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Frequent Non-Storm Washover of Barrier Islands, Pacific Coast of Colombia

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ABSTRACT

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Barrier islands of the Pacific coast of Colombia repeatedly experience severe washover even when breaking waves in the eastern Pacific are low and onshore winds are calm. On the barrier island of El Choncho, recent non-storm washover events have breached a new inlet, caused rapid beach retreat, destroyed a shoreline protection structure, and flooded a small village of indigenous people so frequently that it had to be relocated. Barrier washover may be augmented by lowered land elevations associated with earthquake-induced subsidence or long-term beach retreat, but temporally it is most closely associated with a 20 to 30 cm regional increase in sea level caused by El Niño. The contradiction of a tranquil tropical island scene simultaneously disturbed by hostile turbulent washover may be unique at present, but it exemplifies how coastal plains throughout the world would be affected if sea level were to rise rapidly as a result of global warming.

ADDITIONAL INDEX WORDS: *Barrier islands, Pacific coast, Colombia, El Niño.*

INTRODUCTION

Washover is a common coastal process that occurs when abnormally high water levels and waves of oceans, estuaries, or lagoons exceed the elevations of adjacent land surfaces. Because this global phenomenon is usually associated with storms, the accepted geological definitions and descriptions of washover specifically state that it is a storm related phenomenon (BATES and JACKSON, 1987; SWARTZ, 1982). In this paper we document frequent intense washover of barrier islands along the Pacific coast of Colombia (Figure 1) during meterological quiescent periods when ocean waves are less than 1 m high and onshore wind speed is less than 2 km/hr (Figure 2A). We also present evidence pertaining to the possible causes of non-storm washover, and discuss the implications for future habitation of the barrier islands.

The Pacific Coast of Colombia is near the zone of subduction between the Nazca and South American plates and because of this tectonic setting, earthquakes of at least magnitude 7 and associated tsunamis are not rare (HERD *et al.,* 1981). The coastal region also is characterized by a high tide range (4 m), moderate wave energy (mean wave height of 1 m), and high annual rainfall (6 m/yr) that produces lush, dense vegetation including extensive mangrove swamps and tropical rain forests (WEST, 1957).

Our study focuses on the San Juan delta and associated barrier islands that form the seaward margin of the delta complex (Figure 1). The barrier islands typically lack eolian sand dunes because the high rainfall and rapid growth of vegetation prevents sand mobilization. Consequently the highest elevations on these barriers (≈1m) coincide with the berm crest or accumulations of washover sand in the backbeach (Figure 3).

FIELD OBSERVATIONS

Prolonged intense washover of El Choncho was observed twice-daily during spring high tides in May and August, 1997 (Figures 4 and 5). Initial flooding of the barrier was minor because percolation into unsaturated sand prevented landward penetration of washover waves. After the ground became saturated and the water table rose, then the full force of the surging waves of the deep-water swell (estimated 0.75 m height and 4 sec period) was directed into the village of wooden houses. The longest continuous period of observed washover was in August when flooding at high tide occurred during 7 consecutive days.

Repeated inundation of the barrier island and associated village came from both oceanic washover flowing landward down gradient (Figure 2A) and static water levels without waves (Figure 2B) rising in the adjacent estero. Prior to their destruction or removal, houses nearest the beach were elevated on stilts, whereas houses nearest the estero were built on the land surface with dirt floors. These location-dependent types of construction suggest that minor flooding was expected near the beach, but frequent flooding was not previously experienced near the estero. Surging waves of the washover were so strong that a low bulkhead constructed of timbers (Figure 2A) was destroyed. Flooding was so severe (Figure 2B) that the remaining houses were moved off the

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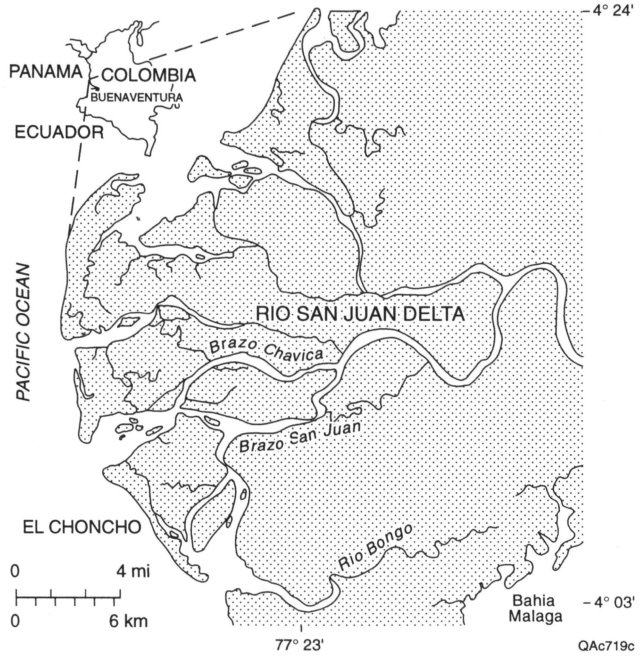

Figure 1. Locations in Colombia, S. A. of the San Juan delta, associated barrier islands, including El Choncho, and Buenaventura, where the tide gauge is located.

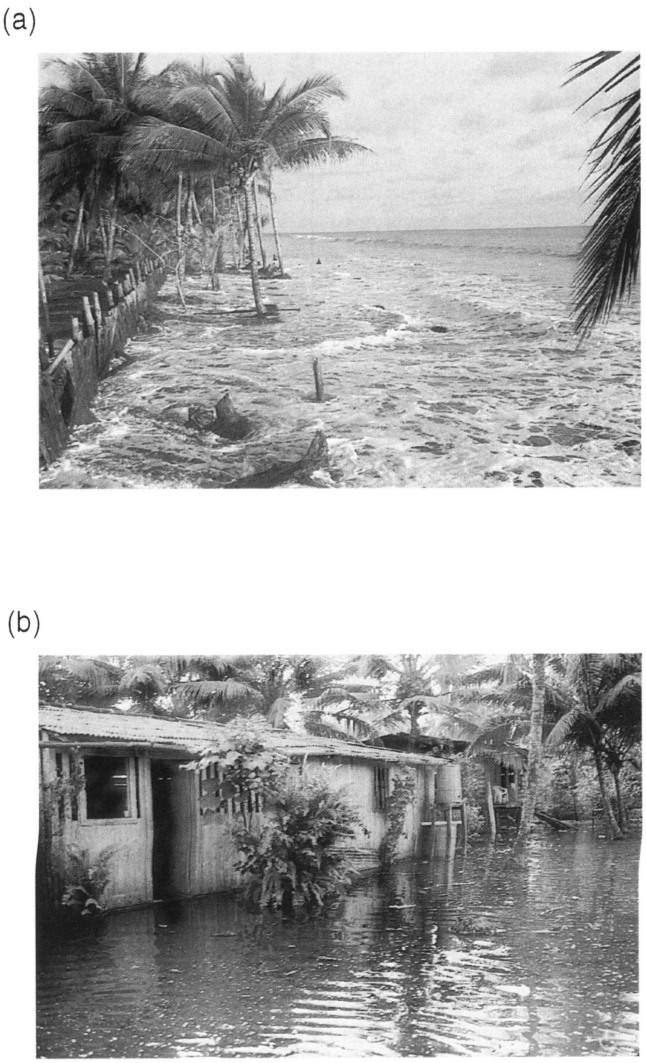

Figure 2. Photographs of non-storm washover at the caserio on El Choncho. Note the lack of high waves in the Pacific (A) or strong onshore wind. Frequent non-storm washover has caused such rapid beach retreat and frequent flooding (B) that recently the small village was relocated.

barrier island and onto a higher beachridge complex landward of the estero.

During a spring-tide washover event in July 1996, a new inlet was breached across El Choncho at its narrowest position between the Pacific and the estero. The inlet, which by May 1997 had rapidly enlarged to be 50 m wide and 10 m deep, has altered water circulation patterns in the estero and increased beach erosion at El Choncho by intercepting some of the sand that previously was transported uninterrupted along the beach and shoreface. Before the new inlet opened, floor-tidal waters in the estero flowed to the north, but now they flow to the south on the incoming tide, and sand that formerly was transported southward along the beach by littoral currents is being diverted into the estero and deposited on the updrift (northern) side of the inlet. High current velocities near the inlet are destroying fringing mangroves and removing large volumes of sand from the barrier and associated littoral system.

POSSIBLE CAUSES OF WASHOVER

Subsidence

There is no direct evidence of recent coastal subsidence along the barrier islands of the San Juan delta and there are no permanent bench marks in the region that can be releveled to verify tectonic subsidence. The only accurate elevation reference in the region is the tide gauge at Buenaventura, a port city which is located about 70 km southeast of the San Juan delta (Figure 1). AUBREY *et al.* (1988) analyzed water level records at Buenaventura between 1941 and 1969 and concluded that the Pacific coast of Colombia near Buenaventura is being submerged by a relative rise in sea level of about 1.0 mm/yr. Subsequent water-level records at the same gauge (University of Hawaii, Internet communication, 1997) confirm the systematic gradual increase in relative sea level, which is about the same rate (1.2 mm/yr) as reported for the average eustatic rise in sea level (GORNITZ and LEBEDEFF, 1987). Regardless of its cause, the regional rate of submergence is too slow to explain the historical land-sea relationships inferred by the washover events and accelerated beach erosion in the San Juan delta region.

Segments of the barrier islands that front the San Juan delta may have subsided rapidly as a result of recent major earthquakes, such as those in 1979 and 1991 that had magnitudes of 8 and 7 respectively (HERD *et al.,* 1981; MEYER *et al.,* 1992). However after the 1979 earthquake, field obser-

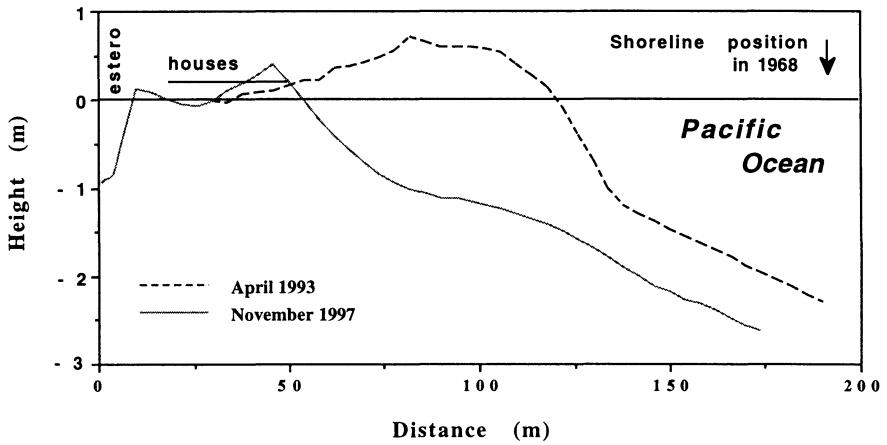

Figure 3. Topographic profiles across El Choncho illustrating island morphology, rapid beach retreat, and former positions of houses in the caserio. Dense stands of tall (20 m) mangroves and palm trees cover the island.

vations by HERD *et al.* (1981) showed that the arc of subsidence only extended about 200 km north of Tumaco and did not include the San Juan delta region. After the 1991 earthquake, which had an epicenter just north of the San Juan delta (MEYER *et al.*, 1992), island residents observed that some wooden houses constructed on stilts sank as much as 80 cm, cracks opened in the land surface, and the flow of fresh-water wells diminished. These post-quake observations are probably related to temporary liquefaction of the sandy sediments of the barrier core and they are not unequivocal evidence of lowered surface elevations. Perhaps the most reliable indicator of local land subsidence after the 1991 earthquake is the frequency of washover and flooding, which local residents stated increased from about 3 to 17 times per year (CORREA *et al.*, 1995).

The recent washover at El Choncho is not likely a result of non-tectonic subsidence related to dewatering and sediment compaction. This is because the San Juan delta is a sand-rich system that lacks abundant organics and thick pro-delta mud deposits that are requisite conditions for substantial compactional subsidence.

Beach Retreat

Beach erosion of the barrier islands is widespread along the Pacific coast of Colombia north of Buenaventura (GONZALEZ *et al.*, 1990; MARTINEZ *et al.*, 1995). In the past few decades, the central segment of El Choncho has retreated as much as 100 m at average rates of about 4 m/yr (NEAL and GAONZALEZ, 1990; CORREA *et al.*, 1995). Repeated washover of the barriers may be caused by highest spring tides encountering progressively lower elevations at the Pacific shore as the beaches retreat. Long-term beach retreat has narrowed the core of the barrier island (Figure 3) destroying citrus groves, a coconut plantation, a soccer field, and houses that were built at surface elevations about 0.5 m above flood levels of the highest spring tides. Beach retreat has accelerated as some of the barrier sand is transferred landward from

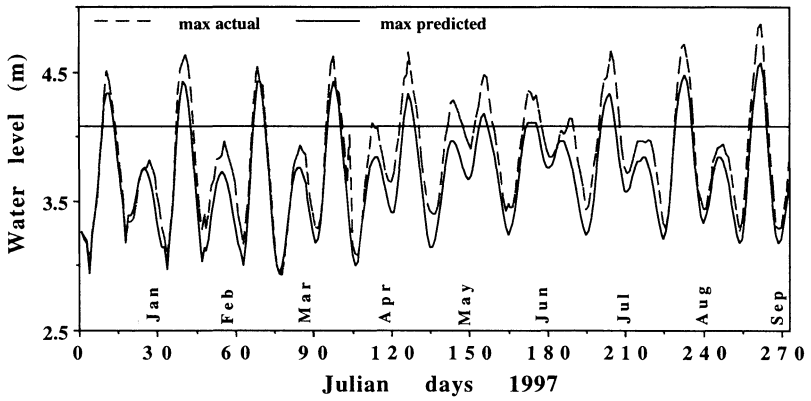

Figure 4. Actual and predicted highest daily water levels at the Buenaventura tide gauge between January and September, 1997. Data from the Ministerio del Medio Ambiente. Buenaventura is shown in figure 1.

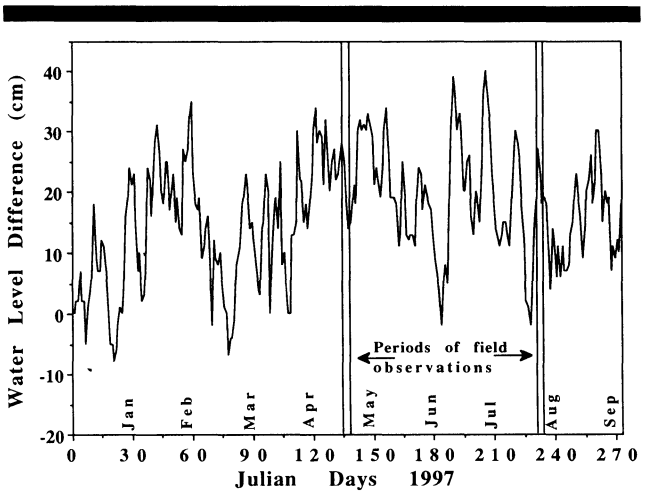

Figure 5. Difference between actual and predicted sea levels in the eastern Pacific near El Choncho during August based on records at the Buenaventura tide gauge. Data from Ministerio del Medio Ambiente.

the beach, but the berm crest does not aggrade above the level of spring high tides because beach retreat is so rapid.

In this remote region, long-term diminished influx of littoral sand as a result of human activities would be difficult to explain because there are no engineering projects either in the river basin or along the coast that would intercept sand and either prevent it from reaching the beach or being transported along the Pacific shore. Rainfall in the drainage basin is abundant and there continues to be an ample supply of sand to the littoral system at the mouths of the distributaries as demonstrated by the accumulations of sand on the adjacent beaches and ebb tidal-deltas (CORREA *et al.*, 1995).

Increased Sea Level

When barrier islands of western Colombia are innundated, water levels in the eastern Pacific may be elevated by riverine flooding, a tsunamis, or some other phenomenon such as El Niño. Field observations show that periods when major distributaries of the San Juan River are near bankfull correspond with high tide phases in the Pacific rather than with periods of abnormally high fluvial discharge. This relationship is also confirmed by the fact that washover and flooding of El Choncho barrier island was cyclical and primarily from the Pacific, not from the estero. During flooding events, water levels in the estero were always lower than those in the Pacific. Partial flooding of the village from the landward side of the barrier may be related to opening of the new inlet, which now allows water on the flood tide to rise more rapidly in the estero.

A train of low amplitude, long-period waves, such as a tsunamis, could also increase ocean water levels causing non-storm barrier washover and coastal flooding. However the waves impinging on the San Juan delta did not have characteristics of a tsunami; they were more frequent (4 sec period) and numerous than expected with a tsunami, they did not have a noticeable spectral distribution (wave heights of 0.75 m were relatively uniform), and they coincided with the predicted astronomical high tide.

Another long-period wave phenomenon that can raise ocean levels for prolonged periods is El Niño. The intensities of these events are classified on the basis of anomalously high sea-surface temperatures (QUINN *et al.*, 1987), which are manifested as abnormally high water levels. The National Oceanic and Atmospheric Administration and affiliated groups use satellite altimetry to generate maps that depict global sea-level variations from the expected mean ocean topography every 10-days. The maps that coincide in time with our field observations show abnormally high water levels adjacent to the northwest coast of South America (Figure 6). When frequent washover was observed on the barrier islands, equatorial waters in the eastern Pacific were 3° to 4°C warmer and 20 to 30 cm higher than normal. The anomalous height of the sea surface in the eastern Pacific measured by satellite altimetry is confirmed by the greater than predicted tide measurements at Buenaventura (compare Figures 5 and 6).

DISCUSSION

Non-storm washover is not restricted to sparsely vegetated segments of El Choncho island or just to barriers of the San Juan delta. Reports of recent destructive washover at Soldado Island south of Buenaventura confirm that it is a regional phenomenon and that washover intensity increased to the south where sea levels were higher. Apparently El Choncho is washed over when combined astronomical and atmospheric forcing produce water levels greater than 4.1 m above the local datum at Buenaventura (Figure 4). These conditions persisted for 4 to 7 days each month in 1997 coinciding with the spring high tides, which were increased by El Niño conditions. Considering the available data, we believe that El Niño is the primary reason that El Choncho is experiencing severe non-storm washover, but we are unable to rule out the possibility that flooding is augmented by subsidence caused by the 1991 earthquake.

Prior studies of coastal inundation in northwestern South America related to El Niño have focused on Holocene events that caused deep overbank flooding of rivers (WELLS, 1990) and possible increased sediment supply that contributed to the construction of beach ridges at the Pacific shore (SANDWEISS, 1986). The 1997–98 El Niño conditions, which were comparable in strength to the very strong 1982–83 event, has caused short-term coastal degradation rather than coastal construction and it is doubtful if there will be increased volumes of sand transported by the rivers associated with this recent El Niño event that will eventually promote beach stabilization or progradation along the Pacific coast of northern South America.

CONCLUSIONS

Barrier islands typically do not form along tectonically active coasts because the rate of uplift or subsidence is much faster than the rate of barrier island formation. Consequently, the recent discovery of a chain of barrier islands in Colombia provides an unparalleled opportunity to study the re-

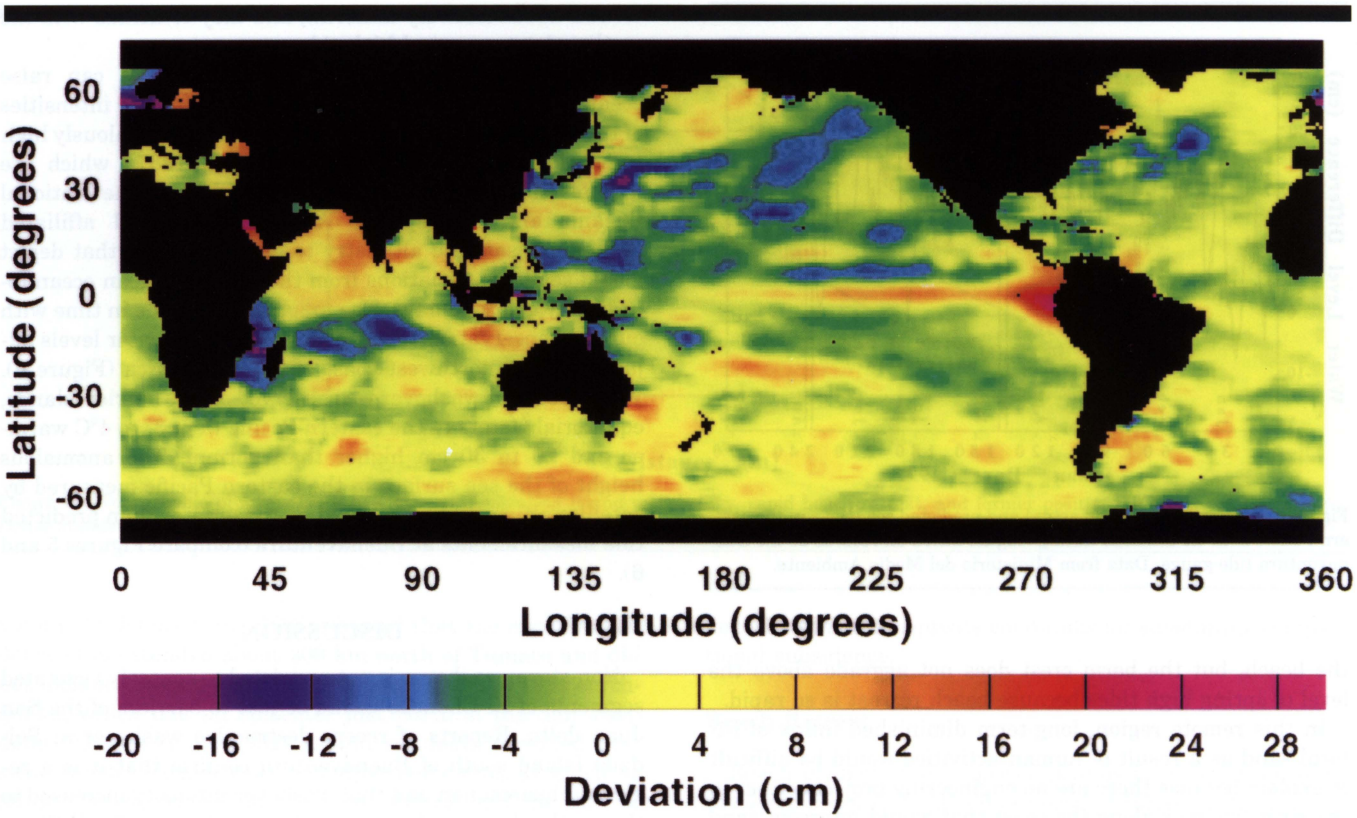

Figure 6. Global sea-surface anomalies for the ten-day period beginning May 5, 1997. Satellite altimetry measurements are displayed as deviations from expected mean topography. El Niño effects caused sea level near the coast of Colombia to be as much as 28 cm higher than expected. Map image of sea-surface anomalies was provided by the Center for Space Research, The University of Texas at Austin.

sponse of barriers to physical agents at or near their upper limits. Elevated water of the Pacific Ocean associated with El Niño events persist much longer than winter storms or tropical cyclones that are responsible for most of the geological work and destruction of other barrier islands of the world. These relatively frequent coastal disturbances coupled with the high tide range are conditions that cannot be easily investigated elsewhere. Coastal geological models that incorporate morphological and sedimentological characteristics not currently included in existing models will greatly extend the understanding of these modern barriers and also offer clues for recognizing similar geological settings preserved in the rock record of leading-edge coasts.

This study documents non-storm washover of barrier islands so severe that it is capable of physical destruction and social disruption similar to that resulting from major storms. The Pacific coast of Colombia does not experience major storms caused by meterological forces that ravage other coastal regions. As a consequence of these calm, presumably predictable weather patterns, most of the villages on the barrier islands are built at extremely low elevations because flooding is not expected. Therefore the indigenous population is totally unprepared for prolonged flooding regardless of its cause.

Washover and flooding are nature's response to a relative rise in sea level that is faster than the rate of coastal plain aggradation. Rapid erosion and narrowing of the barrier island at El Choncho, breaching of a new inlet, and inundation of areas that either did not flood or flooded only rarely, illustrates how fringing barrier islands of the world will be affected by warming of the atmosphere and concomitant thermal expansion of ocean waters that are predicted for the next century.

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