Natural Landscapes Along Brazilian Coastline

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Abstract

The Brazilian coastline extends from 8500 km from Northern Hemisphere 4° to the 34° in South Latitude, covering different natural landscapes. By landscapes, we understand the relationship between geomorphological and geological conditions and vegetation cover, and process involving climate and oceanography that shape the landscapes. This chapter presents a synthesis or an overview of different landscape patterns observed along the Brazilian coastline. Using this simple approach, we regionalized five different segments where we observe common landscape characteristics. The first two segments (northern and northeastern) is part of Caraíba alignment, i.e., NNE to SSW alignment. Three others refer to Brasiliana direction, where the coastline assumes predominant NNE to SSW pattern. The northern segment is classified as tidal flats in association of several estuaries, covered by mangroves in an equatorial zone and extended from Cape Orange to São Marcos Bay. Coastal dunes and Neogene predominant rocky coasts, with savannas distributed in the semiarid zone, are classified as northeastern landscape domain. This second segment marks the landscapes individualized from São Marcos Bay to Cape Calcanhar. The inflection to the S/SE direction, from Cabo Calcanhar to Cape Frio, the eastern coastline is marked by Neogene rocky coasts and wave-dominated deltas covered by Atlantic rainforest, along the tropical zone. It is important to mention that series of coral reefs disperse close to the coastline. From Cape Frio to Cape Santa Marta, the southeastern region is defined by granitic and gneisses rocky coast, and narrow coastal

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plains, covered by Atlantic rainforests, in the tropical zone. The last segment, in the southern part of Brazil, is characterized by Quaternary plains formed by coastal sandy barriers and lagoons with Restingas vegetation, distributed in tempered climate condition. At the end of this chapter, we present some information regarding oceanic volcanic islands as part of Brazilian territory, showing predominant landscapes vary from shore platforms and beaches formed by carbonate materials and siliciclastic sediments. Along each segment, we mention some problems regarding coastal erosion and other typical problems associated with pressure of socioeconomic activities.

Keywords
Coastal sandy barriers · Rocky coasts
Coastal dunes · Estuaries

10.1 Introduction

The Brazilian coastline extends approximately 8500 km from Cape Orange, in the north, around latitude 4° 0′ 40″N, in the state of Amapá, to Chuí, in the south, at latitude 33° 44′ 38″S, in the state of Rio Grande do Sul (Fig. 10.1). Along the shoreline, due to the different geobiophysical factors, it is possible to observe several different landscapes, involving the relationship between geological and geomorphological characteristics, with a hydrodynamic process, such as waves, tides, and currents, in relation with climate and vegetation. In fact, we assume that a landscape reflects elements from climatic conditions, vegetation pattern, geological and geomorphological components, and oceanography. The continuous interrelationship between these factors, noted along the regional scale, will determine coastal segments with similar landscapes characteristics, and for instance, individualizing certain landscape units. Other authors as Silveira (1964), Villwock and Tomazelli (1995), Muehe (1998), Tessler and Goya (2005), Dominguez (2009), and more recently by Klein and Short (2016), interpreted the coastline with different objectives and present some regionalization that we consider and support the regionalization proposed here. To facilitate the understanding of the boundaries of these regions or segments, we define some specific points geographically along the coast, which are easily recognized, such as cables and bays. In this way, we analyze these landscapes based on the main physical elements of the coast, considering a brief presentation of the main geological and geomorphological elements that mark the South American platform, the latitudinal distribution of the winds and their relationship with wave climate, and the vegetation patterns. After the briefing words, we prepare a series of maps and pictures to represent and hope to create the conditions for a better understanding of Brazilian coastal landscapes, and we recognize that is a challenge to summarize 8500 km of highly diverse environments in five different regional sectors.

Observing the Brazilian shoreline alignment, we can divide the coastline into two different segments, using the Cape Calcanhar as a vertex (Fig. 10.1). In this case, the shoreline between Cape Orange to Cape Calcanhar is called **Caraíba** alignment, and another one, between Cabo Calcanhar to Chuí, is named **Brasiliana** segment. These two shoreline alignments differ regarding orientation, where the first one **Caraíba**, refers to NNW to SE direction, and **Brasiliana** is from Cabo Calcanhar to the south; assume NE to SW direction. These two different areas refer to geological inheritance regarding breakup of Pangea, occurring during late Jurassic to Cretaceous (Muehe 1998; Tessler and Goya 2005). The rift and drift phases since the Mesozoic to Cenozoic promote this division. During the drift phase, continental and ocean sediments filled several ocean basins are observed along the Brazilian margin, as a result of tectonism occurred since the origin of the Atlantic. Along the coastline the most prominent geological aspect is regarding to Barreiras formation. The Barreiras formation is composed by marine and continental sediments, deposit since the Neogene to Pleistocene, forming a series of table relief cover more than 5000 km, from Amazonas to

Fig. 10.1 Brazilian map with the main capes and geographic points that divide different landscapes along the coastline. The northern littoral is defined between Cape Orange to São Marcos Bay, where the coastline is marked by Quaternary coastal plain, influenced by the macrotidal regime by forming estuaries and mangroves. The northeastern coastline is marked by transgressive coastal dunes and cliffs covered by savannas, distributed between São Marcos Bay and Cape Calcanhar. These two segments represent Caraíba alignment; i.e., the coastline assumes NNE to SSE direction. From Cape Calcanhar to the south, the shoreline presents NNE to SSW predominant alignment. The east segment covers the coastline between Cape Calcanhar to Cape Frio, and landscape is marked by cliffs and wave-dominated deltas, covered by rainforest named Mata Atlantica. From Cape Frio to Cape Santa Marta, the coastline is defined by rocky coasts, a narrow coastal plain, mainly covered by Mata Atlantica. The southern segment is defined by wave-dominated Quaternary coastal plains covered by the same vegetation mentioned. See the text for more details

Rio de Janeiro (for a excellent explanation about specific issues about the geological patterns of Barreiras, see Rosseti et al 2013). We instead in parts of the country, rocks formed during the Precambrian, domain the landscapes, identified by granites and gneisses, noted along the southeast coast. During the Oligocene to Miocene, series of rifts and grabens formed close to the Atlantic inhibit large coastal plains formation.

Quaternary deposits and coastal plains are the main geomorphological features observed along northern part and southern part of Brazil. The differences between these areas remain to be tide-dominated deposits in the north, forming low gradient mud flats, and in the south, the coastal plains are characterized by series coastal sandy barriers and lagoons. The sediment provenience observed in the north comes from a modern material mainly from Amazon River and influenced by the macrotidal regime. On the other hand, in the Quaternary deposits observed in the south, the sediment source is derived from the shoreface and inner continental shelf.

Regarding oceanographic conditions, the distribution of the main wave directions was defined by Pianca et al. (2010) that summarizes the pattern of wave heights and wave periods along the Brazilian coast. In this work, the authors analyzed eleven years of time series, modeling in NWW3 reanalyzes, between January 1997 and December 2007. The results provide by Pianca et al. (2010) found that the southern sector (Cape Chuí to Cape Santa Marta) and southeastern sector (Cabo Santa Marta to Cape Frio) receive the most energetic waves, generated by cold fronts, formed in high latitudes, and migrate to the north. The waves observed by these synoptic events, especially during autumn and winter, normally reach more than 4 m, with south to southwest directions. The fair weather conditions create waves from northeast to east, which rarely reaches more than 2 m. The wave height diminishes in the east, northeast, and north sector. The semipermanent anticyclone generates trade winds and fair weather waves, which reach the coastline with southeast to east directions.

The tide distribution along the Brazilian coast trends to the opposite pattern, compared to the ocean waves. In the northern coast, we observe macrotidal regime and trends to mesotidal in the northeast and east sector. In southeastern and south coastline, the tidal amplitude is less than 2 m, classified as microtidal area.

The climate conditions observed along Brazilian coastline was summarized by Alvares et al. (2013), using Koppen criteria. According to the authors, the northern part of Brazil is dominated by Am (Tropical—monsoon) climate type. In northeastern part, the climate moves to As (Tropical—with dry season) and reach BSh (semi-arid—low latitude and altitude), close to Cape Calcanhar, showing the trends in a decrease of rainfall in eastern direction. From Cape Calcanhar to Cape Frio, the climate varies from As to Af (tropical without dry season), especially from 10° to 20° in latitude. From Cape to the south, Alvares et al. (2013) identified the predominance of humid subtropical with hot summer (Cfa).

After this brief introduction, this chapter is dedicated to explaining the landscapes observed along the Brazilian coast.

10.2 Northern Coast: Macrotidal Estuaries and Mangroves/ Amazon Rainforest Along Equatorial Zone

The northern coast of Brazil reaches from Cape Orange, close to the border with French Guyana, to São Marcos Bay (Fig. 10.2—Top). It is possible to observe some differences along the northern coastline considered sub-regions observed in Fig. 10.2a and b, both representing the landscapes formed by intensive modern fine sediments derived from the fluvial input, macrotidal regimes, equatorial warm, and rainy climate conditions and vegetated by mangroves and in some parts of the coastline by Amazon rainforest.

From the Cape Orange to the south, we noted a tidal flat formed by mud material (Anthony et al. 2010), which comes from Amazon River, and derived in north direction by southeast waves. Along the coastline, it is possible to note

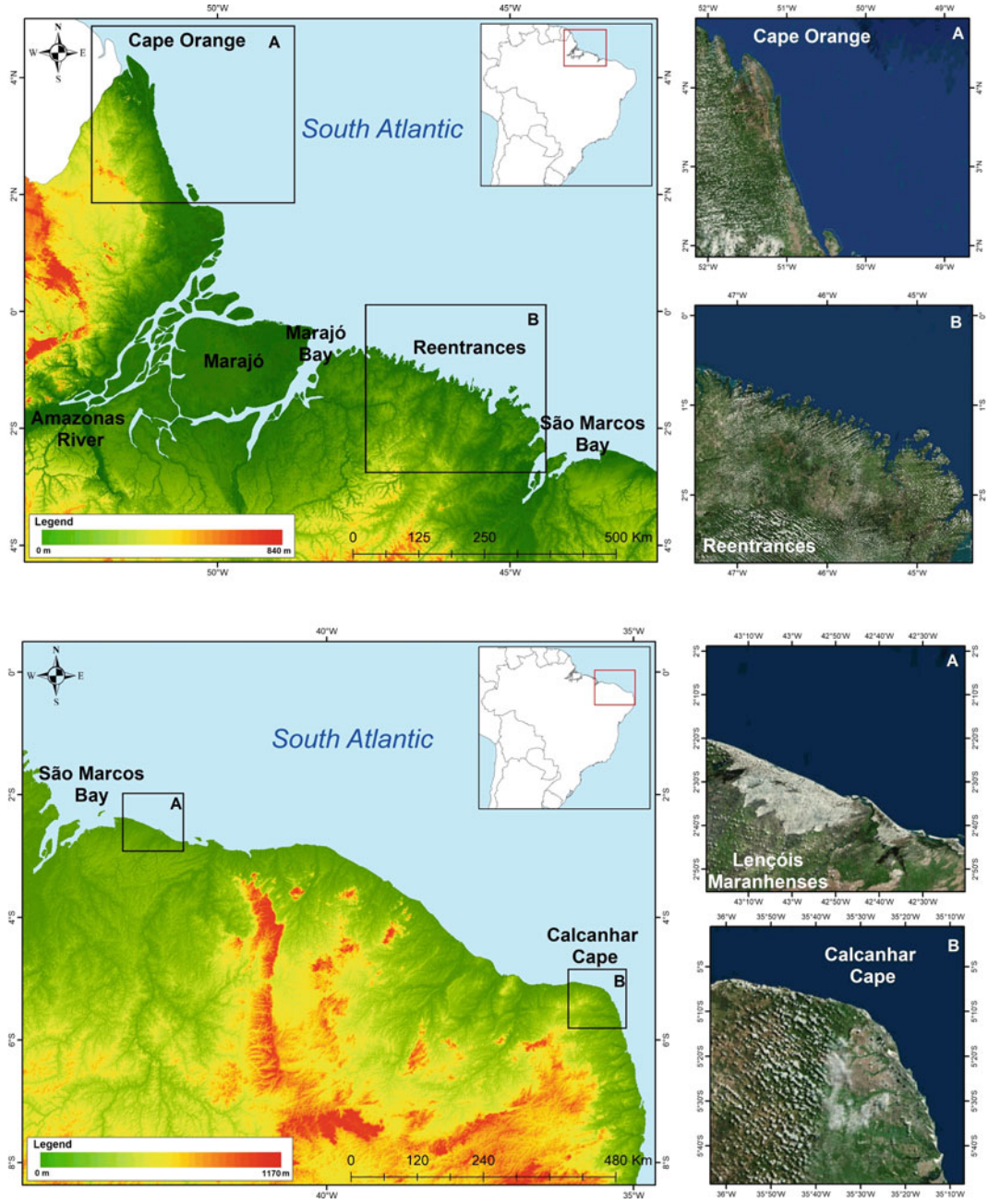

Fig. 10.2 Caraíba alignment, where included the northern and northeastern segments. In the **top**, the northern coastline characterized by fluvial input from Amazon River, Quaternary tidal flats and covered by mangroves. In detail (**a**) the extreme part of the coast, this area presents a continuous coastal flat feature, highly influenced by Amazon sediments that move northward by waves and currents, and influenced by macrotidal regime. (**b**) This area is markedly influenced by modern sediments and reworking material by waves, tides, and winds, forming the "Reentrâncias," which means sequences of estuaries. The end part (eastern direction) of this coast is commonly observed transgressive coastal dunes and macrotidal beaches. The map **above**, the northeastern coastline of Brazil between São Marcos Bay and Cape Calcanhar. This area presents main representative landscapes by transgressive dunefields and Neogene coastal cliffs. The typical vegetation is called Caatinga (savanna). **a** Landsat satellite image from Lençois Maranhenses, the largest transgressive dunefields. **b** The influence area of Cape Calcanhar, where coastal cliffs are the most common morphology but are possible to notice the occurrence of transgressive dunefields, and inflection of coastline direction

the formation of a series of river/marine banks as shown in Figs. 10.3a. In this area, Santos et al. (2016) among the predominant tidal flats noted the occurrence of some sandy beaches along the coastline, and the authors noted that, even with high sediments available, most of the coastline presented some erosional aspects. Therefore, beach and tidal sand/mudflats and the predominant mangrove vegetation can define the major landscape in the sub-region.

Close to the Amazon River mouth, we can observe probably the most impressive river/marine archipelago, where Marajó Island represents the largest island in Brazil (Fig. 10.2—Top). Santos et al. (2016) presented a synthesis of the beach morphodynamics observed and noted the influence of fine sands along the coastline, promoting ultra-dissipative beaches. The fine sandy beaches improve the tourism and recreation, even in mangrove and

Fig. 10.3 Representative landscapes along the northern coast from Brazil. **a** Tidal flats exposed during low spring tide close to Cape Orange (Amapá coastline). **b** Mangrove forest along Pará coastline; note that sand sediments can be found along the margins, close to Salinópolis (0° 36′ 24″N; 47° 22′ 13″W)

predominant mud coastline (Sousa et al. 2011). The Quaternary history of Marajó Island was recently presented by Cohen et al. (2015), and the influence of global climate in the distribution of mangrove and the rainforest is identified. It is possible to identify some areas with predominant mangroves and others, with less influence of salt water and cover by Amazon rainforest.

From the south of Amazon River to the São Marcos Bay, the landscapes change from a continuous and maybe monotonous mud/fine sand coastline, from a series of estuaries, predominantly covered by mangroves, called Reentrâncias (Souza Filho et al. 2009), observed in detail in Fig. 10.2b. Fine fluvial sands input and tide-dominated deposits influence directly this landscapes pattern, and the mud materials support the mangroves as noted for example by (Asp et al. 2016). The landscapes observed along the estuaries are well represented by Fig. 10.3b, where it is possible to see during the low tide the mangrove forest. The increase of sand materials available from the rivers is a result of dissection from Barreiras Formation (see in detail in the northeastern landscapes). In contact between the fluvial and ocean environments, it is possible to identify beaches presenting ultra-dissipative characteristics, with several sandbanks exposed during the low tide (Carneiro et al. 2016), as shown in Fig. 10.3b. Souza Filho et al. (2009) also mentioned the formation of transgressive dunefields along the coastline. These dunefields are directly associated with southeast prevail winds that remove sand materials in onshore direction. The intensity morphodynamics between beach dune and fluvial supply causes in several parts coastal erosion, noted by dead mangroves trees.

Therefore, in the eastward direction, the coastline landscapes move from typical tidal flats covered by mangroves and Amazon rainforest to a complex estuarine and transgressive dunefields, reaching the largest Bay in Brazil, observed in Maranhão state, São Marcos Bay, that geographically ends the northern landscapes.

10.3 Northeastern Landscapes: Coastal Dunes and Tertiary Coastal Cliffs Covered by Savannas in a Semiarid Zone

The coastline between São Marcos Bay and Cape Calcanhar (Fig. 10.2) is characterized by transgressive coastal dunes, influenced directly by trade winds from the southeast direction (see, e.g., Hilbert et al. 2015; Guedes et al. 2017). In the same region, it is possible to notice active cliffs and paleo cliffs, geologically formed by Barreiras Formation. Barreiras Formation maybe the most important geological unit that prevails along the Brazilian coastline (Rosseti et al. 2013). These Neogene deposits spread from the south continental area close to Amazon River month to Cape Frio (23° S) and have domain more than 5000 km along the equatorial and eastern margin of Brazil. The geology of Barreiras is characterized by unconsolidated siliciclastic and in some areas is possible to identify lawyers of carbonates materials, developed during transitional marine to fluvial environments, capped by Quaternary sediments (Rosseti et al. 2013). It is relatively easy to identify the geomorphology of Barreiras Formation by tablelands and in contact with the Atlantic, forming active and inactive rocky coasts. The effect of transgressive and regressive events along the Quaternary, eroding the Barreiras Formation, promotes a sandy continental shelf along most of the Brazilian coastline, and it is an important source for sediment supply for beaches and dunefields observed in northeastern Brazil (Paula et al. 2016; Pinheiro et al. 2016; Vital et al. 2016).

Between São Marcos bay to Cape Calcanhar, rainfall tends to decrease (Alvares et al. 2013) and the vegetation cover changes from rainforest and mangrove to Caatinga (Savannah) and/or Restinga. This type of vegetation registers the impact of the semi-arid conditions observed eastward. Along the coastline, close to the river mouths, specially in Ceará and Rio Grande do Norte coastline, the estuaries recently receive many marine shrimp farms, becoming an important socioeconomic activity and environmental issue.

Close to the São Marcos Bay, the most representative transgressive dunefields of Brazil, named Lençois Maranhanses, mark this region. Hilbert et al. (2016) indicate that the sediment supply comes from different river mouths surrounding the area, also to sandy sediments available in the shoreface. The transgressive dunefileds present sequences of bachanoids, and during March to June, it is common between the coastal dunes, the formation of several lagoons along the coastal plain (Fig. 10.4a).

In eastward direction, the transgressive dunefields trend to become the most representative landscape with the increase of semi-arid conditions. The impact of semi-arid conditions is noted by savanna vegetation (IBGE 1992). Before describing the landscapes in Ceara and Rio Grande do Norte, the Parnaíba Delta marks the northeast coastline. The Parnaiba Delta includes

Fig. 10.4 Landscapes prevailed along northeastern coastline. **a** Lençois Maranhenses National Park where it is possible to see the water table, forming lagoons, between sequences of bachanoids dunes (2° 31′ 47″ S/42° 58′ 50″W). **b** Cliff-top dunes and nebkas dunes formed in Beberibe Beach, Ceará (4° 01′ 55″S/38° 03′ 49″W)

a complex system including dissipative sandy beaches, series of coastal lagoons, estuarine islands, barrier islands, and coastal dunes, recently studied in detail by Paula et al. (2016).

Westward from Parnaíba River Delta, the landscapes show sequences of transgressive dunefileds and rocky cliffs. The dunes morphology varies as free dunes, such as barchans and bachanoids or even cliff-top dunes. In Fig. 10.4b, we noted cliff-top dunes classified as nebkas dunes, one of the most representative examples of semi-arid aeolian deposit (see Pye and Tsoar 2009). Some parabolic examples can be observed too. These two examples of coastal dunes suggest the intrinsic relationship between vegetation and sand supply that define some specific dune morphology. Hesp et al. (2009) noted that the transgressive process form sequences of headland bypass as in Jericoacoara, where series of barchans and bachanoids moves from a beach to another, showing an intensive aeolian process. In eastern direction close to Cape Calcanhar, Vital et al. (2009) identify a complex of mesotidal and wave-dominated barriers and transgressive dunefields. The authors also noted the formation of barriers islands and ebb-tidal deltas in consortium with beachrocks, observed close to Cape Calcanhar. These landscapes shift dramatically southward.

In areas that the Neogene deposits (Barreiras Formation) are predominant, we observe shore platforms, notably by wave erosion process. Recently, Pinheiro et al. (2016) identify several areas where coastal erosion is prevalent, probably because of reduced sediment supply and human-induced promotes by intervention in urban areas, specially observed in Fortaleza city, to prevent coastal erosion to support port expansion, by jetties constructions.

10.4 Eastern Landscapes: Neogene Coastal Cliffs and Wave-Dominated Deltas Covered by Mata Atlantica Rainforest in a Tropical Zone

Cape Calcanhar is the vertex from Caraíba direction (NW/SE) to Brasilana direction (NNE/SSW). The coastline from the south of

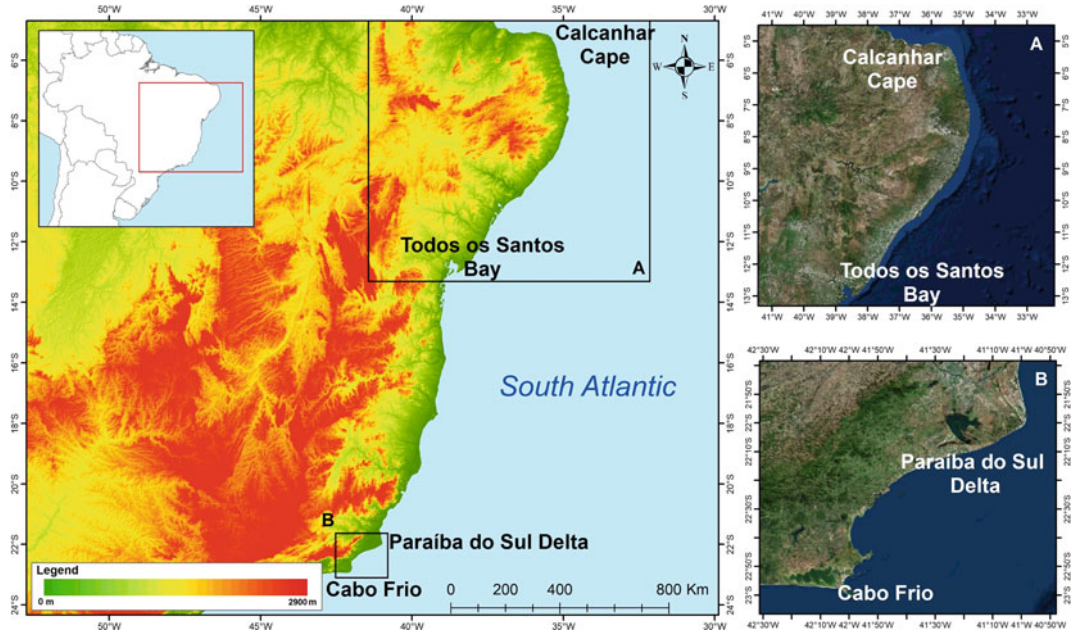

Fig. 10.5 Eastern Brazilian coastline between Cape Calcanhar to Cape Frio. This segment presents rocky coasts (active cliffs) defined by Neogene deposits and wave-dominated deltas. We select some other important areas that are not directly mentioned in the manuscript. (**a**) The coastline marked by rocky coasts and in the southern part Todos os Santos Bay. We consider a landscape enclave observed along this segment, representing controlled structural bay, as Guanabara Bay or Paranaguá Bay, observed in detail in the southeast coast. (**b**) Caravelas Delta, one of the sequences of wave-dominated delta along the eastern coast

Cape Calcanhar to Cape Frio (Fig. 10.5) is characterized by the predominant and continuous contact between Barreiras Formation and the Atlantic, where it is easy to notice series of active sea cliffs, shore platforms, beachrocks, and coral reefs. In fact, as the result of the retreat of sea cliffs, the shore platforms formed close to the shoreline promote the substrate for growth of coral reefs, especially in areas with reduced sediment supply (Fig. 10.6a). In the same segment, on the other hand, it is possible to observe the most representative wave-dominated deltas along the Brazilian coastline, defined by São Francisco, Jequitinhonha, Doce and Paraíba do Sul. This area presents an increase of rainfall from the north to the south, and predominant vegetation is defined by Atlantic rainforest (Mata Atlântica).

In detail, different from northeast landscapes, the sea cliffs observed from Cape Calcanhar to

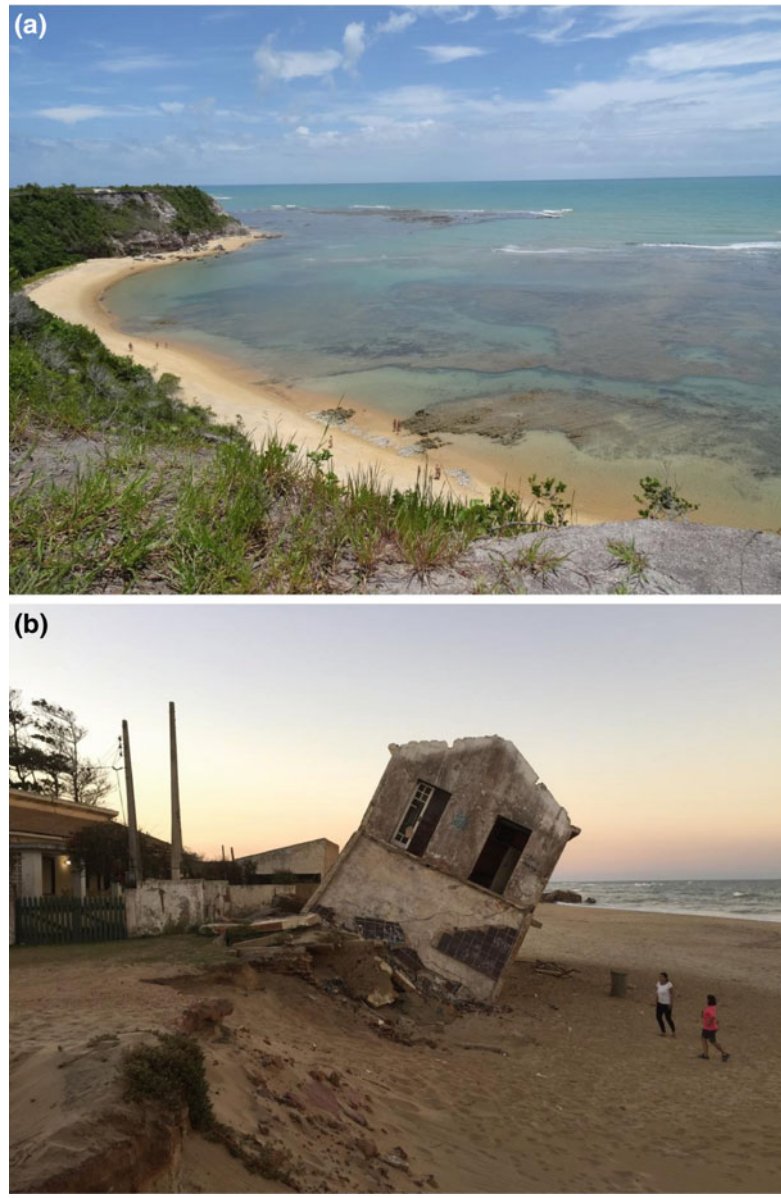

Fig. 10.6 Landscapes observed along the eastern coastline. **a** Coastal cliffs and coral reef that domain some parts of the east coast of Brazil, observed in Praia do Espelho Beach, Bahia State (16° 43′ 23″/39° 07′ 15″). **b** Coastal erosion observed in Atafona Beach (21° 37′ 31″/41° 00′ 48″) south part of Paraiba do Sul, Rio de Janeiro. This erosion consumes more than three blocks, including a gas station and one church

the south are continuous and trend to be interrupted by small estuaries associated with incipient drainage basins. The absence of fluvial sediment supply in a large portion of the coastline inhibits the transgressive dunes and coastal plains formation. Dominguez (2009) classifies this area as a starve coast regarding low sediment supply from the coast. The sea cliff is shaped directly by wave attack that comes from northeast to east wave predominant direction. This wave process promotes the erosion of sea cliffs and formation of shore platforms that support several colonies of coral reefs.

Not only shore platforms are observed but shore parallel lines of beachrocks are very common landscape along eastern Brazil, and are mentioned in the first description from Portuguese navigators, in 1500, by Pero Vaz de Caminha's letter to the Portuguese crown. These beachrock lines mark ancient shoreline positions, close to the river mounts, becoming an excellent natural port, especially for small boats. Regarding coral reefs observed, Leão et al. (2016) reviewing not only the distribution, but the structures of the coral reefs indicate that the Brazilian species differ from other typical areas, as the Caribbean or Great Barrier Reef in Australia, by form, low diversity, and influence by sediment suspended. It is interesting, because even with the small drainage, it is sufficient to establish stress for high diversity, and the last 50 years of deforestation become a major problem to bleaching the coastline coral reefs (Leão et al. 2010).

Other important landscapes in eastern part of Brazil are typical wave-dominated deltas. Dominguez et al. (1987) identified four examples of this type: São Francisco (10° 29′ 53″S/36° 24′ 00″W), Jequitinhonha (15° 50′ 3053″S/38° 51′ 22″W), Doce (19° 38′ 54″S/39° 48′ 58″W), and Paraíba do Sul (21° 36′ 17″S/41° 01′ 42″ W). The first interpretation regarding the Quaternary geomorphological evolution, provided by Dominguez et al. (1987), suggests the regressive coastal plain, along both sides of rivers, was resulting from reworking sandy dominated deposits along the shoreface by waves. Dominguez et al. (1987) suggest the progradation observed was directly associated with sea level fall during the late Holocene. It is interesting that Dominguez (2009) recognizes that this first interpretation was imperfect and assumes that in fact the fluvial input presents an essential role for sediment supply for the coastal plains, and for sure, these features represent wave-dominated deltas.

In detail, the main landscape observed in these Deltas is a series of regressive barriers or beach ridges that mark different positions of the shoreline along the Quaternary. Some specific features, for example, in the north part of São Francisco is a notable transgressive dunefield. It is necessary to mention that these deltas suffer many environmental problems in the last years, as for example coastal erosion, pollution, and implementation of new socioeconomic activities as ports and urban growth. Recently, in Doce River Basin in 2015, the worst environmental disaster occurred, by a failed dam with different geochemical components from mine activity. Millions of mining residues contaminated the river basin and affected the coastline not only the environmental conditions, but socio-economic activities. This disaster killed 19 people and changed the landscape of Doce. Other problems, like coastal erosion, are critical in Paraíba do Sul River Delta (Fig. 10.6b), where more than five blocks were completely eroded since the 1950s (Rocha et al. 2018).

10.5 Southeast Landscapes: Serra do Mar Ridge (Rocky Coast) and Coastal Plains and Covered by Mata Atlântica Rainforest, Along the Tropical Zone

The landscapes between Cape Frio to Cape Santa Marta are characterized by Serra do Mar ridge, forming series of rocky coasts and inhibiting large coastal plains formation (Fig. 10.7). The coastal plains normally contain series of barriers and coastal lagoons, especially between Cape Frio and Guanabara Bay (Fig. 10.8). The Mata Atlântica vegetation covers not only the ridge, but the coastal plains, assuming a different name:

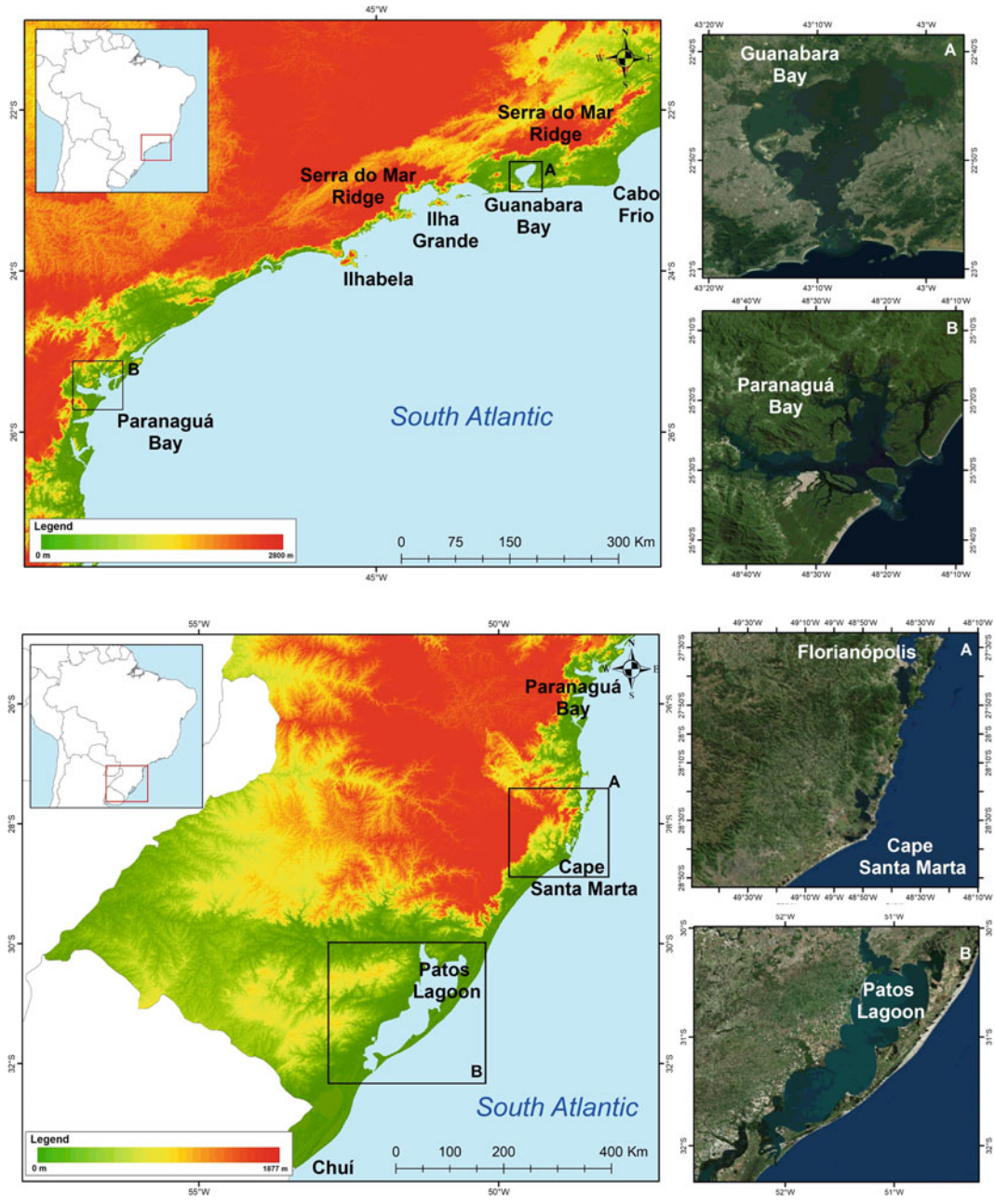

Fig. 10.7 Southeast coastline (top) defined by geological control and embayed areas note the Serra do Mar ridge positioned very close to the ocean, especially between Ilha Grande and Ilha Bela. **a** Landsat image from Guanabara Bay, the most occupied Bay in Brazil, impacted by Rio de Janeiro city. **b** Landsat image from Paranaguá much less occupied compared with Guanabara Bay showing different controlled channels filling the estuary. Above the southern region of Brazil, in (**a**) the Santa Catarina Island, separated from the continent from a small channel, but it is possible to note several embayed beaches. (**b**) Patos Lagoon (the most representative lagoon in Brazil, with more than 10.000 km^2)

—Restingas. Restingas is a part of Mata Atlantica rainforest but is formed only in Quaternary sandy deposits. The geology of Serra do Mar ridge is part of Ribeira Belt and can be identified as granites and gneisses rocks formed during Precambrian, as a result of a collision between the South American plate and African plate, during Brasiliano Orogeny that occurred in Precambrian (see, e.g., Heilbron et al. 1995). The coastline defined by a series of coastal massifs and ridges (horsts) is the result of rift tectonics, during the Neogene, from reactivation of previous geological structure. The grabens are notable by coastal plains dominated by wave deposits (barriers) and different estuaries, as Guanabara Bay and Paranaguá Bay, or completely flooded by the ocean, where the coastal plains are almost absent, as Ilha Grande Bay (Fig. 10.7). Some of the massifs can be separated from the continent, as Ilha Grande or Ilha Bela (Fig. 10.7).

Fig. 10.8 Typical landscapes observed in southeast Brazil. **a** Eastward view of Itaipuaçu Beach from Elephant Rock (22° 58′ 29″ S/43° 01′ 13″W), in Marica, Rio de Janeiro. This segment showed sequences of the barrier and lagoon systems formed during late Quaternary, developed between the coastal massifs and the Atlantic. **b** The most iconic landscape of Brazil, Sugar Loaf and Corcovado located in Rio de Janeiro in another perspective. Sugar Loaf limits the west entrance of Guanabara Bay, and Corcovado is part of Ribeira Belt (geology) and sequences of horst and grabens that mark the southeast coastline

Observed in more specific aspects, the southeast coastline is dominated by granitic and gneisses rocks, formed during the Precambrian, and tectonically reactivated during the Cenozoic, forming series of grabens and horsts. The Precambrian is marked by the convergence between African and South American plates, forming a typical orogenetic belt, surrounding the São Francisco Craton. Between the Cretaceous to Neogene Cenozoic, during ocean drift tectonics, isostatic efforts reactivate a series of previous faults and results in grabens and horst positioned close to the Atlantic, marked the southeast region and reduced the space for developing coastal plains.

Oceanographically, the southeast coastline is directly impacted by storm surges and at the same time fair weather conditions. In this case, both southwest and northeast waves and winds define the coastal and climate conditions.

Figure 10.8a shows the main aspects of the westward coastline from Cape Frio to Guanabara Bay, where it is possible to observe the coastal plains formed by coastal barriers, foredunes and lagoons, limited by coastal massifs. The coastal plain evolution is directly determined by sea-level oscillations, during the late Pleistocene to the Holocene. The Holocene barrier suffers from storm impacts, during April to June, as demonstrated by Fernandez et al. (2016). This work mentions the impact of storm waves and fair weather winds along the beach and foredunes.

The Guanabara Bay can be described as the most intense occupied area along Brazilian shoreline, especially by Rio de Janeiro city and other municipalities in the surrounding area. The entrance of Guanabara bay is marked by Sugar Loaf (Fig. 10.8b) that contacts the granitic and gneisses geology directly to the ocean. Southward, between Guanabara Bay and to Ilha Grande, the contact between the Serra do Mar creates a scenario of several kilometers of the coastline marked by rocky coasts and embayed beaches.

In the southern direction, the Serra do Mar trends to displace from the ocean and forming the narrow coastal plains in São Paulo and Parana states (see in detail Gianini et al. 2009; Angulo et al. 2009). As the Serra do Mar displaced from the ocean, in southern direction it is possible to note the presence of transgressive dunefields, as noted in Ibiraquera beach in Santa Catarina (Gianini et al. 2009). These transgressive dunefields observed close to Cape Santa Marta are the previous example of predominant landscape in the southern coastline.

10.6 Southern Coast Landscapes: Quaternary Coastal Sandy Barriers Covered by Pampas Vegetation in a Tempered Climate Conditions

The southern coastline of Brazil (from Cape Santa Marta to Chuí/La Coronilla-UY) is dominated by landscapes formed by complex Quaternary environments as sandy coastal barriers, lagoons, salt marshes and vegetated by Restingas (Fig. 10.7a).

This segment has warm temperate or humid subtropical climate, with generally warm to hot temperatures occur in the summer and cool temperatures in the winter. The NE wind is dominant, particularly from September to March. From April to August, winds from the S and SW are dominant. The annual rainfall ranges from 1000 to 1500 mm and is evenly distributed throughout the year. Swell waves generated in southern latitudes and wind-generated waves produced by strong spring–summer sea breezes from the northeast vary from 1.0 m south of Bujuru to 1.5 m to the north (Tozzi and Calliari 2000; Motta 1969). Due to variations in the coastline orientation (azimuth varying from 10 to 60°) and the inner shelf morphology and gradient (varying from 0.027 to 0.125°), the beaches are exposed to approximately 60% of the variation in wave energy (Dillenburg et al. 2003; Martinho et al. 2009). During autumn and winter storms (April–July), the wave height may frequently exceed 2 m, and the sea level can surge up to 1.3 m along the coast (Barletta and Calliari 2001; Calliari et al. 1998). The littoral drift dominates in a northeast direction. The coast is microtidal,

with semidiurnal tides that have a mean range of only 0.5 m. Consequently, sediment transport and deposition along the open coast is dominated by wave action. The beaches vary from multi-bar dissipative stage to intermediate morphodynamic stages.

Geologically, the southern coast integrates a large low-relief coastal plain that represents the younger emerged surface expression of the Pelotas Basin (Fig. 10.9a), as documented by Barboza et al. (2011). This coastal is a seaward open basin, on land limited by basement rocks, and alongshore confined between the structural heights of Polônio Cape (Uruguay) and of the Platform of Florianópolis High (state of Santa Catarina) in according to Dillenburg and Barboza (2014). Close to the coastline, we noted deposition of a large amount of post-rift, primarily clastic sediment which produced wide (100–200 km), shallow (100–140 m), and gently

Fig. 10.9 Landscapes along southern region. **a** Typical landscape in southern Brazil, series of barriers and foredunes and inlets that connects the lagoons with the ocean. **b** The dramatic coastal erosion in Hermenegildo Balneary (33° 39′ 59″ S/53° 15′ 35″W), proving the intense coastal morphodynamics observed in southern Brazil

sloping (0.03–0.12°) continental shelf. On land, the coastal plain (50–100 km wide) was formed during the Quaternary by a juxtaposition of sedimentary deposits of alluvial fan systems and four barrier–lagoon systems designated from I (oldest) to IV (youngest) by Villwock et al. (1986). These systems, respectively, are correlated to isotope stages 9, 7, 5, and 1 (Rosa et al. 2017). Such systems have been developed during the Upper Quaternary, due to the combination of allochthonous and autochthonous processes, such as the eustasy, tectonics, coastal climate dynamics, and sedimentary budget (Dillenburg et al. 2017). Each barrier/lagoon system corresponds to a high-frequency depositional sequence (Rosa et al. 2011, 2017).

The recent sea-level history of this coast extends back approximately 17.5 ka when the sea level was approximately 120–130 m lower (Imbrie et al. 1984; Rohling et al. 1998). After that time, sea level rose at an average rate of 1.2 cm/year. There are no reliable data on sea-level behavior during the middle to late Holocene time along this coast (Lopes et al. 2014). Sea-level curves for areas immediately to the north indicate that the culmination of the eustatic sea-level rise occurred at 6–5 ka, when sea level was approximately 1–3 m above its present level (Tomazelli and Dillenburg 2007), after which it slowly fell (Angulo et al. 2006).

The gentle coastal plain formed a series of barriers and foredunes that isolate coastal lagoons. These lagoons normally face the ocean by inlets. The intensity of coastal storms causes an intense coastal morphodynamics, and in some parts of this coastline, several areas suffer the impact of coastal storms. For example, Conceição lighthouse was completely damaged for decades of coastal erosion. During the winter and spring, some balnearies areas were directly affected by storm waves, as Hermenegildo, experiment problems regarding to coastal erosion caused by high waves, producing several damages in building and urban facilities (Fig. 10.9b). The end of this segment is Uruguay boarder and marks the limits with Brazil, and it is our final description.

10.7 Oceanic Islands

The Brazilian territory includes too four geographic oceanic island areas, which present highly diverse geological and physiographical characteristics: São Pedro and São Paulo (0° 55′ 01″N/29° 20′ 43″W), Fernando de Noronha (3° 51′ 17″S/32° 25′ 24″W), Trindade and Martin Vaz archipelago (20° 30′ 38″ S/29° 19′ 24″W), and Rocas Atoll (3° 52′ 00″ S/33° 48′ 07″W). All of them present highly erosional coastal morphology and reduced coastal sediments supply. Sea cliffs, algal reef and biogenic calcareous sand and gravel beaches are the main coastal features.

São Pedro and São Paulo Archipelagoes is an exceptional active seismic site where mantle rocks outcrop, uplifted by the active São Paulo transform fault zone (Hekinian et al. 2000). It has constituted by five small islands and several islets, which present erosional rocky and coasts. Sediments occur only at depths higher than 4 m and are constituted by lithic and bioclastic gravel and sand (Angulo et al. 2013a).

Fernando de Noronha Archipelago and Rocas' Atoll is located on the Fernando de Noronha chain and correspond to emerged portions of volcanic edifices rising more than 4000 m above the ocean floor. Fernando de Noronha Archipelago is composed mainly of volcanic rocks and aeolian and beach sandstones (Branner 1889, 1890; Almeida 1955). The coast is characterized by conspicuous volcanic rocks and sandstones sea cliffs and by bioclastic calcareous sandy beaches (Angulo et al. 2013b). Rocas' Atoll is the only Atlantic Ocean atoll (Leão et al. 2002). It is constituted by an annular calcareous algal reef (~3 km in diameter), a central lagoon, and two small islands (600 and 350 m in length) (Leão et al. 2002). Most of the island surface is located in the intertidal zone, and only the two sandy islands and several *rocks* remain emerged at high tide (Andrade 1959). The *rocks* correspond to algal reef remains and give the atoll's name (Andrade 1959). The island coasts are characterized by calcareous biogenic sandy beaches and low (2 m high) beachrock sea cliffs (Andrade 1959).

Trindade and Martin Vaz are two isolated islands (1140 and 1190 km far from the Brazilian mainland) located at the eastern end of the Vitoria–Trindade seamount range. Martin Vaz is 170 m high rocky island with inaccessible vertical sea cliffs along the entire coast. Trindade Island is a scarped hill (660 m height, 9 km^2 in area) with steep slopes and talus and alluvial fan deposits. At the southwest end of the island occurs the unique volcanic cone of the Brazilian. The Trindade Island coast is characterized by sea cliffs and gravel and sandy beaches composed of volcanic rock and biogenic calcareous fragments (Almeida 1961; Angulo et al. 2017).

Abrolhos Archipelago is constituted by five islands composed of volcanic and sedimentary Cretaceous rocks (Hartt 1870). The islands are the last emerged remains of a larger continental coastal zone drowned during the last post-glacial sea level rise (Vicalvi et al. 1978). The archipelago presents conspicuous volcanic and sandstone sea cliffs and gravel and sand beaches.

Fernando de Noronha, Rocas Atoll, and Trindade Island present conspicuous island shelves level around 60 m, which were eroded by a wave during Quaternary when sea level was lower than the present one. In the other hand, oceanic Brazilian archipelagos and islands present evidence oceanic Quaternary sea levels higher than present one as ancient sea cliffs, notches, wave-cut terraces, algal reef, and beaches (Angulo et al. 2013a, b, 2017).

10.8 Summary

This brief presentation from Brazilian coastline suggests that around more than 8.500 km, the littoral presents high diverse landscapes. The relationship between biotic and abiotic aspects promotes a complex of environments. In summary, we can define the north part of Brazil as a macrotidal coastal plain, where the Amazon rainforest and mangroves are the predominant vegetation, in an equatorial to tropical climate conditions. It is necessary different regarding sediment supply that comes from Amazon, which mud material moves predominantly to the north and the south is more sandy, forming sequences of estuaries. The northeastern coast is defined as the semi-arid coast. The transgressive dunefields and shore platform cover with sparse or absent vegetation is the main characteristic in this segment. From Cape Calcanhar to the south, series of rocky coasts, coral reefs, wave-dominated deltas, the mark may be the most complex coastline. The southeast landscape is defined by rocky coast and coastal plains, limited or even absent, by the Serra do Mar and coastal massifs. In this areas, the most preserve areas from Mata Atlantica rainforest is possible to observe, especially between Ilha Grande to Paranaguaá Bay. The south coastline presents the most wave-dominated coastal plain, forming series of barriers and lagoons and transgressive dunefields, covered by Restingas. The oceanic islands formed by volcanic activity normally show erosional landforms.

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