres wide in most areas, but widens to 180 kilometres off the Orange River and narrows to 30 kilometres near the Angolan border (Figure 24). The edge of the continental shelf south of the Walvis Ridge is relatively deep at around 350–400 metres below sea level, while off the Kunene River it is comparatively shallow at only 150 metres. West of the shelf edge the sea floor drops to the abyssal plain which reaches depths of more than 5,000 metres.The Walvis Ridge is a mountain chain of extinct volcanoes that extends under the ocean south-west from the Namibian coast at Cape Frio (Figures 21 and 24). It runs for over 2,500 kilometres towards the mid-Atlantic ridge and rises over 4,000 metres above the surrounding sea bed. The ridge divides the Cape Basin to the south from the Angola Basin in the north, forming a major barrier to the circulation of deep oceanic waters. Isolated extinct volcanoes form mountains that rise from the sea bed around the Walvis Ridge.

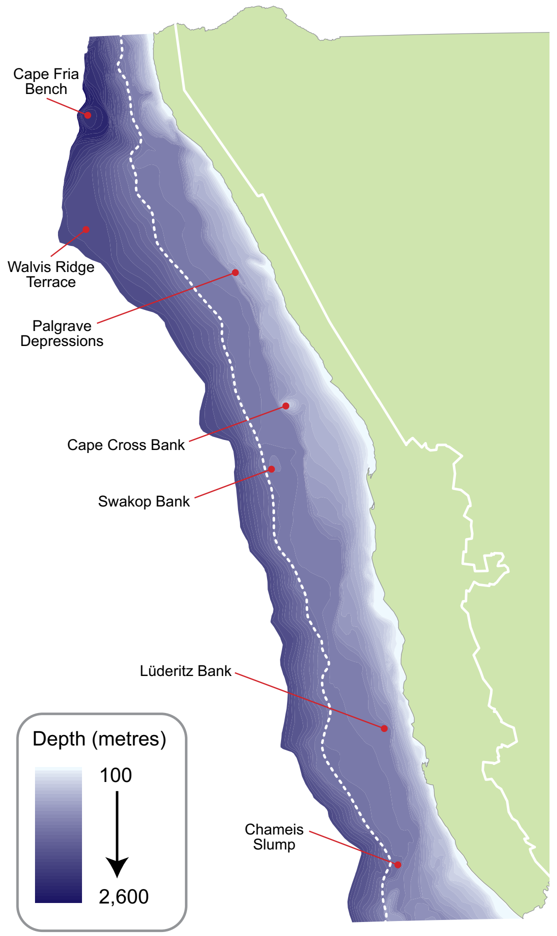


Figure 24. The bathymetry or depths of the ocean between the coastline, continental shelf (dotted white line) and the narrow zone that falls to the abyssal depths of the Atlantic Ocean.[8]

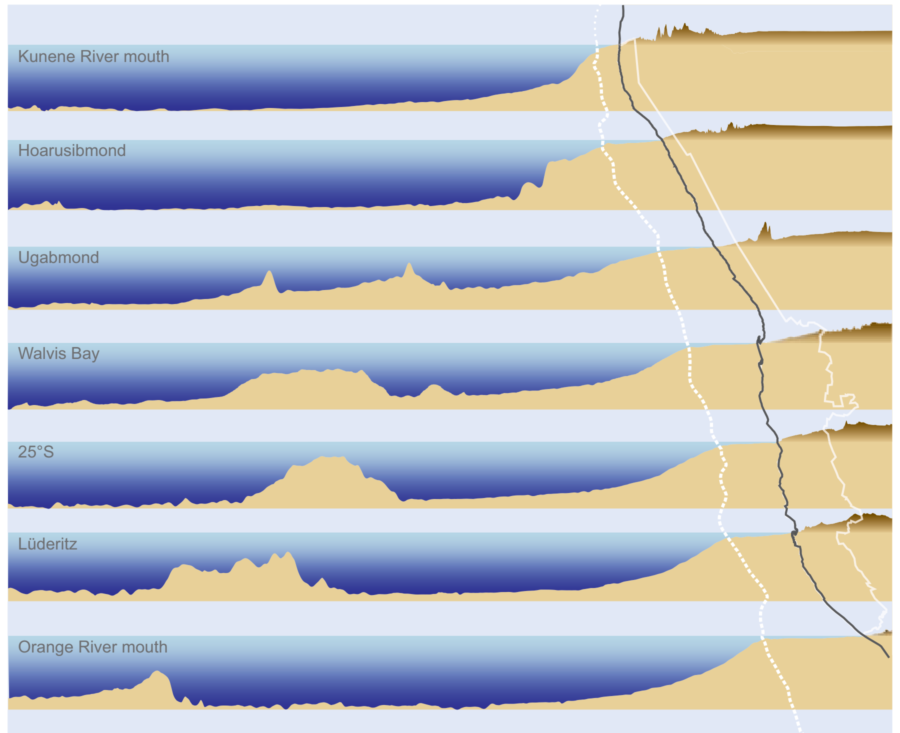
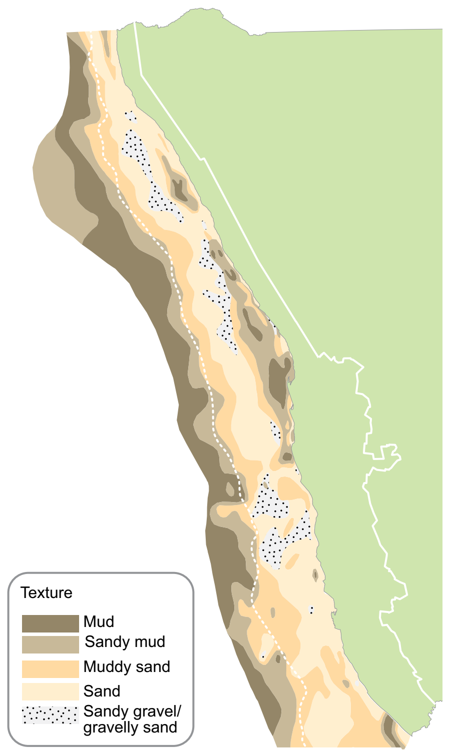
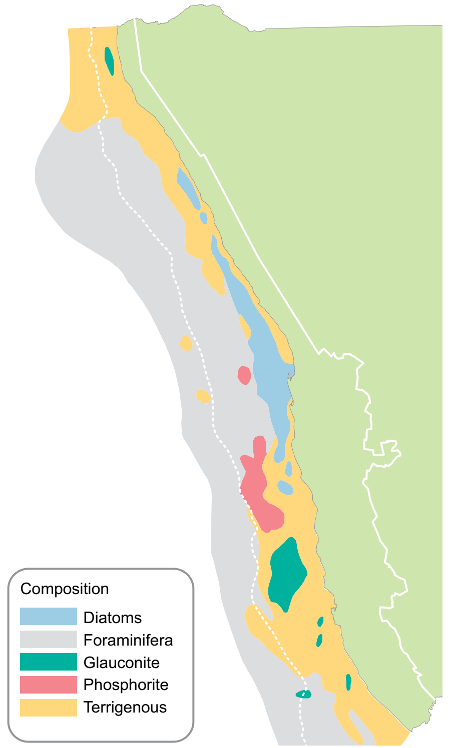


Figure 25. Cross sections from west to east at various places along the coast. The three boundary lines are, from west to east, the continental shelf, the coastline at sea level and the eastern boundary of the protected areas.





The narrow shelf north of the Walvis Ridge is cut by several broad valleys. Large areas of ice-like methane hydrates have been discovered on the sea floor in this area.[9] These are typically found on land in areas of permafrost but methane hydrates also occur in deep, cold oceanic waters. Hydrates are generally unstable compounds and can explode catastrophically, releasing large amounts of methane gas and sometimes causing areas of the sea bed to slump down to greater depths. Slumping caused by hydrates may have formed the broad valleys in the Walvis Ridge. One of these – called the Cape Frio Bench – has a depth of 2,200 metres. The sudden release of large amounts of methane may cause major climatic changes since methane is a far more potent greenhouse gas than carbon dioxide.

On the rather wide continental shelf south of the Walvis Ridge there is a smaller break at a depth of about 150 metres, whereas the main continental shelf breaks away at a depth of about 500 metres. South-west of Walvis Bay the orientation of this shallower, inner break can be related to ancient structures in the underlying Damara rocks and it may have also affected the distribution of sediments on the shelf (Figure 26). The inner shelf break is also important in concentrating the upwelling of the Benguela Current since shallow water on the shelf is more affected by surface wind than deeper water (see page 37).

Isolated raised banks such as the Cape Cross Bank and Swakop Bank may well be buried remnants of igneous rocks that emerged when Gondwana broke apart. Since the banks are just offshore of the area where other igneous or volcanic rocks then surfaced, they may be undersea equivalents to such well-known landmarks as the Brandberg, Spitzkoppe and the Erongo Mountains.

The ocean floor is covered in sediment of various kinds and origins. One way of classifying sediment is by grain size; for instance, does it comprise gravel, sand, mud, or a combination of these? Figure 26 shows that Namibia's continental shelf is dominated by sand and muddy sand. Mud predominates in deeper water west of the continental shelf edge, as well as close inshore near some of the river mouths. Gravelly sediments are composed largely of old, broken shells of mussels, oysters and other molluscs, and the occurrence of the gravels corresponds closely to the location of the upwelling cells and the inner shelf break.

By contrast, the map of sediment composition in Figure 26 gives an idea of how the sediments were formed. Because they originate from rivers, terrigenous sediments are largely found in the shallower, inner areas of the continental shelf. North of Cape Frio the continental margin is almost entirely terrigenous. South of this area the shelf is dominated by biogenic sediments, the deeper offshore zones consisting

Figure 26. The texture of surface sediments (top left) and the predominant sedimentary material (bottom left). The continental shelf is shown as a dashed white line.[10]

mainly of the shells of foraminifera (tiny, single celled organisms). The inner shelf margin is dominated by diatoms as a result of their prolific production in areas of upwelling (see page 85).

Glauconite and phosphorites were formed on the seafloor by chemical and biological processes. There is interest in the mining of phosphates (see page 143) from the phosphorite found south-west of Walvis Bay.

Recent mapping has provided evidence for extensive erosion of the sea bed by strong currents, both recently and in the distant geological past.[11] The erosion is particularly widespread south-east of the Walvis Ridge and offshore from the Orange River. Sediment is constantly moved back and forth, effectively sand-papering the sea floor. Elsewhere, isolated mounds have been recently discovered. These may have developed as extremely deep reefs built over the aeons by animals and plants that feed on nutrients that leak from the seabed.

The edge of the very wide (180 kilometres) continental shelf off the Orange River mouth is called the Orange Bank because the edge of the shelf is actually shallower than the area between the shelf and the shore. Major depressions are also found on the northern margin of this bank in an area known as the Chameis Slump. Some 370 kilometres west-southwest of the Orange River an eroded volcanic mountain (called a guyot) forms a prominent, but submarine mountain. This is the Tripp Seamount (see Figure 21). Further out to sea, the Vema Seamount rises over 4,000 metres from the sea floor; by comparison, Brandberg, the highest mountain in Namibia, rises only 1,800 metres from the surrounding plain.

Ephemeral rivers along the coast transport large amounts of sediment into the sea. This delta, which only lasted a few days before being reworked and destroyed, formed at the mouth of the Hoarusib River after more than 200 millimetres of rain fell in parts of its catchment in 48 hours in March 1995.

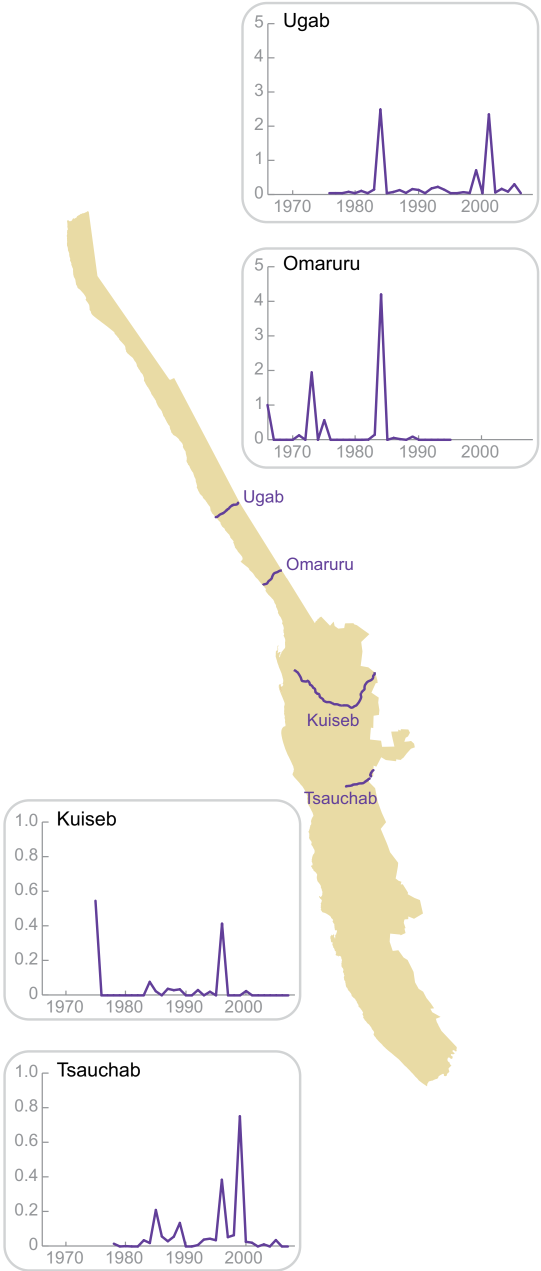


Figure 27. Flows along four of the major ephemeral rivers in the central coastal region. The Tsauchab River terminates at Sossusvlei, while the Kuiseb River ends just inland of Walvis Bay. The units of water volume on the y-axis are cubic metres per second.[12]

Ephemeral rivers

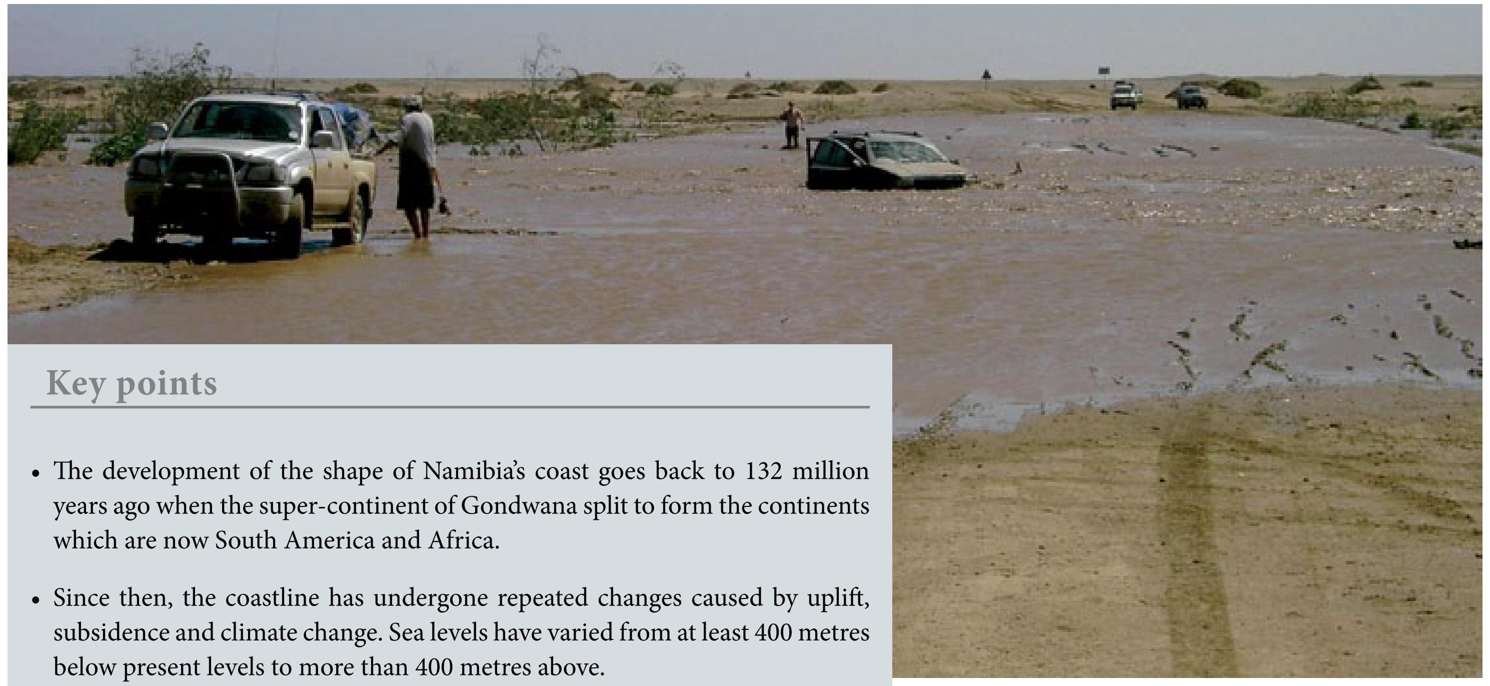
North of Walvis Bay many ephemeral rivers flow down to the coast, or at least reach some of the way before petering out in the sand. All are lifelines of riparian vegetation where the plant life is completely different from that in the surrounding desert (see page 76).

Several major features characterise ephemeral rivers. With the exception of occasional springs and pools that may hold water for extended periods, the rivers are dry for most of the time. Flows are highly unpredictable or sporadic, as the graphs in Figure 27 clearly show. Years may pass before sufficient rain falls in their catchments inland to supply enough runoff for the rivers to flow. Even in years when rain is abundant, flows are intermittent, some lasting just a few hours while others persist for days.

Flows are sometimes sudden, strong and rapid, with the river transforming from a parched dry river course into a raging torrent. These are flash floods, which occur when there are high rates of run-off in catchment areas. Often this happens in areas that have little soil or vegetation to absorb the water. The gradients along stretches of some of the rivers are also quite steep, thus speeding along the flow of water and reducing the possibility of water soaking into the river beds.

The erosive power of rivers in flood can be significant, and this is how the Kuiseb and Hoarusib Rivers block the northward advance of massive seas of sand dunes (see page 58). Some rivers can carry large volumes of sediment when in full flood and these sediment loads occasionally reach the sea. Long-shore currents then transport the sediments north and often back onto the coast where they ultimately feed more sand into the northern dune fields. Sediments in the Tsauchab and Tsondab rivers never get that far, instead ending up in Sossusvlei and Tsondabvlei, respectively.

Trees growing along the rivers obtain water from groundwater reserves that are recharged during surface flows. Levels of recharge are greatest when the flows last for extended periods, allowing the water to soak down to the bedrock, while short-lived flows often saturate only the top layers of the ground. Much of this water is subsequently lost through evaporation. Recharges also occur most frequently in the upstream, eastern sections of the rivers where flows are most regular and long-lasting. Consequently, the chances of aquifers being replenished are slimmest in the western-most sections of the rivers where the environment is driest and groundwater here has the highest value. Large volumes of groundwater reserves are pumped from the Kuiseb and Omaruru Rivers to supply the water needs of the central coastal towns and mines. However, these reserves and the rates at which they are recharged by surface flow will be inadequate if water demand rises significantly due to more uranium mines and other industries being developed in the area (see page 144). Alternative water supplies, such as from desalination of sea water, are being established to satisfy this need.



Flash floods down a westward flowing ephemeral river have trapped many an unwitting adventurer. Floods can occur quickly after heavy rains in the desert and caution is needed when camping in or crossing these rivers.

Key points

- The development of the shape of Namibia's coast goes back to 132 million years ago when the super-continent of Gondwana split to form the continents which are now South America and Africa.
- Since then, the coastline has undergone repeated changes caused by uplift, subsidence and climate change. Sea levels have varied from at least 400 metres below present levels to more than 400 metres above.
- The Namibian coastline is one of the most high-energy in the world, being attacked by swells rolling in from the south Atlantic, and the strong southerly winds and the Benguela Current that drive vast quantities of sediment northwards and onshore to form great fields of shifting dunes.
- These forces cause the shapes and positions of many prominent features, such as the sand spits at Walvis Bay and Sandwich Harbour, to frequently shift over significant distances.
- Salts, sulphates and fog carried inland by onshore winds have eroded and corroded soils and rocks, which have also been scoured by the strong winds.
- The Orange River is the major source of diamonds which the river carried down to the sea from the interior of southern Africa. Longshore drift then transported diamonds northwards up the coast.
- Offshore, the seabed falls to depths of a few hundred metres on the continental shelf which extends west before it breaks away to depths of several thousand metres.
- Extensive sedimentary basins on the sea bed are filled with material carried down by large rivers that no longer exist.
- Ephemeral rivers form important linear oases in the desert landscapes along the northern coast. South of Walvis Bay, no ephemeral rivers reach the coast.