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Paleocirculation and foraminiferal assemblages of the Cenomanian–Turonian Bridge Creek Limestone bedding couplets: Productivity vs. dilution during OAE2

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ABSTRACT

The limestone–marlstone (or limestone–calcareous shale) bedding couplets of the lower Bridge Creek Member of the Greenhorn Formation coincide with Oceanic Anoxic Event 2 and the Cenomanian–Turonian stage boundary at 93.9 Ma, and are characterized by fluctuations in microfossil and macrofossil biofacies, and organic carbon. Since G.K. Gilbert (1895), these strongly alternating lithofacies have been attributed to climate and/or productivity cycles. Heretofore, only the calcareous shale and marlstone parts of the Bridge Creek bedding couplets have been quantitatively analyzed for planktic and benthic foraminiferal assemblages. In this study, foraminiferal assemblages extracted from the hard limestone beds are comparable with the muddier lithologies thereby allowing a quantitative evaluation of the foraminiferal response to cyclically changing conditions in the U.S. Western Interior Sea (WIS) that resulted in the deposition of these lithologic couplets. The results reveal a modest cyclical response of foraminiferal assemblages extracted from limestone beds compared to adjacent calcareous shale or marlstone. These include the absence of planktic planispiral morphotypes (*Globigerinelloides*), increase in the proportion of planktic biserial and triserial morphotypes (*Heterohelix* and *Guembelitria*, respectively), and an increase in the proportion of benthics relative to total foraminifera (decrease in percent planktics) in the limestone beds. Such conditions suggest that the limestones may have been more productive than the adjacent shales and marlstones. Reduced surface salinity and greater stratification of the upper water column may have also contributed to the differences in assemblages preserved in the marlstones and calcareous shales. The onset of OAE 2 in the late Cenomanian is marked by an abrupt benthic oxygenation event ('Benthonic Zone') as Tethyan waters were drawn well north into the WIS, and cool Boreal waters spread across northwest Europe, known as the Plenus Cold Event. At this time, the WIS became an important ocean gateway for surface ocean circulation with rising sea level that helped facilitate the development and spread of OAE 2. A cyclonic (counterclockwise) gyre circulation in the WIS during deposition of the lower part of the Bridge Creek was driven by the difference between precipitation in the north and evaporation in the south. The gyre is represented by two modes, strong and weak, responsible for deposition of the limestone and marlstone, respectively. For the middle and upper parts of the studied section representing the plateau of OAE 2 and subsequent peak transgression of the WIS, the counterclockwise gyre was driven less by E-P gradient but by the amount of surface runoff from both margins of the WIS with deposition of limestone beds during the wetter (strong) phase and marlstones during the drier (weak) phase. Highest levels of TOC redevelop after OAE 2 in the early Turonian with the incursion or development of an oxygen minimum zone at the time of peak transgression.

1. Introduction

During the late Cenomanian to early Turonian (~95–93 Ma), transgression flooded the asymmetrical foreland basin to form the relatively shallow Greenhorn Seaway (Fig. 1). Deposition of rhythmically bedded sequences occurred in the central portions of the

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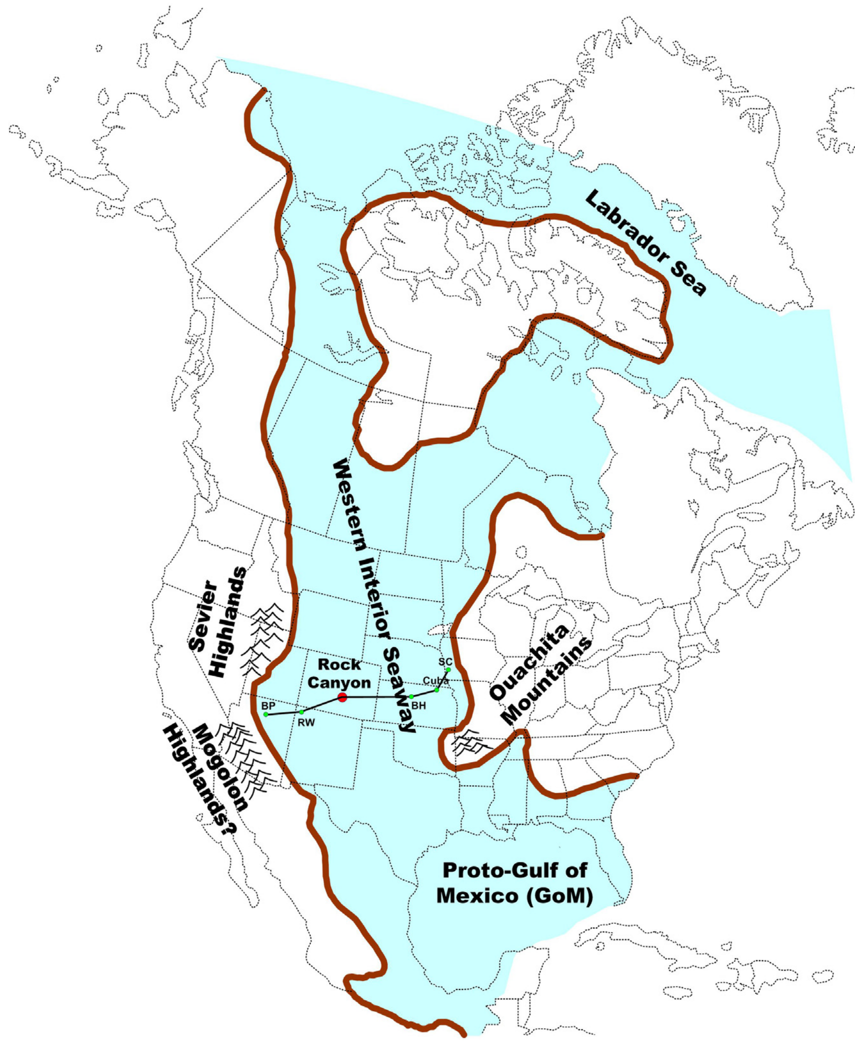

Fig. 1. Map of the Western Interior Sea during Greenhorn maximum transgression in the early Turonian connecting the Boreal Sea and the Proto-Gulf of Mexico. The figure also shows the location of the Rock Canyon section within the seaway and relative to other important sections span the C–T boundary that make a west–east transect across the seaway; modified after Cobban et al. (2005).

seaway during late transgression and highstand, including the Bridge Creek Limestone Member of the Greenhorn Formation and its equivalents (Eicher and Worstell, 1970; Cobban and Scott, 1972; Kauffman, 1977, 1984; Barron et al., 1985; Eicher and Diner, 1985; Elder and Kirkland, 1985; Hattin, 1985; Leckie, 1985; Elder et al., 1994; Sageman et al., 1997a; Leckie et al., 1998; Arthur and Sageman, 2005). These strata were linked to Oceanic Anoxic Event 2 (OAE 2) spanning the Cenomanian–Turonian (C–T) boundary at 93.9 Ma (Meyers et al., 2012b). OAE 2 was a short-lived event (563–601 kyr, Sageman et al., 2006; 430–445 kyr, Voigt et al., 2008) characterized by a >1‰ positive shift in $\delta^{13}C$ of organic carbon and carbonate (Fig. 2; Scholle and Arthur, 1980; Pratt and Threlkeld, 1984; Pratt, 1985; Schlanger et al., 1987; Arthur et al., 1988; Pratt et al., 1993; Sageman et al., 1998; Jarvis et al., 2006, 2011; Jenkyns, 2010), and by micro- and macrofossil extinctions and diversifications (e.g., Elder, 1985, 1987, 1989; Leckie, 1985; Watkins, 1985; Kennedy and Cobban, 1991; Gale et al., 2000, 2005; Leckie et al., 2002; Erba, 2004). But unlike records of OAE 2 elsewhere around the world, the event begins as an abrupt improvement of oxygenation of the seafloor in the WIS, from the laminated, organic carbon-rich Hartland Shale to the initiation of interbedded limestone and marlstone/calcareous shale of the Bridge Creek Limestone.

The limestone/marlstone bedding couplets of the Bridge Creek Member of the Greenhorn Formation are characterized by fluctuations in biofacies, bioturbation, and organic carbon (Sageman et al., 1997a, 1997b, 1998; Savrda, 1998). Two general models have been proposed to explain the deposition of the Bridge Creek alternating lithofacies, both tied to Milankovitch climate cycles. The dilution model is based on wet–dry cycles of increased and decreased detrital input to the basin to account for shale and limestone deposition, respectively (Fig. 3; Pratt, 1984; Barron et al., 1985; Watkins, 1985, 1989; Flögel et al., 2005). The productivity model, by contrast, posits that increased or decreased carbonate production at the surface of the ocean was primarily responsible for the carbonate-rich or carbonate-poor beds (Fig. 3; Eicher and Diner, 1985, 1989, 1991). Here we present new evidence that both models contributed to the observed cyclicity; productivity was more dominant in the earliest phases of Bridge Creek Limestone deposition due to external influences on the seaway, while dilution became the dominant driver of cyclicity with rising sea level and the development of a stronger influence of factors internal to the WIS.