Shoreline of Puerto Rico

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PUERTO RICO COASTAL TYPES

The simplest description of the Puerto Rico coast involves a division into three basic categories:

- rocky cliff and headlands
- mangrove coast
- sand or gravel beaches

Kaye discussed the types of shoreline along the coast of Puerto Rico. These developed in response to a number of factors including:

- the presence of a central ridge, ruptured by long strike slip faults extending from the west to the east coasts and flanked on the north and south by shallow water sediments
- the difference climatic regimes between the north and south coasts
- the transformations with time of the original features by broad climatic and erosional changes
- past tectonic activity of the area.

Coastal System

From Aguadilla to Punta Cabo Rojo, the coast is dominated by the effect of the termination of structural mountain ridges separated by broad alluvial valleys (Figure 1). The ridges form a rocky coast, and the shoreline bordering the alluvial valleys is occupied by sand beaches.

Figure 1. Volcanoclastic hills to the north and alluvial valley to the south are separated by the Great Southern Puerto Rico fault

South of Mayaguez, The shelf is relatively broad and reefs and shoals with depths of less than 10 meters extend 20 kilometers offshore (Figure 2). The same pattern of ridge with rocky shoreline and valley with sand beach is present, but there are also areas of mangrove coastline and fringing reef coast because of the protection offered by the shoal continental shelf area.

Figure 2. Narrow insular shelf off Mayagüez- Añasco bays and wide carbonate shelf off Punta Guanajibo and south

The southwest coast is very irregular, with projecting brush- covered points of limestone between shallow coves and bays (Figure 3). There are fringing reefs along part of this coast. Except for the eastern and western ends of the south coast, and the Guánica area, the land is generally low near the shore.

Figure 3. Irregular shoreline from wave action on south coast limestones

The shoreline development is closely related to whether the adjacent land area of the coast is Cretaceous-Tertiary limestones, igneous rock, or low Tertiary sediment fans and alluvial plains. The limestone outcrops generally form a rocky coast with small, very local sand or gravel beaches (Figure 4). In many places, this type of shoreline has been altered by the growth of mangrove and the subsequent development of a mangrove shoreline (Figure 5).

Figure 4. Rocky north coast, massive limestone

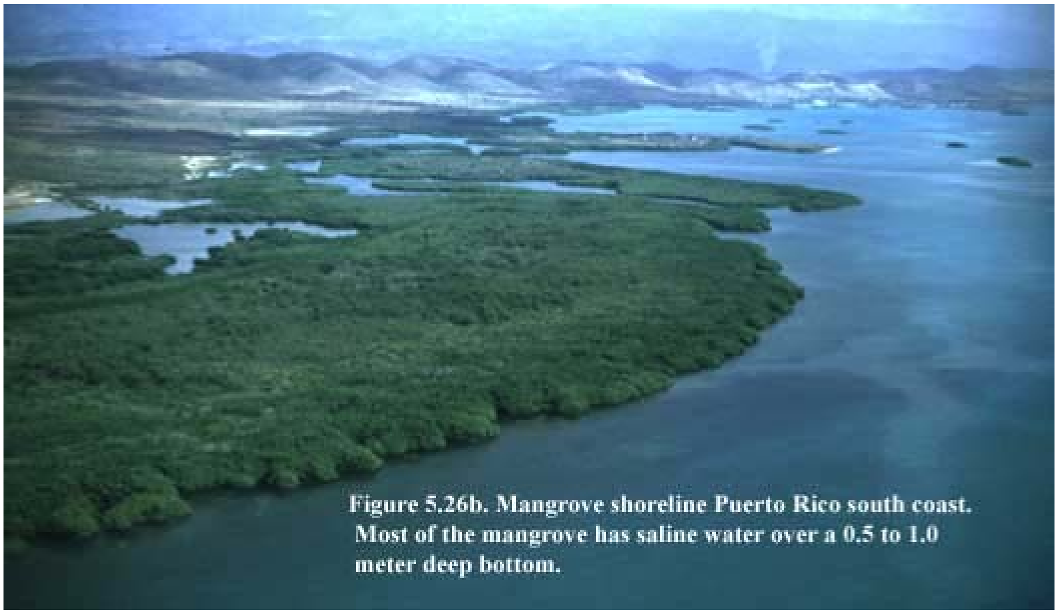


Figure 5. Mangrove shoreline extending offshore near La Parguera

The alluvial plains are either beach areas or unconsolidated cliffs that are retreating under the attack of strong wave action.

The southeast coast of Puerto Rico is mainly rocky coastline with some broad beach under the attack of strong wave action areas developed in front of alluvial valleys and a few areas of fringing reef coastline. This pattern extends along most of the east coast where irregular projecting rocky bluffs separate numerous small shallow coves and bays (Figure 6). In these areas, as on the west coast, the hills are within a mile of the coast. Shoal water extends offshore as part of the platform connecting Puerto Rico and the Virgin Islands.

Figure 6. Rocky bluffs with small beaches, southeast Puerto Rico

There is fairly widespread mangrove coast along the northern half of the east coast. The north coast from the east end of the island to San Juan is low and sandy (Figure 7) except for occasional eolianite bluffs (Figure 8).

The low land extends three to seven kilometers inland. The coast is indented by many coves that are protected by reefs and rocky islets lying only one to two kilometers offshore. Most of the coast is sandy beach. The large mangrove areas that lie east of San Juan do not form the coast, but lie several hundred meters behind the sand beaches and dune system.

Figure 7. Low coastal plain with sandy beach

Figure 8. Eolianite bluff, Vacia Talega

From San Juan to Arecibo, the coast lies in front of a low-lying coastal plain (Figure 9). Beach sand, cemented dunes, beach rock, and mangrove swamps dominate this region. There are sandy beaches and dunes with occasionally rocky eolianite coast and beach rock coast from San Juan to Vega Baja. The mangroves lie close to shore on the coastal plain but do not form the coastline along any part of the northern coast. From Vega Baja to Arecibo, the coast is dominantly eolianite with numerous small lunate bays bordered by beaches (Figure 10). There is some movement of the beach sand from one bay to another behind the eolianite ridges.

Figure 9. Coastal plain north of Manati

Figure 10. Lunate bays are common on north coast – Marchiquita

The north coast from Arecibo to Aguadilla is a series of rocky cliffs with sand beaches and dunes between them (Figure 11). The prominent features are the high hills in the interior and high cliffs along the coast. Where low coastal plains with beach are present, they are less than a kilometer in width.

The north shelf is only two to four kilometers wide and there are few offshore reefs beyond a half kilometer from shore. In most places the open ocean waves break directly against the shore. It is a high energy coast with a rugged shoreline and active beach systems.

Figure 11. Rocky cliffs and beaches, north coast

PUERTO RICO BEACH SYSTEM

The coastal zone of Puerto Rico is remarkably diverse. Unlike the shorelines of many major continents, there are no long interrupted stretches of basically similar beach. The beaches of Puerto Rico are relatively short and are divided into separate and distinct beach systems that have restricted communication with one another (Figure 12). Each is a closed or semi-closed unit receiving its supply of sediment from limited local sources and transmitting little of its longshore moving sand to another beach system. In analyzing the sand and beach systems to determine the extent of isolation, mineralogy, metal content and biogenic constituents have been studied; also the actual physical parameters of separation have been analyzed.

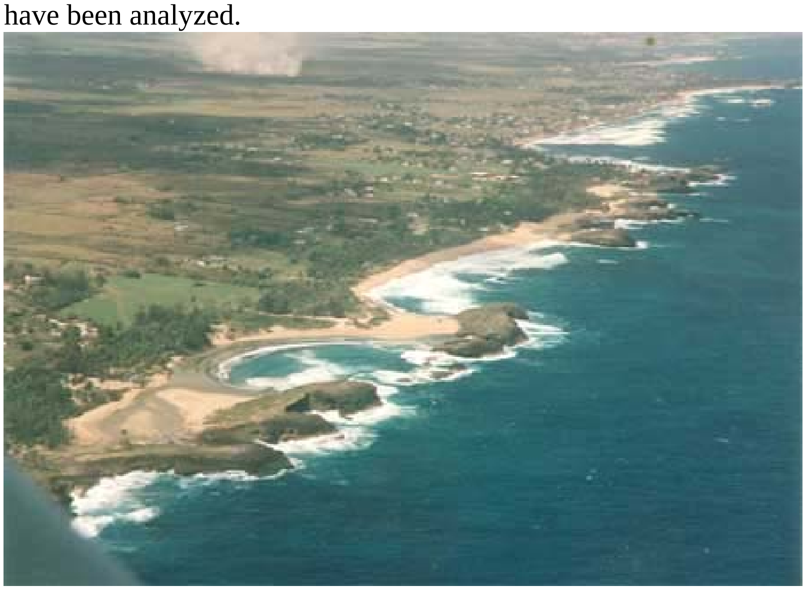


Figure 12. Restricted communication between beaches

The sources of beach sand are relatively limited and the total available volume of sand that can be added to the system is not very large. These sources include:

offshore sands

- modern erosional residue
- relict Pleistocene deposits
- rivers and estuaries directly

erosion of land

- alluvial river valleys
- cliff erosion alluvial
- or rock
- eolianites and beachrock

biogenic material

- from coral reefs
- shell accumulations

DRAINAGE BASIN AND BEACH COMPOSITION

The beaches of Puerto Rico contain sand grains derived from several major sources. Erosion of land areas and transport of rock material by rivers to the beach supplies terrigenous sand grains. The composition variances are a function of the source area where the material is eroded and added to the river sand system. Areas of river drainage underlain by basaltic type rocks supply dark minerals and dark igneous rock fragments. Granite rock outcrops supply quartz and feldspar to the beach. Feldspar is a relatively unstable mineral that breaks down to clay minerals. The presence of feldspar in a beach system is indicative of a geologically young environment.

Calcium carbonate is supplied to the beach by the shoreward transport of the shells of marine organisms. The composition changes in calcium carbonate and terrigenous material are a function of available supply and transport system.

Along parts of the coast containing major rivers, there is an increase in terrigenous content in the beach sands. There is also a shift toward terrigenous beaches where an offshore carbonate source is lacking. By analyzing the availability of supply we can draw conclusions about the transport system and beach dynamics. Larger concentrations of calcium carbonate can indicate shoreward transport. In an area such as Guanajibo Beach (Mayaguez) the absence of carbonate grains in the beach sands coupled with the presence of reefs just offshore shows that shoreward transport of beach material is negligible. This is part of the reason for the erosion on this relatively protected beach environment.

BEACH EROSION

Examination of the coast by aerial reconnaissance, beach surveys, and comparative analysis of aerial photographs shows that there is erosion on all coasts. The data available for the Caribbean, Central America, Mexico, and the southern part of the United States indicates that erosion is the dominant activity in the beach and coastal areas. There was a history of aggradation beginning roughly 5,000 years ago and then a shift from deposition to erosion during the past 500 years. Although the rate of beach erosion fluctuates, there is presently a general state of recession of Caribbean beaches and shorelines.

The causes of this erosion may be:

- changes in sea level,
- diastrophism,
- erosion of barrier reefs and eolianites
- activities of man modifying the system
- maturing of the coastal system - to present sea level

These factors are not isolated, but are complexly inter-related. Although the rapid rise of sea level ended some 5,000 years ago, measurements lead some geologists to believe that there has been a slow rise of several centimeters during the last fifty years. In an area of limited tidal range such as Puerto Rico, a rise of several centimeters would lead to changes in the beach equilibrium. However, the change from aggradation to erosion throughout the middle America region is not synchronous as would be expected if the controlling mechanism were continued sea level rise.

Diastrophism, producing changes in the height of the land by vertical rise or fall, also affects the stability of the shoreline. If the land has dropped relative to sea level, there would be increased erosion. These movements and the accompanying effect may be local in nature.

The eolianites and beachrock along the north coast of Puerto Rico form a relatively continuous barrier which protects the shore. Behind this protection, lagoons, tombolos, and other depositional features have formed. This protection is being breached and removed by the natural force of the waves. Where the eolianite is breached, erosion has cut into the land to form lunate bays. Because eolianites on the north coast are loosely cemented, they are being reduced in height and are being destroyed, allowing waves to penetrate to the beaches with greater force. This has upset the established equilibrium and caused retreat of the shore and erosion of the beaches. Beachrock is separated from the coast by tens of meters in many places, indicating recent erosion (Figure 13).

Figure 13. Beachrock at Levittown

Many beaches are protected by fringing and offshore coral reefs. Increased sedimentation and other factors have led to the diminished ability of many of these reefs to survive, with a resulting increase in coastal erosion as they cease to be a barrier to wave energy. The development of agriculture on the Island and later heavy urbanization and industrialization have been major factors contributing to the loss of reefs.

Human activity is important locally. The activities of man have been varied and striking in contributing to the loss of coastal areas. In some cases the natural transfer of sand from one area to another has been blocked by the construction of new structures such as the causeway between Punta Tocones and Isla de Cabras (Figure 14). This has not only cut off a source of sand nourishment, but has altered the prior circulation patterns, and tombolo of Punta Salinas is now being eroded (Figure 15).

Figure 14. Isla Cabras causeway

Figure 15. Eroding Pta. Salinas tombolo, Levittown

Removal of sand from river mouths includes the collection of littoral drift sand and results in erosion such as that seen near the mouths of the Anasco and Loiza rivers (Figure 16). Removal of sand dunes and beach sand for use as fill and aggregate have certainly contributed to the depletion of many beach systems. In areas where sand dunes have been removed, leaving only a small barrier, waves have started to break over the barrier and are carrying sand away (Figure 17).

Figure 16. Removal of sand from the mouth of the Loiza River

Figure 17. Breaching of north coast sand dune

Construction activities have crowded close to the shoreline because of limited land areas and reduced construction costs on the low coastal plain (Figure 18). This has not only aggravated the erosional process, but has put valuable new property in areas of natural erosion. This has in turn created the need to institute urgent and expensive protective techniques to protect the investment. These remedies may have effects not immediately recognized.

Figure 18. Urbanization of the shoreline. Note incursion of the beach east of the construction

Construction close to the beach south of Mayaguez Harbor was being rapidly endangered by erosion. Riprap was emplaced to protect this property, which then cut off a source of sand – natural coastal erosion – from the area to the south. The next step was riprap protection for houses to the south which were being threatened by the erosion generated by the riprap. As the problem moved south the entire beach was eventually replaced with riprap. The coast is now stabilized, with a basic change in coastal classification from sandy beach to rocky shoreline, man-made (Figure 19).

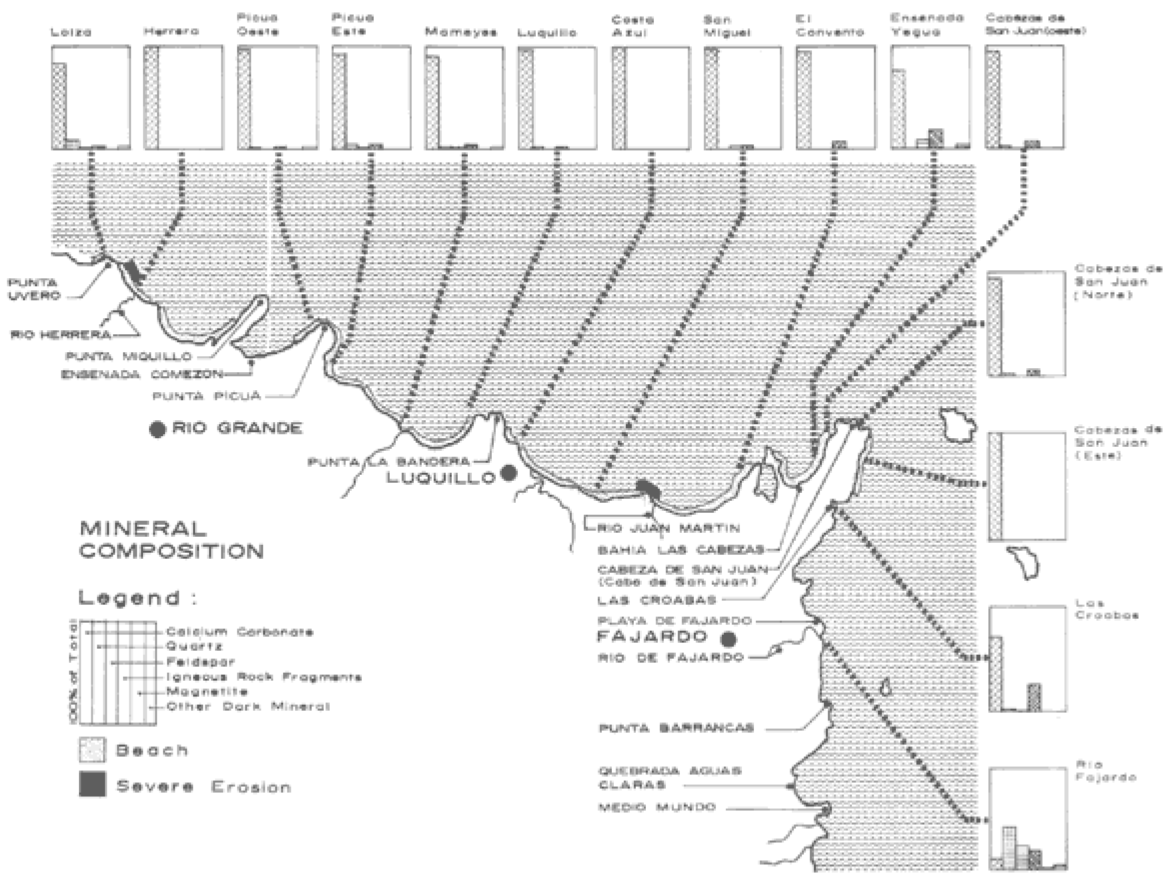
Figure 19. Armoring the shoreline with boulders and tires

It has been suggested that the broad change from aggradation of beach and coastal land to the present widespread state of erosion is part of maturing of the system. The entire process may be an evolving adjustment to the present sea level. There are many areas in Puerto Rico such as the accretionary beach ridges east of Ponce, the Humacao coastal region, and the many tombolos that show past periods aggradation. There is also evidence of a shift to erosion in these same areas.

Beaches are fragile and transitory geological features and require, care and consideration if we are to transmit to our children the joys of a day at the beach.

COASTLINE AND BEACH ANALYSIS

Fajardo to Loiza



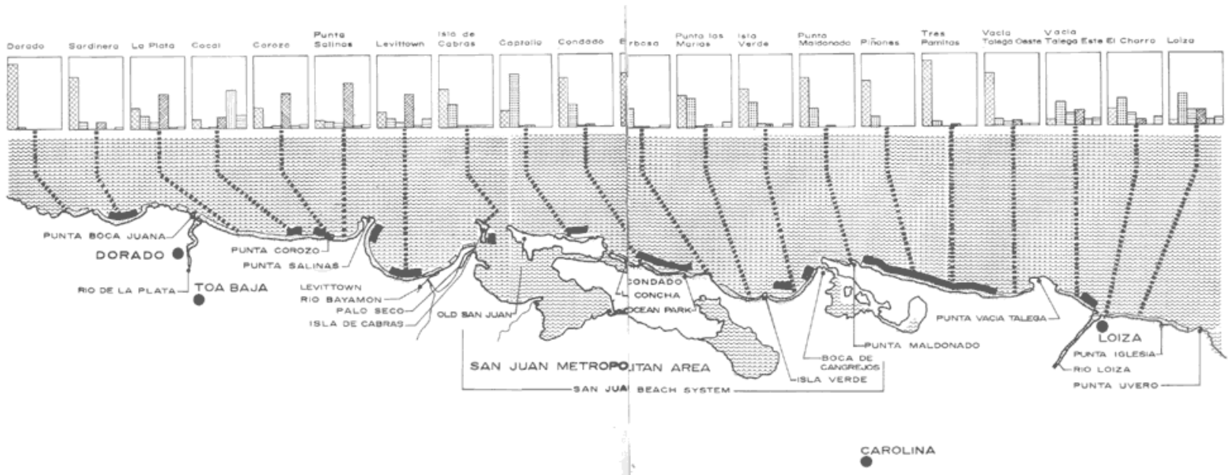
The southern part of Medio Mundo is a mangrove coast and the northern part is beach plain. North of Quebrada Aguas Claras, there is a short mangrove coast and then northward a rocky shoreline to Punta Barrancas. From here to Playa de Fajardo the coast is mangrove (Figure 20).

Figure 20. Mangrove shoreline Ceiba

From Fajardo to Cabeza de San Juan, the shoreline is fringing reef with a narrow beach developed behind the reef. Bahia Las Cabezas is a beach plain and west of this there is a narrow stretch of fringing reef coast. The coast westward to San Juan is beach plain with the exception of a limited amount of mangrove coastline at Ensenada Comenzon, a barrier coast at the mouth of the Loiza River, and an eolianite coastline at Punta Vacia Talega and Punta Maldonado. Much of this coast is partially protected by a narrow band of shoal offshore reefs and rocks. Reef development occurs off Punta La Bandera, Punta Picua, Punta Miquillo, and from Punta Uvero to Punta Iglesia.

There is a narrow, fine-grained beach at Playa de Fajardo composed of quartz, feldspar, and igneous rock fragments. Most of this sediment has been carried by the Fajardo River. The beach is interrupted in several places by riprap, but erosion does not appear to be severe. Bahia Las Cabezas and Las Croabas beaches are narrow carbonate beaches lying behind a fringing reef which supplies most of the beach material. There are igneous rock fragments in the Las Croabas beach, derived from local sources. Neither of these beaches show signs of severe erosion. From Cabo San Juan to Rio Herrera, the beach sands are carbonate shell material derived from offshore. Minor amounts of quartz, feldspar, and igneous rock material are supplied by local erosion. The beaches are relatively broad and essentially continuous. Rocky outcrops interrupt the beach system at the point west of Rio Juan Martin and Punta La Bandera. At Punta Picua, there is also an interruption of the beach, but from composition and bathymetry it appears that a single beach system is present from Cabezas de San Juan to Punta Vacia Talega. The increases in quartz and heavy minerals near the Herrera and the Loiza Rivers are local additions of sediment by the rivers. The sand bypass from one beach to another in the shoal offshore zone.

Loiza to Dorado



Between Punta Uvero and the Loiza River, there are several areas of erosion. Just east of Punta Uvero to Rio Herrera and east and west of Punta Iglesia and Punta las Carreras there is erosion (Figure 21). In both cases, this is strikingly shown by palm trees in the ocean, many of them lying at the water's edge.

Figure 21. Coastal erosion at Pta. Iglesia

The composition of the Loiza beach from Punta Uvero to Vacia Talega is strikingly different from the rest of the beach system in having a very high quartz content. This is contributed by the Loiza drainage system. Erosion is marked from the mouth of the Loiza River halfway to Punta Vacia Talega.

West of Punta Vacia Talega there is an entirely different beach system from the Luquillo beach complex and specifically from the Loiza beach. Quartz is almost absent from the beach sands which are 70 to 95 percent calcium carbonate of marine shell origin. The Loiza sands are apparently carried offshore in passing Punta Vacia Talega and only limited amounts return to the beach. Erosion is present west of Punta Vacia Talega. There is a high stabilized dune system behind the beach which is affording some protection to the land area (Figure 22). The beach foreshore is relatively steep. Maldonado Beach is a short, narrow beach between Punta Maldonado and Punta Cangrejos. Erosion is severe on this beach (Figure 23).

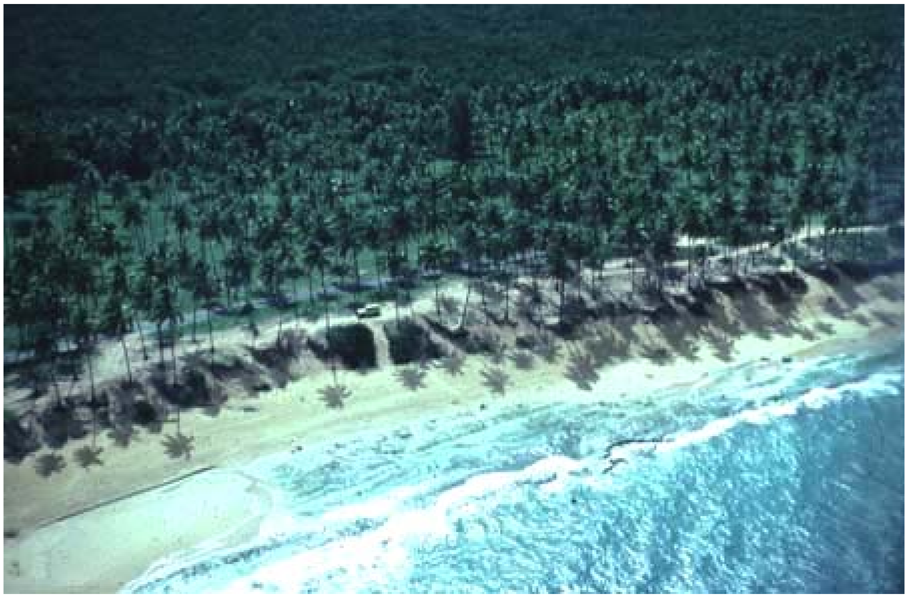


Figure 22. High dune at Piñones

Figure 23. Erosion at Punta Madonado

From Boca de Cangrejos to Punta Chivato the coast is beach plain interrupted by numerous outcrops of eolianite, forming an eolianite shoreline, and several local beach-rock coastlines (Cibuco and Puerto Nuevo). The mouth of Rio de la Plata is a barrier coastline.

The beach sands from Boca de Cangrejos to Old San Juan are a mixture of carbonate grains and quartz. There are about seven separate beaches separated by rock outcrops, but the water depths and composition indicate that there is probably transference of material from one beach to another resulting in essentially one beach system. The addition of a groin at La Concha has interrupted the westward migration of sand (Figure 24). There are sand deposits in deep water (40-50 meters) off Boca Cangrejos which may result from the offshore transport of the beach sands.

Figure 24.

The beaches are thin coverings of sand over a rocky shoreline. Erosion at Boca de Cangrejos has threatened the road. The remedial action has been emplacement of rip-rap (Figure 25). There is active erosion at Ocean Park and Isla Verde. There is loss of sand offshore and also windblown into the streets in the Condado area. Although the composition of sand on Isla Cabras is similar to the San Juan beach system, there is probably no transport of sand across the deep entrance channel of San Juan Harbor.

Figure 25. Armored shoreline (boulder riprap) at Cangregos

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From Levittown to Rio de la Plata, the beach is dominantly igneous rock fragments with other dark minerals, quartz, feldspar, and carbonate grains. There is erosion at Levittown and Palo Seco (Figure 26). The erosion of sand from behind the beachrock at Levittown is fairly recent and shows the rapid changes in beach position since the construction of the Isla Cabras causeway and the Bayamon canal. This construction has drastically altered the current and wave patters and set up new conditions in the large lunate bays between Isla Cabras and Punta Salinas. Punta Salinas is a tombolo of fairly recent origin that is now being eroded (Figure 27).

Figure 26. Erosion of shoreline at Levittown has left beachrock offshore

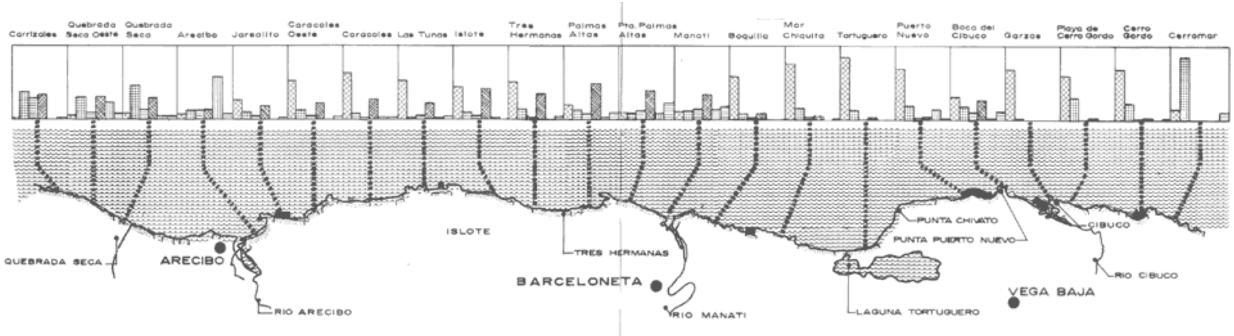
Figure 27. Riprap on east side of Pta. Salinas tombolo

Within the last few hundred years there has been a marked retreat of the coastline between Punta Salinas and Rio de la Plata. There are several meanders of the Cocal channels that have been cut off by the retreating beach line (Figure 28). There is severe erosion just west of Punta Corozo that has been partially controlled by riprap to protect the highway (Figure 29).

Figure 28. Meanders cut off by encroaching shoreline at Cocal

Figure 29. Highway armored with boulders

Dorado to Corrizales



From Boca Juana to Rio Cibuco, the sands are dominantly carbonate with some quartz, except for the Cerromar Beach. This is a man-made beach, nourished by truck with quartz sand. The high level of quartz in the next beach west shows that sand transport and bypassing occurs. There is erosion at Sardinera beach evidenced by the continuing loss of palm trees at the shoreline. There is an input of dark minerals and igneous rock fragments by the Cibuco River. There is also erosion in the bay west of the river mouth. The shoreline in this area is beachrock and is separated from an earlier shoreline by a widening expanse of water (Figure 30). The interferance of refracting and defracting waves behind the isolated eolianite creates zone in which sand is deposited to form a tombolo.

Figure 30. Offshore beachrock shows shoreline erosion.

From Laguna Tortuguero to Penon Afuera, the coastline is beach and eolianite. More of the coast is eolianite than to the east. The sands from Punta Chivato to Rio Manati are carbonate with some quartz grains and igneous rock fragments. The material is from offshore production by marine organisms and weathering of the eolianite. There are numerous lunate bays, formed by erosion of the land when the eolianite is breached, and numerous examples of tombolos, where the sand connects remnants of eolianite to the receding shoreline. In many of these, there is no obstruction to the passage of sand behind the eolianite. Most of the beaches are thin sand deposits over a rocky lower foreshore.

During winter storm periods these sands may move offshore temporarily. The Manati River carries large amounts of igneous rock material, dark minerals and magnetite. The beaches to the west of the river mouth are dominated by these minerals. There is a slow decrease in these grains and an increase in carbonate material toward Jarealito. Although the beach materials have been transported behind the eolianite, many of the tombolos are now stabilized by the growth of vegetation, and sand is no longer passing across the tombolo.

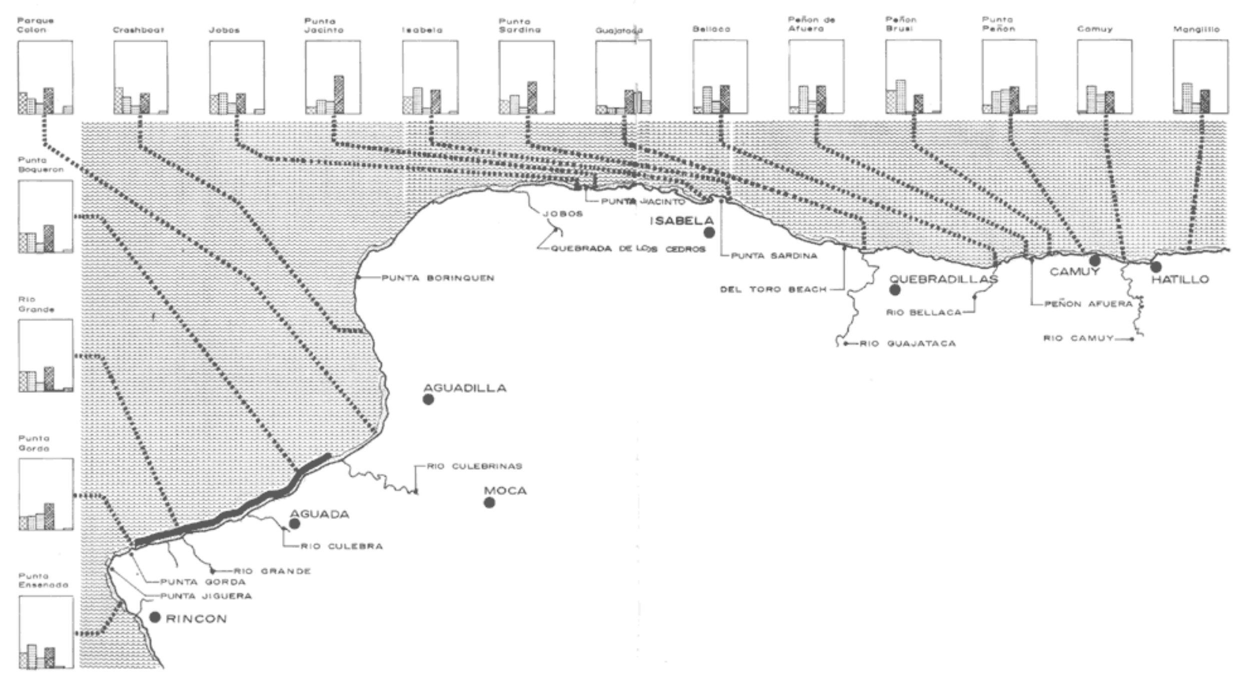
Between Tres Hermanas and Jarealito, the beach is dominantly carbonate with some igneous rock fragments. From Rio Arecibo west, the beach is quartz, feldspar and igneous rock fragments in roughly equal portions. On some of the beaches (Arecibo, Quebrada Seca West) the magnetite content is very high. Both the Arecibo and Camuy Rivers carry sediments to the beach system.

Near Islote, part of the beach sands are being lost from the system by wind erosion (Figure 31). The sands are being incorporated into dunes behind the beach, and evidence of recent activity is shown where the sand has blown over the vegetation.

Figure 31. Inshore migration of beach sand – dune system

The coastline west of Penon Afuera is secondary type resulting from wave erosion of a rocky coast.

Corrizales to Ríncon



From here to Aguadilla, the coastline is formed by the bluffs of Tertiary limestone and is shaped by wave erosion. However, in about half of the coastal areas the limestone bluff is several hundred meters to several kilometers from the shoreline, and the coastal type is beach plain. West of Jobos beach, there is a short stretch of coast that is primary, resulting from subaerial deposition by wind and is classed as a dune coastline. Eolianite coastline is much less common than to the east.

The beach at Bellaca is a small local sand accumulation or pocket beach (Figure 32). Most of the beach material is carried to the area by the quebrada. The Guajataca beach is quartz, feldspar, and igneous rock material carried to the area by the Rio Guajataca. It is isolated from the other beaches by rocky headlands (Figure 33). The beaches east of Isabela are generally narrow, thin veneers of sand over a rocky shoreline (Figure 34).

Figure 32. Pocket beach at Bellaca

Figure 33. Guajataca beach

Figure 34. Rocky shoreline, northwest coast

From Del Toro beach westward, there is a thick and wide dune system behind the beaches which probably supplies most of the beach sands by landward erosion. There is no permanent drainage system into this part of the coastline, but the sands are dominantly igneous rock material, quartz, and feldspar. Carbonate grains make up only a small part of the beach sand. There are numerous rocky headlands interrupting the beaches, but there is probably lateral migration of the sands in the nearshore region.

The dunes behind the beaches have been extensively mined for sand, and in places (Sardina) the beach sands have been removed. The beach at Punta Jacinto (Figure 35) shows the wide and thick accumulation of sand that lies in front of the vegetation covered sand dunes. West of Jobos beach, there has been major removal of the dune sands (Figure 36). Both the composition of the beach, and the presence at the lower part of the beach of beachrock outcrops suggests that the major source of beach sand is the dune system.

Figure 35. Punta Jacinto east beach

Figure 36. Sand dune mining near Punta Jacinto, northwest coast

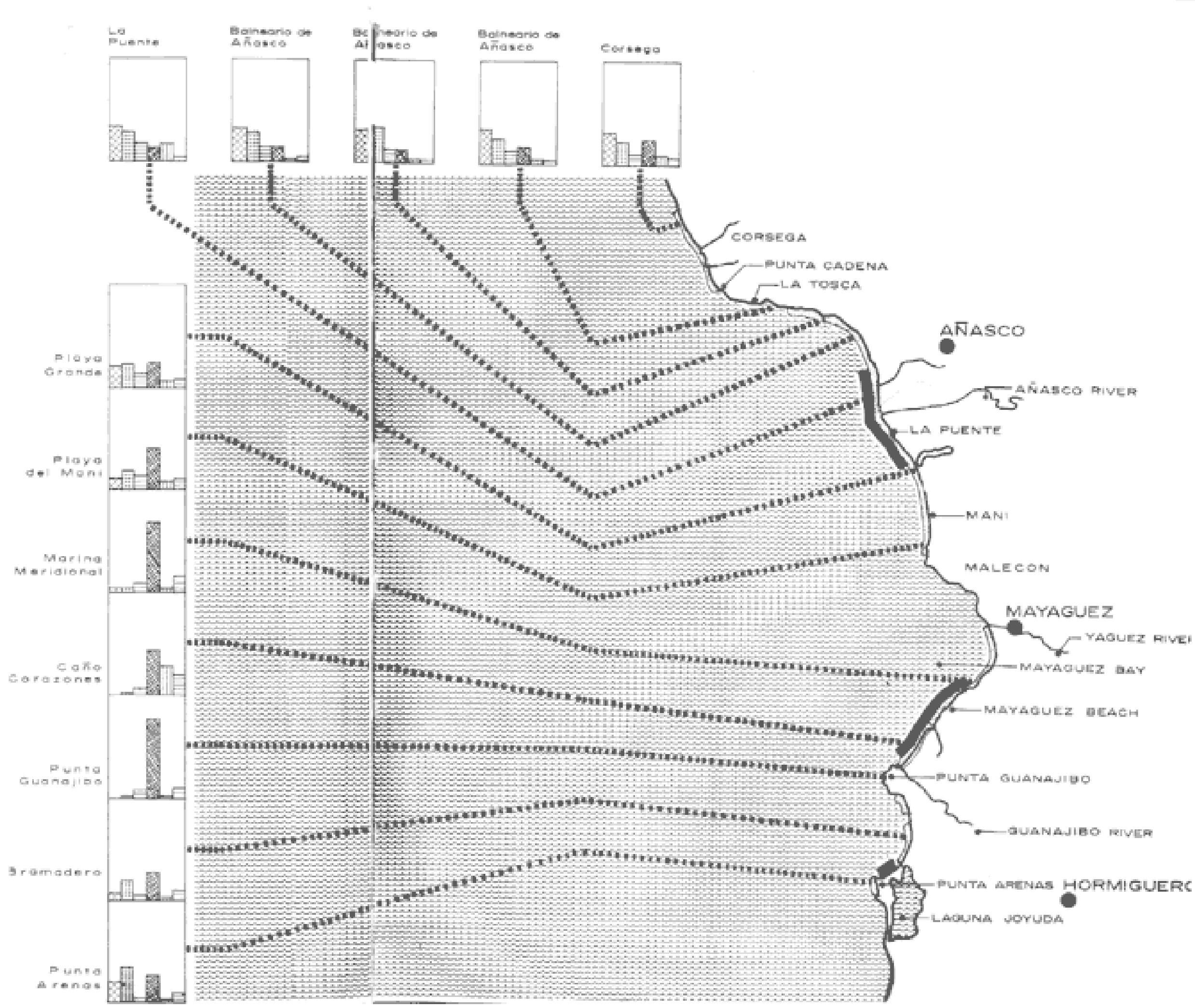
Punta Borinquen and Crashboat beaches are isolated beaches bounded by rocky shoreline (Figure 37). The beach is continuous from Aguadilla to Punta Gorda, and the coastal type is beach plain.

Figure 37. Crashboat beach, north of Aguadilla

There is erosion from Rio Culebrinas to Punta Gorda. The beach sediments are approximately equal parts carbonate shell material, quartz and feldspar, and igneous rock fragments. Sediments from a large drainage basin are carried to this part of the coast by Rio Culebrinas and Rio Grande. There is strong littoral drift to the southeast, but no evidence of severe erosion except near Ríncon (Figure 38).

Figure 38. Beach erosion at Ríncon

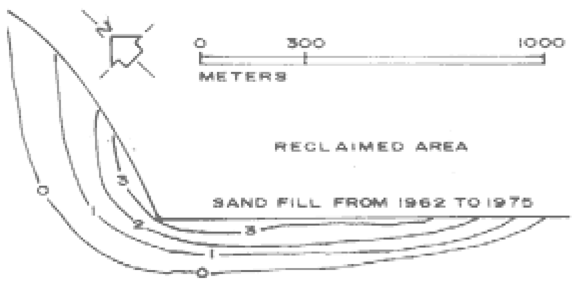
Ríncon to Joyuda



Most of the coastline between Punta Jiguera and Punta Guanajibo is beach plain. There are three beach systems: Corcega, Añasco, and Mayagüez beaches. These are separated by rocky headlands, at La Tosca and by man-made facilities at Mani. From Punta Guanajibo to Punta Melones there are a variety of coastal types. About half of the coast is beach plain. There are several rocky shorelines of secondary wave erosional type and several stretches of mangrove shoreline. At Punta Guaniquilla, the shore is fringing reef.

The Corcega beach sands are carbonate, quartz, and igneous rock fragments with minor amounts of feldspar. It is a fairly broad beach with a steep foreshore face. The beach terminates at Punta Cadena, where the shoreline is rocky. Sampling off this point indicates that much of the sand is moving offshore at Punta Cadena. Some of this sand bypasses the point and is added to the Añasco beach system.

The north end of the Añasco beach is calcium carbonate with quartz, feldspar, and igneous rock fragments. There is an offshore source of calcium carbonate shell material south of Punta Cadena. The carbonate content decreases southward until at Mani beach the dominant component is igneous rock fragments with quartz and feldspar and some carbonate grains. The beach terminates at the land fill of the Malecon industrial site. There is erosion from E1 Puente to Mani beach north. The flooding associated with hurricane Eloise moved large amounts of river sand offshore. Shoreward transport of this sand has (temporarily) halted erosion at E1 Puente. During normal flow conditions, most of the Añasco River sand size sediments are trapped in the estuary. However, during floods and high rainfall these sands are carried offshore and some of this material may join the beach system. There is relatively little offshore movement of the sand and most of it is accumulating at the Malecon landfill site and offshore from Mani beach south. The accumulation at the Malecon landfill is a potential sand source (Figure 39). Mayagüez beach is composed of igneous rock fragments, magnetite, and other dark mineral grains, and minor amounts of feldspar grains. The mineralogy is very different from the Añasco beach system. The deep water of the Mayagüez Harbor entrance blocks transport of sand from the Añasco system to Mayagüez beach.



Malecon sand isopach. The volume of available sand can be calculated from the change in depth since construction of the landfill area. Each isopach line is thickness of sand fill in meters.

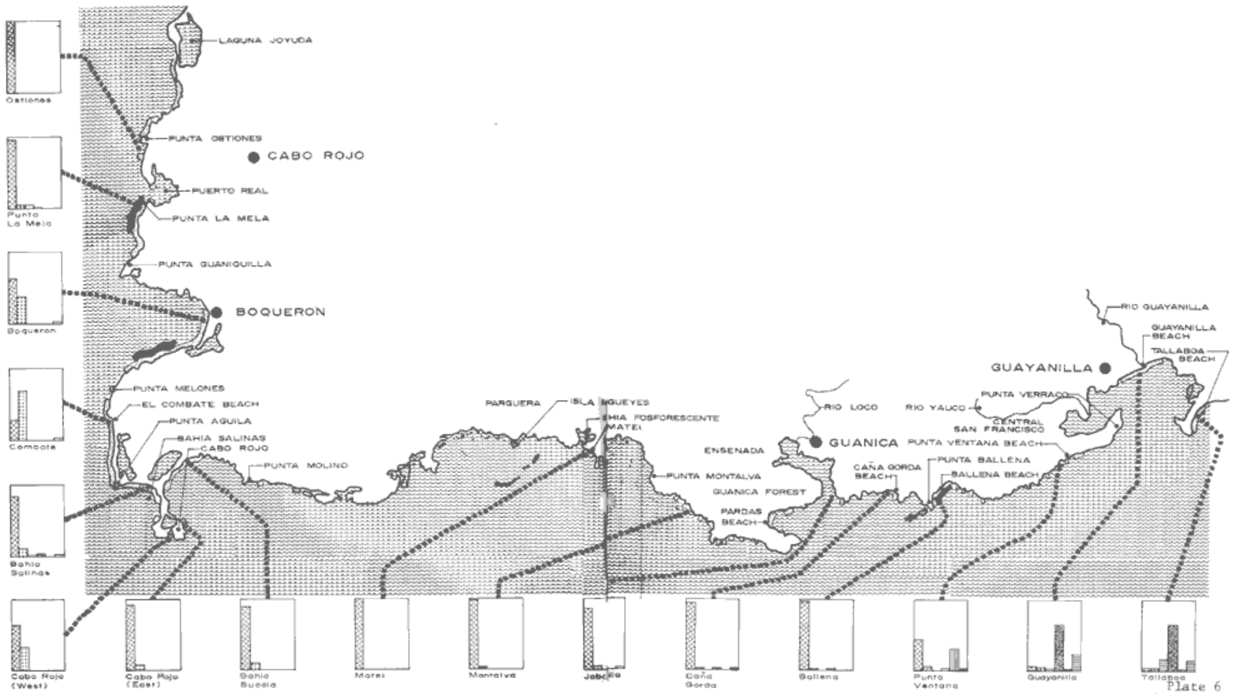
Figure 39. Sand accumulation at Malecon

There is erosion along the southern half of Mayaguez beach. Riprap has been added to long stretches for protection until the coastline is no longer beach (Figure 40). This has slowed the loss, but has also shifted the erosion to another part of the beach until riprap now extends to the Guanajibo River. The September 1975 flood made major alterations to the beach and ripped out both highway and riprap . Prior to the flooding, the severity of the beach erosion was shown by the undermining of homes on the beach (Figure 41). The flood carried large amounts of sand offshore. Some of these sands may return to the beach system, but most will be covered by the marine silts that are the dominant sediment beyond the three meter depth contour.

Figure 40. Riprap shoreline, San Jose

Figure 41. Undermining of house in San Jose

Joyuda to Tallaboa



The beaches south of Punta Guanajibo are carbonate, quartz, and igneous rock fragments. Some of the terrigenous materials in the beaches north of Punta Arenas are passing the rocky Guanajibo Point and returning to the beach system. At Ostiones (Figure 42), the beach sands are 100 percent carbonate, dominantly *Halimeda* plates (calcareous algae). The sands at Boqueron beach are carbonate and quartz. The alluvial plains west of Boqueron are the source of the quartz grains. There is erosion at Punta Arenas, Punta la Mela, and southwest of Boqueron Beach.

Figure 42. Ostiones beach – the sand is largely *Halimeda* plates and fragments

Between Punta Melones and the Parguera forests, the coast is beach plain with short stretches of rocky wave erosion coast at Cabo Rojo and Punta Molino. There are short expanses of mangrove coast on the west and east side of the Cabo Rojo tombolo and west of Playa Sucia. From a point just east of Punta Molino to Punta Montalva, the coastline is dominantly mangrove (Figure 43). There are areas of striking growth of land contributed by the spread of mangrove, and several former beach lines can be seen as much as half a kilometer inland.

Figure 43. Puerto Real mangrove

At Parguera there is a tidal flat coastline behind fringing mangrove. The land immediately behind the coast is a low range of limestone hills that are the southern limb of a syncline (Figure 44). Isla Magueyes and Isla Matei are outcrops of this limestone. Visual observations, seismic surveys, and collected data show that the shelf south of La Parguera is underlain by the same limestone, and it has been suggested that the lines of offshore reefs may be localized by outcrops of the southern flank of the limestone syncline.

Figure 44. The hills behind La Parguera are southward dipping limestones

Both Magueyes and Matei are surrounded by fringing mangrove (Figure 45). Bahia Fosforescente is also bounded by mangrove. From Parguera east, there are low tidal flats and Salinas behind the mangrove shoreline.

Figure 45. Mangrove is the deep red vegetation along the shoreline

East of Montalva the coastline is formed by wave erosion of the southern limestone platform. The coast can be generally classed as secondary wave erosion made irregular by waves. There are numerous small pocket beaches of sand and gravel at the base of the limestone cliffs, with no apparent connection to one another.

E1 Combate beach is quartz and calcium carbonate sand. There is no evidence of strong erosion. Punta Aguila (Figure 46) separates Combate beach from Aguila beach which is dominantly calcium carbonate with minor amounts of quartz and igneous rock fragments. Considering the change in composition and the prevailing pattern of longshore drift, transportation of sand between the two beaches is probably of limited extent.

Figure 46. Punta Aguila

Cabo Rojo beach is a small pocket beach at the base of the limestone cliffs (Figure 47). It is composed of carbonate and quartz grains. Cabo Rojo is an outlier of the limestone forming the coast and is connected to the mainland by the deposition of a sand spit which joins the two. This has been used as an example of a tombolo. Playa Sucia is a carbonate and quartz beach that gets its name from the unique circulation patterns in the bay between Cabo Rojo and Punta Molino. As the surface currents move westward along the south coast of Puerto Rico, part of the flow passes Cabo Rojo and continues into the Mona Passage. Part of the flow is diverted into the bay and carries surface debris to Playa Sucia. The bay contains large quantities of sand which are being moved southwest past Cabo Rojo (Figure 48). Since the longshore drift is south from Punta Aguila, this sand is being moved out of the beach system and is a potential sand source for offshore mining.

Figure 47. Small pocket beach between the two limestone outcrops

Figure 48. Sand waves outside Bahía Sucio. The sand continues south and west of Pta. Cabo Rojo

From Punta Molino east to Punta Verraco, there are only small pocket beaches at the base of limestone cliffs or isolated in a mangrove coastline. There is no evidence of communication and passage of sand from one to another of these beaches. All of the beaches are composed of calcium carbonate grains derived from erosion of the limestone cliffs and from the shells of marine organisms living offshore. The largest of these beaches are Montalva, Pardas, Cana Gorda, and Ballena.

Montalva is a pleasant bathing beach easily reached by car from Ensenada. The area is rapidly being built up by construction of a condominium and an urbanization of small houses (Figure 49). Pardas is bounded by national forest and access for the public is difficult. Several aerial observations suggest that surface oil may be carried to this beach from Guayanilla.

Figure 49. Playa Santa urban development

Caña Gorda beach is a public balneario with a hotel at the east end, and is a popular and pleasant beach area (Figure 50). Ballena is relatively easy to reach by the dirt road that continues along the coast past Caña Gorda. This is the only beach of this group that shows signs of erosion.

Figure 50. Caña Gorda beaches

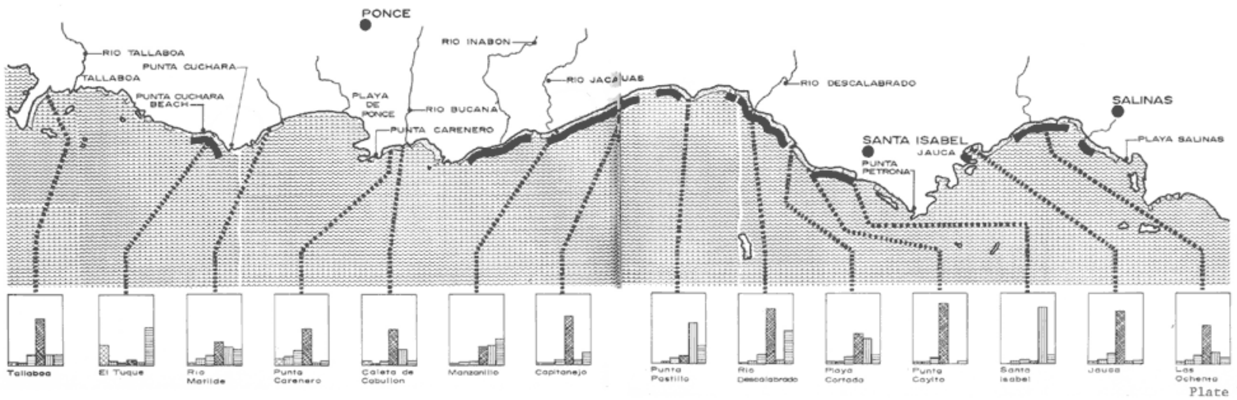
The small pocket beaches at the base of cliffs west of Ballena are composed of calcium carbonate sands. The beach at Punta Ventana is different in composition. It is a mixture of calcium carbonate quartz, and dark minerals and igneous rock fragments. The Yauco River once flowed to the coast at Punta Ventana and cut a deep submarine canyon in the shelf to the south. The quartz and dark minerals were transported to the area from the interior by the river and are relict sediments. Since the course of the river has been diverted, probably by faulting, the only modern sediments being contributed are calcium carbonate. Playa Ventana is virtually inaccessible to the public (Figure 51). The road to the beach runs through lands owned by Central San Francisco and signs on two locked gates warn of prosecution of trespassers.

Figure 51. Punta Ventaña beach

From Punta Verraco eastward, the coastline and beaches are drastically different. The coast is a low lying alluvial plain except for a short stretch between Tallaboa and Punta Cuchara. Here the coastline is wave erosional and fringing reef. The rest of the coastline is either beach plain or mangrove.

The composition of the sands and distribution of beaches is very different from the preceding area. Guayanilla beach is dominantly igneous rock fragments with quartz and dark minerals. Tallaboa beach is dominantly igneous rock fragments with some carbonate grains and Punta Cuchara is of dark monomineralic composition with igneous rock fragments. The rocky shoreline between these two beaches has only small and isolated pocket beaches.

Tallaboa to Salinas



There is almost no carbonate material in the beach sands eastward from Punta Cuchara. The beaches are composed of igneous rock fragments, magnetite, and dark monomineralic components with minor amounts of quartz and feldspar.

The beach at Punta Cuchara is being eroded and a large amount of the land behind the beach has been removed. The low beach to the east, Matilda Beach, is a free sand removal area and a garbage and junk dump site. It is one of the worst looking stretches of coastline in Puerto Rico (Figure 52). From Punta Carenero east to Punta Petrona, there is almost continuous beach plain interrupted by mangrove eroding alluvial plain, and rock riprap. More than fifty percent of this coast is suffering erosion. The materials range from sand to gravel and are dominantly dark minerals and rock fragments Several of the beaches have especially high concentrations of magnetite.

Figure 52. Matilda beach

The coastline from Jauca to Playa Salinas is a combination of beach plain and mangrove. East of Salinas there is considerable mangrove coast. The Cayos Caribe are small mangrove islands that are behind a fringing reef coastline. From Las Mareas eastward the coast is dominantly the result of wave erosion of the relatively unconsolidated alluvial plain material that lies south of the central mountains. There is extensive development of narrow beaches at the base of wave cut cliffs (Figure 53). From Arroyo eastward, the coastline is dominantly beach plain.

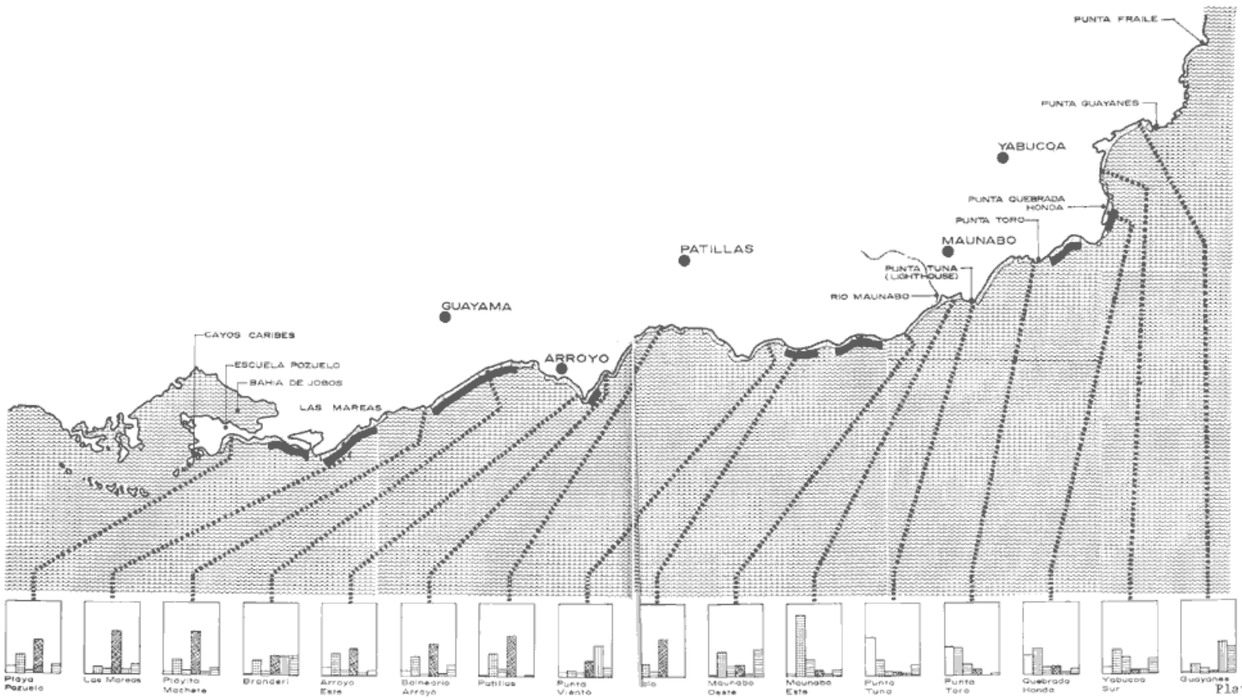
Figure 53. Arroyo cliffs with narrow beach at base of cliffs

The beach materials are fragments of igneous rock material with magnetite, dark minerals, and some quartz and feldspar. There is considerable increase in the amount of quartz and feldspar east of Las Mareas and the beach at the mouth of Rio Manuabo is almost entirely quartz and feldspar composition. There is very little calcium carbonate material except at Libre Florida.

Much of the beach material in this part of the Island is gravel-sized (Figure 54). The gravel appears to be residual alluvial plain material left in the surf zone as the alluvial plain is cut back by wave action on many of the beaches.

Figure 54. Beach gravel, lag material.

Salinas to Pta Friales



There is erosion over almost one-third of the coastline shown on this plate. Only the mangrove area surrounding Bahia de Jobos and the beaches off Patillas and Rio Maunabo are not showing some signs of erosion. The coast from Las Mareas west to Escuela Pozuelo is one of the marked areas of erosion on the Island (Figure 55).

Figure 55. Coastal erosion at Las Mareas

The coastline from Punta Tuna to Naguabo is an alternation of rocky headlands that have been partly shaped by marine erosion and valleys of alluvial material that have been worked on by wave action and marine deposition to form broad beach plains. North of Punta Lima the coastline is mangrove coast, rocky headlands, and a few small beach plains and pocket beaches (Figure 56).

Figure 56. Pocket beaches at the southeast tip of Puerto Rico

The eastern end of the island is bordered by a shallow shelf with abundant coral and marine organisms forming carbonate sands. As a consequence the beaches are a mixture of calcium carbonate grains from offshore and quartz and feldspar and igneous rock material and dark minerals from the land area.

Although the composition of the beaches is similar, physical boundaries formed by rocky headlands divide the coast into eight distinct beaches. There may be limited transfer of sand from one beach to another in the offshore zone, but they are distinctly separated physically.

Punta Tuna beach is a beautiful coarse carbonate sand beach with some quartz and igneous rock material that lies east of the Punta Tuna lighthouse (Figure 57). The land adjacent to the beach is pasture for large herds of cattle, but the owners have provided access to the beach.

Figure 57. Punta Tuna and beach

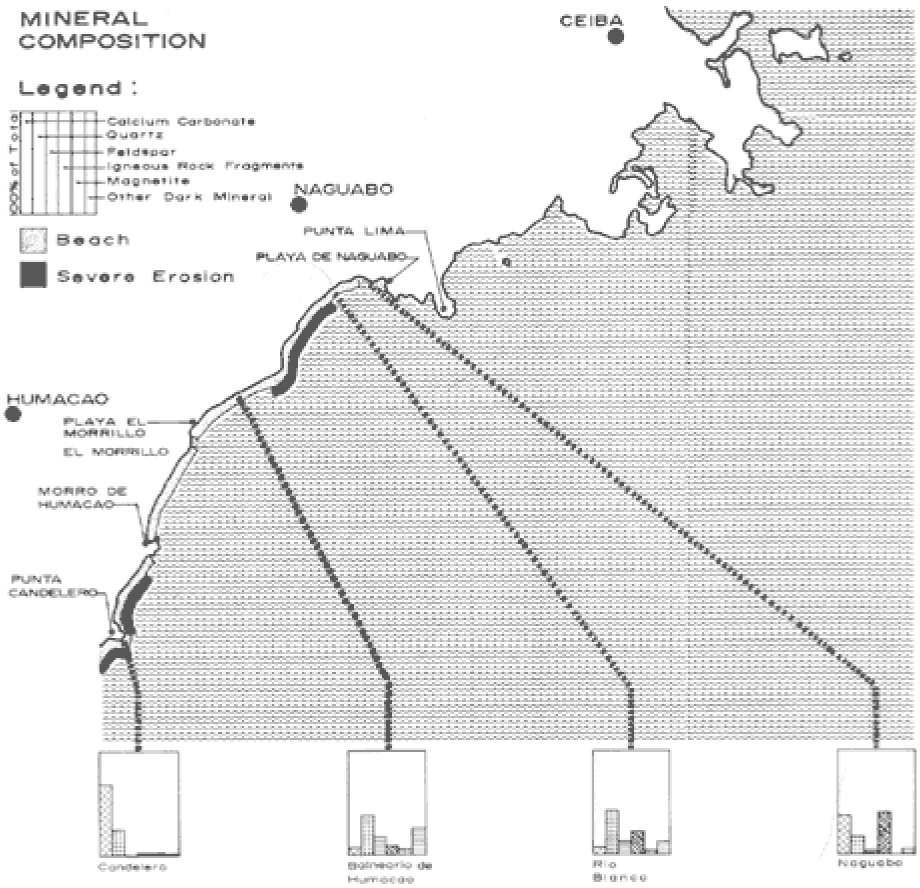
Punta Toro beach is quartz and carbonate with some feldspar. The quartz and feldspar is derived from the plutonic outcrops north of the beach.

From Quebrada Honda to Guayanes there is a series of pocket beaches and some relatively long stretches of wide beach composed of quartz and feldspar, with some carbonate and igneous rock material, Guayanes beach, at the north end of this system is especially rich in magnetite. The transport of sand in this system is now interrupted by the deep channel and jetties constructed as part of the Yabucoa Harbor.

The Candelero beach system starts with a group of small pocket beaches between Punta Guayanes and Punta Fraile. There is a continuous beach plain from the Palmas del Mar marina at Punta Fraile to Morro de Humacao (Figure 58). The composition is dominantly calcium carbonate. There is erosion at Punta Candelero and for a short distance north.

Figure 58. Humacao beach

Pta. Friales to Fajardo



The Morillo beach is quartz with some igneous rock fragments and dark minerals. From here northward, the beach sands are dominantly terrigenous origin. The beach from E1 Morillo to Naguabo is a relatively broad beach of quartz and feldspar with some dark minerals and igneous rock material. There is erosion along the northern half of this beach and extensive rip-rap has been emplaced to protect the highway. Naguabo beach is adjacent but slightly separated from the rest of the beach. The calcium carbonate content is much higher in this beach.

The coastline encompassed by the naval base was inaccessible, and not examined.

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Coastal Morphology