SUPPLEMENTARY MATERIAL

Geological Setting

This study focused on the coastal plain of South Carolina Atlantic seaboard (Fig. 1 SM). The original source data used in the paper are all from marine Pleistocene-aged deposits and their regional authors are listed in Figure 1. We now assign the Marietta unit (informal) to the Pleistocene and therefore it is the oldest Pleistocene unit identified at the surface (Fig. 3g of paper). The Marietta unit of South Carolina (DuBar et al., 1974) was formerly assigned to the Pliocene. The Pliocene age was based on the correlation with the Bear Bluff Formation age of 1.8-2.4 Ma (McCartan et al., 1982). The change of the Marietta unit’s age assignment results from the proposed change in the base of the Pleistocene from 1.8 Ma to 2.558 Ma by the International Commission on Stratigraphy in 2009 (Gibbard and Head, 2009), and from age dates from Weems, Lewis, and Crider (2011) which revised the Marietta unit’s age to 1.6 Ma.

Mapping Compilation

There is a well-established body of work related to these formations and features in South Carolina and their correlations to other states in the southeastern United States (Tables 1 and 2 SM).The geological formations established from mapping and their associated features, escarpments (scarp), terrace, unconformities, are used to establish that the toe elevation of the scarp is our indicator for former relative sea level elevation (terms defined in Table 4 SM). The sea level indicators used in this paper are derived from geological mapping (Fig. 1 of paper; Tables 2 and 3 SM). We assume elevation errors are small since many measurements were made across a substantially large area of study (~ 8000 km2), as were measurements in comparable areas of map coverage in other studies while other studies have larger error ranges (confidence intervals) for possible elevations. For example, Waelbroeck et al. (2002) have estimated confidence intervals of ± 10 m. Our mapping, with elevations derived from USGS 7.5-minute 1:24,000 scale topographic maps, has a much smaller elevation error range.

Regional Stratigraphic Correlation

In southeastern North America the naming of many Pleistocene stratigraphic units are named after their associated geomorphic features (i.e. Shattuck 1901a; 1901b; 1906; Clark et al., 1912), and predate the now-standard North America Stratigraphic Code (North American Commission on Stratigraphic Nomenclature, 2005). For example, a terrace and its genetically related subsurface sedimentary deposits often share the same name, as in the Pamlico terrace and Pamlico Formation (Clark et al., 1912).

Correlatable formations, and geomorphic features, are critical to interpreting relative sea-level history. Locally there are difficulties correlating some of the stratigraphy and geochronology this has resulted in some inconsistent stratigraphic assignments. These differences in stratigraphy can confuse the correlation of formations with Marine Oxygen Isotope Stages and modeling isostatic corrections. We provide a summary of the evolution of the stratigraphy for reference.

During the 1960’s and 1970’s, Colquhoun (1974) and DuBar et al. (1974) both proposed stratigraphies for the Pleistocene of South Carolina. Colquhoun (1974) proposed a stratigraphy based on Cooke (1936) in the Charleston, SC area (Fig. 2 SM). DuBar et al. (1974) produced a generalized geological map of Neogene formations in NE South Carolina and SE North Carolina (Fig. 3 SM), creating a different stratigraphy from Cooke and Colquhoun. The resulting competing stratigraphies (Cooke vs. DuBar) for the same-aged sediments have produced complications for later workers. For example, based on remapping currently underway by the South Carolina Geological Survey (Doar, 2012), we feel that the samples attributed to the Canepatch (DuBar et al., 1974) were derived from three separate depositional episodes that may correlate to the Ten Mile Hill, Pamlico, and Princess Anne Formations (Fig. 4 SM) just as the Talbot terrace of Colquhoun (1974) is divided by the Bethera scarp and composed of two depositional episodes- the Ladson and Mile Hill formations.

Quaternary geochronologic data for the area are available from numerous studies (e.g., Colquhoun, 1962; Wehmiller and Belknap, 1982; McCartan et al., 1984; Szabo, 1985; Wehmiller et al., 2004; Mallinson et al., 2008; Wehmiller et al., 2010) and all of the geochronological data used herein, except for our 14C data (on file at the South Carolina Geological Survey), is sourced from existing publications.

Our mapping (Table 3 SM), and the mapping noted in Supplementary Tables 1 and 2 (e.g. Hoyt and Hails, Colquhoun, Healy, Weems and multiple workers, Berquist and multiple workers), all use a directly correlatable stratigraphy (Table 2 SM). Doar (2012) mapped three highstands adjacent to the Santee River near Georgetown, S.C. as Ten Mile Hill, Pamlico, and Princess Anne Formations yet DuBar et al. (1974) mapped the same area as the Canepatch or Socastee Formations (Fig. 3). Wehmiller and Belknap’s (1982) explanations were complicated by this same stratigraphic confusion, particularly when attempting to date the Pamlico deposits correlated to samples from the Canepatch of DuBar et al. (1974) and the Wando of McCartan et al. (1980). The dates range from 74 ka to 180 ka. In the Charleston, S.C. area, Wehmiller and Belknap (1982) mention that four coral Uranium-series dates were 90-120 ka. Cronin et al. (1981) report dates from the Wando Fm of 139-87 ka. We feel that these samples are from two separate depositional episodes; the ~ 139-120 ka dates are from the Pamlico Formation and the 90-87 ka dates are from the Princess Anne Formation. We support this interpretation with two additional data sets. Between Charleston and Georgetown, Willis (2006) reports Optically Stimulated Luminescence (OSL) dates of ~100 ka (± 18.15 ka) (Table 1 of paper) for mapped Princess Anne deposits. Also, York et al. (2001) report a Uranium-series date of 80 ka from mapped Princess Anne deposits south of Charleston and Wehmiller et al. (2004) also report Uranium-series coral dates from Charleston-area Princess Anne deposits of 75.5+/- 9.8 ka and 85.5+/- 10.8 ka. Additionally, since it was established as a formation, the Canepatch Fm has been restricted by various workers (Cronin, 1980; Soller and Mills, 1991) and no longer encompasses the entire stratigraphic and chronological ranges. The restrictions to the Canepatch places the interpretations of the Socastee Formation into question. Any previous models based off of the Canepatch or Socastee Formation’s data may have issues related to the lack of detail as to which Marine Isotope Stage the samples were collected from (5e, 5c, or 5a). The Wando Formation used by the USGS encompasses 2 sets of highstand deposits (MIS 5e and 5a). Any models based on data from this formation may not be as accurate as models based on the ages and elevations of the separately-mapped highstands.

The 100 ka age for the Silver Bluff reported by Zayac (2003) from the Beaufort, S.C. area is suspect since it has been related to the stratigraphic context of the Princess Anne Formation landward of the sample site (Doar, 2003 g). Possible explanations for this older than expected age are: the sample area may have been incorrectly identified during our mapping; or the cores used may have crossed an unconformity and sampled from the underlying unit. The work of Zayac (2003) was focused only on the restricted area of Hunting Island State Park in South Carolina, whereas the Silver Bluff Formation mapped as stratigraphically higher than the Princess Anne Formation in more than 12 quadrangles (Table 8). Our samples for carbon dating have all given ages of >48,000 14C BP (GX-33442 and GX 33448). Based on these data, the possibility exists that samples, which yielded 14C ages of ~ 34 ka (Weems and Lemon, 1993) could have been contaminated with modern materials and represent composite dates of older deposits. Conservatively, we interpret that the Silver Bluff deposits are older than Holocene and younger than 100 ka.

Glacio-isostatic Adjustment Data

Several sets of workers have produced models to calculate the glacio-isostatic effects along the Atlantic coast of North America resulting from the last glacial maximum (LGM). The interpreted glacio-isostatic adjustment (GIA) from those models provides insight into the post-depositional elevations changes to mapped shorelines along the coast (Peltier, 1994; Potter and Lambeck, 2003). A note of caution should be made here- if these GIA models use onshore observations as calibration points, then refinements in the stratigraphy and geochronology should be addressed. For example, the issues with age-dates in South Carolina for the MIS 5 deposits noted in the Stratigraphic Correlation section above can add significant errors to any calculations of elevation. The range of ages for the Canepatch Formation (DuBar et al., 1974), Wando Formation noted in Cronin et al. (1981), and the Charleston area samples from Wehmiller and Belknap (1982) encompass MIS 5 e through MIS 5a. MIS 5 e and MIS 5a were mapped as highstands in the area- the Pamlico Formation (+ 6.7 m MSL) and the Princess Anne Formation (+ 5.18 m MSL). Colquhoun (1974), Hoyt and Hails (1974), Healy (1975), and Doar (2012) all map those separate highstands. The age of the Pamlico deposits is ~ 120 ka and the age of the Princess Anne deposits is 100 to 78 ka.

Hydro-isostatic Adjustment Data

Hydro-isostatic down-warping and rebound can alter relative shoreline elevations during and after deposition independent of GIA. Along a continental margin where the water does not depress the entire crustal mass, the process is very similar to glacial isostasy. The added weight of water as it transgresses during interglacials can depress the crust beneath the continental shelf and coastal plains. This can lever the crust downward with the center of the continent acting as a fulcrum, or it can create a fore-bulge some distance shoreward of the continental shelf edge with the fulcrum seaward of the shoreline (Fig. 5 SM). When the water is removed from the shelf the crust reverses direction. The rate and magnitude of crustal deflection is determined by weight of the added water column, the crust thickness, and mantle density. Table 5 contain the results of a 2D model (OSXFlex2D software; Cardozo, 2008) for calculating the instantaneous hydro-isostatic effect of water depth change from off the shelf edge inland to the mapped shorelines. We based the differences in water depths for each formation for the modeling on our mapping. The Young Modulus used was 70 Gpa. The Poisson Ratio was 0.25. The elastic thickness of the crust is 60 km and is based on the elastic thickness of viscosity model VM5a in Peltier and Drummond (2008). The mantle density used was 3,300 kg/m3 with the density contrast being 3,300-1.025 kg/m3 (the average density of sea water) = 3,298.98 kg/m3. The water depth changes used were the equivalent to modern bathymetric depths. The total distance onshore and offshore is noted in Table 5 with 0.00 as that highstand’s shoreline position. In the table, the value of “x” is the distance in km from the shoreline (negative numbers are km inland from shoreline), while “t” is the new topographic elevation in meters at each distance, and “u” is the net elevations change in meters (negative values indicate uplift). The model iterations were run assuming the bathymetric depths at each distance offshore at the start. The water was removed and the rebound magnitude (u) and the new elevation of the profile compared to its starting RSL elevation (t) was calculated from 30 km inland of that shoreline to the modern continental shelf edge. The 30 km distance inland captures the isostatic rebound effects on the next one or two inland scarps except for the MIS 3 deposits reported on the shelf by Harris et al. (2013). The distance inland use for the MIS 3 shelf deposits is 120 km in order to calculate the effects on the Pamlico and Princess Anne deposits.

The post HIA rebound topographic deflection is no more than +10.5 m for the Pamlico deposits. If ESL was +5.5-7 m MSL as predicted by other studies (Kopp et al., 2009; Kopp et al., 2013), then the HIA adds that 10.5 m to its elevation during MIS 5d. That resulting elevation is +16-17.5 m MSL.

The +4.9 m calculated HIA rebound effect on the Pamlico deposits for the predicted MIS 5a ESL of -20m of the Princess Anne highstand is the amount that highstand depressed the Pamlico deposits. Removing that 4.9 m from the calculated post-MIS 5e rebound elevation of the Pamlico deposits (+16-17.5 m) results in a HIA-corrected predicted MSL elevation for the Pamlico of +11.1-12.6 m MSL. Currently the difference in mapped elevations of the Pamlico and Princess Anne shorelines is 1.5 m. The ~ 10 m of remaining elevation may be resolved with GIA or other processes.

The + 5.4 m calculated HIA rebound effect on the Pamlico deposits and the +6 m calculated HIA rebound effect on the Princess Anne deposits, resulting from the +3 m MSL for the Silver Bluff highstand are the magnitude this highstand depressed those shorelines. If the predicted MIS 3 ESL of at least -40 m MSL (possibly -80 m) is correct, then the current difference in mapped elevations of 3.7 m and 2.2 m (respectively) versus the predicted MIS 3 elevation is not resolved by the 5-6 m HIA.

A final note to consider is that the 5e (Pamlico) and modern shorelines have experienced similar glacioisostatic conditions, and the elevations should remain consistent relative to each other, as they do. With Kopp et al. (2009) assigning a 95% probability to the MIS 5e sea level having an elevation of at least +6.6 m MSL, these consistent elevations being closer together than predicted by the generally accepted sea level curves offer the potential for further research into this problem.

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