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Geomorphological Landscapes of Ethiopia

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Abstract

This introductory chapter reports about the main geographic and geomorphologic features of Ethiopia. The prevailing soil types are described and soil erosion data are reported and analyzed. A brief description of the natural vegetation is provided as well. The country's main geomorphological landscapes regions are identified as follows: (1) the northern highlands, including (i) the volcanic plug belt of Adwa, (ii) the central highlands and (iii) the southwestern highlands; (2) the Rift Valley, which consists of three main portions, namely the northern, central, and southern trunks and the Afar and Danakil depressions; (3) the southern plateau, which consists of a northern and southern sector and includes also the Ogaden tableland gently descending to Somalia and the Indian Ocean. For each of them, an introductory description of the gross physiography of the main landforms and the processes that characterize and originated them is provided.

Keywords

Ethiopia • Geomorphology • Landforms • Landscapes

1.1 Introduction

Ethiopia is characterized by a wide variety of landscapes and landforms. They were generated by a complex of tectonic, erosive, and depositional processes acting on rocks with different characteristics. The geological evolution of Ethiopia, with alternating phases of orogenesis, peneplanation, crustal updoming, faulting, emplacement of huge amounts of lava, and deep fluvial dissection has imprinted the geomorphological landscapes of the country with specific characteristics, in places unique on Earth. This introductory section is a short summary of the main geographical and landscape regions, with an outline of the most distinctive landforms and associated processes that characterize them.

1.2 Geography

Ethiopia has a surface area of about 1,127,000 km^2, that is almost twice the size of France. It takes up a large portion of the inner Horn of Africa since it has no border on the Red Sea and the Indian Ocean. The Ethiopian landmass consists of a large, high elevated plateau bisected by the Rift Valley into the northwestern and the southeastern highlands, each with associated lowlands The contrast in relief is remarkable as land elevation ranges between −155 m of Asal Lake in the Afar depression (the lowest point in Africa) to the peak of Mt. Ras Dejen at 4,620 m a.s.l. in the Simen Mountains (Fig. 1.1). The plateau stands between 1,500 and 3,000 m a.s.l. and it is strewn with a number of volcanoes making up high mountain ranges, the highest of which are the Simen in the north and the Bale mountains in the south (Fig. 1.1). The northwestern highlands are considerably more extensive and rugged and are divided into northern, central (centered on the Blue Nile River catchment downstream of Tana lake), and southern sections. The southwestern portion of the plateau (known also as Somali Plateau) is also rugged, but its elevation is

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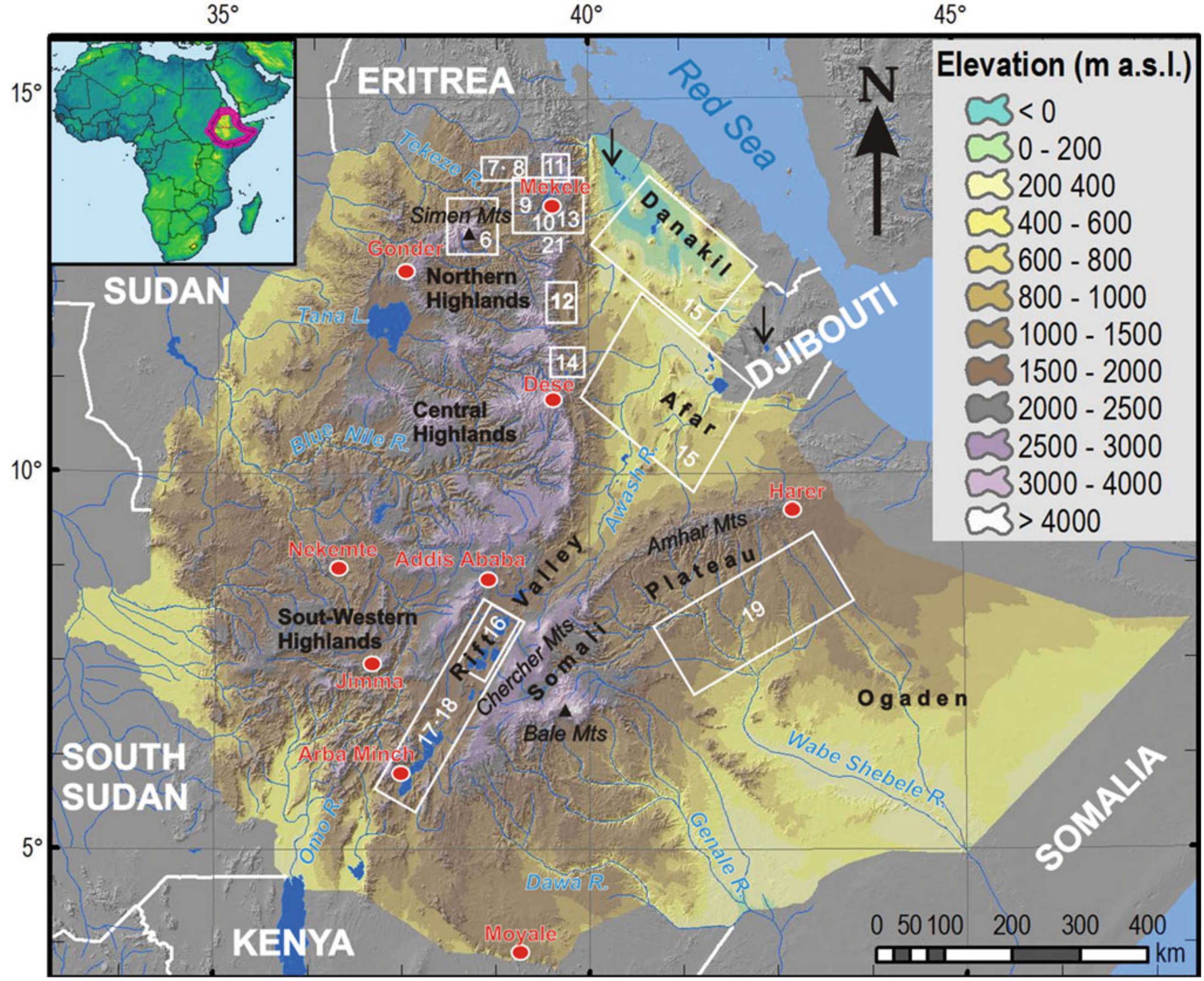

Fig. 1.1 Main geomorphological regions of Ethiopia. *Black triangles* stand for mountain peaks and *downward arrows* indicate lowest points below sea level. The study areas are marked by *white rectangles* and the numbers refer to the specific chapter of this volume

slightly lower (highest peak Mt. Tullu Dimtu, 4,383 m a.s.l.) than in the northern highlands and it can be subdivided into a northern section with the Ahmar and Garamullata mountains, a central section with the Chercher mountains, the southern part with the Bale and Haranna-Mandebo mountains and the Ogaden. Both the northwestern and the southeastern highlands are dissected by deep river valleys, in places as much as 1,500 m deep (e.g., the Blue Nile gorge—Ayalew and Yamagishi 2004), and slope gently toward the Sudan lowlands and the Ogaden and Somali lowlands, respectively, reaching elevations as low as 500 m a.s.l.

The Ethiopian segment of the Great Rift Valley is more than 900 km long between the borders with Kenya and Djibouti and its width varies between 50 and 100 km on average. This extensive fault system is bounded to the north by the Afar triangle and to the south it proceeds beyond the Kenya border and Turkana Lake. The highest points of the Rift floor are between Awasa and Shala lakes (around 1,770 m a.s.l.) and around the Dubeta col (1,670 m s.s.l.) (between Ziway Lake and Koka Reservoir), which forms the divide between the Awash River basin and the endhoreic drainage systems of the Main Ethiopian Rift. The Rift bottom slopes gently to its lowest point at Asal Lake at −155 m b.s.l. in Djibouti and to the 361 m a.s.l. at Turkana Lake in the south. The floor of the Rift Valley is not uniformly flat as scattered volcanoes or volcanic systems, rising for more than 1,000 m (e.g., Zikwala, 2,989, Boset, 2,447, Fantalé, 2,007 m a.s.l.) occur. Seven major lakes, all closed systems, of tectonic or volcano-tectonic origin (Ziway, Langano, Abijata, Shala, Awasa, Abaya—the largest one with a surface area of 1,162 km^2—and Chamo) are located in the main trunk of the Ethiopian Rift. Other lakes are found in the northernmost portion (Abe Lake, 350 km^2, fed by the Awash River) and in the Danakil depression (Afrera Lake, 70 km^2) (Wood and Talling 1988). Large lakes are also present in the northern and central highlands. Tana Lake is by far the largest in Ethiopia with its 3,600 km^2, whereas the other highland lakes such as Hayk (23 km^2) (Demlie et al. 2007) and Ashenge (20 km^2) are much smaller.

The most notable river system is the Blue Nile and its tributaries, the largest of which is the Tekeze/Atbara, joining the Blue Nile in the Sudan territory. Because of the general westward slope of the western highlands, many large rivers are tributaries of the Blue Nile system, which drains an extensive area of their northern and central part. The Blue Nile, the Tekeze, and the Baro account for about half of the country's water outflow. Other important rivers originate from the Somali Plateau (Genale/Juba and Wabe Shebele rivers) and outflow into the Indian Ocean. Several drainage basins of smaller rivers are closed systems and the largest among these rivers are the Awash and Omo.

1.2.1 Soils

Ethiopia presents a large variety of soil types. Berhanu et al. (2013) classified the land mass of Ethiopia into 60 soil types with an area coverage ranging from 1.4 to 208,882 km^2. Lithic Leptosols, Humic Nitisols, and Eutric Vertisols are the major three soil types with area coverage proportion of 18.5, 11.9, and 10.2 %, respectively. These prominent percentages are comparable with those reported by the FAO Soil Database (FAO 1998), though only 45 different soil types were identified by this study.

On the base of the harmonized soil database constructed by FAO (2009), Berhanu produced a textural classification of Ethiopian soils and their relative frequencies of area coverage, which reveals that loam and sandy loam soils are the most common soil textures.

Following the UNDP/FAO (1984) report on the geomorphology and soils of Ethiopia, a short description of the main soil characteristics of different physiographic regions can be outlined.

In western Ethiopia (Gamo Gofa, Ilubabor, Welega, and part of Gojam and Gonder), soils develop mainly on felsic and metamorphic Precambrian rocks and flood basalts. Since in this part of Ethiopia the highlands slope down to the lowlands, soils develop also on alluvial and colluvial deposits. In the highlands, the high rainfall (over 2,000 mm yr^{-1}) is the most important factor in producing very similar soils irrespective of the parent rocks. In western Illubabor, fluvial soils are found on the alluvial plain of the Baro River and its tributaries.

The northern highlands are underlain by Precambrian metamorphic rocks, Upper Paleozoic and Mesozoic sandstones, limestones, and the trap series volcanics. This area shows marked contrasts in topography, rainfall, and land use, hence soils are highly variable and many soil types are present (Nitosols, Vertisols, Andosols, Lithosols, etc.).

The northeastern escarpment of Ethiopia has resulted from strong tectonic activity that produced rugged morphology and significantly influenced soil characteristics. They are, in fact, affected by severe (natural and man induced) erosion processes and show extreme stoniness.

In central Ethiopia highlands, soils developed predominantly on trap basalts and subordinately, on pyroclastic rocks. Rainfall does not vary much spatially (see Chap. 3, this volume) and soils characteristics depend mainly on topography. In deeply incised river valleys, soils are thin and have a high stoniness degree due to very high erosion rates.

In the eastern highlands (Chercher and Ahmar mountains), parent materials consist of Mesozoic sandstones and limestones, flood basalts and, subordinately, of Precambrian basement rocks. In this area, these rocks are very mixed and, due to strong structural influence and intensive cultivation, soils are shallow and similar to those of the northeastern escarpment. To the west, where the structural influence is less marked and rainfall increases, soils show more vertic characteristics.

The northern portion of the Rift Valley includes semidesert areas with the exception of the Awash River valley fill. Parent materials of this area include Tertiary and Quaternary volcanic, alluvial, and colluvial deposits. The very recent age of these parent rocks and the dry weather condition (annual precipitation range between 300 and 500 mm) lead to soils that developed mainly on alluvial and colluvial materials. Eutric and Calcaric Fluvisols are common in the alluvial plain of the Awash River.

By contrast, the geology of the southern portion of the Rift Valley is more complex. Bedrock consists mainly of Tertiary pyroclastics and Quaternary basalts but the Rift floor includes also extensive lacustrine, colluvial, and fan deposits. Vertic and Mollic Andosols prevail in areas underlain by volcanic ash and pumices, whereas Lithosols are more common where Quaternary basalts outcrop.

In the Ogaden, sedimentary rocks prevail, namely limestones, sandstones, and evaporates. In this area, precipitation is scarce (commonly less than 400 mm yr^{-1}), evapotranspiration is high and uniform and topography is comparatively flat, hence it is the parent material to play the most relevant role in soil differentiation and typically Gypsic and Calcic Xerosols and Yermosols occur. In the eastern Ogaden, underlain by sandstones, Cambic Arenosols prevail.

Finally, south of the Bale Mountains, flat landforms dominate and parent rocks consist mainly of deeply weathered rhyolites on which deep Eutric Cambisols occur, whereas steeper slopes are underlain by Precambrian gneisses and granites, and here Lithic phases of the Eutric Cambisols prevail.

1.2.2 Soil Erosion

Soil erosion in Ethiopia varies widely due to the very different physiography, land use, and soil characteristics. Several studies have investigated the rates and causes of soil loss in Ethiopia, but most of quantitative data are derived from plot studies (e.g., Hurni 1985; Soil Conservation Research Project—SCRP—Grunder 1988; Herweg and Ludi 1999) or studies were focused on restricted areas (e.g., Tegene 2000; Nyssen et al. 2004). Bojo and Cassells (1994), however, argued that soil erosion data obtained from plot studies must be corrected including also the delivery ratio factor in order to assess realistic erosion rates, whereas large areas or regional studies are mainly based on soil loss models rather than field measurements.

Soil loss measured in a few sites of the SCRP (Grunder 1988) is reported in Table 1.1. These data show a large range of values given the different physiography, precipitation, soil characteristics, and land use of the regions considered. The plot studies by the SCRP (Grunder 1988) showed also that the traditional conservation practices are the least effective in combating soil erosion. Table 1.2, on the other hand, reports soil erosion data extrapolated for the whole country by different authors and the data range is again large. This is probably due to different reference soil loss values used by the authors.

Berhanu et al. (2013) calculated the erodibility factor (*K*) of different soil types. Unexpectedly, they found relatively low values as *K* ranges between 0.00 and 0.18. Similar results were obtained also by Nyssen et al. (2007) in Tigray and by Shiferaw (2012) in the Borena area of South Welo highlands. These conclusions indicate that in Ethiopia soil erodibility is not an explanation for the magnitude of actual land degradation as the combination of steep slopes, vegetation removal, and erosive rain seems to play a major role. Rainfall intensity of 100 mm in 24 h is calculated by Billi et al. (2015) to have an average return time of 25 year (range 6.3–68.6 years). Land degradation is a common feature of the Ethiopian landscape with severely eroded areas along the rift margins (Fig. 1.2) and in the northern highlands. Other common erosion processes are gullying (Fig. 1.3) and landsliding (Fig. 1.4).

Table 1.1 Soil loss in various parts of Ethiopia (Berehe 1996)

Region	Soil loss (t ha^{-1}yr^{-1})
Gojam	40.2–199.2
South Welo	36.5–53.8
North Shewa	152.4–214.8
Illubabor	18.0–135.3
Harerge	25.5–27.8
Sidamo	41.2–49.5

Table 1.2 Soil loss in Ethiopia

Author/s	Soil loss (t ha^{-1}yr^{-1})
Hurni (1988)	42
Wright and Adamseged (1986)	100
Sutcliffe (1993, cited in Kappel 1996)	40
Bojo and Cassells (1994, cited in Kappel 1996)	20
Stocking (1996)	165
Tamene and Vlek (2008)	14
Average	63

Soil erosion rates obtained from direct measurement of soil dislodgements from slopes is, however, about two orders of magnitude higher than the sediment yield data obtained from river sediment flux measurements. A few authors, in fact, report highly variable sediment yield values ranging from 4 to 3,784 t km^{-2}yr^{-1} (several sources, see Chap. 6 this volume). Nyssen et al. (2004) developed a simple power equation from literature data on 20 river sites in drainage area outside the less-erodible areas in southern Ethiopia as

$$Y_s = 2{,}595\,\mathrm{A}^{-0.29} \qquad (1.1)$$

in which 56 % of the variability of sediment yield (Y_s in t km^{-2}yr^{-1}) is explained by catchment area (A in km^2). This result is partially confirmed by field measurements of Billi (2004) on the Meki River, upstream of the homonymous town (only a few kilometers upstream of the river outlet into Ziway Lake), which gave a sediment yield of about 60 t km^{-2}yr^{-1}. By contrast, field measurements by Haregeweyn et al. (2008) on very small rivers in northern Ethiopia, ranging between 0.72 and 24 km^2 in catchment area, resulted in a much higher average sediment yield of 947 t km^{-2}yr^{-1} (range 446–1,817 t km^{-2}yr^{-1}). Also these authors provided

Fig. 1.2 Severe land degradation on the main Ethiopian Rift escarpment near Alaba Kulito along the Soddo-Shashemene road. The *top* soil has been completely removed by erosion leaving a badland-type morphology developed into in the soft bedrock consisting of poorly consolidated volcanic ashes and pumices

Fig. 1.3 A deep gully incised into the colluvial deposits mantling the base of the Gade Motta caldera rim (7°57′26″ N–38°39′20″E). This box or U-shaped gully is very deep, with steep flanks the hight of which appreciably decreases downstream as far as the gully splay on the rift *bottom*

Fig. 1.4 Block sliding apart due to lateral spreading from the Amba Aradam Mountain near Antalo (13°17′50″N–39°25′07″ E). Notice the varicolored subhorizontal, Jurassic Agula shales unconformably overlain by the Cretaceous Amba Aradam sandstones

an interpolation but, conversely to Nyssen et al. (2004), it is expressed by a less significant ($R^2 = 0.36$) linear equation

$$Y_s = 0.005\,\mathrm{A} + 6 \tag{1.2}$$

which predicts sediment yield to increase with increasing catchment area. This result confirms that in small catchments slope erosion processes are not stationary because of local factors, but are very effective in supplying sediment directly into stream channels. Notwithstanding such wide variations of data from different authors, sediment yield seems to be rather high, especially in the northern highlands (Fig. 1.5) and in the Rift margins as witnessed by a few examples of reservoirs completely filled with sediment (Fig. 1.6).

1.2.3 Natural Vegetation and Land Use

According to Ibrahim (1978), Ethiopia lies within the Sudano-Zambezian phytogeographic region of Africa which comprises one of the largest formations of the continent and can be characterized as tropical, with a long dry season of 4–9 months, annual rainfall between 200 and 1,500 mm, and vegetation typical of Sudanian and Sahelian zones which includes steppe, savanna, and dry (Fig. 1.7) to subhumid woodland and forest. The large differences in physiography, soil types and climatic conditions result in a variety of habitats suitable for evolution of several plant species. Vegetation of Ethiopia, therefore, is very heterogeneous and characterized by considerable endemism which is strongest in the high mountains, in southeastern Ogaden (Soromessa et al. 2004), Borana and Bale lowlands (Woldu 1999 in FAO 2014). In Ethiopia, there are about 6,000 species of higher plants, of which about 10 % are endemic (Kelbessa et al. 1992).

According to White (1965), the Sahel region, which can be characterized as wooded steppe with *Acacia* and *Commiphora* spp. (Fig. 1.8), represents a floristically impoverished western extension of the rich Afro-Oriental domain. *Acacia* species are very common in the Ethiopian Rift Valley and other low rainfall areas but are also found in the southern highlands where they form the basis of a traditional agricultural practice (Poschen 1986). In the arid zone plains, bushed grassland prevails (Fig. 1.9), except some patches of woodland.

The highlands of Ethiopia have climates and vegetations that vary noticeably in relation to altitude, forming part of the Afro-montane region. Ibrahim (1978) includes Ethiopia in the Afro-Oriental domain, which covers also the lowlands of Tanzania, Kenya, and Somalia, and sets an altitudinal limit of 1,100 m for this domain though it extends considerably higher in the Ethiopian Rift Valley.

Fig. 1.5 A mushroom stone witnessing severe soil erosion north of Aksum (14°09′53″N–38°41′58″E)

Fig. 1.6 The Aba Samule Reservoir on the Akaki River, south of Addis Ababa (8°47′15″N–38°42′18″E). The dam was constructed in 1939 but a few decades later it was completely filled with sediment

The forest cover of Ethiopia has been declining rapidly. Most of the remaining forests are confined to the south and southwestern parts of the country (Tilahun et al. 2011).

In these areas, forests are threatened by human activities. Historical documents show that Ethiopia experienced substantial deforestation (Pankhurst 1995; McCann 1997; Dessie and Kleman 2007), soil, and land degradation (Nyssen et al. 2004; Nyssen et al. 2014) over the years. The need for fuelwood, arable land (Fig. 1.10) and grazing areas (Fig. 1.11) are indicated as the main causes for forest degradation (Tilahun et al. 2011). According to Woldu (1999 in FAO 2014), about 34 % of Ethiopia and 57 % of the land above 1,500 m was once covered by dense forests and a further 20 % by wooded savannah. Massive deforestation has reduced these figures to 3.6 % of the total area (Tefera 2011) (Fig. 1.12) and to 9 % of the land above 1,500 m. Widespread deforestation started, particularly in the highlands, at the end of the nineteenth century with the expansion of agriculture.

Fig. 1.7 Example of a natural savannah and dry woodland forest in the southern portion of the Rift Valley, southeast of Konso town

Fig. 1.8 A natural Acacia forest within the Abijata-Shala Park (7°71′34″N–38°39′46″E)

The glorious forests of the past are witnessed by isolated, huge sycamore trees that are present in the Rift and in the highlands below 2,000 m a.s.l. (Fig. 1.13)

Nowadays, the most common trees of Ethiopia are the *Eucalyptus* spp. (Fig. 1.14). This genus was introduced from Australia to East Africa in the late nineteenth and early twentieth century and at that time the largest plantations were in Ethiopia and Rwanda. In Ethiopia, the Eucalyptus genus was introduced in 1894/1895. The purpose was to supply fuelwood and construction timber to the new and

Fig. 1.9 Example of a bushed grassland in “Nech Sar” (*white grass*) Park near Arba Minch (5°57′24″N–37°39′31″E)

Fig. 1.10 Cereals cultivations on the Somali Plateau along the Shashemene-Kofele road. This flat area is underlain by trap basalts and stretches eastward from the Rift margin

growing capital city, Addis Ababa. In the 1970s, the plantation area in the country was about 90,000 ha. Recent estimates indicate the extension of Eucalyptus forests for about 0.5×10^6 ha though huge numbers of trees exist in other land use types, such as homesteads, farm boundaries, and beside roads (Dessie and Erkossa 2011).

In the main Rift Valley, agricultural activity is rapidly expanding and progressive settlement has replaced grazing lands with small (Fig. 1.15) to medium farms, some of which are mechanized (FAO 2014).

1.3 Main Landscape Regions

The geomorphology of Ethiopia is largely controlled by its geological structure, but weathering, erosion, and deposition processes contributed as well in shaping the country into its present association of landforms and landscapes. The crustal evolution, characterized by a marked swelling within one of the most active extensional areas of the planet, resulted in three main morphostructural units, which include also

Fig. 1.11 Pasture on the western portion of the central highlands near Nekemte. Major landforms of this are small volcanic plugs and dome-shaped subvolcanic intrusions

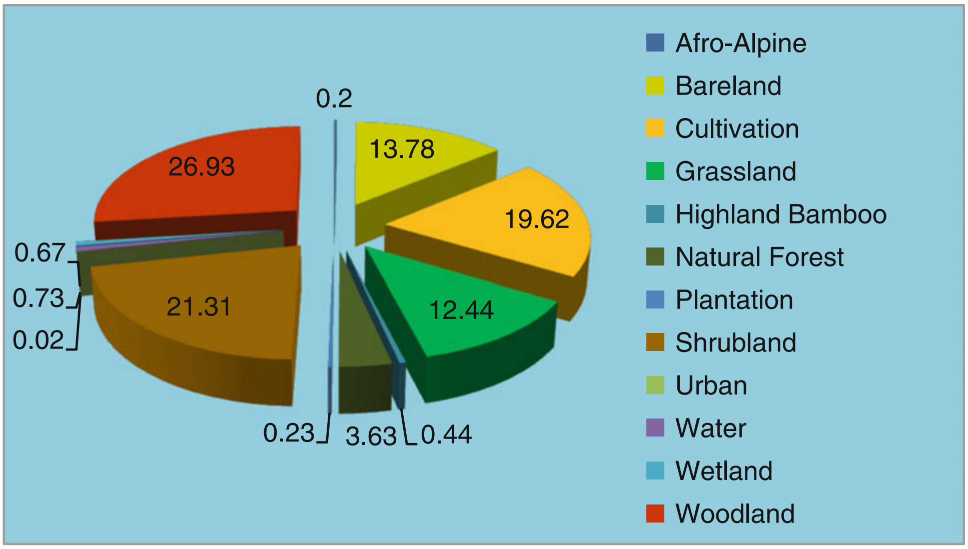

Fig. 1.12 Land cover distribution by percentage of the Ethiopian territory (Woldu 1999)

subregions with specific geomorphic features. These are given as follows: (1) the western plateau that can be divided into (i) the northern highlands, including the volcanic plug belt of Adwa, (ii) the central highlands, and (iii) the southwestern highlands; (2) the Rift Valley which consists of three main portions, namely the northern, central, and southern trunks and the Afar and Danakil depressions; (3) the southern plateau which consists of a northern and southern sectors and includes also the Ogaden tableland gently descending to Somalia and the Indian Ocean.

The plateaus originated by the domal uplift of the Arabian-Ethiopian region (Merla et al. 1979) and accumulation of flood basalts, the thickness of which is commonly around 1,000 m but may reach 2,000 m in some regions (Kieffer et al. 2004) or even 3,000 m in the Chercher mountains (Juch 1975) (Fig. 1.1). The most elevated parts of the plateaus stand at 3,000 m a.s.l., but in places they are surmounted by high volcanic mountains, a few of which reach elevations above 4,000 m. Both main plateaus descend radially and gradually to elevations of about 500–600 m around the border with Sudan and 200–400 m close to the border with Somalia. The main topographic gradient is steeper (about 0.004–0.006) near the rift margins and decreases to 0.001–0.002 in the distal parts where granite inselbergs are a common and typical geomorphological feature (Figs. 1.16 and 1.17). By contrast, the transition from the plateau margins to the rift is decidedly abrupt and marked by stepped topography and a number of elongated grabens (Fig. 1.18), with asymmetrical and unpaired horsts and the bottom locally punctuated by recent trachyte plugs (Fig. 1.19). In places, spectacular fault-generated escarpments occur (Fig. 1.20), with long and high exposed fault planes, at the base of which alluvial fans are commonly found (Fig. 1.21).

Fig. 1.13 A huge sycamore tree

Fig. 1.14 Eucalyptus forest on the Somali Plateau along the Shashemene-Kofele road

Fig. 1.15 A small farm on the shore of Abaya Lake, along the Soddo-Arba Minch road (6°30′00″N–37°46′33″E)

Fig. 1.16 Granite inselbergs, with evidence of exfoliation processes and products, in the eastern side of Kassala

1.3.1 Northern Highlands

The geology of the northern highlands is rather complex and includes a variety of formations ranging in age from Precambrian to Quaternary. Such a geodiversity provides the northern highlands with, likely, the most varied association of landforms and landscapes. In the northernmost sector, low grade Proterozoic metamorphic rocks, Lower Paleozoic granites and, subordinately Mesozoic sedimentary sequences occur, whereas the southern sector is mainly underlain by volcanites of the trap series with the typical tabular morphology of the flood basalts (Fig. 1.22). Continuing volcanic activity resulted in the building up of high mountain areas which include a few of the highest peaks of

Fig. 1.17 Granite inselbergs along the road from Mega to Moyale. Notice typical landforms such as tors originated by crystalline rocks weathering

Fig. 1.18 Structural basins within the western plateau escarpment south of Karakore, along the Debre Birhan-Dese road (10°24′35″N–39°56′05″E). This small graben is asymmetric with the western flank (on the *right* in the photo) higher. The graben floor is also slightly tilted and dipped southward (away from the reader)

Ethiopia. The Simen Mountains massif dominates the western plateau and it is the fourth highest range of Africa after Kilimanjaro, Mount Kenya and Rwenzori, with Ras Dejen (4,533 m a.s.l.) being the highest mountain peak of Ethiopia and among the first ten highest peaks of the African continent. In the northern highlands, other notable high mountain peaks are the Abune Yosef (4,284 m a.s.l.), in the Tekeze headwaters, and a number of high mountains, some ranging in elevation between 3,000 and 4,000 m, the most renown of which, for historical reasons, is Amba Alaji (3,438 m a.s.l.) (Fig. 1.23). *Amba* is a local name that is commonly used to indicate flat-topped mountains (see Chap. 9 this volume). Given the tabular structure with an almost negligible slope of the area and the occurrence of hard Mesozoic sedimentary formations such as the Adigrat Sandstone, consisting of 91 % of quartz components (Getaneh 2002), resting on more erodible glacigenic and metamorphic rocks or, like in the case of the Amba Aradam, on softer and easily erodible Agula Shales (Fig. 1.4), the Amba mountain geomorphology is rather common in Tigray (Fig. 1.24).

Drainage of the northern highlands is predominantly to the west-northwest and includes the largest and longest rivers of northern Ethiopia. By contrast, much smaller and commonly ephemeral streams flow to the east into closed basins or disappear in the Danakil lowlands. All the western

Fig. 1.19 Recent (Quaternary?) intrusions of trachytic rocks protruding from the *bottom* of the Kobo-Alamata structural basin (12°07′39″N–39°41′15″E). View is to the north

Fig. 1.20 Impressive fault escarpment in the Termaber basalts with alluvial fans at the base near Wichale, between Dese and Weldiya

Fig. 1.21 Alluvial fan in the footslope of the eastern margin of the Kobo-Alamata structural basin (12°22′25″N–39°41′31″E)

Fig. 1.22 The typical tabular structure of the northern highlands with a deep canyon incised by a tributary of the Mereb River along the Adigrat-Adwa road. The *right-hand side* of the valley is capped by the Paleozoic Enticho sandstones (Abbate, personal communication), whereas in the opposite side the sandstones are overlain by the Tertiary trap basalts

Fig. 1.23 The Amba Alaji peak (3,438 m a.s.l.) seen from the Korem-Mekele road. The pyramidal morphology of the mountain *top* is carved into Miocene rhyolitic ignimbrites

rivers are tributaries of the two main river systems of this area, the Tekeze and the Mereb. Both these rivers flow on the bottom of deeply incised canyons (Fig. 1.22) and mark the border between Eritrea and Ethiopia for a few hundreds of kilometers. At the large scale, in fact, the geomorphology of the northern highlands is mainly the result of erosion, rather than deposition processes, as would be expected given the remarkable uplift of the area that has proceeded until recent times (Merla et al. 1979; Corti and Manetti 2012). However, in a few places underlain by limestone rocks

Fig. 1.24 Flat-topped (*amba*) mountains along the road from Mekele to Adigrat in Tigray. This tabular structure is formed by sub-horizontal, Triassic Adigrat sandstones which in places include dark brown ferruginous/lateritic beds, very resistant to erosion (Enkurie 2010)

Fig. 1.25 The travertine dam of Romanat, a few kilometers NW of Mekele (13°34′24″N–39°25′04″E)

(e.g., Antalo formation), such as in the Mekele outlier, thick deposits of travertine, forming spectacular natural dams, are present (Fig. 1.25).

Among the northern highlands landscapes, the one around Adwa is unique and remarkable. It is characterized by a large number of spires that rise from the eroded surface of the basement to make a sort of stony tree forest (Fig. 1.26). The Axum–Adwa complex is part of a larger magmatic SW–NE belt extending for about 150 km from west of Axum to as far as Senafe in Eritrea. This magmatic complex is set along an uplifted crustal sector overlying the Proterozoic crystalline basement or, in many places, its Mesozoic sedimentary cover (Zanettin et al. 2006; Natali et al. 2013). The magmatic products consist mainly of an alternation of trachyte and

Fig. 1.26 The volcanic plugs of Adwa seen from Axum

Fig. 1.27 Volcanic plugs near Enticho

syenite plugs and domes reaching their maximum density in the area around Adwa. The world renown obelisks of Aksum were carved from the subvolcanic phonolite-syenite domes that dominate the landscape around the town (see Chap. 7 this volume).

The plugs and domes rise from a few tens of meters to about 300 m above the sedimentary substrate or alkaline basalts (Hagos et al. 2010) (Fig. 1.27). A few of the most peaked and isolated pinnacles host monasteries and churches (Fig. 1.28).

Fig. 1.28 The church of St. Pantaleon on *top* of a pointed trachyte plug near Aksum

Fig. 1.29 The central highlands north of Addis Ababa are deeply incised by the Sodoblé River, a tributary of the Blue Nile near Chancho (9°26′11″N–38°38′47″E). Notice the alternation of softer and harder lithotypes within the trap series on *top*, the sub-vertical fault scarp parallel to the river and cutting the lower portions of smaller transverse divides and the Mesozoic sedimentary formations outcropping in the valley *bottom*

1.3.2 Central Highlands

The central highlands are likely the most monotonous of the Ethiopian highlands since they are almost entirely underlain by basalts of the Tertiary trap series and other, more recent volcanic rocks. Only to the west, Proterozoic metamorphic rocks crop out, whereas the Mesozoic sedimentary sequence is exposed in the Blue Nile valley. The general morphology is therefore that of a tabular structure gently sloping to the west and deeply incised by the Blue Nile and its tributaries

Fig. 1.30 The flat *top* surface of the central highlands north of Addis Ababa with shield volcanoes merged to form a string-shaped ridge in the background

Fig. 1.31 A sharp, sub-vertical fault face, with a hanging river valley, along the road between Karakore and Kombolcha

(Fig. 1.29). The top surface is typically flat and strewn with individual volcanic edifices or groups of a few contiguous apparatuses, commonly arranged in strings along fault lines (Fig. 1.30). Some of these volcanoes may be very large and stand higher on the plateau surface, rising 1,000–1,500 m above it. This is the case of Mt. Guna (4,231 m a.s.l.) near Debre Tabor and Mt. Choke (4,154 m a.s.l.) south of Tana Lake, separated by the Blue Nile which flows to the south and then turns to the west in a large bend right around Mt. Choke. Other high mountains include the Abuye Meda (4,000 m a.s.l.), south of Kombolcha, Amba Farit (3,975 m a.s.l.), west of Dese, and Tulu Welel (3,200 m a.s.l.) in the westernmost portion of the plateau, close to the lowlands across the border with Sudan.

Fig. 1.32 The famous "Afar Window" along the road from Debre Birhan to Debre Sina (9°50′13″N–39°44′30″E). A small fault, transverse to the main rifting system, makes a narrow gap within the plateau edge and from an elevation of about 3,100 m a.s.l. it is possible to see the Afar lowland in the far distance

Fig. 1.33 The rugged landscape of the southwestern highlands. The Omo River valley west of Welkite (8°15′40″N–37°36′09″E)

Apart from volcanoes and their products, the northern highlands gross geomorphology is mainly controlled by faulting and horst and graben structures. Long, high and commonly sub-vertical fault faces are common as well, especially close to the eastern margin (Fig. 1.31). This latter is rather sharp and the relief contrast with the Danakil and Afar lowlands is remarkable (Fig. 1.32). Moving westward, the plateau elevation decreases but the general landscape does not change appreciably, at least as far as Nekemte (Fig. 1.11).

1.3.3 Southwestern Highlands

The southwestern highlands are less even and more rugged compared to the northern and central highlands. In particular in the median part, the landscape assumes a more typical mountainous configuration consisting of deep valleys and mountain groups (Fig. 1.33). The north- and southeastern sides coincide with the margins of the main and the southern Ethiopian Rift Valley, respectively, where the highest mountain peaks are found: Mt Gurage (3,721 m a.s.l.) in the

Fig. 1.34 The main Ethiopian Rift valley floor near Ziway seen from the rim of the Gademotta caldera. The Rift *bottom* is underlain by Quaternary lacustrine, fluvio-lacustrine, volcano-lacustrine, and volcanic ashes

Fig. 1.35 The stepped morphology produced by normal faults on the Rift margin east of Ziway Lake (8°03′20″N–39°07′14″E)

northernmost part, Mt. Guge (4,200 m a.s.l.) west of Arba Minch and Mt. Malgudo (3,390 m a.s.l.) southeast of Jimma. To the west, the southwestern highlands maintain their general mountainous landscape, but the valleys become broader and the mountain and valley bottom elevation decreases gradually as far as the town of Gambela, east of which there is a quite abrupt transition, along a almost north–south alignment, from the 2,000 m a.s.l. of the area close to Fit Makonnen to the tropical lowlands of the western Ilubabor (400–500 m a.s.l. on average), where wetlands are also present (Woldu and Yeshitela 2003).

1.3.4 The Rift Valley

The Great Rift Valley of Africa is one of the largest tectonic structures on Earth and one of the most attractive regions of the whole continent for its geomorphological relevance and

Fig. 1.36 An example of Gilbert-type delta in the recent shore deposits of Shala Lake (7°28′41″N–38°38′14″E)

Fig. 1.37 The Awash River flowing entrenched into the Rift valley floor near Ombole (8°23′22″N–38°45′53″E), with the Zikwala Volcano in the background. The river entrenching is caused by base level drop associated with main Ethiopian Rift lakes shrinkage and Afar tectonics

unique natural environments. The Ethiopian Rift consists of three main sections: (i) the southern portion, from the border with Kenya to the hydrological divide between Abaya and Awasa Lake; (ii) the main portion, commonly indicated also as the Great Lakes Region of Ethiopia, stretching as far as the Awash River; (iii) the northern portion, from the Awash to the apex of the Afar triangle and its northeastern branch, the Danakil depression.

The width of the Rift bottom is relatively constant around 50 km (Fig. 1.34), with the narrowest section being less than 20 km at Arba Minch. By contrast, the top width between the plateaus edges is more variable and depends mainly on

Fig. 1.38 A very small cinder cone along the Nazreth-Metehara road (8°53′57″N–39°48′37″E)

Fig. 1.39 The Fantalè shield volcano seen from the Awash National Park (8°54′17″N–40°02′36″E)

the number and size of the down-faulted blocks making up the stepped morphology of the Rift margins (Fig. 1.35). It is narrowest at Arba Minch and widest at Addis Ababa where it can be as much as 120 km. The Rift margin scarps are mainly cut into the rocks of the trap series in the southern portion and the Danakil, whereas in the Lakes Region and the northern portion (namely around Dire Dawa), more recent volcanic and Mesozoic sedimentary rocks, respectively, prevail.

The Rift floor is generally flat as it is commonly underlain by pyroclastic material and lacustrine and fluvio-lacustrine deposits (Fig. 1.36). Its main geomorphic features include narrow lacustrine terraces (visible especially in the Ziway–Shala lake area), river deltas, and shallow canyons (Fig. 1.37). River entrenchment is mainly due to the base level drop associated with the recent lakes shrinkage (see Chaps. 16 and 17 this volume) and the Afar lowland formation. However, the most distinguished geomorphic features of the Rift bottom are volcanoes and lakes. Volcanoes punctuate the Rift floor as individual or merged edifices ranging in size from small cinder cones (Fig. 1.38) to large strato-volcanoes (Fig. 1.37) or shield volcanoes (Fig. 1.39).

Fig. 1.40 A nice example of maar west of Butajira (8°02′52″N–38°20′58″E)

Calderas are also very common and the largest of them may have a diameter spanning a few tens of kilometers. Calderas host the majority of the main Ethiopian Rift Valley great lakes (namely Langano, Abijata, Shala, and Awasa), whereas a few much smaller lakes are formed within maars (Fig. 1.40). Most of the larger lakes hold saline water (Abaya, Abijata, Awasa, Beseka, Chamo, Langno, and Shala) with total dissolved solids concentrations ranging from 771 ppm of Abaya Lake to 56,300 ppm of Beseka Lake (Wood and Talling 1998; Chap. 18, this volume). The Rift lakes make up the base level for all the rivers draining into the Rift. With the exception of the lakes fed by the Awash River, such as Abe Lake, all other lakes are fed by small rivers (Chap. 16, this volume). In the recent decades, the Rift lakes have shown contrasting hydrological trends with some lakes shrinking (e.g., Abijata) and other—Abaya, Awasa and Beseka—expanding (Chap. 16, this volume). Given the remarkable rate of change in water level observed (e.g., Abijata −6 m, Abaya +2 m and Awasa +3 m in 20 years), not paired by an equivalent change in rainfall in the vicinity of these lakes, it is very difficult to ascribe the lake surface variations to climatic factors only. For Awasa Lake, Gebreegziabher (2004) attributes the lake level rise to the combined effects of land use and climate change, whereas Ayenew and Gebreegziabher (Chap. 16, this volume) conclude that water balances of the main Rift lakes are predominantly controlled by groundwater. A special case is offered by fast and large expansion of Beseka Lake that occurred in the last decades. The maps of Fig. 1.41 show clearly an impressive lake surface increase between 1979 and 1995. The water level is still rising leading to the complete drowning of both the road and the railway to Djibouti. Human impact is likely the main controlling factor of such a remarkable change in water level that started after the construction of a large irrigation scheme, fed by the Awash River water, for a newly set sugar plantation (Fig. 1.41).

The Rift becomes progressively more arid as we move to the Afar triangle and its northern branch, the Danakil depression. These areas are described in detail in Chap. 15 of this volume. Here, it is worth recalling briefly that the Danakil depression is a strip of coastal land 60–80 km wide separated from the Red Sea by coastal hills draining into the inland saline lakes. The Danakil depression is the hottest inhabited and one of the least elevated places on Earth and location of unique landscapes, associated with different magmatic activities, and evaporite deposits as much as 2 km thick forming a vast flat area from which salt domes, a few meters high, protrude (Fig. 1.42). Numerous volcanoes and volcanic landscapes occur in the Danakil, including the most active and renown of them, the Erta Ale (see Chap. 15, this volume).

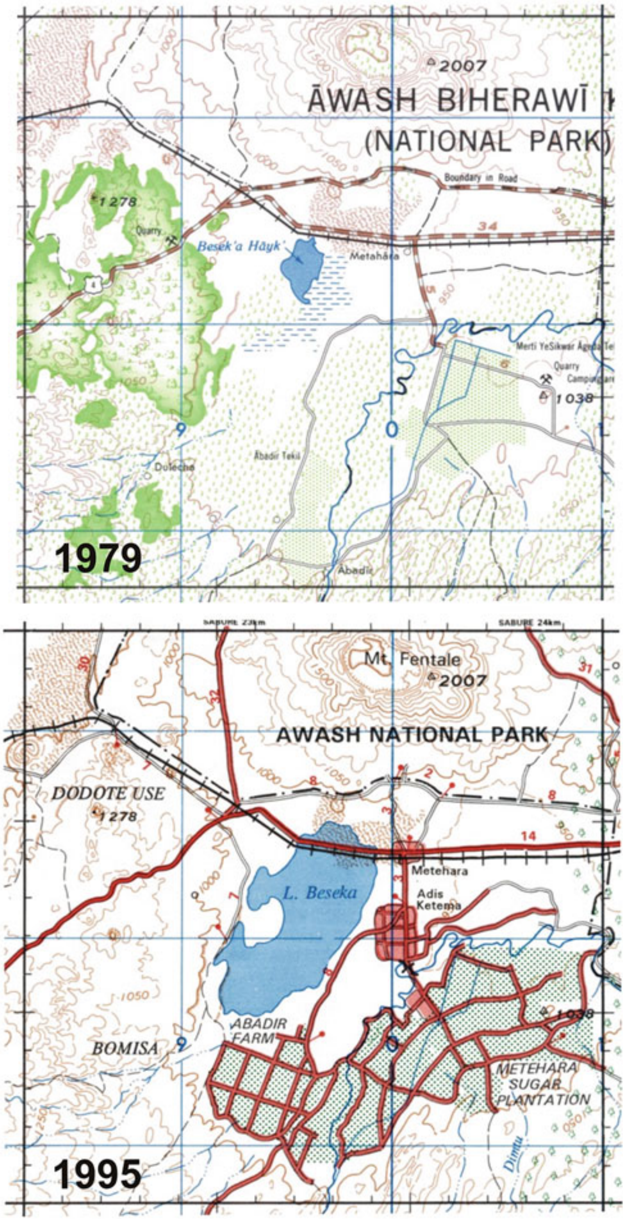

Fig. 1.41 1:250,000 topographic maps of Beseka Lake area reporting the state of the lake in 1979 and in 1995. Notice the huge sugar plantation constructed after 1997 near the lake, south of Metehara

1.3.5 The Somali Plateau

The physiography of the Somali Plateau is similar to the northwestern highlands, but its elevation is slightly lower. The highest mountain ranges, Bale, Chercher, and Ahmar (Fig. 1.1), are aligned with the western margin and close to its stepped escarpment. From here, the plateau gently descends to S-SE and sinks into the Indian Ocean.

In the Bale mountains, we find the highest peaks of the Somali Plateau and among the highest of Ethiopia, Mt. Tullu Dimtu (4,383 m a.s.l.) and Mt. Batu (4,307 m a.s.l.), but other high peaks include Mt. Kaka (4,180 m a.s.l.) and Mt. Bada (4,130 m a.s.l.) in the Chercher range. Moving to the north, along the plateau margin, the mountain height tends to decrease with the highest peak of the Ahmara Mountains, Gara Muleta, being only 3,381 m a.s.l. (Fig. 1.43).

The Somali Plateau is rather flat (Fig. 1.10) and its tabular morphology is interrupted only by deep canyons of the main rivers, i.e., the Wabe Shebele and the Genale-Dawa (Fig. 1.44), and high massifs. Among the latter, the Bale Mountains are decidedly the most prominent and consist of few main volcanoes, that released large amounts of Oligo-Miocene basalts and Quaternary rhyolite ignimbrites and basalt lavas, and fluvio-lacustrine intercalations (Merla et al. 1979). The summit of the Quaternary volcanites is punctuated by volcanic plugs (Fig. 1.45) and glacier erosional and depositional features are present (see Chap. 6, this volume). The latter are particularly evident in the Sanetti plain which is a large plateau at an average elevation of 4,100 m a.s.l., punctuated by small lakes, that has been shaped by an ice cap cover of about 180 km^2 during the last glacial maximum (Osmaston et al. 2005) (Fig. 1.46). Here, erratic boulders, roche mountonnées, and moraines are present, whereas cirques and moraine lakes (tarns) are common in the glaciated valley that radially spread out from the northern side of the plateau (Osmaston et al. 2005).

Evidence of glaciated landforms can be found also on the peaks of Mts. Bada and Kaka in the southern portion of the Chercher mountains (Osmaston et al. 2005), but is missing in the northern, less elevated part in which the most prominent landforms consist of small intermontane, structural basins, especially along the plateau margin (Fig. 1.47).

Most of the central and southern Somali Plateau is known as Ogaden—a large region, which extends from the Chercher and Ahmar mountains (Fig. 1.43) on the northern Somali Plateau margin to the border with Somalia and beyond, to the Indian Ocean. The Ogaden is a relatively flat and geomorphologically rather monotonous tabular land, gently dipping to E-SE. Its main morphological features are associated with large rivers crossing it, namely the Wabe Shebele River and its left side tributaries, the Ramis, Erer, and Fafen rivers (see Chap. 19, this volume). In the most elevated northern portion of the plateau, these rivers have incised deep valleys (Fig. 1.44) which become wider and shallow as the rivers approach the Somali border.

Though most of the Ogaden is underlain by Mesozoic sedimentary rocks, in its northern portion, especially in the Jijjiga area, the flat landscape is interrupted by small

Fig. 1.42 Salt hillocks rising from the Dallol salt plain (14°14′16″N–40°17′51″E)

Fig. 1.43 The Gara Muleta range seen from Kurfa Chele (Curfacelli) village, west of Harar (9°14′11″N–41°49′22″E)

volcanic plugs consisting of Miocene to Pleistocene basalts and rhyolites, whereas the town of Jijjiga stands on about 100 m thick Quaternary fluvio-lacustrine deposits accumulated in a large basin. Small, flat-topped residual hills made of limestone resting on the main gypsum formation rise for a few tens of meters above the surrounding tableland east of the confluence between the Dacata River into the Wabe Shebele (Merla et al. 1979). Elongated basalt hills (see Chap. 19, this volume) runs southward from Jijiga and parallel to the course of the Wabe Shebele, east of Imeey (Merla et al. 1979). Other small, isolated basalt hills occur also in between Warder and the Somali border.

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Fig. 1.44 The Wabe Shebele canyon near Gasera village, northeast of Robe Bale town (7°23′05″N–40°09′03″E)

Fig. 1.45 A number of volcanic plugs towering on *top* of the Bale Mountains, along the Shashamane-Robe road

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Fig. 1.46 The Sanetti plain within the Bale Mountains National Park, at an average elevation of 4,100 m a.s.l. (photograph by L. Orioli)

Fig. 1.47 Unnamed mountains around an intermontane structural basin along the Asbe Teferi—Hirna road in the northern part of the Chercher mountains

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