Rapid Formation of Large Coastal Sand Bodies after Emplacement of Magdalena River Jetties, Northern Colombia

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ABSTRACT / The Magdalena River is noted for its high discharge of river sediment and its importance as the sediment source for a large delta complex and downdrift coastal sand bodies. The emplacement of jetties, completed in 1935 to stabilize the river mouth, contributed to major changes in the downstream coastal sand bodies. The western delta front retreated an average 65 m/yr. Puerto Colombia spit detached and migrated toward Puerto Colombia at rates of 230–430 m/yr, ultimately running into the town's quay and port facility. Galerazamba spit alternately elongated and shortened over the short term, leading to the destruction or damage of coastal town sites. Isla Cascajo acted as a significant sand trap with nearly 12 km² of accretion over a 47-year period. Sand is now bypassing the tombolo, and the accretion zone continues migrating southwest. The small Punta Canaos spit also has shown significant accretion since 1974. The changes imply high rates of sediment transport; furthermore their growth is probably dependent on jetty-caused alterations of wave patterns, causing remobilization of shelf sands as well as delta-derived sand.

Understanding sand body evolution and behavior is important to future development of the northern Colombia coast. Placement of port facilities, recreational beaches, tourist villages, and related support facilities on these sand bodies, as well as utilizing the sand bodies for aggregate, beach nourishment sands for other areas, or heavy mineral resources will require significant planning.

Introduction

The Magdalena River system is the major drainage of the interior of Colombia's cordillera with a length of 1,500 km and drainage basin area of 256,622 km^2 (Koopmans 1971). Milliman and Meade (1983) rank the Magdalena River as having the sixth largest river-sediment discharge in the world at 2.2×10^8 tons/yr. Koopmans (1971) reported an average annual sediment transport of 1.25×10^8 m^3 and estimated that 30×10^6 m^3 of sediment are deposited near the river mouth annually.

The result of the high sediment delivery is a delta complex that has grown seaward and laterally during Pleistocene–Holocene time and that is influenced by neotectonics (Hoover and Bebout 1984). Much of the sediment has crossed the narrow shelf and moved down a channel–canyon complex to form the well-known Magdalena Fan (Kolla and others 1984; Hoover and Bebout 1984; Shepard 1973; Shepard and others 1967).

While the marine sediments have received significant attention, little information exists on the river's contribution to the inner shelf (Vernette 1986) and littoral zone (Correa 1984; Vernette and others 1984). The purpose of this article is to examine the recent historic evolution of the southwestern delta front and four related coastal sand bodies between the delta and Cartagena, approximately 110 km to the southwest and the present down-drift terminus of sand derived from the Magdalena River (Fig. 1). In addition, the influence of sand body development by the construction of a major jetty system at the mouth of the river is considered from a sedimentologic and economic point of view.

Delta-Derived Sediment

Historic maps dating from the 18th century indicate that the mouth of the Magdalena River has migrated after initially infilling its estuary. Typically, the delta front has been asymmetric with the main distributary channel oriented to the west-southwest (Fig. 2). Most of the rivers entering the Caribbean west of Colombia's Sierra Nevada turn sharply to the west-southwest at their mouths and flow parallel to the shore behind barrier bars before entering the ocean. This response reflects the strong northeasterly wind orientation throughout the year (Colpuertos 1969), causing the persistent northeast-to-southwest longshore drift. Figure 2 indicates the position of the delta front in 1843 with large sand bodies defining the mouth of the distributary channel.

Delta-derived sand has been the primary sediment source for downdrift beaches and for large sand bodies (spits and tombolos) that have formed in the Holocene. The city of Cartagena dates from the 16th century and is located on a probable spit, and similar sand accumulations underlie Boca Grande and La Boquilla. The La Boquilla spit is not present on the maps of 1811 and 1864, apparently forming in the late 19th century. Coastal sands from the Magdalena River to Cartagena share similarities in mineralogy and texture.

Mud tectonics on the inner shelf (Vernette 1986) also may play a role in the formation or localization of sand bodies. A large spit is shown at Galerazamba on a map of 1811 and appeared on maps at least through 1864. The spit is unusual in that it is oriented nearly perpendicular to shore, rather than coming off the headland at an angle more parallel to the mainland. The Puerto Colombia spit, discussed below, had a similar orientation in 1947. In both cases, offshore uplift by mud diapir intrusions is suggested as the cause of shoaling that interrupted the drift pattern and resulted in spit formation at a high angle to the shoreline. Why these spits finally detach and migrate rapidly downdrift and onshore remains a question. In any case, such spits have been temporary, and they eventually break up and migrate, forming significant sand masses that continue moving to the southwest.

Destabilization of the Delta

The channel at the mouth of the Magdalena River was stabilized by a large jetty system completed in 1935. Rapid retreat of the "downstream" western delta front, now cut off from its sand supply, began immediately (Fig. 3). The retreat of the delta front along the west jetty is well documented (Colpuertos 1969; Koopmans 1971), and we calculate average annual shoreline retreat rates from 1939 to 1987 of 65 m/yr (range: 21–150 m/yr). Figure 2 gives a qualitative view of the significant land loss (sediment supply for downdrift sand bodies) at the river mouth between 1843 and 1987.

The retreat of the western delta is reflected in the graphic subaerial area loss shown in Figure 4. Because of the difficulties in measuring subaqueous areas on the delta proper (for example, bays, mangrove swamps) from maps and aerial photos, the increase in

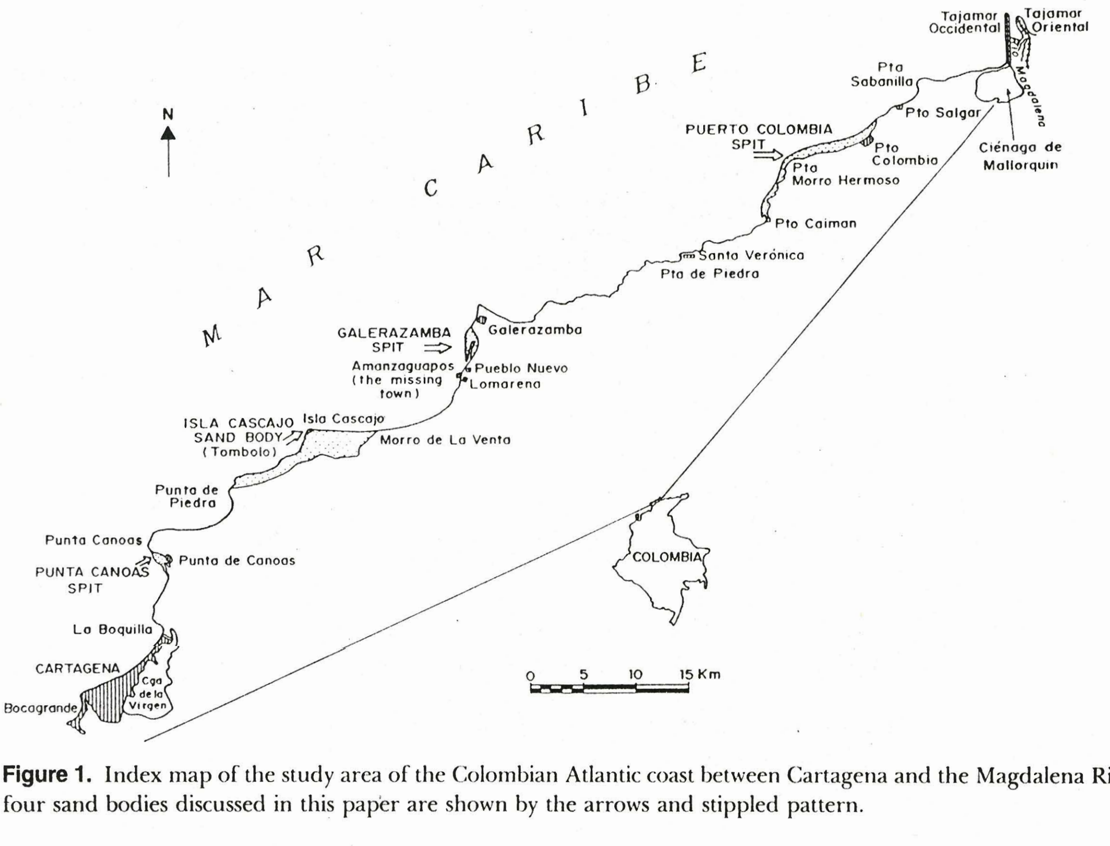

Figure 1. Index map of the study area of the Colombian Atlantic coast between Cartagena and the Magdalena River delta. The four sand bodies discussed in this paper are shown by the arrows and stippled pattern.

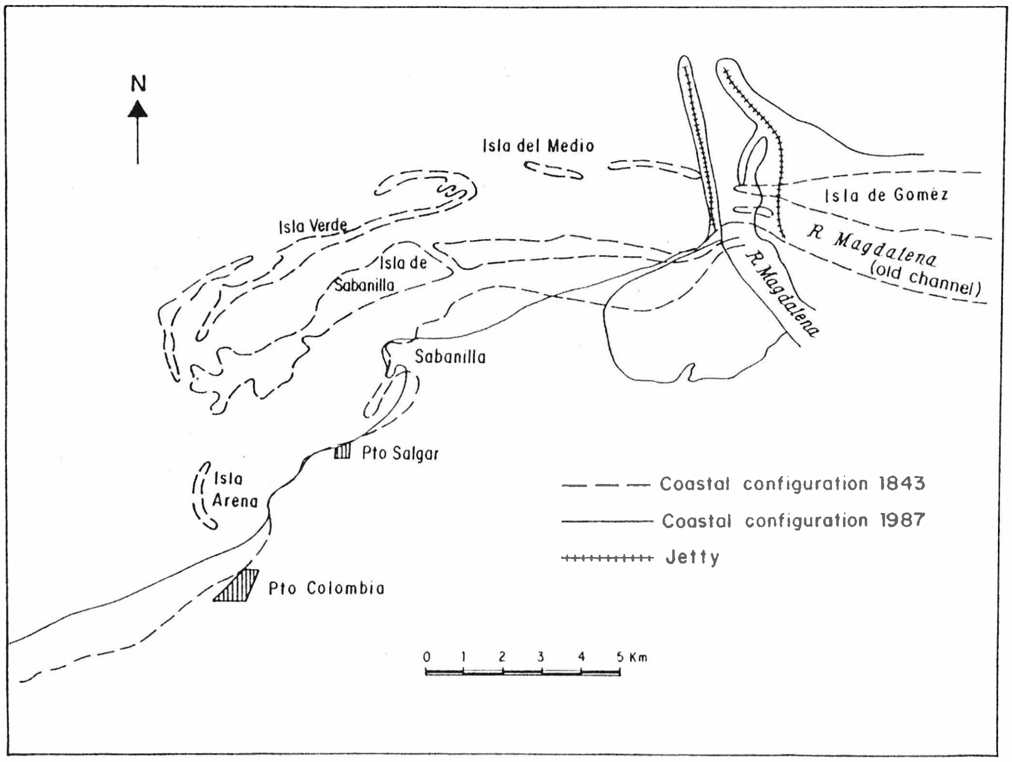

Figure 2. Change in the western Magdalena delta front between 1843 and 1987. The significant change took place after the construction of the jetties in the interval between 1925 and 1935.

open ocean area along a 5-km front west of the jetty was determined as a measure of the area lost from the delta front since 1947. Most of the erosional effect is within 5 km of the jetty; beyond this distance, spit/barrier accretion on the delta proper partially offsets erosional loss (slight net erosion: 0.13 km^2/yr for 28 years of record). From 1947 to 1981, the 5-km front lost approximately 0.5 km^2/yr (Fig. 4). Unfortunately, no data exist to derive reliable volumes of sediment loss from the delta or gain in the downdrift sand bodies.

Clearly, the river has always contributed sediment to form large downdrift sand bodies (for example, Cartagena spit, La Boquilla spit, former Galerazamba spit), but the emplacement of the jetties triggered a 20th-century chain of events in the formation–migration of similar coastal sand bodies. Four sand bodies have either formed, shifted, or accreted rapidly since 1935, as documented in maps dating from 1936 and air photos dating from 1947.

Sand Bodies

Puerto Colombia spit. This existed prior to jetty construction; however, sand masses on the western edge of the delta and this spit were mobilized in the late 1940s and early 1950s (Fig. 5). We speculate that the jetties are at least indirectly responsible. As previously noted, the spit may have formed initially as a result of shoaling due to mud diapirism. The retreat of the delta front probably changed the wave refraction pattern around the delta, as well as altering the bottom profile north and east of the spit. Isla Verde (Fig. 5), the last remnant of the original spit, may have been the approximate location of diapiric activity. Systematic seismic definition of such intrusive features on the inner shelf does not exist, but mud lumps and mud volcanoes are well documented. In the Cartagena area, reefs are localized atop such features (Vernette 1986).

Figure 5 indicates the spectacular detachment and mobilization of the Puerto Colombia spit between 1947 and 1954. In 1947 the spit extended off Punta Sabanilla for approximately 12 km with a narrow neck at its eastern end. The spit sheltered an embayment that allowed port development at Puerto Colombia with the construction of a quay for loading ships. Detachment occurred between 1948 and 1953, probably during a storm or storms that overwashed the narrows. By 1954 (Fig. 5), a small barrier island system was present with Isla Verde, a central island, a small eastern spit now attached southwest of its former position. By 1961, however, the spit had reformed landward of its 1954 position and had moved into the loading quay, rendering the facility useless. During this entire interval, the subaerial extent of the spit system had decreased by a little over 2 km^2 (Fig. 4).

The map and photo sequence indicate that the spit was not destroyed and later reformed, but migrated,

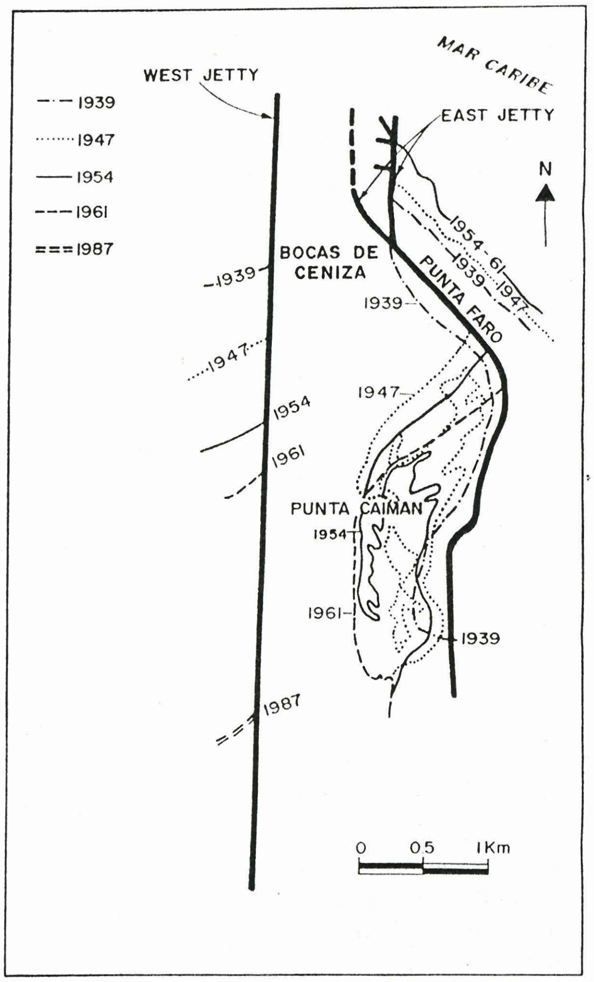

Figure 3. Successive shoreline positions in the vicinity of the Magdalena River jetties from 1939 to 1987. Updated and modified after Koopmans (1971).

sometimes as an island chain, usually as a narrow recurved spit. The migration followed a curved path as the end of the spit moved farther than the attached end. As a result, the rates of migration varied on different portions of the spit. Between 1947 and 1961, the seaward side of the spit migrated at typical rates of between 230 m/yr and 430 m/yr.

As the spit ran aground in front of Puerto Colombia, accretion through beach ridge formation increased the total sand body area significantly (Figs. 4 and 5) and allowed longshore transport to carry sand to the western end of the former spit and around Punta Morro Hermoso. Presently, the accreted spit is providing both a sand source and a bypass avenue for sand to nourish beaches beyond this point.

Puerto Colombia's function as a port ceased when the quay was blocked by the migrating spit. It is ironic that the jetties intended to improve access to the port of Barranquilla caused the closing of the competing port of Puerto Colombia.

Galerazamba spit. This is the next "downstream" sand body of significant size, located about 40 km southwest of Puerto Colombia (Fig. 6). As noted above, a large spit perpendicular to the shore existed in this area in the last century, but its breakup and disappearance are not documented by maps or records. The smaller present spit has grown off of Punta Juan Moreno Sur, more or less parallel to the coast. Although the spit has not shown spectacular change in area (Fig. 4), considerable growth followed by retreat occurred between 1953 and 1984 (Fig. 6), followed by recent stability.

More significant is the spit's historic pattern of elongation, followed by shortening as the downdrift part of the spit erodes away, releasing sand to continue on to the southwest. Correa (1984) illustrated the impact of the loss of the spit's protective role as it retreats. The village of Amanzaguapos, present in 1947, was relocated and renamed Pueblo Nuevo by 1954. By 1964, the narrow spit provided natural protection for Pueblo Nuevo, and enclosed a lagoon by 1974. Sometime between 1974 and 1984, the southern end eroded away, opening the lagoon and exposing the shoreline at Pueblo Nuevo to severe erosion. The northern part of the spit widened by accretion during the same interval. Pueblo Nuevo now faces the same fate as its predecessor village, Amanzaquapus: loss to shoreline retreat.

Isla Cascajo. This is the largest of the coastal sand bodies (Fig. 7), forming a wide accretionary zone that has attached to the offshore island to form a tombolo. Between 1936 and 1983 the addition of nearly 12 km^2 of accreted sand area extended the shoreline seaward and laterally, an average growth rate of over 0.25 km^2/yr (Fig. 4). Growth of the tombolo probably blocked or at least limited the amount of sediment coming from the northeast; however, the growth has reached a point where sand can now bypass the tombolo and continue to and beyond Punta Las Canoas. The accretion zone is migrating to the southwest.

Unlike the spits, the large sand body of the Isla Cascajo area may be more stable, less likely to totally remobilize. As a result of its greater size and semistability, the accreted land may have a greater resource potential than the spits in terms of future land use.

Punta Canoas spit. This is the most distant of the subaerial sand bodies from the delta (104 km) (Fig. 8). The small spit was absent in 1947 but had formed by 1961. In the period between 1947 and 1984, the spit had grown to approximately 1 km^2 in area, a rate of 0.027 km^2/yr. Two thirds of this area, however, ac-

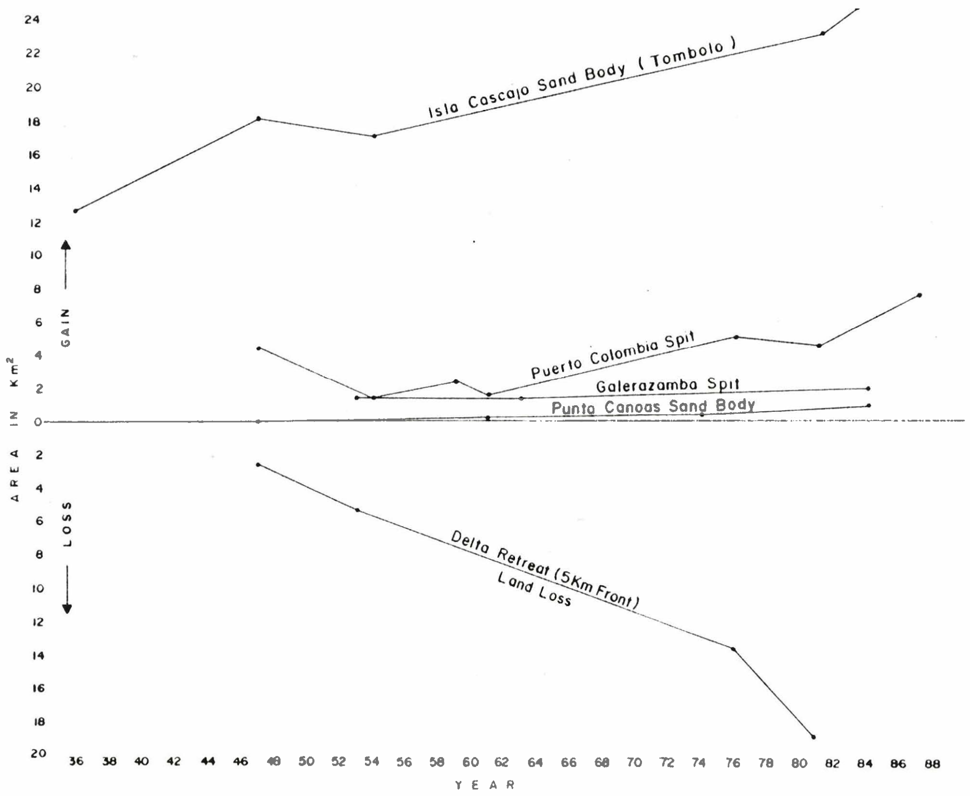

Figure 4. Plot of area changes through time indicating downdrift sand body accretion for the four sand bodies while the western Magdalena delta front was rapidly receding. Magdalena delta land loss is expressed in terms of increased ocean area along a 5-km front, west of the jetties.

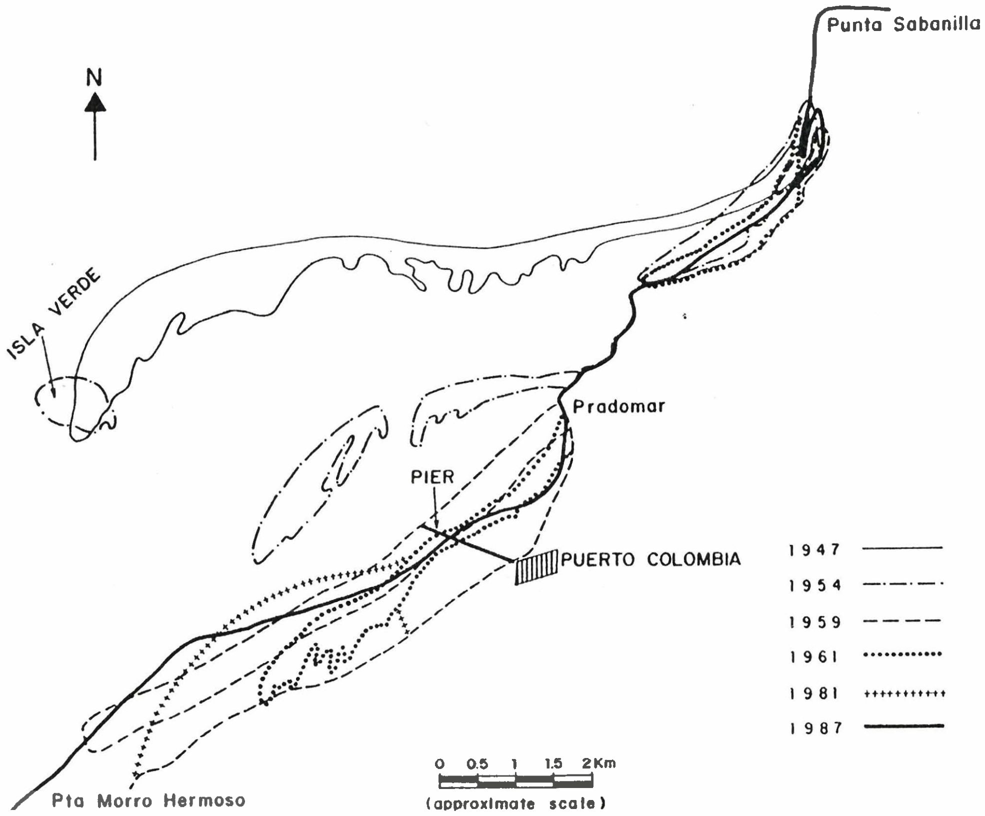

Figure 5. Shoreline changes in the vicinity of Puerto Colombia from 1947 to 1987. Note the rapid shoreward migration of the Puerto Colombia spit from 1947 to 1961, rendering the shipping pier useless. Once the spit attached to the mainland, it became an avenue for sand migration to downdrift beaches.

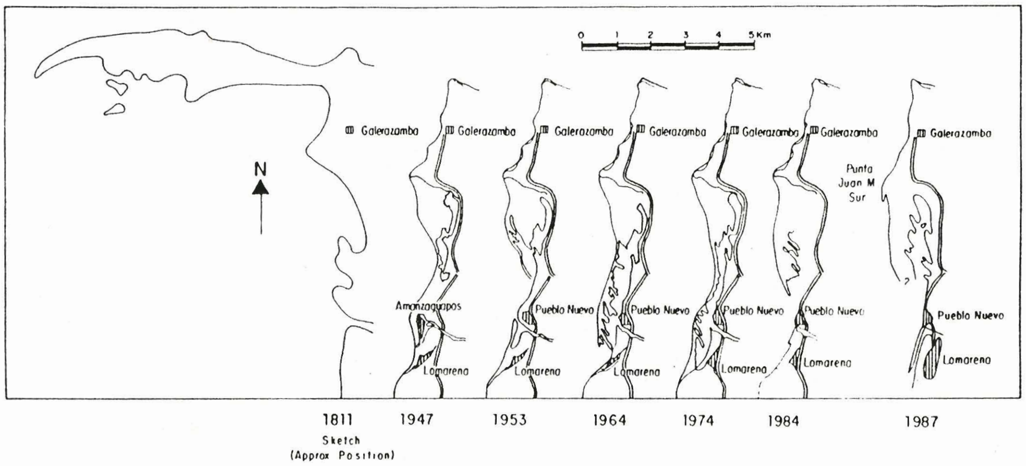

Figure 6. Evolution of the Galerazamba spit from its approximate 1811 position through the past 40 years of change. Note that the village of Amanzaguapos was relocated as Pueblo Nuevo when threatened by shoreline erosion. Pueblo Nuevo is now experiencing the same fate.

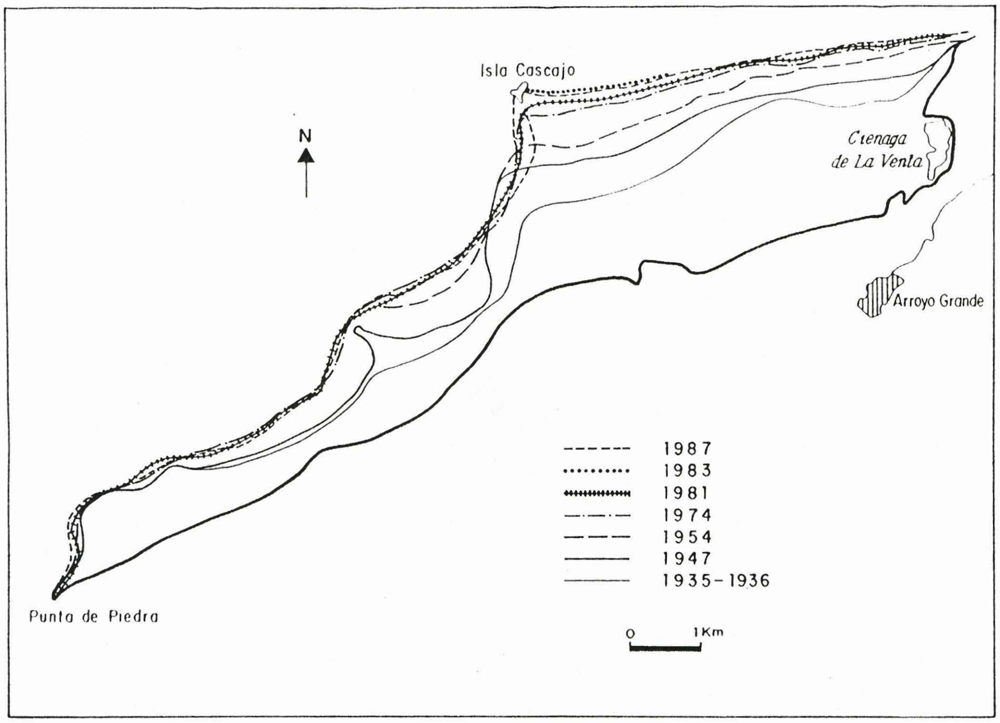

Figure 7. Spectacular coastal accretion is shown for the Isla Cascajo area from the mid-1930s to 1987. The Isla Cascajo tombolo feature probably owes its origin to shoaling and formation of the island by mud tectonics (diapiric intrusion).

creted between 1974 and 1984. By 1987 the spit reformed in its 1984 position. The spit migrated southward and, at the same time, the northern point of the spit widened by accretion as the southern part eroded away.

Rate of Sand Movement

Given the distance of Punta Canoas from the western delta edge, and the approximate time of the beginning of sand buildup, minimum sediment transport rates on the order of 2 km/yr must be postulated. Such a rate does not seem likely, and we have no evidence to prove that the emplacement of the jetties caused sand to flow this far or even to the tombolo at Isla Cascajo.

On the other hand, spit migration rates on the order of 0.5 km/yr occur. The proximity of the Puerto

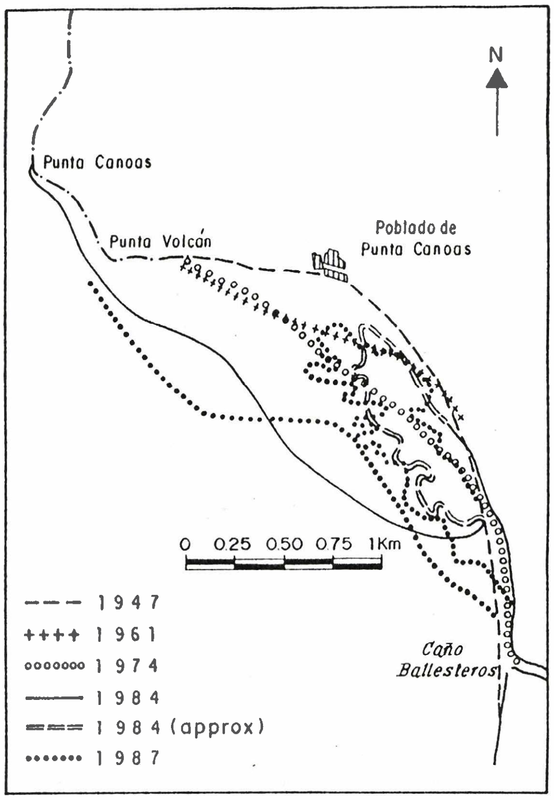

Figure 8. Forty-year evolution of the Punta Canoas spit from 1947 to 1987. Much of the spit growth took place between 1974 and 1984. Attachment to the mainland allows sand to continue to downdrift beaches.

Colombia spit to the delta and its detachment and rapid migration not long after jetty construction suggest that a definite relationship exists. Certainly the rapid retreat of the western delta front was caused by the jetties.

There is clear evidence of simultaneous destruction of the western arm of the Magdalena Delta and buildup of the downstream sand bodies, all beginning with jetty construction. It is tempting to relate jetty construction to sand release, causing sand body buildup, but more likely, large amounts of sand existed on the continental shelf, in part from previously formed features such as the old Galerazamba spit. These sands probably were remobilized after the jetty induced delta retreat and modification of the wave patterns, so that the dominant waves out of the northeast affected long stretches of coast. Sand from the former Galerazamba spit could account for the rapid accretion at Isla Cascajo, which gained nearly 5.5 km^2 in area between 1936 and 1947.

Environmental and Economic Significance

These sand bodies are economically important for several reasons and may have unrecognized potential. In their natural state they provide protection against shoreline erosion of the mainland coast. The wider sand bodies also might be mined safely on their landward sides; however, environmental concerns as well as loss of the feature might preclude mining. Serious beach erosion of recreational beaches at such resorts as La Boquilla, Santa Veronica, Puerto Salgar, and Boca Grande suggest that long-term sand supplies for beach nourishment are needed. Where not serving a protective role or recreational use, the sand bodies are a potential source for providing beach-nourishment project sand.

Beach mining is already in progress on a small scale north of Galerazamba and south of the Punta Canoas spit. In both cases, gravels are being sorted from the beach sands. In this case, the coarse sediment is coming from local sources (low Pleistocene cliffs to the northeast, and Holocene fluvial deposits to the southwest), rather than the distant delta sand source.

Although the sand bodies are temporary, subject to continued migration, and not suitable for permanent or heavy construction, their use as tourist beaches may be possible. Small developments utilizing light structures, capable of being moved as the shore retreats, could be located on the landward sides to accommodate limited tourist populations. More permanent buildings should be sited in accordance with known behavior patterns of the particular sand body. For wide sand areas such as Galerazamba, public transportation might be provided to the waterfront by excursion minirail systems.

The high heavy mineral content of these sand bodies is worth further study for their economic potential. The possibility of increased concentrations of specific minerals in specific sand bodies may be increased by potential longshore sorting.

Summary and Conclusions

Three types of large sand bodies tend to form along the 120-km coast from the sediment source at the Magdalena delta to the terminus of accumulation at Cartagena. Large spits grow nearly perpendicular to the coast, probably under the influence of nearshore shoaling associated with mud diapirs. These large sand bodies are temporary, and when they detach they migrate rapidly downdrift and landward. The Puerto Colombia spit was a modern example of the latter with migration rates as high as 430 m/yr. These spits weld onto the mainland shore and create large volumes of new sand supply to the coast. Smaller spits parallel to the shore have shown significant growth in the period of record since 1947. Sand for these features may be derived in part from the previous spit sources, but they are also ephemeral in form. The Punta Canoas spit, formed since 1947, and the Galerazamba spit have alternately elongated and shortened, leading to the destruction of Amanzaguapos.

The third type of sand body is represented by the Isla Cascajo area, including a tombolo. The largest of the accretionary sand bodies (Fig. 4), this feature has grown out so that sand can now bypass the headland and continue to downdrift beaches. Like the other sand bodies, much of this growth is relatively recent (since 1960).

The result is large volumes of sand, derived from the Magdalena River and Delta, being transported for long distances, by-passing rocky headlands. The construction of jetties at the river mouth in 1935 caused rapid retreat of the western delta front and is believed to be a significant factor in the recent evolution of the downdrift sand bodies. Sand lost from the delta front probably has been added to longshore transport, but the remobilization of offshore sand deposits because of the influence on wave patterns as the delta retreated is of equal importance.

The sand bodies are of economic significance both in terms of natural environmental protection of the mainland from erosion and as an economic resource. In the latter case, these deposits are reserves for beach nourishment of eroding resort beaches and possible sources of economic heavy mineral concentrations. Likewise, the semistable areas may be adequate for light recreational development to promote tourism. The resource value could be better evaluated by a systematic coring program and heavy mineral assessment.

Acknowledgments

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References Cited

Colpuertos. 1969. Las obras de Bocas de Ceniza: Puertos de Colombia, Bogotá, 100 p.

Correa, I. D. 1984. Variaciones historicas de la linea de costa entre la Boquilla y la Punta de la Garita en el Periodo, 1947–1983/84; Informe Inédito, INGEOMINAS, Cartagena, 20 p.

Hoover, J. D., and D. G. Bebout. 1984. Submarine fan diversion by tectonic processes—Magdalena fan and slope, south Caribbean: Gulf Coast Section, SEPM Foundation Research Conference Abstracts, v. 5, p. 43.

Kolla, V., R. T. Buffler, and J. W. Ladd. 1984. Seismic stratigraphy and sedimentation of Magdalena fan, southern Colombian basin, Caribbean Sea: American Association of Petroleum Geologists Bulletin, v. 68, p. 316–332.

Koopmans, B. N. 1971. Interpretación de fotografías aereas en morfología costera, relacionada con proyectos de ingeniería: Centro Interamericano de Fotointerpretación, Bogotá, 23 p.

Milliman, J. D., and R. H. Meade. 1983. World-wide delivery of river sediment to the ocean: Journal of Geology, v. 91, p. 1–21.

Shepard, F. P. 1973. Sea floor off Magdalena Delta and Santa Marta area, Colombia: Geological Society of America Bulletin, v. 84, p. 1955–1972.

Shepard, F. P., R. F. Dill, and B. C. Heezen. 1967. Diapiric intrusions in foreset slope sediments off Magdalena Delta, Colombia: American Association of Petroleum Geologists Bulletin, v. 52, p. 2197–2207.

Vernette, G. 1986. La plate-forme continentale Caraibe de Columbie: importance de diapirisme argileux sur la morphologie et la sedimentation: Memoires de L'Institut de Geologie du Bassin D'Aquitaine, no. 20, (DSc thesis) Universite de Bordeux I, Talence, France, 387 p.

Vernette, G., S. Hincapie, and J. Martinez. 1984. Characteristiques et mise en place des sediments sur la plate-forme continentale Columbienne en Mer Caribe (du Flueve Magdalena au Golfo de Morrosquillo): Bulletin de L'Institut de Geologie du Bassin D'Aquitaine, no. 35, p. 87–102.