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Sea-level change, carbon cycling and palaeoclimate during the Late Cenomanian of northwest Europe; an integrated palaeoenvironmental analysis

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Abstract

A new high resolution sea-level curve for the Late Cenomanian *M. geslinianum* Zone has been generated using sequence stratigraphic analysis on transects through the margins of the Anglo-Paris Basin in the UK and Saxony Basin in Germany. Transgressive sediments that bury a rocky shoreline in the Dresden area have proved particularly useful in determining both the absolute amount of sea-level change and the rate of rise. After a brief fall at the base of the *M. geslinianum* Zone, sea level rose rapidly through the higher part of the zone, resulting in an overall short term eustatic rise of 22–28 m. Biostratigraphy and carbon isotope stratigraphy have enabled detailed correlations to be made between marginal locations and thick, relatively complete, basinal successions. The basinal successions at Eastbourne, UK, and Gröbern, Germany, provide both geochemical proxies for palaeoenvironmental change, including oxygen and carbon isotope records, and an orbital time-scale graduated in precession and eccentricity cycles. Integration of the sea-level history with palaeoclimate evolution, palaeoceanography and changes in carbon cycling allows a detailed reconstruction of events during the Late Cenomanian. Orbital forcing on long eccentricity maxima provides the underlying drive for these changes, but amplification by tectonic events and feedback mechanisms augmented the orbital effects and made the Cenomanian/Turonian Boundary Event distinctive. In particular, variations in atmospheric CO_2 caused by oceanic drawdown and a brief period of intense volcanic outgassing resulted respectively in short term cooling and warming events. The magnitude and high rates (up to 1 m/1 kyr) of sea-level rise are diagnostic of glacioeustasy, however improbable this may appear at the height of the Cretaceous greenhouse.

Keywords: Late Cenomanian; Stable isotopes; Sea level; Carbon cycle; Palaeotemperature; Brachiopods

1. Introduction

The late Cenomanian–early Turonian time interval is marked by a substantial positive $\delta^{13}C$ excursion at a time of anoxic conditions in oceanic deep-sea and surface waters (OAE 2; Schlanger and Jenkyns, 1976; Arthur et al., 1988; Kuhnt et al., 1990; Kuypers et al., 2002; Tsikos et al., 2004), widespread drowning of carbonate platforms (e.g. Masse and Philip, 1981), and major changes in faunal abundance and diversity (e.g. Jarvis et al., 1988; Elder, 1989; Gale et al., 2000). The $\delta^{13}C$ excursion lasted about 400 kyr (Kuhnt et al., 1997; Caron et al., 1999), and is widely attributed to increased oceanic productivity and rates of organic carbon burial.

During the Cenomanian, enhanced intra-oceanic plateau and mid-ocean ridge volcanism initiated a global long-term sea-level rise (Hays and Pitman, 1973), which was accompanied by increased seafloor hydrothermal activity causing the

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seawater $^{87}Sr/^{86}Sr$ ratio to decrease (McArthur et al., 2001). The concomitant effect of both processes is considered to provide boundary conditions for most of the oceanic anoxic events in the Mesozoic, mainly by the maintenance of elevated nutrient levels (Jones and Jenkyns, 2001).

Superimposed on the Cenomanian long-term sea-level rise, several third-order sea-level changes caused the synchronous deposition of sedimentary sequences worldwide (e.g. Robaszynski et al., 1998), and have been shown to be driven by the 400-kyr-long eccentricity cycle (Gale et al., 2002). The positive $\delta^{13}C$ excursion (Cenomanian/Turonian Boundary Event – CTBE) commences at the base of the *Metoicoceras geslinianum* Zone within Sequence 11 of Gale et al. (2002). The enhanced magnitude of sea-level change coincident with the carbon excursion provides evidence that rapid sea-level and carbon-cycle changes are causally related (Jarvis et al., 2006). Although the mechanism or mechanisms controlling shorter term Mesozoic sea-level change is contentious, the consistent relationship between sea level and orbital frequencies implies that changes in palaeoclimate and ocean circulation are involved; possible contenders are the hydrological cycle or glacioeustasy (e.g. Jacobs and Sahagian, 1993; Miller et al., 1999, 2003, 2004). The incompleteness of the sedimentary record in shallow marine successions has to date inhibited a correlation with more complete basinal successions.

A variety of authors have suggested that increased volcanism and hydrothermal activity were the cause of elevated atmospheric CO_2 concentrations, which are responsible for greenhouse climate conditions, and enhanced nutrient availability, considered crucial for both initiation of and response to the Cenomanian–Turonian carbon-cycle perturbation (Larson, 1991; Orth et al., 1993; Sinton and Duncan, 1997; Kerr, 1998). Arthur et al. (1988) suggested that increased rates of organic carbon burial acted as rapid negative feedback for global warming by lowering atmospheric CO_2 levels. Based on changes in the isotopic fractionation between inorganic and organic carbon, this decrease was estimated to be in the order of 20% (Freeman and Hayes, 1992; Kuypers et al., 1999). Such substantial changes in atmospheric greenhouse gas composition should have a significant impact on global climate and ocean circulation. Sudden climate cooling is indicated by a southward incursion of boreal micro- and macrofauna into low-latitude seas (Kuhnt et al., 1986; Gale and Christensen, 1996). On the other hand, substantial warming is indicated for the western Central Atlantic deep-sea by oxygen isotope data (Huber et al., 1999), and for shelf-sea waters in western Europe where a temperature rise of 4–5 °C occurred in the later part of the OAE 2 $\delta^{13}C$ excursion (Voigt et al., 2004). Additional independent palaeotemperature records for the CTBE are not available so far and limit our knowledge about the coupled response of climate and carbon cycle to the initial event.

This study uses a combination of facies analysis and transects from basin margins to depositional centres to investigate the development and lateral relationships of key stratal surfaces (sequence boundaries, onlapping surfaces, condensed sections) in order to reconstruct sea-level change through the Late Cenomanian and Early Turonian in detail (Fig. 1). The curve generated by this study is then compared with new and previously published geochemical proxies for palaeoenvironmental change, including brachiopod $\delta^{18}O$ records to identify palaeotemperature change and $\delta^{13}C$ values of bulk carbonates and total organic carbon to indicate evolution of the carbon cycle. Key to the success of this study is high-resolution correlation, based on integrated carbon isotope stratigraphy and biostratigraphy (Gale et al., 2005) and development of an orbital timescale. Spectral analysis, performed on greyscale values of an expanded borehole succession in Saxony (Gröbern), will improve the orbital time scale through the CTBE developed at Eastbourne (Gale et al., 1999b, 2005). The new data set is used to discuss the carbon cycle variations in relation to changes in sea level and climate and develop an integrated model for palaeoenvironmental change through the Late Cenomanian and Early Turonian.

2. Sampling and methodology

2.1. Identifying and quantifying sea level changes

The basinal successions studied here are dominated by pelagic chalks and marls (England) and hemipelagic siliciclastic siltstones and carbonates (Saxony). Several studies have discussed the application of sequence stratigraphical analysis to chalk and marly chalk successions (e.g. Gale, 1996; Robaszynski et al., 1998; Wilmsen, 2003). A consensus exists as to the significance of the sedimentary criteria used to identify systems tracts (Gale, 1995, 1996; Robaszynski et al., 1998; Gale et al., 2002; Wilmsen, 2003), which can be summarised as follows:

1. Shelf chalks respond to sea-level change in the manner of very fine clastic sands and silts rather than that of either clays or platform carbonates. In contrast to siliciclastic deposits that are shed from the basin margins (river-mouths or coasts), chalks were deposited as planktonic rain with the same sedimentation rates across vast shelf areas. Redistribution by storm-induced currents affected the carbonate mud, which produce hiatuses above storm wave base and enhanced thicknesses in depressions and off the coast (Wilmsen, 2003). Chalks dewatered rapidly to provide relatively firm substrata, prone to reworking to form intraclastic conglomerates during regressions.

2. Sequence boundaries in marginal settings can be identified as erosional surfaces, sometimes channelled, which cut down towards basin margins. These surfaces are commonly coincident with a transgressive surface, especially when they are lithified to form hardgrounds, characteristically coloured green by glaucony (Gale, 1996). In basinal settings, the sequence boundary is represented by a correlative conformity that is characterized by a facies change towards an increased input of clay and silt. In hemipelagic chalks and mixed siliciclastic siltstones and carbonates, lowstand deposits contain more clay than the underlying calcareous highstands.