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Cenomanian–Turonian carbon isotope stratigraphy of the Western Canadian Sedimentary Basin

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The Cenomanian–Turonian boundary was characterized by distinctive positive carbon isotope excursions that were related to the formation of widespread oceanic anoxia. High-resolution geochemical proxies (TOC, $CaCO_3$, $\delta^{13}C_{org}$, and $\delta^{13}C_{carb}$) obtained from bulk rock, planktic foraminifers, and inoceramids from four marine marlstone-dominated stratigraphic sections in the Western Canada Sedimentary Basin (WCSB) were used to establish a regional carbon isotope stratigraphic framework and to investigate paleoenvironmental variability in four different depositional settings. Compared to background $\delta^{13}C_{org,}$ (<−27‰) and $\delta^{13}C_{carb}$ (<2‰) values which were correlative to stable isotope excursions during Oceanic Anoxic Event (OAE) II worldwide, the $\delta^{13}C_{org}$ (>24‰), and $\delta^{13}C_{carb}$ (>4‰) derived from inoceramid prisms in the studied sections within WCSB, were elevated during the Late Cenomanian–Early Turonian. During this interval, TOC and $CaCO_3$ values which increased sporadically to >40% and 7%, respectively, were not consistent enough to be used for stratigraphic correlations. Based on the $\delta^{13}C_{org}$ excursions, two bentonite beds were regionally correlated across this portion of the Western Interior Seaway (WIS). The eruption associated with the “Red” bentonite occurred approximately coeval with the maximum $\delta^{13}C_{org}$-excursion during OAE II in the *Neocardioceras juddii* Zone, whereas the “Blue” bentonite coincides with the termination of OAE II in the latest *Watinoceras devonense* zone. During the Late Cenomanian–Early Turonian in the WCSB, benthic foraminifers were sparse or totally absent, indicating the existence of fully anoxic bottom-water conditions. Planktic foraminifera were common in the well-oxygenated surface waters. A benthic oxic zone characterized by several agglutinated species occurs in the eastern part of the WSCB at the beginning of OAE II in the *Sciponoceras gracile* zone. The termination of the OAE II in the WCSB coincides with the first occurrence of small ammonites (*Subprionocyclus* sp.) in the western part of the basin.

1. Introduction

The Cenomanian–Turonian climate is part of a prolonged hot “greenhouse” episode in Earth’s history (e.g., Kauffman and Caldwell, 1993). Temperatures as high as 17 and 34 °C have been reported in polar and equatorial regions, respectively, during this climate interval (Tarduno et al., 1998; Huber et al., 2002). Global sea-level was also known to have risen to >100 m above current levels (Frakes, 1999; Hay and DeConto, 1999; Poulsen et al., 1999). The temperature increase has generally been attributed to large-scale CO_2 release from volcanic eruptions (e.g., Tarduno et al., 1998) or due to intensified nutrient and CO_2 upwelling along the oceanic margins during the opening of the Atlantic Ocean (e.g., Arthur et al., 1987). The surplus CO_2 and nutrients led to global warming and high marine productivity, respectively. As result, oceanic and other marine anoxia, which commonly lead to the formation, deposition and preservation of organic-rich sediments such as black-shales (Arthur and Schlanger, 1979; Pucéat, 2008), were developed in bottom waters globally. The investigation of many oceanic sites during the Deep Sea Drilling Project in the 1960s and 1970s and continued research with the Ocean Drilling Program (ODP) indicate that anoxic organic-rich sediments were globally distributed in the oceans during several Cretaceous intervals such

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as the Cenomanian–Turonian anoxic interval, the Oceanic Anoxia Event II (OAE II) (e.g., Schlanger and Jenkins, 1976).

Several causes for the distribution and preservation of the anoxic organic-rich sediments during OAE II have been suggested and assigned to particular marine settings. For example, stagnant water circulation during global relative sea-level highstands, which is hypothesized to facilitate the formation and development of anoxic bottom waters, was suggested as an important cause of forming and accumulation of organic-rich sediments (Arthur and Schlanger, 1979).

The impact of substantial submarine volcanism related to the eruption of the Caribbean Plateau Basalt or sub-aerial volcanism has also been considered the ultimate trigger for the OAE II and associated sudden warming (e.g., Kerr, 1998; Snow et al., 2005; Kuroda et al., 2007; Turgeon and Creaser, 2008). These hypotheses suggest that this volcanism caused an expansion of the oxygen minimum zone associated with elevated primary productivity, due to injection of biolimiting metals and/or nutrient-rich deep water into the surface ocean.

Alternatively, Friedrich et al. (2008, 2012) suggested that warm saline intermediate waters influx into the proto-North Atlantic Ocean was due to the presence of shallow sills that limited bottom-water circulation and restricted water exchange in the deep. This restricted bottom-water circulation might have acted as preconditioning factors for the prolonged period of anoxia and black-shale formation in the equatorial proto-North Atlantic Ocean and connected epicontinental seas during the Cretaceous. As a consequence, carbon burial during the Cretaceous oceanic anoxic events produced a positive δ^{13}C shift in global carbon reservoirs. Recently, geochemical methods, such as δ^{18}O and TEX$_{86}$ have provided evidence for changes in sea-surface temperatures and indicated large vertical thermal gradients during the OAEs (e.g., Voigt et al., 2004; Forster et al., 2007). High-resolution carbon isotope and TOC studies in sections from different marine environments worldwide suggest that the positive excursion is a response to increased burial of organic matter in the deep ocean, while a volcanic-driven onset of OAE II is unlikely (Bowman and Bralower, 2005).

Recent studies show that many OAE II sections consisting of marlstone, limestones, or sandstones and characterized by diverse benthic activity, were formed under oxic conditions (e.g., Friedrich et al., 2008; Wendler et al., 2010). In addition, during the OAE II several intercalated intense oceanic overturning and cooling events identified in marine records (e.g., Forster et al., 2007), were related to Milankovitch-cycle driven rapid glacio-eustatic sea-level falls (Bornemann et al., 2008; Wendler et al., 2010). As consequence of the sea-level fluctuations and variability in the ocean circulation, anoxia is not evenly spatially and temporally distributed globally (e.g., Sageman et al., 2006; Forster et al., 2007; Wendler et al., 2010; Van Bentum et al., 2012).

The global rise in sea-level during the mid-Cretaceous resulted in the connection of the Gulf of Mexico with the Boreal Sea forming the Western Interior Seaway (WIS) of America (Fig. 1). The Western Canada Sedimentary Basin (WCSB) represents the Canadian portion of the Western Interior Seaway and stretches over 1500 km west to east from the foothills of the Rocky Mountains to the Manitoba Escarpment. The Cretaceous subsurface sediments in the WCSB contain large petroleum resources and, consequently, their sedimentology, stratigraphy, and depositional environments have been extensively studied (e.g., McNeil and Caldwell, 1981; Bloch et al., 1993, 1999; Schröder-Adams et al., 1996, 2001; Plint et al., 2009). However, studies on stable isotopes from carbonates and organic matter as well as of the seawater chemistry of the WCBS derived from bentonite beds were limited to a few locations and short stratigraphic intervals (Kyser et al., 1993; Cadrin et al., 1996; Bloch et al., 1999; Prokoph et al., 2001).

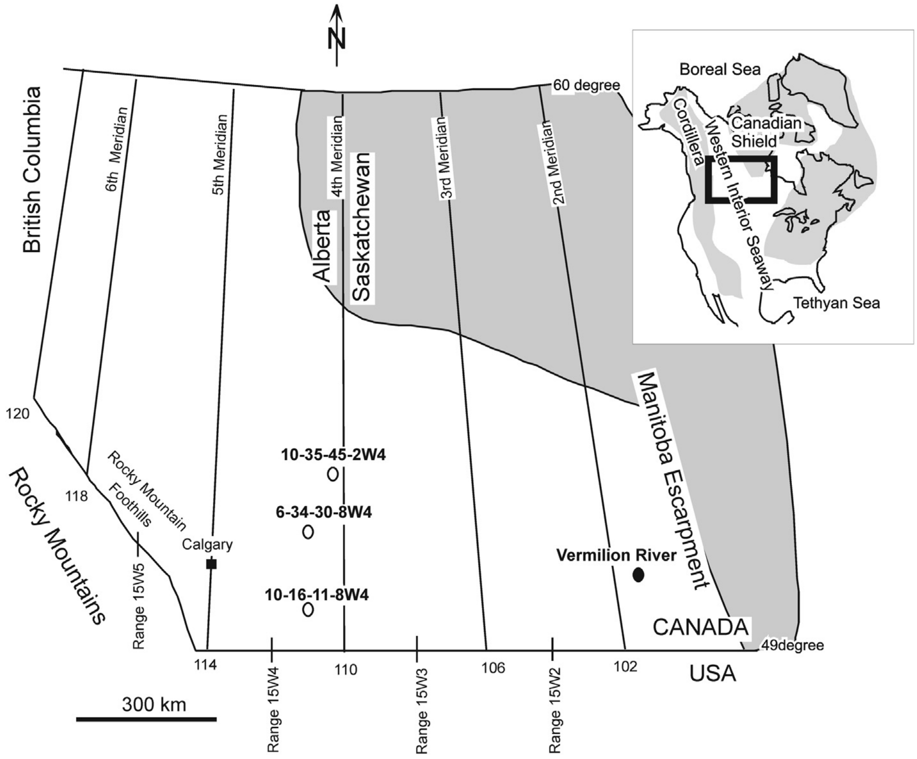

Fig. 1. Sample location map in the WCSB with palaeogeographic map of the Western Interior Seaway during the Late Cenomanian (after Kauffman, 1984); cores – empty circles, outcrop – filled circle. Grey-shaded area: Late Cenomanian Land mass. Black square in palaeogeographic map indicates sample location map border.