

Carbon-isotope stratigraphy and sea level changes in the mid-Cretaceous supergreenhouse: Turonian of the Western Interior Seaway

David Uličný
Institute of Geophysics of the
Czech Academy of Sciences

Bradley B. Sageman
Northwestern University

Guy Plint
University of Western Ontario

Matthew M. Jones*
Northwestern University

Darren R. Gröcke
Durham University

João P. Trabucho-Alexandre
Utrecht University

R. Mark Leckie
University of Massachusetts

Ian Jarvis
Kingston University London

Jeffrey G. Eaton
Natural History Museum of
Utah

Ireneusz Walaszczyk
University of Warsaw

* current address: Geology, Energy & Minerals Science Center, U.S. Geological Survey

Summary

Driving mechanisms of global sea-level change during greenhouse, supposedly ice-free climatic regimes are controversial, with debate focusing on potential brief glacial episodes *versus* storage of liquid water in aquifers, lakes and other surface reservoirs. Here, we use time series of carbon stable isotopes, sedimentological and elemental geochemical data in shallow-marine successions of Turonian age (mid-Cretaceous, c. 94–89 years ago) from tectonically independent depocenters in the Western Interior Seaway (WIS) to: (i) establish the chronology and assess the regional *versus* potentially global nature of long-term (c. 10^6 years) cyclic changes in palaeo-sea level; and (ii) suggest which astronomical cycles and climatic mechanisms may have been involved in driving sea-level fluctuations in this greenhouse regime.

Introduction, Data and Methods

In this study we apply carbon-isotope stratigraphy, in combination with biostratigraphic data and dated bentonite horizons, to explore the synchronicity of major transgressive–regressive events previously reported from siliciclastic depositional systems of Turonian age in the WIS. While not an inter-continental correlation, our study compares datasets from several major fluvio-deltaic systems that filled tectonically separate sub-basins of the seaway marked by different tectonic subsidence and clastic supply histories. We focus on two regions of the WIS in which previous studies of stratigraphic architecture have established an interpretation of relative sea-level changes: southern to central Utah, U.S.A. and Alberta, Canada. While the former region benefits mainly from exceptionally well-exposed Cretaceous strata, the latter has a huge public database of well logs and cores that, with outcrop, allow stratal architecture to be determined in detail. In Utah, outcrop and core sections were studied in a 262 km-long transect parallel with the Sevier orogenic front, from the Kaiparowits Plateau in the south to the southwestern edge of the Uinta

Basin in the north. The Alberta record is a composite of two sections in the Rocky Mountain Foothills – Ram River and the previously published Horseshoe Dam section (Plint et al., 2022) linked by detailed well-log correlation spanning 220 km.

To portray the depositional histories of the sections studied in the time domain, the age model used is based on a biostratigraphically, and partly astrochronologically-calibrated, high-resolution, carbon-isotope time series (Laurin et al., 2023). This chronostratigraphic framework also affords an internally consistent comparison to published European records of Turonian transgressive–regressive history, important for assessment of global *versus* regional sea-level changes recognized in the two studied basins.

Results

As expected, each of the Turonian sections studied show regionally specific features related to local subsidence and clastic supply history; however, comparison of palaeobathymetric indices show several conspicuous stratigraphic features that can be correlated over c. 1700 km along the western margin of the WIS. Three to four major transgressive intervals are time-equivalent, within the resolution of isotopic and biostratigraphic correlations; two transgressive intervals correspond closely to boundaries of genetic sequences previously defined by Gardner (1995) in Utah (basal intervals of his “*hyatti*” and “*ferronensis*” sequences). Importantly however, coeval maximum intervals are also found in the Alberta records. A number of transgressive events can be correlated among most, but not all, sections in the Alberta–Utah transect. A broad correlation among all studied sections is also found in three principal, long-term intervals of shallow-water conditions, characterized by dominantly regressive stratal patterns, separated by major transgressive events. Accurate correlation of subaerial unconformities or their correlative conformities among WIS basins is generally difficult. In parts of the upper Turonian in Alberta, unconformities separated by approx. 400-kyr intervals were resolved by inter-continental correlation (Plint et al., 2022). In the same interval in Utah, the existing bio- and isotope stratigraphic framework does not yet permit comparable resolution, although orbitally forced relative sea-level changes have been suggested (e.g., Bhattacharya et al., 2019). Regional unconformities generated and/or amplified by tectonic movement exist in all sections studied throughout the Turonian Stage.

Comparison to a Central European succession (the Bohemian Cretaceous Basin) documented at a comparably high level of resolution reveals principal transgressive events closely correlative with those in the studied WIS sections, providing further support for their eustatic origin.

Implications

1. Correlation of eustatic events. The duration of the long-term cycles, interpreted here as eustatic, falls within the historically used category of “3rd-order” cycles. We note, however, that the chronostratigraphic timing of sea-level changes documented here differs from, and is commonly anti-phased, with the widely used cycle charts (most recently Haq 2014), adopted in the Geological Time Scale (Gale et al., 2020). This disagreement underlines: (i) the need to interpret deep-time sea-level history using detailed biostratigraphic and isotope stratigraphic frameworks; and (ii) the premise that “global sequence boundaries” are conceptually problematic.
2. Drivers of mid-Cretaceous eustasy and the carbon cycle. Intervals of the Turonian with evidence of pacing of sea-level changes by the long-eccentricity (405-kyr) cycle have

been documented by other recent studies (Plint et al., 2022; Laurin et al., 2023). Long-term cyclicity demonstrated in the WIS Turonian and correlative time-equivalent records in Central Europe suggests a relationship between major sea-level fluctuations and long-term amplitude modulation of obliquity cycles, previously proposed to drive carbon cycling in mid- to high latitudes (Laurin et al. 2015). This c. 1-Myr cycle has been previously proposed as a driver for the “3rd-order” cyclicity (Lourens and Hilgen, 1997). In greenhouse conditions, the interplay of long- and short-term sea-level fluctuations could have been driven by geographically diverse hydrological reservoirs sensitive to different aspects of astronomical forcing.

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