Chapter 2
Physical Geography of the Gulf of Guinea Oceanic Islands

Luis M. P. Ceríaco, Bruna S. Santos, Ricardo F. de Lima, Rayna C. Bell, Sietze J. Norder, and Martim Melo

Abstract The Gulf of Guinea, in the Atlantic coast of Central Africa, has three oceanic islands that arose as part of the Cameroon Volcanic Line. From northeast to southwest these are Príncipe (139 km^2), São Tomé (857 km^2), and Annobón (17 km^2). Although relatively close to the adjacent mainland, the islands have distinct climactic and geomorphologic characteristics, and have remained isolated throughout their geological history. Consequently, they have developed a unique biodiversity, rich in endemic species. We provide an integrated overview of the

L. M. P. Ceríaco (✉)
Museu de História Natural e da Ciência da Universidade do Porto, Porto, Portugal

CIBIO, Centro de Investigação em Biodiversidade e Recursos Genéticos, InBIO Laboratório Associado, Universidade do Porto, Vairão, Portugal

BIOPOLIS Program in Genomics, Biodiversity and Land Planning, Vairão, Portugal

Departamento de Zoologia e Antropologia (Museu Bocage), Museu Nacional de História Natural e da Ciência, Universidade de Lisboa, Lisbon, Portugal
e-mail: lmceriaco@mhnc.up.pt

B. S. Santos
Museu de História Natural e da Ciência da Universidade do Porto, Porto, Portugal

CIBIO, Centro de Investigação em Biodiversidade e Recursos Genéticos, InBIO Laboratório Associado, Universidade do Porto, Vairão, Portugal

Departamento de Biologia, Faculdade de Ciências, Universidade do Porto, Porto, Portugal

BIOPOLIS Program in Genomics, Biodiversity and Land Planning, Vairão, Portugal

R. F. de Lima
Centre for Ecology, Evolution and Environmental Changes (cE3c), Faculdade de Ciências, Universidade de Lisboa, Lisbon, Portugal

Departamento de Biologia Animal, Faculdade de Ciências, Universidade de Lisboa, Lisbon, Portugal

Gulf of Guinea Biodiversity Centre, São Tomé, Sao Tome and Principe

R. C. Bell
Department of Herpetology, Institute for Biodiversity Science and Sustainability, California Academy of Sciences, San Francisco, CA, USA

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physical setting of the islands, including their geographic location, geological origin, topography, geology and soils, climate zones, and prevailing wind and ocean currents—key features that underlie the evolution of their biodiversity.

Keywords Annobón · Geology · Ocean currents · São Tomé · Príncipe · Soils · Volcanism

Introduction

The Gulf of Guinea is a major topographical feature of western equatorial Africa that marks the distinctive shape of the continent on its Atlantic coast (Fig. 2.1). The Gulf of Guinea has three oceanic islands (Príncipe, São Tomé, and Annobón), one land-bridge island (Bioko), and two seamounts, which together comprise the offshore part of the Cameroon Volcanic Line. The biodiversity of the oceanic islands is characterized by a small number of species but exceptional endemism (Jones 1994; Gascoigne 2004; Ceríaco et al. 2022). This chapter provides an introduction to the physical setting of the islands that created the conditions for the evolution of their unique biodiversity, including their geography and topography, geological history, geological substrates and soils, climate, and prevailing patterns of ocean sea currents.

Some of the most complete sources of data for these topics are found in works published under the seal of the Portuguese scientific colonial institute—the *Junta de Investigações do Ultramar*—during the 1950s, 1960s, and 1970s. Of these sources, Lains e Silva (1958) provides key information on climate, soils, vegetation, and agricultural potential of São Tomé and Príncipe islands (see also Lains e Silva and Cardoso 1958). Building on earlier work, Tenreiro (1961) further addressed some of these topics for São Tomé Island. Cardoso and Garcia (1962) is a key reference for the soils of São Tomé and Príncipe—providing detailed maps of the soils of each island. Rodrigues (1974) synthesized the information on climate and soils presented by Lains e Silva (1958) and Cardoso and Garcia (1962). Jones et al. (1991) provide a

S. J. Norder
Copernicus Institute of Sustainable Development, Environmental Science Group, Utrecht University, Utrecht, The Netherlands

M. Melo
Museu de História Natural e da Ciência da Universidade do Porto, Porto, Portugal

CIBIO, Centro de Investigação em Biodiversidade e Recursos Genéticos, InBIO Laboratório Associado, Universidade do Porto, Vairão, Portugal

BIOPOLIS Program in Genomics, Biodiversity and Land Planning, Vairão, Portugal

FitzPatrick Institute of African Ornithology, University of Cape Town, Rondebosch, South Africa

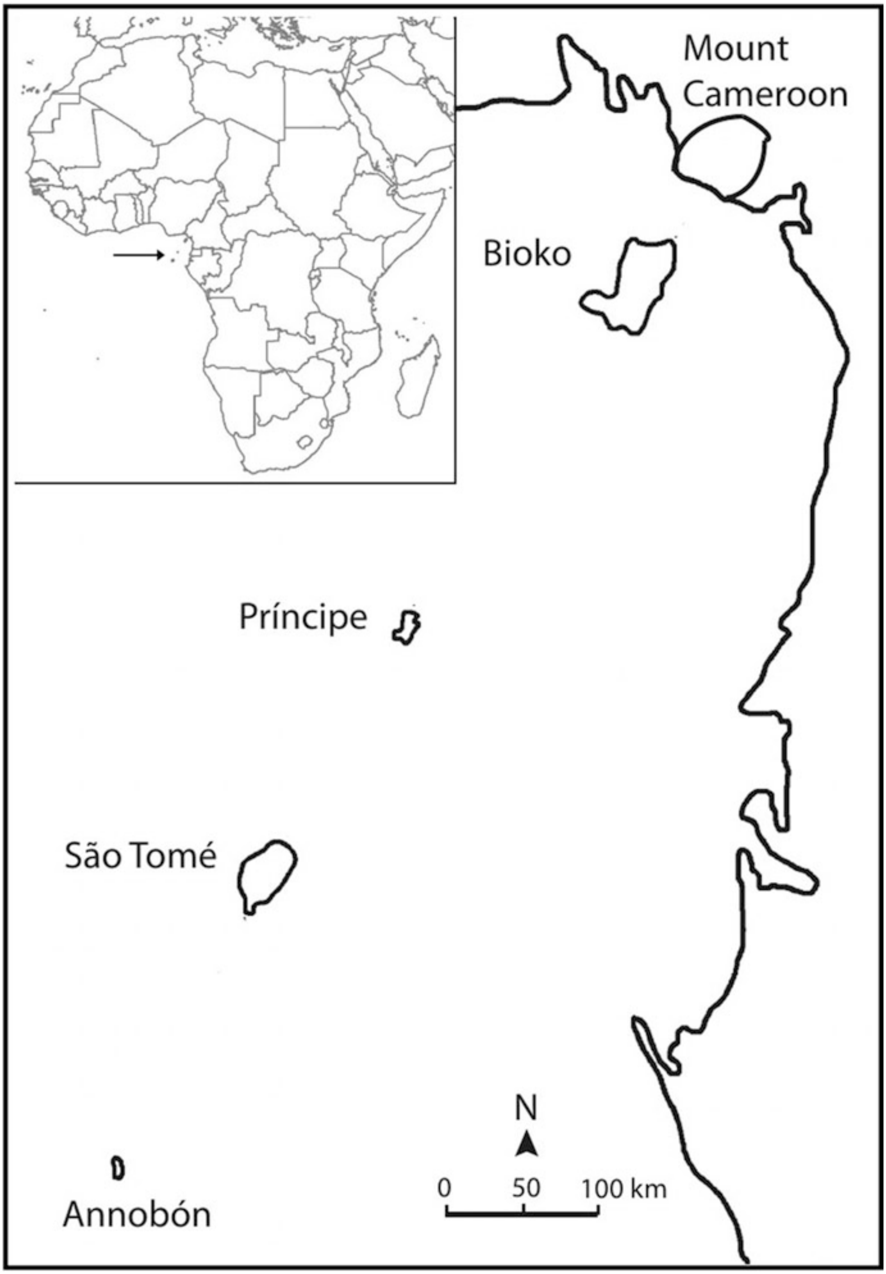

Fig. 2.1 Map of the Gulf of Guinea islands, western Central Africa. This system includes an ecological island (Mount Cameroon), a land-bridge island (Bioko), and the three oceanic islands, which are the focus of this book. Adapted from Jones and Tye (2006)

useful synthesis of background information available at the time. More recently, Diniz and Matos (2002) added to our understanding of the climate and soils of São Tomé and Príncipe islands, providing an updated and detailed map of the ecosystems and land-use types of the islands. A series of geological studies conducted by Munhá et al. (2002), Caldeira et al. (2003), Caldeira (2006), Munhá et al. (2006a, b, c, d, 2007), and Barfod and Fitton (2014) have provided important updates to our knowledge of the geology of São Tomé. Chou et al. (2020) provided the first modern analysis of the climate of São Tomé and Príncipe, downscaling global projections of climate change to these islands. For Annobón, the information is scarcer with initial geological works by Schultze (1913), petrological studies by Fuster Casas (1954) and Cornen and Maury (1980), work on volcanic geochemistry by Liotard et al. (1982), and a review by De Castro and De la Calle (1985), with subsequent additions by Fa (1991) and Velayos et al. (2014). Besides these island specific studies, several reviews summarize the main geophysical characteristics of the Gulf of Guinea islands (e.g., Lee et al. 1994; Jones 1994; Jones and Tye 2006; Juste and Fa 1994; Schlüter 2008).

Location, Extent, and Political Boundaries

The Gulf of Guinea island system (sensu lato) includes the ecological or "sky" island of Mount Cameroon, the land-bridge island of Bioko, and the three oceanic islands of Príncipe, São Tomé, and Annobón (Fig. 2.1). They are, from northeast to southwest:

Mount Cameroon, with an approximate area of 1750 km^2 (50 × 35 km), is an ecological island in the southwest province of the Republic of Cameroon. Mount Cameroon is the highest mountain in West Africa, with a peak elevation of 4095 m above sea level.

Bioko Island is a land-bridge island with an area of 2027 km^2 (roughly 35 km × 72 km). Bioko sits upon the continental shelf 32 km from the coast of Cameroon from which it is presently separated by a sea 60 m deep. During recent glacial periods, however, Bioko experienced recurring cycles of isolation and connectivity (Ali 2018), and was most recently connected c. 11,000 years ago (Einsentraut 1965; Lambert and Chappel 2001). Rising to an impressive 3011 m above sea level, Pico Basilé is the highest point of the island and one of its main landmarks.

The three oceanic islands that are the focus of this book have never been connected to the continent, and they are:

Príncipe Island (Fig. 2.2(1)) with a total area of 139 km^2 (c. 17 km × 8 km) is located 210 km SSW of Bioko and 220 km west of continental Africa. The island has six main satellite islets: Pedra da Galé, Mosteiros, and Bom-Bom in the north, Caroço (also known as the Jockey's Cap; Fig. 2.2(3)) in the southeast, and Tinhosa Grande and Tinhosa Pequena (Fig. 2.2(2)), which are about 20 km to the south. The highest point, Pico do Príncipe, is 942 m above sea level.

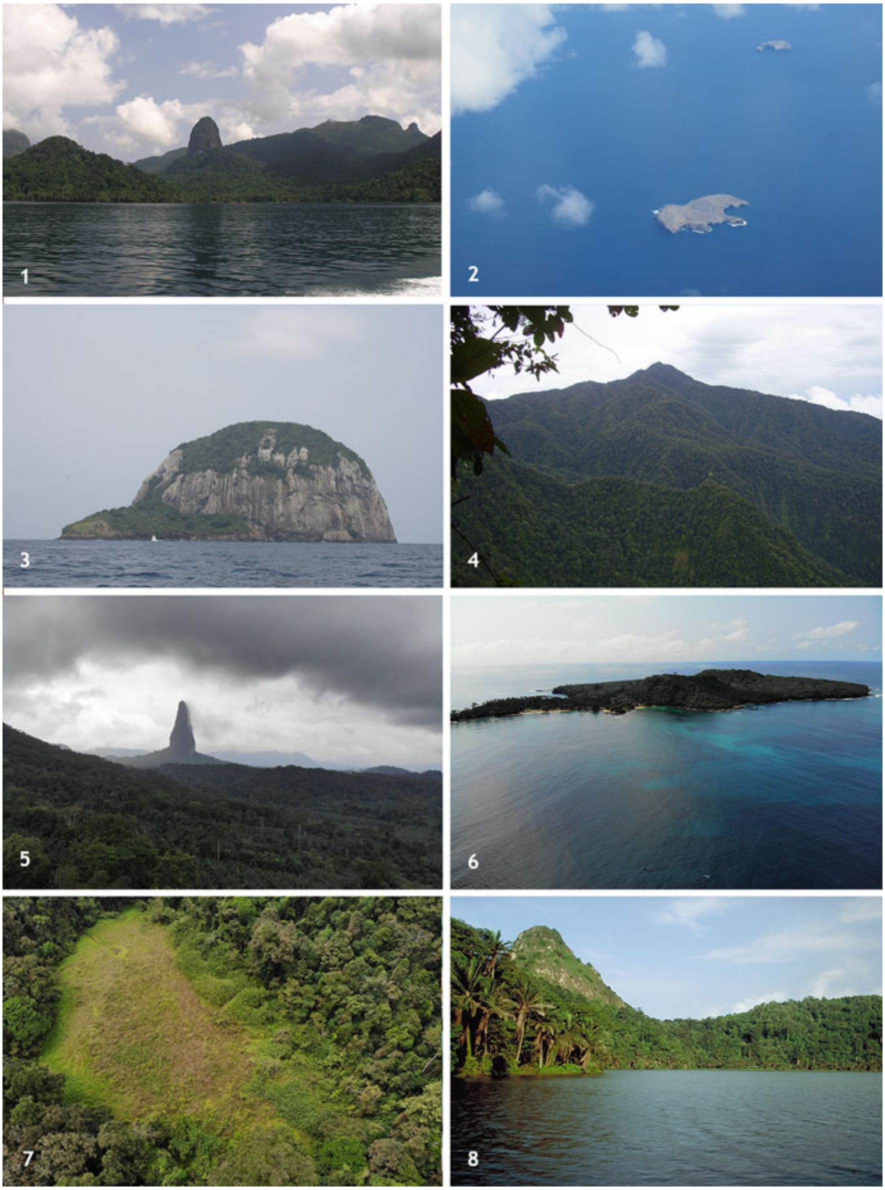

Fig. 2.2 (**1**) Pico Agulhas, Príncipe Island; (**2**) Tinhosa islets; (**3**) Jockey Bonet; (**4**) Pico São Tomé, São Tomé Island; (**5**) Pico Cão Grande, São Tomé Island; (**6**) Rolas islet; (**7**) Lagoa Amélia, São Tomé Island; (**8**) Lake A Pot, Annobón Island. Photo credits: (**1** and **8**) Martim Melo, (**2**, **3**, **5**–**7**) Luis M. P. Ceríaco; (**4**) Ricardo Lima

São Tomé Island with a total area of 857 km^2 (47 km × 28 km) lies 150 km SSW of Príncipe and 255 km west of Gabon. The island has several islets, of which Cabras to the north, Santana in the east, and Sete Pedras and Rolas (Fig. 2.2(6)) in the south

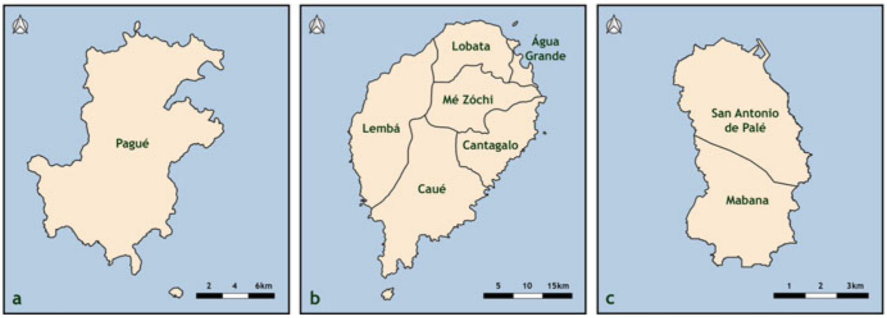

Fig. 2.3 Administrative divisions of Príncipe (**a**), São Tomé (**b**), and Annobón (**c**)

are the largest. The Equator passes through the center of Rolas Islet. The highest point, Pico de São Tomé (Fig. 2.2(4)), is 2024 m above sea level.

Annobón Island has an area of 17 km^2 (6 km $\times$ 3 km) and is the smallest and remotest of the Gulf of Guinea islands. It sits 180 km to the SSW of São Tomé and is about 340 km from the continent. The highest peak is Santa Mina, which rises 610 m above sea level.

Politically, the Gulf of Guinea oceanic islands belong to two countries: the Democratic Republic of São Tomé e Príncipe and the Republic of Equatorial Guinea. São Tomé e Príncipe is a nation state made up of Príncipe and São Tomé islands and the surrounding islets. It was once a colonial province of Portugal, from which it gained independence in 1975. It is one of the smallest countries in the world, with an approximate area of 1001 km^2. The country is internally organized into different levels of political and administrative divisions. São Tomé Island hosts the capital, the city of São Tomé, and is divided into six districts (Água Grande, Cantagalo, Caué, Lembá, Lobata, and Mé-Zóchi); Príncipe Island is an Autonomous Region, and is comprised of a single district, Pagué (Fig. 2.3).

Annobón (formerly known as Pagalu; Fig. 2.3), the smallest and most southwestern of the Gulf of Guinea oceanic islands, is one of eight provinces of Equatorial Guinea. This geographically disjunct country was a Spanish colony from 1778 to 1968. Equatorial Guinea is composed of a territory in continental Africa, Rio Muni, bordered by Cameroon to the north and Gabon in the east and south, the surroundings islets of Corisco, Elobey Chico, and Elobey Grande, the land-bridge island of Bioko (formerly known as Fernando Pó), where the country's capital is (Malabo), and finally the small oceanic island of Annobón. Whereas the mainland territory and Bioko have a long history of human occupation, Annobón was not peopled at the time of its discovery by the Portuguese, in 1473.

Geological History

The Gulf of Guinea islands form the southern part of the Cameroon Volcanic Line, a 1000-km line of volcanoes that has been active since the Cenozoic, and that extends from the Mandara Mountains on the Nigeria-Cameroon border to Annobón Island

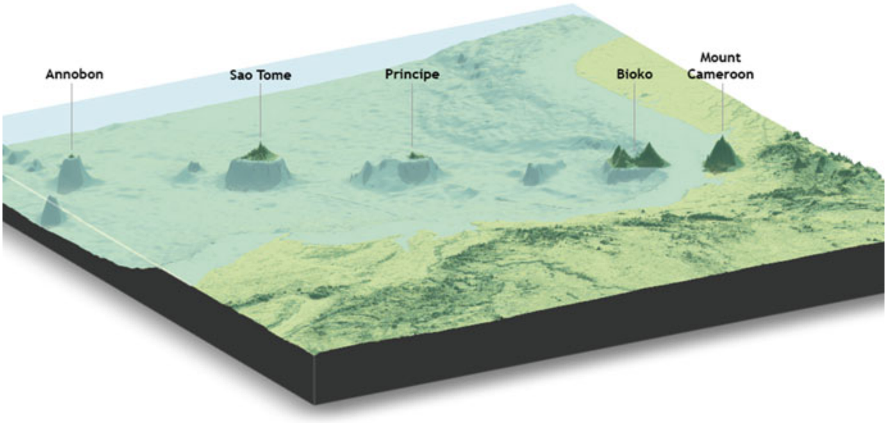

Fig. 2.4 Topographic representation of the offshore section of the Cameroon Volcanic Line. Figure created with the rayshader R package (Morgan-Wall 2021) using GEBCO data (GEBCO Compilation Group 2021)

(Burke 2001). This line runs in a NE-SW direction and includes four islands and two seamounts (Fig. 2.4). Onshore, there are four continental massifs (Mount Cameroon, Mount Manengouba, Mount Bambouto, and Mount Oku), all of which are in the Republic of Cameroon. Often, the Ngaoundéré and Biu swells, also in Cameroon, are considered part of the line, in which case the line becomes Y-shaped and 1600 km long (Fitton 1987; Lee et al. 1994; Fig. 2.5). Volcanic activity in the continental and oceanic sector has been more or less continuous since the Cretaceous (Fitton 1987; Lee et al. 1994; Burke 2001). There is no age progression in the line, except in the offshore section—with the oldest sub-aerial origins estimated at about 31 Ma for Príncipe, 15 Ma for São Tomé, and 6 Ma for Annobón (Lopes 2020).

The age of the oldest lava flows only provides estimates of the minimum age when each island was sub-aerial because older rocks may be buried under the most recent ones. For example, all the exposed lavas on Mount Cameroon are less than one million years old, but the mountain is built upon much older lava flows (Fitton 1987). Furthermore, volcanic activity persisted until recently on all the islands, and is still ongoing in Mount Cameroon and to a lesser extent in Bioko. This dynamic aspect of the islands is well illustrated in São Tomé, where the oldest rocks, at about 15.7 Ma, are from the small Cabras Islet, while the surface rocks of more than half of the island, including its highest peak, date between 1.5 and 0.4 Ma (Caldeira et al. 2003; Barfod and Fitton 2014). Although still poorly understood, the volcanic history of the Gulf of Guinea islands has no doubt played a major role in the assembly of their current biological communities. For instance, landslides or lava flows can split species ranges or cause extinctions, and distinct islands and islets may fuse and split over time (Milá et al. 2010; Gillespie and Roderick 2014; Ramalho et al. 2015).

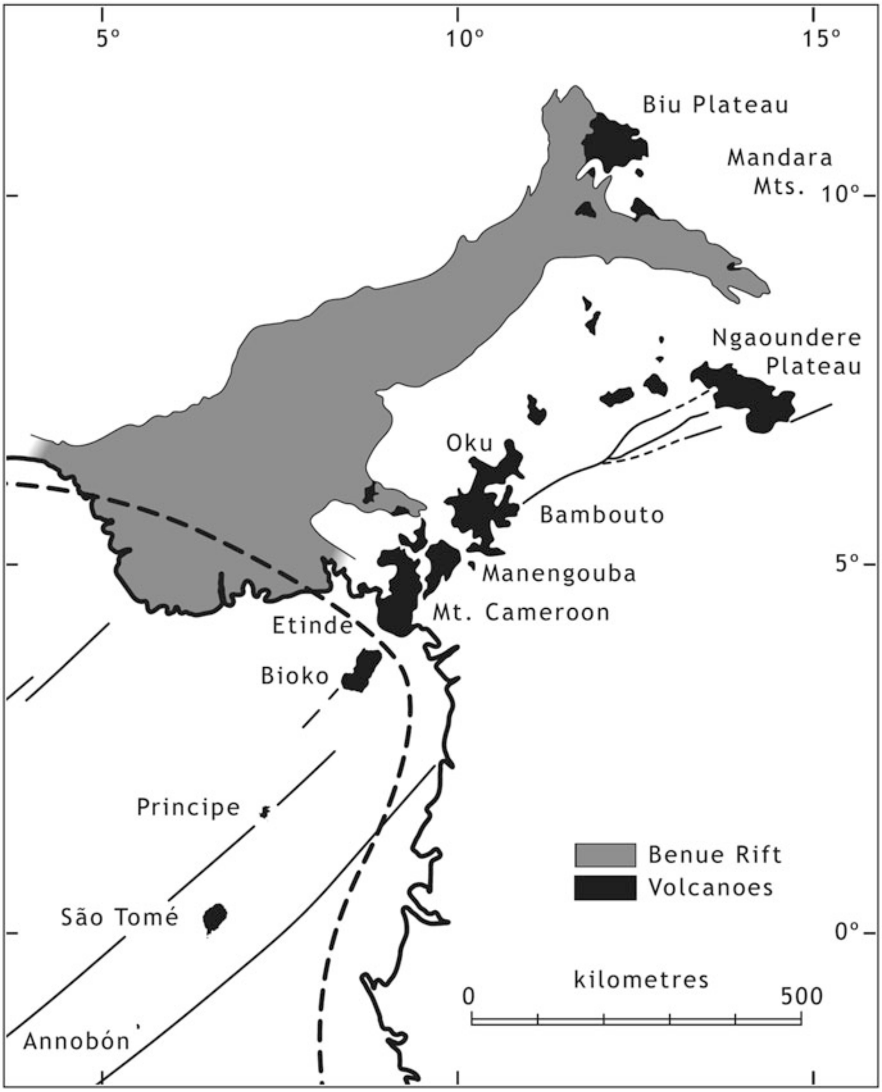

Fig. 2.5 The Cameroon line of volcanoes. Note the similarity in shape between the volcanic line (black) and the Benue Rift (grey). This was likely due to the rotation of the African plate c. 30–35 Ma that displaced the asthenospheric hot zone underlying the Benue Rift to its current position—resulting in a volcanic line without a rift and a rift without volcanoes, a unique feature on Earth. After decades of debate, the alignment of the volcanic centers is now thought to be controlled by the geometry of the northwest edge of the Congo Craton. Adapted from Lee et al. (1994)

Quaternary Sea-Level Fluctuations

Across the globe, glacial-interglacial sea-level fluctuations have shaped insular biodiversity and diversification by repeatedly connecting and isolating populations on coastal landmasses (e.g., Ali and Aitchison 2014; Rijsdijk et al. 2014; Fernández-Palacios 2016; Weigelt et al. 2016; Norder et al. 2018, 2019). Ceríaco et al. (2020) modeled the area of the islands throughout the last glacial period to the present day and demonstrated that the Gulf of Guinea islands show marked changes in area in response to eustatic sea-level fluctuations. During the exceptionally low sea level of the Last Glacial Maximum, as much as 134 m lower than present day (Lambeck et al. 2014), Bioko was connected to continental Africa, Annobón was five times its present size, Príncipe was about six times its present size, and São Tomé was approximately 50% larger than present day (Ceríaco et al. 2020; Fig. 2.6).

Topography and Hydrography

Due to recent volcanic activity, Príncipe, São Tomé, and Annobón are old islands that have the topography of young islands, including rugged mountains with steep slopes, deep valleys, volcanic chimneys, table mountains, and huge waterfalls (Figs. 2.7). The topography varies between islands. São Tomé is dominated by steep slopes and mountains across the majority of the island, with the exception of the flatter areas in the northeast (Figs. 2.7e, f). The maximum elevation reaches 2024 m at Pico de São Tomé, and several other mountain and peaks areas in the center of the island are well above 1000 m (Figs. 2.2(5), 2.7e). Príncipe has a plateau in the north but is mountainous in the south, where several peaks rise above 500 m, including Pico do Príncipe at 942 m (Figs. 2.7b). Annobón is small and steep, except for a small portion in the north, where most of the human population resides. The elevation rises considerably in the center and south, reaching 613 m at Santa Mina (Fig. 2.7h).

The available data on the terrestrial hydrography of the islands are limited. Both São Tomé and Príncipe are mostly covered by the hydrographic basin of a few large rivers in a dense network and also include several small coastal rivers (Fig. 2.7a, d). São Tomé Island has many small lagoons, estuaries, and mangroves, including the Malanza river estuary in the south, which forms the most extensive mangrove in the country. São Tomé also has a unique freshwater palustrine system in the crater of Lagoa Amélia (Fig. 2.2(7)), which is the source of the largest rivers in the north of the island (Fig. 2.7d). Annobón only has a few small streams, but Lago A Pot crater lake (Fig. 2.7g, shown in red; Fig. 2.2(8)) is a dominant feature of the island with a diameter of approximately 700 m at 150 m above sea level.

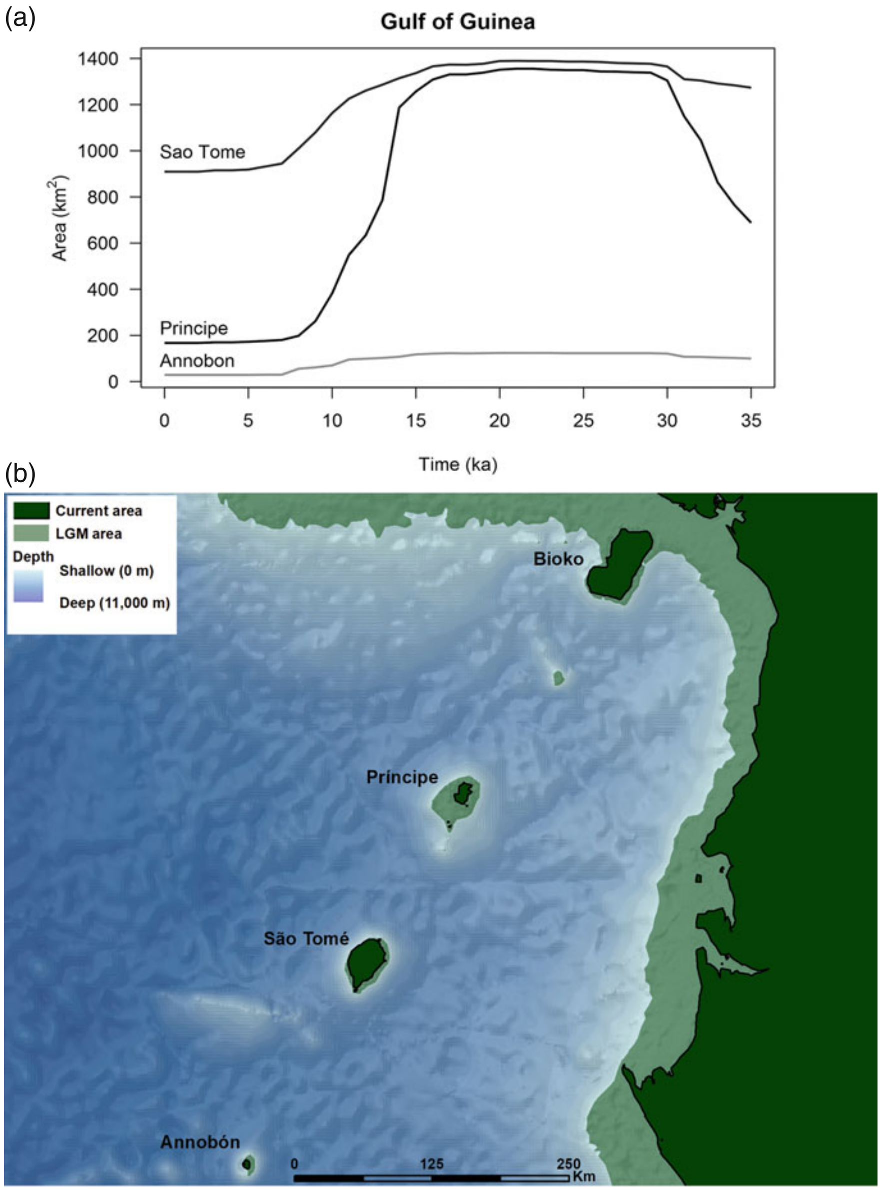

Fig. 2.6 Paleogeographic reconstructions of the Gulf of Guinea: (**a**) Area change curves of Príncipe, São Tomé, and Annobón islands; (**b**) area of islands today (dark green), and extreme area at the last glacial maximum (LGM, approximately 21 ka; light green). Adapted from Ceríaco et al. (2020)

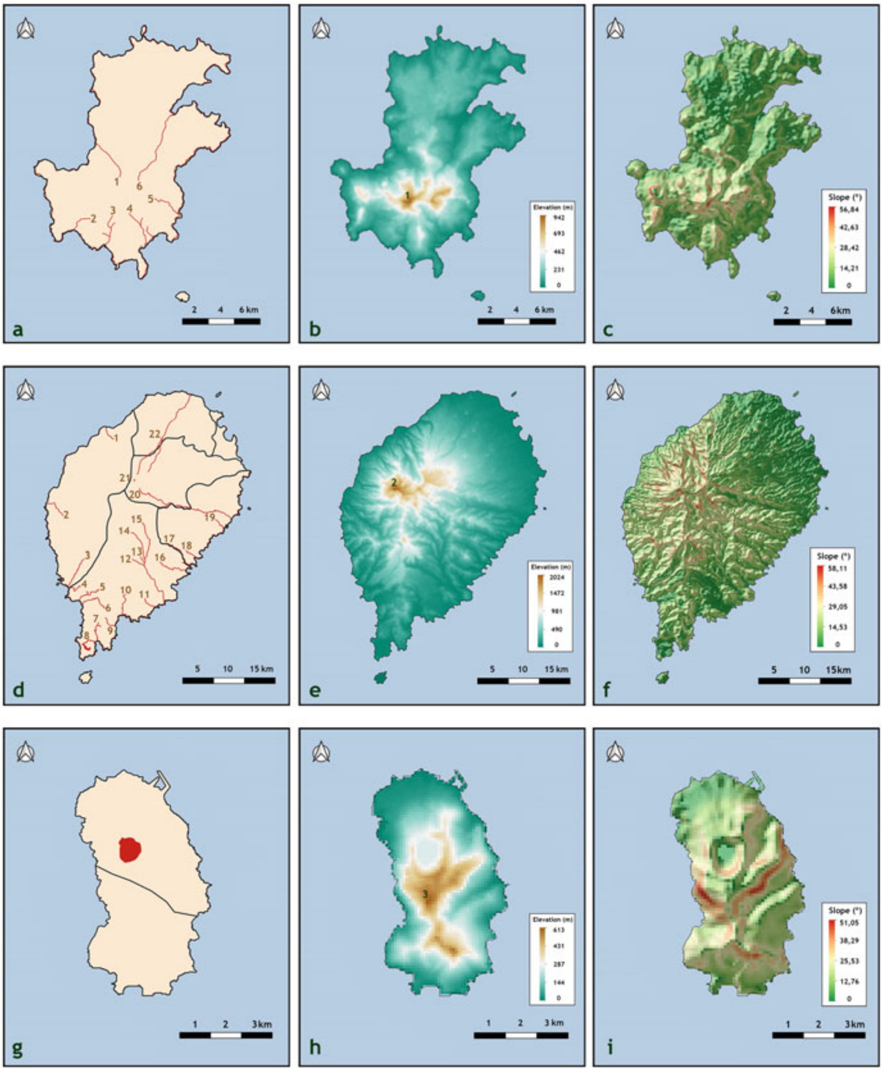

Fig. 2.7 Overview of the hydrography and topography of (**a**, **b**, **c**) Príncipe, (**d**, **e**, **f**) São Tomé, and (**g**, **h**, **i**) Annobón. For each island, elevation is presented in meters above sea level and steepness in degrees. Main rivers and waterbodies: São Tomé Rivers (**d**): 1—Provaz; 2—Lembá; 3—Xufexufe; 4—Quija; 5—Mussacavú; 6—Pedras; 7—Gumbela; 8—Malanza; 9—Gogô; 10—Caué; 11—Martim Mendes; 12—Miranda Guedes; 13—João Nunes; 14—Ana Chaves; 15—Ió Grande; 16—Angobó; 17—Angra Toldo; 18—Pedra Furada; 19—Ribeira Afonso; 20—Abade; 22—Ouro. São Tomé Crater Lake: 21—Lagoa Amélia. Príncipe Rivers (**a**): 1—Ribeira Banzú; 2—Ribeira São Tomé; 3—Ribeira Porco; 4—Chibala; 6—Papagaio. Annobón (**g**) has no significant rivers; the crater lake Lago A Pot is shown in red

Geology and Soils

The geology of São Tomé and Príncipe has been well studied since the early twentieth century. This is partly due to the importance of geology and soils for agriculture, which has been the major driver of the local economy for centuries (Lains e Silva 1958; Lains e Silva and Cardoso 1958; Rodrigues 1974). The first overview of the geology of São Tomé Island was provided by Carvalho *in* Henriques (1917), followed by a more detailed study on the microscopic characteristics of its rocks (Carvalho 1921). Teixeira (1948–1949, 1949) provided a more complete overview of the geology of the islands, followed by a petrological work by Pereira (1943). The most extensive and complete contributions to the geology of the islands were provided by the Portuguese geologist João Manuel Cotelo Neiva (1917–2015), whose work was fundamental to understanding the geochemistry and geomorphology (Neiva 1946, 1954, 1955a, b, 1956a, b, c; Neiva and Pureza 1956; Neiva and Neves 1956). Assunção (1956, 1957) and Barros (1960) also contributed to our understanding of the geochemistry. In the twenty-first century, new research on the geology of São Tomé (Munhá et al. 2002; Caldeira et al. 2003; Caldeira 2006) has resulted in updated geological maps (Munhá et al. 2006a, b, c, d, 2007). By contrast, the geology of Annobón has received far less attention. The first information on its geological history and composition was provided by Schultze (1913), followed by studies by Tyrrell (1934), Fuster Casas (1954), Cornen and Maury (1980), and Liotard et al. (1982). More recently, De Castro and De la Calle (1985) and Fa (1991) provided an overview of the geology of Annobón. On Príncipe, basaltic rocks predominate in the north and phonolites and tephrites in the south, whereas São Tomé and Annobón are mostly built by basaltic lavas (Fig. 2.8). A more detailed description of the geology of the islands is provided by Schlüter (2008).

Regarding the soils of Príncipe and São Tomé, Lains e Silva (1958) and Cardoso (1958) drafted the first maps, with a more comprehensive map and revision by Cardoso and Garcia (1962). Other works were done by Pissarra and Rocha (1963) and Pissarra et al. (1965). The dominant soil types of Príncipe and São Tomé are highly weathered, such as Ferralsols and Lixisols (Lains e Silva 1958; Cardoso and Garcia 1962; Diniz and Matos 2002), which are typical of tropical climates. Vertisols are restricted to the dry north and northeast of São Tomé, while Lithosols can be found everywhere on the island, often associated with ridges, steep slopes, and cliffs near the coast (Diniz and Matos 2002). Fluvisols, as expected, are mostly associated with riparian areas. Very little is known about the soils of Annobón, other than that they are ultrabasic with low silica and high proportions of ferromagnesian elements (De Castro and De la Calle 1985; Fa 1991).

The only reported fossils are from Príncipe and date to the Miocene (Teixeira 1949; Silva 1956a, b, 1958a, b; Serralheiro 1957). These include marine organisms such as gastropods, bivalve mollusks, coelenterates, echinoderms, and fishes' teeth, but also calcareous algae, radiolarians, and foraminifera. Modern foraminifera are known from both Príncipe and São Tomé beaches (Moura 1961). A palaeoecological study is currently taking place on Príncipe and São Tomé collecting data from

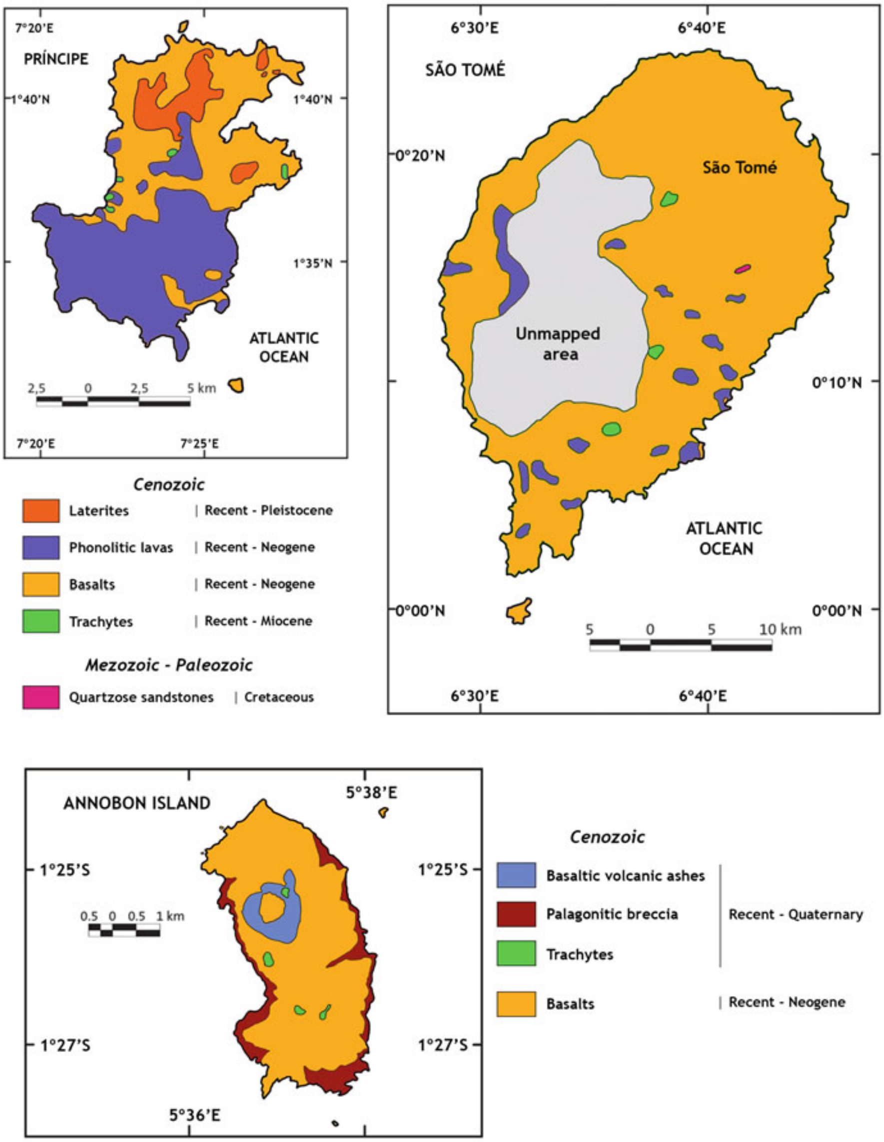

Fig. 2.8 Geological overview of the islands of Príncipe, São Tomé, and Annobón. Adapted with permission from Springer Nature Geological Atlas of Africa by Schlüter © Springer-Verlag Berlin Heidelberg 2006 (2008)

pollen, spores, charcoal, and sedimentology to reconstruct ecosystem changes associated with glacial cycles and the impacts of human activities (unpublished data by Alvaro Castilla-Beltrán).

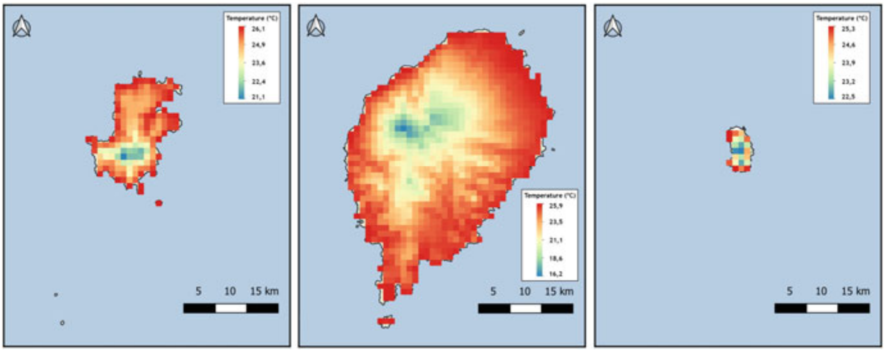

Fig. 2.9 Annual average temperature (in Celsius) for the islands of Príncipe, São Tomé, and Annobón. Data obtained from the Global Solar Atlas 2.0, provided by the World Bank Group

Climate

The Gulf of Guinea oceanic islands have an oceanic equatorial climate. Mean temperatures are above 25 °C at sea level but decrease with altitude (Fig. 2.9). The year is divided into rainy and dry seasons, which are determined by the Intertropical Convergence Zone, and by the interaction between the southern monsoon winds from the Atlantic Ocean and the northern dry harmattan winds from the Sahara. Seasons differ between the continental and the oceanic sectors. On Mount Cameroon and Bioko, the main dry season is from December to March, and a shorter dry season occurs from July to August (Juste and Fa 1994). In Príncipe and São Tomé, the long dry season, locally known as *gravana*, extends from June to mid-September, while a shorter dry season, the *gravanito*, lasts for a few weeks that may fall anywhere between mid-December and mid-March (Lains e Silva 1958). Annobón, south of the Equator, has a single extended dry season from mid-May to the end of October (Jones and Tye 2006).

Due to their small area and heterogeneity, modern rainfall and climate measurements based on remote sensing likely do not accurately describe the climate of Príncipe, São Tomé, and Annobón. To the best of our knowledge, until recently Annobón had no functional meteorological station, while there was only one on Príncipe and five on São Tomé, of which only one had been collecting long-term data systematically (Chou et al. 2020). This network was greatly improved over the last decade (https://www.thegef.org/project/strengthening-climate-information-and-early-warning-systems-sao-tome-and-Príncipe-climate), but detailed long-term information on the climate of the islands is still lacking.

The topography of Príncipe and São Tomé islands is similar, resulting in a similar distribution of climatic zones (Diniz and Matos 2002). The high relief areas of the south and center intercept the predominant warm and moist south-westerly winds, creating a striking north–south divide in precipitation (the Foehn effect). The southern-facing regions are "Super Humid," with annual precipitation above

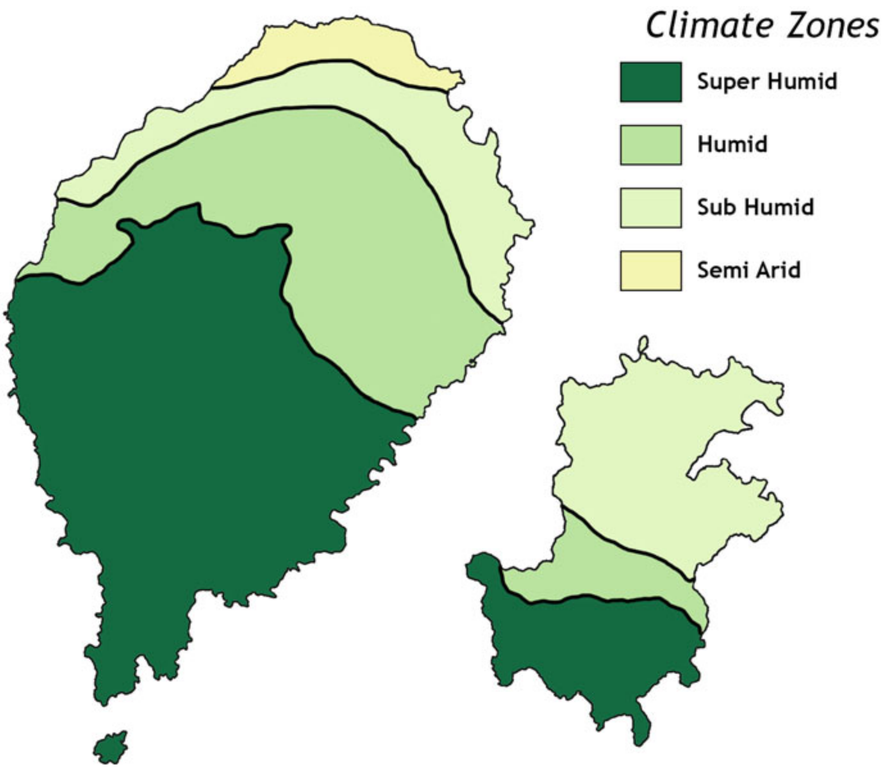

Fig. 2.10 Climatic zones for the islands of São Tomé (left) and Príncipe (right). Adapted from Diniz and Matos (2002)

3000 mm, and often much higher (c. 5000 mm on Príncipe, above 7000 mm on São Tomé—Diniz and Matos 2002), enhanced by extremely high humidity levels and low sun exposure (Fig. 2.10). The north, under the rain-shadow effect, has climatic belts associated with the decreasing levels of humidity with decreasing altitude. The higher slopes benefit from the monsoon winds that pass over the peaks, and have precipitation levels between 1500 and 3000 mm, making the "Humid" belt (Fig. 2.10). Lower down, from the coast to about 400 to 550 m, moderate slopes (below 15%) receive between 1000 and 1500 mm of rain per year, making up the "Sub-Humid" belt, which has a well-defined rainy season (Fig. 2.10). Finally, only on São Tomé, the littoral area in the flatter N-NE platform, below 1000 m, has a "Semi-Arid" belt that has annual precipitation levels between 600 and 1000 mm (Fig. 2.10). This general zonation, with more humid climates in the south and drier climates in the north, also seems to apply to Annobón and to the continental islands. Annual precipitation on the southwestern slopes of Mount Cameroon may be over 10,000 mm, and between 1500 and 2000 mm in the northern slopes. In the south of Bioko Island, annual precipitation can be over 11,000 mm (Juste and Fa 1994) while the capital Malabo, in the north, receives <2000 mm/year.

Wind and Ocean Currents

Understanding the wind and ocean currents is fundamental to infer potential colonization pathways for island fauna and flora. The prevailing winds in the Gulf of Guinea are the southwestern monsoon winds and the northern dry harmattan winds. The southwestern monsoon winds are unlikely to have dispersed colonizers from continental Africa but may have played a role in southwest-to-northeast dispersal between islands. During glacial cycles, the northern dry harmattan winds extended their influence southward, displacing the meteorological equator further south (Lézine et al. 1994), likely having a more important role in bringing colonizers to the island during those periods.

Data on sea surface currents originate from a combination of historical ship drifts, hydrographical data, surface-drifting buoy trajectories, and Argo floats surface drifts (Richardson and Walsh 1986; Arnault 1987; Stramma and Schott 1999; Renner 2004; Lumpkin and Garzoli 2005; Ollitrault and Rannou 2013). The Gulf of Guinea is dominated by two currents (northward and eastward) that follow the shoreline. In the north, the eastward current, also known as Guinea Current (GC), moves west to east along the southern coast of West Africa, and, when reaching the Biafra Bay, converges with the northward current and becomes more diffuse, turning back westward around the Equator (Feiler 1988; Haft 1993; Dupont et al. 2000; Fig. 2.11). In the southeast, the northward current, known as the Benguela Current (BC), moves along the northern coast of South Africa, the coast of Namibia, and is diverted west to the Atlantic around the mouth of the Cunene River, the natural and political border between Namibia and Angola. It also feeds the South Equatorial Current (SEC), which represents the northern limb of the South Atlantic Ocean subtropical gyre (Philander 2001; Rodrigues et al. 2007). Moving north, the coast of Angola is dominated by two different currents, the Benguela Coastal Current (BCC), a cold and less-saline northward flow, and the Angola Current (AC), a fast and narrow southward geostrophic flow of warm and saline water found between the equatorial band and about 15°S. The intersection of these two currents, around 15°S, is known as the Angola Benguela Front (Hopkins et al. 2013; Lass and Mohrholz 2008, their Fig. 1; Houndegnotono et al. 2021, their Fig. 1b). The discharge of the Congo River, which extends offshore as the Congo River plume, is a thin layer (3 m thick at the river mouth) of fresher/lower salinity water. This freshwater plume is entrained mostly westward, through Ekman-driven circulation in which the wind deflects surface water to the left of its direction in the southern hemisphere.

Ocean currents are important for understanding the biogeographic history of aquatic organisms and terrestrial organisms that disperse in water—such as some seed plants—but, in the Gulf of Guinea, they may also hold the key to understanding how many non-volant, non-swimming, or salt-intolerant species made their way to the islands (Melo et al. 2022). The prevailing hypothesis to explain the origin of such unlikely oceanic island taxa proposes that they came as passengers of natural rafts that drifted to the islands along "freshwater pathways" on the ocean surface (Measey et al. 2007). Such rafts would reach the islands along "freshwater pathways" created

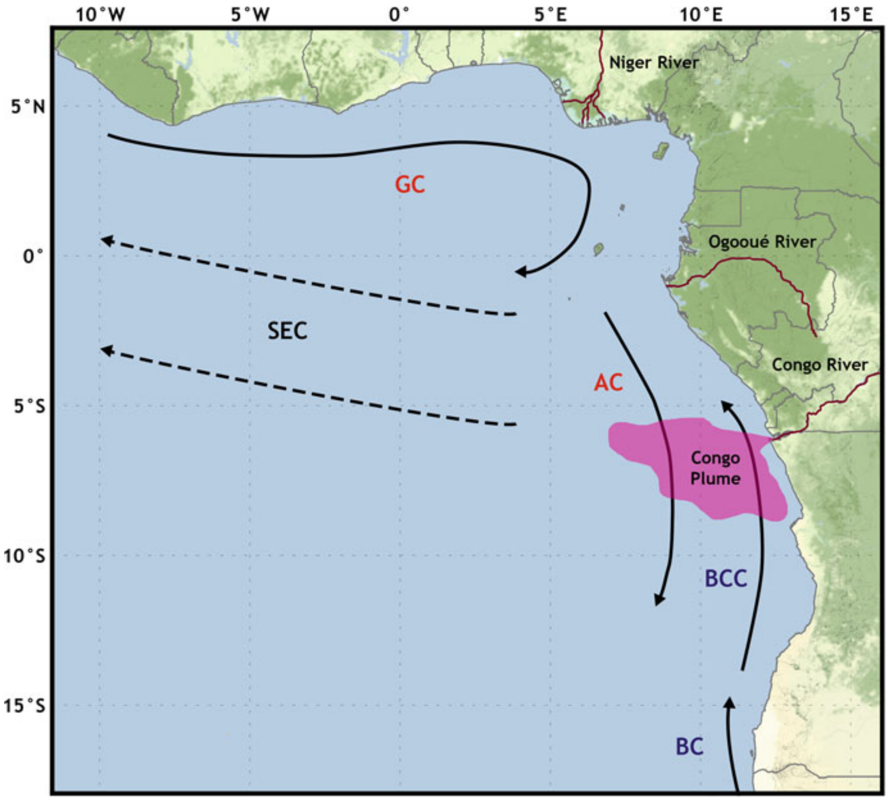

Fig. 2.11 Main ocean currents in the Gulf of Guinea. Angolan Current (AC), Benguela Current (AC), Benguela Coastal Current (BCC), Guinea Current (GC), and South Equatorial Current (SEC). Warm currents in red; cold currents in dark blue

by the large input of freshwater plumes and precipitation into the Gulf of Guinea (Fig. 2.11; Dessier and Donguy 1994; Large and Yeager 2009; Hopkins et al. 2013; Berger et al. 2014). Because saltwater is denser than freshwater, during the rainy season the ocean surface in the Gulf of Guinea exhibits reduced salinity—a well-known phenomenon by local fishermen (Measey et al. 2007; Hopkins et al. 2013). These "freshwater pathways" would give the rafts some protection against saltwater as they cross the sea.

The Gulf of Guinea receives the freshwater discharge of three major rivers that originate from different regions: the Niger in West Africa, the Congo in East-Central Africa, and the Ogooué in West-Central Africa (Fig. 2.12). The Congo River is only second to the Amazon in terms of discharge, having an average discharge of $40\times10^3\ m^3s^{-1}$ (Mahé and Olivry 1999), while the Niger River has about $7\times10^3\ m^3s^{-1}$ (Dai and Trenberth 2002). When reaching the ocean, these waters are directed toward the islands by the surface currents of the Atlantic Ocean.

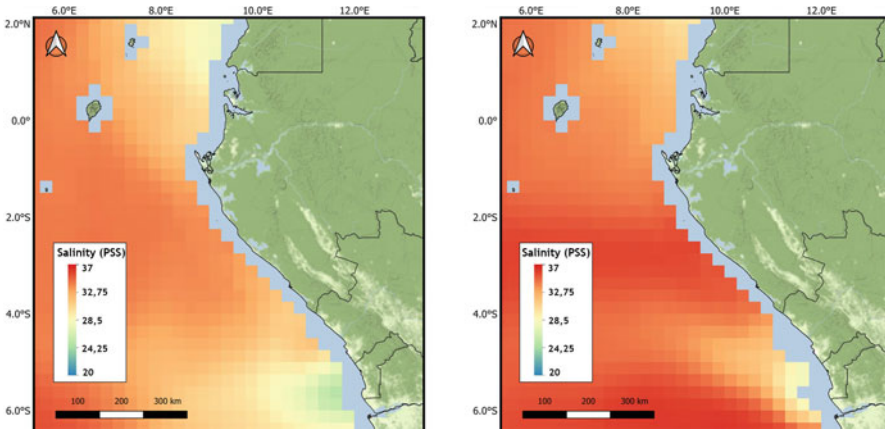

Fig. 2.12 Monthly average sea surface salinity for the months of February (left) and July (right) 2021. Values displayed with a range of 20 and 37 using the Practical Salinity Scale (PSS), roughly equivalent to parts per thousand of salt. Data from the Remote Sensing Systems SMAP Ocean Surface Salinities [Level 3 Monthly] Dataset, Version 4.0 validated release (Meissner et al. 2019)

Although the mouth of the Ogooué River is the closest to the islands (approximately 250 km), the currents in the Gulf of Guinea direct the freshwater plumes from the Niger and Congo rivers toward the islands (Richardson and Walsh 1986), such that vegetation rafts originating in the more distant West and East African drainages may also reach the islands.

Conclusions

Despite their small area, the oceanic islands of the Gulf of Guinea include a wealth of geological substrates and topographical features that underlie the development of diverse soils and micro-climates (Fig. 2.2). This diversity of geological features has been recognized by ten formations being proposed as geosites on São Tomé Island, which have a wide range of cultural, scientific, and scenic values (Henriques and Neto 2015). These landscapes have also promoted the appearance of distinct ecosystems (Dauby et al. 2022) and species (Melo et al. 2022). The location of the islands, at moderate distances from the mainland and at the crossroads of freshwater plumes from three large rivers, has likely further contributed toward the assembly of their rich biological communities. These rivers are thought to have been the source of natural rafts bringing species that would otherwise be unable to cross saltwater barriers.

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References

Ali JR (2018) Islands as biological substrates: continental. Journal of Biogeography 45:1003–1018

Ali JR, Aitchison JC (2014) Exploring the combined role of eustasy and oceanic island subsidence in shaping biodiversity on the Galápagos. Journal of Biogeography 41:1227–1241

Arnault S (1987) Tropical Atlantic geostrophic currents and ship drifts. Journal of Geophysical Research 92:5076–5088

Assunção CFT (1956) Lavas feldspatóidicas de São Tomé. Conf Int Africanistas Ocidentais 6ª Sess 2:11–17

Assunção CFT (1957) Alguns aspectos de petrografia da Ilha de S. Tomé. Garcia de Orta 5(3): 497–515

Barfod DN, Fitton JG (2014) Pleistocene volcanism on São Tomé, Gulf of Guinea, West Africa. Quaternary Geochronology 21:77–89

Barros LA (1960) A Ilha do Príncipe e a "linha dos Camarões" (Estudo Petrológico). Memórias da Junta de Investigação do Ultramar, Segunda Série 17:1–127

Berger H, Treguier AM, Perenne N, Talandier C (2014) Dynamical contribution to sea surface salinity variations in the eastern Gulf of Guinea based on numerical modelling. Climate Dynamics 43(11):3105–3122

Burke K (2001) Origin of the Cameroon line of volcano-capped swells. Journal of Geology 109: 349–362

Caldeira R (2006) Estudo petrológico e geoquímico dos xenólitos e das lavas da ilha de São Tomé (Arquipélago de São Tomé e Príncipe. PhD thesis, Universidade de Lisboa, Lisbon, 322 pp

Caldeira R, Madeira J, Munhá JM et al (2003) Caracterização das principais unidades vulcano-estratigráficas da ilha de São Tomé, Golfo da Guiné. Ciências da Terra (UNL) n° esp. V:A15–A18

Cardoso JC (1958) Os solos de São Tomé e Príncipe (Seu Estudo Preliminar). Revista do Café Português 5(17):9–44

Cardoso JC, Garcia JS (1962) Carta dos solos de São Tomé e Príncipe. Memórias da Junta de Investigação do Ultramar, Segunda Série 39:1–306 + 12 plates + 2 maps

Carvalho AF (1921) Estudo microscópico de rochas da ilha de São Tomé. Memórias e Notícias - Publicações do Museu e Laboratório Mineralógico e Geológico da Universidade de Coimbra e do Centro de Estudos Geológicos 1:9–25

Ceríaco LMP, Bernstein J, Sousa AC et al (2020) The reptiles of Tinhosa Grande islet (Gulf of Guinea): a taxonomic update and the role of Quaternary Sea level fluctuations in their diversification. African Journal of Herpetology 69(2):200–216

Ceríaco LMP, Lima RF, Bell RC, Melo M (2022) Biodiversity in the Gulf of Guinea oceanic islands: a synthesis. In: Ceríaco LMP, Lima RF, Melo M, Bell RC (eds) Biodiversity of the Gulf of Guinea oceanic islands. Springer, Cham, pp 1–12

Chou SC, de Arruda LA, Gomes JL et al (2020) Downscaling projections of climate change in São Tomé and Príncipe Islands, Africa. Climate Dynamics 54:4021–4042

Cornen G, Maury RC (1980) Petrology of the volcanic island of Annobón, Gulf of Guinea. Marine Geology 36(1–4):253–267

Dai A, Trenberth KE (2002) Estimates of freshwater discharge from continents: latitudinal and seasonal variations. Journal of Hydrometeorology 3(6):660–687

Dauby G, Stévart T, Barberá P et al (2022) Classification, distribution, and biodiversity of terrestrial ecosystems in the Gulf of Guinea oceanic islands. In: Ceríaco LMP, Lima RF, Melo M, Bell RC (eds) Biodiversity of the Gulf of Guinea oceanic islands. Springer, Cham, pp 37–70

De Castro ML, De la Calle ML (1985) Geografía de Guinea Ecuatorial. Secretaría General Técnica. Ministerio de Educación y Ciencia, Madrid, 7 pp

Dessier A, Donguy JR (1994) The sea surface salinity in the tropical Atlantic between 10°S and 30°N – seasonal and interannual variations (1977–1989). Deep Sea Research Part I: Oceanographic Research Papers 41(1):81–100

Diniz AC, Matos GC (2002) Carta da zonagem agro-ecológica e da vegetação de S. Tomé e Príncipe. Garcia de Orta, Série Botânica 15(2):1–72

Dupont L, Schmüser A, Jahns S, Schneider R (2000) Marine-terrestrial interaction of climate changes is west equatorial Africa of the last 190,000 years. Palaeoecology of Africa 26:61–84

Einsentraut M (1965) Rassenbildung bei Säugetiernen und vogeln auf der Insel Fernando Poo. Zoologischer Anzeiger 174:37–53

Fa JE (1991) Conservación de los ecosistemas forestales de Guinea Ecuatorial. IUCN, Gland and Cambridge (UK), 221 pp

Feiler A (1988) Die Säugetiere der Insel im Golf von Guinea und ihre Beziehungen zur Säugetierfauna des westafrikanischen Festlandes (Mammalia). Zoologische Abhandlungen – Staatliches Museum für Tierkunde Dresden 44(1):83–88

Fernández-Palacios JM (2016) Island biogeography: shaped by sea-level shifts. Nature 532(7597): 42–43

Fitton JG (1987) The Cameroon line, West Africa: a comparison between oceanic and continental alkaline volcanism. In: Fitton JG, Upton BGJ (eds) Alkaline igneous rocks. Geological Society Special Publication N° 30, pp 273–291

Fuster Casas JM (1954) Estudio petrogenético de los volcanes del Golfo de Guinea. Instituto de Estudios Africanos, Madrid, p 152

Gascoigne A (2004) São Tomé, Príncipe, and Annobón moist lowland forests. In: Burgess N, D'Amico Hales J, Underwood E et al (eds) Terrestrial ecoregions of Africa and Madagascar: a conservation assessment. Island Press, Washington, pp 236–238

GEBCO Compilation Group (2021) GEBCO 2021 grid. https://doi.org/10.5285/c6612cbe-50b3-0cff-e053-6c86abc09f8f

Gillespie RG, Roderick GK (2014) Evolution: geology and climate drive diversification. Nature 509:297–298

Haft (1993) Ein Beitrag zur Biologie der Echsen der Insel São Tomé (Golf von Guinea), mit näherer Betrachtung zur Systematik von *Leptosiaphos africana* (Gray) (Reptilia: Sauria: Geckonidae et Scincidae). Faunistische Abhandlungen - Staatliches Museum für Tierkunde Dresden 19(1–16): 59–70

Henriques JA (1917) A Ilha de S. Tomé sob o ponto de vista histórico-natural e agrícola. Boletim da Sociedade Broteriana 27:1–197

Henriques MH, Neto K (2015) Geoheritage at the equator: selected geosites of São Tomé Island (Cameron Line, Central Africa). Sustainability 7:648–667

Hopkins J, Lucas M, Dufau C et al (2013) Detection and variability of the Congo River plume from satellite derived sea surface temperature, salinity, ocean colour and sea level. Remote Sensing of Environment 139:365–385

Houndegnotono OJ, Kolodziejczyk N, Maes C, Bourlès B, Da-Allada CY, Reul N (2021) Seasonal variability of freshwater plumes in the eastern Gulf of Guinea as inferred from satellite measurements. Journal of Geophysical Research: Oceans 126(5):e2020JC017041

Jones PJ (1994) Biodiversity in the Gulf of Guinea: an overview. Biodiversity and Conservation 3: 772–784

Jones PJ, Tye A (2006) The birds of São Tomé and Príncipe, with Annobón: islands of the Gulf of Guinea. BOU checklist, vol 22. British Ornithologists Union, Oxford (UK)

Jones PJ, Burlison JP, Tye A (1991) Conservação dos ecossistemas florestais na República Democrática de São Tomé e Príncipe. IUCN, Gland Cambridge (UK), 78 pp

Juste BJ, Fa JE (1994) Biodiversity conservation in the Gulf of Guinea islands. Biodiversity and Conservation 3:757–758

Lains e Silva H (1958) São Tomé e Príncipe e a cultura do café. Memórias da Junta de Investigação do Ultramar, Segunda Série 1:I–XII + 1–499 + plates and maps

Lains e Silva H, Cardoso JC (1958) Esboço da carta de aptidão agrícola de São Tomé e Príncipe. Garcia de Orta 6(1):61–86 + four plates

Lambeck K, Rouby H, Purcell A, Sun Y, Sambridge M (2014) Sea level and global ice volumes from the last glacial maximum to the Holocene. Proceedings of the National Academy of Sciences USA 111:15296–15303

Lambert K, Chappel J (2001) Sea level change through the last glacial cycle. Science 292:679–686

Large W, Yeager S (2009) The global climatology of an interannually varying air–sea flux dataset. Climate Dynamics 33(2–3):341–364

Lass HU, Mohrholz V (2008) On the interaction between the subtropical gyre and the subtropical cell on the shelf of the SE Atlantic. Journal of Marine Systems 74(1–2):1–43

Lee D-C, Halliday AN, Fitton JG, Poli G (1994) Isotopic variations with distance and time in the volcanic islands of the Cameroon line: evidence for a mantle plume origin. Earth and Planetary Science Letters 123:119–138

Lézine A-M, Tastet J-P, Leroux M (1994) Evidence of atmospheric paleocirculation over the Gulf of Guinea since the last glacial maximum. Quaternary Research 41:390–395

Liotard JM, Dupuy C, Dostal J, Cornen G (1982) Geochemistry of the volcanic island of Annobón, Gulf of Guinea. Chemical Geology 35(1–2):115–128

Lopes JMR (2020) Geocronologia Ar-Ar e geoquímica isotópica de rochas das ilhas de Ano-Bom, São Tomé e Príncipe da linha vulcânica dos Camarões, PhD thesis, Universidade de São Paulo, São Paulo, 83 pp

Lumpkin R, Garzoli SL (2005) Near-surface circulation in the tropical Atlantic Ocean. Deep-Sea Research Part I 52:495–517

Mahé G, Olivry JC (1999) Assessment of freshwater yields to the ocean along the intertropical Atlantic coast of Africa (1951–1989). Comptes Rendus de l'Académie des Sciences-Series IIA-Earth and Planetary Science 328(9):621–626

Measey GJ, Vences M, Drewes RC et al (2007) Freshwater paths into the ocean: molecular phylogeny of the frog *Ptychadena newtoni* gives insights into amphibian colonisation of oceanic islands. Journal of Biogeography 34:7–20

Meissner T, Wentz FJ, Manaster A, Lindsley R (2019) Remote sensing systems SMAP ocean surface salinities [Level 2C, Level 3 running 8-day, Level 3 monthly], version 4.0 validated release. Available via Remote Sensing Systems. www.remss.com/missions/smap. Accessed 7 Oct 2021

Melo M, Ceríaco LMP, Bell RC (2022) Biogeography and evolution in the oceanic islands of the Gulf of Guinea. In: Ceríaco LMP, Lima RF, Melo M, Bell RC (eds) Biodiversity of the Gulf of Guinea oceanic islands. Springer, Cham, pp 141–170

Milá B, Warren BH, Heeb P, Thébaud C (2010) The geographic scale of diversification on islands: genetic and morphological divergence at a very small spatial scale in the Mascarene grey white-eye (Aves: *Zosterops borbonicus*). BMC Evolutionary Biology 10:158

Morgan-Wall T (2021) Rayshader: create maps and visualize data in 2D and 3D. https://www.rayshader.com. Accessed 12 Oct 2021

Moura AR (1961) Contribuição para o conhecimento dos foraminíferos das praias levantadas de S. Tomé e Príncipe. Garcia de Orta 9(4):751–758

Munhá JM, Afonso RS, Caldeira R, Mata J (2002) Estudo Geologico Preliminar da Região Nordeste da ilha de São Tomé (folha n°2 - Ana Chaves). Garcia de Orta (Serie de Geologia) 18(1–2):1–8

Munhá JM, Caldeira R, Madeira J et al (2006a) Folha 1 (Ponta Figo) da *Carta Geológica da ilha de São Tomé (Republica de São Tomé e Príncipe)* na escala 1:25.000. Edição do Centro de Geologia do Instituto de Investigação Científica Tropical (Ministério da Ciência e Tecnologia), Ministério dos Recursos Naturais e Energia (República de São Tomé e Príncipe) e Instituto para a Cooperação do Ministério dos Negócios Estrangeiros (Governo da República Portuguesa)

Munhá JM, Caldeira R, Madeira J et al (2006b) Folha 2 (S.Tomé) da *Carta Geológica da ilha de São Tomé (Republica de São Tomé e Príncipe)* na escala 1:25.000. Edição do Centro de Geologia do Instituto de Investigação Científica Tropical (Ministério da Ciência e Tecnologia), Ministério dos Recursos Naturais e Energia (República de São Tomé e Príncipe) e Instituto para a Cooperação do Ministério dos Negócios Estrangeiros (Governo da República Portuguesa)

Munhá JM, Caldeira R, Madeira J et al (2006c) Folha 4 (Ribeira Afonso) da *Carta Geológica da ilha de São Tomé (Republica de São Tomé e Príncipe)* na escala 1:25.000. Edição do Centro de Geologia do Instituto de Investigação Científica Tropical (Ministério da Ciência e Tecnologia), Ministério dos Recursos Naturais e Energia (República de São Tomé e Príncipe) e Instituto para a Cooperação do Ministério dos Negócios Estrangeiros (Governo da República Portuguesa)

Munhá JM, Caldeira R, Madeira J et al (2006d) Folha 5 (Ihéu das Rolas) da *Carta Geológica da ilha de São Tomé (República de São Tomé e Príncipe)* na escala 1:25.000. Edição do Centro de Geologia do Instituto de Investigação Científica Tropical (Ministério da Ciência e Tecnologia), Ministério dos Recursos Naturais e Energia (República de São Tomé e Príncipe) e Instituto para a Cooperação do Ministério dos Negócios Estrangeiros (Governo da República Portuguesa)

Munhá J, Caldeira R, Madeira J, Mata J, Afonso R (2007) Geologia da ilha de São Tomé. Notícia explicativa da carta geológica na escala 1: 25000. Cooperação Portuguesa – Instituto Português de Apoio ao Desenvolvimento, Lisboa, 41 pp

Neiva JMC (1946) Notas sobre o quimismo das formações eruptivas da ilha de São Tomé. Boletim da Sociedade Geológica de Portugal 5(3):151–158

Neiva JMC (1954) Quelques laves vacuolaires de l'ile de St. Tomé et de l'ilot de Rolas. Garcia de Orta 2(1):53–59

Neiva JMC (1955a) Phonolites de l'ile du Prince. Note préliminaire. Memórias e Notícias – Publicações do Museu e Laboratório Mineralógico e Geológico da Universidade de Coimbra e do Centro de Estudos Geológicos 38:46–52

Neiva JMC (1955b) Phonolites de l'ile du Prince. Garcia de Orta 3(4):505–515

Neiva JMC (1956a) Contribuição para o estudo geológico e geomorfológico da ilha de S. Tomé e dos ilhéus das rolas e das cabras. Conferência Internacional dos Africanistas Ocidentais, 6ª Sessão 2:147–153

Neiva JMC (1956b) Contribuição para a geologia e geomorfologia da ilha do Príncipe. Conferência Internacional dos Africanistas Ocidentais, 6ª Sessão 2:157–162

Neiva JMC (1956c) Contribuição para a petrografia das ilhas de São Tomé e Príncipe e dos ilhéus das Rolas, das Cabras e Boné-de-Jockey. Conferência Internacional dos Africanistas Ocidentais, 6ª Sessão 2:155

Neiva JMC, Neves JMC (1956) Laterites da ilha do Príncipe. Conferência Internacional dos Africanistas Ocidentais, 6ª Sessão 2:169–176

Neiva JMC, Pureza FG (1956) Contribuição para o conhecimento das areias das praias das ilhas de São Tomé e Príncipe. Conferência Internacional dos Africanistas Ocidentais, 6ª Sessão 2:163–197

Norder SJ, Baumgartner JB, Borges PAV et al (2018) A global spatially explicit database of changes in island palaeo-area and archipelago configuration during the late Quaternary. Global Ecology and Biogeography 27(5):500–505

Norder SJ, Proios K, Whittaker RJ et al (2019) Beyond the last glacial maximum: island endemism is best explained by long-lasting archipelago configurations. Global Ecology and Biogeography 28(2):184–197

Ollitrault M, Rannou J-P (2013) ANDRO: an argo-based deep displacement dataset. Journal of Atmospheric and Oceanic Technology 30(4):759–788
Pereira JS (1943) Subsidios geológicos e petrológicos para o conhecimento da ilha de S. Tomé. Boletim da Sociedade Geológica de Portugal 3(3):125–144
Philander SG (2001) Atlantic Ocean equatorial currents. In: Steele JH (ed) Encyclopedia of ocean sciences. Academic Press, Oxford (UK), pp 188–191
Pissarra JB, Rocha AT (1963) Contribuição para o estudo mineralógico e da microfauna dos regossolos psamíticos calcários de São Tomé. Garcia de Orta 11(1):171–178
Pissarra JB, Cardoso JC, Garcia JS (1965) Mineralogia dos solos de São Tomé e Príncipe. Memórias da Junta de Investigação do Ultramar, Segunda Série 118:1–118
Ramalho RS, Winckler G, Madeira J et al (2015) Hazard potential of volcanic flank collapses raised by new megatsunami evidence. Science Advances 1(9):e1500456
Renner S (2004) Plant dispersal across the tropical Atlantic by wind and sea currents. International Journal of Plant Sciences 165(4 Suppl):S23–S33
Richardson PL, Walsh D (1986) Mapping climatological seasonal variations of surface currents in the tropical Atlantic using ship drifts. Journal of Geophysical Research 91:10537–10550
Rijsdijk KF, Hengl T, Norder SJ et al (2014) Quantifying surface-area changes of volcanic islands driven by Pleistocene sea-level cycles: biogeographical implications for the Macaronesian archipelagos. Journal of Biogeography 41(7):1242–1254
Rodrigues FMC (1974) S. Tomé e Príncipe sob o ponto de vista agrícola. Junta de Investigações Científicas do Ultramar, Estudo, Ensaios e Documentos 130:1–180 + 25 plates + maps (130-A)
Rodrigues RR, Rothstein LM, Wimbush M (2007) Seasonal variability of the south equatorial current bifurcation in the Atlantic Ocean: a numerical study. American Metereological Society 37:16–30
Schlüter T (2008) Geological atlas of Africa. Springer, Berlin, Heidelberg, I–XI, 307 pp
Schultze A (1913) Die insel Annobón im Golf von Guinea. Petermann's Geographische Mitteilungen Jahrbuch 59:131–133
Serralheiro AR (1957) Novos elementos para o conhecimento da fauna fóssil do Miocénico da ilha do Príncipe. Garcia de Orta 5(2):287–296
Silva GH (1956a) O Miocénico da ilha do Príncipe. Conferência Internacional dos Africanistas Ocidentais, 6ª Sessão 2:231–256
Silva GH (1956b) La fauna Miocène de l'ile du Prince. Memórias e Notícias – Publicações do Museu e Laboratório Mineralógico e Geológico da Universidade de Coimbra e do Centro de Estudos Geológicos 42:29–51
Silva GH (1958a) Nota sobre a microfauna do Miocénico marinho da ilha do Príncipe. Memórias e Notícias – Publicações do Museu e Laboratório Mineralógico e Geológico da Universidade de Coimbra e do Centro de Estudos Geológicos 45:56–60
Silva GH (1958b) Contribuição para o conhecimento da microfauna do Miocénico marinha da ilha do Príncipe. Garcia de Orta 6:507–510
Stramma L, Schott F (1999) The mean flow field of the tropical Atlantic Ocean. Deep-Sea Research Part II 46:279–303
Teixeira C (1948–1949) Notas sobre a geologia das ilhas de São Tomé e Príncipe. Estudos Coloniais 1(1):37–46
Teixeira C (1949) Geologia das ilhas de S. Tomé e do Príncipe e do território de S. João Baptista de Ajudá. Anais da Junta das Missões Geográficas e de Investigações Coloniais 4(2):1–20
Tenreiro F (1961) A ilha de São Tomé. Memórias da Junta de Investigação do Ultramar, Segunda Série 24:1–289 + 73 plates
Tyrrell GW (1934) Petrographical notes on rocks from the Gulf of Guinea. Geological Magazine 71(1):16–22
Velayos M, Barberá P, Cabezas FJ et al (2014) Checklist of the vascular plants of Annobón (Equatorial Guinea). Phytotaxa 171:1–78
Weigelt P, Steinbauer MJ, Cabral JS, Kreft H (2016) Late quaternary climate change shapes island biodiversity. Nature 532:99–102