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Tecolutla and Nautla Deltas, Veracruz, Mexico: Texture to Evaluate Sediment Entrapment on Deltaic Plains and Bypassing onto the Gulf of Mexico Margin

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ABSTRACT

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This study uses grain-size distributions to contrast sediment transport processes in the Tecolutla and Nautla deltas on the high-energy Veracruz coastal margin, southwestern Gulf of Mexico. Both tropical deltas formed at mouths of short, seasonal high-flood discharge rivers that carry large volcaniclastic loads down steep mountain slopes directly to the coast. Baseline studies of deltaic sediments are needed to help develop protection measures for the increasing delta populations endangered by devastating floods. Eleven environments in each delta are distinguished on the basis of mean size, standard deviation and skewness in surficial sediment samples. These textural parameters are used to interpret transport processes that prevail in the environments of the two deltas.

The Tecolutla system discharges more water and carries a greater sediment load than the Nautla. The Tecolutla loses a greater proportion of coarser fractions by overbank transport on its natural levees and flood-plain, and it also traps more finer-grained fractions in its larger marshes, mangroves and upper estuary. Consequently, grains reaching the Tecolutla's lower estuary are of finer mean size and better sorted than those reaching the Nautla's lower estuary. Moreover, a larger proportion of the Tecoluta's sediment load bypasses the lower estuary and is released seaward beyond the river mouth. This conclusion is independently confirmed by the delta's prograding, gentle cuspate form and higher proportions of fluvioclastic light and volcanic mineral components traced from its lower estuary to nearshore settings. In contrast with the Tecolutla, textural evidence suggests erosion and reworking from marine environments and accretion onto the Nautla coast and lower estuary by wave-driven currents. Corroborating evidence is the Nautla's truncated coastal configuration and, in its lower estuary, a masking of the river's volcanic and light minerals by locally concentrated heavy minerals and carbonates.

ADDITIONAL INDEX WORDS: *Deltas, Gulf of Mexico, lower estuary, mangrove, overbank deposition, selective bypassing, sediment entrapment, size analyses, Veracruz.*

INTRODUCTION

This study contrasts depositional patterns in two adjacent deltas (about 35 km apart) using textural analyses. The Tecolutla and Nautla deltas are located in tropical settings on the Veracruz margin of the southwestern Gulf of Mexico (Figure 1). These small Holocene depocenters are positioned at mouths of short, high flood-discharge rivers that originate at elevations of >4000 m in the Sierra Madre Oriental mountain chain of eastern Mexico. Both Tecolutla and Nautla rivers have steep profiles, descending from mountain sources to the narrow (~15 km), low-lying coastal plain and flowing to the microtidal, high-energy coastal margin. Sediment discharge is swift and direct to the Gulf coast, subject to seasonal rainfall but unaffected by dams or major channel diversion structures. As populations continue to grow on the coast, annual floods cause increasing damage to human habitation in the region. The most recent devastating event occurred in September and October 1999. To date, little work has been done on these two delta systems that are typical of those where large sediment loads are transported to the coast from adjacent mountain sources at time of flood (*cf.* RESTREPO and KJERVE, 2000). The present research is part of an initial compilation to formulate information on sediments in the two depocenters to better identify sedimentary responses to climatic change (including *El Niño* events; WILKERSON, 1994).

In this Veracruz sector, as in most deltaic systems, unidirectional river flow carries sediment loads seaward and differentially distributes various size fractions across diverse deltaic and coastal environments. Upon reaching coastal and nearshore sectors, fluvio-deltaic sediments are further dispersed by a different set of transport processes in the receiving basin (FERNANDEZ-EGUIARTE, 1992). Although located in similar climatic and geological settings (SELF, 1971, 1975; LENTELL, 1975), the two depocenters display differences in sedimentary petrology (CHEN *et al.*, 2000). These variations,

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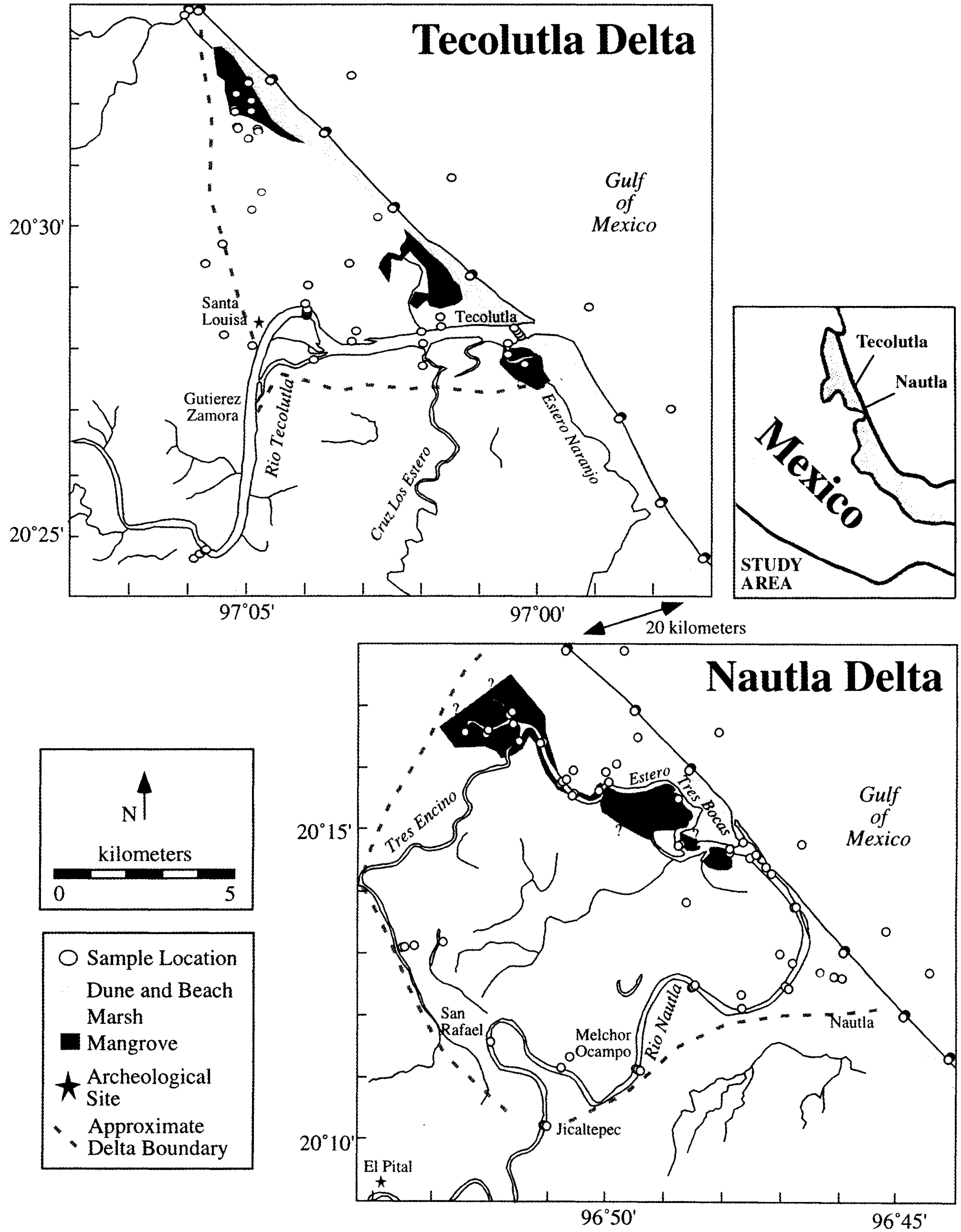

Figure 1. Maps of the Tecolutla and Nautla deltas located on the Veracruz, Mexico, margin of the southwestern Gulf of Mexico. Positions of the 197 sample sites in the deltas and contiguous nearshore sectors are indicated.

Table 1. *Averaged grain-size measures (mean size, standard deviation, skewness) for samples (n =197) collected in each of 11 deltaic environments in both Tecolutla and Nautla deltas.*

	River [1]	Natural Levee [2]	Flood-Plain [3]	Marsh [4]	Mangrove [5]	Upper Estuary [6]	Lower Estuary [7]	Dune [8]	Beach [9]	Breaker Zone [10]	Inner Shelf [11]
Tecolutla	Ma = 356.84	153.9	76.13	27.78	32.65	37.25	152.29	226.13	227.24	274.99	179.14
	SD = 200.75	141.13	108.8	44.21	42.06	76.14	99.68	72.51	67.6	97.01	75.64
	Sk = 0.21	2.00	3.34	3.23	3.27	4.44	1.89	0.21	0.58	0.72	1.1
Nautla	Ma = 397.45	98.88	43.81	96.21	44.22	36.86	193.93	262.26	279.37	336.41	149.86
	SD = 223.82	121.24	76.24	122.31	63.93	54.6	158.47	86.11	85.04	112.99	78.28
	Sk = 0.14	2.51	3.13	2.34	3.02	3.18	1.93	0.38	0.47	0.58	0.36

Notes: Ma = Mean size (in μm); SD = Standard deviation (in μm); Sk = Skewness (in μm).

primarily compositional, relate largely to differences in fluvial discharge in the two systems, drainage basin configuration and area, and selective dispersal and storage of particles of different density.

Quantitative analysis of grain-size characteristics in the present study has identified similarities and differences among surficial samples, and textural attributes have been used to help distinguish different depositional conditions in the environments of each delta. This approach should provide a means to determine similarities and differences in (1) overbank flow, (2) sediment entrapment on deltaic plains and accretion in lower estuaries, and (3) possible bypassing of sediment to the nearshore environment sectors of the two deltaic systems.

COMPARING THE TWO DEPOCENTERS

Sediment source areas on slopes above the delta plains include Cenozoic volcanic terrains widely exposed in the Neovolcanic Cordillera of the Sierra, and also Cretaceous and Tertiary to Quaternary exposures (Garfias and Chapin, 1949; Moran-Zenteno and collaborators, 1994; Carranza-Edwards and Rosales-Hoz, 1995; Kasper-Zubillaga *et al.*, 1999). As documented in a previous study (Chen *et al.*, 2000), river sediments in both Nautla and Tecolutla systems are the primary source of material for all examined environments in both deltas. The two rivers carry large sediment loads, with concentrations of suspended solids at times of flood exceeding 1.0 part/1000 (Tamayo, 1962), and fluvial sediments of the two rivers record similar textural characteristics. Differences include distances between the Sierra Madre Oriental headlands and the coast (~220 km, Tecolutla; ~160 km, Nautla). Tecolutla and Nautla drainage basin areas are approximately 8080 km^2 and 2270 km^2, respectively, and mean annual average river discharge is 7529 million m^3 for the Tecolutla and 2465 million m^3 for the Nautla. The Tecolutla's drainage basin area and volume of total discharge are about 3 times larger than those of the Nautla and, during flood stage, the Tecolutla carries one of Mexico's largest volumes of water and sediment (Tamayo, 1962; Mexico, Direccion General de Geografia, 1984).

Coastal processes also act on the margins of these depocenters. Tidal range is low (<1.5 m). However, both the Tecolutla and Nautla delta coasts experience erosion, primarily the result of wave-driven currents along this NW-SE trending stretch of the Veracruz margin (Fernandez-Eguiarte *et al.*, 1992). In winter, mean wind velocity ranges from 10–12 knots, primarily from the east and north, with longshore currents oriented toward the southeast (Leipper, 1954a, b). In summer, wind velocities diminish to 6–8 knots with prevailing force from the southeast and somewhat weaker longshore currents oriented toward the northwest (Carranza-Edwards *et al.*, 1996). Sediment discharged from river mouths to the inner shelf are dispersed toward the SE in winter and NW in summer.

METHODS

A total of 197 surficial sediment samples (upper 5 cm) on and adjacent to the Tecolutla (n = 96) and Nautla (n = 101) deltas (Figure 1) were collected in February 1996 (Chen *et al.,* 2000). In each delta, between seven and twelve samples were recovered in the eleven environments from land to sea (*1–11* in Table 1): river, natural levee, flood-plain, marsh, mangrove, upper estuary (tidal creeks in the Nautla, tidal ponds in the Tecolutla), lower estuary (about 2 km landward from the mouth of the river), dune, beach, breaker zone, and inner shelf to about 1 km offshore (to a depth of ~8m off the Tecolutla, and ~14m off the Nautla).

For each sample, grain-size distribution and moment measures were determined for the fraction ranging from 0.4 to 1000 μm using a Coulter Counter laser (LS 200) diffraction particle analyzer (data for each sample available from the senior author). Several replicate size runs were made on each sample, and the average of these analyses were used here. On the basis of textural analyses of small samples, we were able to distinguish the various deltaic environments (*cf.* Ethridge *et al.*, 1975). In the present study, we use mean grain size, standard deviation, and skewness to deduce dominant sediment transport and dispersal trends in the study area, applying conventional petrologic approaches (Folk and Ward, 1957; Pettijohn *et al.*, 1973; Lewis and McConchie, 1994).

COMPARING TEXTURE IN THE STUDY AREA

Calculated averages of mean size, standard deviation and skewness in each of the 11 environments of the two deltas are listed in Table 1.

Similarities

The following similarities are recorded based on comparison of size distributions in environments of the two deltas:

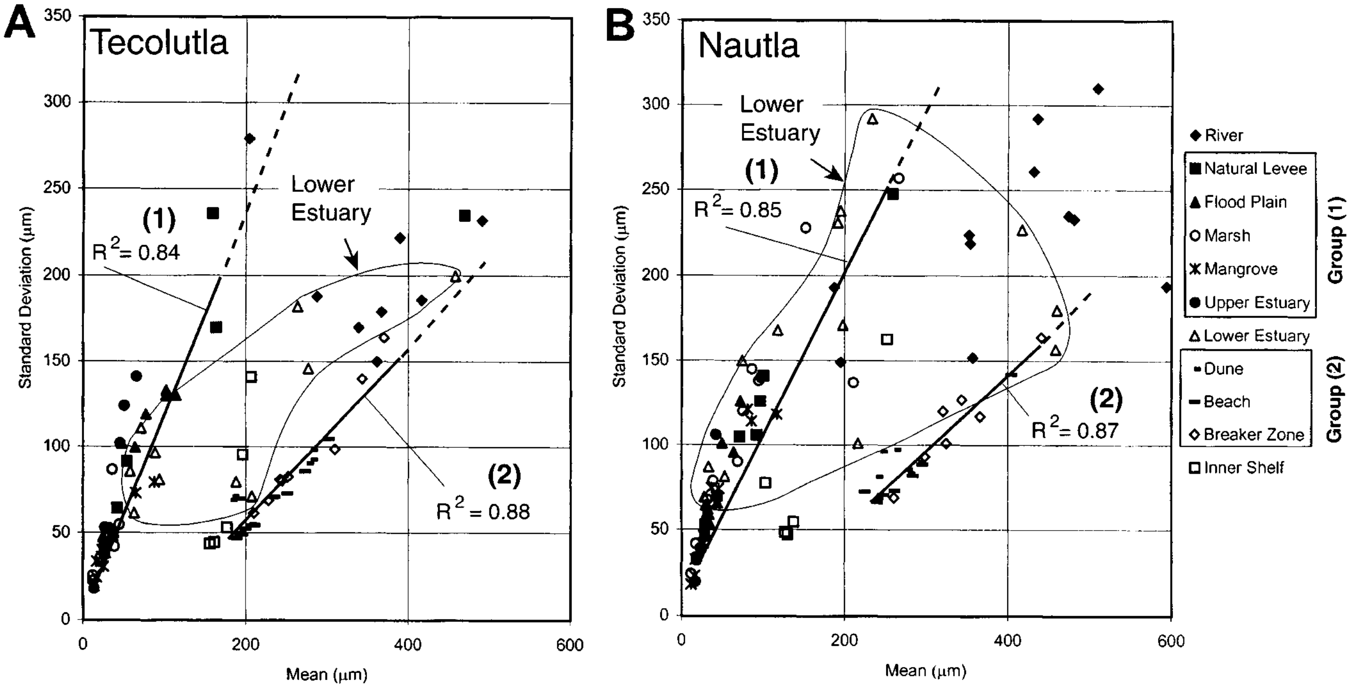

Figure 2. Scatterplots showing standard deviation against mean grain size for (A) sediment in the Tecolutla delta, and (B) in the Nautla delta. In each delta, two textural groups can be separated statistically according to environment (R^2 values are shown): group (1) on the delta proper (Tecolutla, n = 42; Nautla, n = 48), and group (2) on the coast and nearshore (Tecolutla, n = 25; Nautla, n = 21). Note that lower estuary textural data overlap groups (1) and (2) differently in the two deltas.

- River sediments in both Tecolutla (n = 8) and Nautla (n = 11) deltas record similar textural characteristics; of all 11 environments, river sediments are coarsest, most poorly sorted and skewed toward coarsest fractions.
- Plots of mean size versus standard deviation for the 197 samples in 11 environments show generally similar patterns (Figure 2). Two size trends for each delta are identified on the basis of data for eight environments: one finer grained (group 1) and the other coarser grained (group 2). Both reveal a statistically significant positive correlation (shown by linear regression, Linest program, using Excel). Group 1 (Tecolutla, n = 42; Nautla, n = 48) includes sediment in the natural levee, flood-plain, marsh, mangrove and upper estuary; group 2 (Tecolutla, n = 25; Nautla, n = 21) includes sediment in dune, beach and breaker zone. The three environments excluded from the two groups (Figure 2) are river (source for all other environments), lower estuary (influenced by fluvial and coastal processes) and inner shelf (reworked primarily by offshore processes).
- Skewness values are generally similar in comparable environments of both systems (Table 1).

DIFFERENCES

There are also differences between sediment textures in the Tecolutla and Nautla deltas:

- In 6 of 11 environments, Nautla sediments are coarser and more poorly sorted than those of the Tecolutla (Table 1).
- The Tecolutla's natural levee and flood-plain sediments are coarser and more poorly sorted than those of the Nautla (Table 1).
- In the Nautla's lower estuary and breaker zone, sediments are coarser grained but more poorly sorted than in the same environments of the Tecolutla (Table 1).
- Lower estuaries of both deltas (Tecolutla, n = 12; Nautla, n = 14) comprise two sediment subtypes: (I) finer grained, and (II) coarser grained (Figure 3). In the Tecolutla, the subtype (I) field shows restricted mean and skewness values, a function of unimodal size distribution. In the Nautla, subtype (I) records a broader range of size and skewness values, the function of bimodal size distribution. Differences between subtype (II) sediment in lower estuaries of the two deltaic systems are more subtle, with Tecolutla samples showing a somewhat broader range of grain size.

DISCUSSION

Textural parameters vary according to characteristics of original source material and energy of transport and depositional processes, with particles segregated according to their hydrodynamic behavior (INMAN, 1949; MIDDLETON, 1976). Sediments released on natural levee and flood-plain environments of the Tecolutla are coarser and more poorly sorted than those in the same environments of the Nautla (Table 1). This difference records the larger amount of coarser material transported by overbank flow in the Tecolutla delta

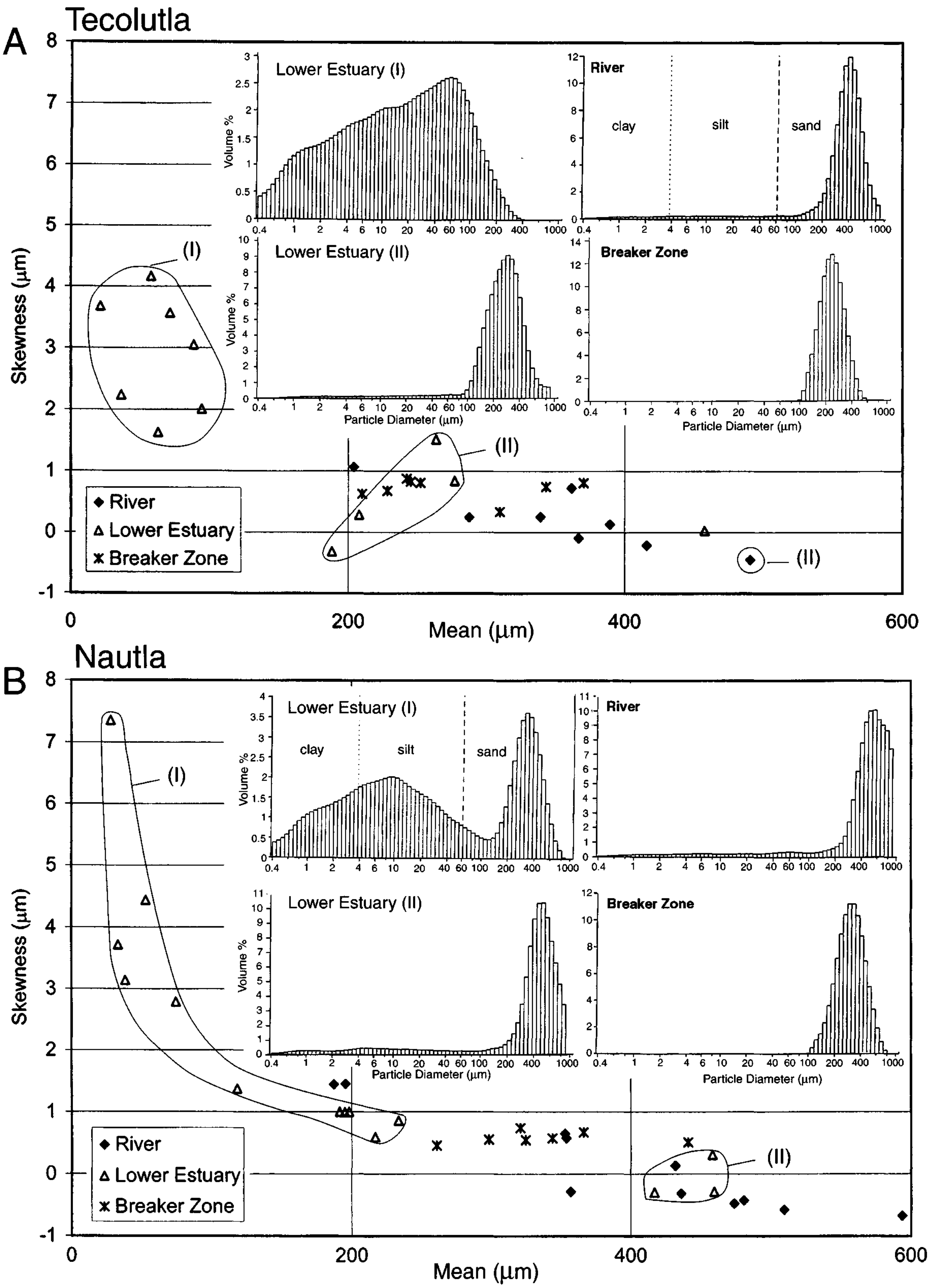

Figure 3. Scatterplots for the Tecolutla (A) and Nautla (B) showing skewness against mean size for river, lower estuary and breaker zone sediment. Examples of grain-size distributions are shown, including those for two lower estuary sediment subtypes (I and II). Note differences in lower estuary subtype I in the Tecolutla (unimodal size distribution), and in the Nautla (bimodal distribution). There is greater overlap between lower estuary subtype II and breaker zone sediment in the Tecolutla than in the Nautla.

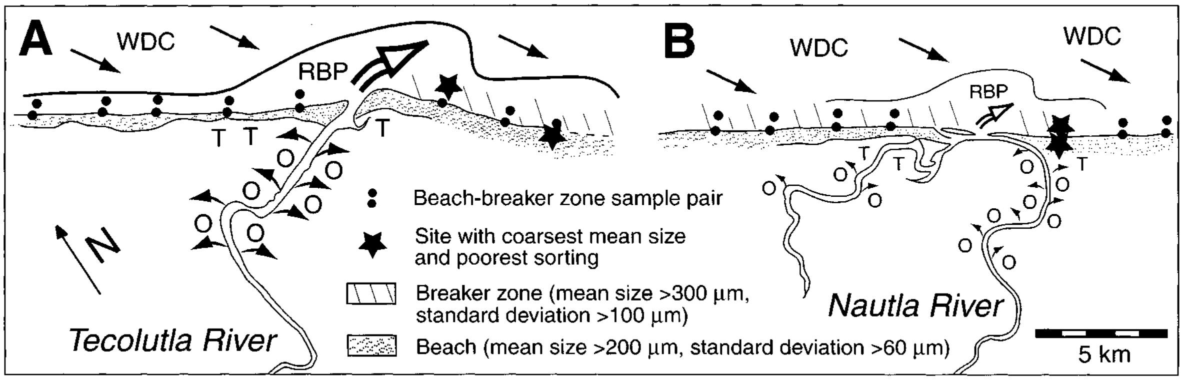

Figure 4. Interpretive scheme depicting transport and dispersal trends in the Tecoluta and Nautla deltas and contiguous Gulf of Mexico coastal margins. There is greater overbank deposition (O), sediment entrapment in vegetal-rich marshes, mangroves and upper estuary setttings (T), and river bypassing of sediment (RBP) in the Tecolutla system. Strong erosive wave-driven currents prevail along the coast (WDC) throughout the region. Coarse grained, poorly sorted fluvio-deltaic and offshore sediment admixtures are transported along the coast to SE of river mouths (predominant winter path) and also into the Nautla's lower estuary by strong wave-induced currents.

at times of flood (Figure 4), a result of much greater river discharge (~3 times that of the Nautla). Moreover, the larger marshes and mangroves (primarily *Rhizophora mangle*) on the Tecolutla plain (Figure 1) help account for selective entrapment of finer and better sorted sediment than in comparable environments of the Nautla. Textural analysis indicates that vegetation in these Tecolutla settings actually traps a greater proportion of fine sediment fractions during floods than do smaller marshes and mangroves of the Nautla (Figure 4). This conclusion is independently supported by results of compositional analyses showing that larger proportions of less dense volcanic particles are selectively retained in Tecolutla mangroves along with organic matter formed *in situ* (CHEN *et al.*, 2000). The entrapment process also helps explain why fluvial sediment reaching the Tecolutla's lower estuary is finer grained and better sorted than that reaching the Nautla's lower estuary.

River mouth sediment bypassing and nearshore alteration of fluvial texture varies with discharge volume on the coast and intensity and direction of longshore currents (COLEMAN and WRIGHT, 1975; CARRANZA-EDWARDS *et al.*, 1996). Changes in grain size between Veracruz sediments in their lower estuaries and those in the nearshore should provide some record, albeit indirect, of bypassing. In fact, mean size, standard deviation and skewness measures in lower estuary sediments of both Tecolutla and Nautla overlap with deltaic plain (group 1) and nearshore (group 2) sediments (fields denoted in Figures 2 and 3). Dune, beach and breaker zone sediments seaward of both deltaic plains are coarser grained, better sorted and more skewed toward coarser fractions than in their lower estuaries (Table 1). This change at the delta-nearshore boundary indicates a mixing of several sediment types, each with different textural attributes. The mixing results primarily from strong, wave-driven longshore currents on the coast and nearshore (FERNANDEZ-EGUIARTE *et al.*, 1995).

Mean size, standard deviation and skewness values of Nautla's dune and beach sediments are similar to those of the Tecolutla. However, the Nautla reveals a larger textural discontinuity (mean size, standard deviation) between its lower estuary and breaker zone. Sediments in both of these Nautla environments are coarser grained and more poorly sorted than in comparable Tecolutla environments. This difference and the bimodal size distribution of its lower estuary subtype I (Figure 3B) indicate that, when not in flood, sediment from the nearshore enters and is deposited in the Nautla's lower estuary. Consequently, the Nautla's lower estuary subtype II sediment overlaps less with the breaker zone than does the Tecolutla's lower estuary subtype II (Figure 3).

Additional evidence in support of greater bypassing in the Tecolutla includes the gentle cuspate form of its coastal margin and compositional changes of the sand-size fraction at its coast-nearshore boundary (Figure 4). At this interface there are high relative amounts of fluvioclastic light and volcanic mineral components in both lower estuary and nearshore environments (CHEN *et al.*, 2000). In contrast, evidence for landward-directed dispersal of sediment into the Nautla deltaic system includes diversion of the main river to a course that parallels the coast and development of an eroded, truncated shoreline (Figure 1). Compositional study of sediments collected during a non-flood period also records masking of the fluvially-derived Nautla volcanic and light mineral components by heavy minerals and carbonates concentrated along the coast (CHEN *et al.*, 2000).

Interaction of river discharge and dispersal by longshore currents produces a zone of coarser, more poorly sorted sediment near the mouths of both Tecolutla and Nautla rivers and along the shoreline between the two deltaic systems (Figure 4). Sites where sediments are the coarsest and most poorly sorted prevail along the coast southeast of each river mouth. This distribution records the influence of dominant southeast-driven longshore currents in winter (FERNANDEZ-EGUIARTE, 1992; CARRANZA-EDWARDS *et al.*, 1995), a phenomenon visible on aerial and satellite images (CHEN *et al.*, 2000).

Seasonal flooding, particularly by the Tecolutla, will remain a major hazard to the human populations living in these low-lying, vulnerable Gulf of Mexico coastal settings. Implementation of viable protection measures requires more ground-truth documentation of sediment trends between, during and following flood events in these systems.

SUMMARY

(1) Sediment texture in the Tecolutla and Nautla deltas can be divided into two groups: that of the deltaic plain environments (natural levee, flood-plain, marsh, mangrove, upper estuary); and that of the deltaic coastal margin environments (breaker zone, dune, beach). This differentiation occurs because fluvial sediment fractions that bypass river mouths are selectively dispersed along the coast by strong wave-driven longshore currents.

(2) Differences in grain-size attributes in the various deltaic plain environments result as various fractions of the river's sediment load are separately dispersed. On the basis of the present analysis, we conclude that the Tecolutla plain more effectively traps selected fractions during flood than does the Nautla.

(3) Grain-size distributions between lower estuary and nearshore environments indicate that sediment bypasses river mouths of both deltas; however, Tecolutla sediment is distributed farther offshore than that of the Nautla. This bypassing difference is largely due to greater Tecolutla river discharge at time of flood. In contrast, the Nautla, when not in flood, shows less offshore transport and dispersal, greater modification of river sediment by coastal processes, and deposition of nearshore material at its mouth. This is indicated by marked differences of textural and compositional attributes between the Nautla's lower estuary and breaker zone.

(4) There is a marked statistical distinction between grain-size parameters in terrestrial environments and in nearshore and beach environments in the two SW Gulf of Mexico deltaic settings studied herein. We identify this textural distinction as one that is particularly characteristic of wave-dominated deltas.

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