CHAPTER 69

VARIATIONS OF WAVE-ENERGY LEVELS AND COASTAL

SEDIMENTATION, EASTERN NICARAGUA

by

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Abstract

High rates of weathering, abundant rainfall, and high discharge rates combine to supply large volumes of sediment to the This terrigenous sediment is coastal zone of eastern Nicaragua. confined to a narrow section of the inner shelf (<30 km wide) due to the circulation pattern within a coastal boundary layer. Sediment transport within the inner shelf and shore zone is to the south. This simple transport pattern is considerably modified by variations in wave-energy levels that are a function of shelf width, bottom friction, and wave sheltering. In northern sections, the shelf is up to 200 km wide but narrows to less than 20 km in the south. A direct result is that wave-energy levels at the shoreline are of the order of three times greater in the south. In the north the Rio Coco delta is prograding seaward in a fluvially dominated environment, whereas the Rio San Juan delta in the south has a wave-dominated morphology characterized by deflected dis-tributaries. Other major accumulation features have developed where wave-shadowing is produced by offshore reefs and cays. Alongshore a spatial variation was recorded, with straight beaches and simple linear bars in the north that change to rhythmic beach topography and crescentic nearshore bars as wave-energy levels increase toward the south.

Introduction

A 2-year multidisciplinary study (1976-77) on the eastern Nicaragua shelf (Figure 1) was directed toward the investigation of macro- and meso-scale shelf and nearshore processes (Murray et al., in preparation). One aspect of the investigations was to determine the regional pattern of sediment supply, transport, and deposition for the shelf and nearshore environments. This subject is considered in more detail elsewhere (Roberts et al., in preparation) but forms the basis for the present discussion, which focuses on an explanation of the variations in the morphology of the beach and nearshore sediments as a function of spatial variations in wave-energy levels at the shoreline.

The primary characteristics of the Caribbean shelf of Nicaragua are (1) persistent northeast trade winds with high average speeds (15 to 20 km/hour) throughout the year; (2) rainfall values in the coastal zone that increase from 2500 mm/year in the north to 5500 mm/year in the south; (3) a large drainage basin of volcanic rocks, with high weathering and erosion rates; (4) high river discharge; (5) a unidirectional wave approach out of the northeast; (6) a dominant system of north to south nearshore and inner shelf currents; (7) a narrowing of shelf width from 200 km in the north to less than 20 km in the south; (8) shallow depths on the shelf, generally less than 30 m; and (9) a microtidal environment (20 to 60 cm range).

Supply of Sediment to the Coast

The continental divide in this section of Central America is adjacent to the Pacific coast (Figure 1), so that the drainage basins that discharge into the Caribbean Sea are relatively large. The eastern Nicaragua drainage basin is approximately 133,000 km², and erosion rates are very high. Intense weathering of the



Figure 1. Shelf and coastal currents, Eastern Nicaragua. The wind rose indicates annual frequency (percent) by direction.

volcanic rocks, which are the major geologic outcrop in the mountains of the upper basins, results from high temperatures and large rainfall amounts, coupled with the seasonality of the rainfall distribution. The abundant rainfall also leads to high erosion and high river discharge rates.

Although the data base is limited for this region, extrapolation from available discharge and sediment load measurements indicates a total sediment supply to the shelf by rivers that is in the order of 25 to 30 x 10^6 m^3 /year (Table 1). This sediment yield is equivalent to an estimated basin erosion rate of 4.0 x 10^5 kg/km^2 /year, a rate that is comparable with the high-rainfall, high-temperature, and high-relief areas of southwestern Asia that have erosion rates at the same order of magnitude (Strakhov, 1967).

Drainage Basin	Area (km²)	Estimated Annual Discharge (m³xl0 ⁶)	Estimated Annual Sediment Supply (m ³ x10 ⁶)
Coco	24,761	36,460	5.5 - 7.4
Prinzapolka	10,548	20,766	3.1 - 4.2
Grande	17,556	29,104	4.5 - 6.0
Escondido	12,308	26,464	4.0 - 5.4

Table 1 Major Terrestrial Sediment Sources

Estimated total sediment supply to shelf from rivers: 25 - 30 \times $10^{\,6}m^{\,3}/year$

For further comparison, in terms of unit lengths of coast, the Nicaragua shelf receives about three times more fresh water and about thirty-three times more sediment from river discharge than does the Atlantic shelf of the United States (Murray et al., in preparation).

Coastal erosion as a source of sediments is limited to a 5- to 10-km section of shoreline in the north, near Puerto Cabezas, where 10-15-m cliffs of sands and gravels are undergoing wave attack. Elsewhere, sections of barrier beaches are subject to erosion, but this process involves redistribution of sediments rather than the supply of new sediments to the coastal zone.

An estimated 16 to 22 x 10^6 m³/year, the majority of the sediment that is supplied to the shelf, enters the coastal zone in that section to the north of and including the Rio Grande (Figure 1). This northern section accounts for two-thirds of the eastern Nicaragua drainage basin due to the geometry of the Central American isthmus, which narrows from north to south in this region. Shelf Processes and Sediment Transport

The distribution of terrigenous sediments supplied to the coastal zone and shelf is characterized by two major features. The first is the dominant north to south transport of sediment along the Nicaraguan coast, and the second is the confinement of the terrigenous sediments to a narrow (less than 30 km) band of the inner shelf adjacent to the coast.

The percentage of calcium carbonate in sediments collected on a transect from the mainland coast (between Punta Perlas and El Bluff) to the shelf edge reflects the rapid facies change to carbonates away from the coast (Figure 2). In less than 20 km terrigenous sediments of the strong longshore drift system are replaced by in situ derived carbonates. Sediments confined to this narrow band along the coast vary from coarse volcanic sands near the river mouths and in the beach and bar systems to finegrained kaolinitic-montmorillonitic clays in coastal recesses and away from the shoreline. Variations in river discharge and therefore sediment input, as well as perturbations in the strength and direction of the northeast trade winds, cause the sediment-rich coastal plume to expand and contract.

The transition areas between dominantly terrigenous bottom sediments and carbonates are generally found to be rather flat and featureless depositional plains. In these areas, terrigenous clays are deposited in association with in situ generated aragonitic muds derived from the growth and disintegration of numerous varieties of calcareous green algae. Geomorphically, the belt of terrigenous sediments and the terrigenous-carbonate transition areas are associated with a depositional ramp that interfaces with the coast (see zone 1 of Figure 3).

Beyond the limits of the belt of terrigenous sediments (approximately 20 km from the coast), the shelf sediments are generally composed of more than 95% calcium carbonate. The shelf interior consists of vast flat areas blanketed by bimodal sediments consisting of Halimeda-rich carbonate muds. These intermediate shelf areas of carbonate deposition generally have very



Figure 2. Percent calcium carbonate in bottom sediment samples across the south-central part of the Eastern Nicaragua shelf. Sample locations are given on the inset diagram. X-ray diffraction of representative bottom sediments is shown for sample stations 2, 5, and 15.

little relief and are found in water depths between 20 m and 30 m (see zone 2 of Figure 3).

Extremely rough-bottomed topography, resulting from the growth of coral-algal reefs, is associated with well-defined areas of the shelf (see zone 3, Figure 3). Island platforms such as the Pearl Cays, the Mosquito Cays, and the Corn Islands, as well as submerged topographic highs and a belt along the seaward margin of the shelf, exhibit active reef growth (Figure 3). These reef zones are important source areas for carbonate sediments derived from both biological and mechanical degradation of reef components. In addition to being generation sites for carbonate debris, the extremely irregular bottom topography of these zones is a major factor in the attenuation of open-ocean waves as they intersect the shelf and translate across it. Reefs commonly have



Bottom roughness zonation of the Eastern Nicaragua Figure 3. shelf can be defined by three categories:

- Zone 1--Smooth depositional ramp near the coast. Zone 2--Featureless mid-shelf areas of carbonate deposition.
- Zone 3--Rough-bottomed conditions reflecting reef growth on island flanks, mid-shelf platforms, and the shelf margin.

(a) Examples of echo-sounder records for the three zones; (b) geographic distribution of bottom roughness types.

relief of 10 m, and at the shelf margin relief in excess of 20 m is The shelf margin reefs are continually bathed in not unusual. open ocean water and are developing in an environment free of terrigenous sediment, whereas shelf and island platform reefs, for example the Pearl Cays, may be subject to various levels of interaction with terrigenous sedimentation.

The north to south transport of terrigenous sediment is a function of both oceanic and wave-induced currents. In the near-

shore zone the dominant wave approach is out of the northeast, as a result of the effects of the northeast trades, and this situation produces a strong littoral current and longshore drift at the shoreline. Adjacent to the coast wave heights are less than 1.5 m for 75% of the year, with significant periods of 5 to 7 s in the north and 7 to 9 s in the southern areas (Livesey and Henderson, 1968).

Offshore, oceanic currents are characterized by an onshore movement across the shelf of the central Caribbean drift and by a bifurcation of the drift toward the northwest and southwest (Figure 1). Although the mean drift is to the northwest in northern sections of the shelf, the shallow-water countercurrent adjacent to the coast moves toward the south under the influence of the northeast trades and of quasi-geostrophic adjustment to the large freshwater influx along the coast. On the inner shelf the currents are confined to a 10-30-km-wide coastal boundary zone characterized by strong baroclinic structures and by the frictional effects of the northeast trades (Crout and Murray, 1979). In addition, these currents are enhanced by the surface slope of the nearshore waters, so that velocities of 40 to 70 cm/s are common in the upper layers of the coastal currents (Murray et al., in preparation). The primary effect of the oceanic currents is to confine the terrigenous sediments to a relatively narrow (less than 30 km) band adjacent to the coast (Roberts et al., in preparation).

The primary north to south sediment transport system along this 450-km section of coast reverses direction at the Nicaragua borders. In the north the change in coastline orientation from north-south to northwest-southeast at the mouth of the Rio Coco (Cabo Gracias a Dios) leads to a divergence in the littoral drift system and a coastal current that transports sediment to the

northwest along the northern shore of the Coco delta (Figure 1). In the south the coast of Costa Rica also trends northwest-southeast, and this section is affected by easterly and southeasterly winds that become progressively more important toward the south. These winds generate a strong south to north current along the coast of Costa Rica that meets the north to south current in the vicinity of the Rio San Juan delta at the Nicaragua border (Figure 1). The result of these reversals in sediment transport directions is that the Rio Coco delta is a zone of sediment divergence and that the Rio San Juan delta is a zone of convergence.

Coastal Processes and Sedimentary Responses

The macro-scale coastal geomorphology of eastern Nicaragua is characterized by four major sediment accumulation features. Two extensive deltaic systems have developed at the mouths of the Coco and San Juan rivers, and two large cuspate forelands at Punta Gorda and Punta Perlas represent sedimentation in the lee of offshore reef systems. Also, at the regional scale there is a longshore spatial variation in beach and nearshore morphology that is a response to a major change in shoreline processes along this coast.

(a) <u>Comparison of the Coco and San Juan deltas</u>. The variability of shoreline processes on this coast is best exemplified by comparison of these two major deltaic systems. Although only 450 km apart, they represent morphological responses to totally different sets of shoreline processes.

The delta of the Rio Coco (Figure 4a) has assumed a large prograding cuspate shape that reflects the dominance of fluvial over marine processes. The cuspate form has developed as a single river channel has extended the delta by flank deposition. This seaward growth results from the high discharge and high sediment



Figure 4. Generalized morphology of the (a) Coco and (b) San Juan-Colorado deltas.

load of the river (Table 1) and from the inability of marine processes to redistribute the sediments alongshore.

Despite the dominance of fluvial processes, evidence of wave action is given by the relatively smooth outline of the delta. Therefore, applying the terminology of Wright and Coleman (1973), the Coco delta is defined as characterized by a river-dominated morphology with a low level of wave modification. In terms of morphology, this delta is comparable to the Ebro of northeastern Spain (Wright and Coleman, 1973, Fig. 4). The low wave-energy levels at the mouth of the Rio Coco are a function of the wide (up to 200 km), shallow shelf offshore that is characterized by numerous reefs and cays. Incoming waves therefore are subject to considerable frictional attenuation, and at the shoreline waves are generally of short period and low amplitude.

The morphology of the Rio San Juan delta, 450 km to the south, is totally different (Figure 4b). Although the estimated discharge rates and sediment loads of the two rivers are similar (Table 2), and although this is a zone of convergence of the longshore currents, the delta protrudes only slightly onto the adjacent shelf. The river has two major distributaries, both of which have been deflected toward the north. In particular, at the mouth of the Rio Colorado a series of blocked distributary channels that parallel the shoreline (Figure 4b) are evidence of a seaward progradation that is controlled by marine reworking of the deltaic sediments. The shelf adjacent to the San Juan delta is less than 20 km wide (Figure 1), with a mean slope of 1:80 (cf. the shelf adjacent to the Coco delta, which has a slope less than 1:200, Table 2). The morphology of this delta clearly reflects the dominance of marine over fluvial processes on this section of coast.

The variation that exists between these two delta systems is due to the significant change in the balance between fluvial and marine processes. This change results from a variation in waveenergy levels at the shoreline that is controlled by shelf width. As the shallow shelf narrows toward the south, and as frictional attenuation therefore also decreases, wave energy at the shoreline increases significantly. (Computed values for wave energy show a

	Сосо	San Juan
Shelf width (km) Shelf slope Wave-energy levels (ergs/m/s)	150-200 <1:200 Low: ~1.2 x 10 ¹⁰	<20 1:80 High: ~4.3 x 10 ¹⁰
Discharge (m³/year) Estimated sediment load (m³/year)	~40 x 10 ⁹ 5.5-7.4 x 10 ⁶	~25 x 10 ⁹ 4.0~5.4 x 10 ⁶
Littoral drift	Zone of divergence	Convergence, domi- nantly to north
Primary processes	Fluvial	Marine (wave dominated)
Delta morphology	Single protruding channel	Straight coast, deflected distributaries

Table 2 Comparison between the Deltas of the Rios Coco and San Juan

threefold increase, from 1.2 x 10^{10} ergs/m/s in the north to 4.3 x 10^{10} ergs/m/s in the south.)

(b) <u>Punta Gorda and Punta Perlas</u>. In addition to the systematic alongshore changes in wave energy at the shoreline, the presence of offshore reef and cay complexes causes local variations in the coastal geomorphology. The Mosquito Cays and Pearl Cays (Figure 3) act as barriers to incoming waves, and accretion of sediments within the longshore transport system has occurred in the lee of these two reef systems. Both Punta Gorda and Punta Perlas have developed on the low-lying swampy coastal plain by the seaward progradation of a series of well-defined beach ridges.

Punta Gorda is in the lee of the Mosquito Cays (Figure 5a) and has developed downdrift of the Coco delta. As much of the sediment supplied by the Coco is diverted to the northwest at the mouth of the delta (Figure 4a), the estimated annual supply of fluvial sediment from the Coco and Ulang rivers is in the order of 3 to 5 x $10^6 \text{ m}^3/\text{year}$.

Farther to the south, Punta Perlas (Figure 5b) lies downdrift of several major rivers, including the Prinzapolka and the Grande, so that sediment input in this section is much greater, in the order of 9 to $12 \times 10^6 \text{ m}^3$ /year. Therefore, although the Pearl Cays are a less effective filter to incoming waves, when compared to the Mosquito Cays, there is more sediment in the longshore transport system. This situation has favored the development of a large cuspate feature that now extends 10 km seaward from the general trend of the coast. The Punta Perlas system acts as a large groin-like feature with a resulting downdrift offset of the coast to the south.

(c) <u>Comparison of river-mouth characteristics</u>. As a measure of wave competence and its effect on local coastal geomorphology,



Figure 5. Generalized morphology of (a) Punta Gorda and (b) Punta Perlas (from topographic maps and aerial photographs).

a comparison has been made between the river exits of the Rio Ulang (Figure 5a) and the Rio Indio (Figure 4b). Both rivers have relatively small drainage basins and enter the shore zone at sections of unimpeded sediment transport. Although the Ulang drains an area twice the size of the Indio (Table 3), the increase in annual rainfall amounts between the two areas (from 2500 to 5000 mm) results in similar discharge rates and sediment loads. The Ulang river mouth is characterized by a large ebb-tidal delta system in which the main ebb channel has been deflected to the south by waveinduced littoral currents (Photograph 1). Although this deflected channel system is characteristic of rivers with small drainage basins, such as the Wawa and Kukalaya, the tidal deltas associated with large rivers in the northern half of the shelf (the Prinzapolka and Grande) show no evidence of channel deflection. In

these cases the very high discharge rates are sufficient to counterbalance the processes associated with the longshore transport system.

In contrast to the Ulang, the channel of the Rio Indio has been deflected 15 km to the south due to the effects of strong wave-induced longshore currents. The channel parallels the shoreline and is separated from the sea by a narrow (300-400 m), low (<3 m) barrier (Photograph 2). The mouth of the Rio Indio has become part of the outlet system associated with the northern distributaries of the San Juan delta (Figure 4b).

(d) Beach-nearshore morphology variations. At a smaller scale, field measurements and reconnaissance observations have shown that there is a marked change in beach and nearshore planform morphology from north to south on this coast. This systematic alongshore variation is a direct function of the changes in wave-energy levels at the shoreline.

In northern sections of this coast, to the north of Punta Perlas, the beaches are narrow (~10 m) and straight. A single continuous linear bar is present in the nearshore zone, usually at

Comparison	Between the Ulang a	and Indio Rivers
	Ulang	Indio
Drainage basin (km ²)	3830	1820
Discharge (m³/year)	5840 x 10 ⁶	5140
Sediment load	0.9-1.2 x 10 ⁶	0.8-1.1
River-mouth morphology	Large ebb-tidal delta - partially deflected channel	River channel deflected 15 km to south
Wave energy at shoreline (ergs/m/year)	~1.2 x 10 ¹⁰	~4.3 x 10 ¹⁰

Table 3



Photograph 1. Low-altitude aerial photograph of the mouth of the Ulang River. Note the deflection of the main (ebb) channel, which closely follows the south (left in this photo) shore of the estuary.



Photograph 2. Aerial photograph of the lower course of the Rio Indio. The river exit is indicated by the arrow.

about 60 m from the shoreline (Photograph 3). Generally trough and bar depths are in the order of 1.5 and 1.0 m, respectively. Due to the wide shelf (up to 200 km) and shallow gradients, frictional attenuation values are high, particularly as much of the outer shelf is composed of active coral reefs. Computed energy levels at the shoreline are in the range 0.7 to 1.2 x 10^{10} ergs/m/s.

The central section, between Punta Perlas and Punta Mico (Figure 5b), is a transition zone. Beaches are generally wider and steeper, and the morphology is a series of irregular protuberances and embayments (Photograph 4). The nearshore zone is characterized by rip cells and by a nonlinear bar system with some longshore periodicity that has wavelengths in the order of 50 to 70 m. Trough depths vary between 1.0 and 2.0 m on the landward side of the inner bar, and the inner bar shoals to 1.5 to 2.5 m. Computed shoreline energy levels are between 0.9 and 1.5 x 10^{10}



Photograph 3. Straight shoreline with a single linear nearshore bar near Laguna de Wounta, to the north of Prinzapolka (12 April 1977).

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Photograph 4. Wide breaker zone and irregular beach-nearshore topography north of El Bluff (12 April 1977).



Photograph 5. Well-defined rhythmic topography at Cano El Pescado, approximately 25 km north of the San Juan-Colorado delta (12 April 1977).

ergs/m/s as shelf width decreases to between 100 and 150 km.

The beaches to the south of Punta Mico exhibit a rhythmic morphology (Photograph 5). This configuration is mirrored in the nearshore zone by a well-developed crescentic bar system with wavelengths in the order of 100 to 125 m. No field data were collected in this section, but computed wave-energy values are in the range 2.5 to 4.3 x 10^{10} ergs/m/s.

The increase in energy levels alongshore results in a distinct transition from simple morphological features to a complex system of rhythmic topography (Table 4).

	North	Central	South
Shelf width (km)	200	100-150	20
Wave-energy levels	Low	Moderate	High
Nearshore wave power (ergs/m/sec)	0.7-1.2x10 ¹⁰	0.9-1.5x10 ¹⁰	.2.5-4.3x10 ¹⁰
Beach morphology	Straight narrow beaches	Irregular protuberances and embayments	Wide beach, rhythmic morphology
Nearshore morphology	Single linear bar 60 m from shore	Nonlinear bar(s), some longshore periodicity (50-70 m wavelength)	Well-developed rhythmic bar system (100-125 m wavelength)

Table 4 Eastern Nicaragua Beach/Nearshore Morphology

Conclusions

1. Although the Nicaragua shelf receives an estimated three times more fresh water and thirty-three times more terrigenous sediment per unit length of coast than the Atlantic shelf of the United States, the shelf has developed as a vast carbonate

province with terrigenous sediments confined to a narrow, welldefined belt (<20 km) along the coast.

2. The shelf margin (50-70 m depth), mid-shelf platforms, and island flanks are sites of active coralgal reef growth. These areas of extreme bottom roughness affect energy levels along the shoreline by the combined effects of frictional attenuation and sheltering.

3. Decreasing shelf width and decreasing frictional attenuation from north to south cause a threefold increase in wave-energy levels at the shoreline.

4. The spatial variation in nearshore and shoreline waveenergy levels results in (a) a fluvial dominated deltaic environment at the mouth of the Rio Coco, in the north; (b) a marine (wave) dominated deltaic environment at the mouth of the Rio San Juan, in the south; and (c) a systematic change from straight linear bars and beaches in the north to rhythmic topography in the south.

5. The distribution, transport, and morphology of sediments supplied to the shelf and shore zones on this coast are controlled by shelf and coastal currents and by the spatial variation in shoreline wave-energy levels.

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