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Integrated paleoenvironmental analysis of the Niobrara Formation: Cretaceous Western Interior Seaway, northern Colorado

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ABSTRACT

This study presents a regional chronostratigraphic framework and paleoenvironmental reconstruction of the Niobrara Formation in northern Colorado based upon multidisciplinary biostratigraphic and lithostratigraphic data. A local biostratigraphic zonation is described for the Coniacian to earliest Campanian of this region of the Western Interior Seaway based primarily upon the distribution of calcareous nannofossils. Three key paleoenvironmental packages are also identified and linked to the evolution of regional sedimentary facies.

During the Early to Late Coniacian, Tethyan water masses interacted with Boreal surface currents to produce regional upwelling along tectonically-controlled bathymetric highs. A well mixed, relatively well oxygenated water column with warm surface water temperatures and high fertility sustained a rich microflora/fauna and promoted higher carbonate production.

Enhanced fluvial input and a weakening of Tethyan influence during the Early Santonian mark the onset of a regional environmental shift. This period of transition extends through the Middle Santonian and is characterized by pulses of transported material and relatively frequent turnover of faunal associations. Increased terrigenous runoff likely produced eutrophic surface waters and intensified water column stratification, leading to a general deterioration of the bottom water environment in a progressively dysoxic setting.

Continued strengthening of fluvial input during the Late Santonian to Early Campanian resulted in surface water freshening and sustained primary productivity. This surface water environment—in conjunction with stifled vertical mixing—promoted the development of a stagnant and intensely stratified water column. The basin was therefore severely dysoxic (possibly anoxic) and corrosive with chemically reducing bottom waters and an expanded oxygen minimum zone, thereby limiting biotic development and causing the deposition of finely laminated, mud-rich (carbonate poor) seciments.

1. Introduction

The recent increase in North American unconventional oil and gas production has spurred exploration efforts into organic rich formations throughout the continental interior (Newell, 2011; Helbling, 2013). Robust geologic models are critical to successful development of unconventional systems. Biostratigraphic data contribute to such models by providing a stratigraphic framework from which vertical and lateral variability in resource distribution and quality can be described. Accurate paleoenvironmental reconstructions are also essential for detailed reservoir characterization and an improved understanding and prediction of stratigraphic intervals with favorable rock properties. Thus, by providing a stratigraphic framework and models of facies variability, biostratigraphic tools can play an important role in early exploration and assist in resource mapping and sweet spotting in unconventional petroleum systems.

This study presents a regional stratigraphic framework and paleoenvironmental reconstruction of the Niobrara Formation in northern Colorado (Fig. 1) based upon multidisciplinary biostratigraphic and petrographic data. In doing so, this analysis provides an integrated biofacies/lithofacies model of sediment deposition and regional paleoenvironments that will assist in reservoir characterization and enhance our understanding of basin evolution.

1.1. Geologic setting

The Niobrara Fm. was deposited in an asymmetrical foreland basin of the Western Interior Seaway (WIS) during the Late Turonian to Early Campanian (~89–82 Ma) (Kauffman, 1977a, b; Bloch et al., 1993; Plint et al., 1993; Kreitner and Plint, 2006; Locklair and Sageman, 2008; Merewether et al., 2011; Fig. 2). Accelerated subsidence in the western foredeep relative to the central and eastern parts of the

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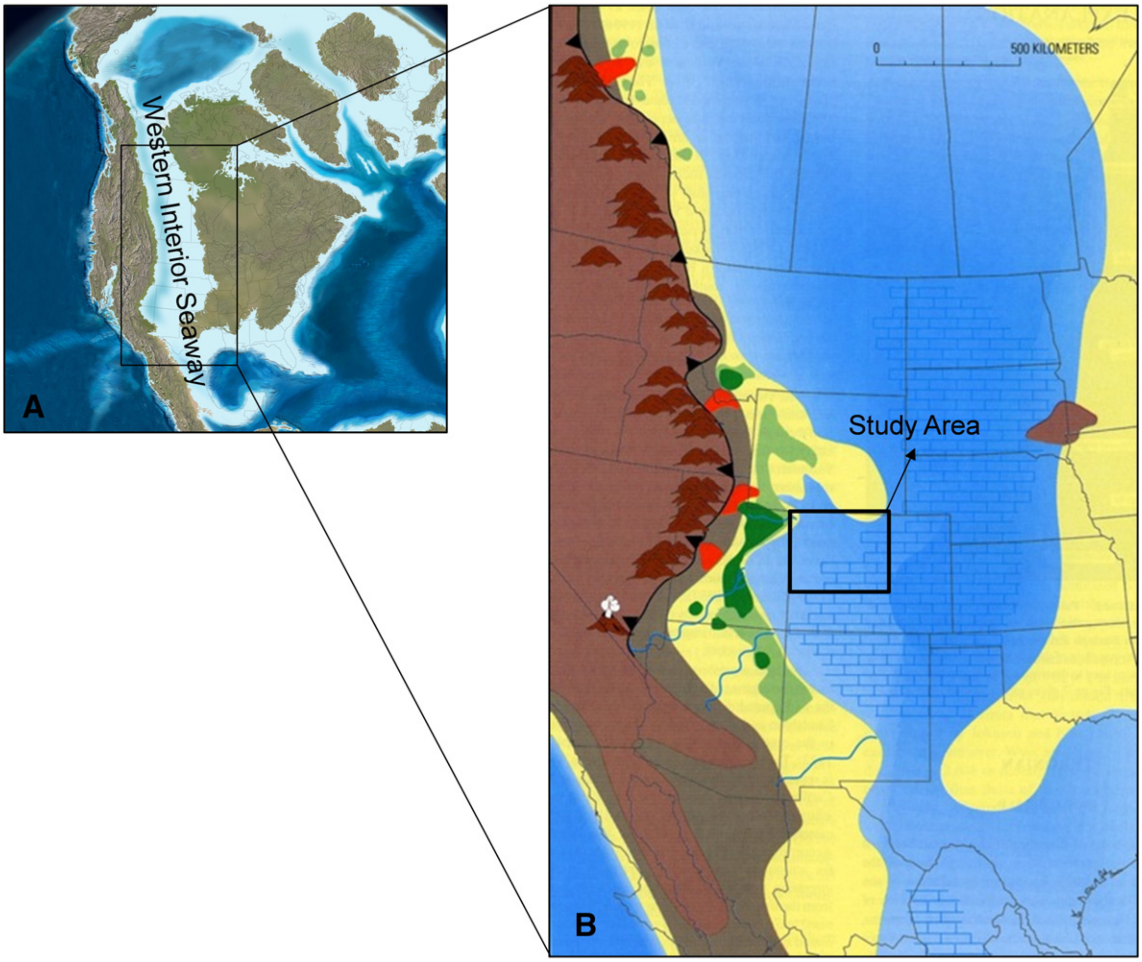

Fig. 1. (A) Regional paleogeography of North America during the Santonian (85 Ma) from Blakey, 2011. (B) Schematic diagram of the WIS during deposition of the Niobrara Fm. (modified from Roberts and Kirschbaum, 1995) with identification of the approximate study area.

WIS resulted in deposition of a wedge shaped, eastward thinning ramp of Niobrara sediments (Leckie et al., 1994; Fig. 2). The Niobrara Fm. is subdivided into two members, the Fort Hays Limestone (typically ~10 m thick) and the Smoky Hill Chalk (typically >80 m thick), which is subdivided into 7 marl and chalk sub-members (Weimer, 1960; Scott and Cobban, 1964; Kauffman, 1969, 1977a,b; Hattin,

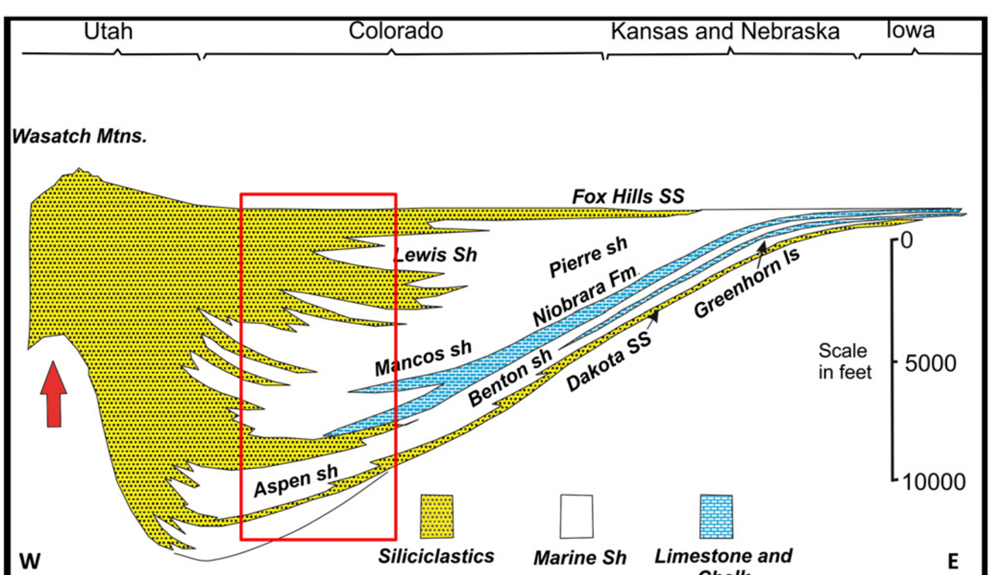

Fig. 2. Regional cross section through the Cretaceous WIS showing generalized stratigraphic architecture and basin geometry. The approximate location of the study area is shown in red. Modified from Kauffman (1977a).