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Inter-regional sequence-stratigraphical synthesis of the Plänerkalk, Elbtal and Danubian Cretaceous groups (Germany): Cenomanian–Turonian correlations around the Mid-European Island

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A B S T R A C T

Sequence-stratigraphical case studies of lower Upper Cretaceous shelf successions deposited in the periphery of the Mid-European Island (MEI) have been undertaken to precisely date sedimentary unconformities and corresponding depositional sequences, to test their inter-regional correlation, and to relate the observed stratigraphical architectures to a tectonic or eustatic control. In total, ten 3rd-order sequence-bounding unconformities (SB) have been identified in Cenomanian–Turonian sections from the Münsterland (MCB), Lower Saxony (LSB), Saxonian (SCB) and Danubian Cretaceous basins (DCB). SB Ce 1–3 are of early, mid- and late early Cenomanian age, while SB Ce 4 has been recognized in the uppermost middle and SB Ce 5 in the mid-upper Cenomanian strata. SB Tu 1 has been placed in the early–middle Turonian boundary interval and SB Tu 2 is a mid-middle Turonian unconformity. Sequence boundaries SB Tu 3–5 are of earliest late, mid-late and latest Turonian age, respectively. These inter-regional unconformities define depositional sequences DS Ce 1–5, DS Ce–Tu 1 and DS Tu 2–4 that are stacked into a 2nd-order cycle with a major onlap phase during the Cenomanian and early Turonian, culminating in a late middle Turonian 2nd-order maximum flooding. SB Ce 3 and Ce 5 as well as SB Tu 2 and Tu 4 represent major unconformities associated with eurybatic sea-level falls and subsequent rises of significant amplitude based on their stratigraphical and sedimentological signatures. Plate margin deflection or plate buckling are rather unlikely causes of the inferred sea-level changes given the considerable distance (>500 km) between the investigated basins and the long-distance persistence of the unconformities in identical stratigraphical positions. Inversion tectonics, however, influenced sedimentation from the mid-Turonian, increasing subsidence of marginal troughs along basin-bounding future thrust faults. However, careful intra- and inter-basinal correlations allow recognition of these tectonic signals. The present sequence-stratigraphic synthesis is in good agreement with recently published Cretaceous eustatic charts and thus provides a strong case for the inter-regional nature of early Late Cretaceous unconformities and corresponding depositional sequences in Europe, supporting a predominant eustatic control on Cenomanian–Turonian sequence architectures.

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1. Introduction

Sea-level changes of the geological past and their driving mechanisms (eustasy *versus* tectonics) are a matter of debate since decades (e.g., Suess, 1906; Sloss, 1963; Haq et al., 1987, 1988). Today, ancient sea-level changes can be reconstructed by a number of different and methodologically independent approaches, e.g., by the study of coral reef records, of $\delta^{18}O$ and Ca/Mg proxies of ice volume as well as by means of sequence-stratigraphical analyses of continental margin and epicontinental sea sequences (e.g., Miller et al., 2011). Sequence stratigraphy, i.e., the subdivision of sedimentary basin fills into genetic packages of strata (= sequences) bounded by unconformities and their correlative conformities, is an important tool for intra- and interbasinal chronostratigraphical correlations widely used in industrial and academic applications (e.g., Emery and Myers, 1996; Coe, 2003; Catuneanu, 2006; Miall, 2010; Catuneanu et al., 2011; Simmons, 2012). The influential

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sequence chronostratigraphy of European basins (Hardenbol and Robaszynski, 1998; Hardenbol et al., 1998) has been published more than 15 years ago, but the high-resolution numerical dating of stage boundaries has made big steps forward in the meantime (Gradstein et al., 2012). This work thus aims at testing the isochrony of sea-level-driven sedimentary unconformities within an improved stratigraphical framework by means of detailed sequence-stratigraphical correlations of well-dated sections around the emergent Mid-European Island (MEI) in several German key areas, i.e., the Münsterland (MCB), Lower Saxony (LSB), Saxonian (SCB) and Danubian Cretaceous basins (DCB). It will also allow to evaluate the effects of eustasy and tectonics on development of lower Upper Cretaceous stratigraphical architectures in Central Europe. Furthermore, the correlation of the results of this study with the recently published charts on Cretaceous eustasy (Haq, 2014) is discussed.

2. Geological setting

The Mid-European Island (MEI) is one of the main palaeogeographical elements of the Cretaceous in Central Europe, consisting of the Rhenish and Bohemian massifs (Rhenobohemia) as emergent land masses (Fig. 1). It separates the northern temperate Boreal shelf sea form the southern Tethyan warm-water realm (cf. Vejbaek et al., 2010). In the periphery of the MEI, several Cretaceous basins are situated, preserving key successions of high importance for the understanding of the palaeogeography, stratigraphy and palaeontology during this period. Sections from the Münsterland (MCB), Lower Saxony (LSB), Saxonian (SCB) and Danubian Cretaceous basins (DCB) have been studied in detail (Fig. 1). In the following, each area will be briefly introduced.

2.1. Münsterland (MCB) and Lower Saxony Cretaceous basins (LSB)

The western part of the MEI, the Rhenish Massif (Fig. 1), is formed by a block of Devonian and Carboniferous rocks. Throughout Permian–late Early Cretaceous times, the Rhenish Massif was an area of non-deposition and erosion, including also the Münsterland. The northern margin of the Rhenish Massif is marked by the Teutoburger Wald, and the northeasterly adjacent area forms another major tectono-sedimentary unit, the LSB. During the Late Jurassic–Aptian, the LSB underwent rapid subsidence and sedimentation patterns were controlled by divergent dextral shear movements, related to contemporaneous rifting in the Central North Sea Graben (e.g., Baldschuhn et al., 1991; Mutterlose et al., 1998; Vejbaek et al., 2010) while the Albian–Late Turonian was a period of relative tectonic quiescence. The global Albian–Turonian sea-level rise caused a major onlap of nearshore as well as hemipelagic strata onto the northern part of the MEI, transferring the Münsterland into an area of deposition (2nd sedimentary megacycle of Hiss et al., 2005) and representing the origin of the MCB. The MCB and LSB were parts of the wide North German epicontinental shelf and during the Cenomanian–early Coniacian, the Plänerkalk Group has been deposited in this setting. The facies is formed by greensands, hemipelagic marls, marl-limestone alternations (so-called Plänerkalke) and limestones, constituting coast-parallel facies belts of a homoclinal ramp system (see Wilmsen et al., 2005 for a synopsis; Fig. 1). The Cenomanian and Turonian of the MCB and LSB comprise the Essen Grünsand, Herbram, Baddeckenstedt and Brochterbeck formations of the Lower Plänerkalk Subgroup as well as the Hesseltal, Büren, Söhlde, Oerlinghausen, Salder and Erwitte formations of the Upper Plänerkalk Subgroup (Fig. 2; see also Niebuhr et al., 2007).

2.2. Saxonian Cretaceous basin (SCB)

The Elbtal Group of the SCB has been sedimented in a relatively narrow strait between the Westsudetic Island (in the northeast) and the Osterzgebirge (in the southwest; part of the Bohemian Massif, central MEI), forming an important link between the Boreal shelf and the Tethyan region via the Bohemian Cretaceous Basin in the southeast (Fig. 1). The northeastern margin of the SCB is represented by the Lausitz Fault. The thickness and facies changes of Cretaceous strata within the basin show that from the late Cenomanian and with increasing intensity from the middle Turonian onwards, deposition was influenced by synsedimentary activity of this fault (Voigt, 1994, 2009). The depositional facies of the Elbtal Group comprises partly fluvial, but mainly marine siliciclastics (nearshore sandstones), marly–silty limestones (Pläner) and hemipelagic marls (Fig. 1). Lithostratigraphical units are the Meißen, Niederschöna, Oberhäslich and Dölzschen formations as well as the Brießnitz, Räcknitz and Strehlen formations of the distal Dresden–Meißen area (northwestern SCB), corresponding to their contemporaneous counterparts, the Schmilka, Postelwitz and Schrammstein formations in the proximal Elbsandsteingebirge (southeastern SCB; see Fig. 2 and Niebuhr et al., 2007). First marine transgression from the north into the SCB occurred in late early Cenomanian times, but only reached the area around Meißen (Meißen Formation). During the late Cenomanian, a major transgression occurred, submerging a pronounced relief of valleys and highs and leading to more homogeneous sedimentation patterns of a graded, storm-influenced shelf during the Turonian (Voigt, 1994, 2011). The area of the Elbsandsteingebirge was characterized by sandy nearshore facies, whereas in the Dresden–Meißen area, offshore marls and Pläner prevailed, with a transitional zone of intercalated Pläner and sandstone deposition (Faziesübergangszone of the Pirna area; for details see Voigt, 1994; Tröger, 2003 and Janetschke and Wilmsen, 2014).

2.3. Danubian Cretaceous basin (DCB)

The deposition of the Danubian Cretaceous Group took place at the northern Tethyan margin, reflecting dynamic neritic–terrestrial conditions in a peri-continental depositional environment in front of the southwestern margin of the Bohemian Massif (Fig. 1). Correspondingly, lithology and facies are strongly variable in the DCB and comprise clays, marls, opokas (a porous calcareous sedimentary rock with more than 25% biogenic silica), limestones, calcarenites, sandstones and conglomerates. The study focuses on six units that have been defined for the Cenomanian–Turonian, i.e., the Regensburg, Eibrunn and Winzerberg formations as well as the Kagerhöh and Großberg formations of the more distal Regensburg–Kelheim area, the latter two corresponding to the coeval Roding Formation of the proximal Bodenwöhrer Senke (Fig. 2; Niebuhr et al., 2009). Initial marine transgression from the Tethyan Ocean in the south into distal areas of the DCB occurred in earliest Cenomanian times (Wilmsen and Niebuhr, 2010; Wilmsen et al., 2010a). With a north- to northeastward-directed trend, transgression arrived in the proximal regions in the mid-late Cenomanian–earliest Turonian (Wilmsen et al., 2010a; Richardt et al., 2013). Until Coniacian times, predominantly marine influenced deposition continued, interrupted in the Bodenwöhrer Senke by some non-marine episodes during the middle–late Turonian (documented by the Freihöls and Seugast members of the Roding Formation; Niebuhr et al., 2011). Due to the proximal position, sections of the Bodenwöhr area display a condensed facies development compared to the lithostratigraphically equivalent successions of the Regensburg–Kelheim region during the Cenomanian and earliest

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