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The Morphology and Sediment Character of the Coastline of Nigeria—the Niger Delta

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ABSTRACT

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The shoreline of Nigeria was divided into five distinct regions based on coastal geomorphology and sedimentological parameters. During a 4-year period (1982 through 1985), 60 beach profile stations were established and monitored, covering the entire country's shoreline. Data gathered at these field stations were complemented with extensive aerial overflights conducted off the coastline during all phases of the study. The purpose of the study was to define the detailed sedimentological and morphological aspects of the Nigerian coastline from field data. The morphological regions defined along the Nigerian coast from west to east are: (1) barrier-lagoon coast, (2) transgressive mud coast, (3) delta flanks, (4) arcuate delta, and (5) strand coast. These shoreline segments exhibit distinct beach/inlet morphologies and sediment characteristics in response to their available sediment sources and to the hydrodynamic process active along each segment. Sediments on the beaches range from silt and clay (transgressive mud coast) to medium-grained sand (barrier-lagoon coast) with beach slopes ranging from 1:90 to 1:6, respectively. The coastal sediments are composed mostly of well-sorted, fine- to medium-grained, quartz-rich sand. Coastal vegetation is highly variable with over 40 different coastal plant species identified, with the greatest diversity of species occurring within the Niger Delta region.

ADDITIONAL INDEX WORDS: *Coastal geomorphology, Niger Delta, sedimentology, shoreline segments, inlets/river mouths, and hydrographic regime.*

INTRODUCTION

The coastline of Nigeria extends for approximately 800 km along the Gulf of Guinea between the countries of Benin to the west and Cameroon to the east (Figure 1). The Niger Delta occupies half of the country's shoreline and is one of the larger arcuate river deltas in the world. The Delta has 21 major inlets that intersect the coast, breaking it up into a series of barrier islands. Barrier islands are typically 15 to 20 km long and 3 to 5 km wide, with the western side of the delta exhibiting better developed barriers than the eastern side. Coastal dunes and associated beach ridges are found only in areas of abundant sediment supply and rapid shoreline accretion (spits, inlet-influenced portions of barriers). The inlets on the delta exhibit varying morphologies in response to differences in tidal and wave energies, tidal prism, and freshwater input. The western side of the delta has significant active freshwater input while the eastern side is influenced primarily by marine processes (waves and tides).

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The shape of the Niger Delta is similar to that of the Nile River Delta with a profile that is curved or bowed with its convex outer margin facing the ocean. This shape is the result of a combination of variables, such as the drainage basin, alluvial valley, deltaic plain, receiving basin, distributive network, and fluvial/marine processes that directly impact the delta. This study defines some of the shoreline characteristics of the distributive network.

Previous studies of the coastline of Nigeria on geomorphology, physical processes, and near-surface sediments were conducted by PUGH (1953, 1954), ALLEN (1962, 1963, 1964, 1965a, 1965b, 1970), NEDECO (1954, 1959, 1961), IBE (1983, 1984), and MURDAY (1986). The study of PUGH (1954) was a broad classification of the Nigerian coastline, dividing it into nine different geographic sections based on data collected from large-scale maps, aerial photographs, and very limited field data. The work conducted by NEDECO (Netherlands Engineering Consultants) focused on collecting enormous amounts of data. Most of this data was collected on the Niger Delta and involved riverine processes, nearshore ocean pro-

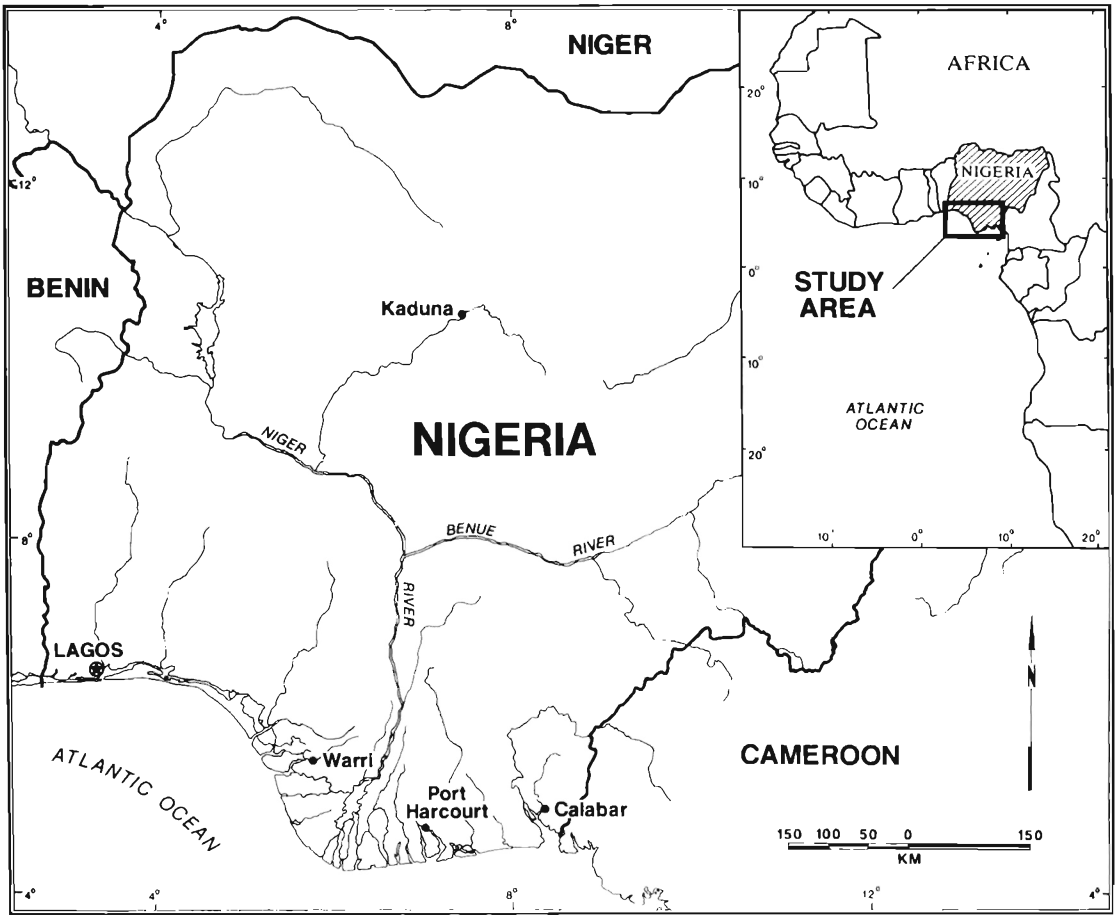

Figure 1. Study area location map. The Benue River joins the Niger and flows down onto the Niger Delta. The coastline of Nigeria is dominated by the Niger Delta occupying over half of the country's coastline.

cesses, sediment character, and baseline mapping of the outlying islands and river mouths. This research was then complemented by work done by J.R.L. Allen. His efforts focused on the Niger Delta and were of a sedimentological nature looking at the sediment characteristics from beyond the prodelta to the fluvial component of the delta system.

During and immediately after the NEDECO and J.R.L. Allen research, several studies involving the subsurface geology of the Niger Delta with reference to oil-producing areas were published by SHORT and STAUBLE (1967), WEBER (1971), OOMKENS (1974), and DAILLY (1976). The cyclic nature of delta deposition followed by erosion of the delta's coastline was described by WEBER (1971) and OOMKENS (1974). They discussed the cyclic sedimentation patterns that occur on the Niger Delta. This process is active today on the Niger Delta, with the eastern side of the delta generally being erosional, marine dominant (destructive); the western side of the delta is depositional, fluvially dominant (constructive). These cycles of sedimentation affect the present-day morphology and sediment character of the beaches of the delta.

The purpose of the present study was to define in detail the Nigerian coastline as related to morphology and specific sediment character. This research involved a detailed study of the outer beaches along the entire Nigerian coastline from the Benin border to the entrance of the Cross

River Estuary (Figure 1). The coastal geomorphology, sediment character, physical processes, and vegetation were investigated between 1982 and 1985. The results were used to classify the coastline of Nigeria into five distinct geomorphological zones.

PHYSICAL SETTING

The hydrographic regime (tides, waves, currents) active on the coastline of Nigeria is variable and is reflected in the land forms present on the shoreline. Tides are semidiurnal with a range generally increasing from about 1 m in the west (Benin border) to 3 m in the east (Cross River Estuary) (Figure 1) (U.S. DEPARTMENT OF COMMERCE, 1986). Wave heights exceeding 1 m are common on the western beaches and the exposed delta front and are noticeably higher during the rainy season (May through October). During the rainy season long period waves (12 sec, 1.5 m high) are common on the more exposed beaches. During the dry season (November through April), shorter period waves (5 sec, 0.9 m high) are more common (NEDECO, 1961).

The dominant wind on the coast of Nigeria is southwesterly (200° to 230°) and blows throughout the year with slightly stronger and more sustained winds during the rainy season from June through November (NEDECO, 1961). This dominant southwesterly wind and the resultant wave regime have a pronounced effect on the overall coastal morphology of Nigeria, affecting the orientation of coastal sand deposits and longshore transport directions. Figure 2 summarizes the longshore current directions and locates the 60 profile stations established during this study. Longshore transport was physically measured in the field at all coastal stations, during both the dry and the rainy seasons. Note the longshore transport reversal along the western side of the delta (Figure 2). This reversal has been reported previously in studies by NEDECO (1961) and ALLEN (1965a, 1965b).

Annual rainfall ranges from 100 cm in the western coastal areas to 300 cm in the east. Hot and humid conditions (up to 30°C with 90 percent humidity) are present year-round on the coast.

Sediment supply for the western coastline of Nigeria as described by IBE (1974), has a source of sediment derived mainly from longshore transport from as far west as the Ivory Coast. The Volta River system and delta complex is thought to play a significant role in the sediment supply on the western beaches of Nigeria (MURDAY, 1986). Direct fluvial sediment contributions to the western beaches of Nigeria from the Niger Delta are not significant. The other main source of sediment for Nigerian beaches is attributed to the Niger River/delta system which supplies sediment to the central and eastern beaches of Nigeria. The average annual sediment supply of the Niger River at Onitsha (the point of river bifurcation) has been computed to be 19×10^6 m^3 (NEDECO, 1961). More than 80 percent of the sediment that is presently being carried down the river systems onto the delta is discharging on the western side of the Niger Delta (NEDECO, 1961). Once sediment reaches the coastline on the outer fringes of the delta, it enters into a complex system of dispersal involving tidal currents, littoral currents, wave-generated currents, and deeper-water currents. The sediments active on the coastline are constantly being molded into barrier islands, recurved spits, river-mouth bars, and tidal delta deposits. This combination of sediment supply and physical processes is responsible for shaping the morphology of the Nigerian coast.

METHODS

The geomorpholgical components of the Nigerian coastline (with emphasis placed on the Niger Delta) were defined from aerial photographs and field observations data collected at 60 beach stations established along the Nigerian shoreline (Figure 2). Several aerial reconnaissance surveys were conducted from low-altitude helicopter flights between 1982 and 1985. Observations and photographs taken during these surveys were used jointly with field data, 1:50,000 scale topographic maps, navigational charts, and vertical photographs to describe the shoreline morphology and sediment character.

At each of the 60 beach stations, the following data were collected: (1) detailed topographic profile of the beach; (2) beach sketch and ground photography, used to record overall morphology at a station; (3) littoral environment observations (LEO): data collected on wave parameters (period, height, breaker type, and breaker angle), longshore current velocity measurements, wind direction and velocity; (4) sediment samples collected along the topographic profile; (5) trenches and shallow cores (less than 6 m); and (5) coastal vegetation (species and species frequency). A total of 117 sediment samples were collected and analyzed during the study to describe the textural

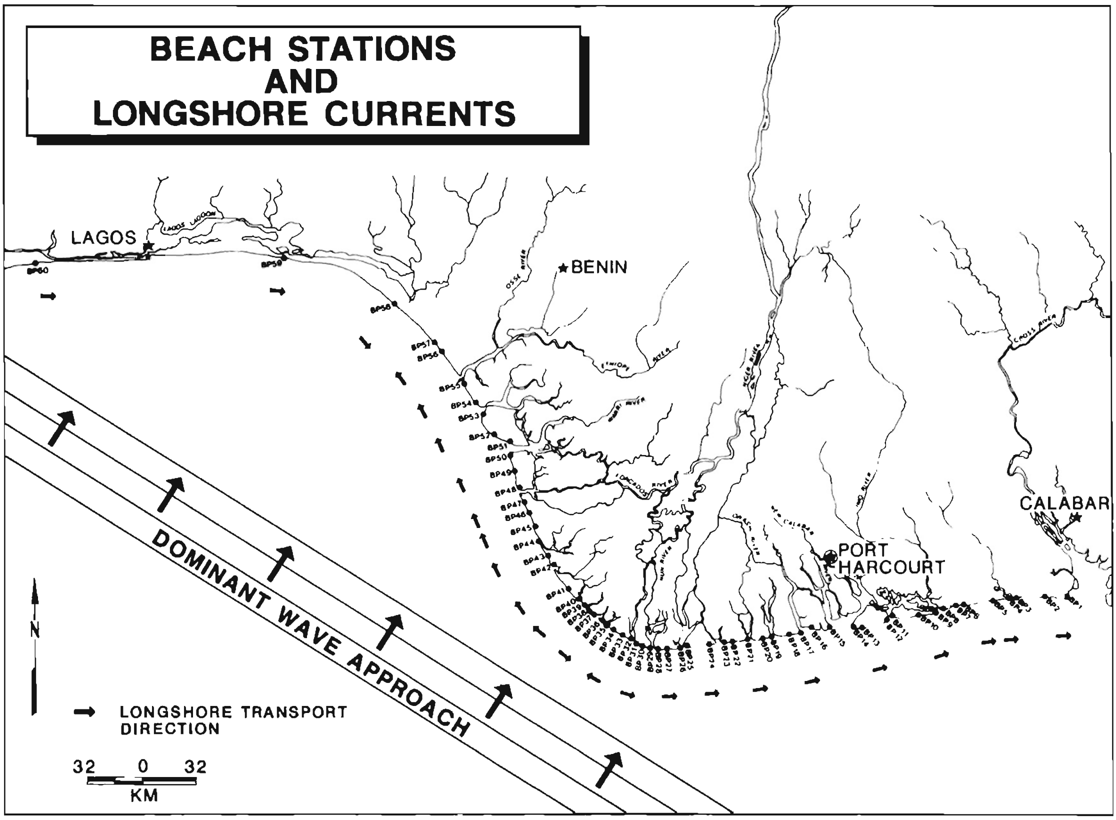

Figure 2. A total of 60 beach profile stations were established along the Nigerian coast. Dominant wave approach on the shoreline is out of the south-southwest generating multiple directed longshore currents.

characteristics of the coastal deposits. For each sample, the percentage of sand, silt, and clay was determined, and sand-size material statistics were calculated using "the methods of moment," after FOLK (1974). Beach profiles were monitored twice using the EMORY (1961) method, once in the dry season and once during the rainy season.

Many of the sample sites monitored during the study were established in a mid-barrier island position. This was accomplished to more accurately represent the coastline, not a given river mouth. Field data collected during the study were analyzed, and summary results were used in determining the geological distinction of each proportion of the Nigerian coastline.

DATA SUMMARIES

Analysis and interpretation of the beach profile, grain size and physical processes data collected during the project were used to determine the various shoreline segments. Figure 3 presents results of beach grain size, beach slope, wave height, and longshore current measurements made during the study. Sediment samples were collected from the middle of the active beach face. Beach slopes were measured on the intertidal beach face at each profile station and averaged. Wave height and longshore current were averaged for each station.

Beach slopes and the mean grain size of beach sands are presented in Figure 3. There is a good correlation of beach slope and mean grain size of beach sands. Generally, the slope increases with increasing grain size and decreases with finer beach sands. There is also a wide variety of sediment sizes found along the Nigerian coastline with the finer-grained sand beaches occurring along the flanks of the Niger Delta (Stations 54, 52 & 10 & 6 in Figure 3).

The measured wave heights have a correlation

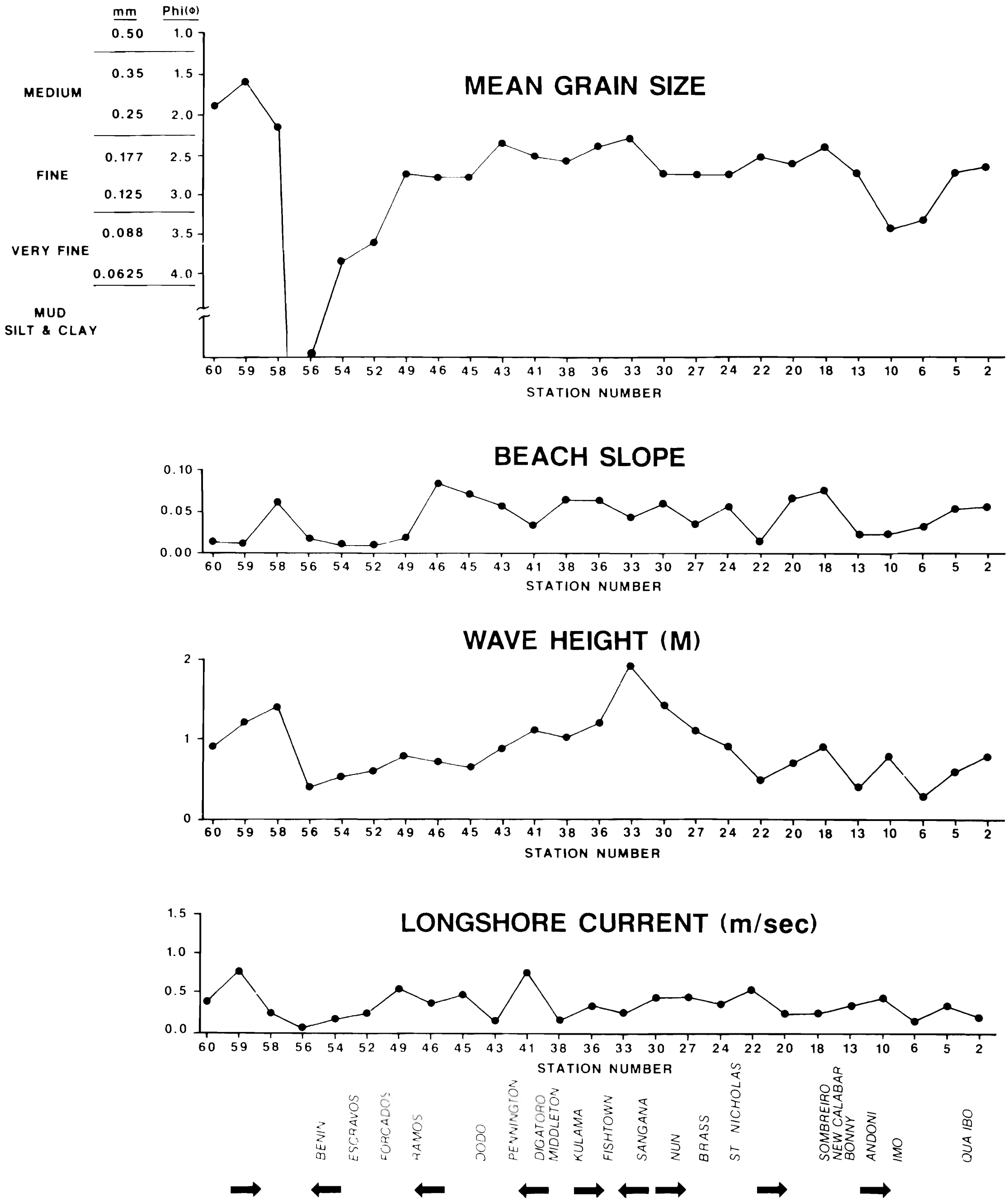

Figure 3. Mean grain size, beach slope, wave height and longshore current data plotted by station. The sediment samples for the grain size analysis were collected from the mid-beachface. Beach slope was measured on the intertidal beach face at each profile station. Wave height and longshore current were averaged for each station.

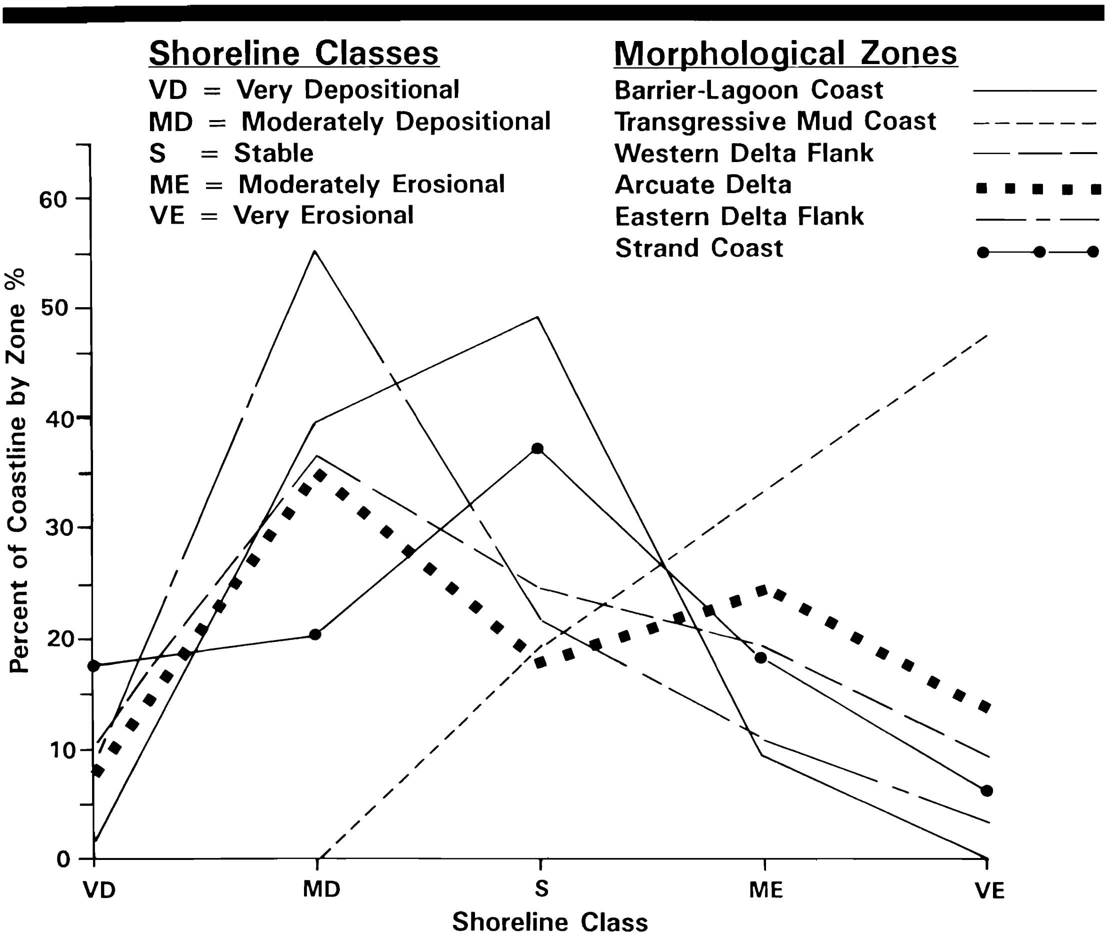

Figure 4. Observed erosion, deposition beach state along the Nigerian coastline. Morphological zones are outlined in Figure 5. Most of the Nigerian coastline is stable to depositional.

with the longshore current velocities recorded in the field, although the wave angle is expected to play a significant role in this comparison (Figure 3). Note the reversal of longshore currents at Fishtown River on the delta front and just west of the Benin River. The most pronounced longshore current transport reversal was found west of the Benin River mouth (Figures 2 & 3). The coastline in this area is predominantly composed of fine grain sediments (silt & clay) (Figure 3). Wave heights were greatest in the vicinity of Lagos (Stations 59 and 58) and the Sangana and Nun River mouths, 1.5 and 2 m respectively (Figures 2 & 3). One meter high waves were frequently measured on the Nigerian coastline.

Another aspect of the field data collection program was general observations of beach erosion/deposition made along the shoreline during low altitude (500 ft and less) overflights. Two complete shoreline surveys were made along the entire open ocean facing coastline of Nigeria. During these overflights, the observed shoreline condition was recorded on 1:50,000 scale topographic maps. Figure 4 is a graph of the percentage of each coastal morphological zone (shoreline kilometers) with respect to the shoreline state (depositional, stable, or erosional). Note that the coastline of Nigeria is predominantly depositional with only the transgressive mud coast exhibiting a dominance of erosional shoreline.

MORPHOLOGY AND SEDIMENTS

The coastal geomorphology and sediment character for the coastline of Nigeria are best dis-

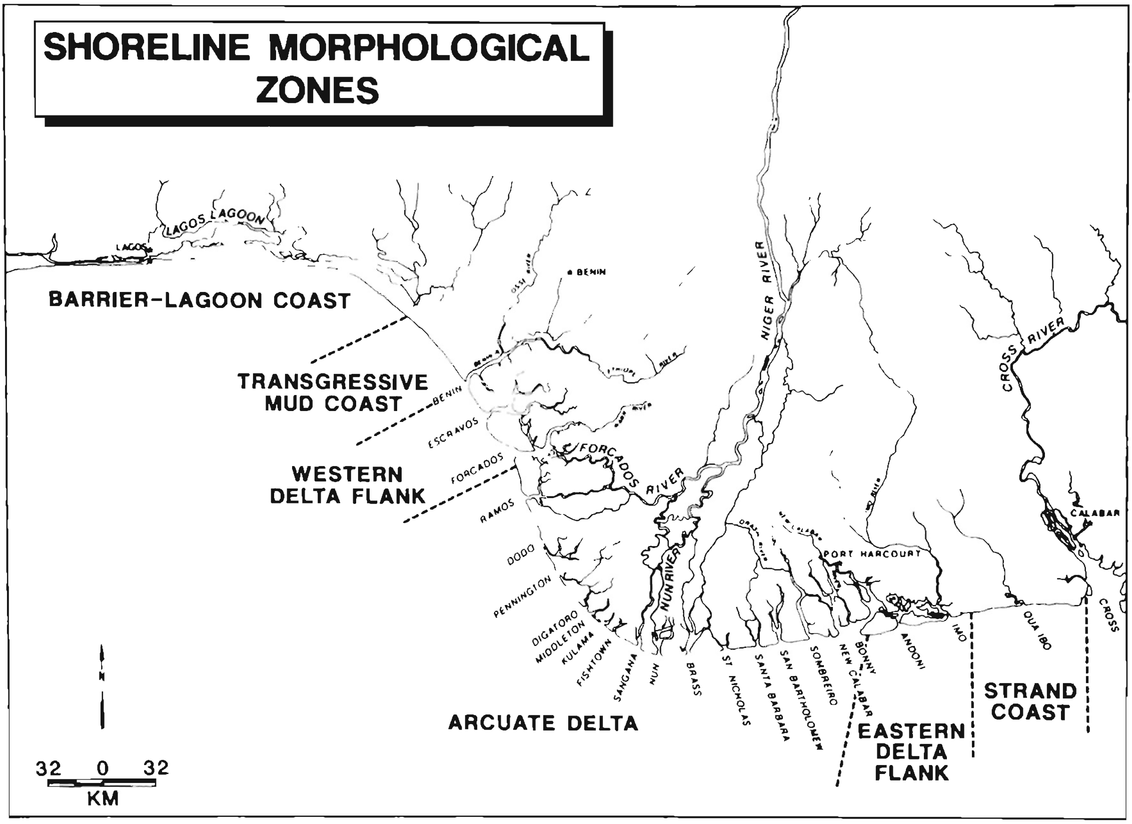

Figure 5. The shoreline of Nigeria has been divided into five distinct morphological zones. This classification is based on large- and small-scale geomorphic differences as well as numerous physical characteristics (*i.e.*, beach sediment grain size and coastal processes).

cussed after dividing the coast into distinct morphology zones based on field data collected during this study (Figure 3). The shoreline was divided into five segments:

(1) Barrier-lagoon coast
(2) Transgressive mud coast
(3) Western and eastern delta flanks
(4) Arcuate delta
(5) Strand coast

Figure 5 outlines the distribution of the shoreline geomorphic units as defined by this study. This classification is somewhat similar to that proposed by Pugh (1954) based on limited maps and little field work. Pugh stated that his subdivisions (9 of them) might require revision when more information became available. The present study is based primarily on field data and focuses on specific coastal morphology and sedimentology. The only abrupt change between geomorphic units found during the field study occurs at the demarcation between the barrier-lagoon coast and the transgressive mud coast. Other boundaries between geomorphic zones are gradational.

Barrier-Lagoon Coast

This western geomorphic unit is a continuation of a similar coastline stretching from eastern Ghana and occupies 220 km of coastline in Nigeria (Figure 5). The barrier-lagoon coast has a straight, sandy shoreline backed by lagoons (the Keta, Nokoue, Lagos, and Lekki), and the coastline vegetation is mainly palm and coconut trees. There is only one break in the coastline along the entire length of the barrier-lagoon coast at the entrance into Lagos Lagoon/Harbor.

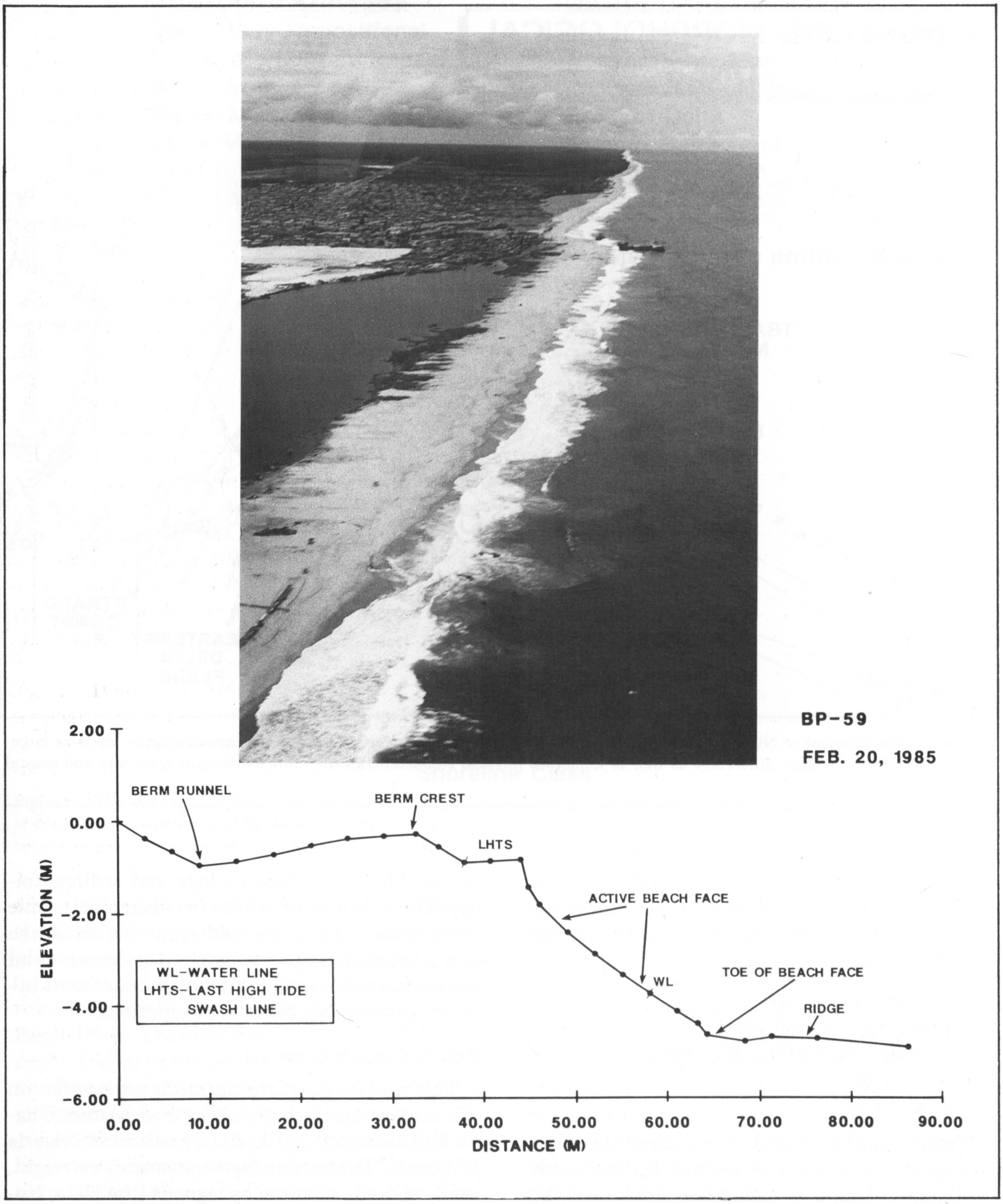

Figure 6. Typical beach profile plot on the barrier-lagoon coast. Beaches consist of medium-grained sand; slopes are steep (1:17). Photo taken at Bar Beach, Lagos.

The tidal range on this section of coast is microtidal between 0 and 2 m (DAVIES, 1964), generally around 1 m. The beaches consist of medium-grained (0.4 mm mean grain size), well-sorted, strongly, coarse-skewed sand. The beaches along this section of the coastline of Nigeria (which includes the city of Lagos) are the most heavily used in Nigeria. The beaches have well-developed berm complexes and steep slopes (1:6 to 1:12) (Figure 6). Wave energy is high with plunging waves most commonly approaching from the southwest, with average wave periods of 12 sec. and significant breaker wave-heights of over 1.0 m. The longshore current is predominantly directed toward the east, and net longshore sediment transport values exceeding $1.0 \times 10^6 m^3/yr$ have been calculated (NEDECO, 1961).

The barrier-lagoon coastline is presently depositional except for localized erosion zones (Lagos, Bar Beach). The two most dominant depositional features found along the coast are a combination of very long continuous spit systems, separating the lagoons from the open ocean, and parallel beach ridges. Storm washover deposits are present and increase in occurrence in an easterly direction.

Transgressive Mud Coast

This 70 km stretch of mud coast is found where the Nigerian shoreline changes from an east/west to a southeast/northwest orientation (Figure 5). The change in shoreline orientation is a result of the Niger Delta protruding out into the Gulf of Guinea. Also within this reach of shoreline, longshore transport current directions change from an easterly direction to a westerly direction (Figures 2 & 3). A complex network of creeks and dredged canals run parallel to the mud beach, with a few of them emptying into the sea. The dredge canals were constructed as part of oil exploration activities adjacent to the present-day Niger Delta.

Beach ridges are absent, and the vegetation consists predominantly of red and black mangroves. The beaches commonly have steep mud or organic-rich peaty scarps on the upper beach with gentle slopes of about 1:40 on the more active portions of the beach face (Figure 7). Beach sediments are predominantly composed of silt and clay (Figure 3). The shoreline is generally either scarped/grooved or tidal flats merging with the high-water shoreline.

Waves begin breaking approximately 3 km offshore and are small, (typical wave height, 0.5 m), by the time they reach the shoreline. The lowest breaker heights recorded on the Nigerian coastline were measured along the transgressive mud coast. Only the short period (6 sec) wave component is active in the nearshore zone. Convergence of longshore currents from the west and east occurs aong the central portion of this reach of coast.

Several trenches and shallow cores were taken along the transgressive mud coast and revealed a commonly occurring sediment sequence. The cores were observed to fine up from mixed fine-grained sand and silt to a predominantly burrowed, reduced mud (silt and clay). Iron stained evaporite deposits were observed in the trenches and at the top of the cores at the two mud beach stations. These deposits occurred as thin, tan bands mixed in with very fine grained sand and silt, and clay. Below this was a black reduced mud that was extensively burrowed by a large *Uca tangeri*. This burrowing occurs only in the active intertidal zone and extends down some 50 cm. Throughout the 5 m long cores, mica content in both the sand and mud fractions was abundant. Also, sand stringers or lenses of sand were found throughout the core but increased in occurrence with depth down-core. It was often observed that mica content was greater within the sand stringers.

The lack of sand-size material along this reach of coastline has been attributed to two factors: (1) the offshore canyons (Mahin, Avon) are acting as chutes for sand that would otherwise accumulate in this area (MURDAY, 1986), and (2) the sediment storage capacities of the river mouths/tidal inlets to the east have not reached equilibrium and are acting as sediment sinks not allowing sand-size sediment to pass into this area (PUGH, 1954).

Western and Eastern Delta Flanks

The delta flank coasts on either side of the Niger Delta account for 115 km of Nigerian coastline (Figure 5). On the western side of the Niger Delta, the delta flank extends from the Benin River to just east of the Forcados River Estuary, while the eastern delta flank extends from just east of the Bonny/New Calabar Estuary entrance to immediately east of the Imo River (Figure 5).

The delta flanks have intertidal beach faces that are very wide, often greater than 175 m, and are composed of fine- to very fine-grained, moderately well-sorted sand (Figure 3). Abundant mica accumulations were commonly found in the troughs

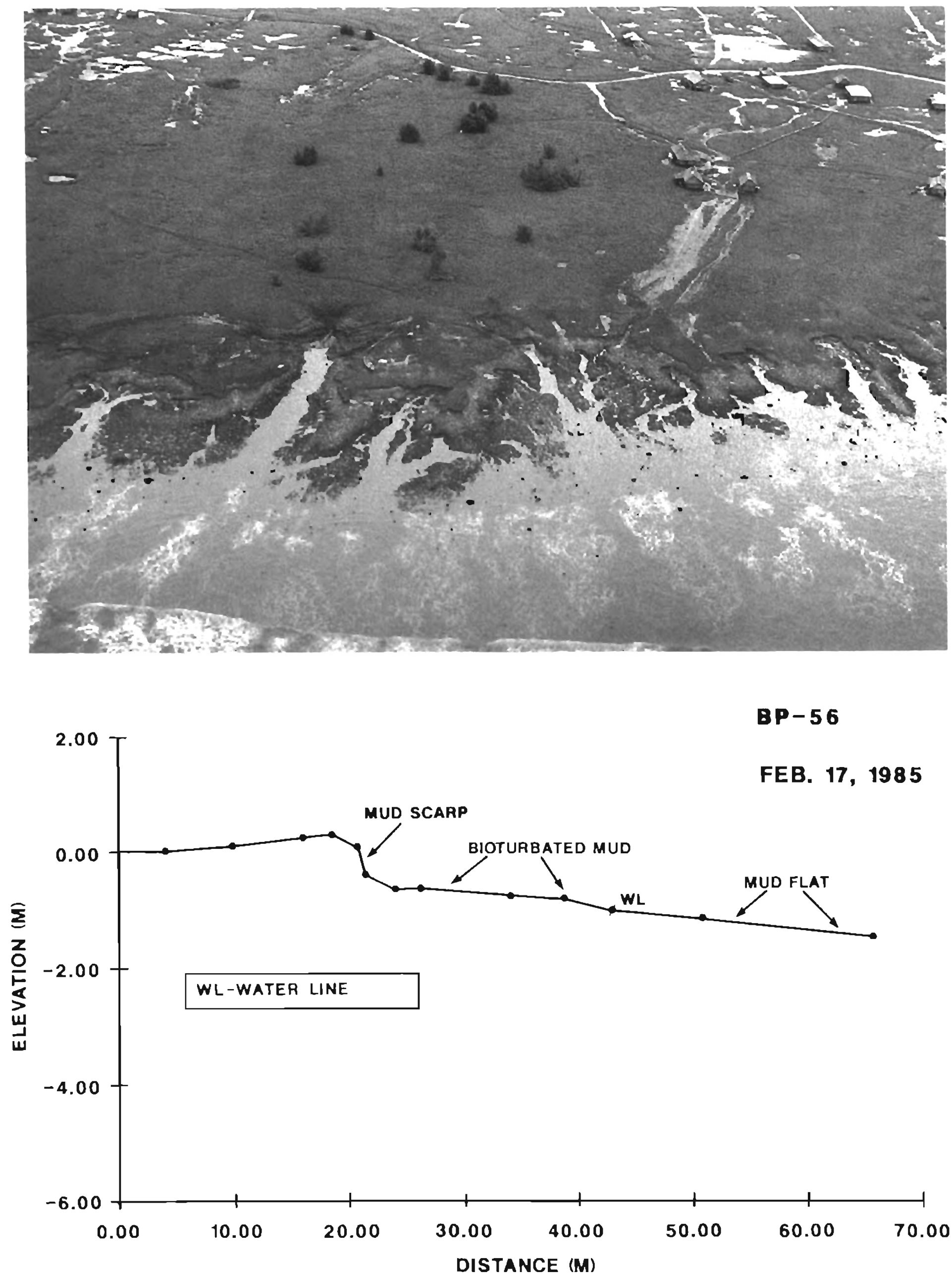

Figure 7. Typical beach profile plot of the transgressive mud coast. Beaches are erosional with pronounced scarps and consist of bioturbated mud and peat. Beach slopes are gentle (1:40) compared with the barrier-lagoon coast (1:17).

of anti-dunes and small-scale ripple bedding on the intertidal beach. The beach slopes on the intertidal portion of the profiles range from 1:50 to 1:90, and the number of species of coastal vegetation is greater than at either the barrier lagoon coast or the transgressive mud coast. In areas where the active beach interfingers with the marine forest, the number of species of coastal vegetation is generally sparse. It is possible that this sparseness of vegetation diversity is due to salt water encroachment, although no measurements were taken.

The formation of anti-dunes is a common phenomenon on the broad, flat beaches. At low tide, the active beach face is covered with the sinuous patterns of anti-dune traces. The most common physical sedimentary structure found in trenches dug on the delta flank beaches was near-horizontal laminae with only a slight seaward dip (1° to 2°) (Figure 8). Wave heights are moderate in size on both delta flanks (less than 1 m), while the tidal amplitude for the eastern delta flank is significantly larger than that on the western delta flank, 2.5 m as opposed to 1.5 m.

The beaches along the delta flank regions of the Nigerian coastline are part of the Niger Delta and are interrupted frequently by river mouths and tidal inlets. This is a common feature along the entire coastline of the delta. Accompanying these breaks in the shoreline trend are extensive reticulate patterned mangrove swamp/tidal creek systems. The barrier islands located between the river mouths/tidal inlets are relatively short with many depositional spits. This type of barrier island shoreline is found on both the eastern and western delta flanks. In contrast to the depositional western delta flank, erosion often occurs on the barriers along the eastern delta flank. Beaches on the western delta flank are slightly finer-grained and flatter than beaches on the eastern delta flank.

The delta flanks have been studied in some detail by DAILLY (1976) who described the pendulum effect of the delta flanks and their importance to the Niger Delta prolific belt in reference to hydrocarbon exploration. The low-lying area (delta flanks) adjacent to the active delta periodically serves as a corridor for future delta growth.

Arcuate Delta

The Niger Delta proper is an excellent example of an arcuate-shaped delta. This mixed energy delta occupies 284 km of Nigeria's coastline (not including the delta flanks). The geomorphic unit has 16 major river mouths/tidal inlets that intersect the coast, breaking it up into a series of barrier islands. The barrier island beaches on the arcuate delta have moderate intertidal beach faces (50 m) with slopes of 1:15 to 1:20 composed of fine- to medium-grained, well sorted sand (Figure 3). The largest waves measured during the study (2 m) (Figure 3) were found on the more exposed delta front beaches in agreement with the findings of NEDECO (1961). With this increase in wave energy are slight coarsening of the beach sands and steeper beach profiles along the arcuate delta in relation to the delta flanks. The barrier islands on the delta are generally 15 to 20 km in length and 3 to 5 km wide. The barrier islands are better developed on the western side of the delta than on the eastern side. The eastern side is presently undergoing a destructional or erosional phase. The coastline is being reworked by marine processes while the western side of the delta is more constructional or depositional and fluvially dominant.

The eastern side of the delta is generally erosional as compared to the more depositionally active western delta shoreline. This can be attributed, primarily, to the present configuration of the active river systems on the delta's surface. The Niger River bifurcates to form the Nun and Forcados Rivers on the upper reaches of the delta plain (Figure 1). Both of these rivers and nearly all of their tributaries presently exit along the coast on the western side of the Niger Delta. Greater than 80 percent of the freshwater discharge on the delta occurs along the western side, and 50 percent of this freshwater discharge can be attributed to the Ramos and Nun Rivers (NEDECO, 1961).

From the beach profile data collected at 35 stations along the shoreline of the arcuate delta, several trends in shoreline morphology and sediment character are apparent. The beaches generally had well-developed depositional berms on the upper portion of the active beach face (Figure 9). These berms were often associated with the high energy/storm washover deposits found landward of the berm. Berm runnels (low-lying area landward of the active berm often seaward of an earlier berm complex) were common. The combination of berm and berm runnel couplet develops a ridge-and-swale type topography. This is the typical theme when one walks back across the barrier island. Often, in many geological settings worldwide, the berm tops (Figure 6) are capped by coastal dunes.

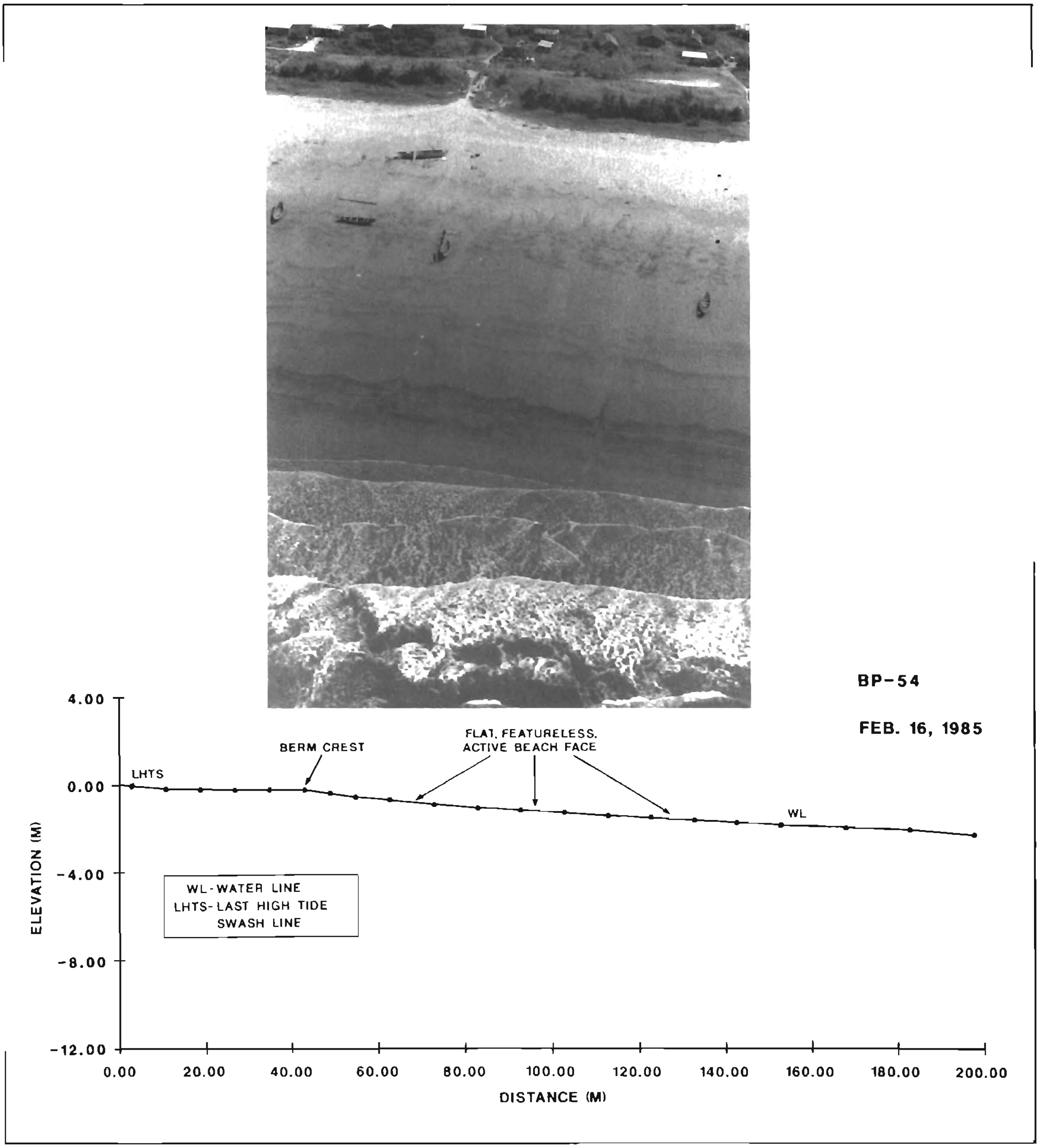

Figure 8. Typical beach profile plot for the beaches on the delta flanks. Beaches located on both flanks of the delta are wide and consist of very fine-grained, mica-rich sand. Slopes are gentle (1:50). Anti-dunes are often present on the active beach face.

Along the coastline of Nigeria including the arcuate delta, there is infrequent occurrence of coastal dune deposits. The only areas where coastal dunes were found were in areas of very rapid deposition (spits, river mouths, and tidal inlets. This near absence of coastal dunes had been observed previously by ALLEN (1965a).

Possible causes for the lack of coastal dunes may be attributed to two factors: (1) the abundance of coastal vegetation along the barrier-is-

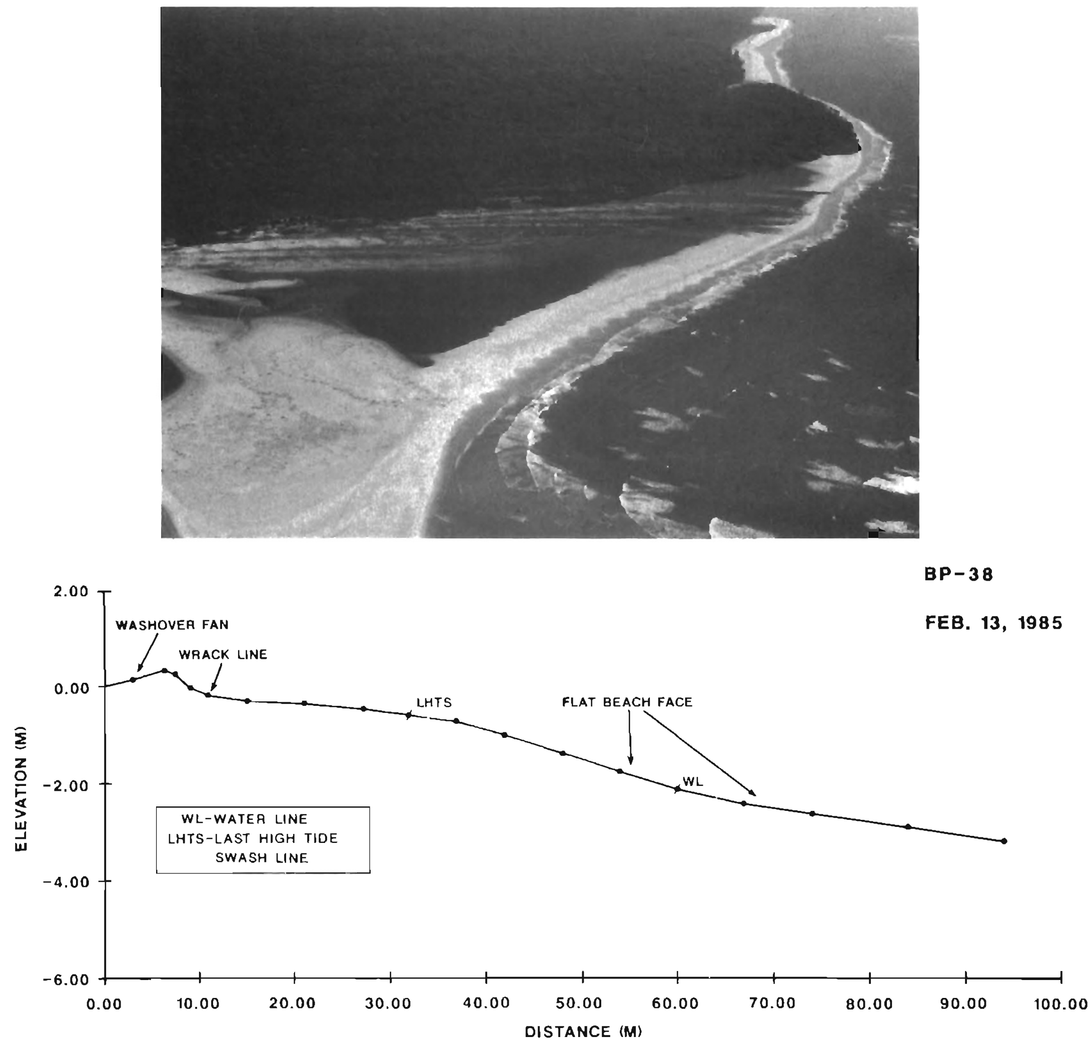

Figure 9. Representative beach profile plot of the beaches on the arcuate delta. High wave-energy beaches have slopes of about 1:15 and consist of fine- to medium-grained sand.

land coasts (delta flanks and arcuate delta), and (2) the rapid progradation or retreat of the coastline. Forty-three different and common coastal plant species were identified seaward of the mature coastal forest during the study. Thirty-seven of these species were often found along the arcuate delta coastline.

The most common coastal plant found was the creeping vine *Impomoea aquatica*. This plant can keep pace easily with deposition rates along the barrier-island shorelines, often forming a dense undergrowth of vines on the upper beach face and back beach areas. The rapid coverage of back beach by a dense coverage of predominantly *Impomoea aquatica* vines may be inhibiting the aeolian transport of sand.

Sediment supply and aeolian processes are not lacking with the frequent, onshore, southwesterly

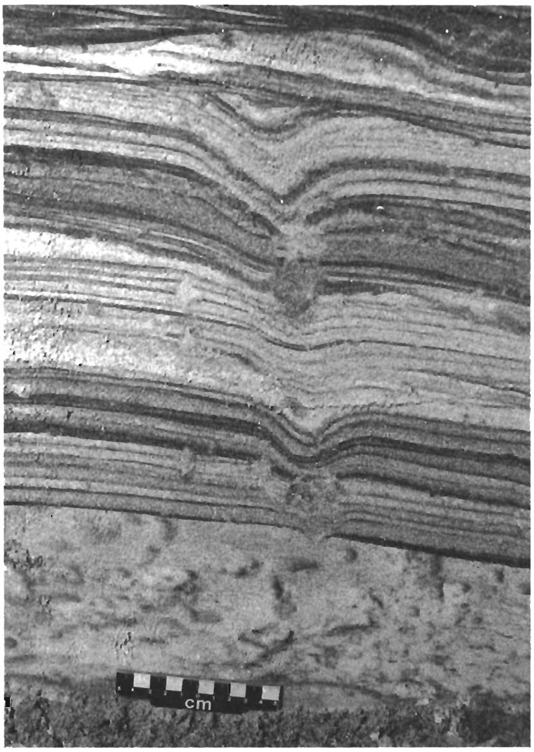

Figure 10. The lower portion of a trench dug on the upper beach face at Beach Station 18 on the eastern side of the Niger Delta. Note the abrupt erosional contact at the base of the trench. Recently-deposited beach sediments overlie older, iron-stained rooted sands.

winds and abundant supply of sediment derived from the delta complex.

The beach sediments sampled at the 35 stations on the arcuate delta typically had noticeable concentrations of dark-colored heavy minerals. Some of the more common minerals found in an earlier study on the eastern side of the delta were predominantly quartz with the accessory/minerals of epidote, hornblende, and zircon (NEDECO, 1961). During the present study and in earlier studies by NEDECO, heavy minerals were found to be concentrated along the upper reaches of the active beach. Sedimentary sequence often found in trenches associated with more erosional or transgressive coastal areas on the arcuate delta is shown in Figure 10. This trench dug on the upper beach face at Beach Station 18 on the eastern side of the Niger Delta revealed an older sand-soil profile at the base with more recent beach sediments above. No physical structures were observed in the sediments at the bottom portion of the trench. This unit was extensively rooted and iron stained. Immediately above the rooted soil horizon was a sharp erosional contact with more recent, gently landward-dipping horizontal laminae. The upper beach-face sediments often were burrowed, and the most common burrower found in this environment was a small ghost crab.

Observations made on the subdeltas along the arcuate delta coast revealed a difference in their overall morphology. This difference appeared to be controlled primarily by two factors: (1) physical processes active on a given subdelta, and (2) sediment supply. There were two different styles of subdeltas within the arcuate delta: (1) river-mouth bars/deltas, and (2) tidal-inlet deltas (Figure 11). The western side of the arcuate delta is strongly influenced by freshwater rivers which often have well-developed river-mouth bars (subdeltas) that are symmetrical, lobate shaped, and generally subtidal (Figure 11).

These river-mouth subdeltas are being shaped by a combination of riverine (near constant, ebb directed current) and marine processes (tides, waves, and longshore currents). As shown in Figure 11, the more river dominated subdeltas often had a very symmetrical shape with few, if any, intertidal shoals. In contrast, the eastern side of the arcuate delta more often had tidally influenced deltas with intertidal shoals that were commonly deflected in a downdrift direction by the dominant longshore currents in an area (Figure 11). The difference in subdelta morphology was somewhat predictable due to the increasing tidal range from west to east along the Nigerian coastline. The difference in tidal amplitude is accentuated because of the low volumes and frequency of freshwater discharge at the subdeltas on the eastern side of the arcuate delta, thereby allowing the marine processes to play a more active role in shaping the subdelta morphology.

During the monitoring of the nearly fifty beach stations in the vicinity of the Niger Delta (both arcuate delta and delta flank geomorphic zones), very little rafted organic material was observed. In review of the previous work conducted on the Niger Delta, the only mention of organic-rich soils or peat was made in reference to the mangrove swamp environment (ALLEN, 1965a, 1965b; NEDECO, 1961). This finding is confirmed by the present research. Several cores taken on the delta in the mangrove swamp and outcrops of mangrove

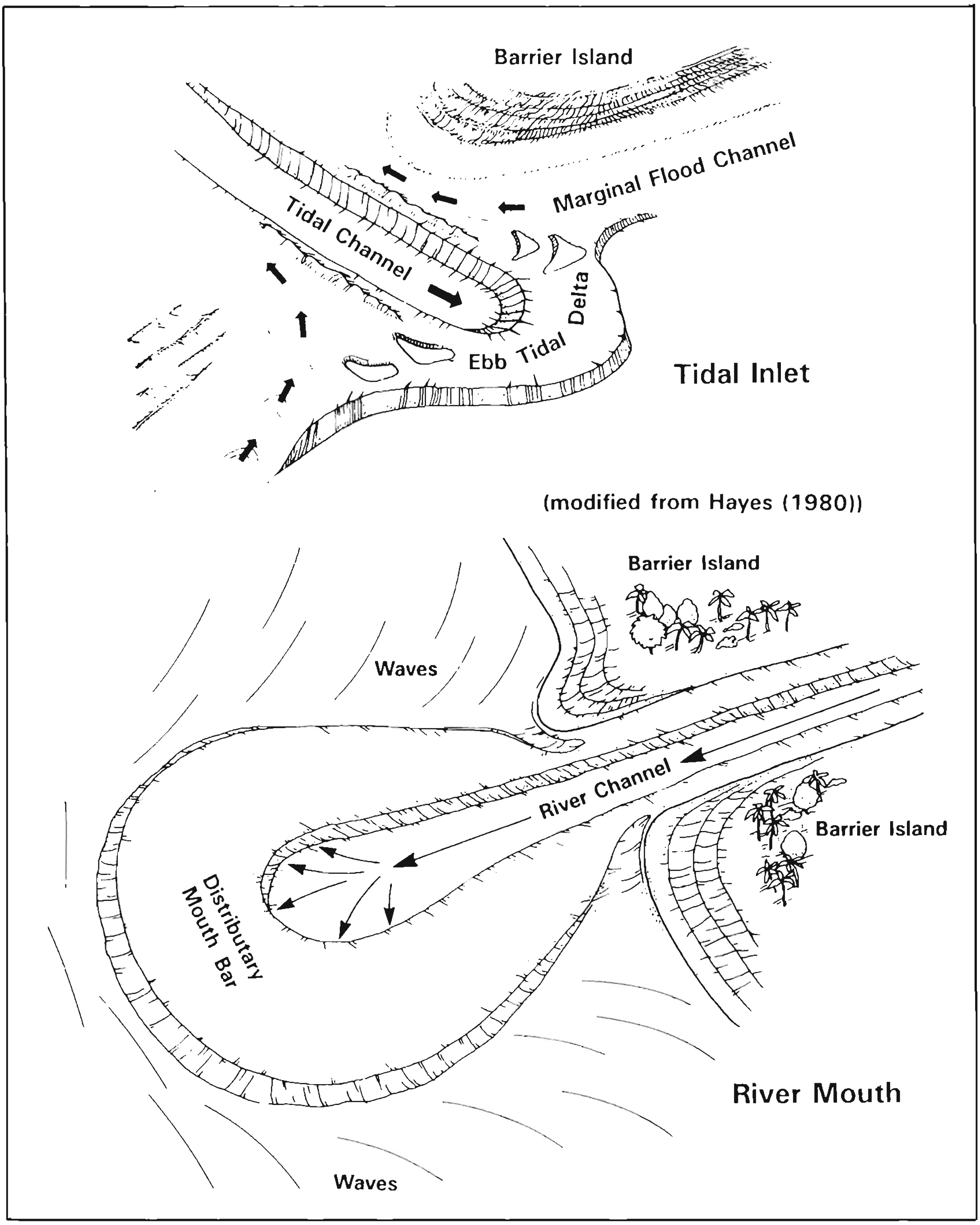

Figure 11. Subdelta types found at the river mouths and tidal inlets on the Niger Delta. River mouth subdeltas generally are subtidal, whereas the tidal inlet subdeltas are intertidal.

swamp sediments were the only areas where organic-rich sediments of significant quantities were encountered. Mangrove peats with thicknesses of 2 to 3 m were common. It would appear that the majority of the organic debris produced by the expansive mangrove swamp environment on the delta is either not transported out of the swamp onto the delta front or transported seaward beyond the delta front beaches.

Strand Coast

The strand coast is a 70 km long stretch of Nigerian coastline that extends from just east of the Imo River to the Cross River Estuary (Figure 5). The coastline is typified by moderately wide (75 m), gently sloping (1:20), active beach faces (Figure 12). These beaches are composed of fine-grained sand that is moderately well sorted, and the back beach often is covered with the climbing vine *Ipomoea aquatica*. Landward of the beaches is an extensive, forested, beach-ridge plain with only a few, small, swamp systems present.

The coastline is continuous with only one significant interruption in the strand beach: the Qua Ibo River mouth. Beaches in the vicinity of smaller river mouths or small tidal creeks that intersect the coast generally have small subdeltas. These beaches also have well-developed recurved spits indicating longshore transport of sediment in an easterly direction along this segment of the Nigerian coastline. The spits are oriented west to east in the direction of dominant longshore currents. Associated with the more active depositional areas along the strand coast are some low amplitude (less than 60 cm) coastal dunes. This geomorphic zone has the most frequent occurrence of coastal dunes along the Nigerian coastline.

DISCUSSION

The coastal morphology of Nigeria was divided into five broad categories based on a number of physical parameters (grain size, beach slope, shoreline character, et cetera). Field data collected for mean grain size, beach slope, wave height and longshore current are presented in Figure 3. There is a wide range in the parameters presented in Figure 3 which indicates the diversity of the Nigerian coastline. Division of the geomorphological zones have been highlighted in Figure 3. Using data collected during the present study, trends were evident along the shoreline allowing the subdivision into specific zones.

The sediment samples analyzed to produce the mean grain-size plot (Figure 3) were collected from the midbeach face at each beach station. Also, the sample sites were located in exposed beach settings (midbarrier island) away from the immediate influence of a river mouth/tidal inlet. The selection of sample sites was made to represent the open coastline of Nigeria. The variation in grain size along the coast ranges from medium-grained sand to silt and clay. Beach slopes reflected this variation in grain size with the coarser-grained beaches typically having slopes of 1:10 while the finer-grained beaches had slopes of 1:50.

The physical processes along the 800 km stretch of coast varied considerably. Wave heights of 50 to 200 cm were recorded under similar weather conditions throughout the study area, and both spilling and plunging waves were observed. The longshore current velocities ranged from a high of 90 cm/sec along the barrier-lagoon coast and arcuate-delta front to a low of 10 cm/sec along the transgressive mud coast. The tidal range generally increased from 1 m in the west to 3 m on the eastern shoreline of Nigeria. The change in tidal amplitude has affected the gross morpholoy of the coastline, with the lower-tidal range coasts more often having long, continuous beaches with few interruptions. The coastal areas experience large tides, more commonly having frequent breaks in the shoreline (tidal inlets) and better-developed embayments/estuaries.

The cores collected from the transgressive mud coast indicate a fining up sequence with an overall decrease in grain size and well-developed sand stringers toward the base of the core. One possible depositional environment for these sediments would be a moderate- to high-energy lagoonal setting that infilled after the late Pleistocene/Holocene rise in sea level until a mangrove swamp/tidal flat complex developed. Due to a slight rise in sea level or subsidence in the area, or a combination of both factors, the mangrove swamp is presently being eroded or transgressed.

The Niger Delta (arcuate delta and delta flank geomorphic zones) is the most dynamic section of the coastline of Nigeria. The diversity of the area with over 21 river mouths/tidal inlets, associated barrier islands, and subdeltas provides a variety of coastal geomorphic features.

Previous work conducted on the Quaternary sediments of the Niger Delta (Oomkens, 1974; Weber, 1971) have pointed out the importance of tidal channel sediments in the recent geologic

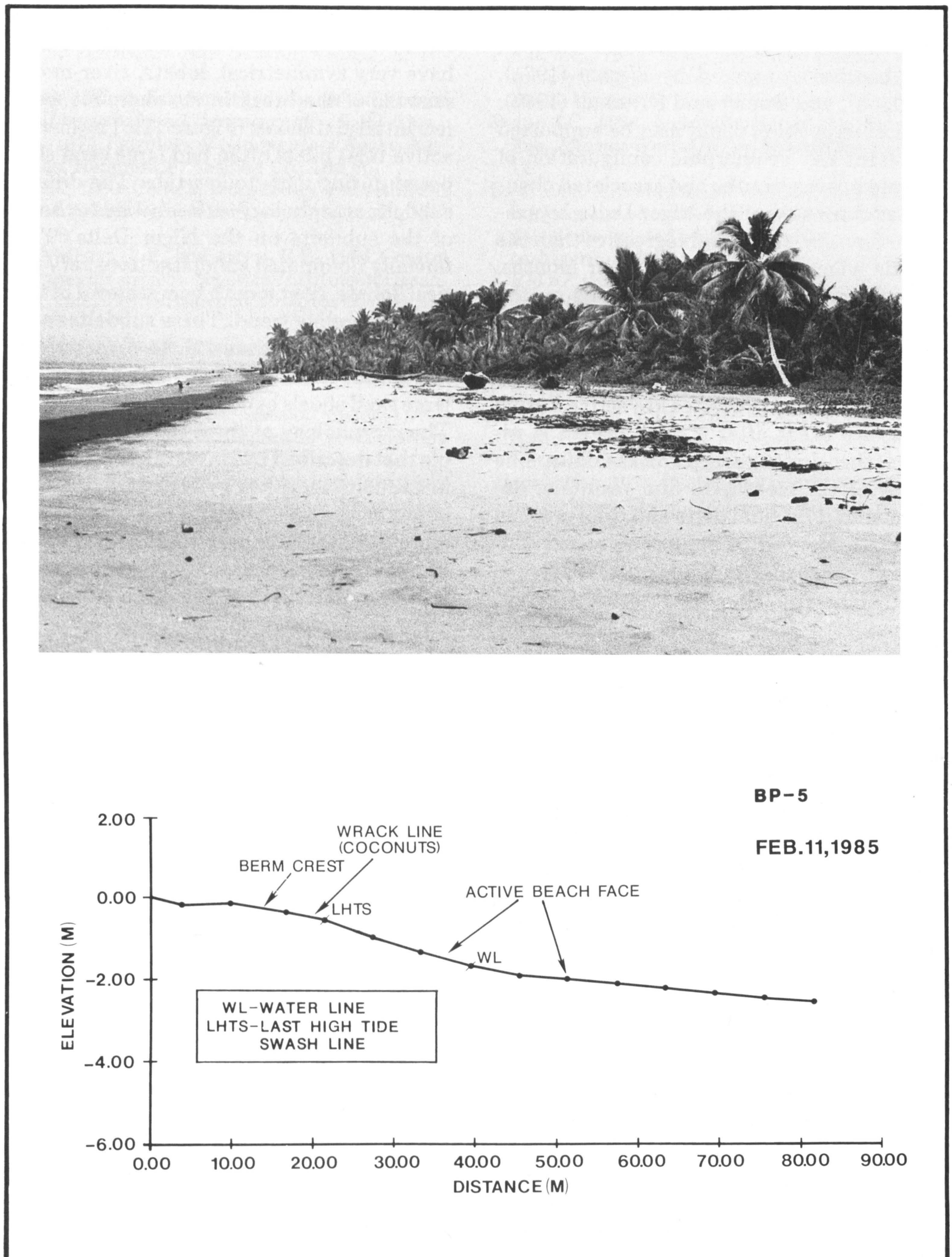

Figure 12. Typical beach profile plot for the beaches along strand coast. Beaches are fine-grained and slope gently (1:20); low-amplitude dune fields are common.

record. The mechanism of cyclic sedimentation on the Niger Delta (periods of regression followed by transgression during a relative still stand in sea level) has been proposed by WEBER (1971), ALLEN (1965b), and SHUNT and STAUBLE (1967). This style of deposition could also be supported by the present day geomorphic configuration of the tidal inlets/river mouths and associated channels. The western side of the Niger Delta is presently more fluvially-active and regressive than the eastern side which has few active river mouths. This periodic switching of river systems on the delta produces a cycle of sedimentation. The fluvial deposits on the lower delta plain of the delta is periodically reworked by marine processes. This happens when marine processes are active during a transgressive event after a river system is pirated to another drainage basin on the delta. The cyclic style of sedimentation and resultant deposition of abundant tidal delta and tidal channel sediments is evidenced by studies on recent sediments on the Niger Delta (OOMKENS, 1974).

CONCLUSION

Analysis of field data collected at 60 beach stations along the coast of Nigeria, general observations, and a review of previous work conducted on the shoreline, enabled the authors to divide the coastline into 5 broad geomorphic zones. The 5 zones are as follow: (1) barrier-lagoon coast, (2) transgressive mud coast, (3) western and eastern delta flanks, (4) arcuate delta, and (5) strand coast. These shoreline segments reflect the variations in geologic setting, sediment supply, and physical processes active along the 800 km stretch of coastline. The beaches of Nigeria are composed of sediments ranging from coarse-grained sand to silt and clay and have corresponding beach slopes of 1:6 to 1:90.

The coastline of Nigeria has few wind-blown sediment deposits (coastal dunes), and this may be attributed to the abundance (43 species) of coastal plant species identified in the study or their lush prolific nature. Because of the lack of dune deposits, the beach-ridge barrier islands tops are composed of a ridge and swale topography and not a series of foredune ridge deposits. The delta front beaches have only occasional rafted organic material present either on the surface or in the shallow subsurface. This would indicate that the organic detrital material produced on the delta is remaining in the mangrove swamp forest or being transported well offshore.

Differences in subdelta morphologies were observed at the 21 major inlets active on the Niger Delta. The more fluvially dominated subdeltas have very symmetrical, lobate, river-mouth bars seaward of the break in the shoreline trend with few intertidal shoals (Figure 11). The less fluvially active tidal inlets often had large sand shoals exposed during mid- to low-tide. The difference in subdelta morphology is closely tied to the position of the subdelta on the Niger Delta. The more fluvially dominated subdeltas have very symmetrical, lobate, river mouth bars seaward of the break in the shoreline trend. These subdeltas are essentially subtidal (Figure 11). In contrast, the tidal inlets with their associated ebb tidal deltas have large sand shoals exposed during mid- to low-tide. The morphology of these features closely resemble that described by Hayes (1980). The difference in subdelta morphology is closely tied to the position of the subdeltas on the Niger Delta. The more fluvially dominant western side of the delta frequently have river dominated subdeltas while on the eastern side of the delta ebb tidal deltas are most common.

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