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Geomorphic characterization of four shelf-sourced submarine canyons along the U.S. Mid-Atlantic continental margin

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ABSTRACT

Shelf-sourced submarine canyons are common features of continental margins and are fundamental to deep-sea sedimentary systems. Despite their geomorphic and geologic significance, relatively few passive margin shelf-breaching canyons worldwide have been mapped using modern geophysical methods. Between 2007 and 2012 a series of geophysical surveys was conducted across four major canyons of the US Mid-Atlantic margin: Wilmington, Baltimore, Washington, and Norfolk canyons. More than 5700 km^2 of high-resolution multibeam bathymetry and 890 line-km of sub-bottom CHIRP profiles were collected along the outer shelf and uppermost slope (depths of 80-1200 m). The data allowed us to compare and contrast the fine-scale morphology of each canyon system. The canyons have marked differences in the morphology and orientation of canyon heads, steepness and density of sidewall gullies, and the character of the continental shelf surrounding canyon rims. Down-canyon axial profiles for Washington, Baltimore and Wilmington canyons have linear shapes, and each canyon thalweg exhibits morphological evidence for recent, relatively small-scale sediment transport. For example, Washington Canyon displays extremely steep wall gradients and contains ~100 m wide, 5–10 m deep, v-shaped incisions down the canyon axis, suggesting modern or recent sediment transport. In contrast, the convex axial thalweg profile, the absence of thalweg incision, and evidence for sediment infilling at the canyon head, suggest that depositional processes strongly influence Norfolk Canyon during the current sea-level high-stand. The north walls of Wilmington, Washington and Norfolk canyons are steeper than the south walls due to differential erosion, though the underlying cause for this asymmetry is not clear. Furthermore, we speculate that most of the geomorphic features observed within the canyons (e.g., terraces, tributary canyons, gullies, and hanging valleys) were formed during the Pleistocene, and show only subtle modification by Holocene processes active during the present sea-level high-stand.

1. Introduction

The U.S. Atlantic continental margin is one of the most extensively studied passive margins in the world. High-resolution geophysical surveys conducted by federal and state government agencies and academic institutions have generated unprecedented views of the seafloor morphology across the outer continental shelf, slope and rise between Cape Hatteras and Georges Bank (Andrews et al., 2013; Brothers et al., 2013a, 2013b; Chaytor et al., 2009; Twichell et al., 2009). Select surveys were aimed at filling gaps in data coverage and at examining the fine-scale relationships between form and process within a series of major submarine canyons. Submarine canyons on passive margins are primarily the result of erosion induced by sediment flows, but other forces such as tidal currents, internal and storm waves, submarine landslides, and biological reworking, also play important roles in canyon formation (Cacchione et al., 2002; Canals et al., 2006; Palanques et al., 2005; Paull et al., 2003, 2011; Shepard, 1981; Twichell et al., 1985; Xu et al., 2004). One goal of submarine canyon research is to better understand the relative influence of these processes in canyon development.

The shelf-edge represents a major physiographic boundary that separates fundamentally different oceanographic and sedimentary regimes (Stanley and Moore, 1983). Submarine canyons can be split into two broad categories based on their relationship to the shelf-edge: shelf-sourced and slope-sourced canyons. Shelf-sourced

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canyons, also called "shelf-breaching" canyons (Farre et al., 1983), can extend several kilometers landward of the shelf-break. Slope-sourced canyons tend to be closely spaced (1–2 km separation), have heads located deeper than the classically defined shelf-edge (Kennett, 1982) and primarily capture sediment released during local slope failures (Brothers et al., 2013b; Pratson et al., 1994; Twichell and Roberts, 1982). During Pleistocene sea-level low-stands rivers delivered significant volumes of sediment to the outer shelf, much of which was transported directly into shelf-sourced canyons and funneled offshore to deep sea fans (Poag, 1992; Shepard, 1981). During sea-level high-stands many shelf-sourced canyons remain inactive due to being disconnected from fluvial sources (Covault and Graham, 2010; Palanques et al., 2009; Paull et al., 2011; Puig et al., 2003; Sanford et al., 1990; Shepard, 1981) but some remain active, particularly those on active margins with narrow shelves. Shelf-sourced canyons are long-lived features that continuously influence the physical and biological processes near the shelf-edge; however, the sources of sediment and down-canyon transport mechanisms during high-stand conditions remain poorly understood.

The U.S. Atlantic margin contains between 30 and 40 shelf-sourced submarine canyons (Andrews et al., 2013). Hudson Canyon, to the east of New Jersey, is perhaps the most widely recognized due to its significant relief (>1000 m at the shelf-edge), prominent shelf-valley and well-developed deep sea channel that extends hundreds of km seaward of the continental slope (Butman et al., 2006). This paper is focused on four major, shelf-sourced canyons located to the south of Hudson Canyon (from north to south): Wilmington, Baltimore, Washington, and Norfolk canyons (Fig. 1). Our analysis of new high-resolution bathymetric and sub-bottom data provides a new approach to delineating some of the physical boundary conditions that govern the sedimentary, oceanographic and biologic processes operating in and around shelf-sourced canyons. Using these data, we aim to answer the following questions: (1) what are the first-order morphological differences between the four canyons? (2) What are the potential linkages between fine-scale canyon morphology and sedimentary and oceanographic processes? and (3) What is the magnitude and relative importance of modern sedimentary processes in canyon formation?

2. Background

Although the formative relationship between slope-sourced and shelf-sourced submarine canyons remains uncertain, both types of canyons are influenced by changes in base level (sea-level fluctuations) and sediment flux at the shelf-edge. The "headward erosion" hypothesis proposed by Farre et al. (1983) states that "young" slope-confined canyons propagate up-slope via local mass failure, capturing smaller canyons and rills along the way, until the shelf itself is breached, becoming a "mature", shelf-sourced canyon. Once breaching the shelf, canyons are more likely to capture river systems that cross the continental shelf during sea-level low-stands, in addition to becoming a conduit for sediment that is not terrestrially sourced (such as sediment entrained in along-shore currents) (Farre et al., 1983; lo Iacono et al., 2011; Twichell et al., 1977). During periods of sea-level low-stand, rivers discharge sediment near the shelf-edge and the locus of deposition shifts to deeper waters of the slope and rise (Catuneanu, 2006; Piper and Normark, 2001; Posamentier and Vail, 1988). Rivers discharging sediment-laden water directly into shelf-sourced canyon heads may generate hyperpycnal flows (Mulder and Syvitski, 1995) that bypass and erode the upper reaches of canyons, leading to further landward entrenchment (Farre et al., 1983). During sea-level high-stands, shelf depocenters shift landward and most sediment becomes trapped in coastal estuaries and embayments, particularly along passive margins with wide continental shelves (Catuneanu, 2006; Posamentier and Vail, 1988). Along the U.S. Atlantic margin, sediment delivery to the shelf-edge during sea-level high-stands is reduced dramatically and many canyons become sites of enhanced hemipelagic sediment accumulation (Mountain et al., 2007; Sanford et al., 1990).

During sea-level high-stands, the primary sediment transport mechanisms into shelf-sourced canyons include the following: (1) storm induced transport of relict shelf sand and silt (Stanley et al., 1986; Xu et al., 2010); (2) transport of fine grained sediment

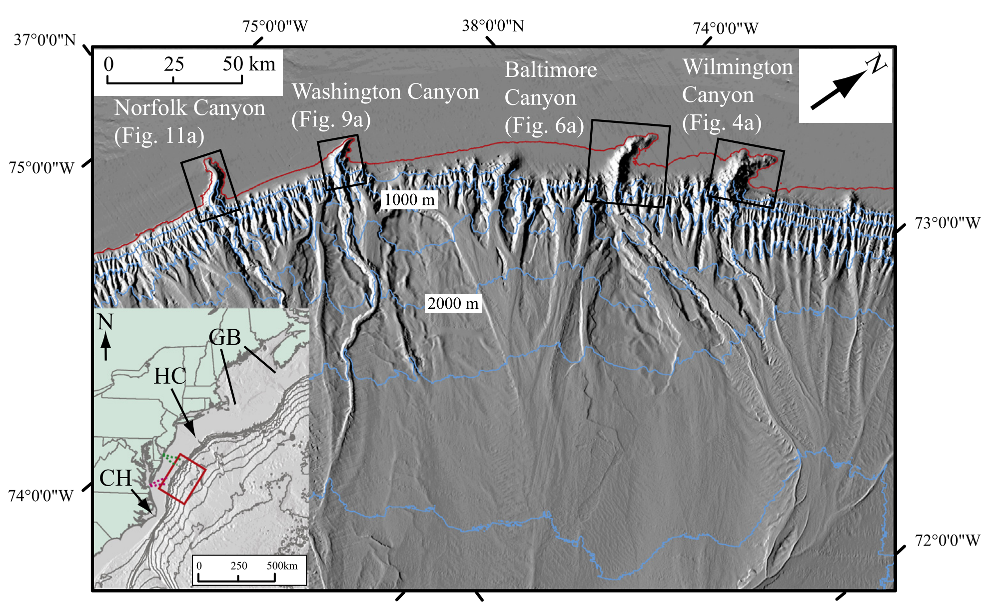

Fig. 1. Shaded relief map of study area. Illumination angle is 315° (this applies to all hillshades presented in this paper).The red contour represents the 120 m isobath, and blue contours represent 500 m isobaths. *Lower left inset*: Red box is extent of relief map. Contours are every 500 m. Abbreviations: CH: Cape Hatteras; GB: Georges Bank; HC: Hudson Canyon. Dashed green lines are paths of paleo-Delaware River and dashed purple lines are paths of paleo-Susquehanna River. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)