# Chapter 12
# Beaches in the State of Bahia: The Importance of Geologic Setting

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**Abstract** The state of Bahia with approximately 1000 km of shoreline, a great heterogeneity of exposed rock types and subjected to varying degrees of sediment supply allowed us to investigate the controls exerted by these factors in determining the beach types.

The modal morphodynamic states of the beaches of Bahia is dominantly controlled by sediment grain size, which in its turn results from the long term history of the coastal zone. Locally sourced sediments, eroded from the coastal tablelands (Barreiras Formation), are predominantly coarse grained favoring reflective beaches (Sediment Starved Southern Coast). Distally sourced sediments, as in the case of large rivers are predominantly fine to very fine sands, resulting in a dominance of dissipative and high-energy intermediate beaches (Deltaic Coast of the Jequitinhonha River). Shoreline stretches nourished by small rivers are characterized by medium size sands and a dominance of intermediate high energy beaches (Northern Littoral Coast Compartment). Finally, the stretch of the coast fronted by Mesozoic Rifts, characterized by a great heterogeneity of sedimentary rock types and small sediment supply, have a very irregular shoreline, bordered by fringing reefs. In this section low energy sheltered beaches dominate.

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## 12.1 Introduction

Bahia has the longest open coastline in Brazil (approximately 1000 km) (Fig. 12.1) and its coastal landforms include cliffs and rivers, a wave-dominated delta, beach-ridge plains, coral reefs and large bays. The evolution of these landforms during the Cenozoic has affected certain key features of sandy beaches along the Bahia coast. This chapter summarizes the characteristics of these beaches based primarily on data collected over the previous 15 years, most of which are unpublished or were reported only in dissertations, theses and monographs. These data were collected during overflights and field surveys along the coastline. During the field surveys, samples of beach-face sediment were collected at 1-km intervals, the beach face gradient was measured, and the type and number of breakers in the surf zone were recorded simultaneously. This database enabled quantitative assessment of the spatial variation of these parameters along the Bahia coastline, which enabled us to gain an understanding of the spatial variability of the modal morphodynamic states of Bahia's beaches and their main controlling factors when combined with geologic data and modeling of wave transformation (refraction) and sediment characteristics along the coast. This is the main focus of this chapter.

## 12.2 Geology and Geomorphology of the Coastal Zone

Bahia's coastline configuration was established and controlled by the separation of the South American and African Plates beginning in the Early Cretaceous (145 Ma) (Silva et al. 2007). This separation largely produced the general coastline physiography. The interactions between this physiography and other factors, including variations in sea level and climate, the supply of sediments, and the evolution of marginal sedimentary basins shaped the final coastal configuration and produced the variety of coastal features that are now present.

The following pre-Quaternary geologic units are exposed along the coast (Fig. 12.1):

(i) Metamorphic rocks (primarily high grade) that compose the São Francisco Craton of Archean–Paleoproterozoic age (Alkmim et al. 2001; Barbosa and Sabaté 2004) and their marginal fold belts of Neoproterozoic age (Almeida 1977; Cruz et al. 2012; Oliveira 2012).

(ii) Mesozoic sediments deposited in basins formed during the split of the South American and African Plates (Recôncavo, Camamu and Almada basins: Mohriak et al. 2008).

(iii) Detrital material of marine–transitional origin (Barreiras Formation) deposited during an Early–Middle Miocene transgression that flooded the continental edge of Brazil (Rossetti et al. 2013); these deposits underlie the coastal plains, and form coastal tablelands.

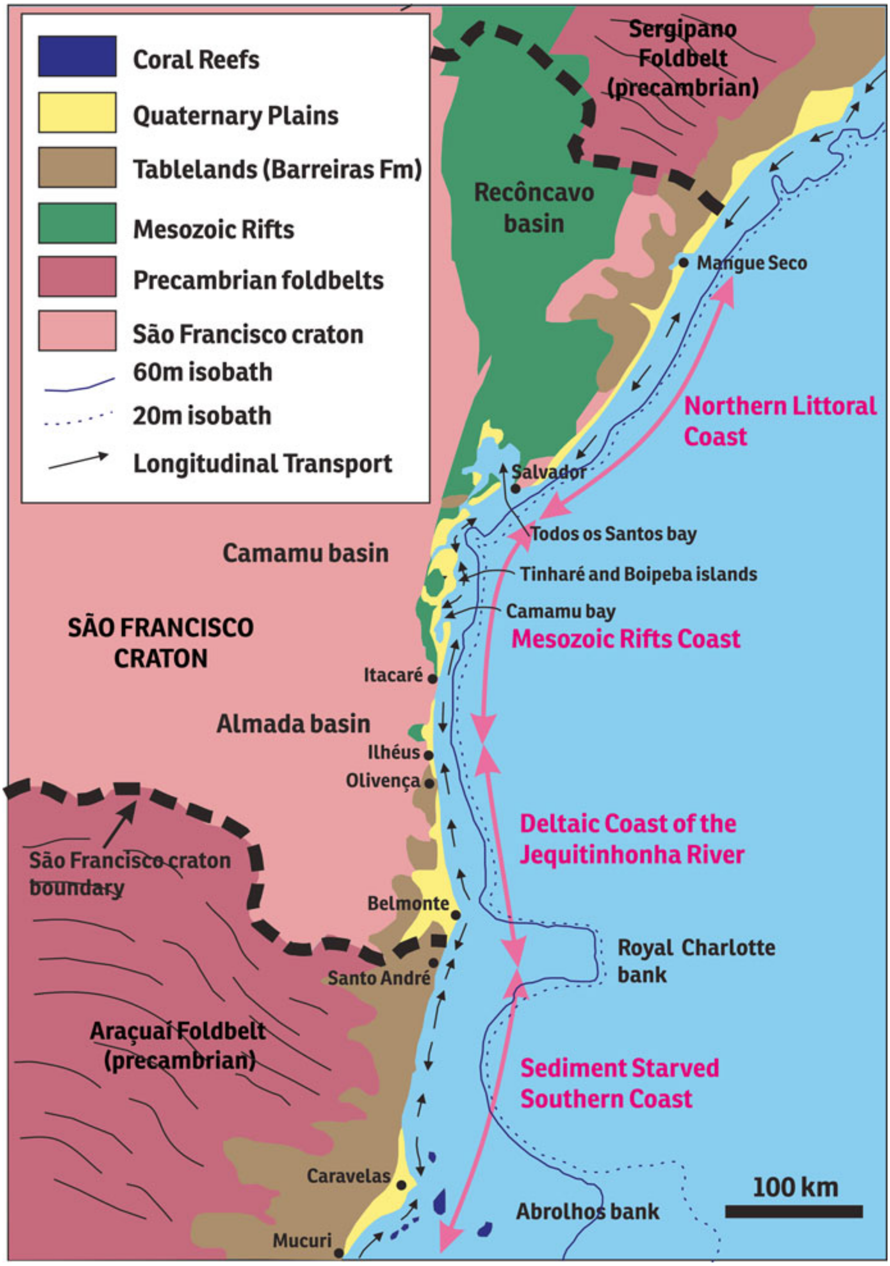


**Fig. 12.1** Geological framework of the Bahia coastal zone and its major coastal compartments. Bahia's coast extends from Mangue Seco to Mucuri

The northern-central coastal zone faces the São Francisco Craton and is generally narrow. The Recôncavo, Camamu and Almada sedimentary basins are located in this section. Differential erosion between rocks of the older cratonic basement (more resistant) and the Mesozoic sedimentary rocks (less resistant) produced a topographic lowering of the region dominated by the latter rocks (Dominguez and Bittencourt 2009; Dominguez 2015). These low-lying areas were flooded during high sea-level stands, including the current highstand, resulting in bays and estuaries and the complete filling of the Almada basin. The most-rugged stretch of coast corresponds to the area where these bays have not yet been filled (Todos os Santos and Camamu bays and associated estuaries) (Fig. 12.1).

In southern Bahia, the portion of the coastal region beyond the limit of the São Francisco Craton, widens and is primarily underlain by the widespread Barreiras Formation, which forms active sea cliffs along the shoreline. This wide coastal zone is associated with a wide continental shelf that has been affected by volcanic activity dating from the beginning of the Tertiary (40–60 Ma) (Mohriak 2006; Sobreira and França 2006), which favored the development of the Royal Charlotte and Abrolhos Banks (200 km maximum width; Fig. 12.1). The largest coral reefs in the western Atlantic Ocean are located on the shallowest portions of these banks (Leão et al. 2003).

### 12.2.1 Sediment Sources

Two main sources of siliciclastic sediments supply the coastal beaches of the State of Bahia (Fig. 12.2): these are fluvial sediments transported by rivers of various sizes and material eroded from active cliffs of the Barreiras Formation. The latter is typically coarser, due to the close proximity to the source area and because the Barreiras Formation itself is composed of coarse sediments.

Siliciclastic sediments dominate a narrow strip fringing the coastline to maximum depths of 10–15 m (Dominguez et al. 2012, 2013). Offshore of this belt, bioclastic sands mainly composed of coralline algae fragments, are present. Therefore, there are apparently no significant sources of siliciclastic sands along the continental shelf that may have supplied the coast. However, locally, particularly adjacent to bank reefs, a few beaches may consist dominantly of bioclastic fragments produced on reef tops, as in the case of beaches on the islands of Tinharé and Boipeba (Rebouças et al. 2011) (Fig. 12.1).

The Jequitinhonha River transports a significant amount of sediment to the coastal zone ($27 \times 10^6$ t year$^{-1}$) (Bernal 2009) and has built, along with the Pardo River a typical wave-dominated delta. The other rivers emptying along the coast have lower discharges, as is the case with the Contas (100 m$^3$ s$^{-1}$), Paraguaçu (83 m$^3$ s$^{-1}$) and Itapicuru (27 m$^3$ s$^{-1}$) rivers. The contribution of fluvial deposits is even less along the southern coast of Bahia. The Mucuri River is the largest river flowing to this stretch of coastl (liquid discharge of 74 m$^3$ s$^{-1}$; solid discharge of $1.2 \times 10^6$ t year$^{-1}$) (Queiroz 2003).

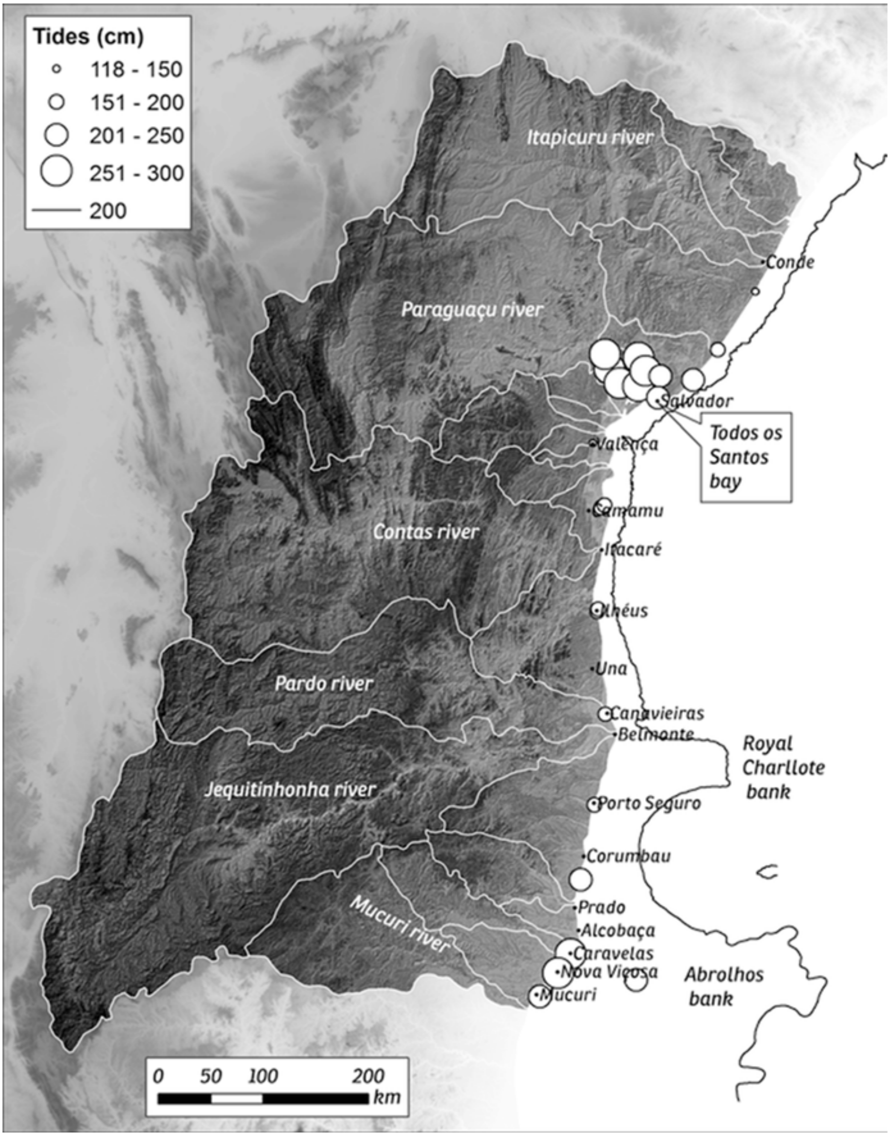


**Fig. 12.2** Digital elevation model of drainage basins emptying in the study area. Also shown is the variation in tide range along the shoreline

The 3–4 m drop in relative sea level that affected the coast of Brazil during the last 5700 years (Angulo and Lessa 1997; Martin et al. 2003) may have also contributed sediment to coastline progradation through a mechanism that acted in accordance with the inverse of the Bruun rule (Bruun 1962).

## 12.3 Coastal Processes: Waves, Tides, Winds and Precipitation

The highest average annual rainfall in the coastal area of Bahia usually occurs in the section between Salvador and Ilhéus (1800–2600 mm $year^{-1}$) (Fig. 12.2), with rainfall decreasing southward toward Caravelas (1400 mm $year^{-1}$) and northward toward Mangue Seco (1400 mm $year^{-1}$). The tide ranges from 1.18 to 2.71 m (Fig. 12.2), with the largest tides observed within Todos os Santos Bay and in the area of Caravelas (Sales et al. 2000; Cirano and Lessa 2007). Mean wave heights and periods range from 1 to 3 m and from 6 to 10 s, respectively (Pianca et al. 2010). The wave propagation directions vary during the year depending on changes in the wind regime. East–northeast waves predominate in the spring and summer, southern waves are more common during the autumn and winter, due to changes in the direction of trade winds and a greater frequency of cold fronts.

Figure 12.1 shows the dispersion of sandy sediments along the coastline by wave action as modeled by Bittencourt et al. (2000) and Dominguez et al. (2009). A significant effect of the seasonal variation in the wave directional frequency is a rotational circulation on beaches enclosed between rocky headlands, as reported by Farias et al. (1985) for Armação Beach in the city of Salvador (Fig. 12.2).

The combination of seasonal changes in the wave direction and extensive coral reefs positioned offshore has produced local convergences in the sediments transport in southern Bahia (Fig. 12.1). This convergence has resulted in a tombolo at Corumbau and a mega-salient at Caravelas, where a broad progradation of the shoreline occurs in an otherwise sediment starved region (Fig. 12.1). The coral reefs also protect long sections of coast from wave action (Fig. 12.3), which has affected beach morphodynamics, including modifications imposed by tidal action, by altering the relative tidal range (RTR) (Masselink and Hegge 1995).

## 12.4 Coastal Compartments and Beach Types

Bahia's coastal zone can be subdivided into four compartments based on their physiographic features (Dominguez et al. 2012). These compartments, described below, are designated the Northern Littoral Coast, the Mesozoic Rift Coast, the Deltaic Coast of the Jequitinhonha river, and the Sediment Starved Southern Coast (Fig. 12.1). The compartments exhibit various beach morphodynamic stages given their different geologic heritages in addition to their very different physiographic characteristics.

**The Northern Littoral Coast Compartment** Extends from Salvador to the border with the state of Sergipe (Mangue Seco) (Fig. 12.4). This compartment is characterized by a nearly linear northeast–southwest-aligned coast, and the presence of small rivers. The crystalline basement is exposed in numerous locations along the coastline, particularly in the southern portion. The supply of sediments, although small a

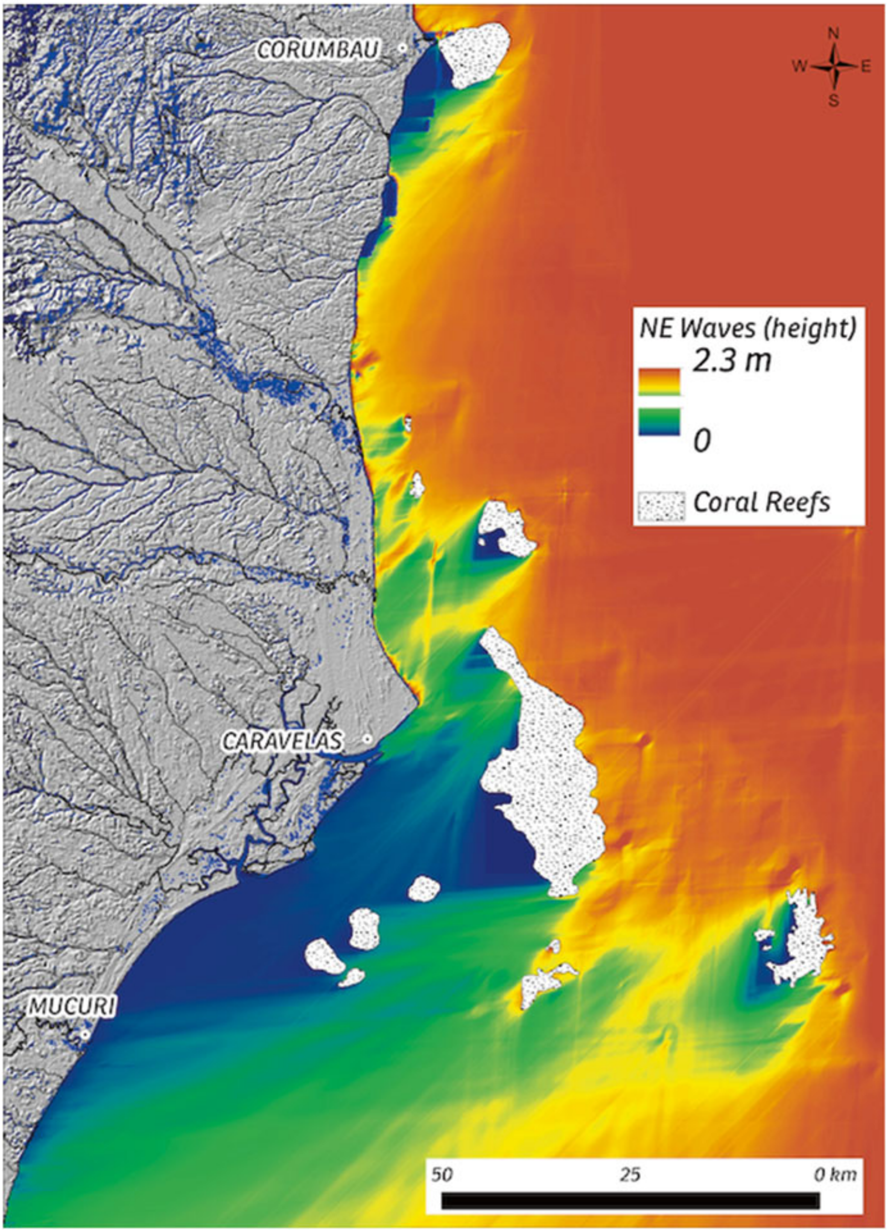


**Fig. 12.3** Effects of coral reefs on wave refraction and attenuation along the "Sediment Starved Southern Coast" of Bahia (see Fig.12.1 for location). (**a**) NE waves. (**b**) SSE waves

b

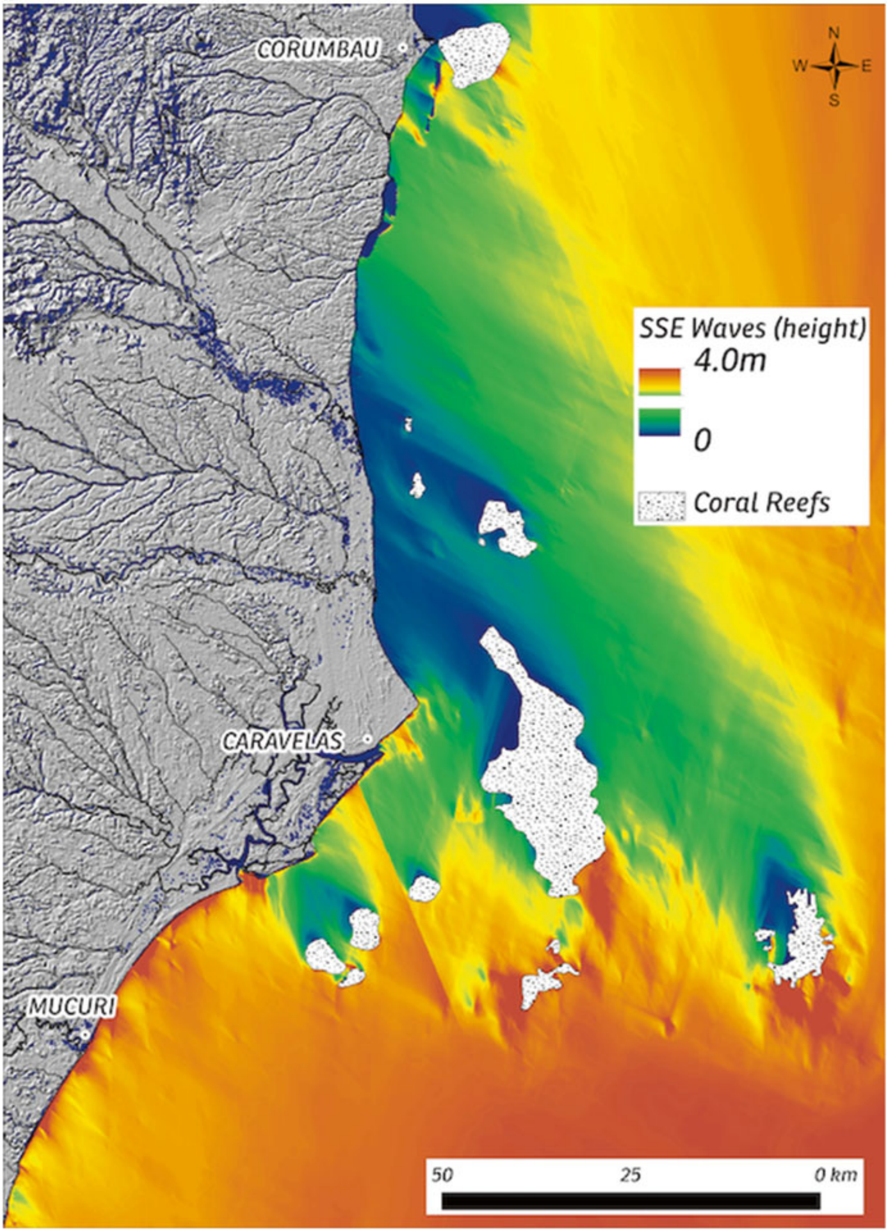


**Fig. 12.3** (continued)

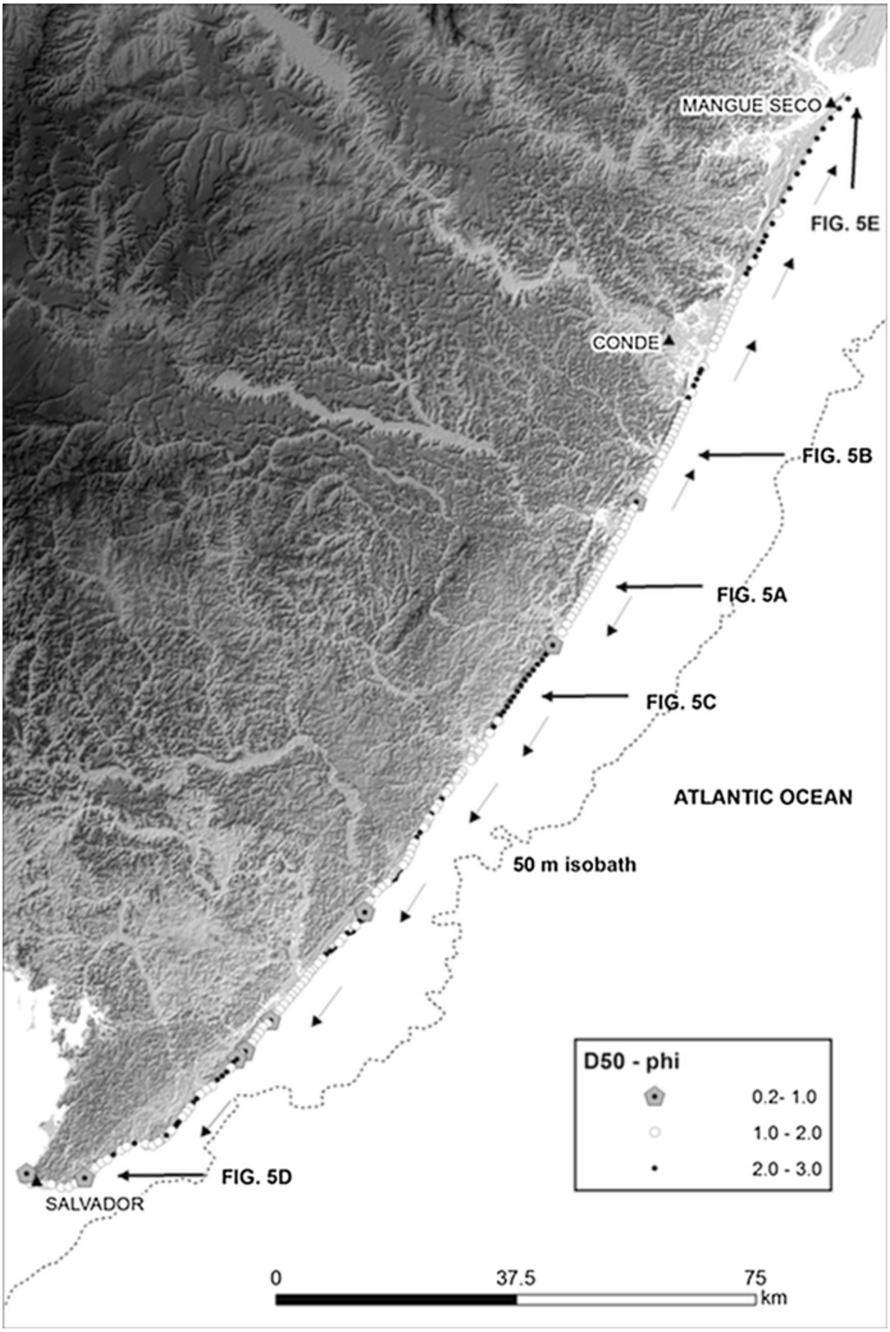


**Fig. 12.4** Variation of $D_{50}$ values of beach face sediments along the Northern Littoral Coast. Arrows indicate location of photos shown in Fig. 12.5. Small arrows show sediment dispersal along the shoreline


**Fig. 12.5** Photographs of beaches present in the Northern Littoral Coast compartment. (**a**) a foredune ridge a few meters high is very common in this compartment; (**b**) example of transverse bar and rip intermediate beach; (**c**) example of longshore bar-trough intermediate beach; (**d**) the beaches at Salvador city are limited by small rocky promontories, which favors seasonal beach rotation, such as at Armação beach shown in photo; and (**e**) dissipative beach near the locality of Mangue Seco (see Fig. 12.4 for location of photographs)

(Genz et al. 2003), has enabled the accumulation of beach deposits associated with marine isotope stages 5e and 1, and possibly with older isotope stages including stages 9 or 11 (Dominguez et al. 2009; Dominguez and Bittencourt 2012). This is the only compartment on the Bahia coast where coastal dunes are present. These dunes are predominantly of the blowout type and are present on beach deposits of isotope stages 5e and 9/11. On deposits associated with the current highstand only foredune ridges are present. In most places, the coast is bordered by a foredune approximately 5–6 m high, most likely resulting from a coast which has remained essentially stationary or experienced minor erosional retreat (Fig. 12.5a). This compartment is also characterized by the presence of beachrock reefs and exposures of crystalline basement, particularly in the southernmost stretch, in the city of Salvador. Medium-grained sands predominate along the beach face, which, combined with moderate to high wave energy (particularly in the winter), results in a dominance of intermediate beaches at various morphodynamic stages (longshore bar-trough and transverse bar and rip states; Fig. 12.5b and c). Coarse sands are present near the river mouths. A gradual decrease in particle size is generally observed in the transport direction. The presence of numerous crystalline basement exposures in the southern portion of this section limits the longshore continuity of the beaches and creates conditions for their seasonal rotation in response to changes in wave directional frequency, as happens at Armação Beach (Farias et al. 1985; Fig. 12.5d). Conversely, the beach sediment at the north end of this compartment become increasingly finer, which is accompanied by a change in the morphodynamic behavior of the beach to more dissipative, with numerous blow-outs in the backshore (Fig. 12.5e).

**The Mesozoic Rifts Coast** Extends from the mouth of Todos os Santos Bay to Itacaré and is characterized by exposures of Mesozoic sedimentary rocks of the Recôncavo, Camamu and Almada basins (Figs. 12.1 and 12.6). The progressive lowering of relative sea level since the Middle Miocene (Miller et al. 2005) and the humid climate in this region favored differential erosion between the sedimentary rocks (less resistant) and crystalline basement rocks (more resistant), which caused a topographic lowering, particularly during the Quaternary low sea-level stands (Dominguez and Bittencourt 2009). The resulting low-lying areas were flooded during high sea-level stands, such as the current stand, which created bays, including Camamu and Todos os Santos and their islands, tidal channels and indented coastlines (Dominguez et al. 2009; Dominguez and Bittencourt 2012; Dominguez 2015). Erosional terraces carved into sedimentary rocks of the Mesozoic basins, some of which were colonized by corals, forming fringing reefs, are common in this area (Leão et al. 2003). The tops of these reefs act as a source of bioclastic sediment for the beaches, which is evident in the composition and particle sizes (Rebouças et al. 2011).

The Mesozoic Rifts compartment with its indented outline and the presence of nearby fringing coral reefs exhibits the highest variability in beach particle size and wave energy. The sediment sources, except for the Contas River, are also local because regional rivers flow into the local bays and large estuaries, where the thickest deposits have accumulated. Other sediment sources include current and past erosion of Jurassic aeolian sandstones, which are exposed, for example, at Morro de São Paulo. Other rocks exposed along the coastline are limestones of Cretaceous age (Algodões Formation). Therefore, most sources of sand available to this stretch of coastline are fine to medium grained, except along the sections where carbonate detritus from eroding reef supplies coarse sand and bioclastic gravel, as on the islands of Tinharé and Boipeba. The beaches in this section include high-energy intermediate types with transverse and longshore bars on the Maraú Peninsula (Fig. 12.7a), reflective to low-energy intermediate beaches enclosed between bordering fringing coral reefs (Fig. 12.7b), sheltered beaches behind coral reefs, several of which exhibit a variety of features reported by Jackson et al. (2002) and Masselink et al. (2006) (Fig. 12.7c), and beaches fronted by reef flats, which only receive waves at high tide

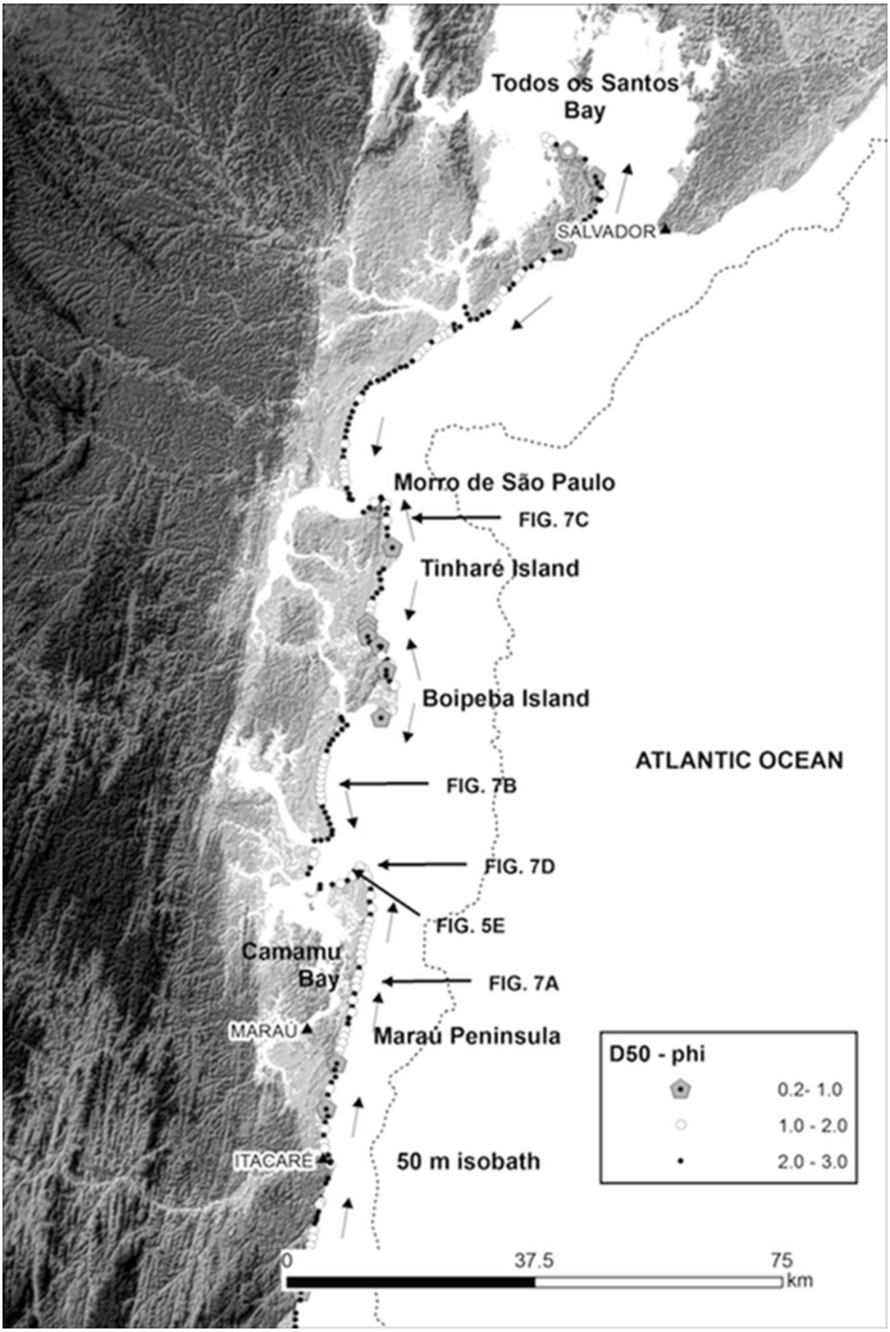


**Fig. 12.6** Variation of $D_{50}$ values of beach face sediments along the Mesozoic Rifts Coast compartment. Arrows indicate location of photos shown in Fig. 12.7. Small arrows show sediment dispersal along the shoreline


**Fig. 12.7** Photographs of beaches present in the Mesozoic Rifts Coast compartment. (**a**) example of transverse bar and rip intermediate beach at the Maraú peninsula. Camamu bay seen in background; (**b**) reflective beaches are common in embayments between fringing reefs; (**c**) sheltered beach behind fringing reefs at Tinharé island; (**d**) beach and intertidal reef flats at the Maraú Peninsula; and (**e**) sheltered beach at the interior of Camamu bay (see Fig. 12.6 for location of photographs)

(Fig. 12.7d). Low-energy (reflective) beaches with numerous intertidal bars are present in the interior of Camamu and Todos os Santos Bays (Fig. 12.7e).

**The Deltaic Coast of the Jequitinhonha River** The Jequitinhonha is the main river flowing through Bahia and, has a typical wave-dominated delta (Dominguez 1983, 1987). The sediment delivered by this river is transported predominantly northward by the longshore drift. The coastal deposits generally consist of fine sands, except for coarse sand in the immediate vicinity of the mouth of the Jequitinhonha River (Fig. 12.8), and displays a clear trend of decreasing grain size with distance from the river mouth (Gasparini et al. 2004; Frings 2008) and entrainment in longshore transport (Fig. 12.1). Because of the lack of coral reefs along the coastline, the wave energy is higher which combines with the fine sand to promote the development of beaches with more-dissipative to intermediate character (Figs. 12.9a, b, d), except in the immediate vicinity of the river mouth, where the coarse sands favor beaches with more-reflective characteristics (Fig. 12.9c).

**The Sediment Starved Southern Coast** Extends from the village of Santo André to the border with the state of Espírito Santo (Ponta dos Lençóis) (Fig. 12.10). This compartment contains the largest area of coastal tablelands of the Barreiras Formation (Fig. 12.1). River basins that drain into this section are small, which explains why this section receives virtually no input of fluvial siliciclastic sediments. The lack of sediments results in the presence of numerous active cliffs carved into the coastal plains. The erosion of these cliffs by waves, rainfall and landslides is the main source of coastal sediments, which produced the Caravelas mega-salient and the Corumbau tombolo behind the Abrolhos and Itacolomis reef complexes, respectively (Fig. 12.3). The presence of these coral reefs, induce wave refraction, and convergence of sediment transport, resulting in the accumulation of the sandy plains (Andrade et al. 2003; Bittencourt et al. 2008; Dominguez et al. 2009). The reduced availability of sediment in this compartment promoted the development of coral reefs along sections where suitable substrates were available, including erosional terraces in the lateritic horizons of the Barreiras Formation, on volcanic rocks and on karstic surfaces carved in continental shelf carbonates in the region of Abrolhos (Bittencourt et al. 2008). The sheltering from waves by coral reefs; the greater energy dissipation due to the wider continental shelf; the increase in tidal action; and the supply of coarse sands derived from the Barreiras Formation resulted in a dominance of reflective beaches (Fig. 12.11a, b, c and d), sometimes with well-developed low-tide terraces (Fig. 12.11e).

### *12.4.1 Shoreline Behavior*

The sandy beaches of Bahia were assigned to four categories, i.e. eroding, equilibrium, prograding and highly variable (Fig. 12.12), in terms of their shoreline behavior between 1960 and 2000 (Dominguez et al. 2006).

(i) Eroding shorelines were characterized by evidence of continued erosional retreat, e.g. vegetation with exposed roots, cliffs and threatened property, based on field observations; vertical aerial photographs, satellite images; and interviews with residents. The most severe evidence of erosion in Bahia includes the following: sediment retention by engineering works associated with port facilities (e.g. the Port of Ilhéus); sediment retention on unstable capes (e.g., the Caravelas Plain); negative long-term sediment budget (e.g. the Sediment

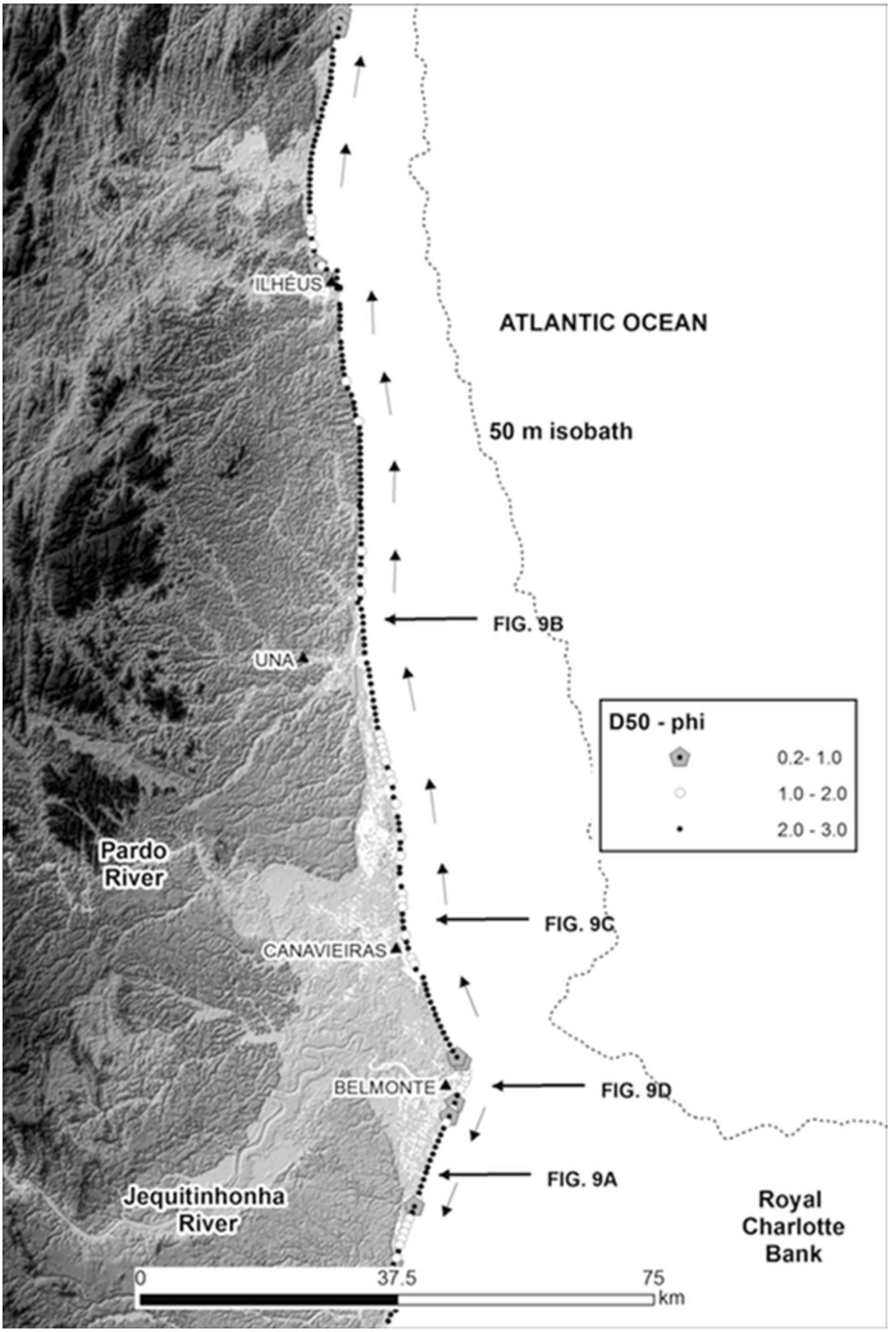


**Fig. 12.8** Variation of $D_{50}$ values of beach face sediments along the Deltaic Coast of the Jequitinhonha river compartment. Arrows indicate location of photos shown in Fig. 12.9. Small arrows show sediment dispersal along the shoreline

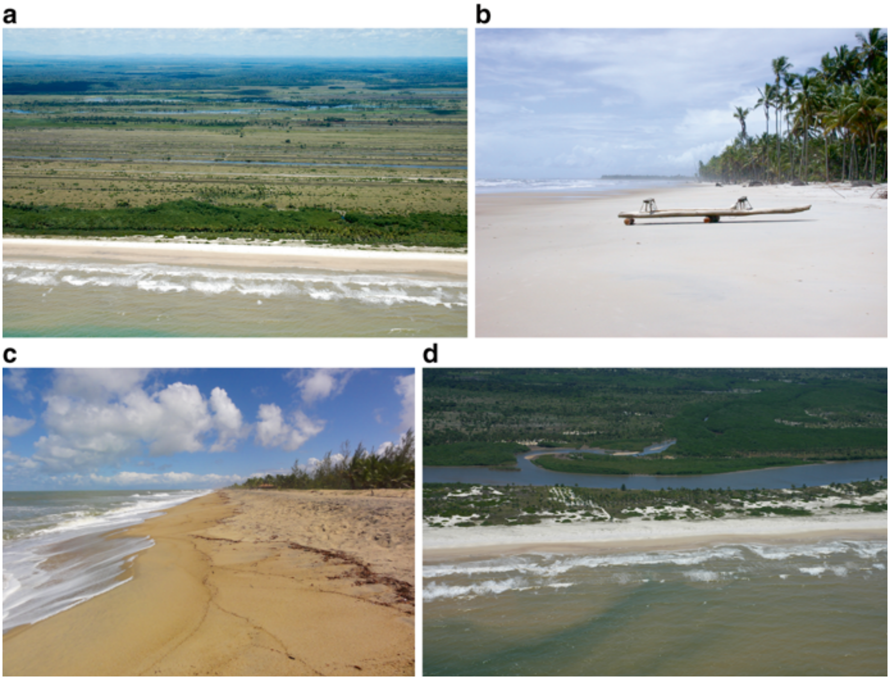

**Fig. 12.9** Photographs of beaches along the Deltaic coast of the Jequitinhonha river compartment. (**a** and **b**) dissipative and high energy intermediate beaches area dominant in this compartment; (**c**) reflective beach at the Jequitinhonha river mouth and (**d**) example of rhythmic bar and beach intermediate beach (see Fig. 12.8 for location of photographs)

Starved Southern Coast); reductions in solid and liquid stream discharges resulting from natural processes or human intervention; and longshore migration of small river mouths.

(ii) Equilibrium coastlines display no significant alteration of the coastline position during the four-decade study period, although seasonal variations may be observed. This category includes coastal sections characterized by long segments of straight coastlines (e.g. Northern Littoral Coast, Maraú Peninsula) and the presence of wide embayed beaches (e.g. coastal plains of Guaibim, Pratigi, and northern portion of the Caravelas Plain).

(iii) Prograding coastlines that displayed significant progradation during the last four decades. The sections with the greatest coastline progradation in the study area are located immediately north and south of the Jequitinhonha River mouth, where the shoreline prograded as much as 500 m.

(iv) Highly variable coastlines occur where the coastline position displays high spatial and temporal variability associated with the transport and deposition of sediments. In these sections, progradation and erosion have alternated. The processes associated with this type of behavior include the sedimentary dynamics of small river mouths and the entrances of bays and estuaries, owing to changes in mouth bars (ebb deltas) and adjacent coast.

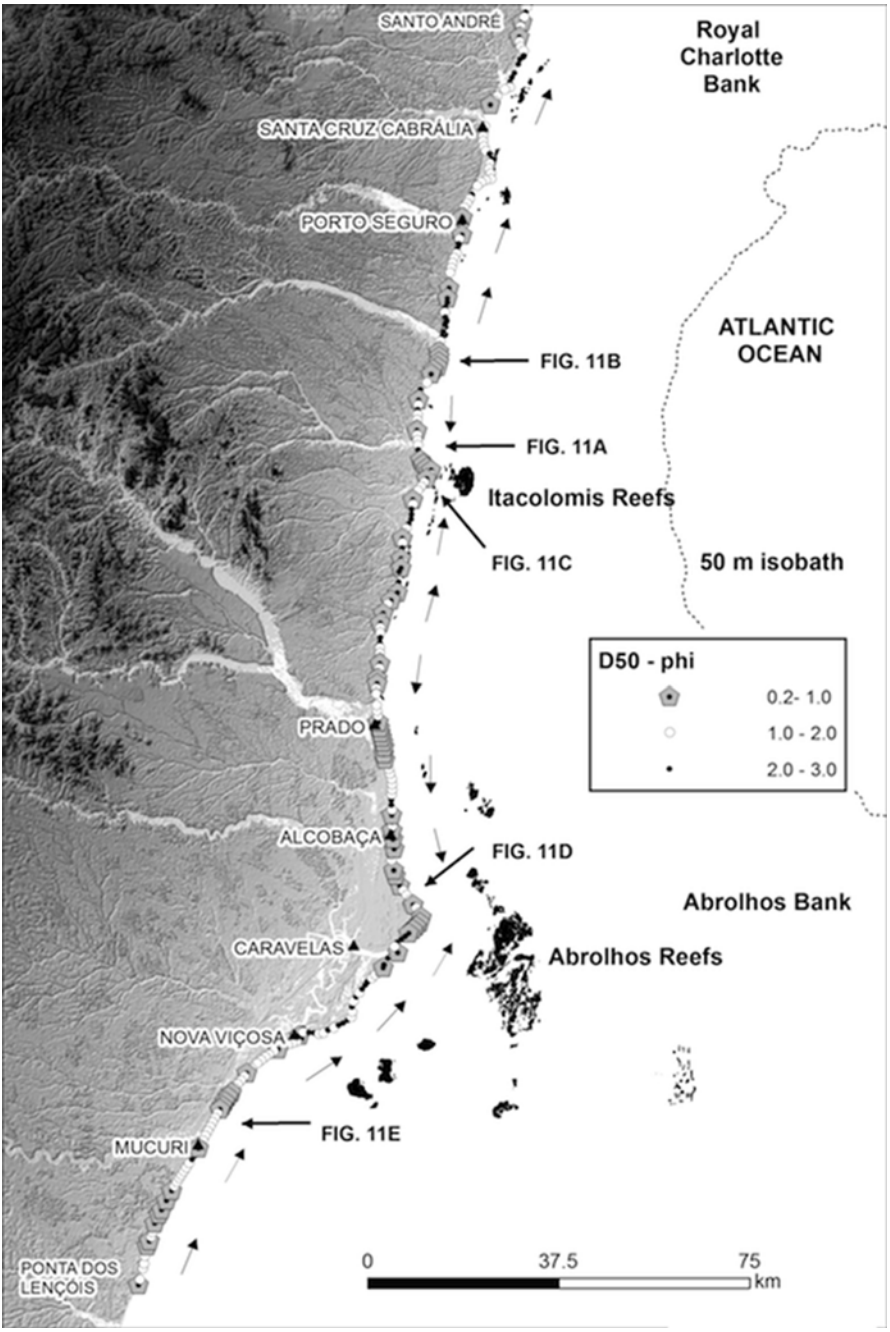


**Fig. 12.10** Variation of $D_{50}$ values of beach face sediments along the Sediment Starved Southern Coast Compartment. Arrows indicate location of photos shown in Fig. 12.11. Small arrows show sediment dispersal along the shoreline

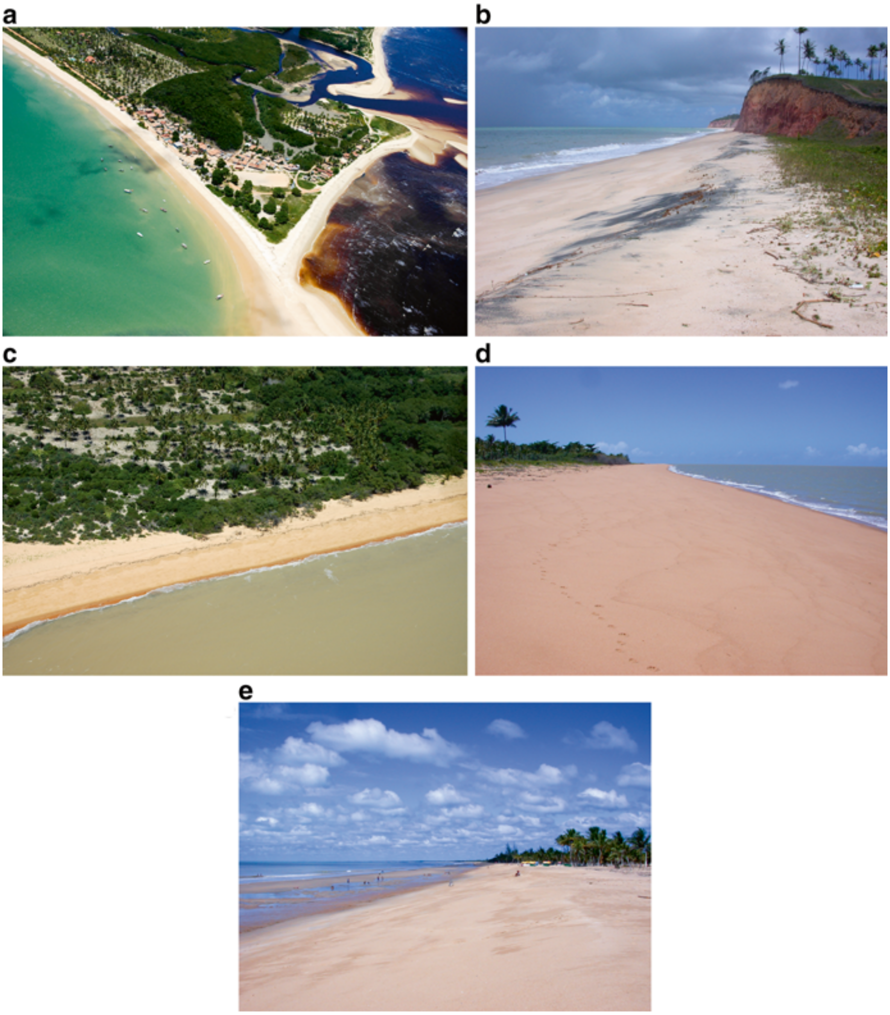


**Fig. 12.11** Photographs of beaches present in the Sediment Starved Southern coast. (**a**) reflective beach at Corumbau sheltered by the Itacolomis reefs; (**b**) active cliffs on the Barreiras Formation and associated reflective beaches. (**c**) reflective beach at Corumbau; (**d**) reflective beach at Caravelas strandplain; and (**e**) reflective beach with well developed low-tide terrace (see Fig. 12.10 for location of photographs)

Quantitatively, the shoreline behavior in the study area indicates that eroding sections (26 %) may be explained by processes typically associated with dispersion and accumulation of sediments along the coastline, river mouth dynamics, human intervention and long-term trends of negative sediment budgets. Sixty percent of the coast is categorized as balanced, at least during the four-decade study period, with the most significant cases of progradation (6 %) associated with the small number of local river mouths.

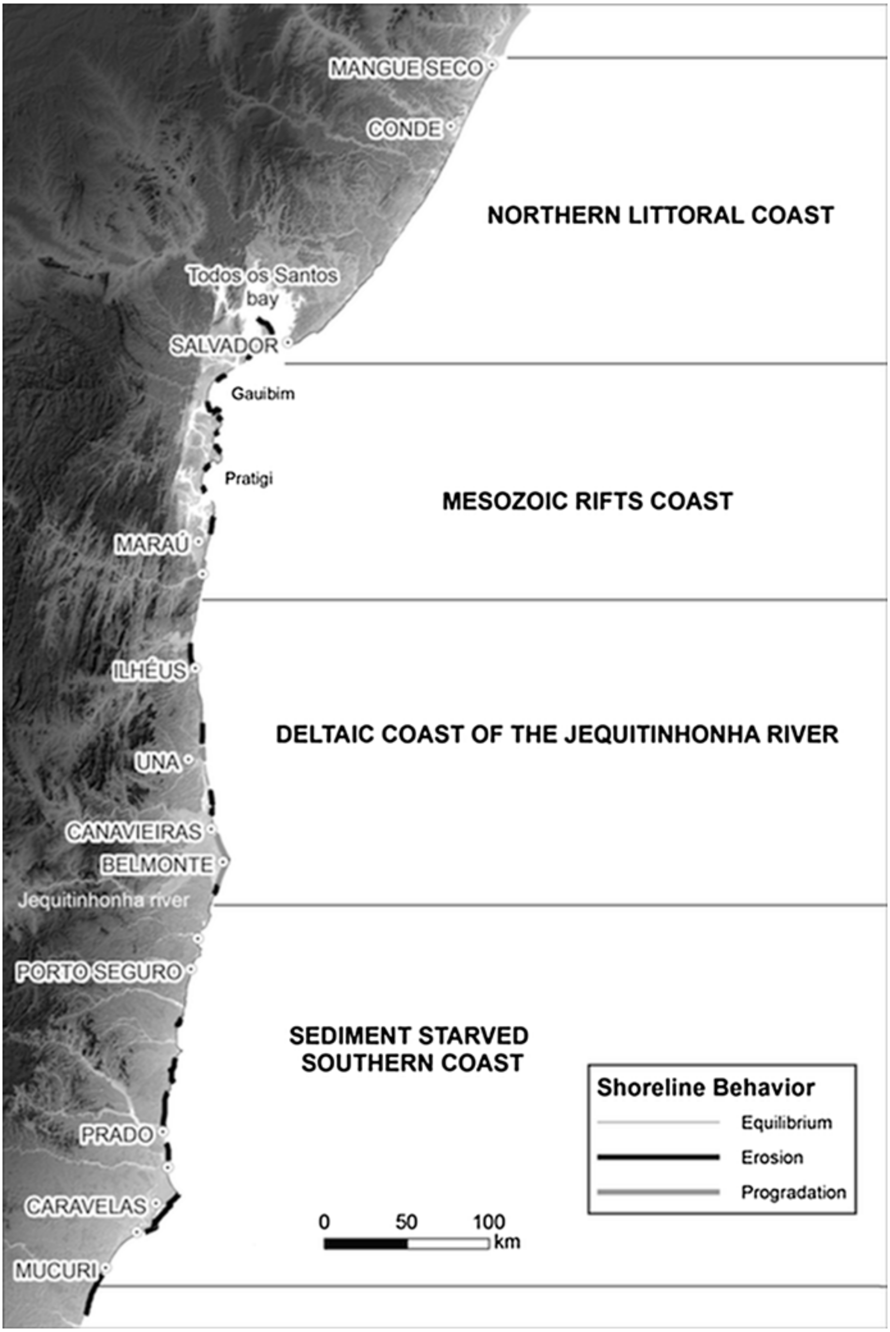


**Fig. 12.12** Shoreline behavior of Bahia state coastline between 1960 and 2000

## 12.5 Beach Safety: Case Study of Salvador Beaches

Studies of beach safety in Bahia are scarce. Carvalho (2002), performed a detailed analysis of Salvador's urban beaches and found that spring is the season with the highest percentage of accidents (44.8 %) involving beachgoers. This timing of accidents apparently results from the following combination of factors: (i) a high numbers of beachgoers due to improved bathing conditions following the winter and the occurrence of important national holidays (Independence Day, Children's Day and All Souls' Day); (ii) an average incident wave height in the spring of approximately 1.13 m versus 1.08 m in the summer; (iii) steady trade winds producing stronger coastal currents than in the summer; (iv) a beach profile characterized by transverse and longshore bars that are inherited from the most-energetic winter events; and (v) astronomical tide height that is approximately 8 % greater than that during the summer. The last three factors enhance the rip currents, which leads to a higher number of accidents involving beachgoers when combined with the increased public use of the local beaches. The risk increases with more bathers exposed to high-velocity rip currents along the beach.

These findings from the Salvador beaches may be extrapolated to other beaches in Bahia and used to develop a risk framework, as shown in Fig. 12.13. The beaches in the Mesozoic Rift compartment, excluding the Maraú Peninsula, pose the lowest risk to beachgoers, given the dominance of reflective and sheltered beaches. The beaches of the Sediment Starved Southern Coast compartment, although predominantly reflective, display one characteristic that adversely affects beach safety: active cliffs subject to collapse. The beaches in the Deltaic Coast of the Jequitinhonha River and the Northern Littoral Coast compartments North Shore sections have the highest risk, given their dominance of high-energy intermediate (longshore and transverse bar) and dissipative morphodynamic states. The southern portion of the Northern Littoral compartment (metropolitan area of Salvador city) exhibits the highest values of ambient population (average number of people over a 24-h period; LandScan dataset: http://web.ornl.gov/sci/landscan/), and, therefore, beach safety is a key concern there. Although beaches in the Deltaic Coast of the Jequitinhonha River compartment also pose a high risk to beachgoers, this risk is of lesser importance, due to the low population, except at Ilhéus, which is an important tourist destination and where accidents involving beachgoers are common.

## 12.6 Geologic Inheritance and Texture/Composition of Beach Sands

Several studies have highlighted the role of the geologic inheritance in controlling beach morphodynamics (McNinch 2004; Jackson et al. 2002; Short 2010). These authors primarily emphasize issues including the degree of embayment of beaches, the presence of rips and megarips, beach rotation and glacial heritage. The effect of

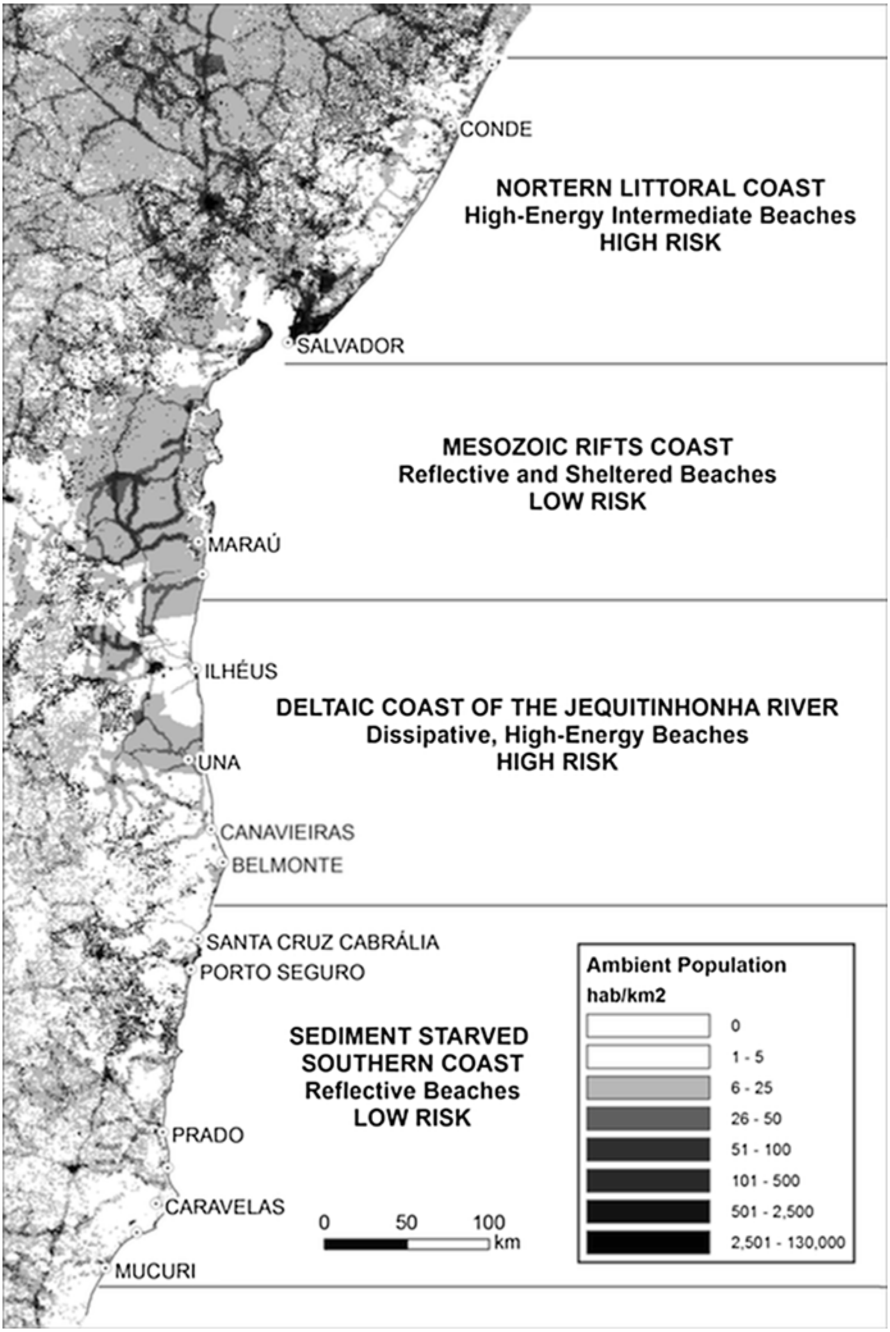


**Fig. 12.13** Distribution of ambient population in the Bahia coastal zone and level of beach safety. The portions of the coastal zone exhibiting greatest population concentration are the state capital (Salvador) and Todos os Santos bay, followed by the Porto Seguro region. Otherwise the coastal zone is scarcely populated. The Ambient Population is from the Landscan 2010 dataset (The LandScan 2010™ High Resolution global Population Data Set copyrighted by UT-Battelle, LLC, operator of Oak Ridge National Laboratory under Contract No. DE-AC05-00OR22725 with the United States Department of Energy)

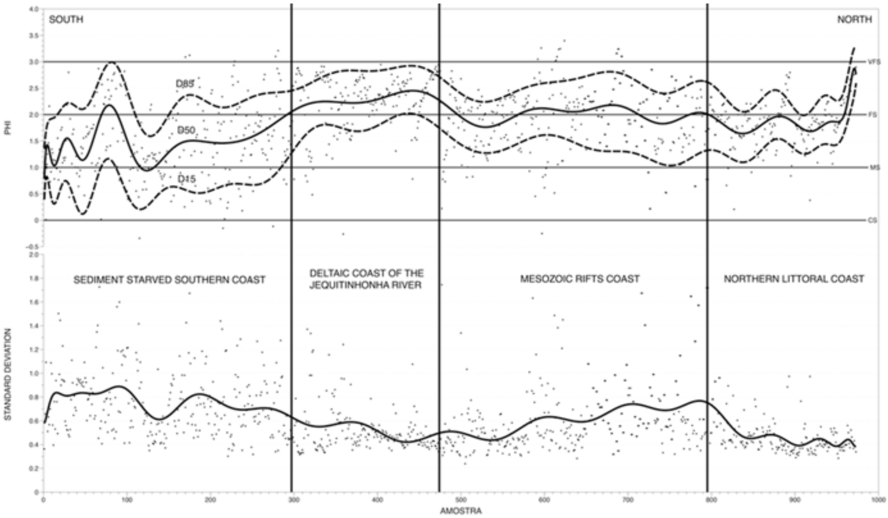


**Fig. 12.14** (**a**) variation in the values of $D_{50}$, $D_{15}$ and $D_{85}$ of beach face sands along the shoreline of Bahia; and (**b**) variation of degree of sorting (Folk's formulation) of beach sands along the shoreline of Bahia

geologic heritage is primarily analyzed in the present study in regard to factors controlling the beach particle size, which in turm exerts a major control on the morphodynamic state of Bahia's beaches.

Based on the foregoing findings, a conceptual model was developed for relating the geological heritage to beach morphodynamics. The main control exerted by the geology is on the sediment particle size available to this coastline. The large river drainage basins tend to supply finer sediments (Gasparini et al. 2004; Frings 2008), as occurs in the Deltaic Coast of the Jequitinhonha river compartment (Figs. 12.8 and 12.14). The combination of high wave energy and fine sediments produce a dominance of high-energy dissipative and intermediate beaches (transverse/longshore bar). Conversely, small and medium rivers tend to transport coarser sediments to the coastline, which occurs in the Northern Littoral Coast Compartment (Figs. 12.4 and 12.14). Therefore, high-energy intermediate beaches (transverse and longshore bars) predominate in this stretch. Furthermore, foredunes a few meters tall are associated with these beaches because the supply of sediment is just sufficient to maintain the coastline in a position of balance or low retreat. A trend of the sediments fining in the direction of drift was also observed in both sections (Fig. 12.14). The unimpeded transport of sediments without obstructions driven by constant erosion and transport by waves sorts beach sediments as indicated by the longshore fining in part of the southern and the two central compartments (Fig. 12.14).

Where fluvial contributions are absent, the main source of beach sediment is erosion of older sediments or rocks exposed along the coastline. The main source of sediments in the Sediment Starved Southern Coast Compartment is the erosion of active cliffs in the Barreiras Formation, which consists primarily of coarse sediment (Figs. 12.10 and 12.14a). These coarser, partly gravelly sands in combination with the reduction in energy provided by the offshore coral reefs promote the development of reflective beaches with steep gradients. This reduction in wave height and a slight increase in the tide height in this section increase the RTR, resulting in tide-modified beaches typified by a reflective high tide beach and the common presence of low-tide terraces. Reduced reworking by waves and restricted transport of sediments results in the most poorly sorted beach sand among the Bahia beaches (Fig. 12.14b).

The Mesozoic Rifts Coast Compartment is also characterized by a reduced supply of sediments because all the rivers there except the Contas are small and flow into bays and estuaries, where the coarser sediments settle out. Consequently, the sediments supplied to the coastline are typically fine sands and silts. The eroded sediments from the few rock outcrops in the region, consisting mostly of eolian fine-grained sandstones of Mesozoic age (Tinharé Island), are added to these fluvial sediments (Figs. 12.6 and 12.14a). Other minor exposed rocks consist of limestone and crystalline basement. The fine sands are ultimately trapped in the ebb-tide deltas at the mouths of the bays and estuaries. The erosion of Mesozoic sedimentary rocks resulting from wave action creates erosional terraces that are colonized by coral reefs. These reefs lead to decreased wave energy and localized production of bioclastic sediments of gravel and coarse sand sizes supplying the coastline (Figs. 12.6 and 12.14a). Therefore, a large number of reflective enclosed beaches, typically fetch limited and sheltered, and beaches fronted by reef/rock flats, in which sediment is mobilized by waves only during high tide or high-energy events, are formed. Thus, the beaches form only thin sandy prisms resting on older rocks or coral reefs. Reduced wave energy and impeded transport of sediments also lead to more poorly sorted beach sediments in this compartment (Fig. 12.14b).

## 12.7 Summary

The state of Bahia with approximately 1000 km of shoreline, a great heterogeneity of exposed rock types and subjected to varying degrees of sediment supply allowed us to investigate the controls exerted by these factors in determining the beach types.

The modal morphodynamic states of the beaches of Bahia is dominantly controlled by sediment grain size, which in its turn results from the long term history of the coastal zone. Locally sourced sediments, eroded from the coastal tablelands (Barreiras Formation), are predominantly coarse-grained favoring reflective beaches (Sediment Starved Southern Coast). Distally sourced sediments, as in the case of large rivers are predominantly fine to very fine sands, resulting in a dominance of dissipative and high-energy intermediate beaches (Deltaic Coast of the Jequitinhonha River). Shoreline stretches nourished by small rivers are characterized by medium size sands and a dominance of intermediate high-energy beaches (Northern Littoral Coast Compartment). Finally, the stretch of the coast fronted by Mesozoic Rifts, characterized by a great heterogeneity of sedimentary rock types and small sediment supply, have a very irregular shoreline, bordered by fringing reefs. In this section low-energy sheltered beaches dominate

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