Middle Holocene Evolution of the Central Texas Coast

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Abstract

Recent work along the central Texas coast has suggested that middle Holocene sea level was slightly higher (+ 2 m) than present. This paper discusses some newly-recognized and/or reinterpreted mainland erosion surfaces and beach ridge plains of Holocene age that may represent the geomorphic manifestation of this highstand. Extensive erosion surfaces occur along bay margins, truncate weathered Pleistocene Ingleside sand at elevations of +2 m or more, and are overlain by swash zone and/or other bay margin deposits. Holocene beach ridge plains occur farther seaward from these erosion surfaces, and are underlain by more than 4 m of unweathered, massive to stratified sand. Holocene beach ridge plains are similar in scale to the modern barriers, since they attain elevations of +2.5 m, extend for tens of km along the mainland shore between Matagorda, San Antonio, Copano, and Corpus Christi Bays, and can be 1-3 km in width. Erosion surfaces are interpreted to represent wave ravinement along the shoreline of maximum transgression, whereas beach ridge plains are interpreted to represent progradation after maximum highstand, during sea-level fall to present elevations or lower.

Introduction

The Texas shoreline has long served as a natural laboratory for the study of coastal processes and landforms and their evolution in response to post-glacial sea-level rise. Well-known early studies include the work of Fisk (1959) on Padre Island, Bernard et al. (1970) on Galveston Island, Wilkinson (1975) on Matagorda Island, and Wilkinson and Basse (1978) on Matagorda Peninsula. The general process framework for development of the present shoreline is summarized in Morton (1979; 1994).

Most studies of Texas shoreline evolution have in common the assumption of rapid sea-level rise during the early Holocene, and slower rise with continued submergence through the middle to late Holocene until ca. 4-3000 yrs BP or later. This paper presents an alternative model for middle Holocene coastal landscape evolution.

Background

The study area is situated on the passive margin Texas coastal plain, extending from Matagorda to Corpus Christi bays (Fig. 1). The coastal plain consists of a series of low-gradient, fan-shaped alluvial-deltaic plains that emanate from each major river valley, as well as correlative estuarine and shorezone landforms and deposits (DuBar et al. 1991).

Sea-Level Change and Coastal Evolution: The Traditional View

The extensive Pleistocene alluvial-deltaic plains are referred to as the Beaumont Formation, and represent a succession of valley fills that developed during middle to late Pleistocene oxygen isotope stages (OIS) 10 to 5 (Blum and Price, 1998). The Ingleside shoreline is a distinct sandy barrier island / strand plain trend that comprises the mainland shore, is genetically related to the youngest Beaumont valley fills, and is well-developed along the central Texas coast between alluvial-deltaic headlands of the Colorado-Brazos and Rio Grande. Traditional views have considered the Ingleside to be from the last interglacial highstand (ca. 125,000 yrs BP - OIS 5e; DuBar et al., 1991), or to represent a mid Wisconsin highstand (OIS 3; Wilkinson et al., 1975; Shideler, 1986). The latter view is now unrealistic, given recent data that shows global (Chappel et al., 1996) and Gulf of Mexico (Rodriguez et al., 2000) middle Wisconsin sea-level was well below present, and could not have impacted landscapes at the elevation of the present-day mainland shoreline. Almost by default, this would place the deeply weathered Ingleside sands in the OIS 5e highstand, the most recent period prior to the Holocene when sea-level elevations were similar to present.

At the beginning of the OIS 4-2 glacial period (ca. 70-80,000 yrs BP), large coastal plain rivers cut valleys across Beaumont alluvial-deltaic plains and the Ingleside shoreline, and extended their courses as sea level fell across the newly-emergent shelf. Holocene coastal evolution is directly coupled to the sea-level rise that accompanied deglaciation, beginning ca. 20,000 yrs BP (see Fairbanks, 1989). A number of late Pleistocene to Holocene sea-level

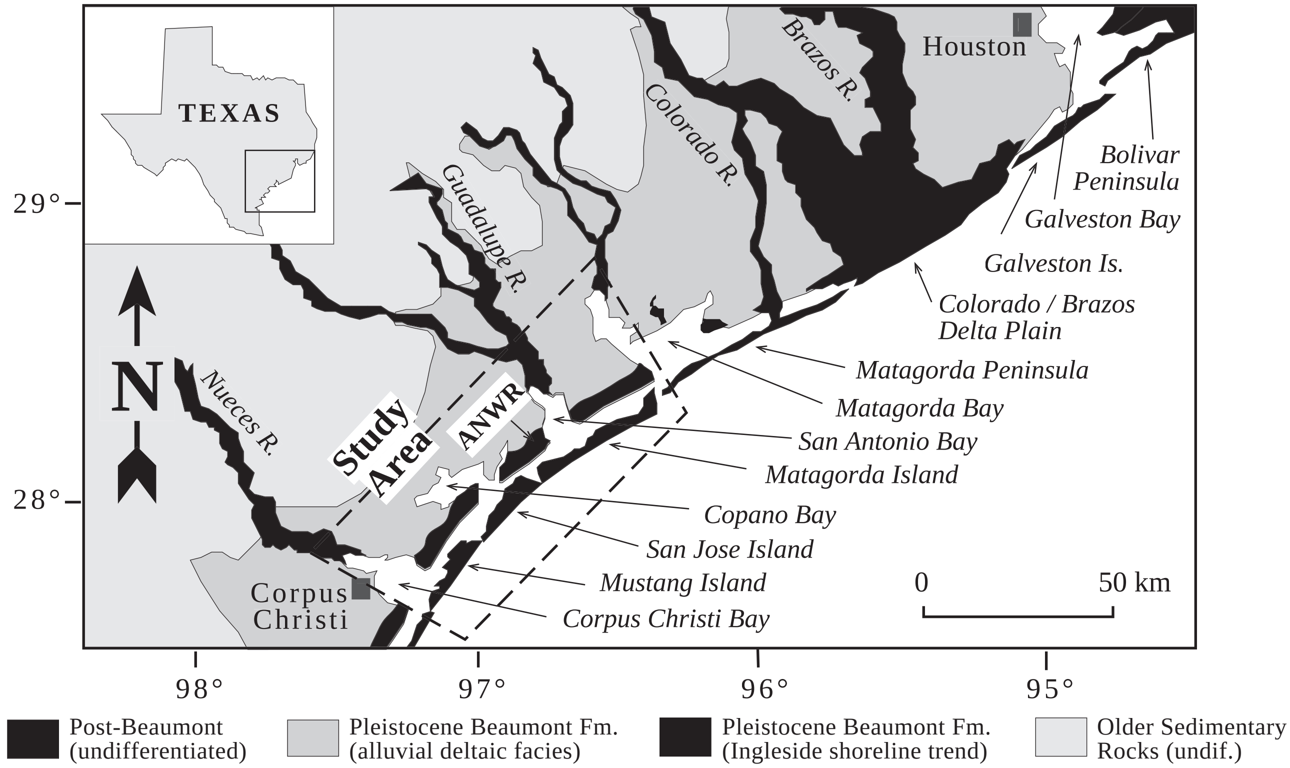

Figure 1. Simplified map of study area, with locations of headlands, bays, and barrier systems. ANWR indicates location of Aransas National Wildlife Refuge.

curves have been published for the western Gulf of Mexico (Curray 1960; Shepard 1963; Coleman and Smith, 1964; Nelson and Bray 1970; Frazier 1974; Thomas 1990), with each showing continual submergence until ca. 4-3000 yrs BP or later (Fig. 2A). During this transgression the Colorado, Brazos and Rio Grande filled their previously incised valleys and prograded delta plains, whereas the Sabine, Trinity, Guadalupe, and Nueces still discharge to bayhead deltas and "drowned-valley" estuaries or bays that are fronted by barrier island systems (Blum et al., 1995; Morton et al., 1996; Durbin et al., 1997; Aslan and Blum, 1999).

Wright (1980) used seismic data to estimate that initial flooding of OIS 2 incised valleys to form precursors of present-day bays occurred ca. 8-10,000 yrs BP, and present bay outlines were not reached until ca. 4000 yrs BP. Work by Paine (1991) in Copano Bay, as well as Anderson and Thomas (1991), Anderson et al. (1991; 1992), Siringin and Anderson (1993), and Rodriguez (1999) in Galveston Bay refined this general model. Most recently, Rodriguez (1999) argued that (A) seismically-identified "flooding surfaces" at -14 and -10 m demarcate rapid landward translation of environments and modification of bay morphologies due to episodic sea-level rise, (B) the last event of this kind occurred ca. 4000 yrs BP, and (C) modern sea-level positions were not reached until ca. 3000 yrs BP.

Holocene barriers are thought to have originated offshore ca. 9-7000 yrs BP, migrated landward late in the transgression, then accreted alongshore during the late Holocene highstand (Bernard et al. 1970; Wilkinson 1975; Morton 1994). Rodriguez (1999) also examined sand banks offshore from Galveston Island, the youngest of which is Sabine Bank, now ~30 km offshore and in water depths of -12 m. He used seismic data and a number of 14C ages to suggest that Sabine Bank originated as an early to middle Holocene barrier and has been reworked landward, the Sabine Bank shoreline was active until ca. 4000 yrs BP, and that Galveston barrier must have formed after ca. 3000 yrs BP. Rodriguez' view differs from that of Wilkinson (1975) primarily in that offshore barriers are not interpreted to have migrated landward to form cores to modern barriers, but instead were overstepped, and new barrier sandbodies formed farther landward during the highstand.

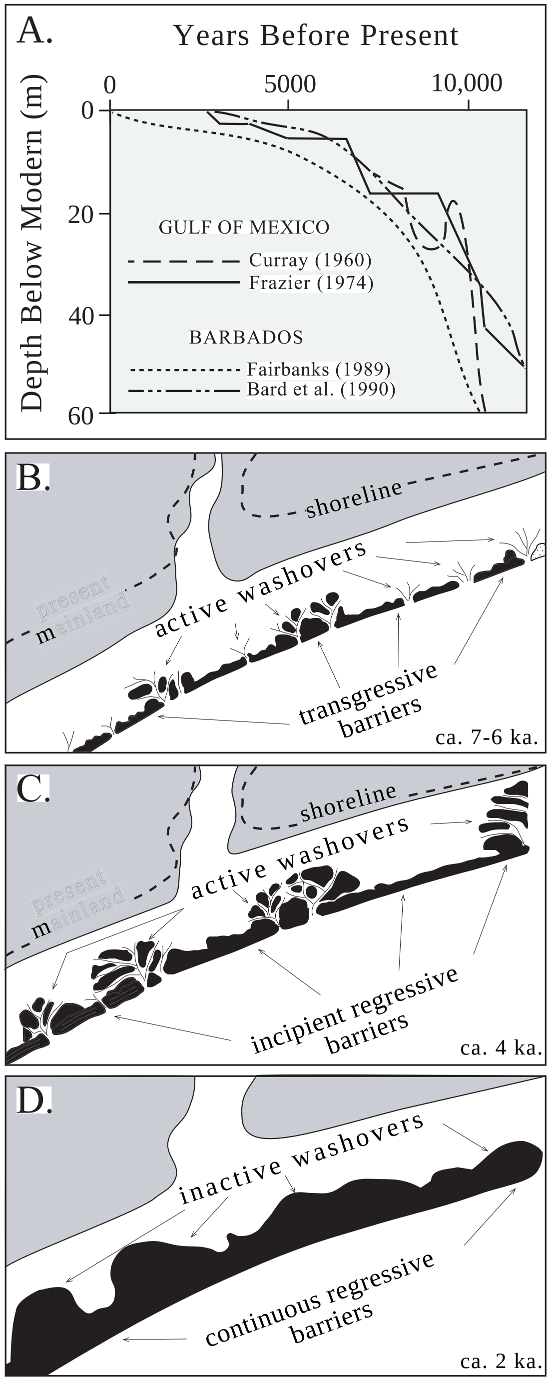

Figure 2. Conventional model for sea-level rise and coastal evolution. (A) Sea-level curves from the Gulf of Mexico and Barbados. Note the Bard et al. (1990) curve is in calendar years, whereas all others are in uncalibrated radiocarbon years. (B-D) Model for evollution of barrier shoreline (adapted and modified from Wilkinson, 1975). Recent model for Sabine Bank, presented in Rodriguez (1999), would place incipient barriers to the east farther offshore than what original Wilkinson model suggested.

Sea-Level Change and Coastal Evolution: Holocene Highstands?

Views of submergence until the late Holocene are based on data from now-submerged contexts where it would be difficult to resolve sea-level positions at or above modern. However, there is a long history to suggestions of Holocene highstands that draw on a variety of land-based data. Older interpretations are linked to high beach ridges in Mexico south of Rio Grande delta (Behrens 1966), subtidal foram assemblages above modern sea level on Rio Grande delta (Fulton, 1975), raised marshes on Rio Grande delta (Neck 1985), raised wind-tidal flat/clay dune complexes on the central Texas coast (Paine 1991), and high beach ridges in northwest Florida (Stapor et al. 1991; Tanner, 1992; Tanner et al., 1989). Previous claims of Holocene highstands have been criticized for a variety of reasons (Otvos 1995).

Most recently, Morton et al. (2000) discuss a range of Holocene landforms that are significantly higher in elevation than modern analogs, and suggest that they formed when sea level was higher than present. Key features include (a) higher cores to the regressive barriers, (b) large "washover fans" on the regressive barriers that may actually represent flood-tidal deltas that formed under a higher sea level, and are now emergent due to sea level fall, and (c) sets of accretionary bioclastic beach ridges along bay margins that are 1-2 m higher than modern ridges. At the very least, these landforms raise questions concerning the model of continual submergence. However, even though a handful of 14C ages on shells suggest these landforms are late Holocene in age (< ca. 3000 yrs BP), they remain imprecisely dated and difficult to interpret in terms of sea-level change vs. storm effects.

Middle Holocene Highstand: New Data

Blum et al. (in review) present new data on middle Holocene sea-level from a series of small shore-parallel ridges that occur in the mouths of Copano Bay tributaries (Fig. 3). These ridges trace laterally to relict wave-cut bluffs in Pleistocene surfaces and are intermediate in elevation between Beaumont alluvial plains and the active marsh. Ridge crest elevations are +2 m above mean high water (MHW), which is defined here as the upper limits to the *Spartina alterniflora* marsh (Fig. 3C). Ridges are well-drained and covered by Mesquite and cacti, with modern high marsh vegetation (mostly *Spartina patens*) 1 m below ridge crests.

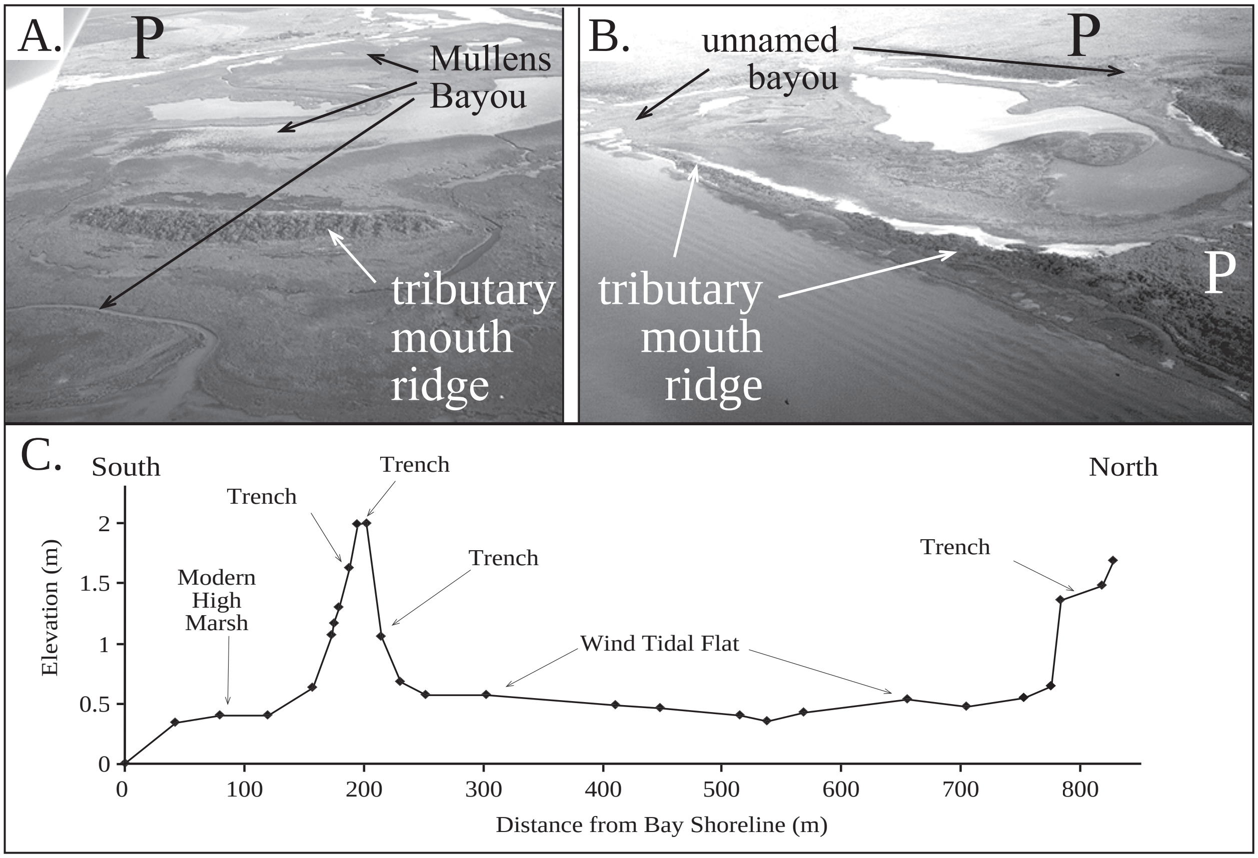

Figure 3. Shore parallel tributary mouth ridges in Copano Bay. (A) Large ridge in the middle of the Mullens Bayou valley, which has been detached from Pleistocene bluff lines by tidal creek migration. (B) Large ridge in unnamed tributary valley which remains attached to Pleistocene upland surface. (C) Topographic profile across tributary mouth ridge segment in Mullens Bayou. In part adapted from Blum et al. (in review).

Trench exposures within Mullens Bayou, one of the small tributaries to Copano Bay, show that Holocene strata under the ridge crest consist of 1.8 m of calcareous, grayish to yellowish brown sets of massive to weakly laminated fine sandy silt interbedded with shell hash. These deposits rest unconformably on weathered, non-calcareous Pleistocene Beaumont fluvial-deltaic deposits. Individual strata are 10-20 cm thick and commonly bounded by discrete shell hash layers 1-5 cm thick. An abundant microfauna is present in Holocene strata, and is dominated by the calcareous foraminifera that occupy shallow subtidal to intertidal bay environments (up to +0.2 m MHW; Williams, 1994). Blum et al. (in review) interpret tributary mouth ridges to be low-energy subtidal to intertidal spits and shoals that formed across the mouths of then-flooded bay tributaries when sea level was = +2 m relative to present MHW. These ridges are now emergent due to more recent sea-level fall and are segmented due to tidal channel migration.

Blum et al. (in review) report six ^{14}C ages from foram tests in Holocene strata at Mullens Bayou. Internal inconsistencies show that more chronological control is needed, yet calibrated ^{14}C ages range from ca. 6800 to ca. 4800 yrs BP, all within the middle Holocene. Hence sea level reached modern positions some 2-4000 years before standard interpretations would suggest, and was greater than or equal to +2 m higher than modern during the middle Holocene.

Middle Holocene Coastal Landforms

A middle Holocene highstand of this magnitude should have a noticeable imprint on the coastal landscape, yet landforms of middle Holocene age have not been identified in previous studies. Our recent field investigations within the Aransas National Wildlife Refuge (ANWR) have identified mainland ravinement surfaces, extensive progradational beach ridge plains, and associated deposits that deserve discussion and scrutiny in this context. Preliminary results are described below.

Mainland Ravinement Surface

Active wave-cut bluffs along the Copano and Guadalupe Bay margins expose a low-relief erosion surface that truncates paleosols developed in Ingleside and Beaumont strata at elevations of +1-2 m MHW (Fig. 4A). Just south of Heron Flats, along the western margins of Guadalupe Bay within the ANWR, the Ingleside landscape is truncated by a scarp that slopes gently towards the bay. Wave-cut bluffs here expose a truncated Ingleside paleosol at +1.65 m MHW, which is overlain by 0.3 m of stratified, medium sand mixed with shell hash and reworked carbonate nodules (Fig. 4B), then 0.5 m of laminated to massive fine sand and silt. The uppermost sandy and silty facies contains reworked blocks of the Ingleside paleosol that exceed 30 cm in diameter. Farther south, wave-cut bluffs at Dagger Point expose the same erosion surface, but here, the truncated paleosol is overlain by 80 cm of massive, strongly burrowed medium to fine sand, then 8 m of massive to cross-stratified eolian sand.

Since these erosion surfaces are commonly planar, ungullied, and occur away from bay tributaries, they are most likely unrelated to fluvial erosion. Instead, these surfaces resemble similar surfaces that are now forming due to wave ravinement, but at elevations of -0.5 to +0.5 m relative to present MHW. Accordingly, these older erosion surfaces are interpreted to have formed by wave ravinement as well, but when sea level was greater than or equal to +1 m MHW. At Heron Flats, the stratified sands that overlie this ravinement surface resemble sandy and shelly swash-zone strata that are now forming immediately in front of this bluff at present sea level, and are therefore interpreted to represent swash-zone strata that was deposited when sea level was greater than or equal to +1 m MHW. Overlying blocks of reworked Ingleside paleosol are interpreted to be of colluvial origin, shed from the adjacent wave-cut scarp after sea level had fallen and the scarp began to degrade, and massive sands and silts are interpreted to be of mixed eolian and sheetwash origin. At Dagger Point, the origin of massive and burrowed sands that rest on the ravinement surface is more problematic, but one interpretation might be a mixed marsh / washover environment slightly inland from an active bay margin swash zone.

Chronological control on this ravinement surface or the overlying deposits is lacking at present. However truncation and reworking of the weathered Ingleside paleosol, coupled with the unweathered, still-stratified nature of overlying deposits clearly indicates a Holocene age. The geographic extent of this ravinement surface has not been fully delineated, but it appears to be a common feature that can be recognized along actively eroding bay margins with surface elevations of less than 3 m.

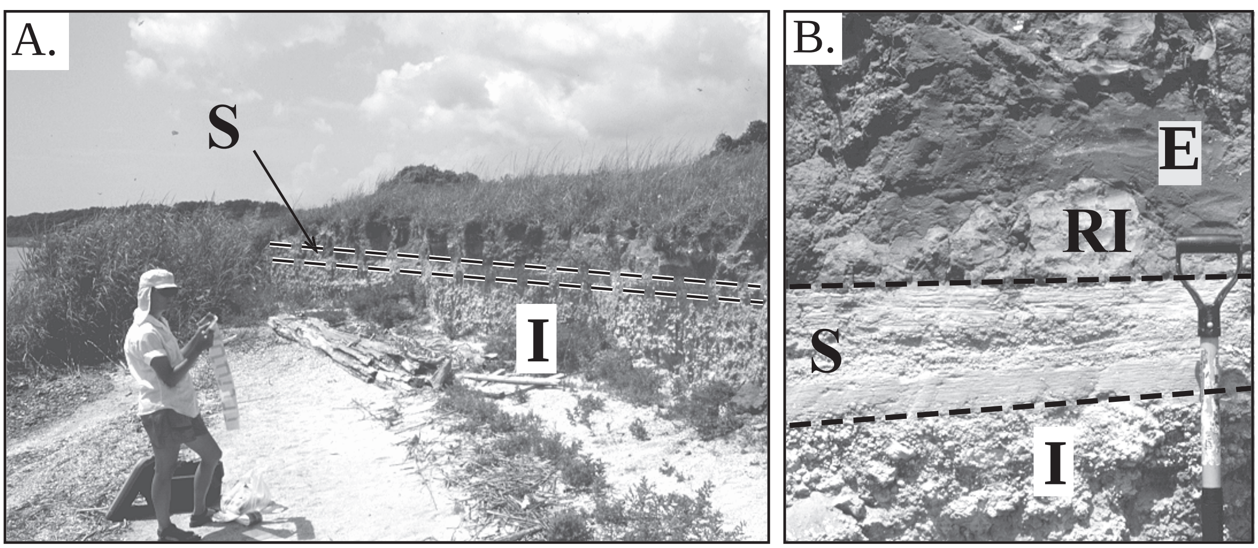

Figure 4. Erosion surfaces cut into deeply weathered Ingleside paleosols (I), as exposed in active wave-cut bluffs along the San Antonion Bay shoreline, within Aransas National Wildlife Refuge. (A) Perspective view, illustrating planar and ungullied nature of surface, as well as elevation above modern bayline (left). (B) Close-up view, illustrating Holocene stratified sand (S) on top of erosion surface at +1.8 m elevation along San Antonio Bay margin. Erosion surface is overlain by reworked Ingleside (RI) as well as eolian silt and sand (E).

Mainland Beach Ridge Plains

A series of shore-parallel landforms on the ANWR, farther seaward from the erosion surface described above, may prove critical in the context of Holocene coastal evolution. Although long considered to represent the “Ingleside” (see Fig. 2 in Wilkinson et al., 1975), these landforms have crisp, well-defined beach ridge and swale patterns, as well as slightly incised and inset relict shore-normal channels, very much unlike the degraded and eolian-modified landscape of the “Ingleside” farther inland (Fig. 5). Ridge heights reach elevations of +2.7 m MHW, and the entire beach ridge plain attains shore-normal widths of 1-3 km (Fig. 6A), roughly the same width as the modern regressive barriers like Galveston, Matagorda, or San Jose Islands. In short, these are large-scale coastal landforms.

Vibracores up to 4 m in depth were collected in two shore-normal transects across this beach ridge plain (Figs. 5 and 6). The most landward core in transect 1 penetrated the Ingleside paleosol at 1.9 m below the surface, which corresponds to -0.3 m MHW. Other cores did not reach the Ingleside, and were dominated by 3-4 m of massive to stratified, unweathered fine to very fine sand. Most sands are massive and burrowed with no preserved primary sedimentary structures. However, cores taken from ridge crests contain thin (up to 20 cm in thickness) lenses of planar and trough cross-strata interbedded within 3-4 m of mostly massive but clean sand. Planar and trough cross-strata are waterlain and resemble forebeach deposits on the modern barriers. Eolian caps are present on ridges to a depth of 1 m and generally increase in thickness in the landward direction. Eolian sediments consist of massive fine sands that have been slightly modified by pedogenesis, with A horizons and roots extending to depths of 20 cm.

Cores taken from swales more commonly display pervasive green and orange mottling at depths below 0.5 m, which is occasionally punctuated by distinct lenses (up to 10 cm) of unmottled, planar stratified sand. Mottling is interpreted to reflect marshy, acidic conditions coupled with a fluctuating water table that promotes alternating oxidizing (orange mottling) and reducing (green mottling) conditions, whereas planar-stratified sand is interpreted to represent high-energy storm washover events when sand was transported inland from the active beach ridge and deposited rapidly within an older pre-existing swale.

This suite of landforms is interpreted as a prograding beach ridge plain that rests unconformably on deeply weathered Ingleside sand, and the most landward core in transect 1 is interpreted to be close to the former shoreline, directly in front of a “shoreline of maximum transgression.” The age of this beach ridge plain is not yet known, but the unweathered and still-stratified nature of deposits clearly indicates a Holocene age. This beach ridge plain is no higher than beach ridges on the modern barriers, and sedimentary structures typical of swash zone enviornments occur at elevations that correspond to present sea level, so this beach ridge plain does not require a higher sea level to have formed. One possible interpretation would be that this beach ridge plain represents progradation of the mainland coastline following maximum highstand during the middle Holocene.

The extent of this Holocene beach ridge plain has not been fully documented. However, preliminary mapping indicates that it extends from Lavaca Bay to just south of Aransas Pass, where the “true Ingleside” of last interglacial age comprises the mainland shoreline. This includes much of the cities of Fulton, Rockport, and Aransas Pass along State Highway 35.

Discussion

Blum et al. (in review) interpretation of a middle Holocene highstand along the Texas coast runs counter to prevailing views, as well as the most recent studies in this same area (Rodriguez, 1999). These contrasting views need to be reconciled, but the concept of a middle Holocene highstand is far from unrealistic. Highstands of similar age and magnitude have been interpreted for many low-latitude coasts that are far-removed from the isostatic effects associated with deglaciation (see Pirazzoli, 1991), whereas Tushingham and Peltier's (1992) geophysical model suggests that a middle Holocene highstand should be recorded along the Texas coast. Moreover, geomorphic data from the eastern Gulf Coast in Florida have long-suggested a middle Holocene highstand (Tanner, 1992). Finally, very recent work in Antarctica suggests minimum ice volumes during the middle Holocene, and glacial expansion with ice thickening after ca. 4000 yrs BP (see Goodwin, 1998). Such data suggest there may be a global ice volume signature in middle Holocene highstands, something that has gone unrecognized in previous “eustatic” curves (see Fairbanks, 1989; Bard et al., 1990) and geophysical modeling efforts (see Peltier, 1998; Fleming et al., 1998). Unsorting isostatic vs. glacio-eustatic mechanisms will be a key issue that deserves close scrutiny.

A middle Holocene highstand would have significant implications for traditional views of landscape evolution along the Texas Gulf Coast. As noted above, a highstand at this time would imply that sea level reached present positions some 2-4000 years before standard interpretations of sea-level history and coastal evolution would suggest. Moreover, a middle Holocene highstand of this magnitude should have a noticeable imprint on the coastal landscape, but landforms of middle Holocene age have not been iden-

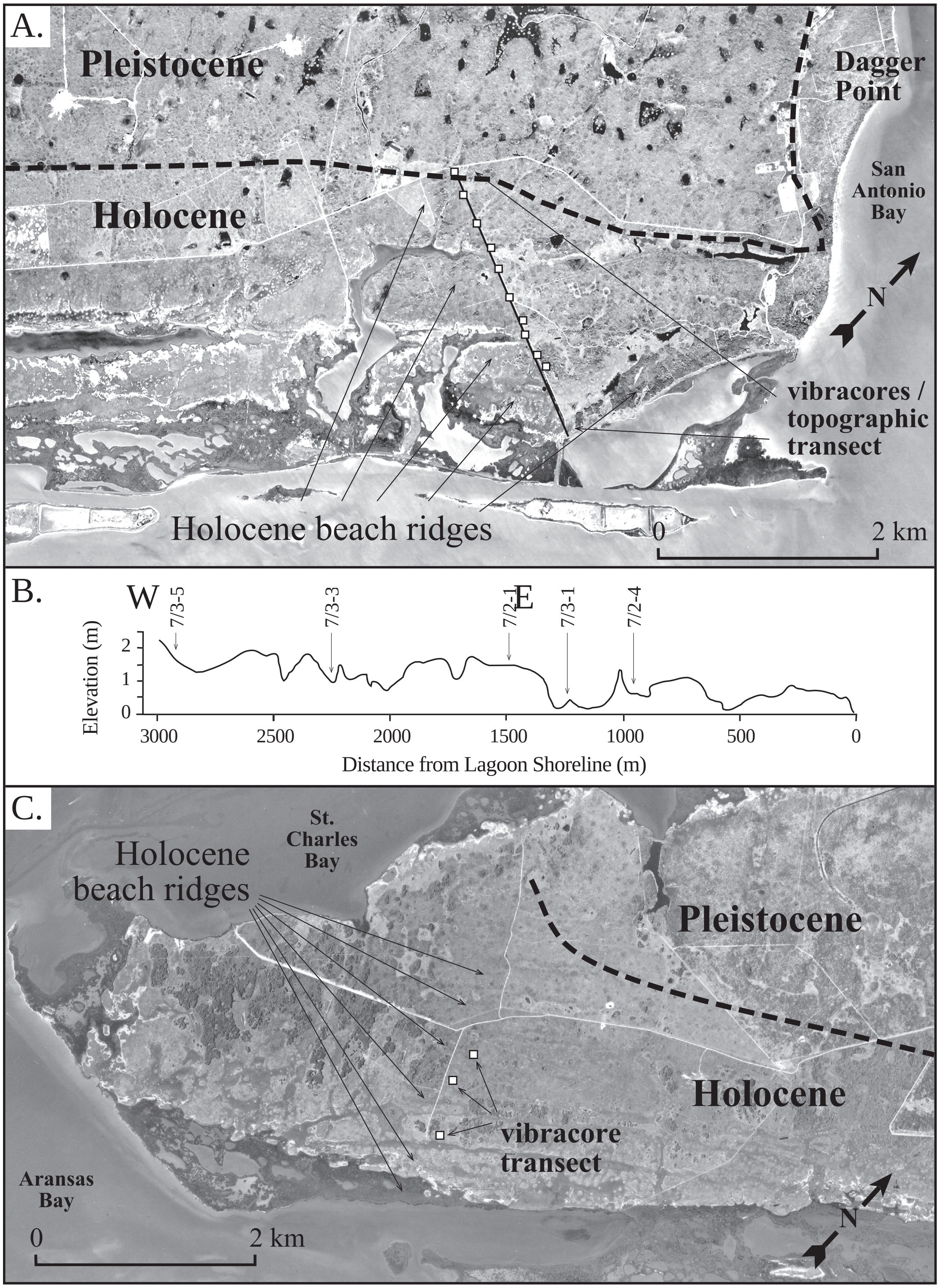

Figure 5. Air photos of mainland beach ridge plains on Blackjack Peninsula, Aransas National Wildlife Refuge. (A) East end of Blackjack Peninsula, with locations of vibracores and interpreted Pleistocene-Holocene boundary. Also shown is Dagger Point locality, where Pleistocene Ingleside sands are overlain by thin marsh strata of Holocene age, then up to 10 m of Holocene eolian sands (see text description of erosion surfaces). (B) Topographic profile of beach ridge plain along east side of Blackjack Peninsula (along vibracore transect in Fig 5A). (C) West end of Blackjack Peninsula, with locations of vibracores and interpreted Pleistocene-Holocene boundary. Scale for 5A is same as 5C.

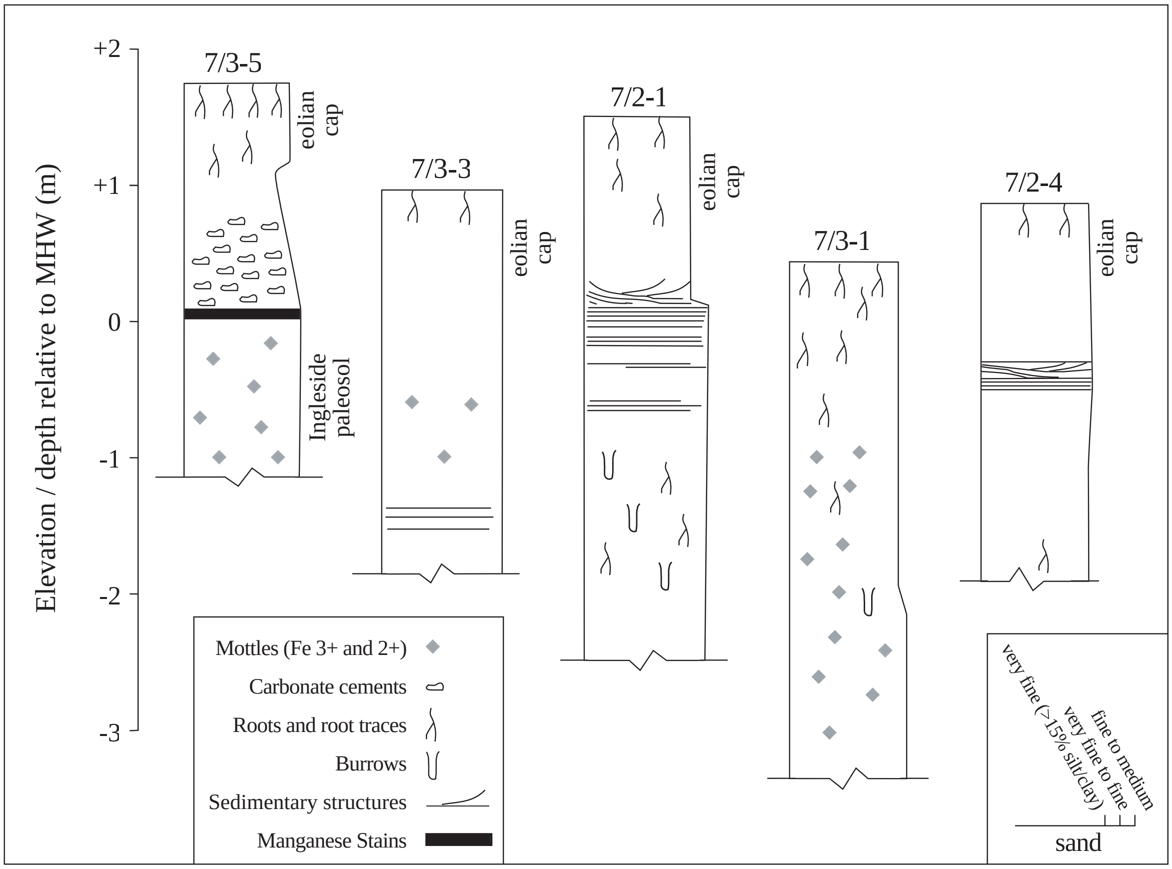

Figure 6. Description of selected vibracores from Holocene beach ridge plain on Blackjack Peninsula. See Figures 5A and 5B for core locations.

tified in previous studies. We argue that the erosion surfaces and beach ridge plains described above represent widespread impact of Holocene coastal processes on the mainland shore, something that is heretofore unrecognized. Although not yet linked through geochronological data, these landforms and deposits may record the impact of a middle Holocene highstand (ravinement surfaces) and subsequent fall to presewnt elevations of lower (prograding beach ridge plains).

Finally, the presence of extensive, large-scale Holocene beach ridge plains on the mainland raises questions about barrier island development and evolution. In their present position near the mainland shore, barriers severely limit fetch and wave set-up in lagoon environments, such that large and continuous features such as the beach ridge plains described above are not forming today. As a result, it can be argued that (A) the barriers were present when the mainland beach ridge plain was prograding, but they were much farther seaward such that they did not significantly limit fetch and wave set-up, or (B) the barriers were yet not present along this stretch of the coast, and the mainland beach ridge plain formed under open marine conditions. The first of these two possibilities may correspond best with new data produced by Rodriguez (1999) for the Sabine Bank shoreline farther offshore and to the east, as well as with original data from Wilkinson (1975) that indicates Matagorda barrier sands overlie lagoon facies and the barrier system had in fact migrated landward for some distance.

At the very least, recognition of mainland ravinement surfaces and beach ridge plains of Holocene age suggests that our understanding of coastal evolution is far from complete. Figure 7 summarizes our current thinking on middle Holocene sea-level and evolution of the central Texas coast, and can serve as an alternative testable model for future studies. We now think it likely that much of the mainland coastal landscape of Texas, at elevations less than +3 m, will bear the imprint of this middle Holocene highstand. This imprint may be in the form of veneers of Holocene strata resting on erosionally truncated Pleistocene landforms, or fully-developed Holocene constructional landforms and their associated deposits. The data presented here represent but a small part of continuing efforts to address these issues.

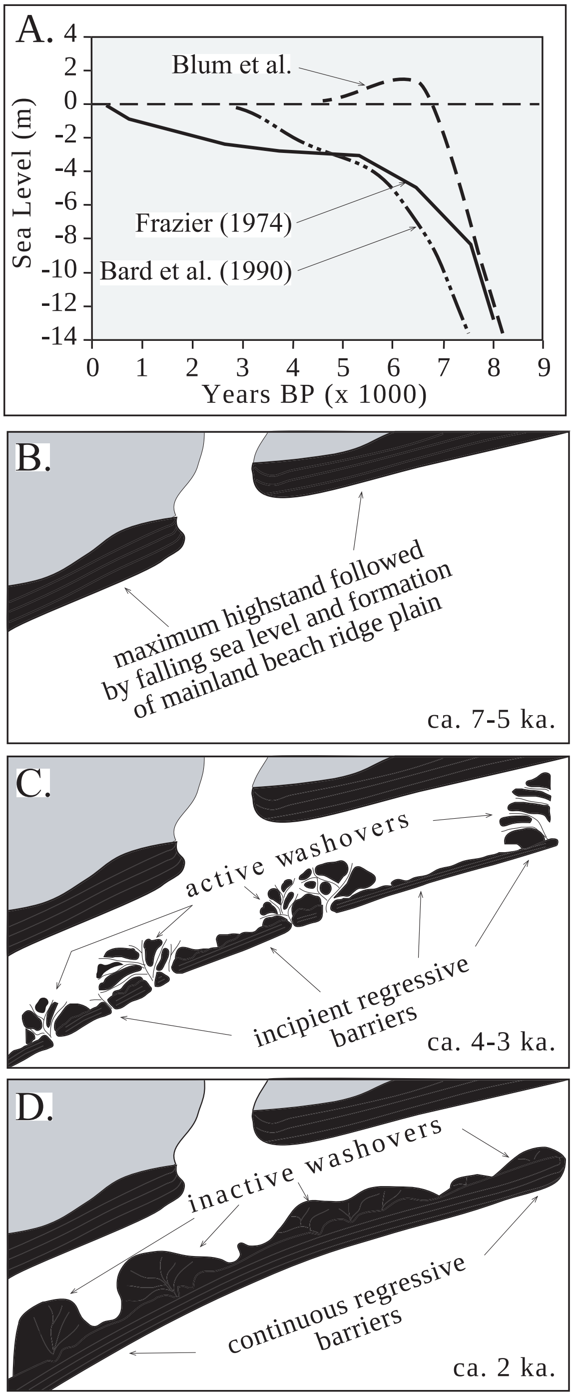

Figure 7. Alternative model for sea-level change and coastal evolution. (A) Blum et al.'s (in review) sea-level curve for the middle Holocene, contrasted with that from Frazier (1974) in the Gulf of Mexico and Bard et al. (1990) in Barbados. Each curve is in calendar years before present. (B, C, D) Revised model for shoreline evolution, emphasizing development of middle Holocene beach ridge plains on the mainland. Barrier island story is hypothetical only, and it is uncertain as to whether they were present but farther offshore during the middle Holocene, or had not yet formed (see text).

Acknowledgments

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References

Anderson, J.B. and M.A. Thomas, 1991, Marine ice sheet decoupling as a mechanism for rapid episodic sea level change: the record of such events and their influence on sedimentation: Sedimentary Geology, v. 70, p. 87-104.

Anderson, J.B., F.B. Siringin, W.C. Smyth, and M.A. Thomas, 1991, Episodic nature of Holocene sea level rise and the evolution of Galveston Bay, in Coastal Depositional Systems of the Gulf of Mexico: GCSSEPM 12th Annual Research Conference, p. 8-14.

Anderson, J.B., M.A. Thomas, F.P. Siringin, and W.C. Smyth, 1992, Quaternary evolution of the Texas Coast and Shelf, in C.H. Fletcher III and J.F. Wehmiller, eds., Quaternary Coasts of the United States: Marine and Lacustrine Systems: SEPM Special Publication 48, p. 253-265.

Aslan, A. and Blum, M.D., 1999, Contrasting styles of Holocene avulsion, Texas Gulf Coastal Plain, in Smith, N.D. and Rogers, J.J., eds., Fluvial Sedimentology VI; Special Publication 28, International Association of Sedimentologists, p. 193-209.

Bard, E., B. Hamelin, R.G. Fairbanks, and A. Zindler, 1990, Calibration of the 14C timescale over the past 30,000 yrs using mass spectrometric U-Th ages from Barbados corals: Nature, v. 345, p. 405-410.

Behrens, E.W., 1966, Recent emerged beach in Eastern Mexico: Science, v. 152, p. 642-643.

Bernard, H.A., C.F. Major, B.S. Parrott, and R.J. LeBlanc, Sr, 1970, Recent Sediments of Southeast Texas: Field Guide to the Brazos Alluvial-Deltaic Plain and the Galveston Barrier Island Complex.: Bureau of Economic Geology, Guidebook 11, The University of Texas at Austin.

Blum, M.D. and D.M. Price, 1998, Quaternary alluvial plain deposition in response to interacting glacio-eustatic and climatic controls, Gulf Coastal Plain of Texas, in K. Shanley, and P. McCabe, eds., Relative Role of Eustasy, Climate, and Tectonism in Continental Rocks: SEPM Special Publication No. 59, p. 31-48.

Blum, M.D., Morton, R.A., and Durbin, J.M., 1995, "Deweyville" terraces and deposits of the Texas Gulf Coastal Plain: GCAGS Transactions, v. 45, p. 53-60.

Blum, M.D., T.J. Misner, E.S. Collins, D.B. Scott, R.A. Morton, (in review) Middle Holocene sea-level rise and highstand at +2m, Texas Gulf Coast: Journal of Sedimentary Research.

Chappell, J., A. Omura, T. Esat, M. McCulloch, J. Pandolfi, Y. Ota, and B. Pillans, 1996, Reconciliation of late Quaternary sea levels derived from coral terraces at Huon Peninsula with deep sea oxygen isotope records: Earth and Planetary Science Letters, v. 141, p. 227-236.

Coleman, J.M. and W.G. Smith, 1964, Late Recent rise of sea level: Geological Society of America Bulletin, v. 79, p. 833-840.

Curray, J.R., 1960, Sediments and history of Holocene transgression, continental shelf, northwest Gulf of Mexico, in F.P. Shepard, F.B. Phleger, and T.H. Van Andel, eds., Recent Sediments Northwest Gulf of Mexico: AAPG, pp. 221-226.

DuBar, J.R., T.E. Ewing, E.L. Lundelius Jr, E.G. Otvos, and C.D. Winker, 1991, Quaternary Geology of the Gulf of Mexico Coastal Plain, in R.B. Morrison, ed., Quaternary Non-Glacial Geology of the Conterminous United States: v. K-2, The Geology of North America: Geological Society of America, p. 583-610.

Durbin, J.M., M.D. Blum, and D.M. Price, 1997, Late Pleistocene stratigraphy of the lower Nueces River, Corpus Christi, Texas; glacio-eustatic influences on valley-fill architecture: GCAGS Transactions, v. 47, p. 119-129.

Fairbanks, R.G., 1989, A 17,000 year glacio-eustatic sea-level record: influence of glacial melting rates on the Younger Dryas event and deep ocean circulation: Nature, v. 342, p. 637-642.

Fisk, H.N., 1959, Padre Island and Laguna Madre Flats, coastal south Texas: Louisiana State University, Second Coastal Geography Conference, Baton Rouge, pp. 103-151.

Fleming, K., Johnston, P., Zwartz, D., Yokoyama, Y., Lambeck, K., and Chappell, J., 1998, Refining the eustatic sea-level curve since the Last Glacial Maximum using far- and intermediate-field sites: Earth And Planetary Science Letters, v. 163, p. 327-342.

Frazier, D.E., 1974, Depositional Episodes: Their Relationship to the Quaternary Framework in the Northwestern Portion of the Gulf Basin: Geological Circular 74-1, Bureau of Economic Geology, The University of Texas at Austin.

Fulton, K.J., 1975, Subsurface stratigraphy, depositional environments and aspects of reservoir continuity, Rio Grande delta, Texas: Unpubl. Ph. D. Dissertation, University of Cincinnati, 314 p.

Goodwin, I., 1998, Did changes in Antarctic ice volume influence late Holocene sea level lowering?: Quaternary Science Reviews, v. 17, p. 319-332.

Morton, R.A., 1979, Temporal and spatial variations in shoreline changes and their implications, examples from the Texas coast: Journal of Sedimentary Petrology. v. 49, pp. 1101-1112.

Morton, R.A., 1994, Texas barriers, in R.A. Davis, ed., Geology of Holocene Barrier Islands; Springer-Verlag, p. 75-114.

Morton, R.A., Blum, M.D., and White, W.A., 1996, Valley fills of incised coastal plain rivers, Southeastern Texas: GCAGS Transactions, v. 46, p. 321-331.

Morton, R.A., J.G. Paine, and M.D. Blum, 2000, Responses of stable bay margins and barrier island systems to Holocene sea level changes, western Gulf of Mexico: Journal of Sedimentary Research, v.70, p. 478-490.

Neck, R.W., 1985, Palaeoecological implications of a Holocene fossil assemblage, lower Rio Grande, Cameron County, Texas: University of Texas at Austin Texas Memorial Museum Pearce-Sellards Series 41, 20p.

Nelson, H.F. and E.E. Bray, 1970, Stratigraphy and history of the Holocene sediments in the Sabine-High Island area, Gulf of Mexico, in J.P. Morgan, and R.H. Shaver, eds., Deltaic Sedimentation, Modern and Ancient: SEPM Special Publication No. 15, p. 48-77.

Otvos, E.G., 1995, Multiple Pliocene-Quaternary marine highstands, northeast Gulf coastal plain - fallacies and facts: Journal of Coastal Research, v. 11, p. 984-1002.

Paine, J.G., 1991, Late Quaternary Depositional Units, Sea Level, and Vertical Movement Along the Central Texas Coast: Unpubl. Ph. D. Dissertation, University of Texas at Austin.

Peltier, W.R., 1998, Post-glacial variations in the level of the sea: implications for climate dynamics and solid-earth geophysics: Reviews of Geophysics, v. 36, p. 603-689.

Pirazzoli, P.A., 1991, World Atlas of Holocene Sea-Level Changes: Elsevier, Amsterdam, 300 p.

Rodriguez, A.B., J.B. Anderson, L.A. Banfield, M. Taviani, K. Abdulah, and J.N. Snow, 2000, Identification of a -15m middle Wisconsin shoreline on the Texas inner continental shelf: Palaeogeography, Palaeoclimatology, Palaeoecology, v. 158, p. 25-43.

Rodriguez, A.B., 1999, Sedimentary Facies and Evolution of Late Pleistocene to Recent Coastal Lithosomes on the East Texas Shelf: Unpublished Ph.D. Dissertation, Rice University, 203 p.

Shepard, F.P., 1963, Thirty-five thousand years of sea level, in Essays in Marine Geology in Honor of K. O. Emory: University of Southern California Press, Los Angeles, p. 1-10.

Shideler, G.R., 1986, Stratigraphic Studies of a Late Quaternary Barrier-Type Coastal Complex, Mustang Island-Corpus Christi Bay Area, South Texas Gulf Coast: Professional Paper 1328, United States Geological Survey, Washington, D. C.

Siringin, F.P. and J.B. Anderson, 1993, Seismic facies, architecture, and evolution of the Bolivar Roads tidal inlet / delta complex, east Texas Gulf Coast: Journal of Sedimentary Petrology, v. 63, pp. 794-808.

Stapor, F.W. Jr, T.D. Mathews, and F.E.Lindfors-Kearns, 1991, Barrier island progradation and Holocene sea-level history in southwest Florida: Journal of Coastal Research, v. 7, p. 815-838.

Tanner, W.F., 1992, Late Holocene sea-level changes from grain-size data: evidence from the Gulf of Mexico: The Holocene, v. 2, p. 249-254.

Tanner, W.F., S. Demirpolat, F.W. Stapor, and L. Alvarez, 1989, The "Gulf of Mexico" late Holocene sea level curve: Gulf Coast Association of Geological Societies Transactions, v. 39, p. 553-562.

Thomas, M.A., 1990, The Impact of Long-Term and Short-Term Sea-Level Changes on the Evolution of the Wisconsinan-Holocene Trinity/Sabine valley system, Texas Continental Shelf: Unpublished Ph.D. dissertation, Rice University, Houston, 247 p.

Toscano, M.A. and J.Lundberg, 1998, Early Holocene sea-level record from submerged fossil reefs on the southeast Florida margin: Geology, v. 26, p. 255-258.

Tushingham, A.M. and W.R. Peltier, 1992, Validation of the ICE-3G model of Wurm-Wisconsin deglaciation using a global data base of relative sea level histories: Journal of Geophysical Research, v. 97, pp. 3285-3304.

Wilkinson, B.H., 1975, Matagorda Island, Texas: the evolution of a Gulf Coast barrier complex: Geological Society of America Bulletin, v. 86, p. 959-967.

Wilkinson, B.H., McGowen, J.H. and Lewis, C.R., 1975, Ingleside strandplain sand of the central Texas coast: AAPG Bulletin, v. 59, p. 347-352.

Wilkinson, B.H. and Basse, R.A., 1978, Late Holocene history of the Central Texas coast from Galveston Island to Pass Cavallo: Geological Society of America Bulletin, v. 89, p. 1592-1600.

Williams, H.F.L., 1994, Intertidal benthic foraminiferal biofacies on the central Gulf Coast of Texas: modern distribution and application to sea-level reconstruction: Micropaleontology, v. 40, p. 169-183.

Wright, S.S., 1980, Seismic Stratigraphy and Depositional History of Holocene Sediments on the Central Texas Gulf Coast: Unpubl. MA Thesis, University of Texas at Austin.

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