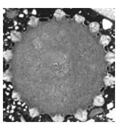
The Late Cretaceous transgression in the Saxonian Cretaceous Basin (Germany): old story, new data and novel findings

Markus Wilmsen, Birgit Niebuhr, Markus Fengler, Tobias Püttmann & Michaela Berensmeier



The stratigraphy of the northwestern Saxonian Cretaceous Basin (Meißen–Niederau area) is revised based on integrated stratigraphic dating and facies analyses. The fauna of the Meißen Formation suggests that it is of early Middle Cenomanian age, rather than late Early Cenomanian as assumed hitherto. At Niederau, the basal Oberau Conglomerate of the Mobschatz Formation forms a contemporaneous equivalent of the Meißen Formation. The age, macro-/nannofossil content and transgressive nature link the bed to the early Middle Cenomanian *Praeactinocamax primus* Event. Up-section, the 70-m-thick Oberau–Gröbern composite section covers the Middle Cenomanian to Lower Turonian shown by nanno- and macrofossil data, substantiated by new carbon isotope analyses from the lower part of the section. The Middle to lower Upper Cenomanian isotope curve has been correlated to the Anglo-Paris and northern German basins, suggesting a stratigraphic gap in the Middle–Upper Cenomanian boundary interval that corresponds to a phase of sea-level fall (sequence boundary Cenomanian 4). The transgression history continued in the early Late Cenomanian with the upper Mobschatz Formation at Oberau–Gröbern, corresponding to the first onlap of the formation onto the Meißen Formation and basement rocks at Meißen-Zscheila. Another sea-level fall is recorded by the contact of the Mobschatz and Dölzschen formations in the mid-Upper Cenomanian (SB Ce 5), followed by a major deepening and siliciclastic starvation of the Meißen–Niederau area during the latest Cenomanian–earliest Turonian. The introduction of the Meißen-Dresden Subgroup is suggested for the lithologically uniform distal strata in order to compensate limitations of the current lithostratigraphic framework of the Elbtal Group. • Key words: Elbtal Group, Cenomanian transgression, biostratigraphy, chemostratigraphy, sequence stratigraphy, lithostratigraphy.

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In Saxony (eastern part of Germany), the area between Meißen, Dresden, Pirna and Bad Schandau is characterised by widespread strata of Late Cretaceous age, constituting the Cenomanian–Coniacian Elbtal Group. Current consensus on the course of the early Late Cretaceous transgression is that a first ingression from the northwest took place in the late Early Cenomanian (Meißen Formation). In the Middle Cenomanian, contemporaneous onlap is allegedly only documented by the fluvial Niederschöna Formation while marine strata are completely absent (see also Hancock 2004, p. 617). In the Late Cenomanian, marine onlap continued with two pulses of sea-level rise, *i.e.* in the *C. naviculare* and *M. geslinianum* ammonite zones, respectively (*e.g.* Voigt 1994, Tröger 2003). However, new observations such as the presence of a Middle Cenomanian index ammonite in the Meißen Formation (Wilmsen & Nagm 2014) and the record of other presumably marine Middle Cenomanian strata (Tröger 2017) cast doubt on these interpretations. Here, we present new integrated stratigraphic and sedimentological data on the timing and extent of the marine inundation of the Saxonian part of the Saxo-Bohemian Cretaceous Basin from the Meißen–Niederau area, including the first evidence of the *Praeactinocamax primus* Event for Saxony. Furthermore, the results of this study require modifications of the current lithostratigraphy of the Elbtal Group.

Geological setting

The early Late Cretaceous witnessed one of the largest marine transgressions of the Phanerozoic Eon (*e.g.* Hallam 1992). Large parts of Europe were covered by a shallow to moderately deep epicontinental sea with only some subordinate positive areas remaining (*cf.* Ziegler 1990, Philip & Floquet 2000, Vejbæk *et al*. 2010). The Mid-European Island (MEI) is one of these palaeogeographic key features of the Cretaceous in Central Europe, consisting of the Rhenish and Bohemian massifs (Fig. 1A, B). Approximately ESE–WNW-striking, it separates the northern temperate Boreal from the southern warm-water settings of the Tethyan Realm. Along the periphery of the MEI, some important sedimentary basins were located, preserving stratigraphic records crucial for the understanding of Cretaceous palaeontology and stratigraphy (*e.g.* Janetschke *et al*. 2015 for a recent summary). The Saxonian Cretaceous Basin (SCB) with its sedimentary infill, the Elbtal Group, is one of these basins (Fig. 1B, C).

The Elbtal Group (Voigt & Tröger *in* Niebuhr *et al*. 2007) comprises Cenomanian to Middle Coniacian strata that have been deposited in a relatively narrow marine passage between the Osterzgebirge in the southwest (belonging to the Bohemian Massif) and the Westsudetic Island in the northeast (Fig. 1B, C). This strait opens towards the Boreal shelf in the northwest and via the Bohemian Cretaceous Basin (BCB) in the southeast to the Tethyan region, forming an important gateway between temperate and warm-water areas (*cf.* Wiese *et al*. 2004). The SCB may either be seen as the southeastern lobe of the Boreal north German shelf or as the northwestern extension of the BCB which formed an interface to the southern Tethyan Realm (Fig. 1B). However, the SCB retained a certain uniqueness as a self-contained basin. The Elbtal Group combines predominantly marine formations consisting of siliciclastics (nearshore sandstones), marly siltstones (Pläner) as well as hemipelagic marls and marly limestones; only the Middle Cenomanian Niederschöna Formation is of fluvial origin. Lithostratigraphic units documenting the complex Cenomanian onlap history of the Elbtal Group are the Meißen, Niederschöna, Mobschatz, Oberhäslich, Dölzschen and Pennrich formations (Fig. 2; lithostratigraphy follows, with emendations, Voigt & Tröger *in* Niebuhr *et al*. 2007). Current consensus is that a first marine transgression from the northwest into the SCB occurred in late Early Cenomanian times, only reaching as far as the area around Meißen (Meißen Formation; Prescher & Tröger 1989). Continued non-marine onlap is allegedly documented by the fluvial strata of the Middle Cenomanian Niederschöna Formation (*e.g.* Prescher 1957, Voigt 1998). Marine Middle Cenomanian strata have not been recorded previously, although Tröger (2017) suggested the existence of marine facies below the inferred Upper Cenomanian Mobschatz Formation in the northwestern part of the SCB.

During the Late Cenomanian, two major transgressions occurred in the *Calycoceras naviculare* and *Metoicoceras geslinianum* ammonite zones, respectively (Petrascheck 1900; Schander 1923; Häntzschel 1933; Tröger 1955; Voigt 1994; Voigt *et al*. 1994, 2006; Föhlisch 1998; Tröger 2003; Wilmsen *et al*. 2011; Wilmsen 2017), separating the West Sudetic Island from the mainland of the MEI, submerging a distinct relief of valleys and highs, and connecting the SCB to the BCB. These Late Cenomanian transgressions, documented in the Mobschatz/Oberhäslich and Dölzschen/Pennrich formations, led to more homogeneous sedimentation patterns of a storm-influenced graded shelf during the Turonian (Voigt 1994, 1999, 2011). In the Meißen–Dresden area, offshore marls and Pläner prevailed (Brießnitz, Räcknitz and Strehlen formations; *e.g.* Tröger & Wolf 1960, Tröger 1988), while the Elbsandsteingebirge was characterised by sandy nearshore facies (Schmilka, Postelwitz and Schrammstein formations), with a transitional zone (Faziesübergangszone) of the Pirna area in between (*e.g.* Voigt 1994, Tröger 2003, Janetschke & Wilmsen 2014). The northeastern margin of the SCB as exposed today is tectonic in origin and represented by the NW–SE-striking Lausitz Thrust Fault, while the patchy occurrences of Cretaceous strata on the Osterzgebirge show the originally larger extent of marine deposition (Fig. 1C). Thickness and facies changes of strata of the Elbtal Group show that (with increasing intensity) from the Middle Turonian onward, deposition was influenced by synsedimentary activity of the Lausitz Thrust Fault (Voigt 1994, 2009; see Kley & Voigt 2008 for further information on Late Cretaceous inversion in Central Europe). Nevertheless, careful sequence stratigraphic analyses by Janetschke & Wilmsen (2014) documented the preponderance of eustatic over tectonic signals for the Cenomanian and Turonian ages. Overviews on the geology of the Cretaceous in Saxony are provided by Tröger (2003, 2008), Voigt (2007) and Wilmsen & Niebuhr (2014).

Material and methods

The sections have been logged in detail bed-by-bed and sedimentary fabrics have been at first hand classified by hand-lens. Characteristic lithofacies have been sampled for the preparation of thin-sections (25 specimens). Microfacies analysis has been conducted using a transmitting-light microscope (Leica M125) and carbonate rocks have been classified using the Dunham (1962) terminology. For calcareous siltstones to silty marlstones, the local name “Pläner” is used. This descriptive lithofacies term

Figure 1. Geological and regional framework. • A – Cenomanian palaeogeography of the western Tethyan area (modified after Philip & Floquet 2000). The map area of Fig. 1B is indicated by a rectangle; small encircled letters a–e refer to the sections of the chemostratigraphic correlation (see Fig. 11). • B – detailed palaeogeography of the Saxo-Bohemian area during the early Late Cretaceous with indication of the depositional setting of the Elbtal Group within the Saxonian Cretaceous Basin (the map area of Fig 1C is outlined). • C – distribution of the Elbtal Group along the Elbe river valley in Saxony (1 – Niederau area with Oberau and Gröbern, see Fig. 1E; 2 – Meißen, see Fig. 1D). The transect of Fig. 12 with the additional locations 3–6 is indicated. • D – location of the sections studied in Meißen. • E – location of the sections studied in the Niederau area.

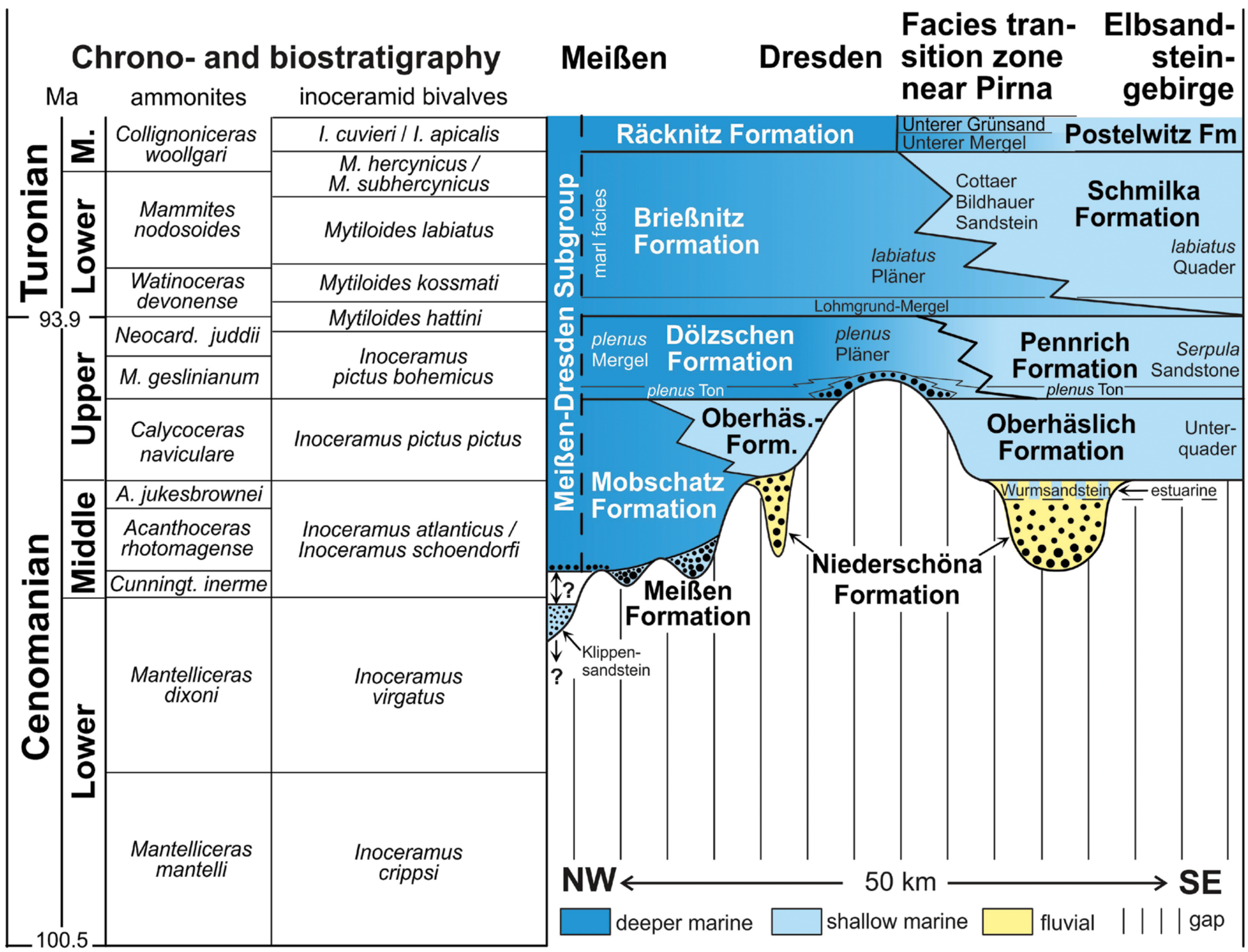


Figure 2. Schematic NW–SE section, following the River Elbe between Meißen and Bad Schandau, illustrating the litho- and biostratigraphy of the lower Elbtal Group (without Zittau Mountains, *cf.* Fig. 1C) as understood herein. Abbreviations: *Cunningt. – Cunningtoniceras*; *A. – Acanthoceras*; *M. – Metoicoceras*; *Neocard. – Neocardioceras*; *M. – Mytiloides*; *I. – Inoceramus*.

is known since the 18th century and has been used in the Dresden area originally for planar, evenly shaped ragstones (Gerber 1717, p. 568; Freiesleben 1836, p. 226). Observations on fabrics, trace- and body-fossil content as well as taphonomy have been integrated into the synoptic stratigraphic logs. Topographic elevations at Oberau have been measured with a GNSS (global navigation satellite system) RTK (real-time kinematic) rover and are reported with respect to the WGS84 ellipsoid (3D error 0.05 m). The fossil specimens and thin-sections are housed in the Museum für Mineralogie und Geologie (MMG) of the Senckenberg Naturhistorische Sammlungen Dresden (repository abbreviation SaK). The Gröbern 2/91 core is stored in the Lithothek of the Technische Universität Bergakademie Freiberg.

In total 32 samples for carbon and oxygen stable isotopes have been collected from the Oberau sections and the lower part of the Gröbern 2/91 core, and were analysed at Erlangen University (isotope lab of GeoZentrum Nordbayern). For stable isotope analyses, carbonate powders were reacted with 100% phosphoric acid at 70 °C using a Gasbench II connected to a ThermoFisher Delta V Plus mass spectrometer. All values are reported in ‰ relative to V-PDB. Reproducibility and accuracy was monitored by replicate analysis of laboratory standards calibrated by assigning $\delta^{13}C$ values of +1.95‰ to NBS19 and −46.6‰ to LSVEC and $\delta^{18}O$ values of −2.20‰ to NBS19 and −23.2‰ to NBS18. Reproducibility for $\delta^{13}C$ and $\delta^{18}O$ was ±0.05 and ±0.05 (1 std. dev.), respectively.

A total of 22 samples (Gröbern – 13 samples; Oberau – 5 samples; Meißen – 4 samples) were processed for calcareous nannofossil analysis by smear-slides, following the preparation technique given in Perch-Nielsen (1985). At least five traverses of each slide were screened under an Olympus BH-2 microscope at a magnification of 1000x. For biostratigraphy, the UC standard zonation for Upper Cretaceous calcareous nannofossils from Burnett (1998) is

Figure 3. Field aspects of the studied sections. • A – the Meißen-Zscheila section at the cooperative wine-growers association (Winzergenossenschaft); note the irregular top surface of the basement (Meißen Massif, dashed line) and the large scattered boulders of the basal Meißen Fm. (arrowed). The Mobschatz Fm. rests immediately on the boulder level but is covered by vegetation. • B – exposure of marl and Pläner beds of the lower Dölzschen Fm. at Werdermannstraße in Meißen-Zscheila; hammer (arrowed, 28 cm in length) for scale. • C – the Oberau railway slope cut exposure showing the basal conglomerate of the Mobschatz Fm. (Oberau Conglomerate, OC; the belemnite find illustrated in Fig. 8A, C is encircled) overlain by strongly glauconitic Pläner (gp) and glauconitic argillaceous marls (gm); hammer (arrowed, 33 cm in length) for scale. • D – overview of the monotonous lithology of the Mobschatz Fm. in the Gröbern 2/91 core (core segments are 1 m long and 10 cm wide). • E – OPAL gas pipeline trench (*ca.* 3 m deep) near Oberau in 2010 exposing argillaceous Pläner of the lower Dölzschen Fm.; note the black band (arrowed, *ca.* 15 cm thick, further details according to the rectangle in Fig. 3F). • F – close-up of the black band (above hammer) in the lower Dölzschen Fm. of the OPAL gas pipeline trench section near Oberau; hammer (arrowed, 28 cm in length) for scale.

applied, which is based on first and last occurrences (FO's, LO's) of marker species. The taxonomic classification follows Burnett (1998) with minor modifications by Shamrock & Watkins (2009) and the data compiled on the Nannotax3 database (Young *et al*. 2018).

The preservation state of each nannofossil assemblage is assigned to five categories, based on observations from Roth (1978) and Thierstein (1980): B – barren (no nannofossils present); VP – very poor (resistant taxa clearly dominate the assemblages, coccoliths are fragmented, etched or overgrown); P – poor (resistant taxa dominate, coccoliths are commonly fragmented, etched or overgrown); M – moderate (delicate taxa are present but are commonly fragmented, etched or overgrown); G – good (delicate taxa are common and rarely fragmented, etched or overgrown).

The nannofossil abundances are estimated from smear slide observations with medium density of particles. The average abundance is described by three categories regarding the number of coccoliths per field of view: L – low (<5 coccoliths); M – medium (5–15 coccoliths); H – high (>15 coccoliths).

Results

In total, four sites and sections have been measured and investigated by means of integrated stratigraphy and facies analysis, *i.e.* the Meißen area, the Oberau railway slope cut, the Oberau gas pipeline trench section and the Gröbern 2/91 core (Figs 1D, E; 3). The sections are described in detail below, including data on litho-, bio- and microfacies.

Sections

Meißen

In Meißen-Zscheila, the Cretaceous cover rocks on top of the reddish granodiorites of the Meißen Massif (Carboniferous in age) were exposed in several old quarries and during building work in the 1990s. Still available is the slope cut at the cooperative wine-growers association (Winzergenossenschaft) in the Joachimstalstraße (Fig. 1D) where the Meißen Formation is exposed, resting unconformably on the basement (Fig. 3A), overlain by the basal glaucony-rich marls of the Mobschatz Formation. The overlying marls and Pläner of the Dölzschen Formation are exposed at the Werdermannstraße, 200 m to the east, close to the branch of the Großenhainer Straße (Fig. 1D). Collection material mainly derives from old quarries and construction work in the Riesenstein area (Fig. 1D).

At the cooperative wine-growers association, the Meißen Formation rests along an irregular basal unconformity surface on basement rocks of the Meißen Massif (Figs 3A, 4A). Boulders up to 2 m in diameter are scattered at the contact and embedded into a sandy, violet-red, ferruginous–calcareous matrix, constituting the characteristic lithofacies of the "red conglomerate of Meißen" (Prescher & Tröger 1989). The sediment between the coarse crystalline components is a bioclastic, quartz and feldspar granule-bearing micritic sandstone to sandy bioclastic float- to rudstone dyed by ferric iron content (Fig. 4B, C). The most common bioclasts include echinoid spines, bivalves, corals and bryozoans. The Meißen Formation is patchily distributed and disappears laterally onto elevations protruding from the crystalline basement (Fig. 4A). It is overlain by glaucony-rich sediments of the Mobschatz Formation which, in the latter situation, may rest directly on the basement. At the Winzergenossenschaft, the lower Mobschatz Formation is developed as glauconitite (glaucony grains >50%, Funk 1971; Fig. 4D). From this part, large brachiopods [*Neoliothyrina biplicata* (Sowerby)] have been collected. These brachiopods also occur concentrated in crevice infills at the base of the Mobschatz Formation where it onlaps the basement rocks directly (Figs 4A, 8O). The basal glauconitites grade up-section into less glauconitic marls and Pläner deposits; the section is continued 15 m higher up with strata of the lower Dölzschen Formation at Werdermannstraße (Figs 3B; 4). In the lower part, Pläner deposits prevail (Fig. 4E). Up-section, a conspicuous facies shift to marly facies is exposed, showing plankton-dominated wackestones with planktic foraminifera and calcified radiolarian; siliciclastic content is subordinate (Fig. 4F, G).

At Meißen-Ratsweinberg (Fig. 1D) in the urban district Niederfähre-Vorbrücke, a 1-m-thick greensand rests directly on the basement of the Meißen Massif, overlain by marls and Pläner (Reinisch 1928). The succession is not exposed anymore, but the glauconitic basal bed was very fossiliferous, also yielding numerous large terebratulids assigned to *N. biplicata*, some of which are now hosted in the collections of the MMG. A small piece of matrix from specimen MMG: SaK 84 has been forwarded to nannofossil analysis (sample M-R, see below).

Oberau railway slope cut

This exposure corresponds to the former Oberau railway tunnel section of the historic literature (*e.g.* Geinitz 1839, Schneider 1843, Petrascheck 1900, Siegert 1906, Gallwitz 1935). Constructed in 1837–1839, the Oberau Tunnel was the first standard-gauge railway tunnel on the European mainland with a length of 513 m. However, due to the limited railway loading gauge and considerable frost/water damages since its construction, the roof of

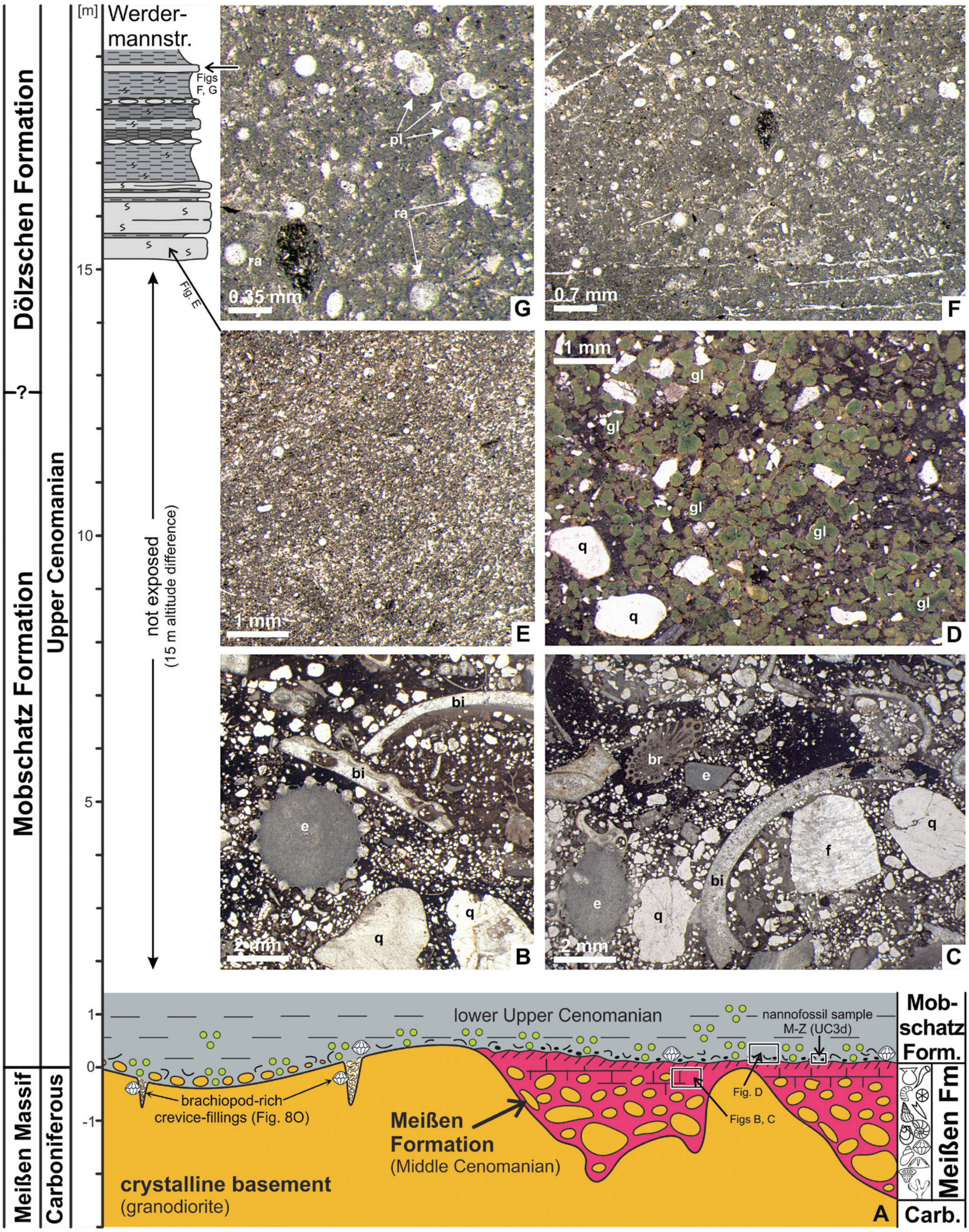


Figure 4. Geological situation at Meißen-Zscheila (key to symbols in Fig. 7; Carb. – Carboniferous; Form./Fm – Formation). • A – stratigraphic arrangement of the Meißen and Mobschatz formations based on Prescher & Tröger (1989) and own observations; the sample position of images B–G are indicated. • B,w C – microfacies of the Meißen Fm. in a sample taken between the coarse crystalline components showing immature bioclastic, quartz (q) and feldspar (f) granule-bearing sandstones to sandy bioclastic limestones with opaque ferruginous–micritic matrix; bioclasts include echinoid spines (e), bivalves (bi) and bryozoans (br). • D – sandy glauconitite from the base of the Mobschatz Fm. (q = quarz, gl = glaucony). • E – marly siltstone (Pläner) from the base of the section at Meißen-Werdermannstraße (lower Dölzschen Fm.). • G, F – calcareous marlstones from the upper part of the section at Meißen-Werdermannstraße showing plankton-dominated wacke- to packstones with planktic foraminifera (pl) and calcified radiolaria (ra) of the Dölzschen Fm.

the railway tunnel was removed in 1933–1934, and it was transformed into a railway cutting (Fig. 1E; see Preuß 1985). Most of the section is now overgrown but the general stratigraphic situation has been documented by Dietze (1961). Furthermore, the basal contact of the Mobschatz Formation with the underlying basement rocks is still fairly well exposed (Fig. 3C) and the stratigraphic relationships can still be evaluated at the northeastern railway slope cut.

Across a length of *ca.* 30 m, a NW–SE-oriented transect on the northeastern slope cut exposes a complex stratigraphic architecture with conspicuous local onlap patterns (Fig. 5A). A small patch of bioclastic sandstones occurs in the southeastern part, corresponding to the "Schicht b" and the "Klippensandstein" of the literature (*e.g.* Geinitz 1839, Schander 1923, Dietze 1961) and representing the lowermost stratigraphic unit resting on the basement rocks. It consists of grey to beige-coloured, well-sorted, fine-grained quartz sandstones with numerous, part-silicified shells; granules of quartz and feldspar are scattered within the sandy–bioclastic fabric (Figs 5B, 6A). Intercalated, cm-thick sharp-based, granule-sized microconglomerate layers contain abundant angular feldspar grains and bioclasts, and show normal grading into the fine-grained sandstone facies. In part, they truncate sand-filled *Ophiomorpha* burrows and/or are penetrated by them. The macrofauna consists predominantly of bivalves (limids, pectinids, trigoniids and oysters) as well as gastropods, brachiopods, bryozoans and echinoderm remains. Sandstone slab MMG: SaK 172 contains a fragmentary internal mould of *Schloenbachia varians* (Sowerby) and another fragment has been collected during field work. The Klippensandstein is erosionally overlain by the basal conglomerate of the Mobschatz Formation (Oberau Conglomerate) that onlaps northwest-ward onto a local high in the basement (Fig. 5A). The sharp, irregular surface suggests that the Klippensandstein was already lithified (Fig. 6B).

The Oberau Conglomerate is of variable thickness and consists of angular to subrounded pebbles and cobbles derived from the basement rocks of the Meißen Massif in a strongly glauconitic, sand- and marl-rich matrix (Figs 5C; 6C, D). From the conglomerate, belemnites, terebratulid and rhynchonellid brachiopods, bivalves (including inoceramids and oysters), gastropods (pleurotomariids, naticids and nerineids), serpulids, small solitary corals and vertebrate remains have been recorded; the large brachiopods are a characteristic feature of its upper part. The *ca.* 0.75-m-thick Oberau Conglomerate corresponds to beds 'a' and 'c' of Geinitz (1839) and grades into quartz-bearing marly glauconitites with conspicuously zoned glaucony grains and glauconitic marls that continue the onlap of the Mobschatz Formation onto the basement (Figs 3C, 4A; bed 'd' of Geinitz 1839).

Up-section, poorly exposed, medium-grey Pläner deposits continue the succession at the slopes of the railway trench (bed 'e' of Geinitz 1839). Approximately 300 m towards the east-southeast, marly Pläner are exposed at the southern side of the road bridge crossing the railway trench (Fig. 1E), yielding *Inoceramus pictus bohemicus* Leonhard (MMG: SaK 16242) and *Euomphaloceras septemseriatum* (Craigin). According to hypsometry, the topographic elevation is 151.4 m for the base of the Oberau Conglomerate and 164 m for the exposure at the bridge. Taking into account the distance of 300 m and the minor regional dip of the strata towards the east (2–3°, *cf.* Dietze 1961), the stratigraphic height between both levels is about 20 m.

Gröbern 2/91 core

The Gröbern 2/91 core (Figs 1E, 3D, 7) was drilled in 1991 for subsurface investigation of a landfill site planned in this area. Overview logs with varying stratigraphic interpretations and initial low-resolution isotope data were provided by Tröger & Voigt (1995), Tröger *et al.* (1996) and Voigt & Tröger (1996), while Voigt *et al.* (2006) presented a detailed isotope stratigraphy as well as calcimetry and greyscale data of the Cenomanian–Turonian boundary interval. Additional microbiostratigraphic, ichnologic and geochemical data for this interval were provided by Ortmann (1994). However, the lower part of the succession, variably assigned to the Oberhäslich and/or Meißen formations, has never been studied in detail or precisely dated. Unfortunately, the lowermost metre of the core including the contact to the basement at *ca.* 70 m depth is not anymore available.

The preserved succession starts at a depth of 69 m below terrain surface (ground level elevation: 179.70 m) with strongly glauconitic, silty to fine-sandy, bioturbated argillaceous marly Pläner of the lower Mobschatz Formation that contain scattered large quartz grains up to granule-size; fragments of brachiopods, oysters and siliceous sponges occur as biogenic components (Fig. 6E, F). The glaucony grains are zoned and the litho- and microfacies is very similar to the strata above the Oberau Conglomerate at the Oberau railway slope cut section (Fig. 5A, C). Above, grain-size and glaucony content decrease up to the 63.80-m-level (Fig. 7). Between 63.80–57.40 m, bioturbated, glauconitic Pläner to silty-marly wackestones predominate in the middle part of the Mobschatz Formation (Figs 3D, 6G). Oblique spreiten structures referred to *Zoophycos* isp. filled with dark, argillaceous material are common in the Mobschatz Formation. At 57.40 m, a conspicuous lithofacies shift to argillaceous Pläner deposits in the upper part of the Mobschatz Formation is evident (Fig. 7); within these marly strata, the planktic foraminifer *Rotalipora cushmani* has its first appearance at 54.50 m (Ortmann 1994). The Dölzschen Formation starts with a dm-thick conspicuous shell bed at 51.40 m depth, ranging up to the 32.50-m-level. It consists of an intercalation of calcareous and more argillaceous Pläner deposits with varying degree of bioturbation (Fig. 6H). Conspicuous marly intervals occur around 48 m (level of last occurrence of *R. cushmani* according to Ortmann 1994), between 45–40 m, between 38–36 m and at 34.50–35 m. At *ca*. 42 m depth, inoceramids of the *I. pictus* group occur and elements of the *plenus* or Pennrich faunas have been reported from the interval between 45–40 m (Tröger & Voigt 1995, Voigt & Tröger 1996, Tröger *et al*. 1996, Voigt *et al*. 2006). The base of a marly interval between 32.50–30 m (Lohmgrund-Mergel) has been used to place the base of the Brießnitz Formation. Above the Lohmgrund-Mergel, the unit is characterised

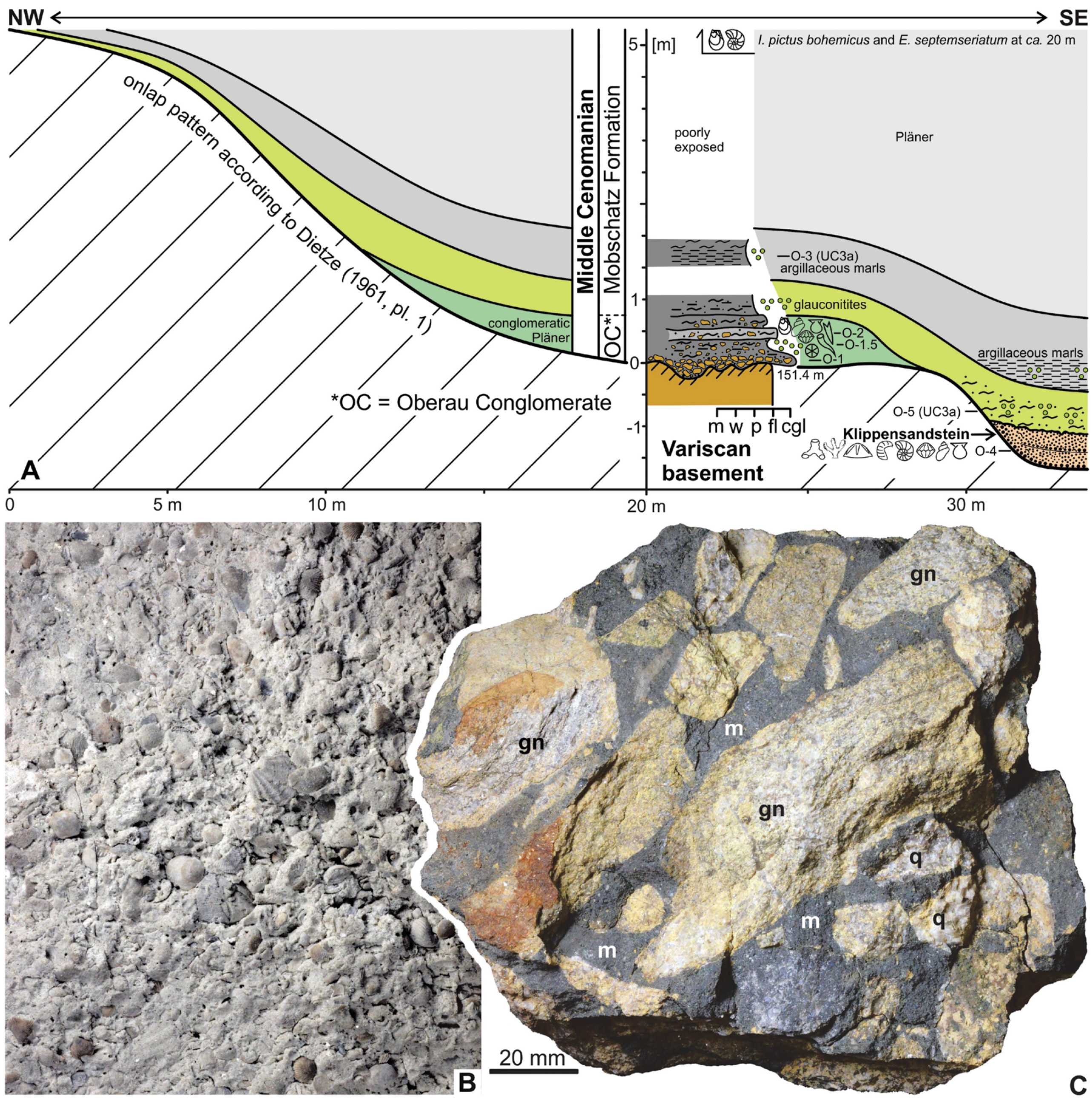


Figure 5. Geological interpretation of the Oberau railway slope cut (key to symbols in Fig. 7). • A – stratigraphic arrangement of lithofacies at the northeastern slope of the railway trench; note the NW-ward directed onlap patterns. • B – bedding surface from a slab of the Klippensandstein (sample MMG: SaK 7836, compare to Fig. 6A, B). Note the preferential convex-up position of the shells (mainly bivalves and brachiopods). • C – slab from the Oberau Conglomerate at the base of the Mobschatz Formation showing poorly sorted, angular to subrounded pebbles and small cobbles of basement rocks (gn – gneiss, q – milky quartz) in a dark, glaucony-rich matrix (m; compare to Fig. 6C, D).

by an overall rise of carbonate content to around 70% (Voigt *et al*. 2006) and bioturbated microbioclastic wackestones with sponge spicules and small planktic foraminifers predominate (Fig. 6I). The monotonous lithofacies persists to the top of the core (Fig. 7).

Oberau gas pipeline trench

This temporary section has been accessible only in 2010 for a few weeks during the construction of the OPAL gas pipeline (Figs 1E; 3E, F; 7). It exposed a *ca*. 3.50 m thick succession from the lower part of the Dölzschen Formation in typical Pläner lithofacies. An interesting lithological feature of the exposure was a 0.20-m-thick black argillaceous bed (black band) in the lower part of the section (Fig. 3F). Macrofossils were extremely rare and only indeterminate inoceramid remains have been found in the upper part of the section containing the black band. From stratigraphically a few metres above, several specimens of the belemnite *Praeactinocamax plenus* have been collected, associated by the serpulid *Pyrgopolon* (*P.*) *septemsulcata* (Fig. 8E, N).

Macrofossils

The macrofauna from the Meißen–Niederau area has been treated in detail by Geinitz (1839), Dietze (1959, 1961), Prescher & Tröger (1989), Löser (1989, 2014), Köhler (1988, 1991, 1993, 1996, 2001, 2004, 2012), Spaeth & Köhler (1997) and Köhler & Spaeth (1998). Thus, only some selected, stratigraphically important Cenomanian macrofossils from the investigated strata are treated herein (Fig. 8).

Meißen Formation

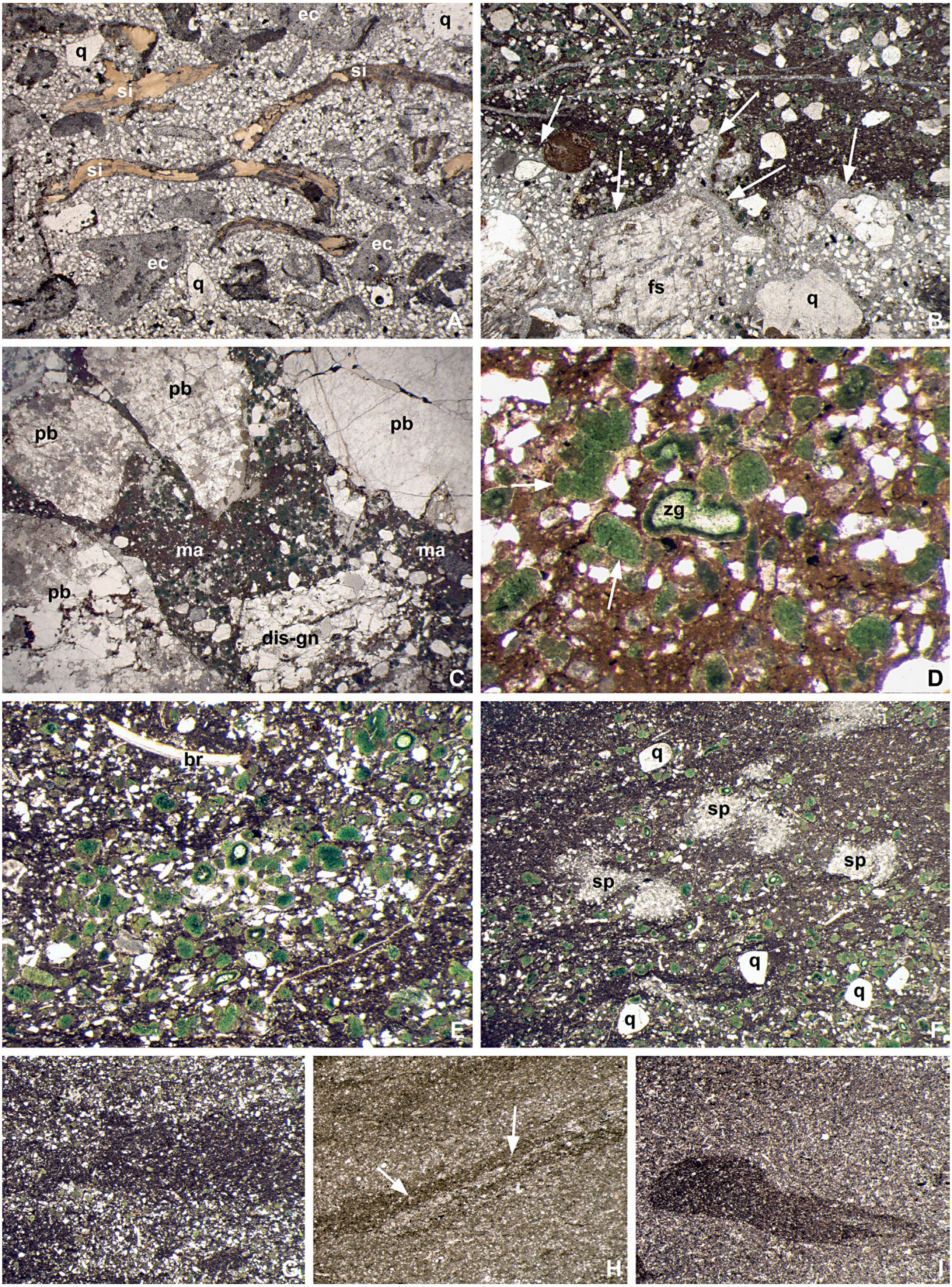
The Red Conglomerate is very fossiliferous with a diverse invertebrate fauna of inferred late Early Cenomanian age based on its inoceramids (*I.* ex gr. *crippsi* Mantell, *I. virgatus* Schlüter; Fig. 8L), ammonites [*Schloenbachia varians* (Sowerby), *Scaphites obliquus* Sowerby and alleged *Turrilites scheuchzerianus* Bosc], and belemnites [*Neohibolites ultimus* (d'Orbigny)] (see Köhler 1988, 1991, 2001; Prescher & Tröger 1989; Spaeth & Köhler 1997; Köhler & Spaeth 1998; Wilmsen & Mosavinia 2011). The single turrilitid ammonite (Fig. 8M), however, in fact is a Middle Cenomanian *T. costatus* Lamarck. Furthermore, *Sciponoceras* cf. *baculoides* (Mantell) (Fig. 8J) has been found.

Niederau (composite Oberau and Gröbern) section

The Oberau Conglomerate of the basal Mobschatz Formation yields belemnites, brachiopods, inoceramid as well as non-inoceramid bivalves, gastropods, serpulids and small solitary corals. The common large, inflated terebratulid brachiopods with conspicuous growth lamellae and biplicate commissure are assigned to *Neoliothyrina biplicata* (Sowerby) (Fig. 8F), small forms with tuberculated radial ribs to *Terebratulina nodulosa* Etheridge (Fig. 8G). Large rhynchonellid forms with sharp radial ribs and round outline are representatives of the genus *Cyclothyris* M'Coy. The small solitary corals are *Micrabacia coronula* (Goldfuss), reported from Oberau also by Löser (2014). A moderately preserved inoceramid bivalve from the base of the section, assigned by Dietze (1959) to *Inoceramus pictus bohemicus* Leonhard, is re-identified as a Middle Cenomanian *I.* cf. *atlanticus* (Heinz) (Fig. 8H). The fragmentary belemnites, allocated to *Belemnites lanceolatus* Sowerby by Geinitz (1849) and *Praeactinocamax plenus* (Blainville) by Wilmsen (2014), are representatives of the genus *Praeactinocamax* Naidin, but, based on their fragmentary preservation, can only be identified at generic level (Fig. 8A–C). However, it needs to be pointed out that they tend to have rather slender rostra (see discussion below).

The marl and Pläner facies of the Mobschatz and Dölzschen formations is very poor in macrofossils.

Figure 6. Microfacies aspects of the Oberau railway slope cut (A–D) and Gröbern 2/91 core (E–I) sections (w – horizontal width of photomicrograph). • A – Klippensandstein: well-sorted, fine-grained quartz sandstones with numerous, in part silicified shells (si) with beige-brown colour, predominantly of bivalves, echinoderms (ec), and scattered granules of quartz (q) and feldspar (w = 14 mm, sample O4). • B – irregular erosional contact of the Klippensandstein (q – quartz, fs – feldspar) and the basal Oberau Conglomerate of the Mobschatz Formation (arrowed); note that the Klippensandstein was already lithified before the deposition of the Oberau Conglomerate (w = 14 mm, sample OK2). • C – Oberau Conglomerate, basal Mobschatz Formation: angular pebbles of crystalline basement rocks (pb, mostly gneisses) with component-supported fabric within a dark, marly-sandy glauconitic matrix (ma) (w = 25 mm, sample O1). Note disintegrating gneiss pebble in the lower right (dis-gn). • D – matrix of the Oberau Conglomerate, basal Mobschatz Formation: sandy glauconitite; note the zoned glaucony grain near centre (zg) and lobate shape of other green grains on left side (arrows; w = 2.8 mm, sample O1). • E, F – lower part of the Mobschatz Formation: strongly glauconitic (green, partly zoned grains), silty to fine-sandy, bioturbated Pläner containing scattered larger quartz grains up to granule-size (q); biogenic components are fragments of brachiopods (br), oysters and siliceous sponges (sp) (wE = 7 mm, wF = 14 mm, samples D1 and D2). • G – bioturbated, glauconitic silty wackestone (Pläner of the middle Mobschatz Formation, w = 7 mm, sample D3). • H – bioturbated marly siltstone with oblique spreiten structure of *Zoophycos* isp. (arrowed) (Pläner of the lower Dölzschen Formation at 49 m, w = 7 mm). • I – bioturbated microbioclastic wackestone with sponge spicules and small planktic foraminifers (marl facies of the lower Brießnitz Formation, w = 7 mm, sample D5).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From the higher parts of the railway cutting at Oberau, different inoceramids of the *pictus* group and *Mytiloides praeturonicus* Tröger as well as *Calycoceras naviculare* (Mantell) (Fig. 8P), *Sciponoceras gracile* (Shumard) (Fig. 8K) and *Praeactinocamax plenus* were reported by Geinitz (1875), Dietze (1959, 1961), Wilmsen & Nagm (2013, 2014) and Tröger (2015). *Inoceramus pictus bohemicus* Leonhard has been collected from the top of the Oberau railway slope cut section, *ca.* 20 m above the Oberau Conglomerate, where it co-occurs with the ammonite *Euomphaloceras septemseriatum* (Craigin); further *M. geslinianum* zonal ammonites (including the index species) and the belemnite *Praeactinocamax plenus* (Blainville), collected loose from the heaps of the tunnel slicing, have been reported by Köhler (1993, 2004, 2012). *Inoceramus pictus bohemicus* also occurs at the 42-m-level in the middle part of the Gröbern 2/91 core (Fig. 8I). From an interval not more than five metres above the black band in the OPAL gas pipeline trench near Oberau (Fig. 7), several specimens of *P. plenus* have been collected (Fig. 8E) which were accompanied by common *Pyrgopolon* (*P.*) *septemsulcata* (Roemer; Fig. 8N).

Calcareous nannofossils

In total, 22 samples have been analysed for calcareous nannofossil contents and biostratigraphic assignments. The results are summarised in Tab. 1 and important species are illustrated in Fig. 9 (for taxonomic information, see Appendix).

Meißen

Four samples from the Meißen area were investigated. The nannofossil preservation varies from moderate/good (samples M-Z and M-R) to barren (samples RC-1 and RC-2); the two prospective samples show medium to high abundances with a species richness of 36 and 57 taxa, respectively (Tab. 1). In the sample from the glauconitic marl (M-Z) at the base of the Mobschatz Formation at Meißen-Zscheila (Fig. 4), a nannofossil assemblage of 57 different species is documented (Tab. 1). These species include *Lithraphidites acutus* (FO at the base of UC3a) and *Corollithon kennedyi* (LO at the top of UC3d). The taxa *Gartnerago theta* (LO at the top of UC3a), *Staurolithites gausorhethium* (LO at the top of UC3b) and *Gartnerago nanum* (LO at the top of UC3c) are not present. The sample M-R from the basal greensand at Meißen-Ratsweinberg yields a nannofossil assemblage of 36 different species (Tab. 1) characterized by the presence of *Lithraphidites acutus* and the absence of *C. striatus*. Two samples (RC-1, RC-2) from the calcareous matrix of the Red Conglomerate of the Meißen Formation are barren of nannofossils.

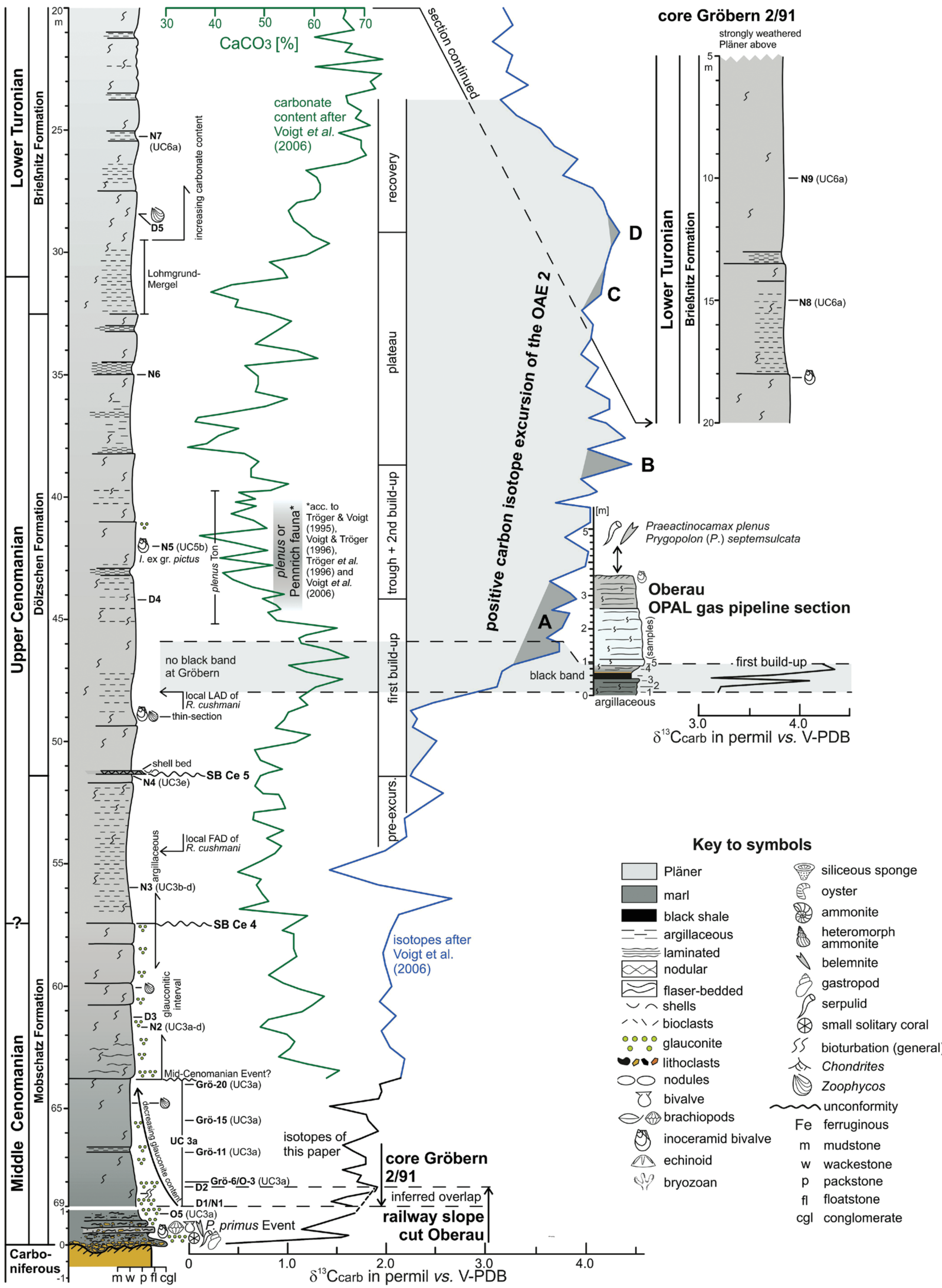
Oberau railway slope cut

Five samples from the Oberau section were prepared for calcareous nannofossil analysis (see Fig. 7, lower part, and Tab. 1). Only two samples (O-5, O-3) contain low to moderately abundant assemblages of 33 and 52 different species (preservation poor to good) while samples O-1, O-2 and O-6 are barren. In both samples, *Lithraphidites acutus* (FO at the base of UC3a, lower Middle Cenomanian) is present. Sample O-3, which is stratigraphically located above sample O-5, contains *Gartnerago theta* (LO at the top of UC3a). The lowermost two samples from the Oberau Conglomerate and the uppermost sample are barren of nannofossils.

Gröbern 2/91 core

A total of 13 samples was investigated from the Gröbern 2/91 core (see Fig. 7). The nannofossil preservation is very poor to moderate with low to high abundances and a median species richness of 33 (min. 13, max. 44; Tab. 1). The samples Grö-6, Grö-11, Grö-15 and Grö-20 are characterized by the presence of *Lithraphidites acutus* (FO at the base of UC3a) in sample Grö-6 and *Gartnerago theta* (LO at the top of UC3a) in sample Grö-20 (Fig. 9). The following sample Grö-N3 shows an absence of *Gartnerago theta* with a presence of *Corollithion kennedyi* (LO at the top of UC3d) while Grö-N4 is characterized by the absence of *Corollithion kennedyi* and *Cylindralithus biarcus* (FO at the base of UC4a). Sample Grö-N5 is marked by the absence of *Axopodorhabdus albianus* (LO at the top of UC5a) and *Quadrum intermedium* and the presence of *Helenea chiastia* (LO at the base of UC6). The samples Grö-N7, Grö-N8 and Grö-N9 are characterised by a typical earliest Turonian nannofossil assemblage, evidenced by the absence of *Helenea chiastia* and *Eprolithus moratus* (FO at the base of UC6b). This assignment to the lowermost Turonian is supported

Figure 7. Stratigraphic logs of the Gröbern 2/91 core (supplemented by the Oberau railway slope-cut section at the base) and the Oberau gas pipeline trench section including carbon stable isotope (black curves: this paper; blue curve: Voigt *et al*. 2006) and proposed correlation. Successive phases of the positive isotope excursion of the OAE 2 after Paul *et al*. (1999), carbonate content (in green) after Voigt *et al*. (2006), local first (FAD) and last appearance datum (LAD) of the planktic foraminifer *Rotalipora cushmani* (Morrow) according to Ortmann (1994). The key to symbols applies to all other line drawings.



Lower Turonian
Brießnitz Formation
Upper Cenomanian
Dölzschen Formation
Middle Cenomanian
Mobschatz Formation
Carbo-niferous
CaCO3 [%]
carbonate content after Voigt et al. (2006)
increasing carbonate content
Lohmgrund-Mergel
N7 (UC6a)
D5
N6
N5 (UC5b)
I. ex gr. pictus
D4
plenus Ton
plenus or Pennrich fauna*
*acc. to Tröger & Voigt (1995), Voigt & Tröger (1996), Tröger et al. (1996) and Voigt et al. (2006)
no black band at Gröbern
local LAD of R. cushmani
thin-section
shell bed
SB Ce 5
N4 (UC3e)
local FAD of R. cushmani
argillaceous
N3 (UC3b-d)
SB Ce 4
glauconitic interval
D3
N2 (UC3a-d)
Mid-Cenomanian Event?
Grö-20 (UC3a)
Grö-15 (UC3a)
UC 3a
Grö-11 (UC3a)
decreasing glauconite content
Grö-6/O-3 (UC3a)
D2
D1/N1
O5 (UC3a)
P. primus Event
isotopes of this paper
core Gröbern 2/91
inferred overlap
railway slope cut Oberau
m w p fl cgl
δ13Ccarb in permil vs. V-PDB
section continued
recovery
plateau
trough + 2nd build-up
first build-up
pre-excurs.
positive carbon isotope excursion of the OAE 2
isotopes after Voigt et al. (2006)
A
B
C
D
Praeactinocamax plenus
Prygopolon (P.) septemsulcata
Oberau OPAL gas pipeline section
black band
argillaceous
(samples)
first build-up
core Gröbern 2/91
strongly weathered Pläner above
N9 (UC6a)
N8 (UC6a)
Key to symbols
Pläner
marl
black shale
argillaceous
laminated
nodular
flaser-bedded
shells
bioclasts
glauconite
lithoclasts
nodules
bivalve
brachiopods
inoceramid bivalve
echinoid
bryozoan
siliceous sponge
oyster
ammonite
heteromorph ammonite
belemnite
gastropod
serpulid
small solitary coral
bioturbation (general)
Chondrites
Zoophycos
unconformity
Fe ferruginous
m mudstone
w wackestone
p packstone
fl floatstone
cgl conglomerate

by the presence of *Eprolithus octopetalus* (FO at the base of UC5c, LO in UC8b; lower Turonian) in sample Grö-N9. In three samples (Grö-N1, Grö-N2, Grö-N6), a precise biostratigraphic zonation is undefined due to very poor preservation and the absence of marker species (Tab. 1)

Isotopes

The carbon stable isotopes from the railway slope cut at Oberau and the lower part of the Gröbern 2/91 core are supplemented by the data from Voigt *et al*. (2006) from the middle and upper part of the latter section. In combination, they form a continuous (Middle Cenomanian to lower Turonian) isotope record. Furthermore, the lower part of the OPAL gas pipeline section across the black band has been analysed.

The $\delta^{13}C_{carb}$ values of the lower part of the Gröbern 2/91 core vary between 1.44–1.94‰ and $\delta^{18}O_{carb}$ values between −6.45 and −7.99‰ while at the railway slope cut Oberau, $\delta^{13}C$ values fluctuate between 0.38–1.88‰ for and −7.11 and −11.27‰ for $\delta^{18}O$. In the latter section, the carbon isotope values increase from the base of the Oberau Conglomerate (*ca*. 0.4‰ $\delta^{13}C$) across the glauconitites to almost 1.9‰ $\delta^{13}C$ in the argillaceous marls *ca*. 2 m above (Fig. 7). The $\delta^{13}C$ values at the base of the Gröbern 2/91 core at 69–68 m are in the same order as at the top of the Oberau railway slope cut section (Fig. 7). They fluctuate between 1.5–2.0‰ $\delta^{13}C$ up to 63.80 m where they can be connected to the curve of Voigt *et al*. (2006) that continues the isotope record up-section. Up to the 57-m-level, $\delta^{13}C$ values are relatively stable around 2‰, followed by a strong oscillation between 2.6 and 1.3‰ $\delta^{13}C$ in the interval 57–55 m. Above, the curve shows some minor fluctuations between 2.25–2.50‰ $\delta^{13}C$ up to the 49-m-level. From 49–24 m of the core, the major positive carbon stable isotope excursion of the oceanic anoxic event (OAE) 2 has been recorded, discussed in detail by Voigt *et al*. (2006) and Jarvis *et al*. (2011). The maximum value is 4.3‰ $\delta^{13}C$ at 38.50 m.

At the OPAL gas pipeline trench, stable isotopes were only measured across the black band (Fig. 7). Values of $\delta^{13}C_{carb}$ are ranging between 3.12–4.36‰ and show a conspicuous increase of *ca*. 1.3‰ $\delta^{13}C$ from the base of the black band into the bed above.

Discussion

Lithostratigraphy

The composite succession of the Oberau railway slope cut and the Gröbern 2/91 core is very monotonous in terms of lithofacies and clearly reveals the limitations of the current lithostratigraphic framework of the Elbtal Group (*cf*. Voigt & Tröger *in* Niebuhr *et al*. 2007, Fig. 3D) with respect to the distal facies zone (marl and Pläner facies of the Meißen–Dresden area). Without bio- or chemostratigraphic support it would be virtually impossible to differentiate the three formations (Mobschatz, Dölzschen and Brießnitz) comprised by the section. The problem will be even worse when it comes to field mapping for which formations as the basic and useful units of geological maps should be defined (*e.g.* Salvador 1994, Steininger & Piller 1999). To provide a solution for this problem and to overcome potential mapping issues, we thus suggest to introduce the Meißen-Dresden Subgroup for the distal marl and Pläner facies of the Elbtal Group. The Meißen-Dresden Subgroup comprises

Figure 8. Selected macrofossils (natural sizes, except G which is ×2.5). Lower Middle Cenomanian Oberau Conglomerate of the basal Mobschatz Formation at the Oberau railway slope cut section (A–C, F–H); upper Upper Cenomanian Dölzschen Formation (E, I, K, N, P); lower Middle Cenomanian Red Conglomerate of the Meißen Formation at Meißen-Zscheila (J, L, M); lower Upper Cenomanian Mobschatz Formation at Meißen-Zscheila (O). • A–C – *Praeactinocamax* sp.; A – find situation of the *Praeactinocamax* sp. illustrated in Fig. 8C; B – *Praeactinocamax* sp. (MMG: Sak 7807), original of *Belemnites lanceolatus* Sowerby *in* Geinitz (1849, pl. 6, fig. 5), alveolar end (B1), ventral view (B2), cross-section (B3); C – *Praeactinocamax* sp. (MMG: SaK 16378). • D – outline of the rostrum of *Praeactinocamax primus* (Arkhangelsky) from the lower Middle Cenomanian *P. primus* Event of Hoppenstedt (Wilmsen & Rabe 2008) for comparison to a typical rostrum of *P. plenus* (Blainville). • E – *Praeactinocamax plenus* (Blainville) from the OPAL gas pipeline trench a few metres above the black band (mid-Upper Cenomanian *P. plenus* Event; Greif collection, Niederau). • F – *Neoliothyrina biplicata* (Sowerby) (MMG: SaK 16380). • G – *Terebratulina nodulosa* Etheridge (MMG: SaK 16379). • H – *Inoceramus* cf. *atlanticus* (Heinz) (specimen MMG: SaK 121), original of *Inoceramus pictus bohemicus* Leonhard *in* Dietze (1959, pl. 2, fig. 5). • I – *Inoceramus pictus bohemicus* Leonhard, Gröbern 2/91 core at 42 m depth (specimen in the Lithothek, TU Bergakademie Freiberg). • J – *Sciponoceras* cf. *baculoides* (Mantell), Köhler collection, Meißen; the arrow indicates a constriction. • K – *Sciponoceras gracile* (Shumard), MMG: SaK 4708 (lateral view) from the Oberau railway slope cut section; original of *Baculites subbaculoides* Gein. of Geinitz (1875a, pl. I.63, fig. 1). • L – *Inoceramus virgatus* Schlüter (specimen MMG: SaK73), original of Prescher & Tröger (1989, pl. 28, fig. 5) and Tröger & Niebuhr (2014, fig. 3d). • M – *Turrilites costatus* Lamarck, lateral view, original of Köhler (2001); Köhler collection, Meißen. • N – *Pyrgopolon* (*P.*) *septemsulcata* (Roemer) from the OPAL gas pipeline trench a few metres above the black band (mid-Upper Cenomanian *P. plenus* Event; Greif collection, Niederau). • O – crevice infill with large brachiopods at the base of the Mobschatz Formation at Riesenstein; Köhler collection, Meißen. • P – *Calycoceras naviculare* (Mantell) from the higher part of the Oberau railway slope cut section (specimen MMG: SaK 4706, P1 in lateral and P2 in ventral view), original of Wilmsen & Nagm (2014, fig. 6d).

B1
D
E
C
cm
B2
A
F
B3
H
L
J
I
K
N
M
G
4 mm
O
10 mm
P1
P2

Table 1. Calcareous nannofossil data compiled from all studied samples. Preservation: B – barren; VP – very poor; P – poor; M – moderate; G – good. Nannofossil abundance: L = low; M – medium; H – high. Nannofossil taxa: ○ – taxon present by single specimen; ● – taxon present by at least two specimens.

	Gröbern core													Oberau section					Meißen section			
Sample	Grö-N1	Grö-6	Grö-11	Grö-15	Grö-20	Grö-N2	Grö-N3	Grö-N4	Grö-N5	Grö-N6	Grö-N7	Grö-N8	Grö-N9	O-1	O-2	O-3	O-5	O-6	M-Z	M-R	RC-1	RC-2
Preservation	VP	P/M	M	VP	M	P	P/M	M	P/M	VP	M	M	M	B	B	M/G	P	B	M/G	M	B	B
Abundance	L	H	H	M	M	M	M	H	M	M	H	M	H	n.a.	n.a.	M	L	n.a.	H	M	n.a.	n.a.
Species richness	24	43	39	24	44	27	31	36	29	13	38	33	33	0	0	52	33	0	57	36	0	0
UC zone according to Burnett (1998)	n.a.	3a	3a	3a	3a	(3a-d)	3b-d	3e	5b	(5b-6a)	6a	6a	6a	n.a.	n.a.	3a	3a	n.a.	3d	4b	n.a.	n.a.
Nannofossil taxa																						
Amphizygus brooksii	-	-	-	-	●	-	●	●	●	-	●	-	●	-	-	-	●	-	●	-	-	-
Axopodorhabdus albianus	●	●	●	●	●	●	●	●	-	-	-	-	-	-	-	●	●	-	●	●	-	-
Bilapillus wadeae	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	●	-	-	-	-	-	-
Biscutum constans	●	●	-	●	●	●	●	-	●	-	●	●	●	-	-	●	●	-	●	●	-	-
Braarudosphaera biglowii	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	●	-	-	-
Broinsonia cenomanica	●	-	-	-	-	●	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Broinsonia enormis	-	-	-	-	-	-	-	-	-	-	●	-	-	-	-	-	-	-	-	-	-	-
Broinsonia furtiva	-	-	-	-	-	-	-	-	-	-	●	●	●	-	-	-	-	-	-	-	-	-
Broinsonia matalosa	-	●	●	●	●	-	●	●	●	-	●	-	-	-	-	-	●	-	-	●	-	-
Broinsonia signata	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	●	●	-	-	-	-	-
Bukrylithus ambiguus	-	●	-	-	-	●	-	-	-	-	-	-	-	-	-	●	-	-	●	-	-	-
Calciosolenia fossilis	●	-	●	-	●	-	-	-	-	-	●	-	●	-	-	●	-	-	●	-	-	-
Calculites cenomanicus	-	●	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Calculites obscurus	-	-	-	-	-	-	-	-	-	-	-	-	●	-	-	-	-	-	-	-	-	-
Chiastozygus bifarius	●	-	●	-	-	-	-	-	●	-	-	-	●	-	-	●	●	-	-	●	-	-
Chiastozygus litterarius	●	●	-	-	-	-	-	●	-	-	●	●	●	-	-	-	●	-	●	-	-	-
Chiastozygus spissus	-	-	-	-	●	-	●	-	-	●	●	●	-	-	-	-	-	-	●	-	-	-
Chiastozygus synquadriperforatus	●	●	●	-	-	-	-	●	-	-	-	-	●	-	-	-	-	-	-	-	-	-
Corollithion exiguum	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	●	-	-	●	-	-	-
Corollithion kennedyi	-	●	●	●	●	●	○	-	-	-	-	-	-	-	-	●	-	-	●	-	-	-
Corollithion signum	-	-	-	-	-	-	-	-	-	-	-	●	-	-	-	●	-	-	●	-	-	-
Cretarhabdus conicus	-	●	●	-	-	-	-	-	-	-	-	●	-	-	-	●	-	-	●	-	-	-
Cretarhabdus striatus	-	-	-	-	●	-	●	●	-	-	-	-	-	-	-	●	-	-	●	-	-	-
Cribrosphaerella ehrenbergii	-	●	-	-	●	-	-	-	-	-	-	●	●	-	-	-	-	-	●	-	-	-
Cyclagelosphaera margerelii	-	●	-	-	-	-	-	●	-	-	-	-	●	-	-	-	-	-	-	●	-	-
Cylindralithus biarcus	-	-	-	-	-	-	-	-	●	-	-	-	-	-	-	-	-	-	-	-	-	-
Cylindralithus sculptus	-	-	-	●	-	-	●	●	-	-	-	-	-	-	-	●	●	-	●	●	-	-
Discorhabdus ignotus	●	●	●	●	-	●	●	-	-	-	-	-	-	-	-	●	-	-	●	●	-	-
Eiffellithus casulus	●	●		-	●	●	●	●	-	●	●	●	●	-	-	●	●	-	●	●	-	-
Eiffellithus parvus	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	○	-	-	-	-	-	-
Eiffellithus turriseiffelii	-	●	●	●	●	●	-	●	●	●	●	-	●	-	-	●	●	-	●	●	-	-
Eprolithus apertior	●	●	-	-	-	-	●	●	●	-	-	-	-	-	-	-	-	-	●	●	-	-
Eprolithus floralis	-	●	●	●	●	●	●	●	●	●	●	●	●	-	-	●	●	-	●	●	-	-
Eprolithus octopetalus	-	-	-	-	-	-	-	-	-	-	-	-	●	-	-	-	-	-	-	-	-	-
Eprolithus rarus	-	-	-	-	-	-	-	-	-	-	-	-	○	-	-	-	-	-	-	-	-	-
Flabellites oblongus	-	-	-	-	-	-	-	-	-	-	-	●	-	-	-	-	-	-	●	-	-	-
Gartnerago chiasta	-	-	-	-	-	-	-	○	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Gartnerago cf. *coxaliae*	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	○	-	-	-
Gartnerago obliquum	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	●	-	-	●	-	-	-
Gartnerago praeobliquum	-	-	-	-	●	-	●	-	-	-	●	-	-	-	-	-	●	-	●	-	-	-
Gartnerago segmentatum	-	-	-	-	-	-	-	-	-	-	●	●	-	-	-	●	-	-	●	-	-	-
Gartnerago theta	-	-	-	-	●	-	-	○	-	-	-	-	-	-	-	●	-	-	-	-	-	-
Grantarhabdus coronadventis	-	●	●	-	●	●	-	-	-	-	●	●	-	-	-	●	●	-	-	●	-	-
Haqius circumradiatus	-	-	-	-	-	-	●	-	●	-	-	●	●	-	-	●	-	-	●	-	-	-
Helenea chiastia	-	●	●	●	●	●	●	●	●	-	-	-	-	-	-	●	●	-	●	●	-	-
Helicolithus anceps	-	-	-	-	-	-	-	-	-	-	●	●	-	-	-	-	-	-	●	-	-	-
Helicolithus compactus	●	-	●	●	●	●	●	●	●	●	●	●	●	-	-	●	●	-	●	●	-	-
Helicolithus trabeculatus	-	-	●	-	-	-	-	●	-	-	●	-	●	-	-	-	-	-	-	-	-	-
Lithraphidites acutus	-	○	-	-	●	-	●	●	-	-	-	-	-	-	-	●	●	-	●	●	-	-
Lithraphidites carniolensis	-	-	-	-	●	-	-	-	-	-	-	-	-	-	-	●	-	-	●	●	-	-
Manivitella pemmatoidea	-	-	●	-	-	-	●	●	-	-	●	-	●	-	-	●	●	-	●	●	-	-
Micrantolithus cf. *obtusus*	○	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Microrhabdulus decoratus	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	●	-	-	●	-	-	-
Microrhabdulus helicoideus	-	-	-	-	-	-	-	-	-	-	-	-	●	-	-	-	-	-	-	-	-	-
Owenia hillii	●	●	●	●	●	-	-	-	-	-	-	-	-	-	-	●	●	-	●	●	-	-
Prediscosphaera columnata	●	-	●	●	●	●	-	-	-	-	●	●	-	-	-	●	●	-	-	●	-	-
Prediscosphaera cretacea	●	●	●	●	●	●	●	●	●	●	●	●	●	-	-	-	●	-	●	●	-	-
Prediscosphaera spinosa	-	●	-	-	-	-	-	-	-	-	-	●	-	-	-	●	-	-	-	-	-	-
Quadrum intermedium	-	-	-	-	-	-	-	-	-	-	●	●	-	-	-	-	-	-	-	-	-	-
Quadrum octobrachium	-	-	-	-	-	-	-	-	-	-	●	-	-	-	-	-	-	-	-	-	-	-
Radiolithus orbiculatus	-	-	-	-	-	-	●	●	-	-	-	-	-	-	-	●	-	-	-	-	-	-
Radiolithus planus	-	-	●	●	●	-	-	-	-	-	●	-	-	-	-	-	●	-	●	-	-	-
Retecapsa angustiforata	-	●	●	●	●	●	●	-	●	-	●	●	-	-	-	-	●	-	●	●	-	-
Retecapsa crenulata	●	●	●	●	●	-	-	●	●	●	●	●	-	-	-	-	-	-	●	●	-	-
Retecapsa ficula	-	●	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Retecapsa octofenestrata	-	●	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	●	-	-	-
Retecapsa surirella	-	●	●	-	●	-	-	-	-	-	●	●	-	-	-	-	-	-	●	●	-	-
Rhagodiscus achlyostaurion	●	●	●	●	●	●	●	●	●	-	●	●	●	-	-	●	●	-	●	●	-	-
Rhagodiscus angustus	●	●	●	●	●	-	-	-	●	-	-	●	●	-	-	●	-	-	●	●	-	-
Rhagodiscus asper	●	-	●	●	●	●	-	●	●	-	-	-	-	-	-	●	-	-	●	●	-	-
Rhagodiscus splendens	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	●	-	-	-	-	-	-
Rotelapillus crenulatus	-	●	-	-	●	●	-	●	●	-	●	-	-	-	-	●	-	-	-	●	-	-
Sollasites horticus	-	●	-	-	●	-	●	-	-	-	-	-	-	-	-	●	-	-	●	-	-	-
Staurolithites ellipticus	-	-	-	-	●	-	-	-	-	-	-	-	-	-	-	●	●	-	-	-	-	-
Staurolithites gausorhethium	-	-	○	-	-	-	○	-	-	-	-	-	-	-	-	○	-	-	-	-	-	-
Staurolithites lafittei	-	-	●	-	-	-	-	●	●	-	●	-	-	-	-	-	●	-	●	●	-	-
Stoverius achylosus	-	●	●	●	●	-	●	●	●	-	-	●	●	-	-	●	-	-	●	-	-	-
Tegumentum stradneri	-	-	-	-	●	-	-	●	-	-	-	-	-	-	-	-	-	-	●	-	-	-
Tetrapodorhabdus decorus	-	●	●	-	●	-	-	●	●	●	-	-	-	-	-	●	●	-	●	●	-	-
Tranolithus gabalus	-	●	●	-	●	●	-	●	●	-	●	●	●	-	-	●	-	-	●	-	-	-
Tranolithus minimus	-	-	-	-	-	-	-	-	●	-	●	-	-	-	-	-	-	-	●	-	-	-
Tranolithus orionatus	●	●	●	●	●	●	●	●	●	-	●	●	●	-	-	●	●	-	●	●	-	-
Watznaueria barnesiae	●	●	●	●	●	●	●	-	●	●	●	-	●	-	-	●	●	-	●	●	-	-
Watznaueria biporta	-	-	-	-	-	-	●	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Watznaueria britannica	-	-	-	-	-	○	-	-	-	-	-	-	-	-	-	-	-	-	○	○	-	-
Watznaueria ovata	-	-	●	-	-	-	-	-	-	-	-	●	-	-	-	-	-	-	-	●	-	-
Zeugrhabdotus acanthus	-	●	●	-	-	-	-	-	-	-	-	-	●	-	-	-	-	-	-	-	-	-
Zeugrhabdotus bicrescenticus	●	●	●	●	●	●	-	●	-	●	●	●	●	-	-	●	●	-	●	●	-	-
Zeugrhabdotus clarus	-	-	-	-	●	-	-	●	-	●	-	-	-	-	-	●	●	-	-	-	-	-
Zeugrhabdotus diplogrammus	-	-	●	-	-	-	-	●	-	-	-	-	-	-	-	●	-	-	-	-	-	-
Zeugrhabdotus embergeri	-	●	-	-	●	●	-	-	-	●	●	●	●	-	-	-	-	-	●	-	-	-
Zeugrhabdotus erectus	-	-	-	-	-	-	-	-	-	-	-	-	●	-	-	●	-	-	-	-	-	-
Zeugrhabdotus howei	●	●	-	-	●	●	●	●	●	●	●	●	●	-	-	●	●	-	●	●	-	-
Zeugrhabdotus noeliae	●	●	●	-	●	●	●	●	●	-	●	●	●	-	-	●	●	-	●	-	-	-
Zeugrhabdotus scutula	-	-	●	●	●	●	●	-	●	-	●	●	-	-	-	●	●	-	●	●	-	-

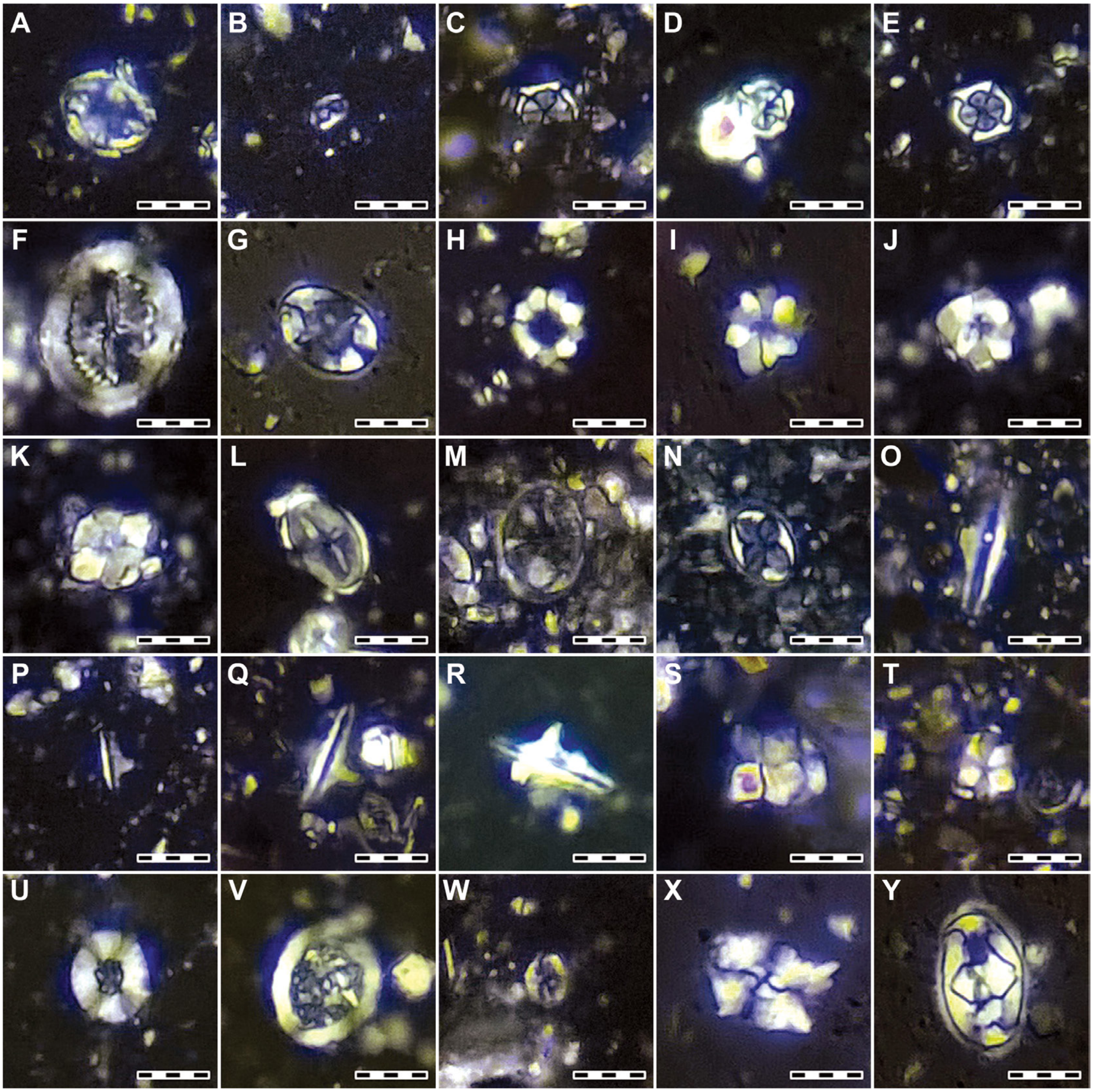


Figure 9. Light-microscopic photographs of diagnostic calcareous nannofossils from the Gröbern 2/91 core, Oberau and Meißen sections (sample numbers in brackets; see Figs 4, 5 and 7 for precise stratigraphic levels). • A – *Axopodorhabdus albianus* (Oberau, O-3). • B – *Bilapillus wadeae* (Oberau, O-3). • C–E – *Corollithion kennedyi*; C – Gröbern, 56 m; D – Meißen, M-Z; E – Oberau, O-3. • F – *Cretarhabdus striatus* (Oberau, O-3). • G – *Eiffellithus turriseiffelii* (Oberau, O-3). • H – *Eprolithus apertior* (Meißen, M-Z). • I – *Eprolithus floralis* (Meißen, M-Z). • J – *Eprolithus octopetalus* (Gröbern, Grö-N9). • K – *Eprolithus rarus* (Gröbern, Grö-N9). • L – *Gartnerago segmentatum* (Meißen, M-Z). • M – *Gartnerago theta* (Gröbern, Grö-20). • N – *Helicolithus compactus* (Gröbern, Grö-N8). • O–R – *Lithraphidites acutus*; O – Gröbern, Grö-N3; P – Gröbern, Grö-6; Q – Oberau, O-3; R –Meißen, M-Z. • S – *Quadrum intermedium* (Gröbern, Grö-N7). • T – *Quadrum octobrachium* (Gröbern, Grö-N7). • U – *Retecapsa octofenestrata* (Meißen, M-Z). • V – *Rhagodiscus asper* (Oberau, O-3). • W – *Staurolithites gausorhethium* (Gröbern, Grö-N3). • X – *Watznaueria barnesiae* (Meißen, M-Z) with overgrown rim. • Y – *Zeugrhabdotus embergeri* (Meißen, M-Z). Scale bar = 5 µm.

chronostratigraphically the Middle Cenomanian to Middle Coniacian and includes the Mobschatz, Dölzschen, Brießnitz, Räcknitz and Strehlen formations (modified according to Tröger & Voigt *in* Niebuhr *et al*. 2007). When a subdivision in the field or a given section is impossible, the monotonous strata can eventually be grouped in this superordinate lithostratigraphic unit without need for further formational classification.

Biostratigraphy

Macrofossils

The Meißen Formation is very fossiliferous, containing a diverse invertebrate fauna (*e.g.* Dietze 1961; Prescher & Tröger 1989; Löser 1989, 2014). Based on its inoceramids (*Inoceramus* ex gr. *crippsi*, *I. virgatus*) and cephalopods (ammonites *Schloenbachia varians*, *Scaphites obliquus* and alleged *Turrilites scheuchzerianus* as well as the belemnite *Neohibolites ultimus*) it has been placed in the upper Lower Cenomanian (Prescher & Tröger 1989; Köhler 1988, 1991, 2001; Spaeth & Köhler 1997; Köhler & Spaeth 1998). However, none of these taxa is confined exclusively to the Lower Cenomanian (Fig. 10B): *I. virgatus* occurs in the upper Lower and lower Middle Cenomanian and also *I. crippsi* ranges from the lower Lower into the lower Middle Cenomanian (Tröger 2009; see also comment on *I.* ex gr. *crippsi* below). *Schloenbachia varians* appears in the Lower Cenomanian but persists into the lower Middle Cenomanian and occurs in the *P. primus* Event of northern Germany (Wilmsen *et al*. 2007; see also Wilmsen & Mosavinia 2011 on the problem of "chronospecies" in *Schloenbachia*). *Scaphites obliquus* is a rather long-ranging (Lower–Middle) Cenomanian scaphitid ammonite (Wright & Kennedy 1996).

A fragmentary rostrum of *N. ultimus* (d'Orbigny), reported by Spaeth & Köhler (1997) and Köhler & Spaeth (1998) from the Meißen Formation in Meißen-Zscheila, has also been used to support the early Cenomanian age of the deposit. However, as already shown by Combémorel *et al*. (1981), the species ranges into the lower Middle Cenomanian *Turrilites costatus* Subzone of the lower *Acanthoceras rhotomagense* Zone (see also Wilmsen 1999; Mitchell 2005). Furthermore, and most importantly, the alleged *T. scheuchzerianus* of Köhler (2001) is in fact a lower Middle Cenomanian *T. costatus* as clearly shown by the conspicuous tuberculation (Fig. 8M, *T. scheuchzerianus* has oblique ribs and no tubercles; see Wilmsen & Nagm 2014 for details). This index taxon has its first appearance datum (FO) in the lower (but not lowermost) Middle Cenomanian, shortly below the *P. primus* Event, and characterises the lower part of the *Acanthoceras rhotomagense* Zone (see Wright & Kennedy 2017 for a state-of-the-art synopsis of Cenomanian ammonite stratigraphy). Further support for a Middle Cenomanian age comes from the first report of *Sciponoceras* cf. *baculoides* (Mantell) from the Meißen Formation (Fig. 8J). The specimen is rather poorly preserved, but its oval cross-section, faint ventral ribbing and spaced oblique constrictions clearly separate it from lowermost Cenomanian *S. roto* Cieśliński. *S. baculoides* first appears in flood abundance at the top of the *T. costatus* Subzone of the *A. rhotomagense* Zone (Wright & Kennedy 1995).

The *P. primus* Event, defined at the type locality of Wunstorf near Hannover (Ernst *et al*. 1983), is a conspicuous bioevent that formed in connection with a strong early Middle Cenomanian transgression (*e.g.* Gale 1995; Wilmsen 2003, 2007, 2012; Mitchell 2005; Wilmsen *et al*. 2007; Wilmsen & Rabe 2008). Apart from the eponymous belemnite, *Praeactinocamax primus* (Arkhangelsky), a number of different invertebrates are typical elements of the so-called *primus* fauna (see Wilmsen *et al*. 2007 for a synopsis), most notably several small brachiopod, serpulid, coral and echinoid taxa such as *Grasirhynchia grasiana* (d'Orbigny) and *Discoidea subucula* (Leske) that are also known from the Meißen Formation (Prescher & Tröger 1989).

In conclusion, the late Early Cenomanian age of the Meißen Formation is not biostratigraphically confirmed by the fauna, and the only reliable index fossil, *i.e. T. costatus*, rather suggests an early Middle Cenomanian age (as for the Oberau Conglomerate, see below). Furthermore, *S. baculoides* first appears at the top of the *T. costatus* Subzone so that all relevant macrofossils have their stratigraphic overlap in the lower *A. rhotomagense* Zone (Fig. 10B). Unfortunately, calcareous nannofossils and foraminifera cannot contribute to a further calibration of the age of the Meißen Formation (see below).

The ranges of biostratigraphically significant macrofossils of Oberau–Gröbern are shown in Fig. 10A. The inoceramid from the Oberau Conglomerate (Fig. 8H) is of specific importance. In its subcircular outline, MMG: SaK 121 resembles the form figured as *Inoceramus crippsi* var. *reachensis* Eth. by Woods (1911, pl. 49, fig. 1), *i.e. I. atlanticus* (Heinz). However, its preservation is rather poor and it is thus kept in open nomenclature. Furthermore, very similar and probably conspecific inoceramids referred to as *Inoceramus* ex gr. *crippsi* have been reported from the *P. primus* Event at Wunstorf near Hannover (Wilmsen *et al*. 2007, fig. 6p) and the Totternhoe Stone of Burwell, Cambridgeshire (Woods 1911, p. 278), the stratigraphic equivalent of the *P. primus* Event in the Upper Cretaceous Transitional Province of England (see Wilmsen & Wood 2004). It is well possible that the *I.* ex gr. *crippsi* reported from the Meißen Formation (Red Conglomerate) by Prescher & Tröger (1989, not illustrated) also belong to this early Middle Cenomanian taxon. The belemnites from the Oberau Conglomerate have been hitherto regarded as *Praeactinocamax plenus* (Wilmsen 2014). This was, however, more of a "stratigraphic identification" because the Oberau Conglomerate has been regarded as the basal conglomerate of the Dölzschen Formation and placed in the upper Upper Cenomanian "Plenuszone" (*i.e.* the *Metoicoceras geslinianum* Zone; Schander 1923, Häntzschel 1933, Dietze 1961; only Petrascheck 1900 correlated the conglomeratic–glauconitic facies at Oberau with the lower Upper Cenomanian "Carinaten-Quader", *i.e.*

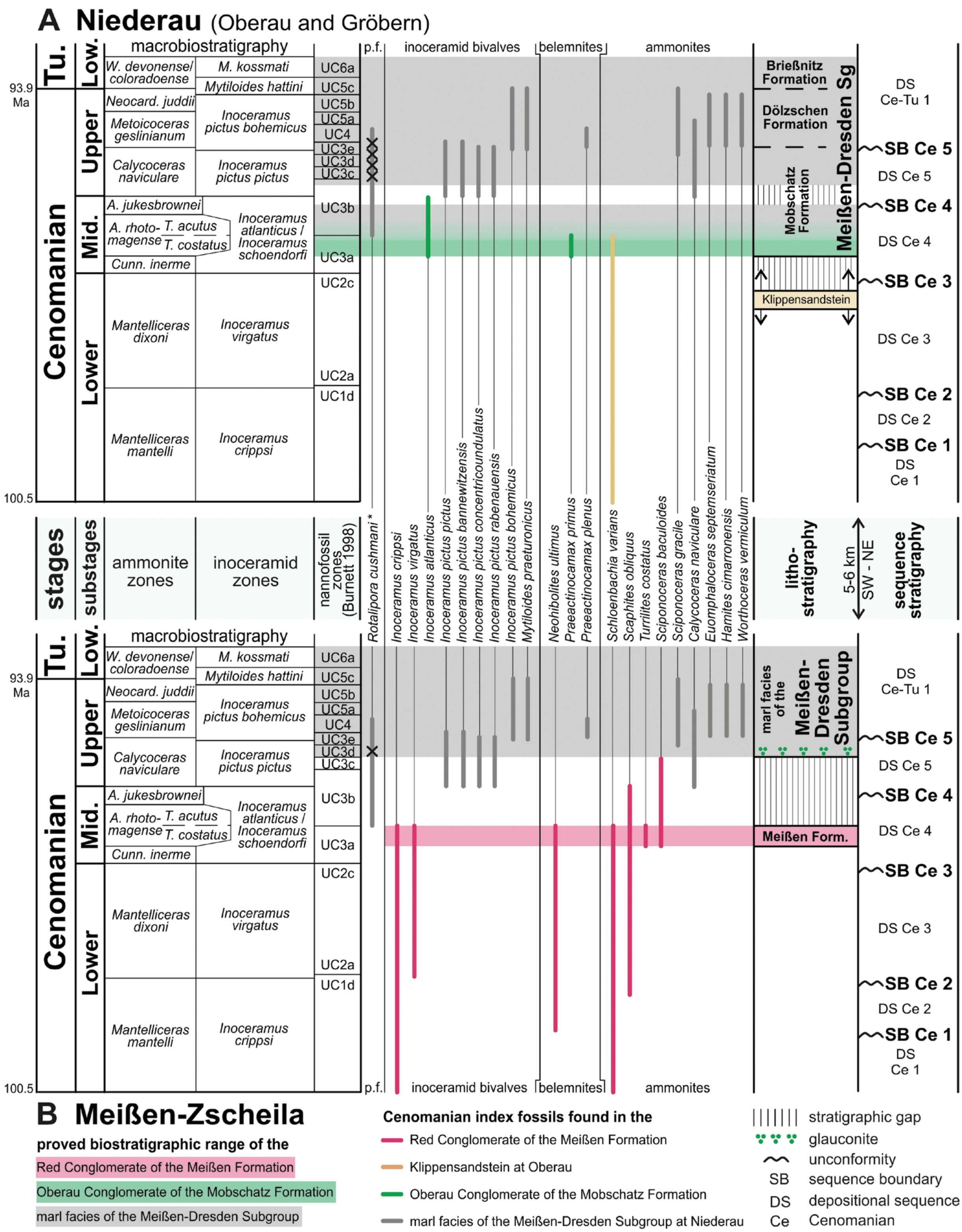


Figure 10. Biostratigraphic synopsis of the Cenomanian at A – Niederau (Oberau and Gröbern, above) and B – Meißen-Zscheila (below) based on index taxa recorded from the sections. The bars shown in the diagram correspond to the ranges for the taxa as reported in the literature (see text). * – occurrences of the planktic foraminifer *Rotalipora cushmani* (Morrow) according to Tröger (1989, 2003) and Ortmann (1994). Cenomanian standard sequence stratigraphy according to Robaszynski *et al.* (1998), Wilmsen (2003) and Janetschke *et al.* (2015). Abbreviations: *A.* – *Acanthoceras*; *T.* – *Turrilites*; *Cunn.* – *Cunningtoniceras*; Low. – Lower; *M.* – *Mytiloides*; Mid. – Middle; *Neocard.* – *Neocardioceras*: p.f. – planktic foraminifer; Tu. – Turonian; *W.* – *Watinoceras*.

the Oberhäslich Formation). The stratigraphic view that the Oberau Conglomerate is the basal bed of the Dölzschen Formation in the area has been followed by all later authors (including Wilmsen & Niebuhr 2014). However, the slender form of the rostra is not typical for *P. plenus*, which has a more club-shaped rostrum at (sub-) adult stage and grows larger, but is more typical of the closely allied earlier species *P. primus* (Arkhangelsky) (*e.g.* Christensen 1974, 1990; Košťák & Pavliš 1997; Wiese *et al*. 2009; see Fig. 8D, E for comparison of adult rostra of the two species). The occurrence of the small brachiopod *Terebratulina nodulosa*, known from the Upper Albian to Cenomanian of England (Owen 1988), and the small solitary coral *Micrabacia coronula* support the early Middle Cenomanian dating of the Oberau Conglomerate as both are typical elements of the *primus* Fauna in northern Germany (Wilmsen *et al*. 2007). Calcareous nannofossils confirm the age assignment (see below).

Biostratigraphically significant macrofossils (ammonites, belemnites and inoceramid bivalves) from the middle and upper part of the Mobschatz and Dölzschen formations in the Niederau area have been discussed and/or illustrated in various publications (Geinitz 1875; Dietze 1959, 1961; Köhler 1993, 2004, 2012; Wilmsen & Nagm 2013, 2014; Tröger & Niebuhr 2014; Tröger 2015). Albeit in some cases collected loose, the fauna clearly indicates the Upper Cenomanian *C. naviculare* and *M. geslinianum* zones (Figs 8, 10A).

Calcareous nannofossils

The calcareous nannofossil analysis documents an overall rare occurrence of marker species, e.g. *Gartnerago theta*, *Staurolithites gausorhethium*, *Gartnerago nanum* and *Corollithion kennedyi* (all taxa with LO's in UC3; Burnett 1998). Nevertheless, the observed nannofloral associations allow important biostratigraphic deductions (Tab. 1, Fig. 10).

The glauconitites of the basal Mobschatz Formation at Meißen-Zscheila can be assigned to an UC3d nannofossil zonal age (early Late Cenomanian; *cf*. Burnett 1998). This correlation was derived by a diverse nannofloral association including *Corollithion kennedyi* and *Lithraphidites acutus* and the absence of *Gartnerago nanum* (Tab. 1). However, at Meißen-Ratsweinberg, only *ca*. 1 km to the southwest of the Meißen-Zscheila sections (Fig. 1D), the presence of *Lithraphidites acutus* and the absence of *C. striatus* in the basal greensand that rests on the basement indicate the biozone UC4b (Burnett 1998). This demonstrates that the transgression occurred later here (mid-Upper Cenomanian *M. geslinianum* Zone) and that the strata are already part of the Dölzschen Formation.

From the Oberau–Gröbern composite section, a fairly consistent nannofossil biozonation emerged based on 15 prospective samples (Tab. 1). From the glauconitites directly above the Oberau Conglomerate, an early Middle Cenomanian age (UC3a) has been derived by the co-occurrence of *L. acutus* and *Gartnerago theta*, supporting the early Middle Cenomanian age of the conglomerate as inferred from macrofossils. UC3a continues up-section in the Gröbern 2/91 core up to the 64-m-level, defined by the presence of *G. theta* in the sample Grö-20. At 61.80 m, an unspecified UC3a–d nannofloral association occurred (Middle to lower Upper Cenomanian). At 56 m and 51.5 m, early Late and mid-Late Cenomanian ages result from calcareous nannofossil analyses (UC3b–d and UC3e; Tab. 1) marked by the LO of *C. kennedyi* at 56 m. Especially the latter datum is very important as it places the boundary between the Mobschatz and Dölzschen formations, as drawn herein, as well as sequence boundary SB Ce 5 at the junction of the *Calycoceras naviculare* and *Metoicoceras geslinianum* zones (*cf*. Burnett 1998; the *C. naviculare* Zone corresponds to the *C. guerangeri* Zone therein). The next sample at 42 m yielded an UC5b zonal age (late Late Cenomanian: upper *M. geslinianum* to lower *Neocardioceras juddii* zones); the UC4a–b and UC5a subzones have probably been missed due to the large inter-sample distance in this interval which is not in the focus of our study (the carbon stable isotope analysis of Voigt *et al.* 2006 provide a precise stratigraphic calibration of this part of the succession). Samples above 25 m consistently provided an Early (but not earliest) Turonian age (UC6a). The calcareous nannofossils thus show that the Oberau–Gröbern composite section covers the early Middle Cenomanian to Early Turonian.

Foraminifers

Foraminifers have not been studied herein, but existing data from Meißen are briefly evaluated herein. Fourteen benthic foraminifera were reported by Prescher & Tröger (1989) from the Red Conglomerate of the Meißen Formation at Meißen-Zscheila. The assemblage contains many long-ranging species and is not very age-diagnostic, only the occurrence of *Arenobulimina preslii* indicates that the strata cannot be older than late Early Cenomanian *M. dixoni* Zone, and *Berthelinia cenomanica* limits the upper range to the Lower Turonian (foraminifer zones Ko-F2 to Ko-F5; see Dölling *et al*. 2014 for a recent synopsis on the Upper Cretaceous foraminifer zonation in northern Germany). From the lowermost part of the overlying Mobschatz Formation at Meißen-Zscheila, Tröger (1989) described an inferred Upper Cenomanian foraminifera fauna of predominantly benthic forms (22 taxa), again including *A. preslii* and *B. cenomanica* along with some planktic forms (unkeeled *Muricohedbergella*

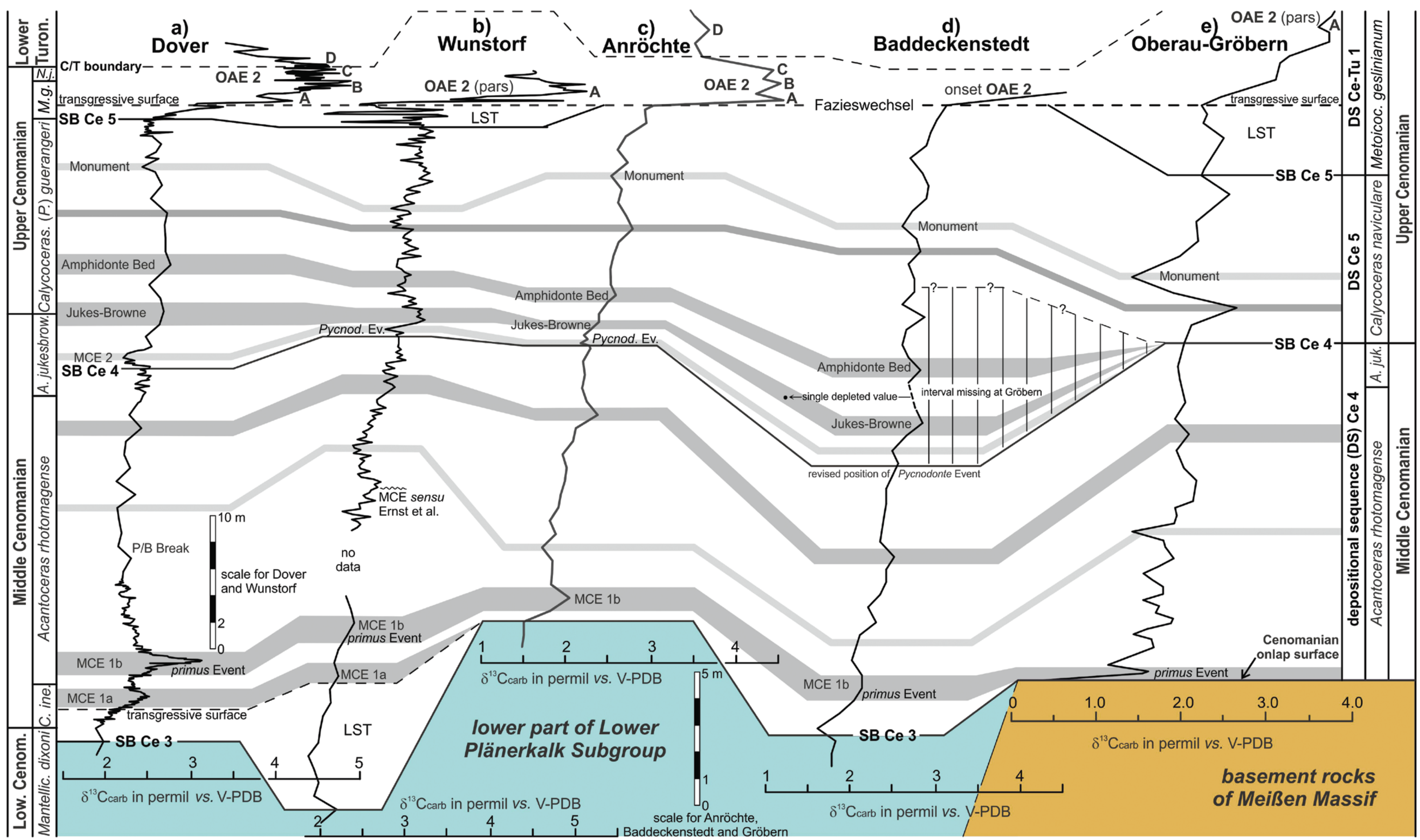


Figure 11. Chemostratigraphic correlation of the Middle to mid-Upper Cenomanian in a transect from southern England (left) to Saxony (right) based on carbon stable isotope records from Dover (a, Jarvis *et al*. 2006), Wunstorf (b, Wilmsen 2007 – lower part, Voigt *et al*. 2008 – upper part), Anröchte (c, Richardt & Wilmsen 2012), Baddeckenstedt (d, Wilmsen & Niebuhr 2002) and Oberau–Gröbern (e, Voigt *et al*. 2006 and this study); note the different scales for Dover/Wunstorf and Anröchte/Baddeckenstedt/Oberau–Gröbern. The base of the rise to the A-peak of the positive isotope excursion has been used as datum line; dark-grey lines connect positive, light-grey lines negative peaks. See text for further explanations and Fig. 1C for location of sections (encircled letters a–e). Abbreviations: *A. jukesbrow*. – *Acanthoceras jukesbrownei*; Ce – Cenomanian; *C. ine*. – *Cunningtoniceras inerme*; Low. Cenom. – Lower Cenomanian; LST – lowstand systems tract; MCE – Mid-Cenomanian Event; *M. g*. – *Metoicoceras geslinianum*; *N. j*. – *Neocardioceras juddii*; OAE – oceanic anoxic event; *P*. – *Proeucalycoceras*; SB – sequence boundary; Turon. – Turonian.

delrioensis and a keeled form loosely referred to "*Globotruncana* sp.", later assigned to *Rotalipora cushmani* by Tröger 2003, p. 3). Once more, this dating is rather poorly constrained by the benthic taxa identified but the presence of *R. cushmani* indicates the eponymous late Middle to mid-Late Cenomanian taxon range zone (*e.g.* Robaszynski & Caron 1979a, b; Caron 1985). Nevertheless, a Late Cenomanian attribute of the fauna corresponds to the age assignment from the same layer based on calcareous nannofossils (UC3d, sample M-Z, see Fig. 4A and Tab. 1). The low planktic/benthic (P/B) foraminifera ratio (*ca.* 1/5) and the high percentage of agglutinating forms indicate relatively shallow-water conditions (Tröger 1989). From the Dölzschen Formation at the Ratsweinberg in Meißen Niederfähre-Vorbrücke (Fig. 1D), sixteen benthic foraminifer taxa have been reported by Rompf (1960), including *A. preslii.*

Chemostratigraphy and sea-level changes

The carbon stable isotope analysis of Voigt *et al.* (2006) provided a detailed stratigraphic dating and correlation of the middle and upper part of the Gröbern 2/91 core that contained a fairly expanded record of the major positive carbon stable isotope excursion of the oceanic anoxic event (OAE) 2 in the Cenomanian–Turonian boundary interval (Schlanger & Jenkyns 1976, Schlanger *et al.* 1987). We thus focus on the hitherto poorly dated Middle to lower Upper Cenomanian part herein (Fig. 11). However, it should be noted that Jarvis *et al.* (2011) presented a chemostratigraphic reinterpretation of the Gröbern 2/91 curve, modifying some of the original results of Voigt *et al.* (2006) based on the correlation of isotope records from the Anglo-Paris and Vocontian basins. Jarvis *et al.* (2011, fig. 6) placed the onset of OAE 2 at *ca.* 51 m at the Gröbern 2/91 core, consistent with the interpretation herein (Fig. 7). This change from the pre-excursion to the first build-up phase of OAE 2 (*sensu* Paul *et al.* 1999) coincides with the sub-*plenus* erosion surface in the Anglo-Paris Basin (Jeffries 1963), matching sequence boundary Cenomanian 5 (SB Ce 5) at the junction of the *C. guerangeri* and *M. geslinianum* zones (Gale 1995, Robaszynski *et al.* 1998) and giving further support for the placement of this surface at the base of the conspicuous shell bed at 51.40 m at the Gröbern 2/91 core (Fig. 7). Originally, Voigt *et al.* (2006) correlated this sequence boundary (their t_1 datum) to the ~57-m-level at Gröbern. However, this lower surface cannot correspond to mid-Upper Cenomanian SB Ce 5, clearly shown by the early Late Cenomanian nannoflora from sample N3 at 56 m, but matches SB Ce 4 in the Middle–Late Cenomanian boundary interval (see below). Finally, the Cenomanian–Turonian boundary (CTB) was inferred by Voigt *et al.* (2006) in the interval between 30–26 m in Gröbern 2/91 core. Jarvis *et al.* (2011) calibrated the CTB to the ~31.5-m-level and we placed it at 31 m, within an argillaceous interval corresponding to the Lohmgrund-Mergel, a marker bed at the base of the Brießnitz and Schmilka formations (Figs 2, 7).

The chemostratigraphic correlation of the Middle and lower Upper Cenomanian is based on an west–east transect of sections from southern England to Saxony, *i.e.* on Dover (Jarvis *et al.* 2006), Wunstorf near Hannover (Wilmsen 2007, Voigt *et al.* 2008), Anröchte in the Münsterland Cretaceous Basin (Richardt & Wilmsen 2012), Baddeckenstedt in Lower Saxony (Wilmsen & Niebuhr 2002) and the Oberau–Gröbern composite record (Voigt *et al.* 2006 and this study). It has to be stressed that the Oberau–Gröbern curve is not very detailed when compared to the high-resolution records of the expanded Dover and Wunstorf sections (Fig. 11). Nevertheless, the general increase in $\delta^{13}C$ values from the lower Middle into the mid-Upper Cenomanian, up to the base of the OAE 2, is well reflected in the curve from Saxony and some contemporaneous isotope events (*cf.* Mitchell *et al.* 1996, Jarvis *et al.* 2006) can be identified with considerable confidence.

Deposition of Cenomanian strata started at Oberau–Gröbern with the early Middle Cenomanian, a phase of major coastal onlap during the Cenomanian 2nd-order sea-level rise (*e.g.* Gale 1995; Mitchell *et al.* 1996; Robaszynski *et al.* 1998; Wilmsen 2003, 2007; Wilmsen *et al.* 2007). This onlap phase consists of two pulses associated by two distinct positive isotope peaks of the Mid-Cenomanian Event (MCE) 1, *i.e.* MCE 1a (the *arlesiensis* Bed) and MCE 1b (the *P. primus* Event; Gale 1995, Mitchell *et al.* 1996). The earlier pulse is commonly missing in proximal positions while the later *P. primus* Event transgression overlaps onto various basin margins (Wilmsen & Niebuhr 2002, Wilmsen 2007, Wilmsen *et al.* 2007, Wilmsen & Rabe 2008, Richardt & Wilmsen 2012; Fig. 11). However, the isotope pattern of this interval is not identifiable in the low-resolution Oberau–Gröbern section and the onlap of the *P. primus* Event in the Oberau Conglomerate is only proved by biostratigraphic data and characteristic elements of the *primus* Fauna. Accepting the revised early Middle Cenomanian age of the Meißen Formation, the same transgression is recorded by the Red Conglomerate at Meißen-Zscheila. The Klippensandstein at the Oberau railway slope cut section records an earlier transgression but we cannot elucidate the precise stratigraphic position of this deposit; it either is a relic of a (late) Early Cenomanian transgression or records the first pulse of the early Middle Cenomanian transgression (*i.e.* the *arlesiensis* Transgression; Wilmsen 2007). The fact that the Klippensandstein already was lithified when the *primus* Transgression occurred favours the former interpretation. Some earlier authors (*e.g.* Geinitz 1839, Dietze 1961) regarded the Klippensandstein as a lateral facies equivalent of the Oberau Conglomerate but this appears rather unlikely given the completely different sedimentary fabrics of the two units and their unconformable contact.

The *P. primus* Event transgression created considerable accommodation space for deposition of Middle Cenomanian strata across the different basins (Fig. 11). The isotope patterns within depositional sequence DS Ce 4 up to the capping uppermost Middle Cenomanian sequence boundary SB Ce 4 at the base of the *Pycnodonte* Event are characterised by a decrease of $\delta^{13}C$ values above MCE 1 towards a minimum in the upper *A. rhotomagense* Zone, slightly above the P/B Break Event of Jarvis *et al*. (2006), followed by a faint increase towards SB Ce 4 split into roughly even segments by a central positive spike (Fig. 11). These isotope patterns can also be identified at Oberau–Gröbern up to the 57.50-m-level where SB Ce 4 has been placed (Figs 7, 11). Above SB Ce 4, a conspicuous sequence of negative (MCE 2; Mitchell *et al*. 1996) and positive isotope events (Jukes-Browne and *Amphidonte* Bed events; Jarvis *et al*. 2006) are readily identifiable and can be correlated confidently from Dover to Baddeckenstedt (Fig. 11). However, at Oberau–Gröbern, this striking isotope pattern is missing, suggesting that a considerable stratigraphic gap is present at the sequence boundary. It appears that the sea-level fall at SB Ce 4 resulted in a lack of accommodation at the Saxonian basin margin until transgressive strata of mid-*C. naviculare* zonal age onlapped the unconformity in the (late) transgressive systems tract of DS Ce 5 (Fig. 11). The conspicuous couplet of positive–negative peaks at Gröbern above SB Ce 4 is inferred to correspond to an unnamed spike and the Monument Event of Jarvis *et al*. (2006), respectively. Above the Monument Event, the German curves all show a bipartite rise in the upper *C. naviculare* Zone towards SB Ce 5 that terminates DS Ce 5 (Fig. 11).

The integrated stratigraphic analysis resulted in the following transgression history for the northwestern part of the Saxonian Cretaceous Basin (Fig. 12): the early Late Cretaceous transgression reached the Meißen–Niederau area in the early Middle Cenomanian and resulted in

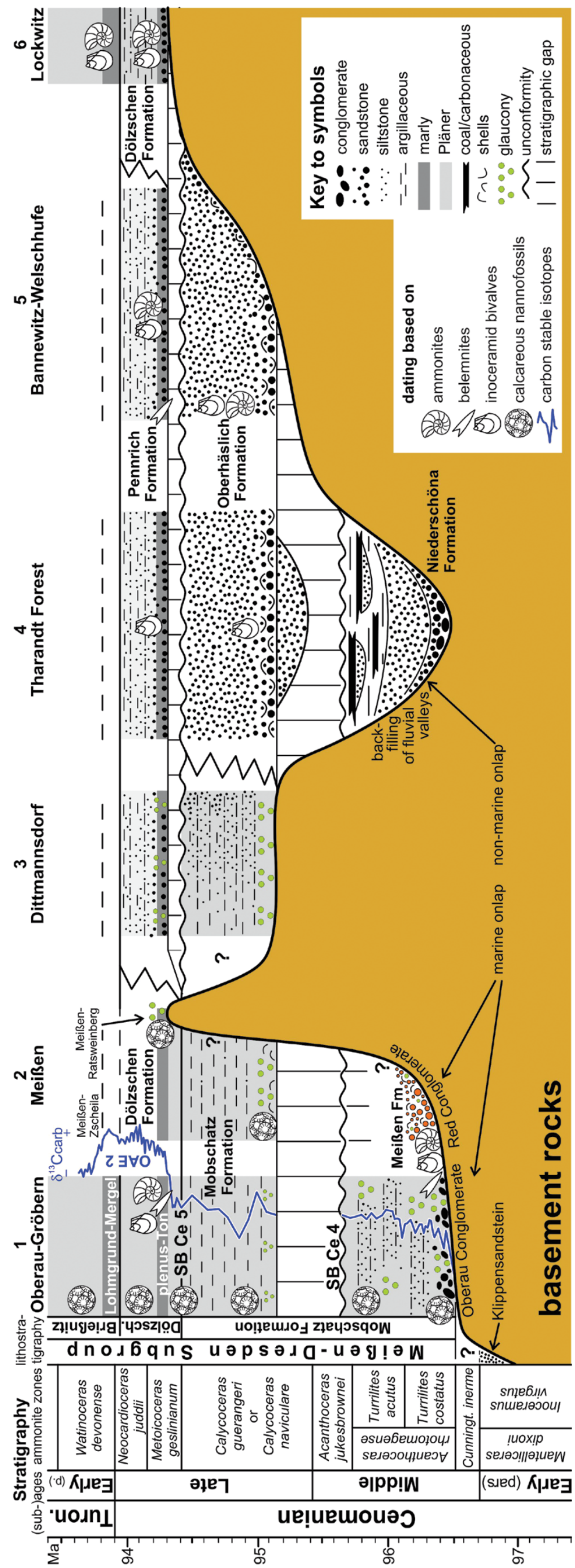


Figure 12. Transgression history of the Cenomanian in Saxony (1, 2 – Oberau–Gröbern and Meißen after this work, carbon stable isotopes after Voigt *et al*. 2006 and this work; 3 – Reinsberg-Dittmannsdorf after Tröger 2017; 4 – Tharandt Forest after Alexowsky *et al.* 2012 and Janetschke & Wilmsen 2014; 5 – Bannewitz-Welschhufe after Janetschke & Wilmsen 2014 and Wilmsen 2017; 6 – Dresden-Lockwitz after Wilmsen *et al.* 2011). See Fig 1C for course of the transect as well as Wilmsen & Nagm (2013, 2014), Tröger & Niebuhr (2014), Wilmsen (2014) and Tröger (2015) for data on ammonite, belemnite and inoceramid bivalve occurrences and biostratigraphy. Abbreviations: Dölzsch. – Dölzschen Formation; p. – pars; Turon. – Turonian.

marine onlap of the lower Mobschatz and Meißen formations onto basement rocks of the Meißen Massif; the sea approached from the northwest and coastline was situated somewhere between Meißen and Dresden (see also Tröger 2017). However, also in the Meißen area, basement highs remained emergent (*e.g.* Meißen-Ratsweinberg), flanked by the high-energy facies of the Red Conglomerate (Fig. 12). The lack of significant sandy input during this time suggests that these basement highs were already disconnected from the mainland of the Mid-European Island and of rather small size, forming isles off the coast. Contemporaneous non-marine onlap is documented by the backfilling of fluvial valleys by the strata of the Niederschöna Formation (Voigt 1998) that shows the typical stratigraphic architecture and facies succession of a fluvial system during a base-level rise (Shanley & McCabe 1993). A sea-level fall in the late Middle Cenomanian (SB Ce 4) terminated depositional sequence DS Ce 4 and resulted in a stratigraphic gap in the Middle–Upper Cenomanian boundary interval in the marine part of the basin and a conspicuous unconformity at the top of the Niederschöna Formation (Janetschke & Wilmsen 2014).

The early Late Cenomanian *naviculare* Transgression caused a significant shift of the coastline towards the southeast and widespread marine onlap of the upper Mobschatz and Oberhäslich formations during DS Ce 5 (Fig. 12). A glauconitic transgression horizon characterises the basal Mobschatz Formation while coarse-grained, shell-rich siliciclastics predominate in the lower Oberhäslich Formation. Only some basement highs remained emergent during this phase of the early Late Cretaceous transgression (*e.g.* Tröger 1955, 2003, 2017; Voigt *et al.* 1994, 2006; Wilmsen *et al.* 2011). This also applies for the Meißen area as the nannofossil data show that the transgression occurred at Meißen-Ratsweinberg in UC4b, *i.e.* not before the *M. geslinianum* Zone (*cf.* Burnett 1998). A sea-level fall at SB Ce 5 at the boundary of the *C. naviculare* to *M. geslinianum* zones caused another stratigraphic gap in the proximal parts of the basin (lack of accommodation space) while in the distal Niederau area, the sea was deep enough to accommodate sediments also during falling and low sea-level of DS Ce–Tu 1 in the early *geslinianum* Zone (Fig. 12). The latest Cenomanian to earliest Turonian sea-level rise overlapped the remaining positive areas (including Meißen-Ratsweinberg), causing the onlap of the Dölzschen and Pennrich formations and a starvation of the distal Meißen–Niederau area (increasing carbonate contents and lack of silt- and sand-sized siliciclastics).

The revised transgression history in Saxony has also significance for the drainage history of the Bohemian Cretaceous Basin because the inferred outflow of Cenomanian fluvial to estuarine systems in the northern, western and central parts occurred along the present-day Elbe Valley (Uličný *et al.* 2009; Peruc-Korycany Formation). Although exclusively fluvial Lower Cenomanian strata are known from the basal parts of infilled palaeovalleys in some areas, brackish and tidal influences appeared with their Cen 2 sequence in the lower Middle Cenomanian and became more significant through time, with a first maximum transgressive surface (mts) in the mid-*A. rhotomagense* Zone (Špičáková *et al.* 2014). The backfilling of palaeovalleys by fluvial to estuarine strata continued during the Middle to Late Cenomanian and the marine flooding culminated close to the Cenomanian–Turonian boundary (Uličný *et al.* 1993, 2009; Uličný & Špičáková 1996; Špičáková *et al.* 2014).

Conclusions

The stratigraphy of the Meißen Formation and distal marl and Pläner facies (Mobschatz, Dölzschen and Brießnitz formations) in the Meißen and Niederau (Oberau–Gröbern) areas of the northwestern Saxonian Cretaceous Basin is revised with important implications for the transgression history of the early Late Cretaceous in Saxony. The study is based on sections in Meißen and Oberau–Gröbern and applies an integrated approach of bio- (macrofossils, calcareous nannofossils), chemo-, event and sequence stratigraphy accompanied by detailed facies analyses (litho-, bio- and microfacies).

A re-evaluation of the faunal content of the Meißen Formation (the Red Conglomerate) suggests that the unit is rather of early Middle (*Acanthoceras rhotomagense* Zone) than late Early Cenomanian age, being unconformably overlain by the lower Upper Cenomanian Mobschatz Formation, the base of which yielded an UC3d nannofloral assemblage. At Oberau (Niederau area), the transgressive Oberau Conglomerate at the base of the Mobschatz Formation, formerly regarded as the basal conglomerate of the Dölzschen Formation and placed in the mid-Upper Cenomanian *M. geslinianum* Zone, forms a contemporaneous equivalent of the Red Conglomerate. The macrofossil content of the bed demonstrates the older age and suggests that the contained belemnites are in fact *Praeactinocamax primus* that migrated to Saxony in connection with the early Middle Cenomanian *primus* transgression. Support for this interpretation comes from calcareous nannofossils which indicate the UC3a biozone for the strata immediately above the Oberau Conglomerate. Up-section, the Oberau section continues in the Gröbern 2/91 core and calcareous nannofossils show that the 70-m-thick Oberau–Gröbern composite section covers the Middle Cenomanian to Early Turonian (from the UC3a to UC6a biozones *sensu* Burnett 1998), supported by sporadic macrofossil occurrences.

The stratigraphic dating and correlation is substantiated by new carbon stable isotope analyses from the lower part of the section that have been combined with published data from the middle and upper part of the succession that include the oceanic anoxic event (OAE) 2 in the Cenomanian–Turonian boundary interval. The Middle Cenomanian to lower Upper Cenomanian isotope curve has been correlated to records from the Anglo-Paris and northern German basins, suggesting a stratigraphic gap in the Middle–Late Cenomanian boundary interval in the middle part of Mobschatz Formation. This gap corresponds to a phase of falling and low sea-level stand connected to Cenomanian sequence boundary 4 (SB Ce 4).

The transgression history continued in the early Late Cenomanian with the upper Mobschatz Formation at Oberau–Gröbern corresponding to the first onlap of the Mobschatz Formation onto the Meißen Formation and basement rocks at Meißen-Zscheila as well as on basement areas further in the southeast towards Dresden. Another sea-level fall is recorded by the formational contact of the Mobschatz and Dölzschen formations in the mid-Upper Cenomanian which can be tracked into a conspicuous unconformity in the proximal parts of the basin (SB Ce 5 at the boundary of the *C. naviculare* to *M. geslinianum* zones). The latest Cenomanian and earliest Turonian document a phase of major deepening characterised by submergence of the last basement highs as well as siliciclastic starvation and pelagic sedimentation in the Meißen–Niederau area.

The monotonous lithology of the composite Middle Cenomanian–Lower Turonian Oberau–Gröbern section clearly reveals the limitations of the current lithostratigraphic framework of the Elbtal Group with respect to the distal marl and Pläner facies zone, where formations can often only be differentiated by means of chronostratigraphic data. Thus, the introduction of the Middle Cenomanian to Middle Coniacian Meißen-Dresden Subgroup is suggested in which the lithologically uniform strata can be eventually grouped without the need for further formational classification.

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Appendix. Taxonomic index of nannofossils mentioned in the text in alphabetical order of genera names.

Amphizygus brooksii Bukry, 1969
Axopodorhabdus albianus (Black, 1967) Wind & Wise, 1983
Bilapillus wadeae Lees 2007
Biscutum constans (Górka, 1957) Black *in* Black & Barnes, 1959
Braarudosphaera bigelowii (Gran & Braarud, 1935) Deflandre, 1947
Broinsonia cenomanica (Black, 1973) Bown 2001
Broinsonia enormis (Shumenko, 1968) Manivit, 1971
Broinsonia furtiva (Bukry, 1969) Wind & Wise, 1980
Broinsonia matalosa (Stover, 1966) Burnett *in* Gale *et al*., 1996
Broinsonia signata (Noël, 1969) Noël, 1970
Bukrylithus ambiguus Black, 1971
Calciosolenia fossilis (Deflandre *in* Deflandre & Fert, 1954) Bown *in* Kennedy *et al*. 2000
Calculites cenomanicus (Jakubowski, 1986) Varol & Jakubowski, 1989
Calculites obscurus (Deflandre, 1959) Prins & Sissingh *in* Sissingh, 1977
Chiastozygus bifarius Bukry, 1969
Chiastozygus litterarius (Górka, 1957) Manivit, 1971
Chiastozygus spissus Bergen *in* Bralower & Bergen, 1998
Chiastozygus synquadriperforatus Bukry, 1969
Corollithion exiguum Stradner, 1961
Corollithion kennedyi Crux, 1981
Corollithion signum Stradner, 1963
Cretarhabdus conicus Bramlette & Martini, 1964
Cretarhabdus striatus (Stradner, 1963) Black, 1973
Cribrosphaerella ehrenbergii (Arkhangelsky, 1912) Deflandre *in* Piveteau, 1952
Cyclagelosphaera margerelii Noël, 1965
Cylindralithus biarcus Bukry, 1969
Cylindralithus sculptus Bukry, 1969
Discorhabdus ignotus (Górka, 1957) Perch-Nielsen, 1968
Eiffellithus casulus Shamrock *in* Shamrock & Watkins 2009
Eiffellithus parvus Watkins & Bergen 2003
Eiffellithus turriseiffelii (Deflandre *in* Deflandre & Fert, 1954) Reinhardt, 1965
Eprolithus apertior Black, 1973
Eprolithus floralis (Stradner, 1962) Stover, 1966
Eprolithus moratus (Stover, 1966) Burnett, 1998
Eprolithus octopetalus Varol, 1992
Eprolithus rarus Varol, 1992
Flabellites oblongus (Bukry, 1969) Crux *in* Crux *et al*., 1982
Gartnerago chiasta (Varol, 1991)
Gartnerago coxalliae Lees 2007
Gartnerago obliquum (Stradner, 1963) Noël, 1970
Gartnerago praeobliquum Jakubowski, 1986
Gartnerago segmentatum (Stover, 1966) Thierstein, 1974
Gartnerago theta (Black in Black & Barnes, 1959) Jakubowski, 1986
Grantarhabdus coronadventis (Reinhardt, 1966) Grün *in* Grün & Allemann, 1975
Haqius circumradiatus (Stover, 1966) Roth, 1978
Helenea chiastia Worsley, 1971
Helicolithus anceps (Górka, 1957) Noël, 1970
Helicolithus compactus (Bukry, 1969) Varol & Girgis, 1994
Helicolithus trabeculatus (Górka, 1957) Verbeek, 1977
Lithraphidites acutus Verbeek & Manivit *in* Manivit *et al*., 1977
Lithraphidites carniolensis Deflandre, 1963
Manivitella pemmatoidea (Deflandre *in* Manivit, 1965) Thierstein, 1971
Micrantolithus obtusus Stradner, 1963
Microrhabdulus decoratus Deflandre, 1959
Microrhabdulus helicoideus Deflandre, 1959
Owenia hillii Crux, 1991
Prediscosphaera columnata (Stover, 1966) Perch-Nielsen, 1984
Prediscosphaera cretacea (Arkhangelsky, 1912) Gartner, 1968
Prediscosphaera spinosa (Bramlette & Martini, 1964) Gartner, 1968
Quadrum intermedium Varol, 1992
Quadrum octobrachium Varol, 1992
Radiolithus orbiculatus (Forchheimer, 1972) Varol, 1992
Radiolithus planus Stover, 1966
Retecapsa angustiforata Black, 1971
Retecapsa crenulata (Bramlette & Martini, 1964) Grün *in* Grün & Allemann, 1975
Retecapsa ficula (Stover, 1966) Burnett, 1997
Retecapsa octofenestrata (Bralower *in* Bralower *et al*., 1989) Bown *in* Bown & Cooper, 1998
Retecapsa surirella (Deflandre & Fert, 1954) Grün *in* Grün & Allemann, 1975
Rhagodiscus achlyostaurion (Hill, 1976) Doeven, 1983
Rhagodiscus angustus (Stradner, 1963) Reinhardt, 1971
Rhagodiscus asper (Stradner, 1963) Reinhardt, 1967
Rhagodiscus splendens (Deflandre, 1953) Verbeek, 1977
Rotelapillus crenulatus (Stover, 1966) Perch-Nielsen, 1984
Sollasites horticus (Stradner *et al*. *in* Stradner & Adamiker, 1966) Cepek & Hay, 1969
Staurolithites ellipticus (Gartner, 1968) Lambert, 1987
Staurolithites gausorhethium (Hill, 1976) Varol & Girgis, 1994
Staurolithites laffittei Caratini, 1963
Stoverius achylosus (Stover, 1966) Perch-Nielsen, 1986
Tegumentum stradneri Thierstein *in* Roth & Thierstein, 1972
Tetrapodorhabdus decorus (Deflandre *in* Deflandre & Fert, 1954) Wind & Wise, 1983
Tranolithus gabalus Stover, 1966
Tranolithus minimus (Bukry, 1969) Perch-Nielsen, 1984
Tranolithus orionatus (Reinhardt, 1966a) Reinhardt, 1966b
Watznaueria barnesiae (Black *in* Black & Barnes, 1959) Perch-Nielsen, 1968
Watznaueria biporta Bukry, 1969
Watznaueria britannica (Stradner, 1963) Reinhardt, 1964
Watznaueria ovata Bukry, 1969
Zeugrhabdotus acanthus Reinhardt, 1965
Zeugrhabdotus bicrescenticus (Stover, 1966) Burnett *in* Gale *et al*., 1996
Zeugrhabdotus clarus Bown 2005
Zeugrhabdotus diplogrammus (Deflandre *in* Deflandre & Fert, 1954) Burnett *in* Gale *et al*., 1996
Zeugrhabdotus embergeri (Noël, 1959) Perch-Nielsen, 1984
Zeugrhabdotus erectus (Deflandre *in* Deflandre & Fert, 1954) Reinhardt, 1965
Zeugrhabdotus howei Bown *in* Kennedy *et al*. 2000
Zeugrhabdotus noeliae Rood *et al*., 1971
Zeugrhabdotus scutula (Bergen, 1994) Rutledge & Bown, 1996