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LINKING COASTAL FLUVIAL STRATIGRAPHY AND EUSTATIC SEA-LEVEL CHANGES: A CASE STUDY IN THE TORNILLO GROUP (BIG BEND NATIONAL PARK, TX)

Abstract

Understanding the sensitivity of coastal environments to sea-level change is important for both reconstructing impacts of past eustatic sea-level changes to coastal environments and developing chronostratigraphic models for continental sedimentary basins. Although fluvial system dynamics in coastal settings are known to be strongly affected by eustatic sea-level change, more work is needed to improve cyclostratigraphic model in coastal environment. Outcrops of Cretaceous and Early Paleocene coastal fluvial and floodplain deposits of the Tornillo Group in Big Bend National Park (BBNP) offer a unique opportunity to study this linkage. These outcrops record the gradual (10^6-10^7 yrs) withdrawal of the Cretaceous Interior

Seaway from North America, with a transition from paralic to coastal and coastal to inland terrestrial deposition environment (Wheeler and Lehman, 2005). Work by Atchley *et al.* (2004) on a Cretaceous Tornillo Group outcrop has suggested that superimposed on this long-term regression trend is the expression of mega-scale (10^4-10^6 yrs) eustatic sea level cycles, reflected as changes in fluvial structure. We will test the hypothesis that in the Tornillo Group (Big Bend National Park), sedimentological and biogeochemical expression of eustatic cycles can be traced along a coast-to-continent gradient. We will generate new lithological records for two outcrops of the Tornillo Group located at different distances from the paleoshoreline and compare their sequence stratigraphic records. This work will also evaluate the sensitivity of combining isotopic chemostratigraphy and descriptive stratigraphy as a potential recorder of coast-to-continent gradient in ancient coastal environment. This idea stems from the recognition that distance to shoreline influences soil water content and therefore carbon and oxygen isotopic composition of pedogenic carbonate nodules.

Significance

The outcomes of this work will impact the research community's ability to use chemostratigraphy for cyclostratigraphic correlation in coastal plain systems, and will improve our understanding of links between eustatic sea level change and terrestrial stratigraphy over millennial timescales. In a practical sense, successful outcomes from this work could lead to improved tools for the chronostratigraphic correlation of terrestrial sedimentary deposits across broad areas of the continental margin and between terrestrial and marine systems.

Background

Sequence stratigraphy of fluvial deposits in response to sea-level changes

Sequence stratigraphy involves the recognition of stacking patterns to define units characterized by distinct geometry and lithofacies. Through identification of the subdividing surfaces that separate these strata, a template of genetically related deposits is developed. This template is related to an explanatory model to determine the evolving character of the depositional setting (Galloway, 1989).

Sequence stratigraphy has been increasingly used in continentally deposited sediments to untangle autogenic and allogenic controls on sediment stacking patterns (Blum and Törnqvist, 2000). Several type of cycles have been documented from this work: short timescale cycles (day to 10^4 yr duration) related to autogenic processes and longer timescale cycles (10^4-10^7 yr duration) driven by allogenic processes - including regional climate, tectonics, and sea-level changes (e.g. Allen, 1978; Read and Dean, 1982; Blakey and Gubitosa, 1984; Posamentier and Allen, 1993; Kraus, 2002; Atchley *et al.*, 2004; Aziz *et al.*, 2008).

In terrestrial coastal areas, sea and land processes interact. Over long time scales (10^4-10^6 years) in tectonically "stable" coastal regions, distance from the shoreline fluctuates with eustatic sea level cycles, modulated by regional sedimentological and tectonic processes. The diminishing marine influence with increasing distance from the coast drives variation in fluvial structure (Blum and Törnqvist, 2000). The influence of eustatic sea-level change on fluvial sedimentary deposits is largely driven by change in longitudinal river profile (Blum and Törnqvist, 2000), although related change in climatic and environmental conditions is another viable possibility. While doubts have been raised concerning the feasibility of correlating fluvial sequence stratigraphy and sea level changes (Van Heijst and Postma, 2001), it has also been shown that low gradient rivers can respond to sea-levels several hundred kilometers inland (Blum and Törnqvist, 2000). A number of published studies have tried to build on this concept to demonstrate eustatic sea level controls on stratigraphic cycles in fluvial sedimentary deposits (Paul Wright and Marriott, 1993; Posamentier and Allen, 1993; Shanley and McCabe, 1994; Atchley *et al.*, 2004).

Previous work in the study area

Paleogeography and sea level changes during the Paleocene in BBNP

Previous work (Lehman, 1991; Nordt et al., 2011) suggests that from the Late Cretaceous to the Paleocene, the climate of BBNP transitioned from dry subtropical to wet and warm temperate conditions. During this interval, BBNP was part of the Tornillo Basin, one of many subsiding basins within the US western interior created by the Laramide orogeny (Galloway *et al.*, 2011). The Early Paleocene is characterized by a regional marine incursion within the Tornillo Basin, where the shoreline lay close to BBNP (Galloway *et al.*, 2011). At this time the Tornillo Basin was part of a large drainage system flowing southeast into a delta at the North end of the Laramide Foreland Sea (LFS). The LFS rapidly regressed during the Paleocene and closed during the middle Eocene, gradually moving BBNP further from the coast and coastal influences. Superimposed on the long term regression of the LFS, BBNP's distance from the shoreline fluctuated with several smaller scale transgression/regression cycles due either to global sea-level changes – middle Danian regression, early-middle Selandian transgression, and the late Thanetian regression (Ruban et al., in press; Ruban *et al.*, 2010) – or to local changes in the rate of subsidence (Galloway *et al.*, 2011).

Geological setting of the Black Peaks Formation of the Tornillo Group

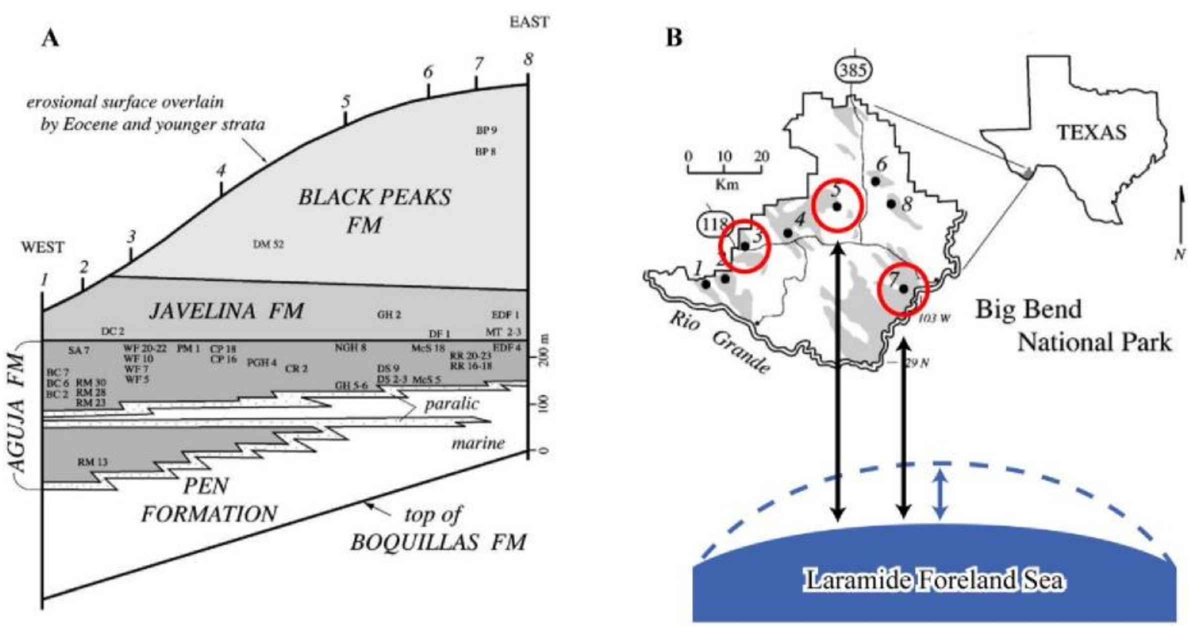

Fig. 1 Cross section showing stratigraphic and geographic relationships of Tornillo Group outcrops (numbered 1 - 8 following Lehman *et al.* (2002)) in BBNP. A) Sections projected on a cross-section of Cretaceous to Paleogene sedimentary deposits in BBNP. B) Section locations shown relative to features in the park and the approximate Paleocene paleo-shoreline position of the Larimide Foreland Seaway (after Galloway *et al.*, 2011). Highlighted sections (red) include Dawson Creek (section 3), previously studied by several authors (e.g. Lehman and Coulson, 2002; Nordt *et al.*, 2011) and discussed in the text, and the two focal sites for our proposed work (Grapevine Hills (section 5) and section 7). Modified from Wheeler and Lehman (2005).

The sequence stratigraphy of the Tornillo Group records the progressive regression of the LFS, from the paralic Aguja Fm grading upward to more inland alluvial plain sediments of the Javelina and Black Peaks Fm. (Busbey *et al*., 1989; Lehman, 1991). The Paleocene Black Peaks Fm. is exclusively composed of fluvial deposits, which alternate between overbank mudstones and channel sandstones (Schiebout *et al.*, 1987; Lehman, 1990). The Black Peaks Fm. outcrops in several places in BBNP and thickens along East-West transect (Fig.1). In the West of the Basin, the Black Peaks Fm. is overlain non-conformably by the Eocene Canoe Fm, whereas in the East it is overlain conformably by the Hannold Hill Fm. (Schiebout *et al.*, 1987; Lehman, 1988). The chronostratigraphy of Tornillo Group deposits is well established based on vertebrate biostratigraphy and magnetostratigraphy (Sankey, 1998) and radiometric dating (Lehman *et al.*, 2006). At the Dawson Creek locality (Fig.1) in the western part of BBNP, mammal fossils indicate that the Black Peaks Fm. spans the Early Paleocene (Lehman and Busbey, 2007). The thicker deposits of the Black Peaks Fm. in eastern BBNP (Fig.1) presumably range into the Late Paleocene and perhaps even the earliest Eocene, but are not as well constrained in time due to a deficiency in mammal fossils (Schiebout *et al.*, 1987) and the ambiguous results of chemostratigraphy (White and Schiebout, 2004).

Sequence stratigraphy in the Black Peaks Fm.

The sequence stratigraphy of the Tornillo Group has been studied in detail by Atchley *et al.* (2004) at Dawson Creek (Fig.1), a section preserving only a thin interval of the lowermost Black Peaks Fm. The authors identified fluvial aggradational cycles (FAC) within these deposits, represented by fining-upward sequences that are gradationally overlain by paleosols or are sharply overlain by the coarser-grained base of the succeeding FAC. Sets of FACs display repetitive patterns characterized by FACs with coarse grained single-story to double-story sandstones transitioning upward into paleosol-dominated FACs. Paleosol maturity increases from the base to top of these packages. Atchley *et al.* (2004) interpreted these repetitive FAC sets as being driven by sea level changes as follows: 1) for high stand and falling stage equivalent, stable channels, characterized by reduced flooding frequency and slowly deposited overbank sediments leading to the formation of well-developed soils in the alluvial plain, 2) for transgression equivalent, destabilized channels, characterized by increased flooding frequency, rapidly floodplain sediment deposition, and formation of poorly-developed soils in the alluvial plain.

Plan of study

Motivating observations

In March, 2010, we described the lithology and sampled carbonate nodules in the upper part of the Black Peaks Fm. at the Grapevine Hills (Fig.1) with the objective to study the Paleocene Eocene Thermal Maximum (PETM), described by White and Schiebout (2004) at this site. While we did not identify the PETM, our preliminary results for the Black Peaks Fm. show that the carbon and oxygen isotopic composition ($\delta^{13}C_{carb}$ and $_{\delta 18Ocarb)}$ vary strongly with lithology. For example, the average $_{\delta 13Ccarb}$ of carbonate nodules collected within and stratigraphically close to (~1m) distinctive black paleosols (-12‰) is substantially lower than that measured from other beds (average = -9.5‰).

Hypotheses

Hypothesis 1: We hypothesize that the alternating of lithofacies in the Black Peaks Fm. is linked to changes in fluvial structure responsive to sea-level changes, and that the sensitivity of these fluvial deposition changes depends upon the distance from the ocean. We will test this hypothesis by generating high resolution lithological records for the Black Peaks Fm. in two sections spanning similar time intervals (Lehman and Busbey, 2000) but located at different distances from the paleoshoreline (Fig.1), and comparing these records. We predict that the section located closer to the paleo-shoreline will show more marked lithological variation due to the stronger influence of sea-level changes on sedimentary system dynamics at this site.

Hypothesis 2: We hypothesize that other recorders of biogeochemical dynamics in the paleosol system will also express variation related to soil water content fluctuations driven by sea-level influences on fluvial dynamics. We will test this hypothesis by producing records of the $\delta^{13}C$ values of pedogenic carbonate nodules (δ_{13}Ccarb and δ_{18}Ocarb) preserved in the two study sections. We predict that we will see through-section variation in δ_{13}Ccarb and δ_{18}Ocarb reflecting changes in soil CO_2 content associated with changes in soil wetness (Sheldon and Tabor, 2009; Breecker *et al.*, 2010).

This work will be carried out in our two focus sections (Fig.1) and will be extended using published data from the Dawson Creek locality (Fig.1). Previous work at Dawson Creek provides records of sequence stratigraphy (Atchley *et al.*., 2004), δ_{18}Ocarb and δ_{13}Ccarb values (Nordt *et al.*, 2002; Dworkin *et al.*, 2005) and soil paleo-biogeochemistry (Nordt *et al.*, 2011) which will be analyzed in a similar fashion and compared with the records from our new study sites.

Proposed work

Field work in the Black Peaks Fm. will be conducted during summer 2012 in order to achieve two goals: 1) generate descriptive lithological records and document paleoenvironmentally-relevant sedimentological features at our two study sites, 2) compile stratigraphically-resolved collections of samples for geochemical study. We will measure each section with a Jacob Staff, documenting stratal thickness, lithostratigraphic boundaries and stratigraphic occurrence of paleosol tops (Atchley *et al.*, 2004). Each paleosol will be described in detail, documenting features such as estimated grain size, Munsell color, and the presence/absence of mechanical and biological structures. For all paleosols we will collect carbonate nodules, if present, for laboratory analysis. We will sample carbonate nodules at the top of the Bk-horizons, documenting the depth of the samples below the paleo-soil surface, and will sample from freshly trenched surfaces. We anticipate that a 3 week field season will be required. Both sections are located within BBNP, and will be sampled under an extension of our current BBNP collection permit. During the course of field description, high-resolution digital photographs of the outcrop exposure will be compiled.

For this work, we will use the explanatory model developed at Dawson Creek by Atchley *et al.* (2004) relating sets of fluvial aggradational cycles (FACs) to sea-level changes. We will identify decameter-scale FACs occurring in each studied section based on lithological boundaries. Generally, FACs are fining upward packages consisting of sandstone or pedogenically un-modified mudstone that either grades upward into a paleosol or is unconformably overlain by the succeeding FAC. Sequences of FACs will be identified as repetitive FACs sets expressing longer-term trends in lithological properties using stacking pattern analysis. The method involves plotting the cumulative deviation FAC thickness and grain size, which display discrete cycles that can be interpreted together with data on facies proportion and paleosol maturity and drainage to reconstruct patterns of fluvial system evolution. The underlying premise and limitations of this method are thoroughly discussed by Atchley *et al.* (2004).

At least two carbonate nodules will be collected for each paleosol Bk horizon in each section. A total of 150 nodules as 300m of sections will be sampled. Nodules will be slabbed and polished in the lab. Their morphology will be described and we will use the criteria of Dworkin *et al.* (2005) to screen nodules to minimize potential for diagenetic bias. Microsamples of micritic carbonate will be drilled under a binocular microscope using a hand-held dental drill, and

δ^{13}Ccarb and δ^{18}Ocarb will be analyzed using an automated carbonate preparation system coupled to a ThermoFinnigan 252 IRMS at the SIRFER laboratory. Microsamples of burial cements will also be analyzed to characterize known diagenetic phases, and isotopic data sets will be screened for diagenetic effects (Bowen *et al.*, 2001; Bowen *et al.*, 2005).

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