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Forced regressive and lowstand Hudson paleo-Delta system: Latest Pliocene growth of the outer New Jersey shelf

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ABSTRACT

Interpretation of the latest Pleistocene stratigraphy of the outer New Jersey shelf has evolved over the last three decades with addition of new geological and geophysical data. During the last decade, new results have described and interpreted various depositional elements within the latest Pleistocene that overlie the regional reflector known as the R-horizon. On the basis of observations made from detailed mapping of the R-horizon and the overlying sediment wedge(s) using high resolution shallow seismic (CHIRP) data acquired in several phases between 2001 and 2006, we revise the depositional model for the offlapping, multi-clinothem sediment wedge on the latest Pleistocene outer New Jersey Shelf as strike-elongated lobes of a falling-stage, wave-influenced delta system fed by a pre-LGM paleo-Hudson River Channel(s) that probably reached the late Pleistocene shelf-edge off New Jersey. This sediment wedge is composed of a series of prograding and offlapping clinothems of varying thickness. Within our data, which does not extend to the basinward termination of the wedge, we seldom observe preserved topsets of these clinothems. Parts of the foresets of some clinothems are also not preserved, particularly in the proximal part of the wedge. The sediment wedge is elongated in strike direction (NNE–SSW), which suggests along-strike sediment movement and possible redistribution of sediment in that direction, by ambient shore-parallel currents. Our data do not record any time-equivalent fluvial channels at the proximal end of the sediment wedge, though there are channel features that cap and cut down into several of the clinothems that make up the wedge farther seaward. We suggest that this can be explained in two possible ways: 1) relatively large spatial separation between the prograding front of the delta system and the delta-plain topset deposits, as is very common under a falling-stage sea-level condition; and 2) lack of preservation of the stratigraphic record of the delta-plain channels because of the likely vigorous falling-stage erosion of topsets during the fall of sea level, and possibly also during the subsequent transgressive ravinement and flooding after the LGM. The clinothems within the sediment wedge show systematic variation in thickness, indicating a northward shift of the main depocenter. This shift might also be an indication of gradual northward migration of the principal fluvial feeder. Such a possibility is supported by previously reported late Pleistocene paleo-Hudson Channel deposits south of the modern Hudson Shelf Valley.

1. Introduction

Significant progradation of shallow marine systems occurs under the condition of steady base-level fall, and river-fed delta systems prograde across a shelf rapidly, often reaching the shelf edge, under such conditions. At various stages of cross-shelf progradation, the delta morphology changes (Muto and Steel, 2002; Porebski and Steel, 2003, 2006), and when deltas reach the shelf edge, they can supply large amounts of coarse sediment to deep-water slope and basin floor (Porebski and Steel, 2003; Johannessen and Steel, 2005). Offlapping stratal architecture, occurrence of long distance regression and absence of fluvial and/or coastal plain/delta plain deposits capping the proximal portion of regressive deposits are characteristic features of falling stage strata (Posamentier and Morris, 2000). The latest Pleistocene (50 ka–25 ka) was such a period of large-scale eustatic sea-level fall (Zachos et al., 2001; Miller et al., 2005). Falling stage sediment wedges on the outer shelves of this age are well-documented from a number of areas across the globe (Chiocci, 2000; Kolla et al., 2000; Posamentier and Morris, 2000; Tesson et al., 2000).

A latest Pleistocene sediment wedge under the modern outer New Jersey shelf has been studied by a number of researchers using a variety of high-resolution shallow seismic data, core data and related biostratigraphic information. Milliman et al. (1990) first described the geometry and thickness variation of this wedge, which overlies a widespread regional reflector, termed by them the

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R-horizon. Assuming the R-horizon to be an erosional unconformity generated during the Last Glacial Maximum (LGM) lowstand of sea level, Milliman et al. (1990) attributed existence of the overlying wedge to sediment supplied by reworking of the Hudson Apron, which they hypothesized was deposited by a large glacial melting event between 18 and 13 ka. In this model, there appears to be no relationship between sea-level fall and the sediment wedge. Subsequent to the work by Milliman et al. (1990), new studies were published based on higher resolution shallow-seismic surveys, biostratigraphy, and C14 age data (Davies et al., 1992; Davies and Austin, 1997; Lagoe et al., 1997; Duncan et al., 2000; Fulthorpe and Austin, 2004; Gulick et al., 2005) that reinterpreted the age of the R-horizon as pre-LGM (~40 ka), and suggested a pre-LGM, regressive origin of the Pleistocene sediment-wedge(s) under the outer shelf. Gulick et al. (2005) highlighted the presence of two distinct sediment wedges, each with an offlapping stacking pattern and with radiocarbon dates that were often out of sequence. They termed these wedges the 'Outer Shelf Wedge' (OSW, proximal) and 'Deep-shelf Wedge' (DSW, distal), respectively, and attributed them to progressive erosion and seaward redeposition of sediments, controlled geomorphically by two inflection zones on the R-horizon that can be observed below the present-day 75 m isobath and 100–115 m isobath, respectively. Gulick et al. (2005) also described a thin onlapping unit stratigraphically between the R-horizon and the OSW and named it as Outer Shelf Sediment Veneer (OSSV). This depositional model for the wedges does explain the inverted age derived from C^{14} dating (Gulick et al., 2005), but does not address the processes of sediment transport or the sediment sources of these areally extensive and volumetrically significant sediment bodies. The total length of basinward progradation of these wedges is more than 25 km. Erosion and redistribution of sediments, without contribution from a terrestrial sediment-source (e.g., a river), is probably an inadequate explanation for the extent of progradation and the sediment volume of these wedges.

On the basis of new observations made from detailed mapping of the R-horizon and the overlying sediment wedge, using an existing series of high-resolution 2D seismic profiles (CHIRP) (Fig. 1), we have been able to reinterpret the depositional model for the offlapping sediment wedge(s). Our primary data sources include surveys conducted in 2001/2002 (studied by Gulick et al., 2005), and new data collected in 2006. The latter provide far more comprehensive coverage and detail of the sediment wedge on the outer shelf. We also draw upon prior coring work to constrain our new interpretation. Detailed observations made from the distal reaches of the sediment wedge(s) provide key information on its depositional character. The observations made from the distal part of the study area also allow us to demonstrate some of the characteristic features of the deltaic strata deposited very close to the shelf edge, as the studied seismic data extends nearly to the present-day shelf edge on the New Jersey margin. The body of sediments under the modern New Jersey outer shelf that overlies the regional R-horizon and include the OSSV, OSW and DSW of Gulick et al. (2005) will be referred to informally as 'the sediment wedge' in this article.

2. Geological background

The New Jersey continental shelf is part of a tectonically quiescent passive margin that has experienced very low subsidence rates in later part of Cenozoic and relatively low sediment supply. The modern sea floor morphology and the late Quaternary shallow stratigraphy of the New Jersey shelf is well studied (Fig. 1; e.g., Uchupi et al., 2001; Goff et al., 2004, 2005; Nordfjord et al., 2005; Goff and Austin, 2009; Nordfjord et al., 2009;). Temporally and spatially variable sediment supply, active erosion processes, and sea-level response to glaciations and deglaciations have been recognized as primary contributing factors in building the New Jersey shelf seascape and the shallow stratigraphic record (the uppermost 30–50 m, ~100 ka) of this area (Duncan et al., 2000; Nordfjord et al., 2009).

The global eustatic sea-level cycle for the last 120 ka, established from various independent studies, has been used by researchers to place chronologic and paleobathymetric constraints on the latest Quaternary stratigraphy of the New Jersey margin (e.g., Milliman et al., 1990; Davies et al., 1992; Duncan et al., 2000; Fulthorpe and Austin, 2004;). Gulick et al. (2005) explained the latest Pleistocene stratigraphy of the outer New Jersey shelf using the upper and lower bounds of the global sea-level curve by Lambeck and Chappell (2001) (Fig. 2a) that show a net fall, with several small-amplitude rises, between 50 ka and their sea-level minimum at ~26 ka. A recent estimate of Pleistocene sea-level based on sequence stratigraphy of the New Jersey shelf (Fig. 2b; Wright et al., 2009) also demonstrates the net sea-level fall between 50 ka and 26 ka. Both eustatic curves show that at the maximum sea-level lowstand, the sea level was approximately 125 m below present.

The New Jersey shelf lies south of the terminal moraines of the Laurentide ice sheet (Fig. 1). The sea floor morphology of the shelf shows multiple oblique ridges, ribbons and two 10–15 m high escarpments known as the Mid Shelf Scarp and the Franklin Scarp respectively (Fig. 1; Duncan et al., 2000).

Duncan et al. (2000) presented a detailed discussion on the stratigraphic surfaces identified from a dip-oriented corridor on the outer New Jersey shelf (which they named the 'Mid Shelf Corridor') using Huntec boomer data. From bottom to top, the seismic stratigraphic surfaces discussed by Duncan et al. (2000) are the R-horizon, S-horizon, 'Channels' surface, and the T-horizon. Another prominent surface above the S-horizon and below the 'Channels' surface (Fulthorpe and Austin, 2004; Goff and Austin, 2009) separates a zone of sub-parallel seismic reflections from an overlying acoustically transparent zone.

The stratigraphic units above the R-horizon within the latest Pleistocene section of the outer New Jersey shelf, as summarized by Duncan et al. (2000) and reinterpreted in part by Gulick et al. (2005), are shown in Fig. 3. Table 1 summarizes these mapped stratigraphic units.

3. Data and methods

A variety of geophysical and geological data have been collected from the outer New Jersey shelf over the last two decades. Goff and Austin (2009) listed some of the important geophysical data sets collected from the outer New Jersey shelf, including multibeam bathymetric data collected in 1996 (Goff et al., 1999), as part of the US Office of Naval Research (ONR) STRATAFORM program (Nittrouer, 1999); CHIRP data collected in 2001 and 2002 as part of the ONR Geoclutter program (Austin et al., 2001) and in 2006 as part of the ONR SW06 program (Goff et al., 2007). Several sets of sediment samples have also been collected from different parts of this shelf, including grab samples, piston cores and gravity cores (Davies et al., 1992; Goff et al., 2004; Gulick et al., 2005), and vibracores collected by the authors in 2007. Radiocarbon age data from the outer shelf are available from several sources, such as the data reported by Lagoe (1994) and Alexander et al. (2003). Radiocarbon ages on shell and bulk clay samples collected in 2007 have been conducted at the University of Arizona Accelerated Mass Spectrometer facility. Radiometric ages from all samples relevant to this study are reported in Table 2. For this study, all available high-resolution shallow seismic data, including parts of the 2001 and 2002 CHIRP seismic surveys, and the latest CHIRP survey conducted in 2006 (2–16 kHz system), have been analyzed (Fig. 1). The seismic images over a major part of the survey area are limited to a depth of ~40–70 m below the sea-bottom, with a vertical resolution ~10–20 cm. Geophysical data rarely imaged stratigraphy below the regional R-horizon. The current data coverage is significantly larger than the data sets used for previous publications (Lagoe