Tempestuous highs and lows in the Gulf of Mexico

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The nature of Holocene sea-level change has been hotly debated ever since absolute dating allowed for detailed sea-level reconstructions (Shepard, 1964). Several decades later, sea-level history in the Gulf of Mexico is still being disputed. Reconstructions using presently submerged samples indicate a gradual sea-level rise during the Holocene (Törnqvist et al., 2006; Wright et al., 2005; Milliken et al., 2008), whereas work on subaerial beach ridges suggests more complex sea-level behavior (e.g., Stapor et al., 1991; Tanner, 1992; Morton et al., 2000). Beach ridge complexes from Texas (Morton et al., 2000) and Alabama (Blum et al., 2003) are interpreted to indicate a mid-Holocene highstand of ~+2 m, followed by a sea-level fall in the late Holocene.

Seemingly, the sea-level history interpreted from beach ridges conflicts with the evidence of gradual submergence. Can this paradox be resolved? Blum et al. (2008, p. 675 in this issue) propose that localized subsidence can explain the gradual submergence indicated by the Mississippi delta sea-level data (Törnqvist et al., 2006; Fig. 1A). This work refines our understanding of isostatic mechanisms active in deltaic regions (e.g., Jurkowski et al., 1984; Ivins et al., 2007; Hutton and Syvitski, 2008) by considering the loading effects associated with deglacial valley incision and subsequent filling and delta growth. The isostatic response of the Mississippi delta and adjacent coasts modeled by Blum et al. provides a tantalizing solution for resolving the apparent contradictions between the Törnqvist et al. (2006) and Blum et al. (2003) data sets, and implies support for the mid-Holocene highstand hypothesis.

The Blum et al. (2008) solution, however, cannot explain the discrepancy between the inferred highstand evidence and other Gulf of Mexico records outside the Mississippi delta. A recent compilation of well-constrained data from northeastern Texas and Louisiana closely matches the Törnqvist et al. record (Milliken et al., 2008). Similarly, salt-marsh samples from northwestern Florida closely track the Mississippi submergence trend, and terrestrial samples provide an upper bound for sea level, inconsistent with a mid- Holocene highstand (Wright et al., 2005; Fig. 1A). The Florida salt-marsh data that are older than 4 ka plot slightly above contemporaneous data from the Mississippi delta; however, the magnitude of the additional subsidence in the latter data set is substantially less than that modeled by Blum et al.

Much of the criticism of the highstand hypothesis is aimed at the accuracy of beach ridge chronologies, as well as the indicative meaning of these features; i.e., how precisely they can be related to past sea levels. Beach ridges have proven difficult to accurately date. Organic carbon and marine shells preserved within ridges are not always contemporaneous with the beach ridges themselves, and radiocarbon dating is possible only by using specimens that indicate minimal reworking before burial (e.g., Stapor et al., 1991; Rodriguez et al., 2004; Giosan et al., 2006). Optically stimulated luminescence (OSL) techniques have also been used to date beach ridges, but at times large analytical and geological uncertainties exist (Otvos, 2005), requiring confirmation by complementary methods such as radiocarbon dating.

Distinguishing between intertidal and supratidal facies in beach ridges is often difficult (Otvos, 1995, 2000). Using ground-penetrating radar profiles coupled with coring, Rodriguez and Meyer (2006) examined the beach ridge complexes of the Morgan Peninsula, Alabama (Little Point Clear and Edith Hammock; Fig. 1C) that Blum et al. (2003, 2008) present as evidence for a highstand. However, the monotonic rise of the contact between the foreshore and eolian deposits in these ridge sets was interpreted by Rodriguez and Meyer (2006) as evidence for a gradual rise in sea level.

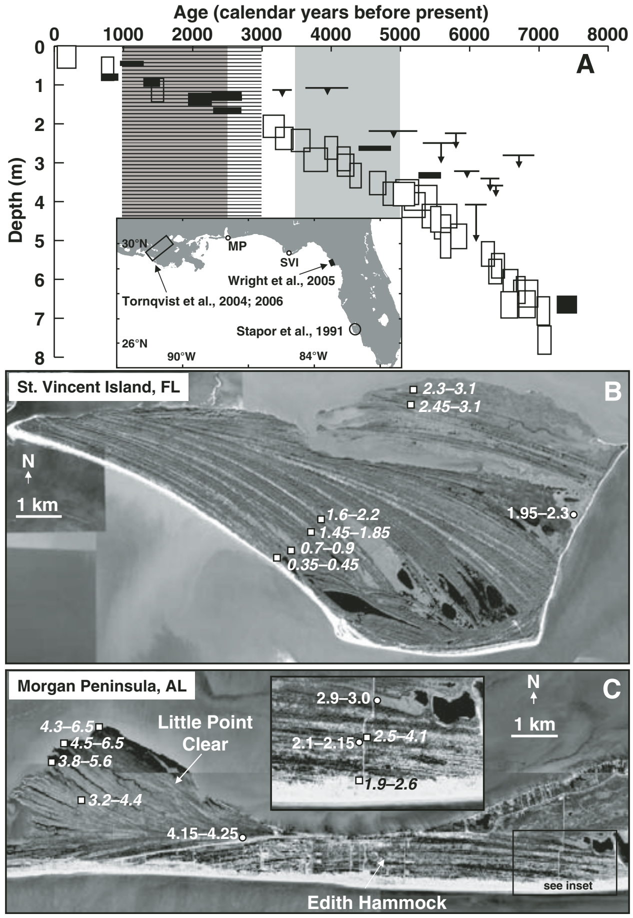

Figure 1. A: Sea-level data from the Mississippi delta (open boxes; from Törnqvist et al., 2006) and northwestern Florida (black boxes; Wright et al., 2005). Boxes represent age and vertical uncertainties. Bars with arrows are dated terrestrial samples from northwestern Florida, and length of the arrow represents vertical uncertainty. Locations of samples are noted in map (inset). Horizontal lines indicate interval of active tropical cyclone regime in the Gulf of Mexico from 1 to 3 ka (Liu, 2004), gray shading indicates active hurricane intervals 1–2.5 ka and 3.5–5 ka in Puerto Rico (Donnelly and Woodruff, 2007). B: Aerial photograph of St. Vincent Island, Florida (SVI on site map). OSL ages in thousands of yr B.P. (from López and Rink, 2008) are noted with italics and squares. Radiocarbon date from Tanner (1992) is noted with a circle. C: Aerial photograph of Morgan Peninsula, Alabama (MP on site map) and the Edith Hammock and Little Point Clear beach ridge sets. OSL ages (from Blum et al., 2003) are noted with italics and squares. Radiocarbon dates from Rodriguez and Meyer (2006) are noted with circles.

Many of the beach ridges cited as support for a sea-level highstand appear to be late Holocene in age. For example, both the St. Vincent Island (Tanner, 1992; Lopez and Rink, 2008) and Edith Hammock (Blum et al., 2003; Rodriguez and Meyer, 2006) systems were constructional primarily between 1 and 3 ka (Figs. 1B and 1C). Beach ridge systems of southwest Florida also developed during this interval (Stapor et al., 1991). Assuming that the data indicating gradual submergence are correct (Fig. 1A), these beach ridge systems formed when sea level was between −2 m and −0.5 m of its present elevation, well within reach of storm waves over the last 3.0 ka (Rodriguez and Meyer, 2006). Could these beach ridge complexes be related to changes in storminess?

Sediment-based proxy reconstructions from the western North Atlantic indicate intervals of increased intense tropical cyclone activity over the later half of the Holocene (e.g., Liu, 2004; Donnelly and Woodruff, 2007). Though paleo-storm reconstructions are relatively few and of varying resolution and quality (e.g., Otvos, 1999, 2002; Lambert et al., 2003), all available records indicate more hurricane activity between 2.5 and 1.0 ka in the western North Atlantic. Reconstructions from the northern Gulf of Mexico indicate more frequent intense hurricane landfalls between ca. 3 and 1 ka (Liu, 2004). Consequently, many of the modern beach ridge complexes in the northern Gulf of Mexico appear to have formed during a period of increased hurricane activity when sea level was less than 2 m below the modern level. Little Point Clear beach ridges on the Morgan Peninsula (Blum et al., 2003; Fig. 1C) may have developed as early as 5.4–4.2 ka when sea level was 3–4 m below modern level. Observations from Puerto Rico suggest an earlier active tropical cyclone interval between 5.0 and 3.6 ka (Donnelly and Woodruff, 2007) and perhaps storminess increased in the Gulf of Mexico during this period as well.

Highstand proponents have argued that beach ridges cannot be built by storms because storms are typically erosional and the rate of beach ridge formation is considerably slower than the recurrence rate of storms at any one location (Tanner, 1995; Morton et al., 2000). Implicit in these arguments is the assumption that changes in storm climatology would simply alter the number of landfalls at any one location. This interpretation overlooks the general change in wave climatology that would result during active tropical cyclone regimes. Direct impact of intense storms, such as hurricanes in the Gulf of Mexico, would likely result in significant coastal erosion at landfall locations (Rodriguez and Meyer, 2006). However, for every direct strike many more tropical cyclones would traverse the Gulf of Mexico, significantly increasing the overall wave climate during hurricane seasons, and potentially leading to an increase in the frequency of constructional swells (Otvos, 1995, 2000). For example, Komar and Allan (2008) document an increase in summer wave heights along the East Coast of the United States since the 1970s associated with the increase in tropical cyclone activity over recent decades.

Increases in “fair-weather” swell frequency and height during periods of more tropical cyclone activity in the Gulf of Mexico may provide an alternative explanation for beach ridges developing a few meters above their contemporaneous sea level. If the storm hypothesis is shown to be valid, it would largely resolve the debate concerning the nature of Holocene sea-level change in the Gulf of Mexico. Testing this hypothesis will clearly depend on the development of reliable proxies for wave energy to reconstruct past storminess, detailed surveying and accurate dating of beach ridge complexes, constraining local variations in sediment supply, and a better understanding of beach ridge morphodynamics.

ACKNOWLEDGMENTS

We thank A. Ashton, I. Buynevich, J. Syvitski, M. Toomey, E. Uchupi, and J. Woodruff for valuable discussions.

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Printed in USA