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Eustatic and climatic control on the Upper Muschelkalk Sea (late Anisian/Ladinian) in the Central European Basin

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ABSTRACT

The Upper Muschelkalk in the Central European Basin (CEB) is a key example of eustatic and climatic controls on inland seas. The late Anisian rapid transgression from Tethyan waters culminated in a large semi-enclosed inland sea stretching across the CEB. Subsequently, the slow but successive retreat in the early Ladinian resulted in a small remnant sea. The pronounced stratal pattern architectures are translated into a framework of 3rd- and 4th-order T–R sequences. The latest Illyrian 3rd-order *maximum flooding surface* corresponds to maximum abundances of carbonates and marine phytoplankton. An euryhaline marine ecology is indicated by prasinophycean algae dominating over acritarchs and $\delta^{18}O_P$ values of 18.9–22.4‰ VSMOW corresponding to Tethyan references. During the 3rd-order *regressive phase* successive freshening up to hyposaline conditions is indicated by up to 3‰ depleted $\delta^{18}O_P$ values, shifts to more radiogenic $^{87}Sr/^{86}Sr$ ratios and maximum abundances of terrestrial palynomorphs. Likewise, 4th-order T–R sequences are constrained by commutated stratal pattern architectures, palynofacies and geochemistry.

The favourable correlation of middle Triassic 3rd-order sequences of Tethyan and peri-Tethyan basins demonstrate the principle control of circum-Tethyan eustatic cycles. 4th-order sequences are evident and, although not yet correlatable in detail, indicate 10^6-year scale eustatic cycles which may be attributed to glacioeustatic sea-level changes. The subordinated control of arid to semiarid low latitude and semihumid to humid temperate mid latitude climates affected the Upper Muschelkalk Sea in particular during 4th-order sea-level lowstands. Substantial fresh water input from Scandinavian sources caused temporal stratification leading to stagnant bottom waters and/or sediments as indicated by palynofacies and U/Th and Ni/Co redox indices. The herein reconstructed middle Triassic zonal climates are in agreement to previously published Late Triassic zonal climates.

1. Introduction

Resulting from Middle Triassic circum-Tethyan eustatic sea-level fluctuations (e.g. Vail et al., 1977; Haq et al., 1987; Hirsch, 1992; Haq and Al-Qahtani, 2005) repeated transgressive–regressive cycles affected Tethyan shelves as well as epicontinental basins of the peri-Tethyan realm (e.g. Brandner, 1984; Aigner and Bachmann, 1992; Gianolla et al., 1998; López-Gómez et al., 1998; Rüffer and Bechstädt, 1998; Szulc, 2000). The shallow marine inland seas of the peri-Tethyan realm were most sensitive to sea-level fluctuations, such as in the Central European Basin (CEB) (e.g. Kozur, 1974; Aigner, 1985). In particular the fossiliferous Upper Muschelkalk, a contemporary of Tethyan carbonate platforms (e.g. Schlern, Wetterstein), witnesses a full 'life-cycle' of a semi-enclosed inland sea (e.g. Szulc, 2000; Franz et al., 2013). So far research almost exclusively focused on the Upper Muschelkalk in the classical outcrop areas of South and Central Germany (e.g. Aigner, 1985; Hagdorn and Simon, 1988; Röhl, 1988; Aigner and Bachmann, 1992). Basin-wide studies that integrate also the large northern part of the CEB aiming at more synoptic reconstructions of the Upper Muschelkalk Sea are missing so far.

Concerning palaeogeographic reconstructions of the Upper Muschelkalk Sea the temporal and spatial resolution is of great

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importance, most notably the proper position of the transgressive maximum. Recently, Franz et al. (2013) proposed an early *maximum flooding surface* (*mfs*) in the interval of the upper *flexuous* to *philippii*/*robustus* zones that challenged previous reconstructions of a late *mfs* (e.g. Aigner, 1985; Röhl, 1988). However, this early *mfs* should be further constrained, for example by high resolution data sets of stable isotopes or palynofacies. In previous studies, Korte et al. (2003, 2005) used δ^{13}C, δ^{18}O values and Sr^{87}/Sr^{86} ratios of brachiopods and proposed normal salinities of the early Upper Muschelkalk Sea followed by up to −2‰ depleted δ^{18}O values (VSMOW — Vienna Standard Mean Ocean Water) of the late Upper Muschelkalk Sea. But, as only brachiopods from South Germany were used, Korte et al. (2003, 2005) reconstructed only the salinity gradient between the Tethyan and the southern CEB. Based on micropalaeontological considerations Kozur (1974); Kozur and Mock (1972) proposed significant S–N directed freshening within the Upper Muschelkalk Sea but this is not constrained by isotope studies so far.

Here we present the first basin-wide reconstruction of the Upper Muschelkalk Sea including palaeogeographic maps for several time-slices. These reconstructions are based on stratigraphical and sedimentological investigations on cored wells and numerous logged wells and supported by extensive data sets of palynofacies, $\delta^{18}O_p$ values, Sr^{87}/Sr^{86} ratios, inorganic and organic geochemistry. The overall eustatic control on the Upper Muschelkalk Sea is demonstrated by 3rd- and 4th-order sequences inferred from stratal pattern architectures, palynofacies and geochemistry of the Upper Muschelkalk in North, Central and South Germany. The subordinated control of zonal climates is concluded from significant differences between southern and northern coastal and hinterland environments of the CEB.

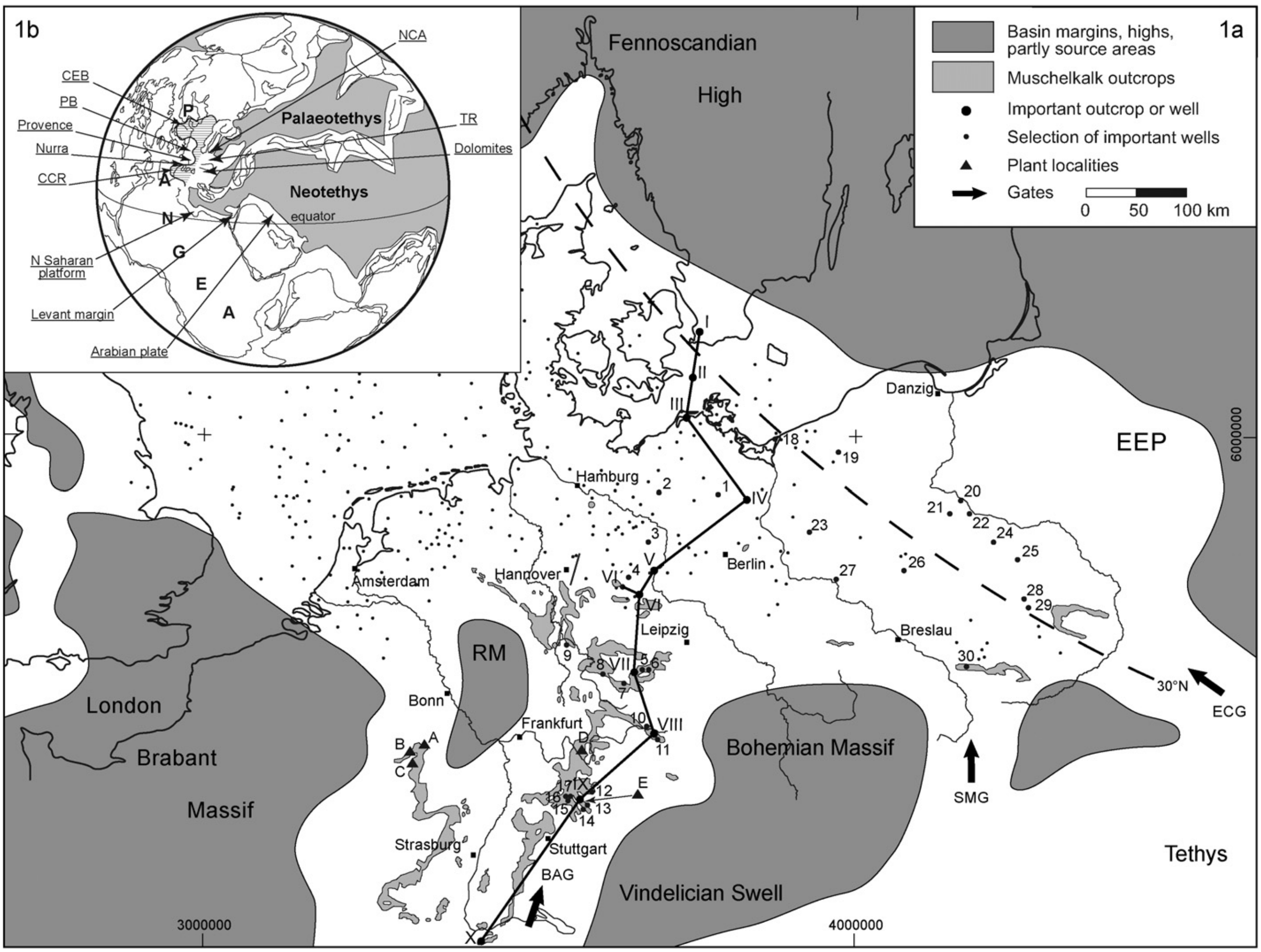

Fig. 1. a. Study area with cored wells and outcrops. Dashed line represents 30°N latitude of Ladinian times (Stampfli and Borel, 2002). Solid line connecting localities I–X refers to NNE–SSW cross-section shown in Fig. 2. I — cored well Höllviken 2, II — Baltic Sea: hypothetic section, III — cored well Barth 10 (this study), IV — cored well Flieth 1/64, V — cored well Kb Wolmirstedt 1/64 (this study), VI — composite of cored wells Wolmirsleben 107/83, 117/83, and clay pit Schöningen II, VII — composite of quarry Troistedt, outcrops BAB 71 NW of Erfurt and Egstedter Trift, VIII — outcrops at BAB 9 Bayreuth/Kulmbach, IX — composite of quarries Wilhelmsglück, Künzelsau and Gottwollshausen, X — Swiss Jura. Further important wells and outcrops: 1 — cored well B Lychen 2/59, 2 — cored well E Marnitz 1/55, 3 — logged well E Meßdorf 1/71, 4 — cored well Dp Morsleben 52A/95 (this study), 5 — outcrop Weimar-Webicht (Naumann, 1914; Wagner, 1919), 6 — outcrop Bucha (this study), 7 — outcrop Mühlberg (this study), 8 — outcrop Georgenthal (this study), 9 — outcrop Bremsbahn/Hoher Meißner (Wagner, 1919; Naumann, 1924; Penndorf, 1924, 1951), 10 — outcrop Kübelhof (this study), 11 — Bindlach (this study), 12 — Neidenfels (this study), 13 — Vellberg-Eschenau (this study), 14 — Gaildorf (this study), 15 — Gundelsheim (this study), 16 — Haßmersheim (this study), 17 — Neudenau (this study), 18 — cored well Kamień Pomorski IG 1 (Gajewska, 1972), 19 — cored well Połczyn Zdroj IG 1 (Gajewska, 1979; this study), 20 — cored well Ciechocinek IG 1 (Narkiewicz, 1999), 21 — cored well Konary IG 1 (Narkiewicz, 1999), 22 — cored well Brześć Kujawski IG 1 (Narkiewicz, 1999), 23 — cored well Gorzow Wlkp. IG 1 (this study), 24 — cored well Krośniewice IG 1 (Narkiewicz, 1999), 25 — cored well Zgierz IG 1 (Narkiewicz, 1999), 26 — cored well Ksiaz Wlkp. IG 2 (Narkiewicz, 1999; this study), 27 — cored well Sulechow IG 1 Dembowski (1972), 28 — cored well Piotrków Trybunalski (Narkiewicz, 1999), 29 — cored well Radziątków 5 (Głazek et al., 1973), 30 — outcrop Laryszów. A — Pickließem (Bitburg), B — Bollendorf a. d. Sauer, C — Saar area, D — Würzburg area, E — Crailsheim. BAG — Burgundy Alemanic Gate, ECG — East Carpathian Gate, EEP — East European Platform, RM — Rhenish Massif, SMG — Sileso Moravian Gate. **b**. Ladinian palaeogeography (modified according to Stampfli and Borel, 2002), CEB — Central European Basin, CCR — Catalan Coastal Ranges, NCA — Northern Calcareous Alps, PB — Paris Basin, TR — Transdanubian Range, hatched — peri-Tethyan lowlands flooded during the Middle Triassic.