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Cyclostratigraphy of the reference section for the Cretaceous white chalk of northern Germany, Lägerdorf–Kronsmoor: A late Campanian–early Maastrichtian orbital time scale

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ABSTRACT

New carbonate records of the upper Campanian–lower Maastrichtian white chalk of northern Germany at Lägerdorf–Kronsmoor represent a continuous succession suitable for time series analysis. The boreal chalk succession is characterized by several intervals of reduced carbonate content in the *basiplana*/*spiniger*, *polyplocum*, upper *langei* and upper *grimmensis*/*granulosus* to *pseudoobtusa* boreal macrofossil zones, which are mainly related to periods of increased detrital supply. Results of spectral analysis on the carbonate time series allow the detection of the periodicities of long and short eccentricity. The long eccentricity signal can be extended to the entire Upper Campanian comprising a total of 15.25 long eccentricity cycles, a minimum time span of 6.2 Ma and an age of 77.5 ± 0.4 Ma for the lower–upper Campanian boundary. The long eccentricity cycles detected from chalk carbonate contents correlate with long eccentricity cycles detected in self-potential logs of boreholes proving their significance within different depositional settings and rates of subsidence in the North German Basin. The biostratigraphic consistent occurrence of long eccentricity cycles provides evidence for the completeness of the sedimentary record. The long-term intervals of increased detrital supply are the expression of increased progradation of clay minerals related to a long-term sea-level fall with superimposed short sea-level falls within a 2.5 million year interval spanning the Campanian–Maastrichtian boundary. It cannot be decided from the present state of knowledge if this signal is controlled by increased erosion due to uplift of inverted structures, by eustatic sea-level fall or a combination of both. The detection of the long eccentricity suggests an orbital forcing superimposed on a long-term regressive trend.

1. Introduction

The Late Cretaceous was a period of long-term climate cooling that occurred after the extreme warmth of the mid-Cretaceous greenhouse world (Jenkyns et al., 1994; Clarke and Jenkyns, 1999; Huber et al., 2002). The climate cooling is mainly considered as a result of changes in ocean circulation due to plate movements. The progressive deep water exchange between the proto-North and South Atlantic after the opening of the Equatorial Atlantic Gateway in the late Santonian to early Campanian has been invoked to have intensified the meridional turnover (Wagner and Pletsch, 1999; Pletsch et al., 2001; Friedrich and Erbacher, 2006). In Campanian–Maastrichtian times, climate cooling has also been attributed to a displacement of intermediate- and deep-water formation sites from low to mid or even high latitudes (Barrera et al., 1997; D'Hondt and Arthur, 2002; Friedrich and Hemleben, 2007). Distinct changes in the oxygen and carbon isotopic composition of benthic and planktonic foraminifera have been interpreted to reflect ephemeral glaciations, which were accompanied by major regressions at that time (Miller et al., 1999, 2005; Kominz et al., 2008).

Only little is known to date about the dynamics of the Campanian–Maastrichtian climatic change. In particular, it is still not well understood whether the cooling was a continuous trend or a stepwise succession of distinct events. A principle objection is the low temporal resolution of biostratigraphic zonations, which makes correlation over long distances ambiguous (Schönfeld et al., 1996a). Pronounced biotic provincialism between tropical and temperate taxa (Burnett et al., 2000), diachronous first occurrence ages of index taxa (Schulz and Schmid, 1983) as well as diagenetic alteration of primary strontium isotope signals (Bralower et al., 1997; Mearon et al., 2003; Bralower et al., 2004) and rock magnetic properties (Urbat, 1996; Riedinger et al., 2005) imply errors in chronostratigraphic ages of more than 500 kyr (e. g. Hinnov and Ogg, 2007; Huber et al., 2008; Gradstein et al., 2008).

An orbital stratigraphy can improve the resolution of the current Campanian–Maastrichtian chronostratigraphic framework and will help to further constrain the temporal dimension of tectonic and climatic processes and their controlling mechanisms. A continuous astronomical time scale has been developed extending back to the

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Oligocene (Pälike et al., 2006), and several options of orbitally tuned age scales were proposed for the Palaeocene and early Eocene (Westerhold et al., 2007; 2008). In the Cretaceous, floating astronomical timescales were developed for the early Cretaceous (Sprovieri et al., 2006), the Cenomanian (Gale et al., 1999), the Cenomanian–Turonian boundary interval (Sageman et al., 2006; Voigt et al., 2008a), and the Coniacian–Santonian (Locklair and Sageman, 2008). Only a few studies have detected orbital oscillations in the Campanian and Maastrichtian (Niebuhr and Prokoph, 1997; Niebuhr, 2005), even though the sedimentary record shows a marked short-term cyclicity (e.g. Ernst, 1963; Abu-Maaruf, 1975; Warren and Savrda, 1998; Damholt and Surlyk, 2004; Lauridsen and Surlyk, 2008).

The Coniacian to Maastrichtian chalk at Lägerdorf–Kronsmoor is together with Hemmoor the standard section for the boreal white chalk of northern Germany, and was the subject of stratigraphic research for more than five decades (Fig. 1). Biozonations with boreal macrofossils, such as belemnites and echinoids, brachiopods, benthic foraminifera, and calcareous nannofossils were established (Ernst and Schulz, 1974; Schulz, 1978; Schulz et al., 1984; Surlyk, 1984; Schönfeld, 1990; Schönfeld et al., 1996b; Burnett, 1998), as well as a strontium isotope stratigraphy (McArthur et al., 1992, 1993). The application of these zonations is confined to the boreal bioprovince of northern Europe (e.g. Jagt and Bongaerts, 1986; Schönfeld and Burnett, 1991; Christensen, 1999; Kopaevich et al., 2007). The sedimentological continuity of the pelagic chalk succession indicates a relative constant sedimentation rate making the Lägerdorf section well-suited for time series analyses and the development of an orbital stratigraphy.

This study will present a detailed documentation of recently exposed parts of the upper Campanian succession at Lägerdorf bridging the gap between this section and Kronsmoor. Two new carbonate records of different resolution are generated and used as time series in order to identify orbital frequencies in the upper Campanian–lower Maastrichtian succession covering about 8 Ma of time.

2. Geological setting

The Cretaceous chalk of northern Germany is usually buried below 500 to 1000 m thick Tertiary and Quaternary deposits (Ziegler, 1982). In the area of Lägerdorf and Kronsmoor, the chalk was uplifted to the recent surface by the northeast–southwest striking elongated Krempe salt diapir that is part of the Triassic Glückstadt Graben system (Fig. 1a) (Hinsch, 1977; Ehrmann, 1986). The diapir formation occurred during the late Triassic and Jurassic, when the Glückstadt Graben experienced extension. The salt structure was uplifted in course of the reactivation of marginal graben faults during the Tertiary (Baldschuhn et al., 1985; Baldschuhn et al., 2001). Parallel reflections in seismic profiles indicate an almost constant thickness of Upper Cretaceous strata suggesting a period of relative tectonic quiescence (Maystrenko et al., 2005). Some movements of the salt diapir are indicated by regional changes of sediment thickness and facies in the middle to late Santonian and in the early Campanian (Voigt, 1954; Niebuhr, 2006).

During the late Cretaceous, the locality of Lägerdorf and Kronsmoor was part of the boreal chalk sea comprising the southern North Sea Basin and the Anglo-Paris Basin (Mortimore and Pomerol, 1987; Surlyk et al., 2003). The 420 m thick succession of Coniacian–Maastrichtian chalk was deposited on a tectonically stable intra-shelf platform at water depths between 50 and 200 m (Ernst, 1978). The mean sedimentation rate was 2.3 ± 0.2 cm/kyr in the Santonian to lower Maastrichtian and increased to 3.3 ± 0.2 cm/kyr in the upper Maastrichtian (Ehrmann, 1986; Schulz et al., 1984). The chalk is poorly cemented and may be classified as extremely soft to very soft chalk (Ehrmann, 1986; Mortimore and Fielding, 1990; Schönfeld et al., 1991). The carbonate content is 95 to 100% in the Coniacian to lower Campanian and decreases to 85 to 95% in the uppermost Campanian to lower Maastrichtian (Scholz, 1973; Schulz, 1978; Schulz et al., 1984).

The chalk quarries Kröpke, Schinkel, and Heidestrasse are close to the village of Lägerdorf and they expose a succession from the Coniacian to the upper Campanian. The quarry Saturn to the south of the village Kronsmoor shows upper Campanian to lower Maastrichtian strata (Schönfeld et al., 1996b). The succession is divided by numbered recognizable beds, such as flints (F), bedding planes (B), marls (M), pyrite impregnated burrow horizons (G) and marly beds (mB) (Ernst, 1963; Ernst and Schulz, 1974; Schulz, 1978; Schulz et al., 1984). At Kronsmoor, the flint band F 600 marks the Boreal Campanian–Maastrichtian boundary. The succession at Lägerdorf terminated with flint F 105, while flint F 575 marks the base of the Kronsmoor section.

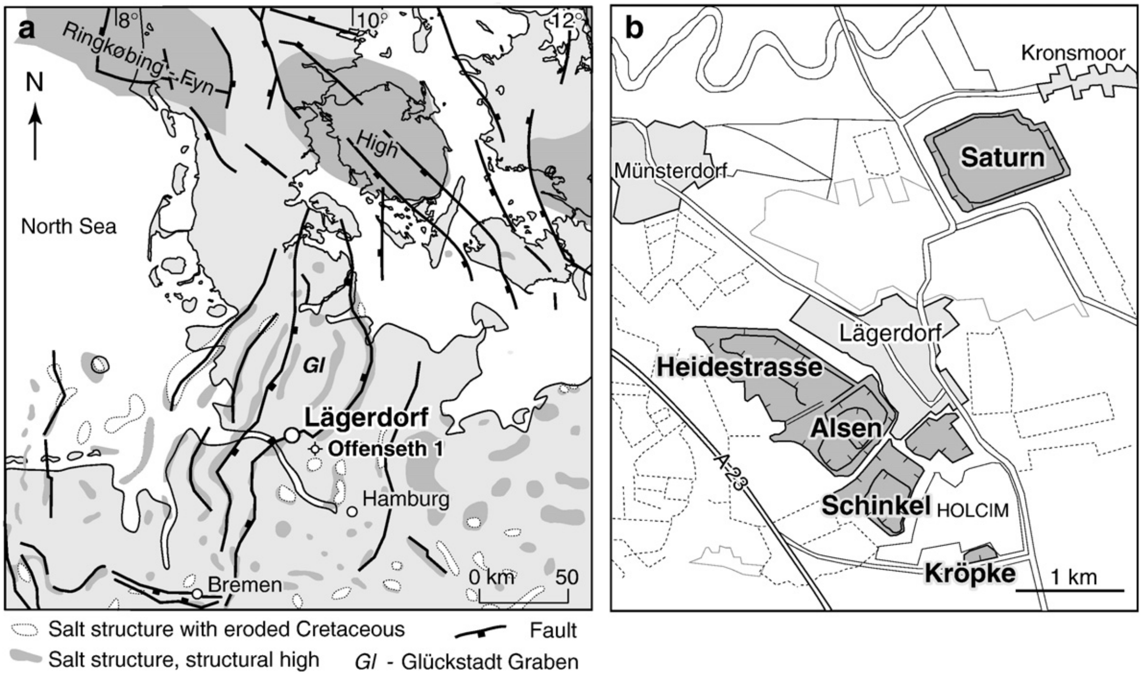

Fig. 1. a) Structural map of northern Germany and southern Denmark showing the location of the Lägerdorf section on top of a salt structure (modified after Voigt et al., 2008b), and b) location of the quarries Kröpke, Schinkel, Heidestrasse and Saturn at Lägerdorf and Kronsmoor.