

Abstract

The landscapes of Namibia owe much of their distinctive nature to the long and complex geological history. Some of the rocks of Namibia are as much as 2,600 million years old, and the first portion of the chapter gives a chronological picture of the geology of the country. This is followed by an analysis of the importance of Cretaceous tectonic activity associated with the opening of the South Atlantic, and then by a discussion of the significance of dolerite intrusions, of planation surfaces and of current neotectonic activity. All of these geological events have had clear impacts on today's Namibian landscape.

2.1 Geological Background

Namibia has a huge array of different rocks that vary in age and character (Schneider 2008). Their history and nature have been described in a monumental 3-volume treatise by Miller (2008), and a valuable travel handbook has been produced by Grünert (2000). The geological history of Namibia is summarised in the timeline shown in Table 2.1, which focuses on the key events which have shaped today's landscapes. The land that now makes up Namibia has been at the centre of many important plate tectonic movements, making it of great interest to geologists.

A useful distinction can be drawn between the geology of the eastern part of the country and that of the west (Fig. 2.1). The eastern part, comprising the Kalahari basin (see Chap. 1), is geologically young and simple being covered by relatively recent materials, including aeolian sands, alluvium, and calcareous crusts (calcretes). The western part consists of a great variety of rock types exposed in a rugged landscape of valleys, escarpments, mountains and plains and is much more geologically complex and ancient. Many of these rocks were formed at depth in primeval oceans and then were subjected to vertical and horizontal movements of the Earth's crust. The amount of movement, vertical and horizontal, that has been involved is almost incredible. For example, around 500 million years ago, Namibia was located in an area that would now be in the South Pacific and then c 360 million years ago passed over the South Pole, before moving northwards to its present position.

The oldest rocks in Namibia (Early Mokolian to Vaalian) are up to 2,600 million years old and occur in the Hoarusib valley northwest of Sesfontein in the Kunene region of northern Namibia. Between 1,400 and 1,200 million years ago, in the Mesoproterozoic, two or more large landmasses collided to form the great continent of Rodinia (Russian for 'motherland'), producing intense volcanic activity, mountain building and the formation of sedimentary basins. Rodinia started to break up by rifting some 850 million years ago. Africa split from South America, and Namibia was split between the Congo Craton in the north and the Kalahari Craton to the south. Such cratons are stable areas of continental crust that are often referred to as shields. Sediments accumulated in the rifts between these cratons. From 750 million years onwards the three landmasses moved still further apart and deep oceans developed, in which sediments accumulated. However, around 550 million years ago the landmasses fused together once again to form the supercontinent of Gondwanaland. As they converged sediments on the ocean floors were folded and heated and mountains were formed during the Late Precambrian Damaran Orogen. Volcanic rocks were also produced. The rocks of the Damaran Orogenic Belt form a c 400 km wide belt in the centre of Namibia and are well exposed in the Swakop valley (Toé et al. 2013). From 300 to 200 million years ago, rocks of the Karoo Supergroup were deposited, and some of these were laid down by glaciers during the Permo-Carboniferous Dwyka phase. Glacial valleys and pavements were also excavated, and some of them are evident as exhumed forms

Table 2.1 A Namibian tectonic and geological timeline

Time (millions of years ago)	Event	Landscape relevance
2,600	Oldest rocks in Namibia formed	Kunene Valley (Chap. 5)
1,600	Start of Mesoproterozoic	
1,400–1,050	Namaqualand metamorphic complex and related rocks	
850	Break-up of Rodinia	
850–600	Damara Supergroup and Gariiep Complex	Otavi limestones and Dolomites (Chap. 6)
650	Damara Granite intrusions	
600–543		
550	Formation of Gondwanaland	
542	End of Precambrian and start of Palaeozoic	
300–180	Karoo Supergroup	
250	Start of Mesozoic	
180	Jurassic. Rifting of Gondwanaland starts from southernmost tip of South America	Etjo sandstones, Waterberg Plateau (Chap. 2, box 3); Twyfelfontein (Chap. 7)
145	Start of Cretaceous	
135–120	Break-up of W Gondwanaland; eruption of Etendeka flood basalts, intrusion of Damaraland igneous complexes and dolerite dikes	Etendeka, Brandberg, Spitzkoppe and Erongo (Chaps. 9, 10 and 11)
80–75	Formation of Bukkaros	Chap. 24
65.5	Start of Cenozoic	
26	Start of Miocene. Formation of Tsondab Sandstone	Calcretes (Chap. 16); Namib Sand Sea Namib sand sea (Chap. 18)
11.8	Intensification of upwelling Benguela current	
7	Start of Pliocene	
7–5	Lake Kunene forms in Etosha Basin	Etosha Pan (Chap. 6)
5–3.7	Roter Kamm formed	Chap. 24
2.5	Start of Quaternary mid-latitude glaciation, and intensification of aridity in Namibia	Homeb Silts (Chap. 15); Sossus Vlei (Chap. 19); Naukluft tufas (Chap. 20); Linear dunes (Chap. 21); Koes Pan (Chap. 23)
0.01	Start of Holocene	Barchans (Chap. 17); Fairy circles (Chap. 25)

in the landscape today (Martin 1968), notably in the upper catchment of the Hoarusib River. The glaciers appear to have been fed by a large ice cap, and the direction of flow was westwards. As the glaciers retreated c 280 million years ago, large spreads of sands and shales were laid down. From 200 to 170 million years ago, an arid phase led to the deposition of sands, some of which now cap the Waterberg Plateau, Mount Etjo, and other hills.

Box 3: The Etjo sandstones: Waterberg Plateau, Mount Etjo and Omatako

Today, a series of flat-topped mountains situated in north eastern Namibia on the edge of the Kalahari and some 60 km east of Otjiwarongo (Fig. 2.2) illustrate the impact of the Etjo Sandstone on Namibia's relief: the Waterberg Plateau (a National Park) (1,930 m

above sea level), Klein Waterberg and Mount Etjo (over 2,080 m above sea level). These inselbergs are formed of Karoo age Sandstone, around 180 million years old, underlain by Omingonde shales and mudstones. The Etjo sandstone contains units that were laid down under arid, aeolian conditions (Holzförster et al. 1999; Mountney and Howell 2000). The presence of sandstones over shales and mudstones has produced ideal conditions for slope failures, and great landslips create scallops into the north side of Mount Etjo (Fig. 2.3). Other notable inselbergs are the cone-shaped Omatako Mountains between Okahandja and Otjiwarongo (Fig. 2.4). These were visited by Francis Galton (1853) who likened the perfection of their shapes to that of Tenerife. Their name is based on the Herero word for 'buttock' and they rise 700–800 m

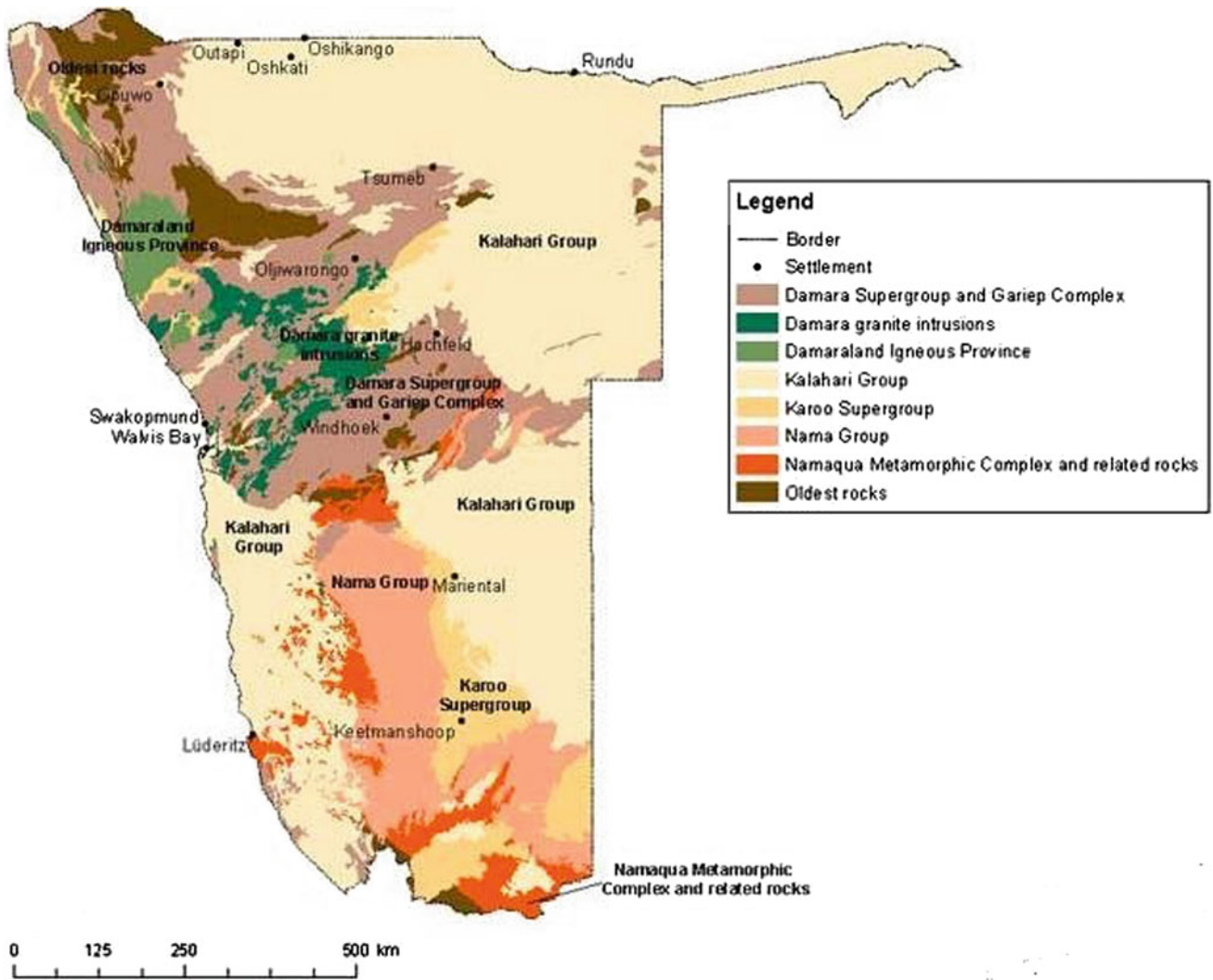
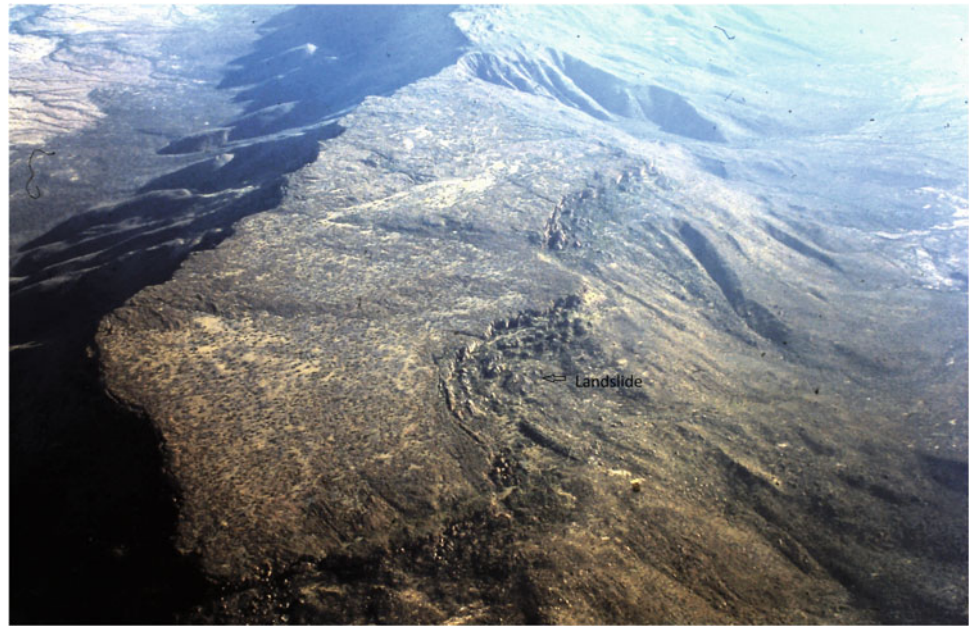


Fig. 2.1 Geological map of Namibia (from Mendelsohn et al. 2002, p. 42, in http://www.uni-koeln.de/sfb389/e/e1/download/atlas_namibia/) (Accessed 30 January 2014)

Fig. 2.2 Google Earth image of the Waterberg Plateau. Scale bar is 10 km (© 2012)



Fig. 2.3 Mount Etjo landslides**Fig. 2.4** Google Earth image of Omatako Mountains. Scale bar is 3 km. (© 2013 Digital Globe)

above their surrounding plains. They are also composed of Etjo Sandstone capped by Karoo volcanic rocks (Grünert 2000, p. 33).

Around 180 million years ago, Gondwanaland began to split apart. Great eruptions of lava occurred over southern Africa. The split between South America and South Africa started about 132 million years ago in the early Cretaceous, causing huge eruptions of lava now seen in the Etendeka Mountains as the Etendeka Volcanics (Fig. 2.5). This was a crucial development for understanding the present geomorphology of

Namibia (Goudie and Eckardt 1999; Dauteuil et al. 2013), with uplift occurring on the continental margin and subsidence offshore.

2.2 The Impact of Early Cretaceous Tectonics

The Central Namib possesses a group of distinctive igneous complexes—known as Damaraland Complexes—of great relief significance to today's landscape associated with volcanic and intrusive activity caused by the opening up of the

Fig. 2.5 Locations of some of the sub-volcanic complexes and the Etendeka Volcanics (from Goudie and Eckardt 1999, based on Milner et al. 1992, Fig. 1 and Milner and Le Roex 1996, Fig. 1)

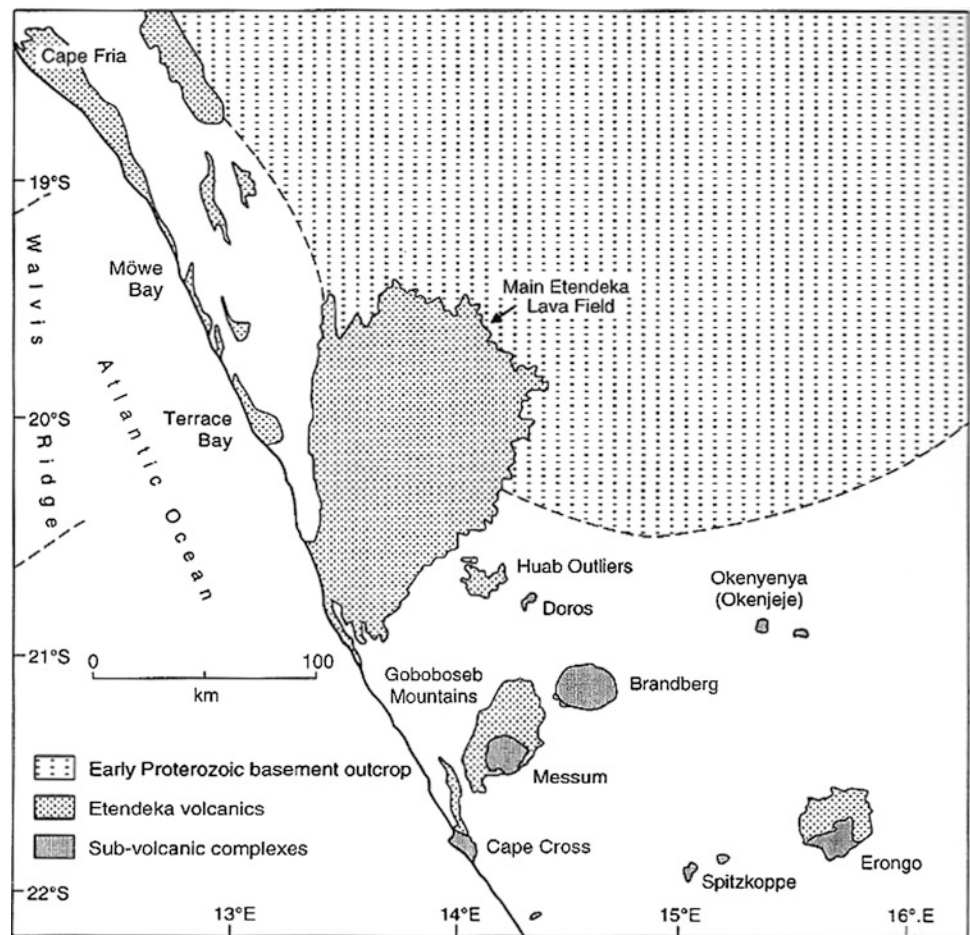
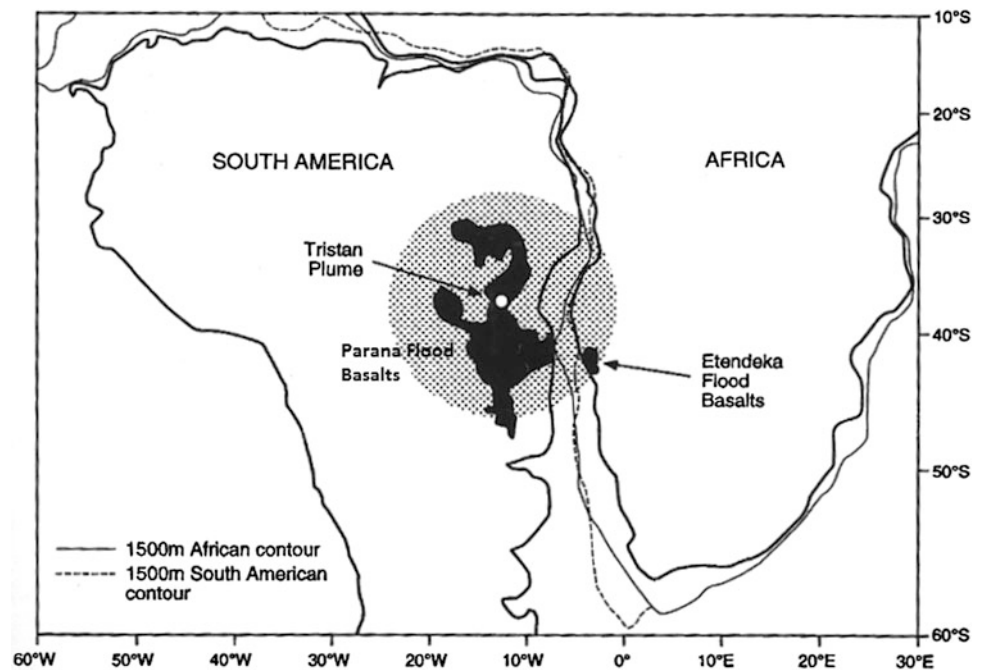


Fig. 2.6 The position of the Etendeka basalts of Namibia in relation to the Paraná basalts in South America at 130 million years ago, prior to the opening of the South Atlantic (from Goudie and Eckardt 1999, Fig. 14 and based on O'Connor and Duncan 1990, Fig. 9a)



South Atlantic, the separation of southern Africa from South America (Fig. 2.6), and the presence of the most important hot-spot track off the coast of Africa—that of Tristan and Gough Islands (Burke 1996), whose topographic expression is the submarine Walvis Ridge (Elliott et al. 2009). Dates for the trail of the Tristan plume along the Walvis Ridge across the South Atlantic show a progressive decrease from Etendeka to the recently active volcanoes of Tristan de Cunha and Gough (O'Connor and Le Roex 1992).

The Damaraland Complexes (Milner et al. 1995) define a prominent northeast trending phenomenon, extending from Cape Cross at the Atlantic coastline, to Okorusu, which is 350 km inland. There are four distinct classes of volcanic/intrusive feature within the area (Pirajno 1994): those formed of granite (Brandberg, Erongo and the Spitzkoppe group), those formed of layered basic rocks (Cape Cross, Doros, Okonjeje, and Messum), those that are peralkaline [e.g. the large Paresis ring complex, located c 280 km inland, which is dominated by rhyolite (Mingram et al. 2000)], and those that are carbonatitic (e.g. Okorusu and Kalkfeld), which are located at the north eastern end of the group. There are also very extensive spreads of continental flood basalts which make up the Etendeka Formation (see Chap. 9) (Fig. 2.7). This outcrops over around 78,000 km² of north-western Namibia and the lavas reach a maximum observed thickness of 800 m at Tafelberg. They are relatively flat-lying and the absence of erosion horizons has been taken to infer that they were poured out rapidly without significant interruption (Milner et al. 1992). Furthermore, numerous dolerite dykes were formed at around 135 Ma, immediately prior to the outpouring of the basalts. They have a strong orientation trend (c NE–SW) and form distinctive ridges. Their trend parallels earlier lineaments that were reactivated

during the Damaran deformational event (which started about 850 Ma) and which may be related to still earlier deep-seated Proterozoic crustal weaknesses (Lord et al. 1996).

Of the basic complexes, Cape Cross is a circular feature, the greater part of which lies beneath the seal-rich waters of the south Atlantic. Doros is an elongated pear or funnel shaped mass, with a long axis length of around 7 km. It has been differentially eroded and weathered to give a landscape which consists of alternating ring-shaped hills and valleys, all centred around the middle of the complex. The elevation of each hill or valley lies progressively lower from the centre outwards. A typical annular drainage pattern exists. Okonjeje (Okonjeje) is the best exposed of the differentiated basic complexes and remnants of metamorphosed, outward-dipping Karoo sediments are preserved around its margins. Ring structures dominate the outcrop patterns of the intrusives, which are exposed over an area of about 20 km² of high relief. The Messum complex, Brandberg and Spitzkoppe are described in Chap. 10, and Erongo in Chap. 11.

A large number of isotopic dates have now been produced for the Damaraland complexes as reviewed by Milner et al. (1995) which span the 137–124 Ma range and can thus be assigned to the early Cretaceous. Milner et al. (1995) suggest that igneous activity among the different complexes was approximately contemporaneous, and that it was probably concurrent with the eruption of the Etendeka lavas.

2.3 Dolerite Dikes/Dykes and Sills

A dike is a sheet-like intrusion of igneous rock, usually oriented vertically, which cuts across the structural planes of the host rock. If it is more resistant than the rock into which

Fig. 2.7 The Etendeka lavas inland from the Skeleton Coast



it is intruded, it will form an upstanding ridge, whereas if it weathers more than the surrounding rock it will create a ditch-like depression. A sill is a magma body that has been intruded more or less parallel to the bedding of the rocks into which it has been pushed, and so is usually a near horizontal feature in the landscape.

In Namibia there are many dikes composed of dolerite, which rise up above the surrounding land, and because they are often covered in dark desert varnish, they often show up clearly as blackish lines (Fig. 2.8) cutting across the countryside and contrasting with the lighter coloured rocks, such as the granites and marbles around them (Fig. 2.9). Their undulating crests have sometimes been likened to a dragon's backbone. The dikes can occur in swarms, as is the case with the enormous Henties Bay-Outjo NE-trending swarm in west-central Namibia (Trumbull et al. 2004, 2007). This contains well over one thousand individual dikes. They are of roughly the same age as the Etendeka lavas and the intrusive complexes of Damaraland and may be the exposed feeders of the Etendeka basalts.

Another major area of dolerite dikes and sills occurs near Keetmanshoop, but these are older, being of Jurassic (Karoo) age and dating back to 180 million years ago. These were intruded into Dwyka and Eccca sedimentary rocks. These are relatively soft materials so that the dolerites are often left upstanding as small hills. Such is the case at the Giant's Playground, which is located in the Quiver Tree Forest on the Farm Gariganus, 23 km northeast of Keetmanshoop. The dolerites have been weathered to produce rounded hillocks and boulders. The dikes are generally 3–6 m wide, and their length varies from hundreds of metres to tens of kilometres. Mostly they trend NW–SE. One of the first travellers to walk across the Kalahari, Farini (1886), who travelled with his cross-dressing colleague Lulu, thought that the jumble of

dikes, boulders and hillocks were man-made and were remnants of a lost city.

2.4 Planation—The African Surface

After the breakup of Gondwanaland in the late Jurassic and early Cretaceous there was in southern Africa through the Cretaceous and into the Miocene a period of comparative stability that led to the erosion of extensive low relief plains, called the African Surface. The surface was possibly eroded under tropical humid conditions, and remnants of kaolinised weathering profiles (saprolite) are locally preserved, not least under Kalahari Group sediments in the Aranos Basin and in the Marienthal-Kalkrand area (Miller 2008, Chap. 23). The surface occurs at low elevations along the coast and at higher levels in the interior behind the Great Escarpment. Above the interior plains some bevelled remnants of the old Gondwana surface remained, as in the rugged Khomas Highlands south of Windhoek (King 1963, p. 240).

The extent of the African Surface in Namibia, and of areas which lie above it, have been mapped in Partridge (1998). In the interior, the African erosion phase is shown by well-developed planation surfaces in the central plateau of the country. This phase was initiated by upwarping of the continental rim associated with rifting and was graded to interior base-levels, such as the Kalahari basin and the Orange valley. In contrast, seaward of the Great Escarpment erosion proceeded to a new, lower, oceanic base level following the rifting. This explains the differences in height of different components of the African Surface. Also, to the seaward of the Great Escarpment, as near Pomona in the Sperrgebiet, the surface was silicified (Partridge and Maud 2000, p.10), as on the Kätchen Plateau (Miller 2008, p. 25–29). The African

Fig. 2.8 Google Earth image of dolerite dykes. Scale bar 1 km. (© 2012 Google Image, GeoEye)

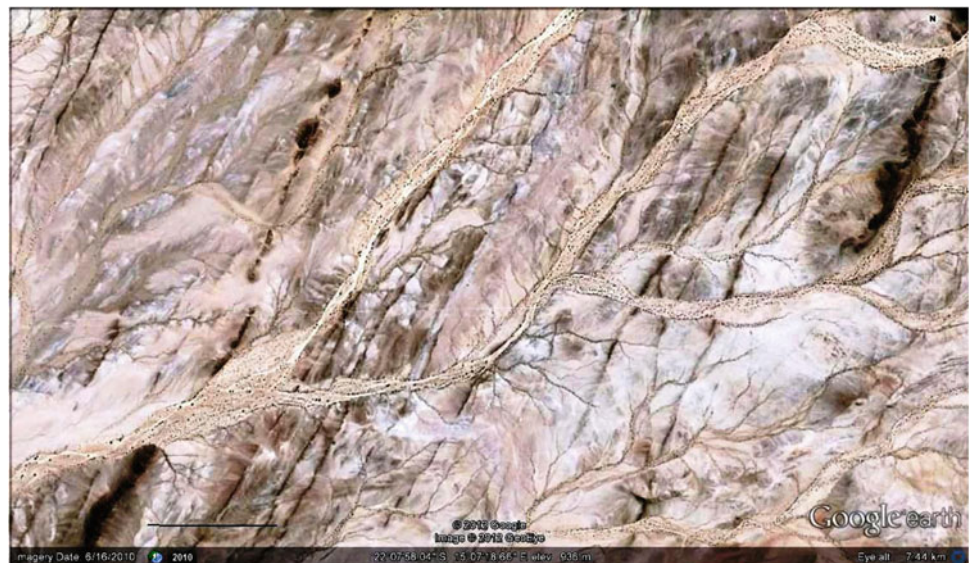


Fig. 2.9 Dolerite dike on the banks of the Swakop River, inland from Swakopmund



erosion phase came to an end with uplift of southern Africa during the Miocene (Moon and Dardis 1988, p. 6).

2.5 Neotectonics

Although Namibia now rests in the middle of a tectonic plate on a passive continental margin, and so has little earthquake activity and no volcanism, there is still probably a certain amount of ongoing tectonic activity in Namibia—a phenomenon called neotectonics. For example, in south west Namibia, the Hebron Fault has a well developed fault scarp, with a downthrow of up to 7 m that can be traced for 35 km, which has disturbed Late Pleistocene dunes (White et al. 2009). In the same area the Dreylingen-Pfalz Fault truncates Pleistocene valley-fill terraces and there are active mud volcanoes offshore of the Orange (Viola et al. 2005). In the northwest the Eisen Graben has had a similar effect on quite recent Kalahari dunes (Wanke 2005). Recent earthquakes in Namibia included a magnitude 5 event near Khorixas on 24th March 2012, and a 5.6 magnitude event on 31st July 2012 between Khorixas and Omaruru. A map of earthquakes in Namibia and neighbouring countries since 1900 appears in: www.earthquake.usgs.gov/earthquakes/world/namibia/seismicity.php (accessed 5th December, 2012).

References

- Burke K (1996) The African plate. *S Afr J Geol* 99:341–409
- Dauteuil O, Deschamps F, Bourgeois O, Mocquet A, Guillocheau F (2013) Post-breakup evolution and palaeotopography of the North Namibian Margin during the Meso-Cenozoic. *Tectonophysics* 589:103–115
- Elliott GM, Berndt C, Parson LM (2009) The SW African volcanic rifted margin and the initiation of the Walvis Ridge, South Atlantic. *Marine Geophys Res* 30:207–214
- Farini GA (1886) Through the Kalahari Desert. Sampson Low, London
- Galton F (1853) Narrative of an explorer in Tropical South Africa being an account of a visit to Damaraland in 1851. John Murray, London
- Goudie AS, Eckardt F (1999) The evolution of the morphological framework of the Central Namib Desert, Namibia, since the early Cretaceous. *Geogr Ann* 81A:443–458
- Grünert N (2000) Namibia. Fascination of geology. Klaus Hess, Windhoek
- Holzförster F, Stollhofen H, Stanistreet IG (1999) Lithostratigraphy and depositional environments in the Waterberg-Erongo area, central Namibia, and correlation with the main Karoo Basin, South Africa. *J Afr Earth Sci* 29:105–123
- King LC (1963) South African scenery. Oliver and Boyd, Edinburgh, London
- Lord J, Oliver GJH, Soulsby JA (1996) Landsat MSS Imagery of a Lower Cretaceous regional dyke swarm, Damaraland, Namibia: a precursor to the splitting of western Gondwana. *Int J Remote Sensing* 17:2945–2954
- Martin H (1968) Paläomorphologische Formelemente in den Landschaften Südwest-Afrikas. *Geol Rund* 58:121–128
- Mendelsohn J, Jarvis A, Roberts C, Robertson T (2002) Atlas of Namibia. Sunbird Publishers, Cape Town
- Miller RMCG (2008) The Geology of Namibia, vol 3. Geological Survey of Namibia, Windhoek
- Milner SC, Le Roex AP (1996) Isotope characteristics of the Okenyenya igneous complex, north western Namibia: constraints on the composition of the early Tristan plume and the origins of the EMI mantle component. *Earth Plan Sci Lett* 141:277–291
- Milner SC, Duncan AR, Ewart A (1992) Quartz latite rheoignimbrite flows of the Etendeka Formation, north-western Namibia. *Bull Volcanol* 54:200–219
- Milner SC, Le Roex AP, O'Connor JM (1995) Age of Mesozoic igneous rock in northwestern Namibia, and their relationship to continental breakup. *J Geol Soc London* 152:97–104

- Mingram B, Trumbull RB, Littman S, Gerstenberger H (2000) A petrographic study of anorogenic felsic magmatism in the Cretaceous Paresis ring complex, Namibia: evidence for mixing of crust and mantle-derived components. *Lithos* 54:1–22
- Moon BP, Dardis GF (1988) *The geomorphology of Southern Africa*. Southern Book Publishers, Johannesburg
- Mountney N, Howell J (2000) Aeolian architecture, bedform climbing and preservation space in the Cretaceous Etjo Formation, NW Namibia. *Sedimentology* 47:825–849
- O'Connor JM, Duncan RA (1990) Evolution of the Walvis Ridge—Rio Grande Rise hot spot system: implications for African and South American plate motions over plumes. *J Geophys Res* 95 (B11):17475–17502
- O'Connor JM, Le Roex AP (1992) South African hot spot—plume systems: 1. Distribution of volcanism in time and space. *Earth Plan Sci Lett* 13:343–364
- Partridge TC (1998) Of diamonds, dinosaurs and diastrophism: 150 million years of landscape evolution in southern Africa. *S Afr J Geol* 101:167–184
- Partridge TC, Maud RR (2000) *The Cenozoic of Southern Africa*. Oxford University Press, New York
- Pirajno F (1994) Mineral resources of anorogenic alkaline complexes in Namibia: a review. *Austral J Earth Sci* 41:157–168
- Schneider G (2008) *The roadside geology of Namibia*. Gebrüder Borntraeger, Berlin and Stuttgart
- Toé W, Vanderhaege O, André-Mayer A-S, Feybesse J-L, Milési JP (2013) From migmatites to granites in the Pan-African Damara orogenic belt, Namibia. *J Afr Earth Sci* 85:62–74
- Trumbull RB, Vietor T, Hahne K, Wackerle R, Ledru P (2004) Aeromagnetic mapping and reconnaissance geochemistry of the Early Cretaceous Henties Bay-Outjo dike swarm, Etendeka Igneous Province, Namibia. *J Afr Earth Sci* 40:17–29
- Trumbull RB, Reid DL, de Beer C, van Acken D, Romer RL (2007) Magmatism and continental break up at the west margin of southern Africa: a geochemical comparison of dolerite dikes from north-western Namibia and the Western Cape. *S Afr J Geol* 110:477–502
- Viola G, Andreoli M, Ben-Avraham Z, Stengel I, Reshef M (2005) Offshore mud volcanoes and onland faulting in southwestern Africa: neotectonic implications and constraints on the regional stress field. *Earth Plan Sci Lett* 231:147–160
- Wanke H (2005) The Namibian Eiseb Graben as an extension of the East African Rift: evidence from Landsat TM 5 imagery. *S Afr J Geol* 108:541–546
- White S, Stollhofen H, Stannistreet IG, Lorenz V (2009) Pleistocene to Recent rejuvenation of the Hebron Fault, SW Namibia. *Geol Soc London Special Pub* 316:293–317