2 Flood Basalt Landscapes

Fig. 2.1 Waterfalls plunging ~200 m over a large amphitheatrical cliff, carved through several flows of Deccan basalt. Rajmachi area near Khandala, Western Ghats, India. Such amphitheatrical valleys abound in this region, which is very dry and hot in summer but very wet, lush green and cool in the monsoon. There is an additional 100 m or so of height traversed by smaller cascades above the cliff Photo © *Chandrahas Halai*

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Chapter Overview

Flood basalts create beautiful and impressive landscapes, whether these landscapes be humid tropical and thickly forested, frozen and snow-covered, hot and arid, or any other. The larger-scale elements of flood basalt landscapes are plateaus and escarpments, canyons and gorges, mesas and buttes, formed on the typically horizontal lava stacks. Sigurdsson (1999, p. 113) ascribes the term "Trap" (referring to their step-like topography, and derived from an Old Norse word *trappa*, a step in a stair), to the Swedish scientist and philosopher Emanuel Swedenborg (1688–1772). Flood basalt landscapes covered in this chapter are necessarily all continental, with the sole exception of Iceland. An emergent oceanic plateau, Iceland is well known for its striking scenery: vast empty plains, broken by high, dark mountains capped by glaciers, whose meltwaters produce thunderous rivers and magnificent waterfalls during summertime. Indeed, flood basalts of the world are home to waterfalls ranging in size from small cascades to those bigger than the Niagara.

Despite their common features, flood basalts of the world show a considerable diversity in landscapes owing to climate conditions. Compare the modern landscapes of the Paraná and the West Greenland flood basalts and the Saudi Arabian *harrats* (volcanic fields). Or compare the modern landscapes on large dolerite sills of the Karoo, Ferrar and Tasmania, formed together in a single Jurassic magmatic burst on Gondwanaland (Ivanov et al. 2017) and now separated by many thousands of kilometers due to continental drift. Even individual flood basalt provinces such as the Deccan show much regional and seasonal variation in climate, rainfall and vegetation cover, and the resultant landscape. The Western Ghats of India receive large amounts of rainfall from the Arabian Sea, are densely vegetated, and are in fact one of the major biodiversity hotspots of the world. In contrast, a large region of the Deccan plateau to the east of the Ghats escarpment, due to the rain shadow effect, is semi-arid to arid. (It is for the same rainshadow effect that a large part of the Columbia River flood basalt province in the Pacific Northwest USA, east of the Cascades Range, is a desert.) There are interesting geomorphological puzzles which remain not only unsolved but also untouched, such as the magnificent Ajanta gorge in the central Deccan Traps, illustrated in this chapter. In an arid region where modern summer temperatures typically reach 47 °C, when were the large incised meanders of the gorge carved, and under what favourable interplay of climate and tectonics?

When you are a geologist and love your work, even a family holiday is a geological field trip and an opportunity for education, just as a geological field trip is equally a pleasure trip. Take the world tour with this book, and return impressed and enriched.

Fig. 2.2 Typical landscape in the high areas in central-western Disko, West Greenland. A thick, monotonous-looking succession of basalt lava flows of the Maligât Formation, dipping very gently to the west (to the right) is seen. The snow accumulates preferentially on the ledges formed by the easier-eroded top rubble of the flows. The mountain wall in the foreground is situated at 1000–1470 m a.s.l.
Photo: *Asger Ken Pedersen, Geological Survey of Denmark and Greenland (GEUS)*

Fig. 2.3 Flood basalt lava flows of the Geikie Plateau Formation of the Blosseville Group. Eastern Gåseland close to the Inland Ice, inner Scoresby Sund region, central East Greenland (Larsen et al. 1989). Footprints in the snow provide a nice human touch and a feel for the experience of field work in this beautiful but harsh terrain
Photo: *W. Stuart Watt, Geological Survey of Denmark and Greenland (GEUS)*

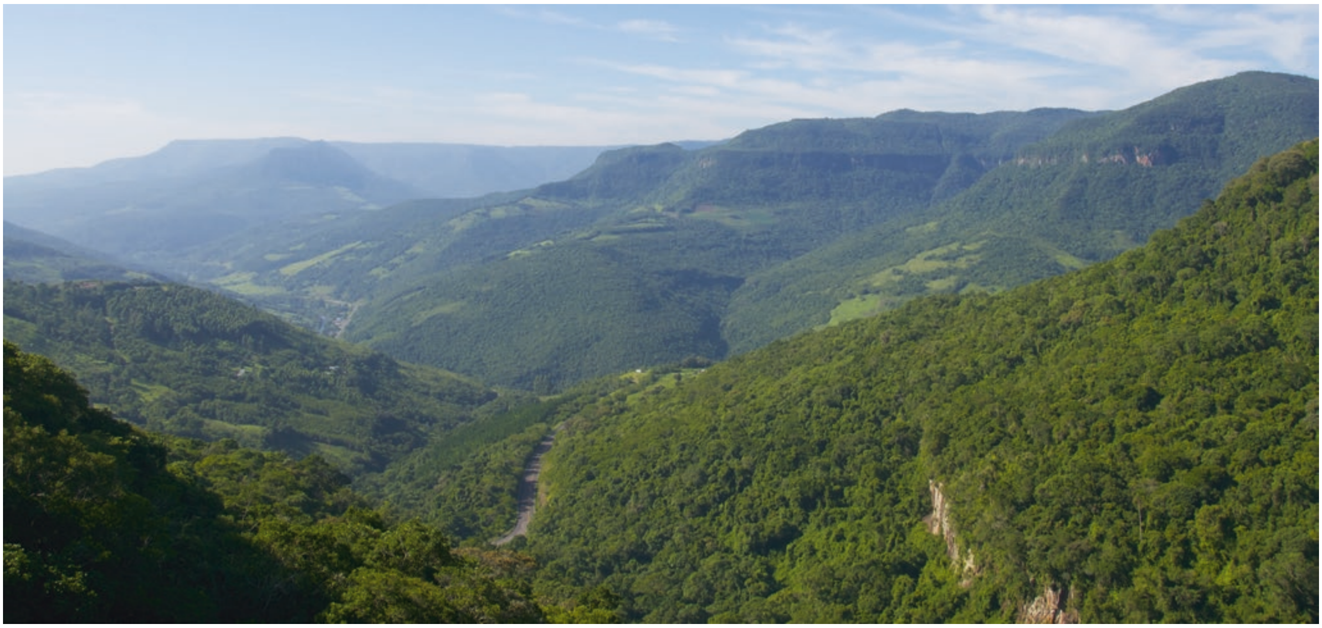

Fig. 2.4 Panorama of basaltic plateaus of the Paraná CFB province, Brazil. The road and the houses in the valley below provide an approximate scale
Photo © *Carla Barreto*

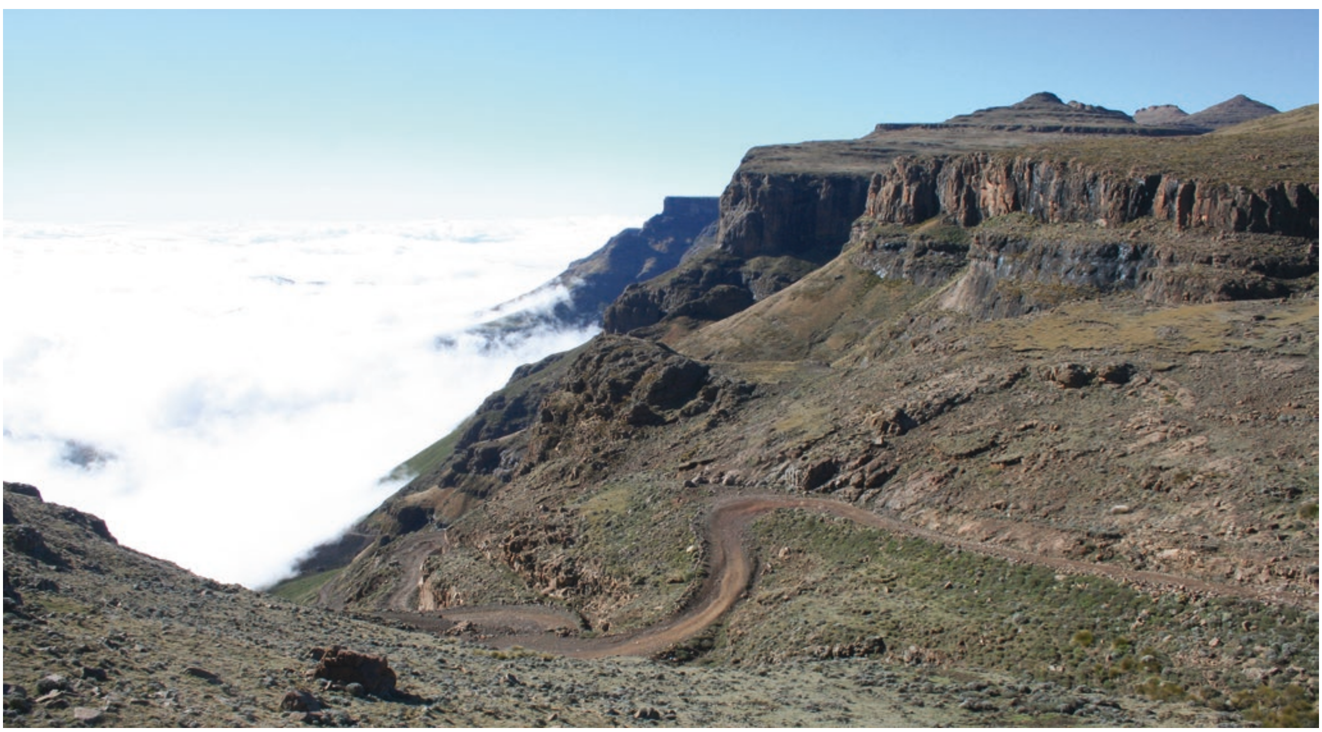

Fig. 2.5 View of the upper part of the 1400 m thick Karoo flood basalt sequence of the Drakensberg Group in the Sani Pass, Lesotho (S29°35′, E29°17′). The winding road provides an approximate scale
Photo © *Adam Bumby*

Fig. 2.6 Aerial view of the Ethiopian Traps (30 Ma) between Addis Ababa and Lalibela, Ethiopia. The Traps are 1500 m thick
Photo © *Hervé Bertrand*

Fig. 2.7 The 1500 km long Western Ghats escarpment in India is cut through the Deccan flood basalts in its northern half. The road from Poladpur town on the Konkan Plain, nearly at sea level, winds through the many spurs that this escarpment sends down to the plain, and through ~1350 m of flood basalts capped by extensive ferricrete (laterite), to reach the hill town of Mahabaleshwar (1436 m) on the top. More information: Ollier and Powar (1985), Gunnell and Radhakrishna (2001), Kale (2010)
Photo © *Hetu Sheth*

Fig. 2.8 The Mesa Range in north Victoria Land, Antarctica, has the greatest thickness (ca. 700 m) of Kirkpatrick Basalt flows. The capping, cliff-forming, black flow is up to about 80 m thick and is tachylitic. More information: Elliot and Fleming (2008)
Photo © *David H. Elliot*

Fig. 2.9 The highly eroded Drakensberg mountain range about 115 km west of Durban, South Africa. The mountains reach 2800 m above sea level, and rise 1500 m above the foreground
Photo © *Saumitra Misra & Kreesan Palan*

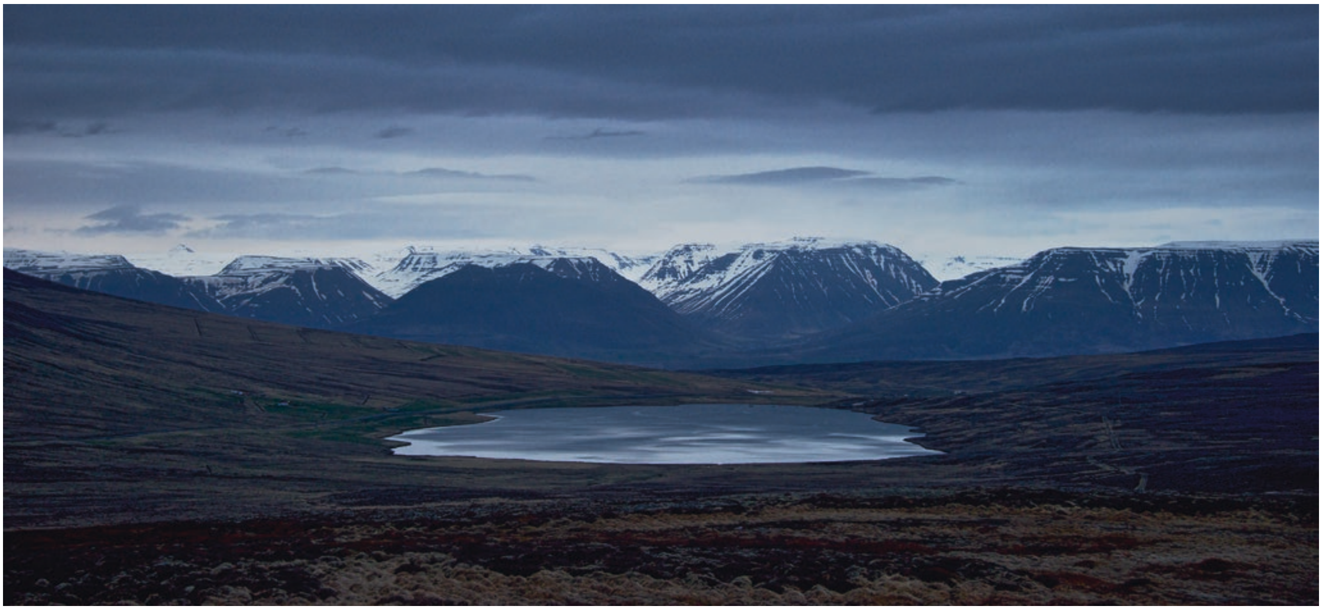

Fig. 2.10 Flood basalts in northern Iceland, forming sequences 500–600 m thick. The lake in the foreground is Vatnshlíðarvatn, next to the circum-Iceland ring road, Route 1, about 10 km from the town of Varmahlíð
Photo © *Dominique Weis*

Fig. 2.11 View from Portree harbour, Isle of Skye, of Ben Tianavaig (413 m), dominated by the Palaeogene Beinn Edra Formation, unconformably overlying Middle Jurassic strata. The Formation comprises basal hyaloclastites (not obvious in photograph), overlain by compound pāhoehoe and simple sheet lavas. More information: Emeleus and Bell (2005)
Photo © *Hetu Sheth*

Fig. 2.12 Scenic view of the Columbia River Gorge, cutting through the Columbia River Basalts, near Portland, Oregon, USA
Photo © *Loÿc Vanderkluysen*

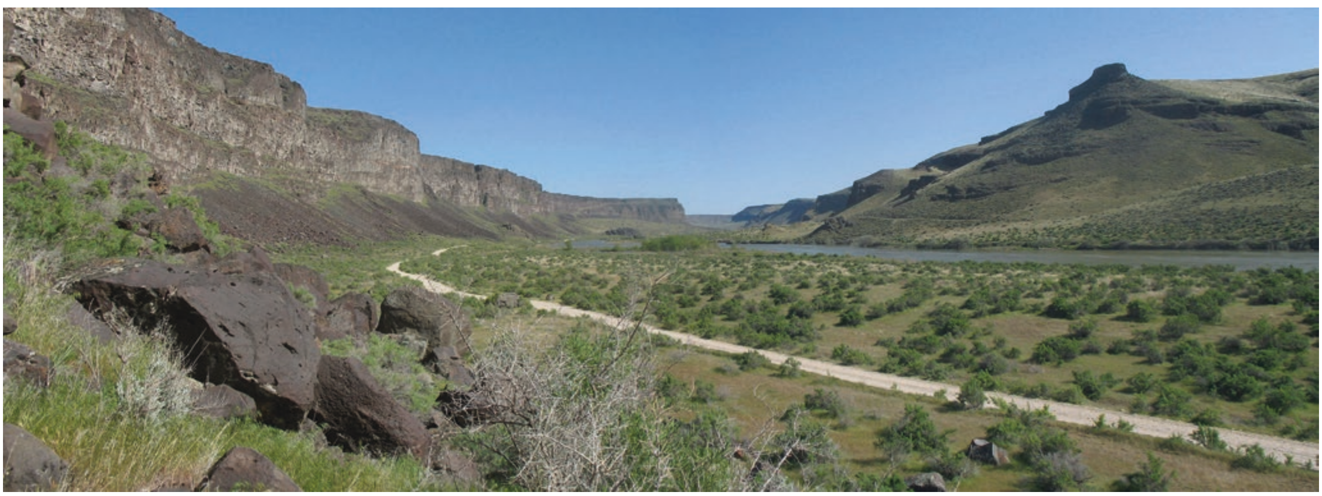

Fig. 2.13 The Snake River canyon (USA) exposes several volcanoes (tuff cones and tuff rings) that formed due to magma-water explosive interaction. However, the presence of lava deltas also indicates that a large portion of the lava flows entered a lacustrine basin. The walls of the canyon to the left expose multiple lava flows, while the walls to the right, capped by the buttes, expose hydromagmatic volcanoes
Photo © *Karoly Németh*

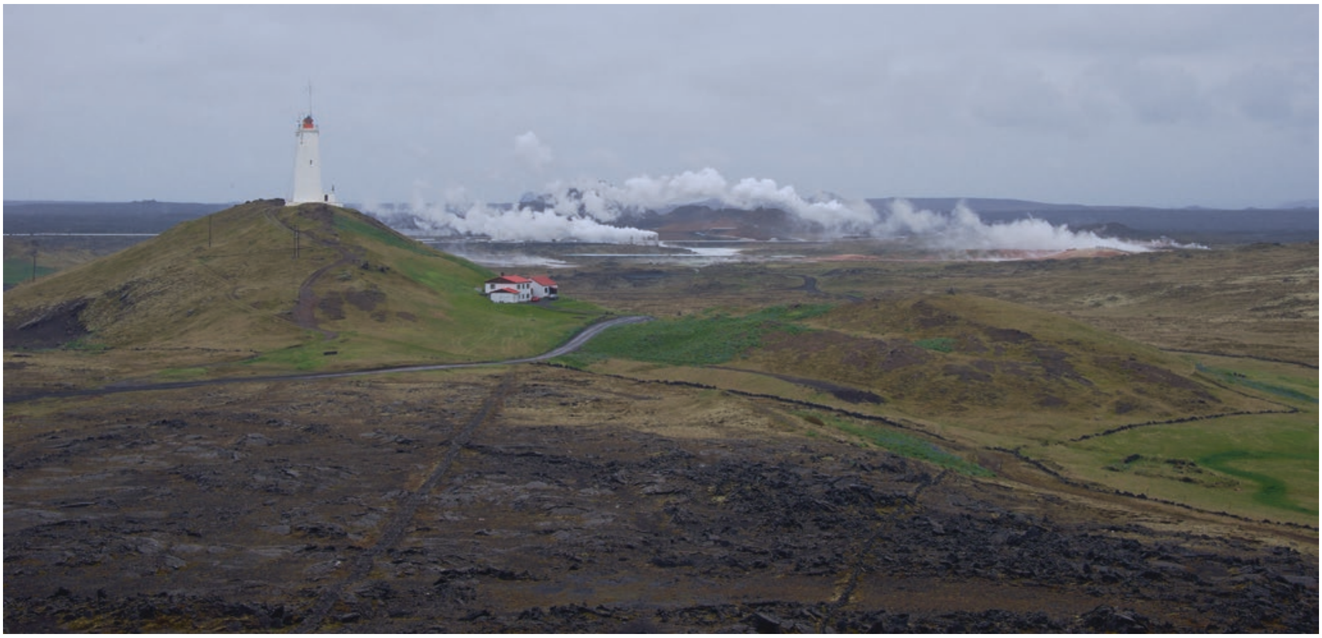

Fig. 2.14 The southwestern tip of the Reykjanes Peninsula (Smokey Point), Iceland, with Holocene lava flows (dark, foreground). Also seen are the Reykjanes lighthouse (Reykjanesviti) and the Reykjanes geothermal field and power plant (Reykjanesvirkjun)
Photo © *Dominique Weis*

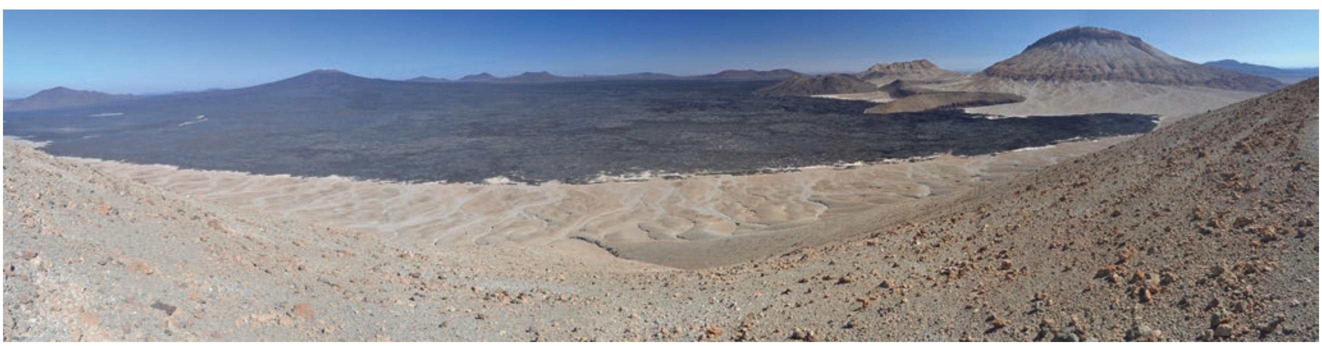

Fig. 2.15 One of the youngest lava flows in the Harrat Khaybar in western Saudi Arabia emitted from the Jebel Qidr volcano (the distant, dark, symmetrical volcano in the lava field). The lava field spreads across older silicic (rhyolitic, trachytic) lava domes, tuff rings and mafic scoria cones. The lava flow shows exquisite pāhoehoe lava surface textures in its proximal areas, but where ground slope angle suddenly increases, or behind breakouts of ponded zones, the lava flow texture becomes more like rubbly pāhoehoe. More information: Camp et al. (1991), Moufti and Németh (2016)
Photo © *Karoly Németh*

Fig. 2.16 Tholeiitic-transition flood basalts (vertical development 600 m, altitude above sea level ~1000 m) in the Baie Larose (Larose Bay), south of Mount Ross stratovolcano (1850 m), Kerguelen Islands, southern Indian Ocean
Photo © *Dominique Weis*

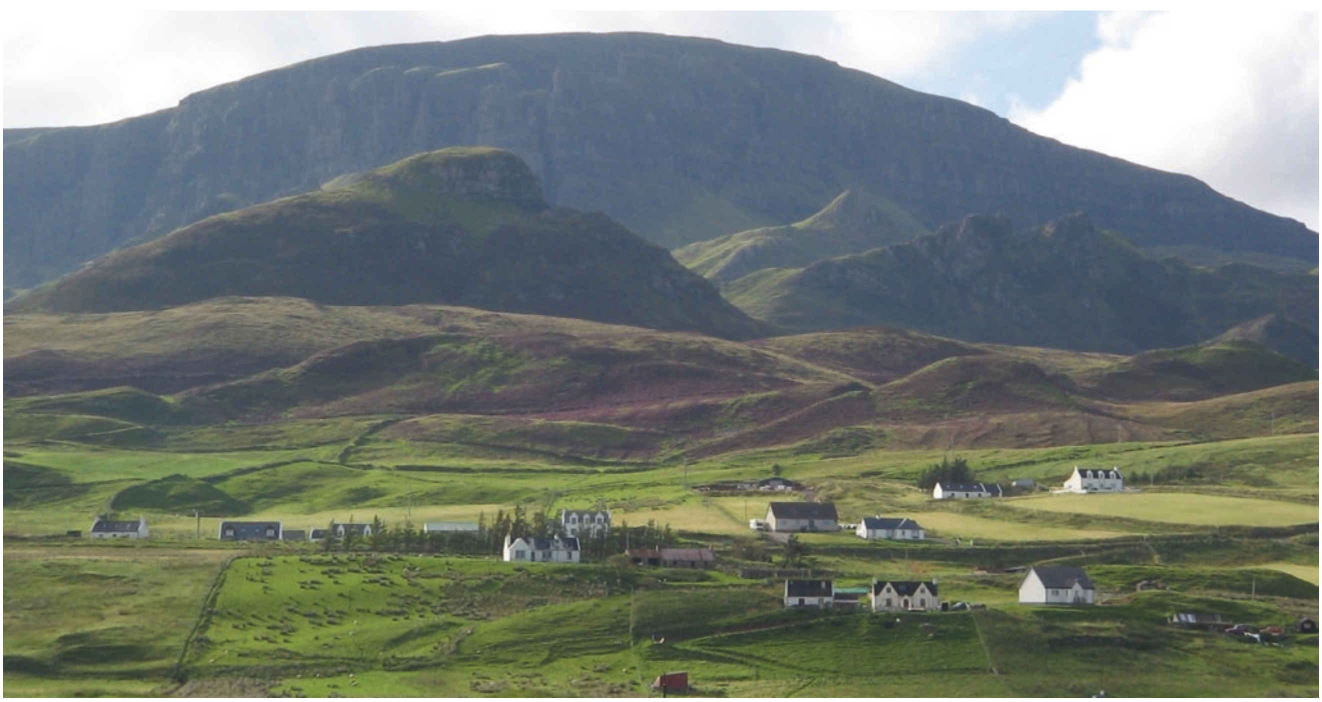

Fig. 2.17 Quiraing on the Trotternish peninsula, northern Skye, Scotland, with rounded topography on flood basalt. Since the Pleistocene glaciations, large basalt masses overlying Jurassic sedimentary rocks have detached from the scarp and slided towards the sea. Some movements continue today. More information: Emeleus and Bell (2005)
Photo © *Hetu Sheth*

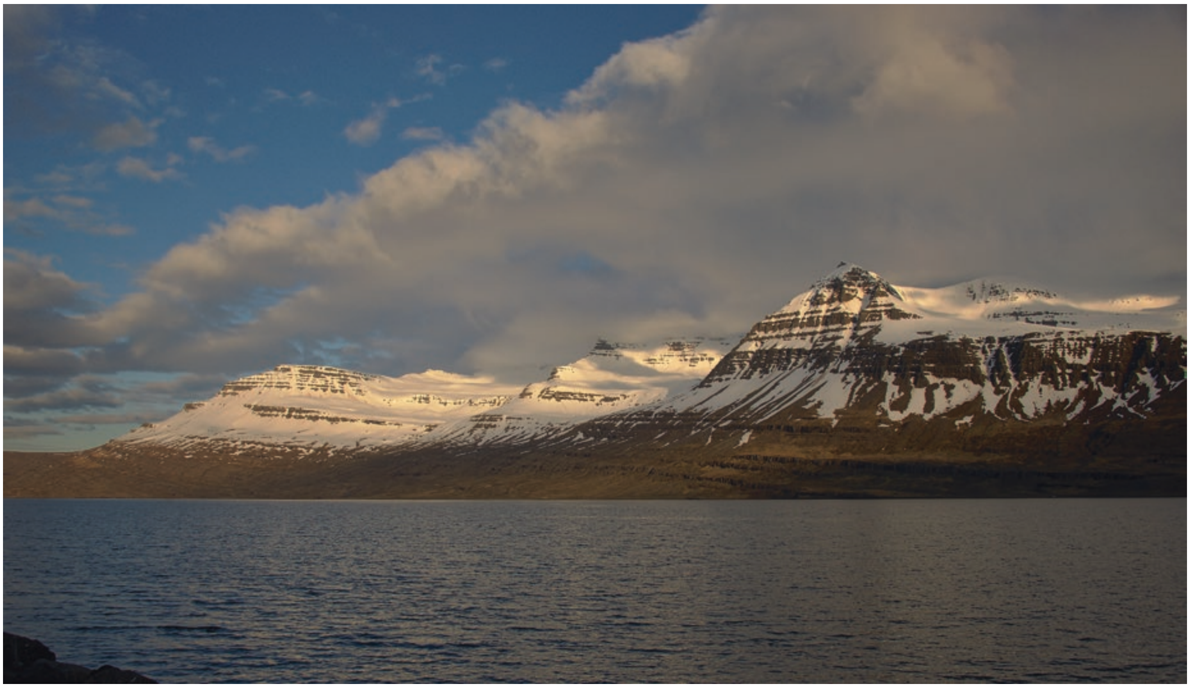

Fig. 2.18 Reyðarfjörður in eastern Iceland, fjord carved by Ice Age glaciers into Neogene flood basalts. The gently-dipping basalts are ~1000 m thick. More information: Walker (1959)
Photo © *Dominique Weis*

Fig. 2.19 Extensive flood basalt flows, mainly of the Geikie Plateau Formation. In the background is the Watkins Bjerge escarpment crowned by the Gunnbjørn Fjeld massif, including Greenland's highest mountain at 3707 m altitude. The basalts were uplifted by the Kangerlussuaq dome (Brooks 2011). Southern Blosseville Kyst, East Greenland
Photo: *Margrethe Watt, Geological Survey of Denmark and Greenland (GEUS)*

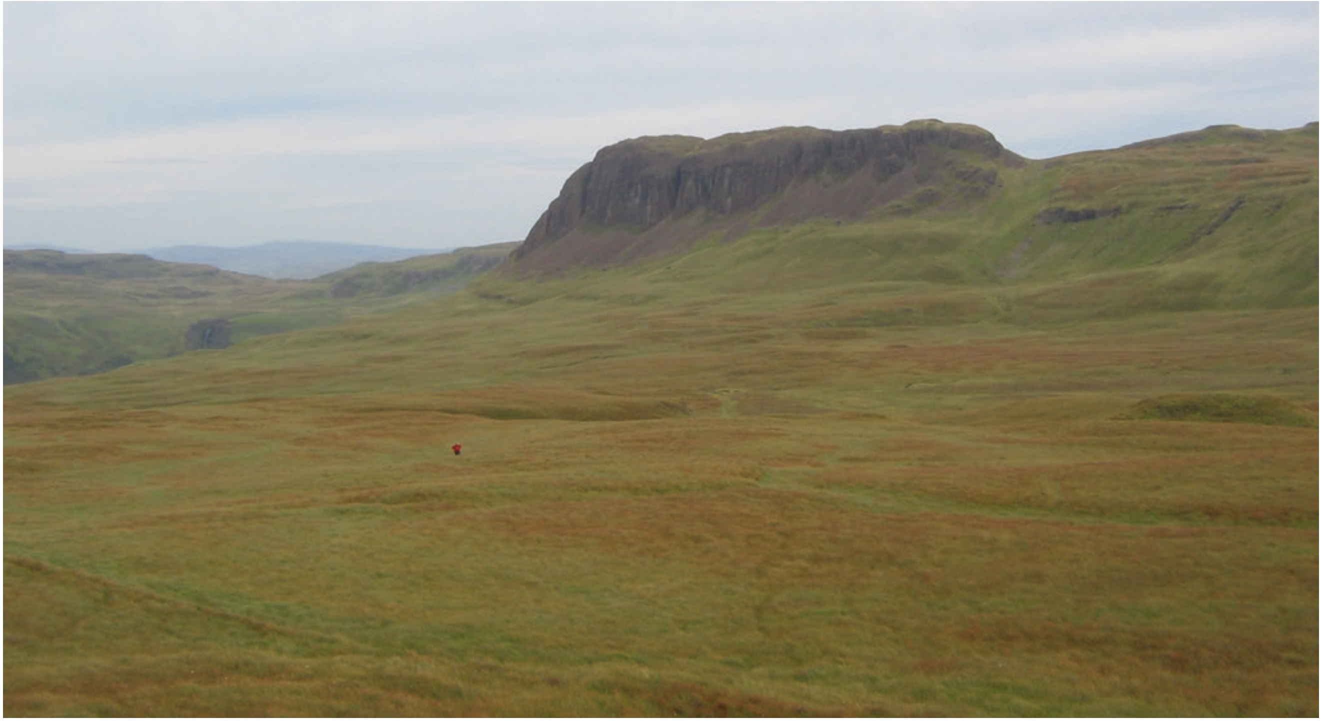

Fig. 2.20 Splendid isolation, especially for someone from a city of 20 million and 25,000 people per square kilometer. Grassy and water-logged summer landscape of the Isle of Skye between Preshal More (dark hill in the background), and Preshal Beg, from where the photograph was taken. Distance between the two is 2 km. A late-arriving member of the field party provides a scale
Photo © *Hetu Sheth*

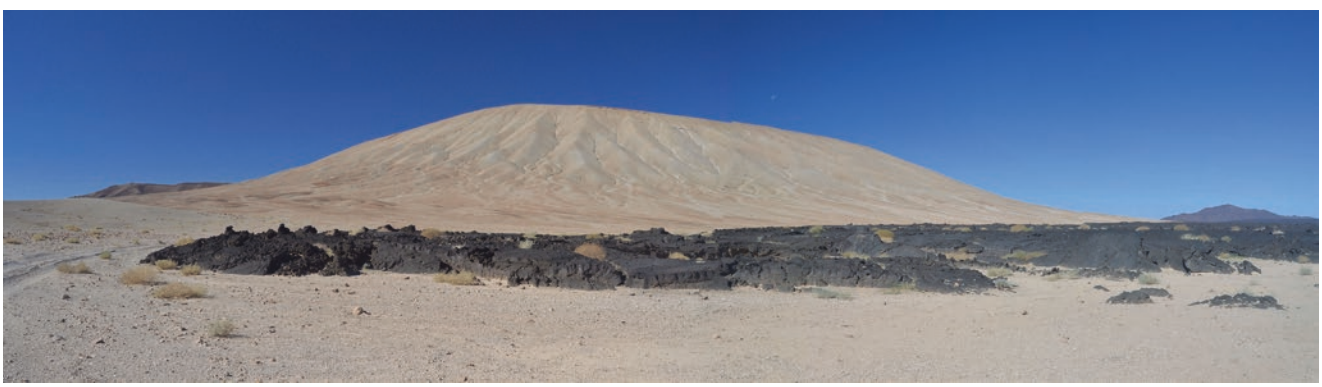

Fig. 2.21 Pāhoehoe lava flow terminus at the foot of Jebel Bayda silicic tuff ring in Harrat Khaybar. Note the uplifted pāhoehoe slabs in the terminus and their slightly rotated nature; flow behaviour was controlled by local topography rather than the location of the main lava flow axis. The silicic tuff ring rises about 100 m above the surroundings
Photo © *Karoly Németh*

Fig. 2.22 Road through the Columbia River flood basalts in the vicinity of Portland, Oregon, with the majestic pyramid of Mount Hood in the background. Mount Hood (3429 m above sea level), a stratovolcano of the Cascade arc, is about 500,000 years old, and thus much younger than the Miocene Columbia River flood basalts. However, the Cascade arc has existed since ~40 Ma, and several of the huge Columbia River flood basalt flows travelled hundreds of kilometers from their sources located inland to the Pacific Ocean, through a "trans-arc lowland" (e.g., Reidel 2006; Reidel and Hooper 1989; Reidel et al. 2013a)
Photo © *Hetu Sheth*

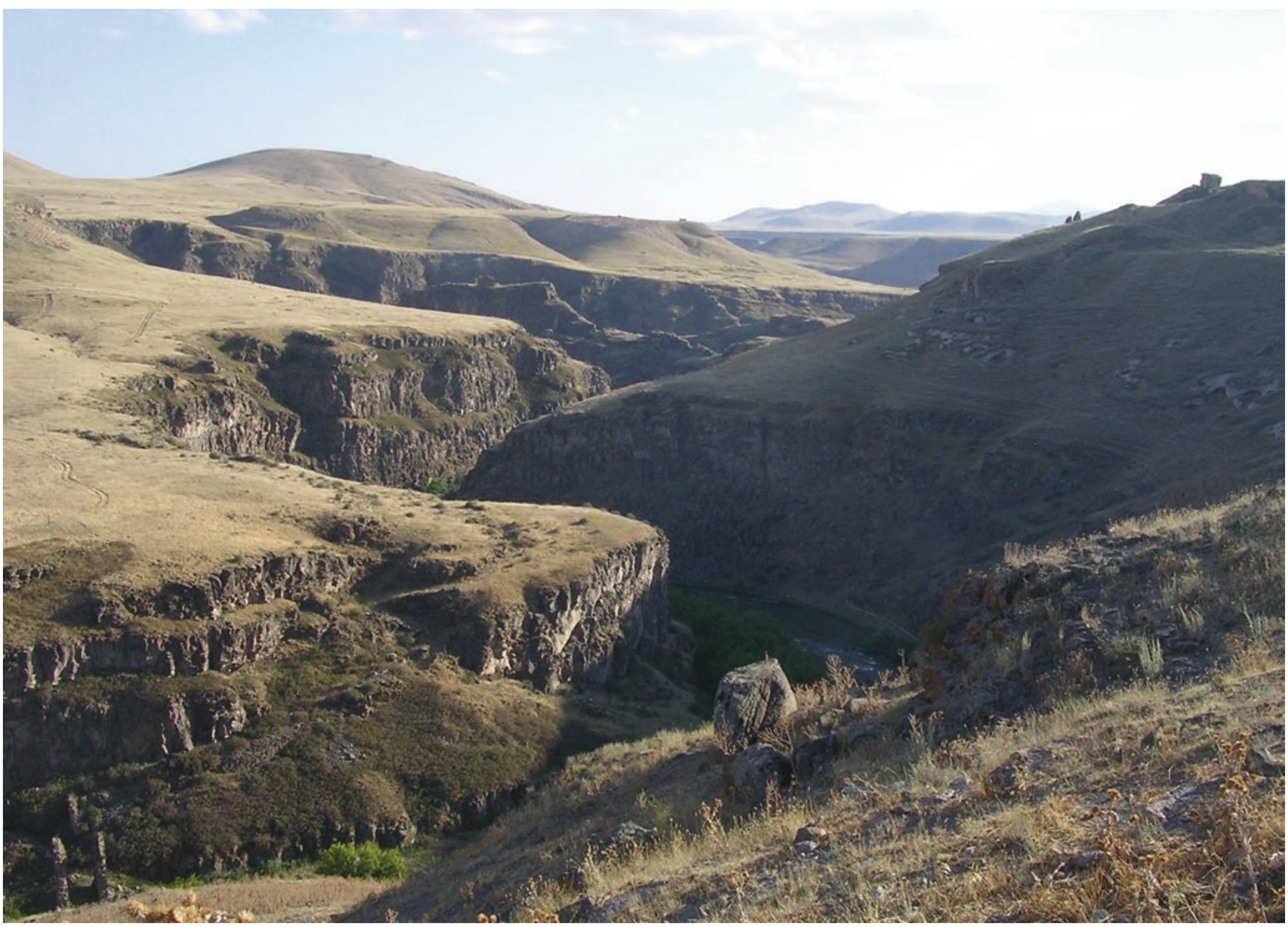

Fig. 2.23 Akhurian (Arpaçay) River gorge carved in the Pliocene basaltic sequence of the Kars plateau (eastern Turkey), near the ruins of the ancient Armenian city of Ani. The gorge here is ~80 m deep
Photo © *Vladimir A. Lebedev*

Fig. 2.24 Upalluk/Giesecke Monument, south coast of Nuussuaq, West Greenland. This 1580 m high landmark peak consists of subaerial basalt flows of the Maligât Formation. The height of the exposed part shown here is 500 m (photogrammetric interpretation in Pedersen et al. 1993) Photo: *Erik Vest Sørensen, Geological Survey of Denmark and Greenland (GEUS)*

Fig. 2.25 Spectacular lava butte with a cleft summit, near Bhamer, 10 km NNE of Sakri, in the arid central Deccan Traps. The butte, which rises 100 m from the foreground, is made up of small-scale compound pāhoehoe. Low ridge in the foreground is a 3.5–5 m wide and 5.2 km long dyke trending N85°. The dyke continues to the back of the butte. More information: Ray et al. (2007) Photo © *Hetu Sheth*

Fig. 2.26 Monsoon scenery of the Deccan flood basalts in the Western Ghats escarpment, a paradise for trekkers (Kapadia 2003). Here, in the Malshej Ghat area, a remarkable waterfall "goes up" rather than down, bathing the surrounding countryside in a fine spray, because of shearing by forceful winds as this is the very edge of the escarpment here, ~700 m above the Konkan Plain. Mountains in the background rise to >1500 m. Person photographing the scenery is Chandrahas Halai
Photo © *Hetu Sheth*

Fig. 2.27 Monsoon at its peak in the Western Ghats, India, with innumerable streams and cascades everywhere, as here on the road to Matheran tableland. The cliff in Deccan basalt is ~100 m high
Photo © *Eraiyoli Sankaran*

Fig. 2.28 The beautiful Ófærufoss in the Eldgjá chasm (A.D. 934–940), southern Iceland. The lower four-fifths of the cliffs are made up of hyaloclastites formed in subglacial eruptions during the last glacial period. The top one-fifth is fountain-fed lavas of the Eldgjá 934–940 eruption
Photo © *Gillian R. Foulger*

Fig. 2.29 Pleistocene basaltic lava pile cut by the mighty and thunderous Gullfoss waterfall, southern Iceland. The spray of fine water droplets present in the air produces rainbows on sunny days. Tourists on the trail on the left and at the edge of the waterfall provide a scale
Photo © *Hervé Bertrand*

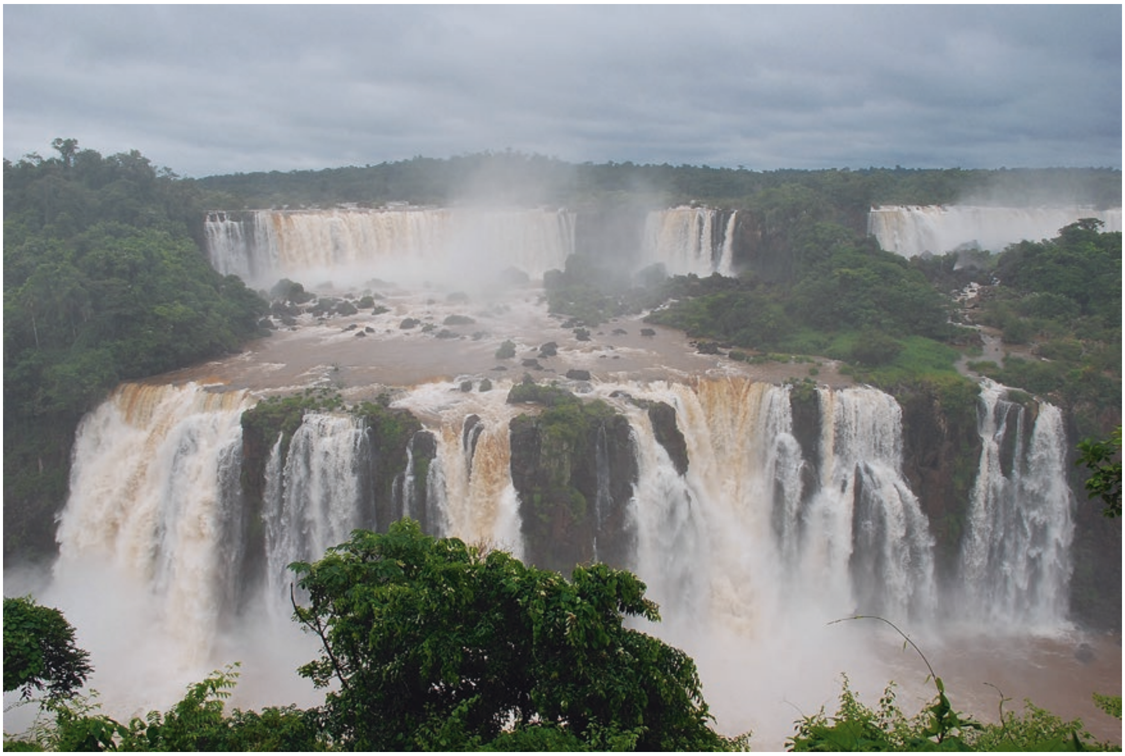

Fig. 2.30 The Iguazu Falls on the border of Brazil and Argentina drop an impressive 82 m over the Paraná Traps basalts; the Niagara Falls on the USA-Canada border are a third shorter
Photo © *Hervé Bertrand*

Fig. 2.31 When the taps run dry: the spectacular Ajanta gorge in the central Deccan Traps, on the walls of which the famous Ajanta Caves are situated. These 26 Buddhist caves, carved in basalt between the second century B.C. and the seventh century A.D., are an Archaeological Survey of India monument and a UNESCO World Heritage Site. A spectacular development of compound flows can be seen here as remarked by Walker (1971); see several photos in this volume. An interesting unanswered question is when and how this horseshoe-shaped gorge of the Waghora River, a huge incised meander, was carved, because the present-day climate of the region is arid, with summer temperatures typically reaching 47 °C. Note already dry riverbed at the beginning of summer in March 2016. Straight-line distance from the bottom left to the bottom right corners of the photo is 500 m; bridge across the river provides a sense of scale
Photo © *Hetu Sheth*

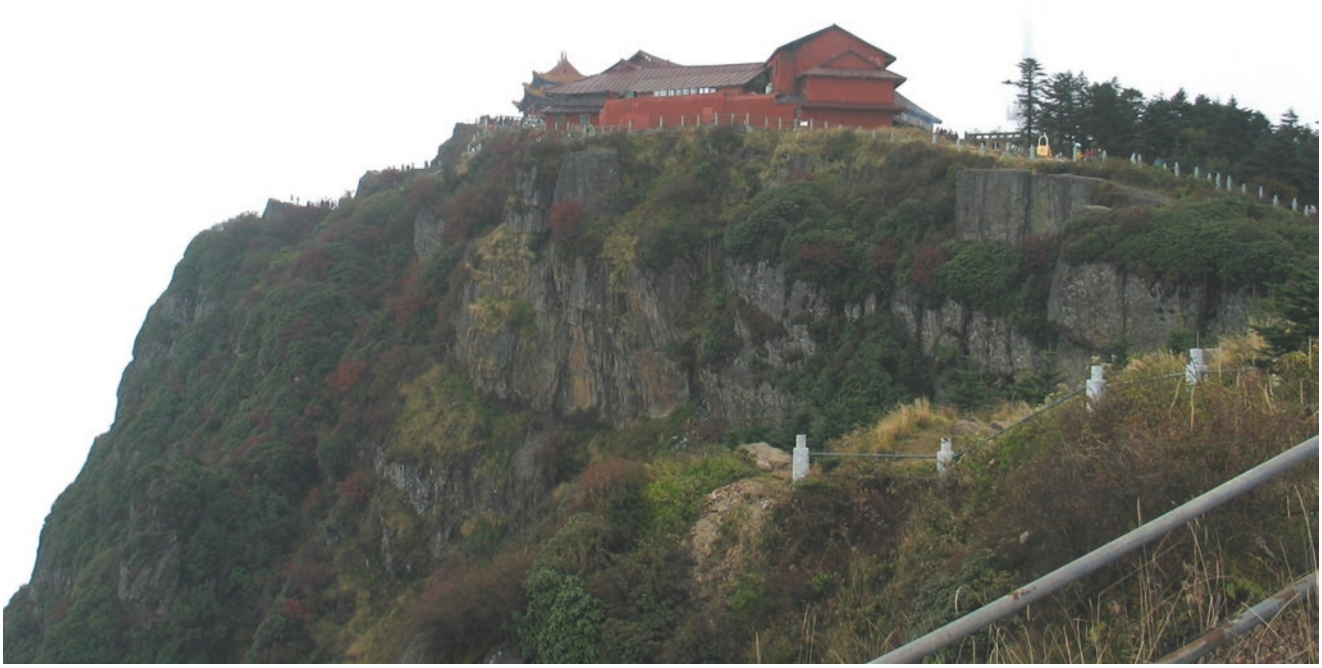

Fig. 2.32 Golden summit of Emeishan, 3099 m above sea level, from where the Emeishan flood basalt of Late Permian age (259 Ma) is named
Photo © *Yigang Xu*

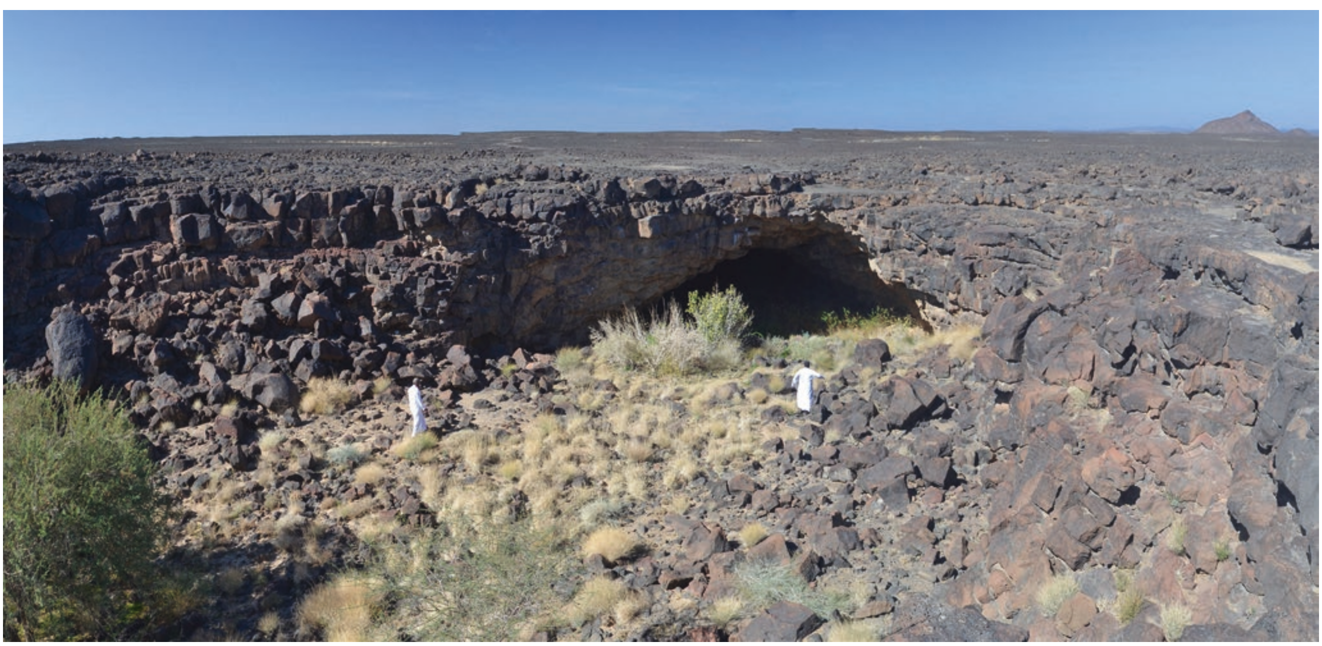

Fig. 2.33 A typical entry point of a large lava tube system in the Harrat Khaybar. Note the whaleback-style, gently sloping surface of the lava field and the few decimeter-thick flow units in the wall of the tube itself. The extreme arid climate and the high altitude (>1500 m above sea level) together strongly affect the lava surface textures, and finer features quickly vanish making the lava field surface fairly smooth in a short time
Photo © *Karoly Németh*

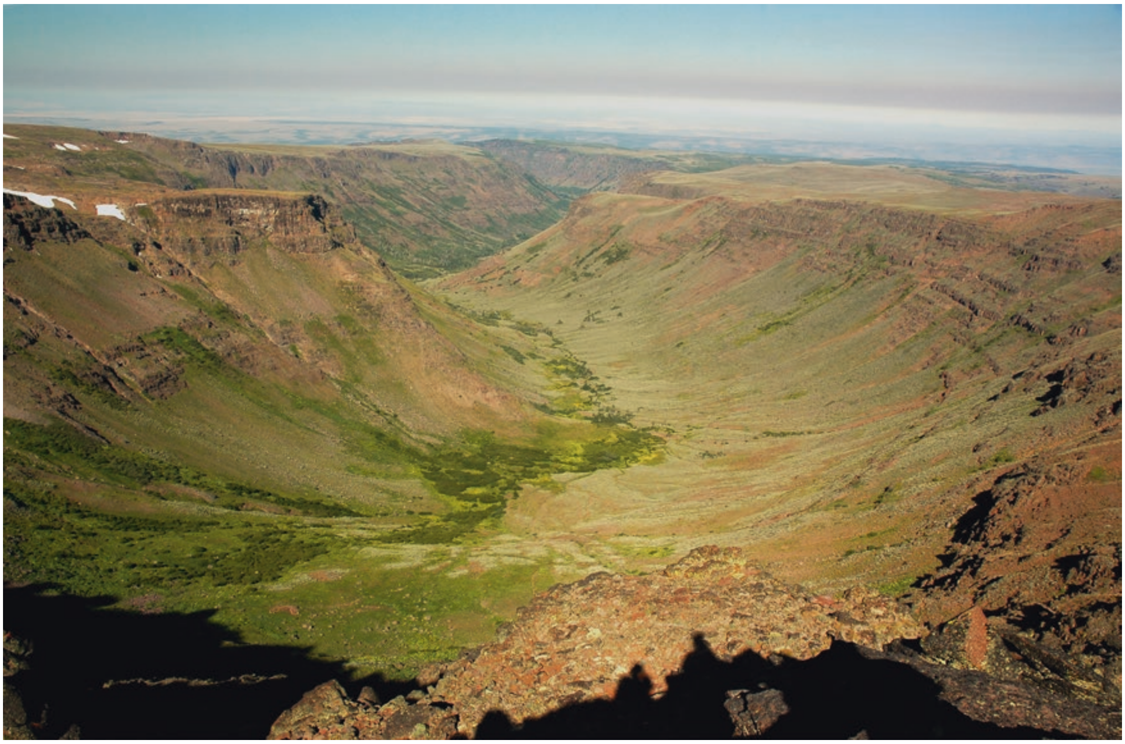

Fig. 2.34 The north-trending Kiger Gorge is a glaciated U-shaped valley near the summit of Steens Mountain, SE Oregon. The eastern wall (left) is juxtaposed against the headwall of the Steens escarpment, thus forming a knife-edge arête from glacial plucking to the east and west. About 500 m of Steens pāhoehoe flow lobes can be observed on both sides of the gorge
Photo © *Victor Camp*

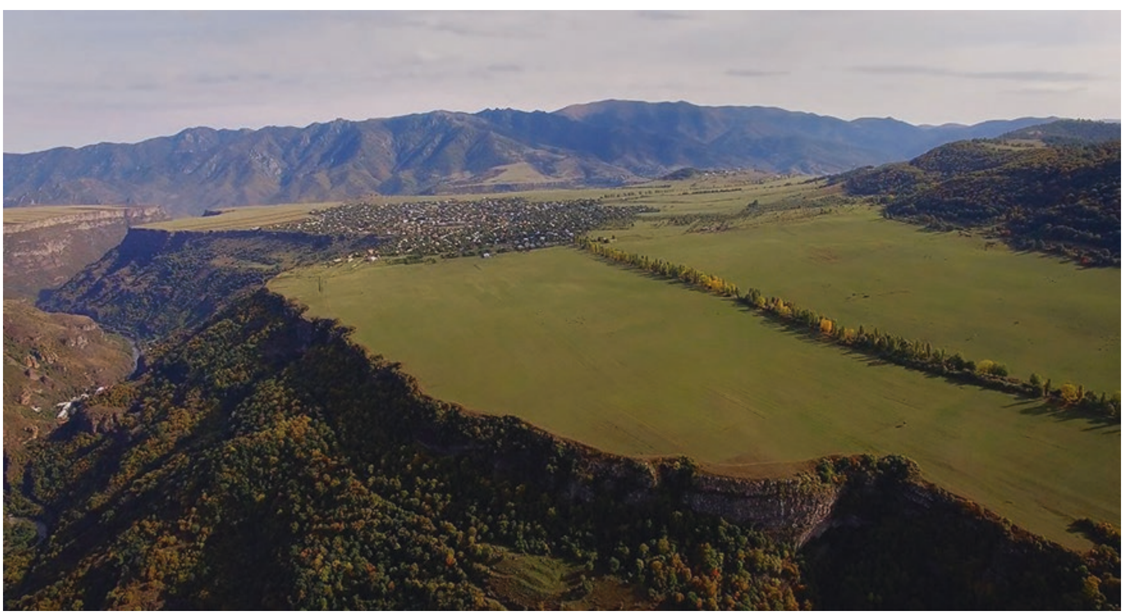

Fig. 2.35 Aerial photo of the flat-topped plateaus formed by the Late Pliocene-Early Pleistocene South Caucasus flood basalts (Sheth et al. 2015), here 300 m thick and dissected by the canyon of the Debed River in the Lori province, northern Armenia. The village of Dsekh is situated on the top of the plateau. The ridge in the background is formed of folded Jurassic to Lower Cretaceous volcanic and volcanosedimentary units of the Lesser Caucasus island arc
Photo © *Andranik Keshishyan*, description: *Khachatur Meliksetian*

Fig. 2.36 The Great Face, SW Staffa, NW Scotland, west of Fingal's Cave, viewed looking towards the NW. The main crag comprises the classic colonnade–entablature doublet of the Palaeogene Fingal's Cave Lava, overlying bedded pyroclastic–volcaniclastic deposits. The lava is approximately 50 m thick (although only ca. 30 m is preserved on The Great Face). The base of the lava is sharp and planar, and dips at a shallow angle towards the east. The cliff is ca. 42 m high. People on cliff top for scale
Photo © *Brian R. Bell*

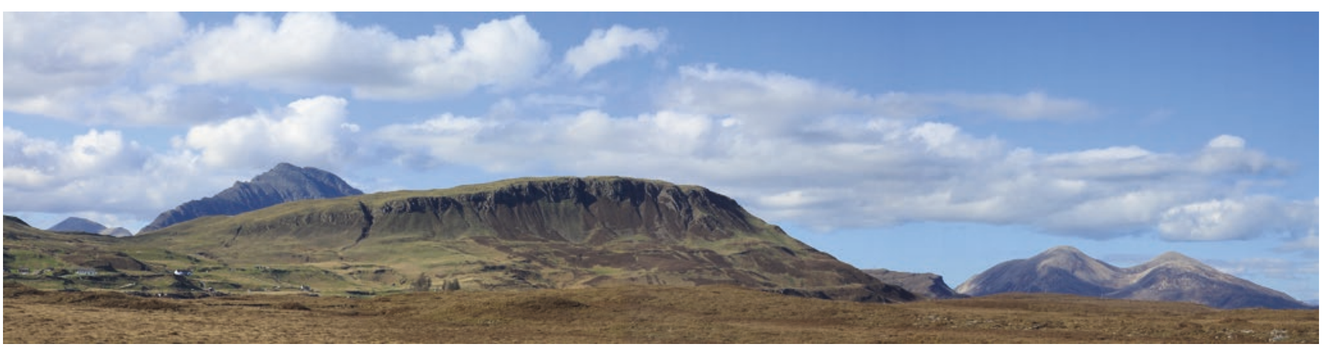

Fig. 2.37 Palaeogene lavas forming the summit of Ben Meabost (345 m) on the Strathaird Peninsula, Isle of Skye, NW Scotland. The underlying strata are part of the Middle Jurassic Great Estuarine Group. Note houses on the left for scale. In the left background is the gabbro-dominated summit of Bla Bheinn (Blaven, 926 m), the easternmost part of the Cuillin Intrusive Complex, whereas in the right background are the rounded granite summits of the Eastern Red Hills Intrusive Complex: Beinn Dearg Mhor (709 m), Beinn Dearg Bheag (582 m), and Beinn na Caillich (732 m)
Photo © *Brian R. Bell*

Fig. 2.38 An inclined Ferrar Dolerite sheet cross-cutting a concordant 200 m thick dolerite sill intruding Devonian sandstones (light-coloured rocks) at Finger Mountain, south Victoria Land, Antarctica. The concordant sill terminates on the left in a dyke-like body. More information: Elliot and Fleming (2004)
Photo © *David H. Elliot*

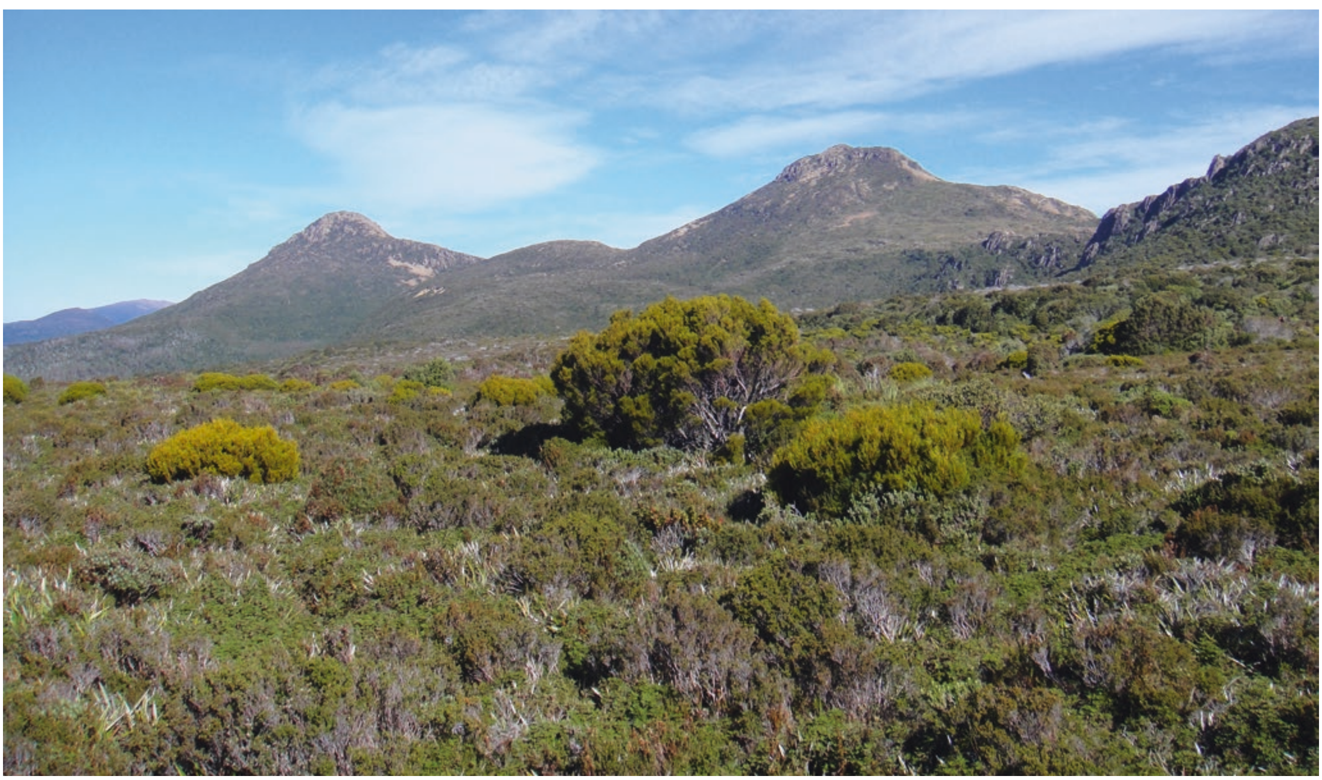

Fig. 2.39 Tasmanian Jurassic dolerite forming peaks in the Hartz Mountains National Park, Tasmanian Wilderness World Heritage Area. Mount Hartz (peak right of centre) is 1254 m high. View is towards the southwest
Photo © *Trevor J. Falloon*

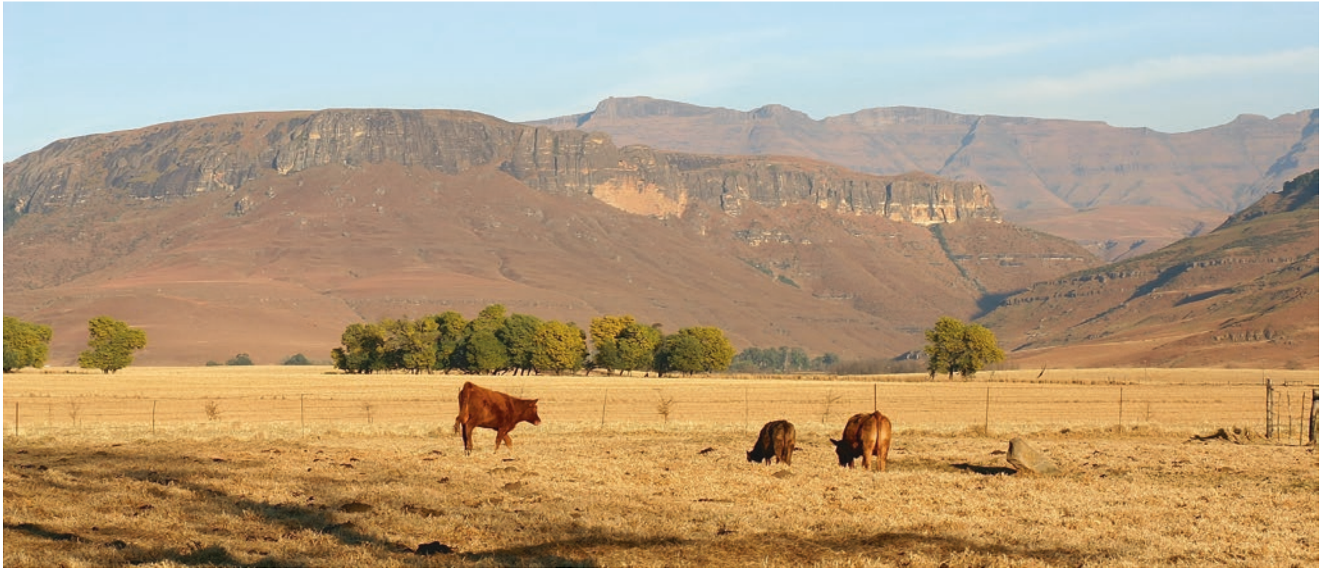

Fig. 2.40 Karoo doleritic sills intruding various levels of Permian-Triassic sedimentary rocks northwest of Maclear, South Africa. The sequence exposed in the foreground is 450 m thick
Photo © *Hervé Bertrand*

Fig. 2.41 Photo to the south from Friis Hills in the McMurdo Dry Valleys, Antarctica. The Basement Sill of the Ferrar large igneous province (LIP) is observed below the Peneplain Sill (each ~250 m thick). Prominent peaks in the background include Beacon Heights and Knobhead Mountain. Geologist is Giulia Airoldi
Photo © *James Muirhead*

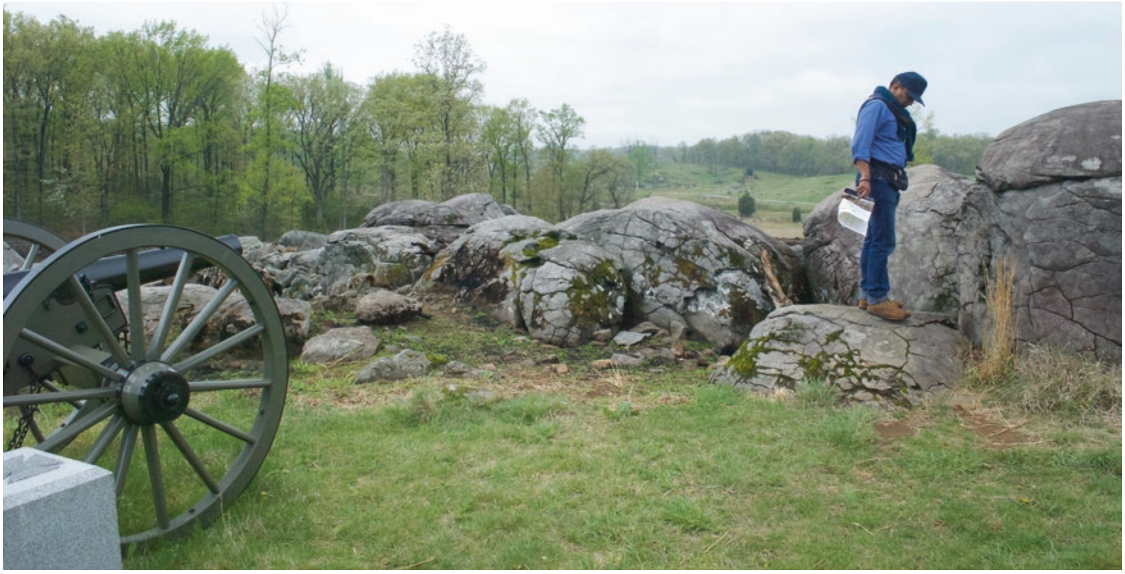

Fig. 2.42 Bouldery outcrop of the York Haven diabase sheet (part of the ~200 Ma Central Atlantic Magmatic Province, CAMP), at Little Round Top, Gettysburg National Military Park, Pennsylvania, USA. The sheet is 330–675 m thick (Mangan et al. 1993). Note irregular polygonal jointing in the rock. Geologist is Hetu Sheth
Photo © *Loÿc Vanderkluysen*

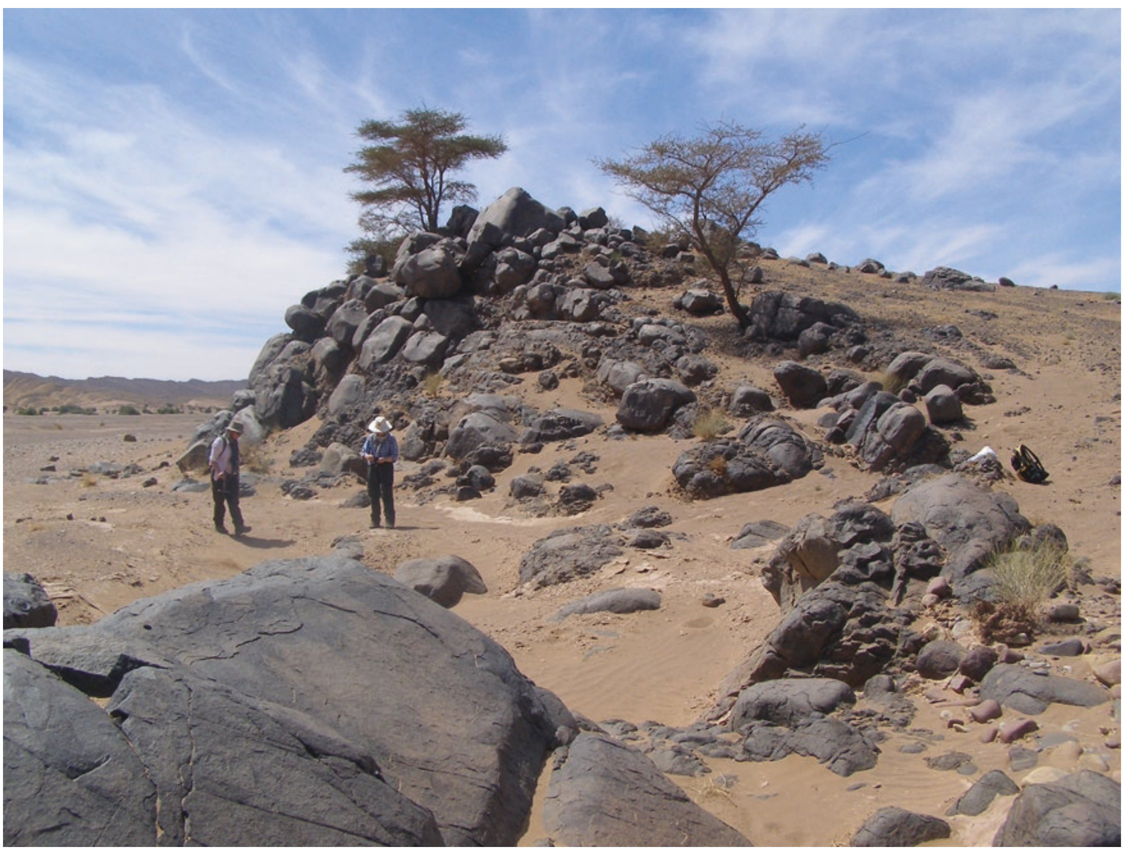

Fig. 2.43 Bouldery outcrop of a sill of the Draa Valley/Zemoul sill complexes intruding the Devonian sedimentary cover of the Anti-Atlas (Morocco), Central Atlantic Magmatic Province (CAMP). Photo was taken from the road between the towns of Foum Zguid and Tissinnt near Mrimnna at Oued Zguid. Geologists are Sofie Lindström and Gunver K. Pedersen
Photo © *Nasrrddine Youbi*

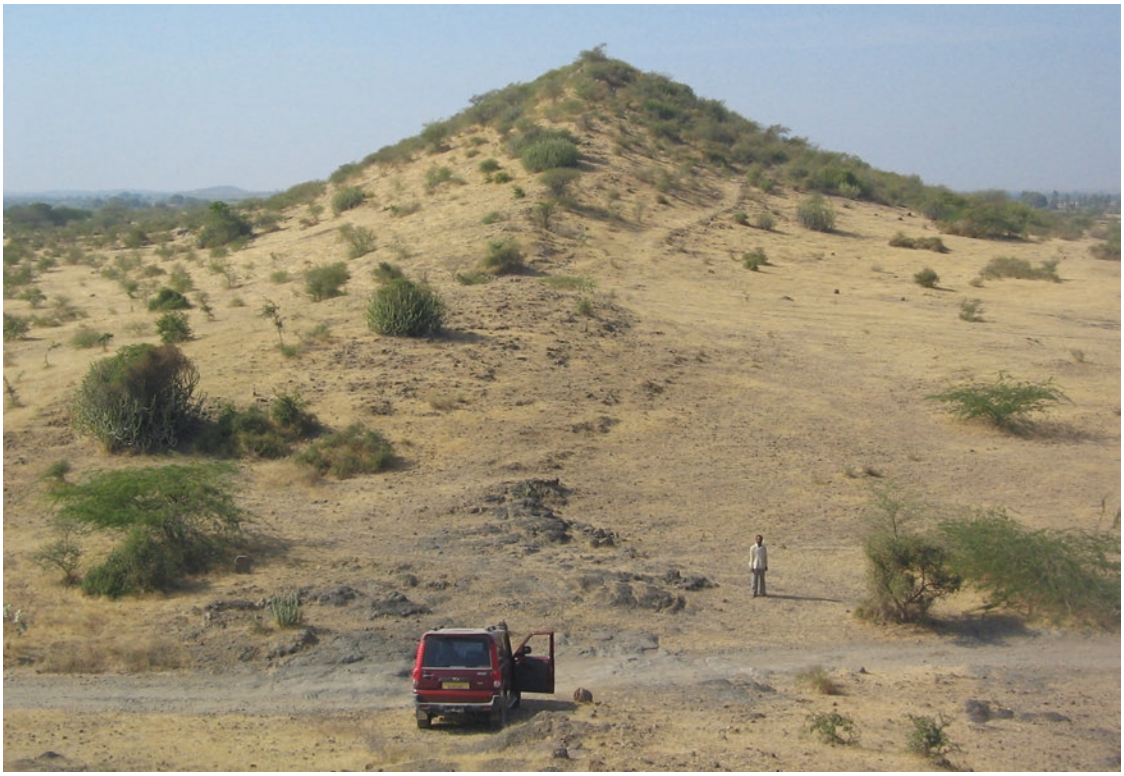

Fig. 2.44 Prominent olivine dolerite dyke ridge near Babra in central Saurashtra. Such long, linear ridges with the erosion-resistant dykes along their central axes are the typical expression of dykes here and elsewhere in the Deccan Traps. Outcrops next to person are of weathered compound pāhoehoe host. More information: Ray et al. (2007), Cucciniello et al. (2015)
Photo © *Hetu Sheth*

Fig. 2.45 Landscape near Foum Zguid town, Morocco, with the famous Great Foum Zguid gabbro dyke forming a ridge 40 m high. The dyke is 201 Ma in age, >200 km long and 100–150 m wide, and belongs to the Central Atlantic Magmatic Province (CAMP) (e.g., Youbi et al. 2003)
Photo © *Andrea Marzoli*

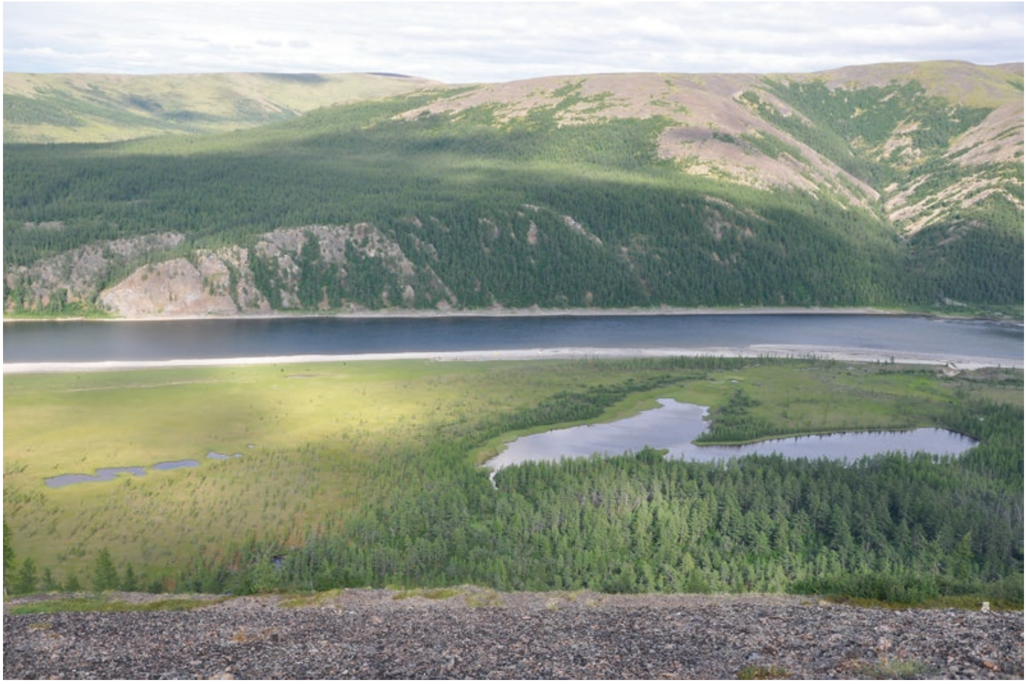

Fig. 2.46 The Guli massif in the Maymecha-Kotui alkaline ultramafic province, at the northeastern margin of the Siberian Traps. The Maymecha River cuts through the massif
Photo © *Benjamin Black*

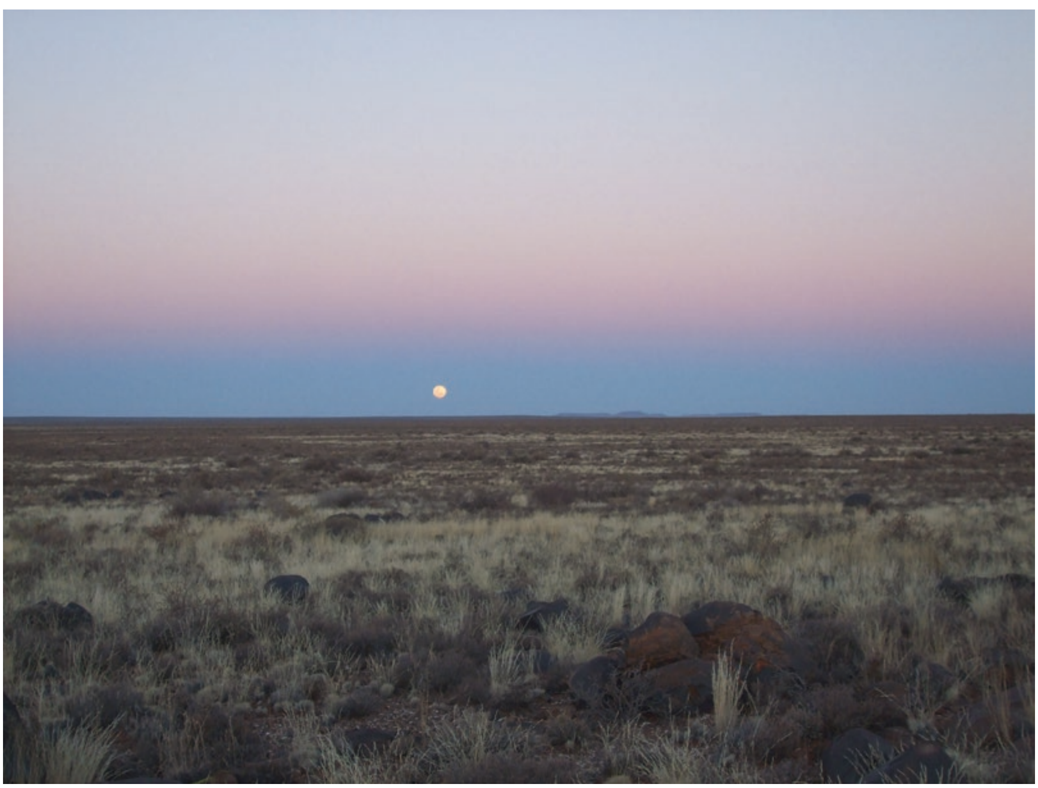

Fig. 2.47 Landscape of the Sodium Group of the Ventersdorp Supergroup between Prieska and Britstown, Northern Cape Province, South Africa. The Sodium Group is ~2739 ± 39 Ma (Altermann and Lenhardt 2012). The Ventersdorp Supergroup is a volcanosedimentary sequence, ca. 4 km thick on average but up to 8 km thick, predominantly composed of subaerial lavas and pyroclastics and sedimentary rocks (mainly lacustrine siliciclastic, but also carbonate). It covers an area of ca. 300,000 km^2 between Johannesburg and Marydale in South Africa and is best exposed in the southern and western Transvaal basin, in the Northern Cape Province and southeastern Botswana. With this extent and thickness, the Ventersdorp Supergroup represents the biggest large igneous province (LIP) on the Kaapvaal craton, with the volcanic rocks ranging from komatiites and basalts to andesites, trachytes and dacites (Altermann and Lenhardt 2012)
Photo © *Nils Lenhardt*

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