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Passive margin sedimentation on Costa Rica's Nortb Caribbean coastal plain, Río Colorado

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Abstract: Geomorphic, sedimentologic, and stratigraphic data obtained from the north Caribbean region of Costa Rica suggests Rio Colorado is a wave-dominated delta which has formed along a passive continental margin. This coastal setting is significantly different from the south Caribbean and Pacific coastlines, which display geomorphic and lithologic features indicative of seismically active continental margins. The distinct aseismic history and passive margin geomorphology of the north Caribbean coastal plain appears to be controlled by the presence of tectonic features (*i.e.*, East Nicoya Fracture Zone) which decouple the region from adjacent, tectonically active areas. Although the data collected during this pilot study, including two radiocarbon dates from the base of surficial wet forest and palm swamp sediment. were not sufficient to document relative sea-level change, they do confirm the region's aseismic setting. A more complete examination of late Quaternary continental margin stratigraphy will help resolve neotectonic and associated rheological problems, which have remained enigmatic in the absence of a stable datum.

Key words: Sedimentation, strata, geology, tectonics.

Costa Rica (Fig. 1) is located in a complex tectonic environment (Suárez *et al.* 1995) where both Pacific and Caribbean coastlines are seismically active (Fig. 2). The Pacific coast is a convergent plate boundary, delineated by the presence of the Middle America Trench (Fig. 2) and composed of uplifted rocky headlands, wave cut notches, and erosional terraces. Even the Caribbean coast, traditionally considered a passive margin (Suárez *et al.* 1995), was recently subjected to tectonic uplift of as much as 2.0 m (Cortés *et al.* 1992; Denyer *et al.* 1994) associated with the 1991 Limon earthquake (M = 7.5; Suarez *et al.* 1995). Geological features (i.e. a vertical succession of wave cut notches) indicate late Quaternary seismic activity has occurred repeatedly in this region.

The only section of Costa Rican coastline that now appears aseismic is located in the north Caribbean region (Fig. 3; Montero 1994; Kolarsky *et al.* 1995). The broad low-relief coastal plain, straight shoreline with numerous topographic and bathymetric coastal alignments (Fig. 4), and recent sea-level data (Pirazzoli 1991) all suggest an aseismic tectonic setting has prevailed throughout the late Quaternary. However, there have been no analyses designed to assess the origin of this coastal geomorphology or it's chronologic context with respect to deglaciation and concomitant global eustatic sea-level rise. Once this has been accomplished, it should be possible to establish a regional eustatic sea-level history (Bloom 1979, Pirazzoli 1991). This in turn will help to resolve regional neotectonic

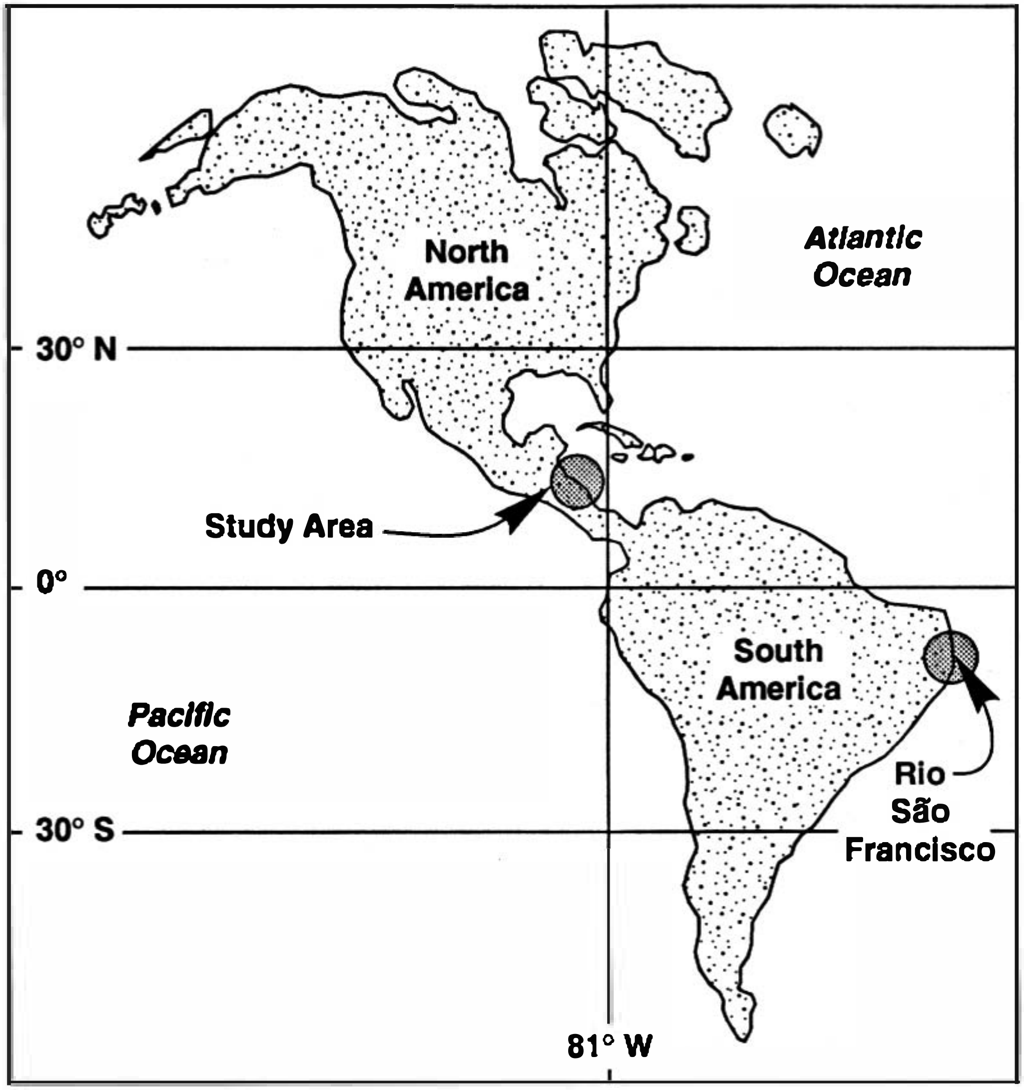

Fig. 1. Map view of western hemisphere indicating location of study area and Río São Francisco, a classic wave-dominated delta plain. Geomorphic similarities between these two areas are use as partial support for suggesting the north Caribbean coast of Costa Rica is located on a passive continental margin.

and associated rheological problems which have remained enigmatic in the absence of a stable datum from which to estimate absolute isostatic motion. This project was therefore designed to test the following null hypothesis (H_0):

The geomorphology, sedimentology, and stratigraphy of Costa Rica's north Caribbean coastline has been significantly affected by neotectonics.

To test this null hypothesis, the following information was obtained:

1) altitude aerial photo analysis of coastal geomorphology,

2) surveys of surface relief, antecedent topography, and lagoon bathymetry,

3) sedimentologic and stratigraphic data, and

4) relevant literature from analogous coastal settings.

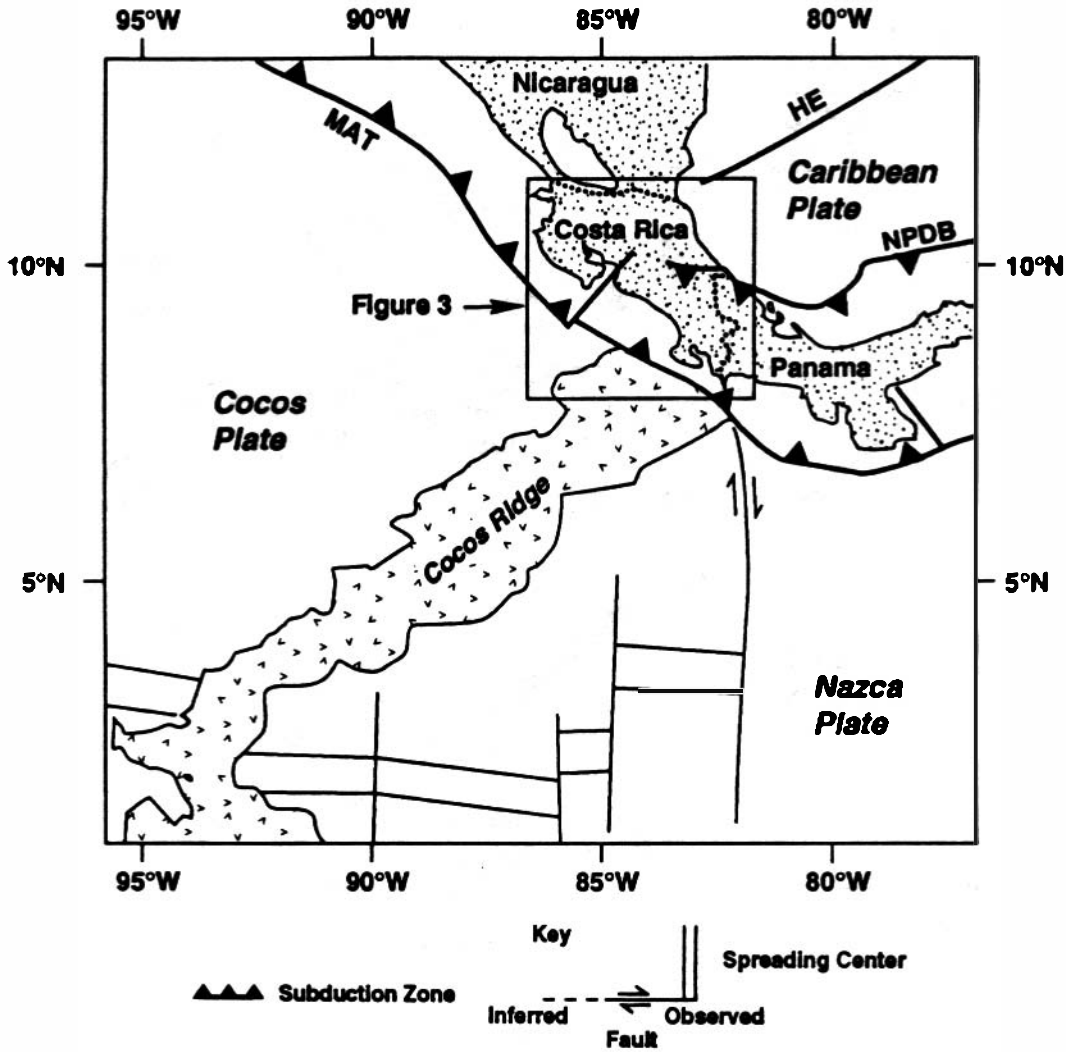

Fig. 2. Tectonic map of Central America showing location of structural features that have influenced the region's coastal geomorphology, sedimentation, and stratigraphy. Structual features extending through Costa Rica are responsible for distinct tectonic behavior of north and south Caribbean coastal plain. Boxed area is enlarged as Fig. 3. HE = Hess Escarpment; NPDB = North Panama Deformed Belt. Data from Fan *et al.* 1993 and Fisher *et al.* 1994.

The Rio Colorado coastal plain (Fig. 4) was identified as the ideal study area in which to test the null hypothesis. The area lies within the Costa Rican Province of Limón and is a component of the Area de Conservación, Tortuguero National Park. The park is located within Barra del Colorado National Wildlife Refuge, the largest refuge in Costa Rica (92 000 ha). Therefore, in addition to providing information on Central American neotectonics and eustatic sea-level history, this study provides insight into the origin of the distinct landscape, which has undoubtably contributed to the rich terrestrial and nearshore-marine biodiversity documented within the refuge (Boza 1996).

MATERIALS AND METHODS

Regional context: Along the western margin of Costa Rica lies the Middle American Trench (MAT), where the Cocos Plate is being

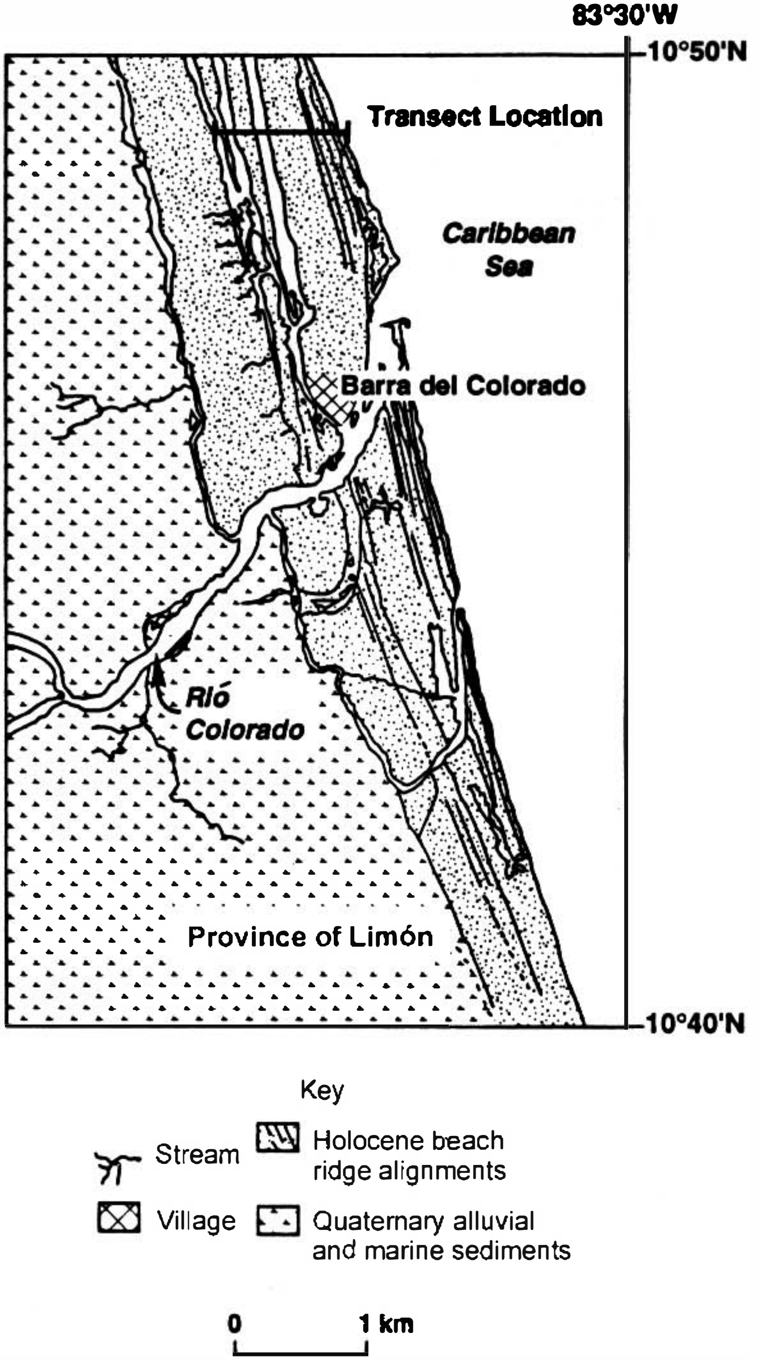

Fig. 4. Geomorphology of Río Colorado coastal plain showing shore-parallel Holocene beach ridge alignments and coastal lagoons, as well as the northward drifting confluence. Map based upon aerial photographic interpretation of 1986 black and white images (1:72 000) assembled to scale of 15' topographic map using zoom transfer scope. *Transect Location* identifies line along which survey data (surface relief, antecedent topography, lagoon bathymetry; Fig. 6) and sediment cores (Fig. 8) were collected in May 1996.

Zone (ENFZ) and the North Panama Deformed Belt (NPDB, Fisher *et al.* 1994, Fig. 2 and 3). These features decouple the two regions and are probably responsible for the distinct tectonic behavior of the northern and southern Caribbean coasts. For example, during the 1991 Limón earthquake as much as 2.0 m of uplift was documented along the coastline south of the city (Fig. 4), while subsidence and liquefaction of recent alluvium were noted to the north (Denyer *et al.* 1994).

Costa Rica's north Caribbean coastal plain is located at ~10° N latitude and therefore the climate is hot and humid (Boza 1996). Tropical climatic conditions prevail throughout the year, with temperatures averaging between 25 °C and 27 °C (Herrera 1985). The region is recognized as one of the wettest in the country with an average annual rainfall of 5.5 m. Vegetation is diverse, with the low lying coastal plain hosting dense wet forest and palm swamp communities (Gómez 1985). Towards the Caribbean coastline the continuity of the coastal plain vegetation is interrupted by eastward flowing braided fluvial systems (i.e. Rio Colorado) that meander through late Quaternary coarse-grained alluvial and marine sediments. Several extinct Quaternary volcanoes (i.e. Cerro del Tortuguero) are also present on the coastal plain, rising above the wet forest canopy and low-lying palm swamps by more than 120 m (Fig. 5).

The north Caribbean coastline is remarkably straight, with a broad (~100m) backshore area and gently seaward dipping foreshore. Beach sediments are composed of coarse- to medium-grained, mineralogically immature sand with abundant heavy minerals and rare occurrences of skeletal material. The wave-dominated coastal geomorphology has apparently developed in response to the unobstructed equatorial trade winds and their associated north equatorial surface currents and water waves. The region is internationally recognized as a high density nesting habitat for green, leatherback, and hawksbill sea turtles (Boza 1996) which, in addition to the presence of a relatively broad backshore zone, suggests the shoreline has remained relatively stable over centennial- to millennial-time scales.

Not much is known about the shoreface and shelf environment seaward of the north Caribbean shoreline. Bathymetric contours obtained from 15' topographic maps (e.g. Punta Castilla) indicate the width of the shoreface is ~5 km and that the shoreface-to-inner shelf transition occurs at a depth of ~20m. This relatively steep shoreface slope (1:250) is a characteristic typical of wave-dominated coastlines. For example, the eastern Florida (USA) seaboard is classified as a wave-dominated coast and has a similar shoreface slope (Venanzi 1992). The shelf break occurs at a distance of ~12 km seaward of the mainland shoreline and at a water depth of ~120 m. This feature is clearly shown on the 1°15' Barra del Colorado topographic map as an abrupt increase in seabed slope (1:20). The extensive, low relief coastal plain topography and adjacent bathymetry of the shoreface and shelf are features typically found in association with passive continental margin settings (Kennett 1982, Galloway and Hobday 1983).

Local setting and study site selection: As an initial step in site selection, the geomorphology of the north Caribbean coast was reviewed using high altitude (1:72 000) black and white aerial photography (1986). After review of the available images, three photo mosaics were constructed from twenty-nine photos. Each mosaic was adjusted to the scale of the corresponding 15' topographic maps (i.e. Punta Castilla, Colorado, Tortuguero) using a zoom-transfer scope. Each mosaic contains numerous narrow, coast-parallel lagoons, islands, and beach-ridge alignments, all generally located within 2 km to 4 km of the Caribbean shoreline. Braided rivers meander across the sandy coastal plain of each region with a distinct coast parallel river mouth offset present at the confluence of the Caribbean Sea and Ríos Tortuguero and Colorado. This offset appears to have evolved in response to a strong northerly littoral drift (Fig. 4 and 5). The coastal plain geomorphology of Costa Rica's north Caribbean coast is very similar to the wave-dominated delta plains that have developed along passive continental margins throughout the world (e.g. Burdekin River Delta, Coleman and Wright 1983, Río São Francisco Delta, Dominguez *et al.* 1987).

Each of the three photo mosaics were evaluated to determine an optimal site in

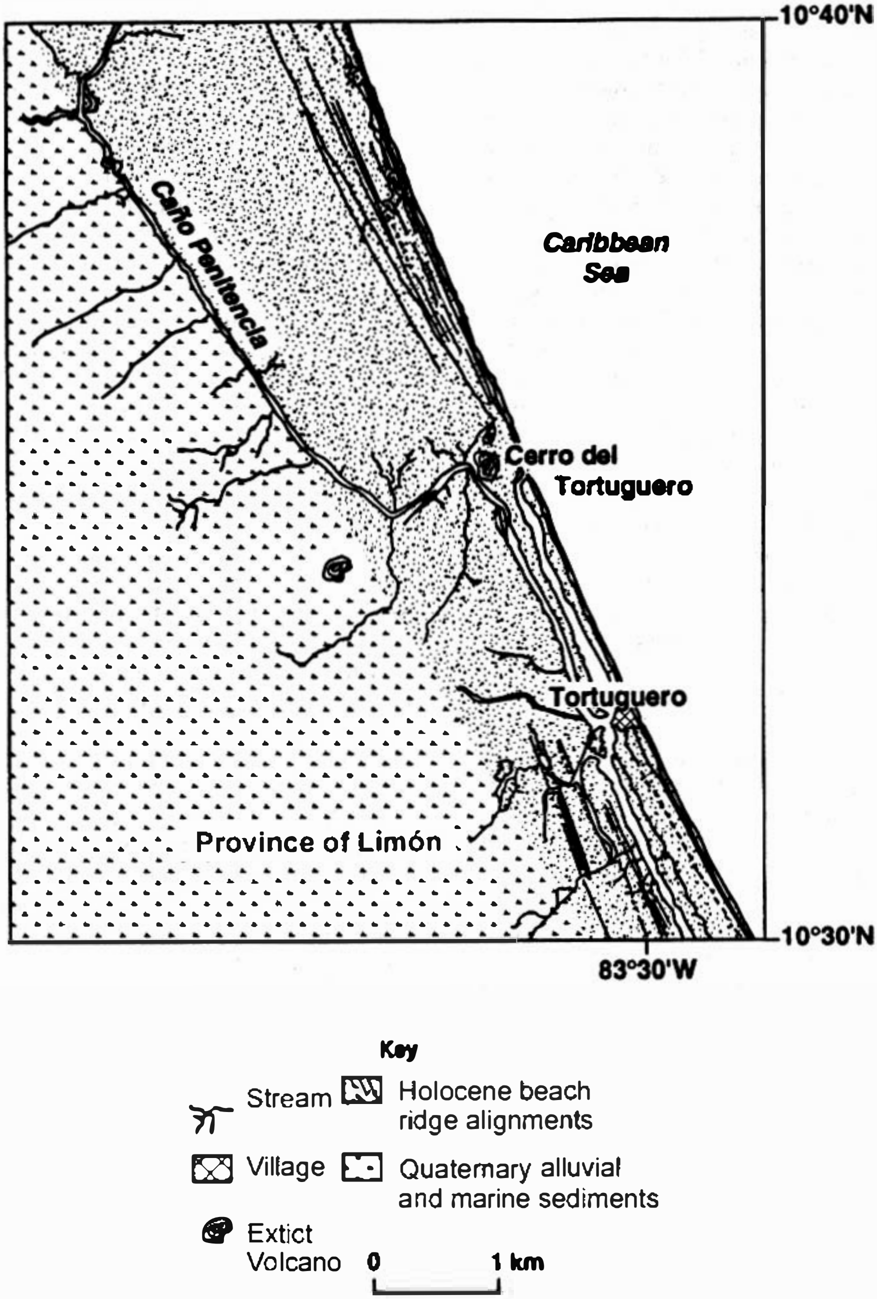

Fig. 5. Geomorphology of Rio Tortuguero coastal plain. The shore-parallel Holocene beach ridge alignments, coastal lagoons, and northward drifting confluence are features shared by Rio Colorado map (Fig. 4), suggesting a common origin. Isostatic movements associated with lithospheric loading from two Quaternary volcanic cones exclude the region as a viable location for assessment of regional sea-level history. Map based upon aerial photographic interpretation of 1986 black and white images (1:72 000) assembled to scale of 15' topographic map using zoom transfer scope.

which to test this study's hypothesis. The Punta Castilla region was rejected because it stratled the Nicaraguan boarder and was not easily accessed. Two extinct volcanoes (Fig. 5) are present on the coastal plain of Río Tortuguero. The presence of volcanic remnants complicate paleo-environmental reconstructions of coastal evolution because they introduce a distinct sediment source and modify local relief, therefore interfering with the natural progression of landscape evolution generated by fluvial processes. In addition, local sea-level history has probably been altered by isostatic adjustments associated with lithospheric loading. Therefore, the Tortuguero region was rejected from further consideration. In contrast, the coastal plain of Rio Colorado is well developed and contains several coast-parallel lagoons within 2 km of the Caribbean shoreline just north of Barra del Colorado (Fig. 4). These provide efficient access into the densely vegetated areas landward of the Caribbean shoreline.

METHODS

Selection of transect location: Once it had been established that the coastal plain at Río Colorado was the optimal location in which to test the null hypothesis, the second most significant component of project planning was to identify a transect location along which the survey and associated geologic data could be collected. There were two principle factors which influenced our selection: 1) extent of topographic disturbance by human subsistence farming, and 2) capacity to ensure completion of required fieldwork within the time available. After reviewing the aerial photography and conducting a field inspection in March 1996, the transect was established ~2 km north of Río Colorado's confluence with the Caribbean Sea (Fig. 4).

Surveys: After delineation of the optimum transect location, a survey was conducted to map: 1) surface relief, 2) antecedent topography, and 3) lagoon bathymetry. Surface relief was quantified by using a hand level and stadia rod to establish station elevations, a survey tape to measure distance between stations, and a compass to maintain the appropriate transect bearing. In addition to recording elevation, other relevant observations were noted, such as the presence of ponded surface water or an abrupt change in local relief. On average, the distance between survey stations was maintained at ~10 m, unless a distinct landscape feature was encountered between stations.

The antecedent topography was revealed by driving a 1 cm diameter steel probe-rod through the surface layer of organic detritus (O soil horizon, Hunt 1972) until refusal. This refusal horizon was later determined by coring to represent the top of late Quaternary alluvial or marine sand surface. Lagoon water depth was determined using a hand held fathometer. The distance between lagoon survey stations was visually estimated by a designated field assistant who had previously demonstrated an exceptional ability (±5 m at a distance of 50 m) to estimate the horizontal distance to an adjacent shoreline.

Sedimentology and stratigraphy: The objective of this component of the field program was to obtain sediment cores from emergent coastal alignments located adjacent to the coast-parallel lagoons (Fig. 4). Because transportation of coring equipment through the wet forest and palm swamp was extremely difficult, all coring sites were located in close proximity (<10 m) to a lagoon shoreline. If local relief was present, the coring site was positioned in a topographically low-lying area to enhance potential penetration. A gas powered Cobra™ pneumatic hammer was used to drive 1.5 m sections of aluminum core tubing (5 cm diameter) into the substrate. After retrieval of the initial section using a tripod and hand winch, 1.5 m extension rods were attached to each additional core tube until penetration or recovery was no longer possible.

Upon return to the laboratory, cores were split longitudinally and allowed to air dry for 24 hrs to enhance visual contrast between sediment types. Lithologic logs were constructed using sediment color, texture, composition, and structure. Representative samples were obtained every 30 cm or at shorter intervals if a significant aspect of the sediment succession would have otherwise been excluded. Sample texture and composition were quantified using standard geotechnical analyses and descriptive statistics (Wentworth 1922, Dean 1979, Lewis 1984).

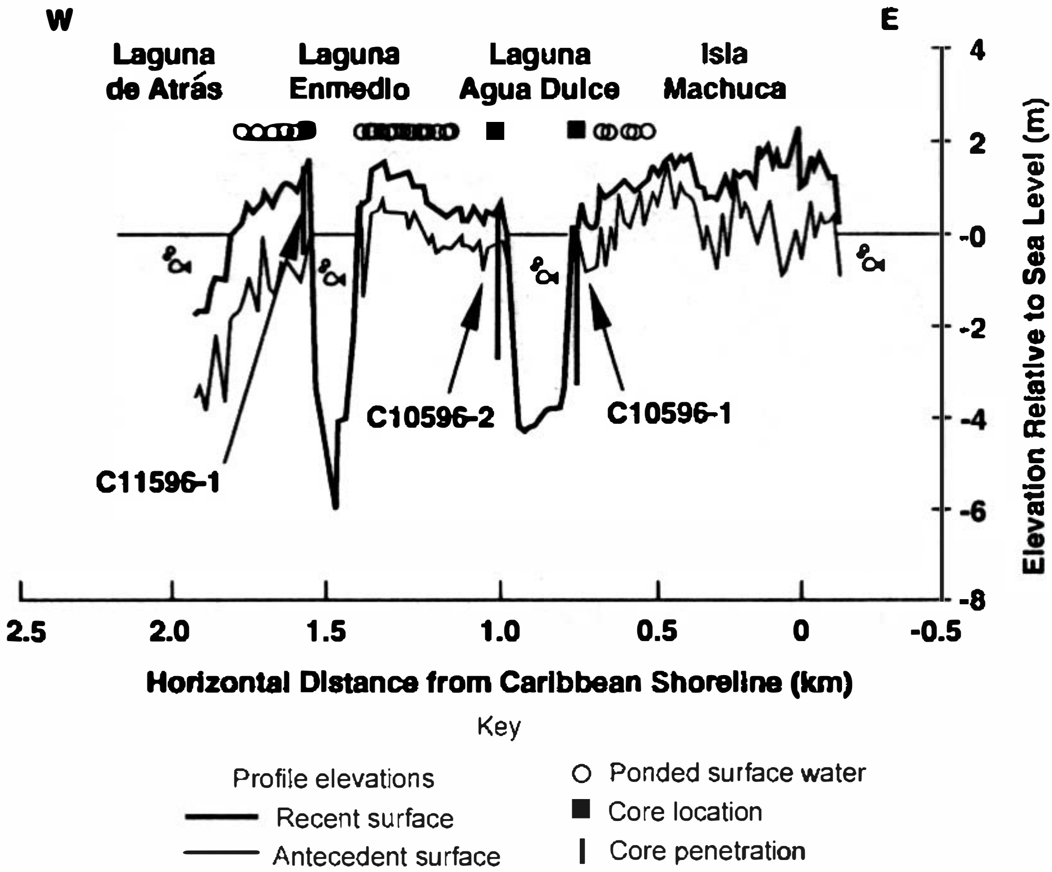

Fig. 6. Profiles of local surface relief and antecedent topography obtained along transect shown in Fig. 4. Data are uncorrected for operator errors introduced during survey. Local relief reflects subtle (<1m) ridge and swale topography present in both recent and antecedent surfaces. Frequency of ponded surface water observations increase towards the western side of each island, as well as towards the western boundary of the transect. Datum is water level height in lagoons or Caribbean Sea. Sediment core logs are shown in Fig. 8.

Stratigraphy and sequence of events: Once the vertical succession of major sediment types was established, a stratigraphic cross-section was constructed by plotting the stratigraphic succession present in each core along the transect line at the appropriate location and elevation. By combining the geomorphic, sedimentologic, and stratigraphic information it was possible to construct a conceptual model of coastal evolution for the Río Colorado area. Additional sediment samples were then selected for radiocarbon analysis to: 1) assign absolute ages to the depositional settings represented by the sediment succession and 2) provide constraints on regional Holocene sea-level history following the methods described by Pirazzoli (1991). Finally, comparisons between the data obtained during this study and relevant literature provided the information necessary to evaluate this study's null hypothesis.

RESULTS

Selection of tansect location and survey data: Using a Magellan 5 000 Global Positioning System, our transect site was established at 10°49.39' N latitude and 83°49.46' W longitude (Fig. 4). The survey was initiated at the Caribbean shoreline and extended ~2 km

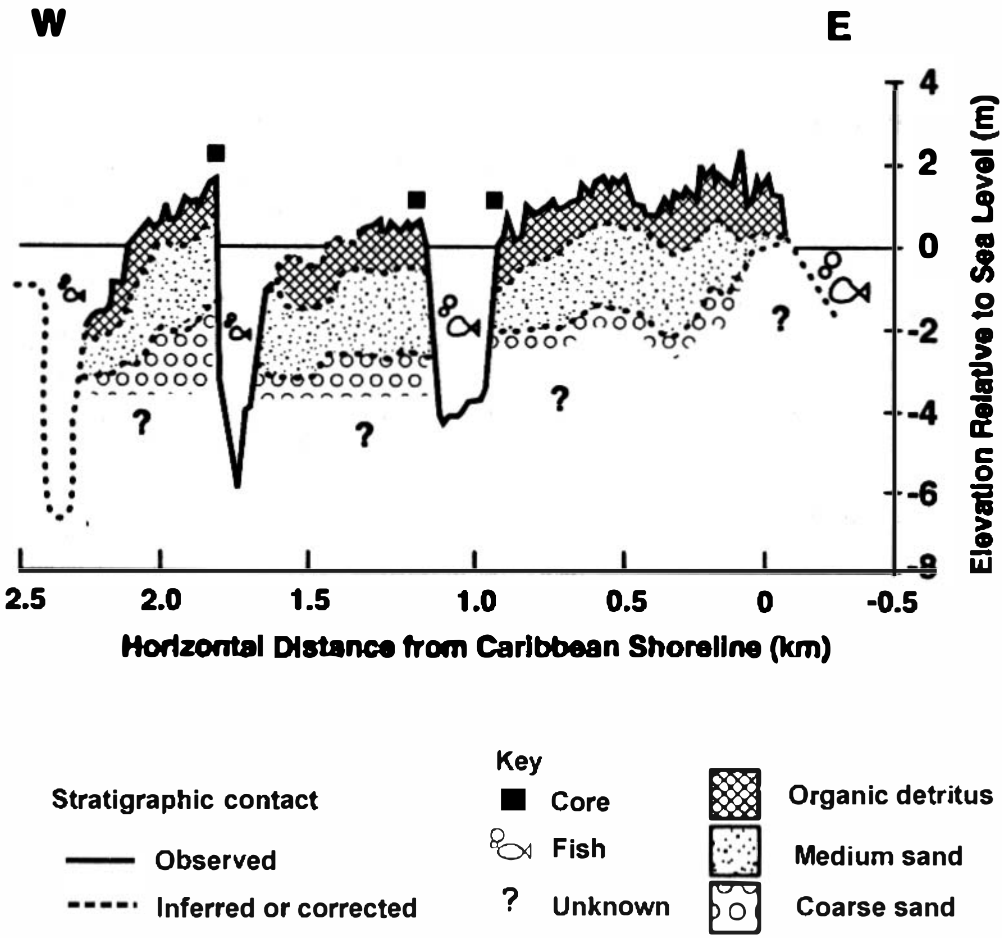

Fig. 7. Profile of local surface relief and antecedent topography adjusted using local ponded surface water elevations (Fig. 6) as a common vertical datum (method of adjustment described in text). Fining-upwards sediment succession and stratigraphy based upon three sediment probe and core data (Fig. 8).

into the coastal plain along an average bearing of 270°. The survey was successful at obtaining elevations across three islands and two lagoons (Fig. 4). The profile of surface relief, antecedent topography, and lagoon bathymetry was constructed using ~200 survey station data points (Fig. 6). However, a comparison of the profile with field notes and aerial photography indicated station elevations systematically increased over the length of each island transect. This error was probably introduced by the hand-level operator's tendency to over estimate the elevation of the stadia rod at each station. The location and depth of ponded surface water was therefore used to generate an *adjusted profile* (Fig. 7). The adjusted profile was constructed by assuming all surface water-level elevations were equivalent and therefore represent an accurate vertical datum. This is a reasonable assumption because: 1) the surficial sediment is highly permeable and 2) the observations were obtained during the dry season, minimizing the probability of these features being temporary, poorly drained topographic depressions in the coastal plain. Comparisons were again made with field notes and aerial photography to ensure the adjusted profile accurately reflected the area's geomorphology. The distance separating surface elevations from antecedent elevations was kept intact during the construction of the adjusted profile.

The survey data indicate the topography of each island is asymmetric. This asymmetry is created by the presence of an elevated seaward (eastern) margin upon which a well-developed

TABLE I

Sedimentological data from three cores (Fig. 8) collected along Rio Colorado coastal plain transect (Figs. 4 and 6)

Sediment Type	Number of analyses	Grain-Size Data					Organic Matter Content (%)
		Gravel (%)	Sand (%)	Sand Mean Φ	Sand Verbal	Mud (%)	
Organic-rich muddy sand	13	tr	89.7 (± 5.4)	1.71 (± 0.1)	medium	10.1 (± 5.4)	11.6 (± 8.2)
Medium-grained sand	27	tr	98.3 (± 1.4)	1.57 (± 0.2)	medium	1.6 (± 1.4)	2.3 (± 0.8)
Coarse-grained sand	5	tr	98.7 (± 0.8)	1.02 (± 0.2)	medium to coarse	1.1 (± 0.7)	2.2 (± 0.3)

tr = trace content (<1.0%); standard deviation shown in parentheses bellow mean occurrence of gravel-, sand-, and mud-size fractions. Verbal size-class of sand fraction assigned using Udden-Wentworth grain-size scale.

ridge and swale relief is superimposed. There is also a systematic landward (west) reduction in the average elevation of each island (Fig. 7). For example, ridge and swale elevations were measured at ~2 m on Isla Machuca's eastern shoreline while the western shoreline is only ~0.25 m above lagoon-water level. In contrast, many of the swales behind the eastern shoreline the island west of Laguna Enmedio (Fig. 6) are submerged. This island's western shoreline is now ~1.5 m *below* lagoon-water level. An attempt to survey the mainland shoreline west of Laguna de Atrás was aborted because the seaward shoreline is ~1.0 m below lagoon-water level.

Probing revealed the antecedent topography of each island is generally similar to the surface with respect to the westward decrease in elevation and local relief (Fig. 6). The bathymetric surveys of Laguna Agua Dulce and Laguna Enmedio are also consistent with the east-to-west trends in recent and antecedent elevation (Fig. 6). The sediment-water interface in Laguna Agua Dulce averaged ~4 m below water level while the substrate in Laguna Enmedio was frequently recorded at ~6 m below water level. No data were obtained from Laguna de Atrás due to time constraints.

Stratigraphy: Three sediment cores were successfully recovered and three distinct sediment types are present in each core: 1) basal medium- to coarse-grained sand, 2) medium-grained sand, and 3) surficial organic-rich detritus (Fig. 8 and Table 1). All sediment samples contain trace amounts (<1wt%) of gravel-sized material that is, in part, a consequence of the absence of skeletal material. Binocular inspection of these samples indicate most grains are subangular to subrounded, although grains were identified in every sample which span the entire range of textural roundness. Most (>50%) of the sand grains are spherical, although non-spherical lath-shaped grains are also common. Opaque, translucent, and transparent sand grains were identified in each sample. No attempt was made to conduct a mineralogical assessment of the subsurface sediments although these data will clearly be useful in subsequent sedimentological work (i.e. source evaluation). The mean occurrence of sand-sized material in the coarse- and medium-grained sediment types is nearly equivalent at ~98wt% (Table 1). These textural and compositional features are similar to modern backshore and foreshore sediment, although some skeletal material was present on the modern Caribbean sandy shoreline. Mean sand content in the surficial organic-rich layer is ~90wt%.

The mean sand-size of the basal sediment type is 1.02 phi, which lies on the Udden-Wentworth grain-size class boundary separating coarse and medium sand. Mean mud and organic content are 1.1wt% and 2.2wt%, respectively. The thickness of this sediment type could not be determined because none of the cores penetrated the entire layer.

Analysis of samples obtained from the medium-grained sandy sediment type generated a mean grain-size of 1.57 phi. Mean mud and

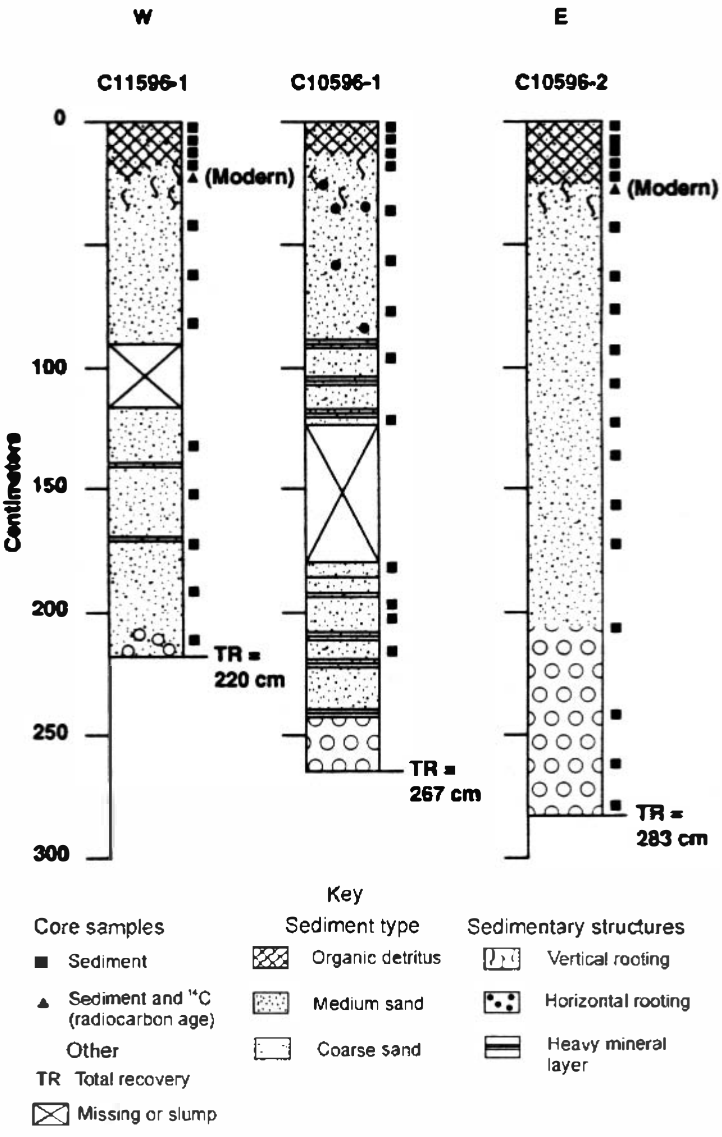

Fig. 8. Vertical success of sedimentary features identified in three cores obtained along tranect (Figs. 4 and 6). Two radiocarbon samples collected from base of organic-rich surface sediment yielded modern ages. Depth measurements uncorrected for sediment compaction, which occurred primarily during core penetration through organic-rich surface layer.

organic content is low and similar to the underlying, coarse-grained sediment type at 1.6wt% and 2.3wt%, respectively. However, in addition to the finer sand-size mean, this sediment type also contains faint visual evidence of horizontal layering, which was confirmed by a preferred parting along horizontal surfaces when air-dried samples were subjected to rupture. It also is distinguishable from the basal layer by the presence of very distinct lamina of heavy mineral (dark grains) concentrations (Fig. 8). The lamina are generally grouped into layers ~2 cm to 4 cm thick. Core 10596-2, obtained along the western margin of Isla Machuca (Fig. 6), contained no heavy mineral layering. Uncompacted sediment thickness ranged between 1.5 m and 2 m, which we suspect is probably a reliable estimate of true sediment thickness since nearly all of the compaction occurred within the surficial organic-rich layer. The contact between the two sandy sediment types was gradational over an interval of ~15 cm.

The surficial layer of organic-rich detritus contains a mean sand content of ~90wt% and a mean sand-size of 1.71 phi. Hence, the grain-size of the sand fraction decreases up section within three sediment types encountered along the transect. Mud (~10wt%) and organic (~11.5wt%) content is an order of magnitude higher in samples obtained from the surficial sediment type in comparison to the two underlying sandy sediment types (Table 1). The organic component of this layer consists of *in situ* fibrous root material and plant detritus. The contact between the surficial organic-rich sediment and underlying sandy layer is gradational and clearly an artifact of wet forest and palm swamp colonization of an antecedent exposure surface. Although the thickness of this surficial sediment is shown to average ~30 cm in the core logs (Fig. 8), probing indicates the thickness of this layer averages ~1 m (Fig. 6). This reduction in thickness occurred as the Cobra™ pneumatic hammer pounded the core tube through the loosely compacted organic-rich surficial sediment. It is for this reason that core penetration and total recovery are not equivalent (Fig. 8). At select stations along the seaward-most portion of the transect the surface of the antecedent exposure surface is not buried by recent forest plant material (Fig. 6). The thickness of the surficial organic-rich layer, while averaging ~1m, is therefore quite variable and in part a function of the antecedent topographic relief of late Quaternary coastal plain sands.

Unfortunately, fossils were not identified in any of the cores. This precluded our ability to determine the absolute agc of the three sediments types using radiocarbon methods and eliminated our ability to place an absolute age on the various stages of coastal evolution. Two samples, obtained from the base of the surficial organic-rich sediment layer in cores 11596-1 and 10596-2 (Fig. 8), were selected for radiocarbon analysis. These two cores were obtained from the seaward margin of the two inner-most islands (Fig. 6). Both islands host geomorphic features indicative of an open ocean paleo-shoreline, including: 1) asymmetrical surface relief and antecedent topography which decreases towards the mainland shoreline (Fig. 6 and 7) and 2) straight seaward facing recent shorelines with distinct ridge and swale topography (Fig. 4). It was therefore postulated the radiocarbon ages generated from the samples could provide: 1) evidence for coastal progradation associated with the formation of the distinct coastal alignments and 2) data to constrain regional sea-level history. Both samples however, yielded *modern* ages (Fig. 8) and were therefore of no use in validating the coastal progradation hypothesis or constraining regional sea-level history. The ages simply attested to the rapid turnover of organic matter from the O horizon of tropical soils.

DISCUSSION

The north Caribbean coast of Costa Rica is receiving abundant fluvial discharge from Rio Colorado, a braided river system which has formed in response to: 1) exceptionally wet tropical climatic conditions and 2) the presence of unconsolidated late Quaternary alluvial and marine sands on the coastal plain through which it meanders. Despite abundant fluvial discharge, the regional wave climate has been sufficient to inhibit delta-plain progradation into the Caribbean Sea. Instead, a relatively straight coastal plain consisting of fluvial-deltaic sands capped by wet forest and palm swamp detritus has formed. This fining-upwards sediment succession has been deposited along the front and margins of the active Rio Colorado river mouth (Fig. 4). A similar geomorphology can be observed at Rio Tortuguero (Fig. 5). Both active river mouths have been displace northward by longshore currents, attesting to the significant effects of water waves on coastal geomorphology. Hence, fluvial sedimentation has had little effect on shoreline geometry; the accumulation of terrigenous sediment has been restricted to a narrow, coast parallel sand sheet.

These geomorphic, sedimentologic, and stratigraphic features are characteristic of wave-dominated deltaic plains which develop primarily along stable continental shelves (Coleman and Wright 1975, Galloway and Hobday 1983). The westward decrease in elevation of surface relief and antecedent topog-

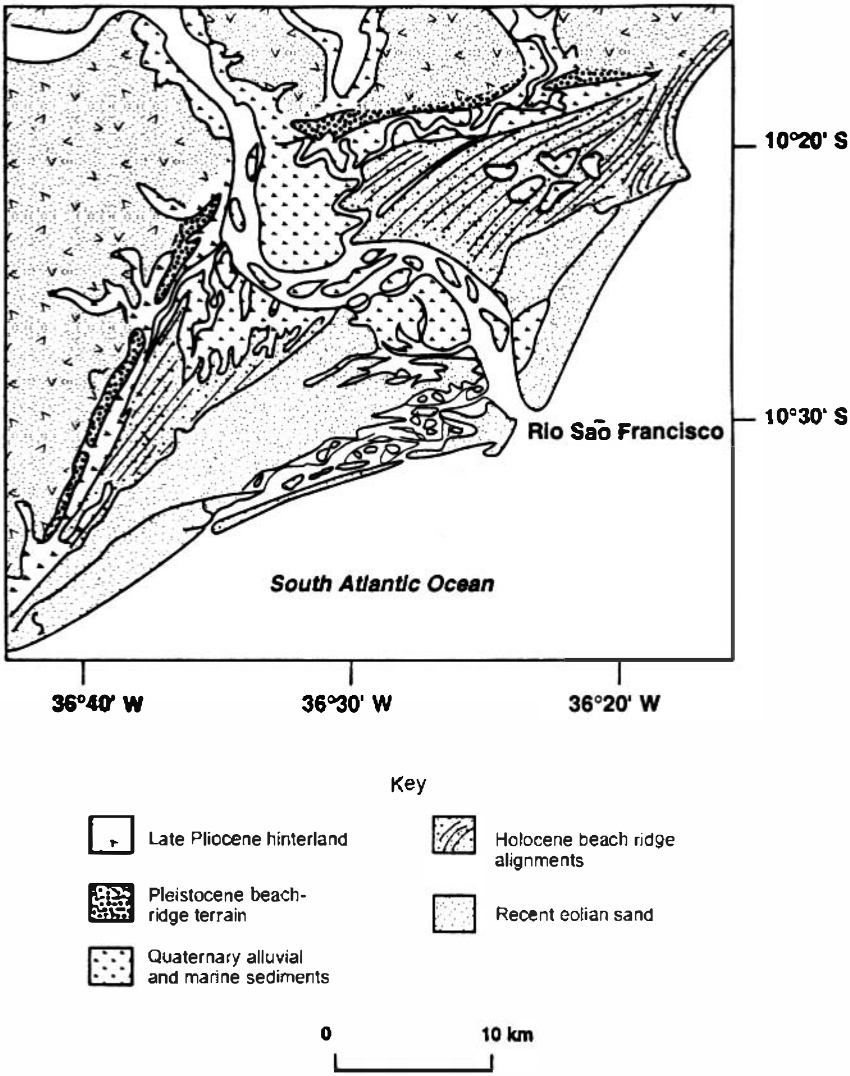

Fig. 9. Geologic map of Brazil's Rio São Francisco wave-dominated delta plain. Geomorphology, including distribution and elevation of Holocene beach ridge alignments, is analogous to Rio Colorado coastal plain (Fig. 4) and used is this study to suggest a common origin and tectonic setting. Redrawn and simplified from Dominguez *et al.* (1987).

raphy at Río Colorado provides additional support for this study's aseismic, passive margin hypothesis. This topographic gradient reflects a relative rise in base-level which, we postulate, formed during fluvial-deltaic progradation into a basin affected solely by global eustatic sea-level rise. Each younger, more seaward island or lagoon therefore established an equilibrium profile slightly higher than the previous one.

The geologic features on the Río Colorado coastal plain (Fig. 6) are analogous to Rio São Francisco (Fig. 9; Dominguez *et al.* 1987) as both consist of a low-relief sandy coastal plain with beach ridge alignments generated during fluvial progradation into a wave-dominated shelf sea. Even the shore-normal elevation gradient is present at Rio São Francisco (Domínguez *et al.* 1987), although topography increases as a function of age at this location.

This topographic distinction is logically explained by the difference in late Holocene sea-level change. Eastern Brazil's continental margin has been subjected to a relative *fall* in sea level over the past 5 000 yrs. As a consequence, the average elevation of the coastal alignments has *decreased* towards the present shoreline. Even the active river mouth of Río São Francisco has been displaced by strong longshore circulation, further attesting to the analogous conditions of fluvial-deltaic sedimentation and dominant wave climate.

The data obtained during this pilot study are sufficient to reject the null hypothesis and accept the contrary; the north Caribbean coastal plain of Costa Rica has evolved without significant tectonic influences. The presence of a passive continental margin adjacent to shorelines where tectonic uplift has been well documented is, at least in part, attributable to the East Nicoya Fracture Zone and North Panama Deformed Belt. These features have restricted the effects of seismic activity to the southern region of Costa Rica's Caribbean coastal plain.

While there was insufficient radiocarbon material obtained during our study to establish a relative sea-level history or assign absolute ages to the events represented by each sediment layer, the presence of Rio Colorado's wave-dominated geomorphology and that of Río Tortuguero could only have evolved along a passive continental margin setting, like that documented for the nearly identical Río São Francisco delta plain of eastern Brazil (Fig. 6, 7 and 9).

Our data are also not sufficiently detailed to explain the presence of numerous coast-parallel lagoons on the Río Colorado coastal plain or those which exist in other regions of the north Caribbean coastline of Costa Rica. These features were undoubtably generated by variations in sediment supply, wave energy, and sea-level rise. We suspect these variations occurred in response to centennial- or millennial-scale climate fluctuations now well documented to have affected areas throughout the world during the late Quaternary (Bond *et al.* 1993; Clark *et al.* 1995, Dowdeswell *et al.* 1995; and references cited therein).

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RESUMEN

Información geomorfológica, sedimentológica y estratigráfica obtenida en la región norte de la costa Caribe de Costa Rica sugiere que el delta del río Colorado es dominado por olas formado en una márgen continental pasiva. Esta situación costera es significativamente diferente del Caribe sur y Pacifico, donde los rasgos geomorfológicos y líticos son indicativos de una márgen continental sísmicamente activa. La distintiva historia asísmica y la geomorfología de márgen pasiva de las llanuras costeras del Caribe norte parecen estar controladas por la presencia de rasgos tectónicos (i.e., la Zona de Fractura de Nicoya Este) que desconecta la región de áreas adyacentes tectónicamente activas. Aunque la información recabada durante este estudio piloto, incluye dos dataciones radiométricas con carbono de la base del mantillo del bosque anegado y sedimentos del pantano de palmas, no fueron suficientes para documentar el cambio relativo del mar, confirmando la situación asísmica de la región. Un examen más completo de la estratigrafía del Cuaternario Tardío de la márgen continental va a ayudar a resolver problemas neotectónicos y reolíticos, que han sido enigmáticos en ausencia de un datum estable.

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