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Assessing Lateral Variability along Modern Transgressive Coastlines to Improve Ancient Analog Comparisons: Examples from the U.S. Atlantic Coast and the Cretaceous Western Interior Seaway

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Abstract

Process-based facies models for estuaries and deltas are largely derived from modern analogs, and generally depict end-member energy settings. It is unclear how applicable these facies models, and other modern analogs, are to interpretations of the rock record, particularly in more complex mixed-energy estuarine, barrier island, and tidal environments. Such ambiguity reflects the difficulty in understanding preservation potential, the close temporal and stratigraphic interplay between end-member systems, and a general knowledge gap for both modern and ancient high-energy, sand-rich tidal settings. More generally, despite the demonstrated utility of applying the theory of uniformitarianism to link modern and ancient environments, critical differences in the temporal and physical scales of observation also pose a challenge to analog studies and their application to subsurface reservoirs.

This research presents a detailed assessment and model for outcrops of a mixed-energy (wave- and tide-dominated) coastline from the Cretaceous Straight Cliffs Formation, southern Utah (Fig. 1A), with quantitative analysis of modern analogs. Along a 1,200 m-wide, 60 to 120 m-thick section, cm-scale measured sections, petrography, and photos are used to document vertical and lateral facies changes (Fig. 1A). The Straight Cliffs Formation at Buck Hollow contains two estuarine intervals capped with transgressive barrier island facies (Fig. 1B). The lower estuary and barrier island interval consists of five depositional units (DU) (Fig. 1B,C): (1) a lowermost interval, ~5-15 m thick, of tidal channels and estuarine fill carbonaceous shales and coals which records the formation of the estuary; (2) overlying that, a 5-20 m thick interval composed of a tidal sheet and washover fan complex; (3) a large ebb tidal channel 10-30 m thick which cuts down into the underlying strata; (4) tidal inlet facies ~5 m thick reflecting the initial barrier island transgression; and (5) an uppermost interval, ~5-15 m thick, of landward-stepping barrier island strata, split into three internally upwards-coarsening packages.

Choosing specific analogs for Buck Hollow is difficult because the geomorphology and migration of modern barrier islands are controlled by a wide variety of processes. Consequently, barrier islands have been classified by parameters including climate, wave and tide regime, depositional setting, transgressive or regressive stratigraphy, sediment grain size, shoreface type, and antecedent geology (see Stutz and Pilkey (2011) p. 207 for references). There is no singular control on barrier island morphology. This complexity is compounded with uncertainty surrounding preservation potential of barrier islands, further exacerbating the problems of modern to ancient analog comparisons. As a whole, the Straight Cliffs Formation at Buck Hollow shows lateral and vertical complexity at the 10-100 m scale. Similar lateral complexity at the kilometer scale is evident along the modern Atlantic coast, but has not been rigorously quantified. To address this, morphologic features along the coastline were measured and classified to reveal the distribution of depositional environments in a single tectonic and sequence stratigraphic setting.

Length and area measurements were performed in GoogleEarthPro along the shoreline of the Atlantic coast between Florida and New York and categorized by depositional environment (Barrier Island (BI), Spit, Tidal Inlet (TI), Strandplain (SP), Estuary Mouth (EM) and other) (Fig. 2A). Significant lateral variability is observed, but the coast is largely dominated by barrier islands, comprising 66% of the coastal length (Fig. 2B). If both barrier islands and their related spits are combined, they comprise 80% of the measured coastal length. The coast was divided into nine equal-length (~250 km) bins which show up to 90% difference in the lengths of barrier islands and spits relative to other features (Fig. 2C), underscoring the variation in environment distribution among the coastal segments. The controls on this variability can be assessed, at least in a coarse sense, by combining this dataset with various publicly available measurements from monitoring stations along the coast.

Tidal range and wave height are thought to govern barrier island morphology along the Atlantic coast (Hayes, 1979). Cross-plots of the tidal range to wave height ratio (TR:WH) versus the percent barrier island and spit length of each equal-length bin show that the TR:WH seems to impact the prevalence of barrier islands and spits (Fig. 2D). However, coastal bins segmented by tidal range (not shown) did not produce a significant correlation between TR:WH and percentage of barrier island and spit length for that bin. This might reflect anthropogenic alteration and/or additional controls such as river input, coastline aspect, and longshore drift. Future research will further investigate the scale and controls on variability along the coast.

It was hypothesized that the length and shape of individual barrier islands is also controlled by TR:WH (Hayes, 1979). To test this hypothesis, the dimensions of individual barrier islands were measured in GoogleEarthPro to better understand scaling relationships. There are visual patterns in the distribution of single barrier islands as a function of tidal range (Fig. 2E). Tidal range is a control on the ratio of barrier island length to adjacent tidal inlet width (Fig. 2F) as suggested by Hayes (1979). There is also a relationship between the length to area ratio and the average barrier island width for individual barrier islands (Fig. 2G). Ongoing statistical analysis on the shape of barrier island polygons may further elucidate controls on morphology.

Barrier islands are the dominant depositional environment along the modern, transgressive U.S. Atlantic coastline. Assuming that lateral variation in coastline features of this modern example is an appropriate analog for the Western Interior Seaway, barrier islands may be under-recognized in the ancient. This could be due to preservation potential or lack of appropriate recognition criteria for barrier island facies. Future research will compare modern barrier island dimensions and thicknesses to ancient examples to assess potential paleomorphodynamic relationships and better predict geobody size, shape, and distribution in the ancient. The barrier island succession at Buck Hollow is ~15 m thick and at least 5 km long. Comparing these dimensions to modern barrier islands may lend insight into preservation potential and conditions (tidal range, wave height, climate, etc.) of the WIS during deposition.

This study highlights areas for improvement in the understanding of barrier island morphodynamics, lateral variability within a single sequence stratigraphic setting, and the modern to ancient to reservoir analog workflow. Despite these challenges, detailed facies characterization and predictive 3-D geobody analysis does elucidate key recognition criteria for transgressive mixed-energy systems, including the preservation of both tide and wave energy indicators, tidal packages, and barrier island facies. Barrier islands form large sandstone geobodies. Understanding modern analogs and improving recognition criteria for these facies in the ancient will help develop better predictive models for barrier island preservation to improve exploration for, and production from, transgressive hydrocarbon reservoirs.

References Cited

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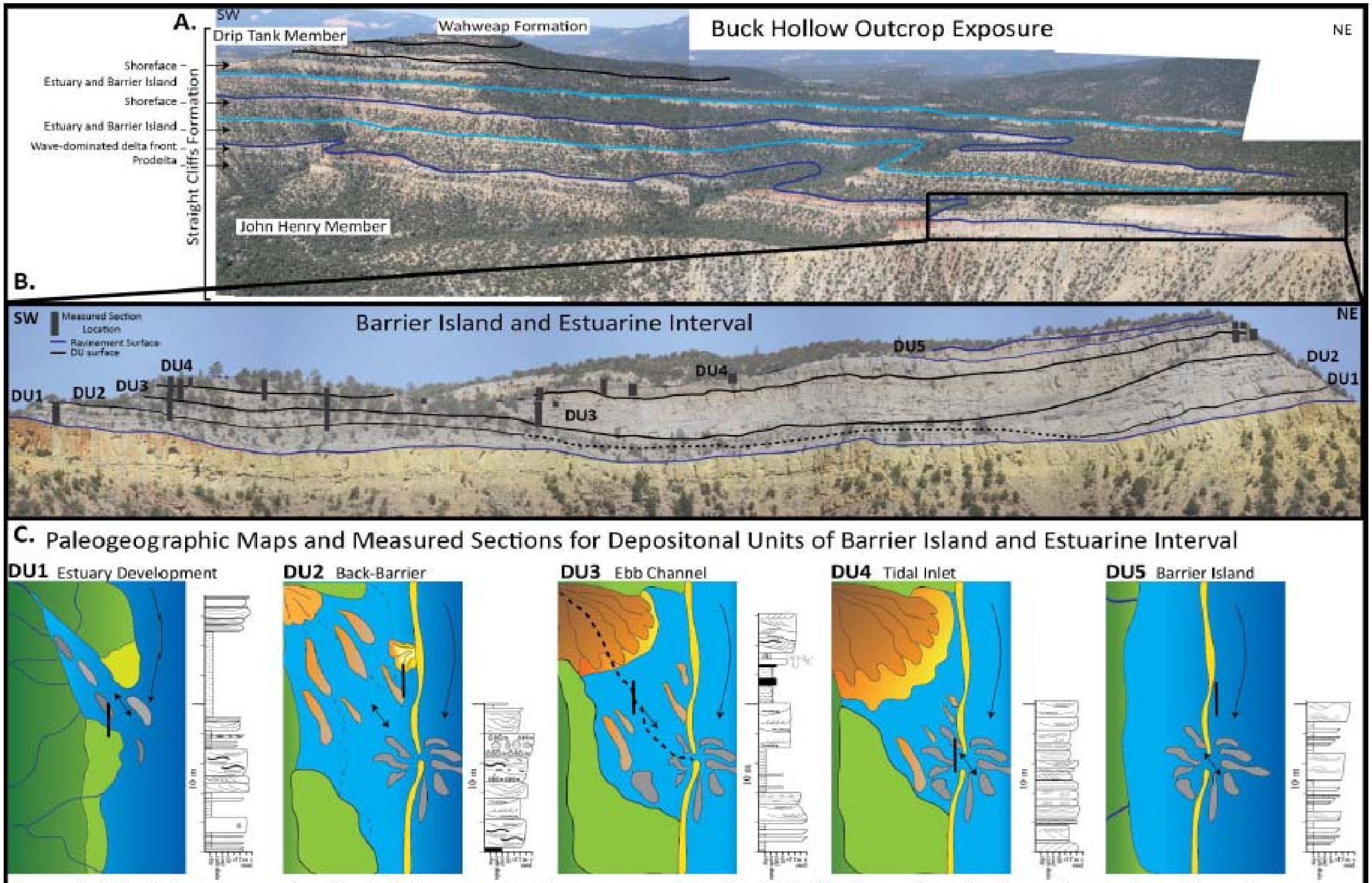

Figure 1: A) Aerial photo mosaic of Buck Hollow showing the exposure of the Straight Cliffs Formation with the major stratigraphic surfaces labeled. B) Interpreted photopan of the northern exposure of the barrier island and estuarine interval in the lower John Henry Member of the Straight Cliffs Formation. C) Schematic paleogeographic maps and measured sections for each of the five depositional units of the barrier island and estuarine interval in the lower John Henry Member. Black bar represents the outcrop interval on each map.

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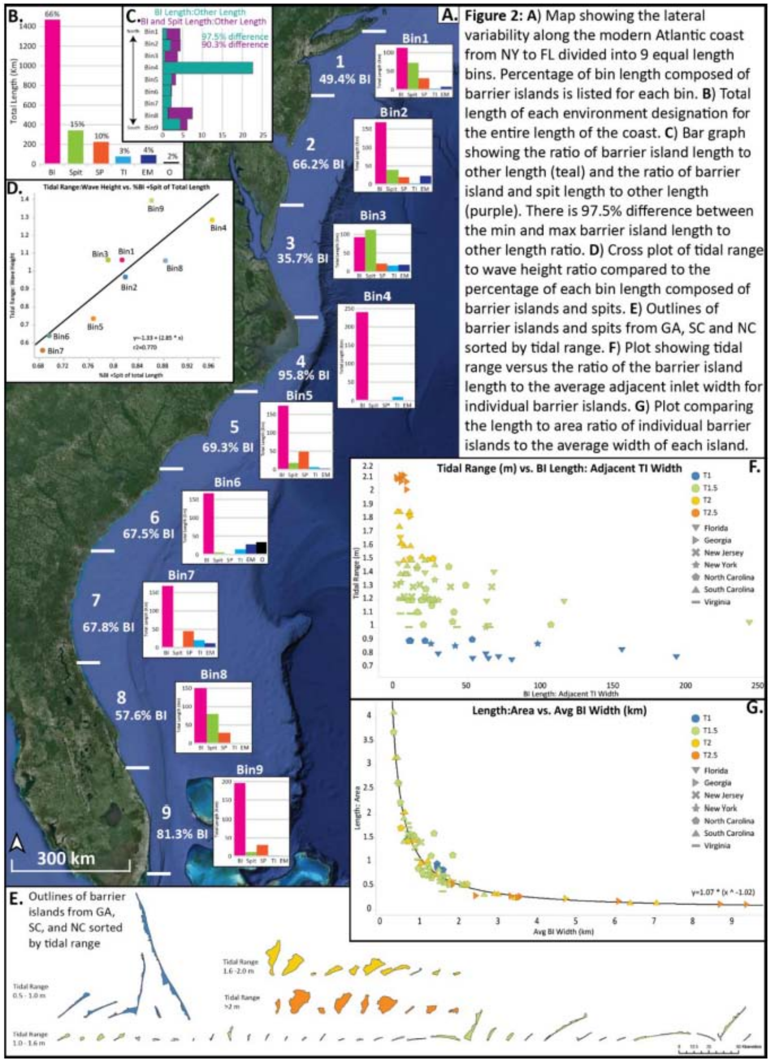

Figure 2: A) Map showing the lateral variability along the modern Atlantic coast from NY to FL divided into 9 equal length bins. Percentage of bin length composed of barrier islands is listed for each bin. B) Total length of each environment designation for the entire length of the coast. C) Bar graph showing the ratio of barrier island length to other length (teal) and the ratio of barrier island and spit length to other length (purple). There is 97.5% difference between the min and max barrier island length to other length ratio. D) Cross plot of tidal range to wave height ratio compared to the percentage of each bin length composed of barrier islands and spits. E) Outlines of barrier islands and spits from GA, SC and NC sorted by tidal range. F) Plot showing tidal range versus the ratio of the barrier island length to the average adjacent inlet width for individual barrier islands. G) Plot comparing the length to area ratio of individual barrier islands to the average width of each island.