

# The Upper Turonian of the Bohemian Cretaceous Basin (Czech Republic) exemplified by the Úpohlavy working quarry: integrated stratigraphy and palaeoceanography of a gateway to the Tethys

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## Abstract

The north Bohemian Cretaceous (Bohemian Cretaceous Basin; Czech Republic) is located between the northern temperate areas and the Tethys. As a gateway to the Tethys, lithology, fauna and integrated stratigraphy (litho-, bio-, event, sequence, stable isotope stratigraphy) of the Upper Turonian succession in the Úpohlavy working quarry are described. Due to a large hiatus, the  $\delta^{13}\text{C}$  curve cannot be used for stratigraphic purposes at the base of the section. Up-section, the curve exhibits the well-known middle Upper Turonian positive excursion. Biostratigraphic and sequence stratigraphic subdivisions permit good correlation with other European Cretaceous basins. The inoceramid bivalve assemblage enables correlation with the US Western Interior. Palaeoceanographically, a positive peak in the  $\delta^{18}\text{O}$  curve above the hiatus indicates the upper part of the Late Turonian cooling event observed in other areas. The cooling was accompanied by a southward shift of a cool/temperate oceanic biosedimentary system, expressed by the sudden turnover from siliciclastic towards pelagic carbonate deposition. It is associated with the establishment of presumed oligotrophic conditions in the immediate vicinity of the West Sudetic Island, as indicated by the sudden decrease of macrofaunal abundance and diversity.

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## 1. Introduction

The Turonian rocks of the Bohemian Cretaceous Basin (Fig. 1A) are palaeogeographically positioned close to the Lausitz Massiv (Ziegler, 1988) and were deposited in a comparatively narrow seaway linking the Boreal Realm in the north with the northern Tethys

shelf in the south. The sediments show a gradual lateral change from siliciclastic nearshore successions towards in part highly fossiliferous basinal marls, marly limestones and marl/limestone alternations of more distal basinal areas (Skoček and Valečka, 1983). While the siliciclastics have recently been re-investigated in great detail (Uličný, 2001), the surface exposures of the marls and limestones have been treated stratigraphically and sedimentologically to a lesser extent. However, borehole data (Macák and Müller, 1965, 1966, 1968; Krutský et al., 1975; Váně, 1979) give a good impression of the basinal Turonian to Lower Coniacian succession. In

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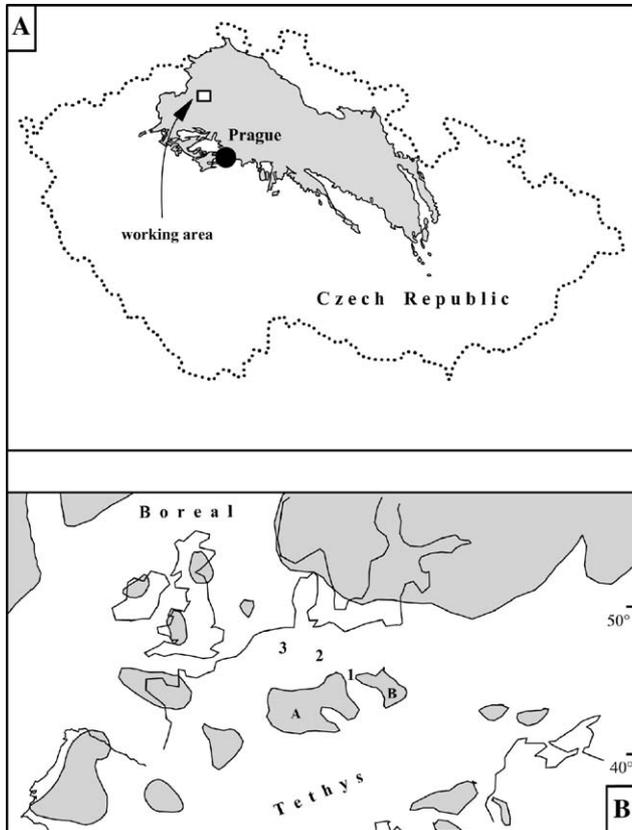


Fig. 1. A, location of the working area within Bohemia. Shaded part: approximate outline of Cretaceous strata of the Bohemian Cretaceous Basin. B, areas and localities mentioned in the text: 1, Bohemian Cretaceous Basin and the “Elbe-Zone” of Saxony, Germany; 2, Salzgitter-Salder and Söhlde, Lower Saxony Basin, northwest Germany; 3, Münsterland Cretaceous Basin, Westphalia, northwest Germany. A, Bohemian Massif; B, West Sudetic Island.

contrast to the small amount of geological literature, the faunal abundance resulted in a wealth of palaeontological work on both vertebrates and invertebrates, which show that the faunas of Bohemia are influenced to a varying extent both from the Boreal and Tethys through time. However, only limited attempts have been made to include part or all of the Bohemian Turonian successions into an integrated, interbasinal stratigraphic framework, as established, e.g., in northwest Germany. On the basis of the section in the Úpohlavý working quarry in northwest Bohemia (Fig. 1), an integrated stratigraphic framework (bio, event and sequence stratigraphy, stable isotopes) for part of the Upper Turonian are developed herein, which will serve to link this section to existing high resolution stratigraphic frameworks.

## 2. Historic account

The first detailed investigation, including the first lithostratigraphical classification of the Cretaceous

strata in northwest Bohemia was given by Reuss (1844, 1845–1846, 1854). He divided the successions into an “Unterer” (lower) and “Oberer” (upper) Quadersandstein and the “Plänerschichten” (Pläner Beds). The latter were further subdivided into a “Plänerkalk” (Pläner Limestones) and a “Plänermergel” (Pläner Marls) member. From these “Plänerschichten” in particular, about 750 micro- and macrofaunal species were described and stratigraphically interpreted by Reuss (1845–1846) in his large monograph. This early stratigraphic subdivision was modified by Rominger (1847). Later, a more refined lithostratigraphic subdivision into several units with the character of formations was established (Krejčí, 1867, 1869; Frič, 1889; Fig. 2). Based on this subdivision, Zahálka (1900a,b) introduced a hierarchical lithostratigraphic classification using Roman numbers for the Cretaceous successions in the vicinity of Úpohlavý. A more recent formal lithostratigraphy of the Bohemian Cretaceous Basin (Čech et al., 1980) follows the classification of Krejčí (1867, 1869).

## 3. Regional geology, lithology and fauna

The Turonian strata in the vicinity of Úpohlavý are tectonically located in the SW–NE-trending Ohře Graben in northern Bohemia. Due to the intensive fragmentation and complicated tectonic setting with overturning, local lithostratigraphic subdivisions and correlation of the, in part, lithologically monotonous strata were often doubtful in the past (Reuss, 1844, 1845–1846, 1854; Zahálka, 1900a,b). The present state of knowledge, based on mapping and borehole analyses, is given by Macák and Müller (1965, 1966, 1968), Krutský et al. (1975) and Váně (1979).

The Úpohlavý working quarry was opened in 1974 for cement production (Krutský, 1966, 1980, 1985, 1989). The exposed strata dip at ca. 1° towards the northwest and form the uppermost part of the Jizera Formation (Zahálka’s Bed IX) and lower part of the Teplice Formation (Zahálka’s Bed X; Fig. 2). The first lithological description was given by Čech et al. (1996). The succession investigated reaches a thickness of ca. 27 m and consists of marls, fossiliferous clayey limestones and marl/limestone alternations. The CaCO<sub>3</sub> content varies between 50 and 85%. The boundary between the Jizera Formation and the Teplice Formation is traditionally taken at the Coprolite Bed (Zahálka, 1900a). In the Úpohlavý area, however, two Coprolite beds (Lower and Upper) were recognized (Čech et al., 1996). Here, the Lower Coprolite Bed defines the base of the Teplice Formation (base Member Xa; Bed 2 in Fig. 2). Based on Zahálka (1900a,b) with further subdivisions of Váně (1976, 1979, 1999; Váně in Krutský et al., 1975), an informal regional

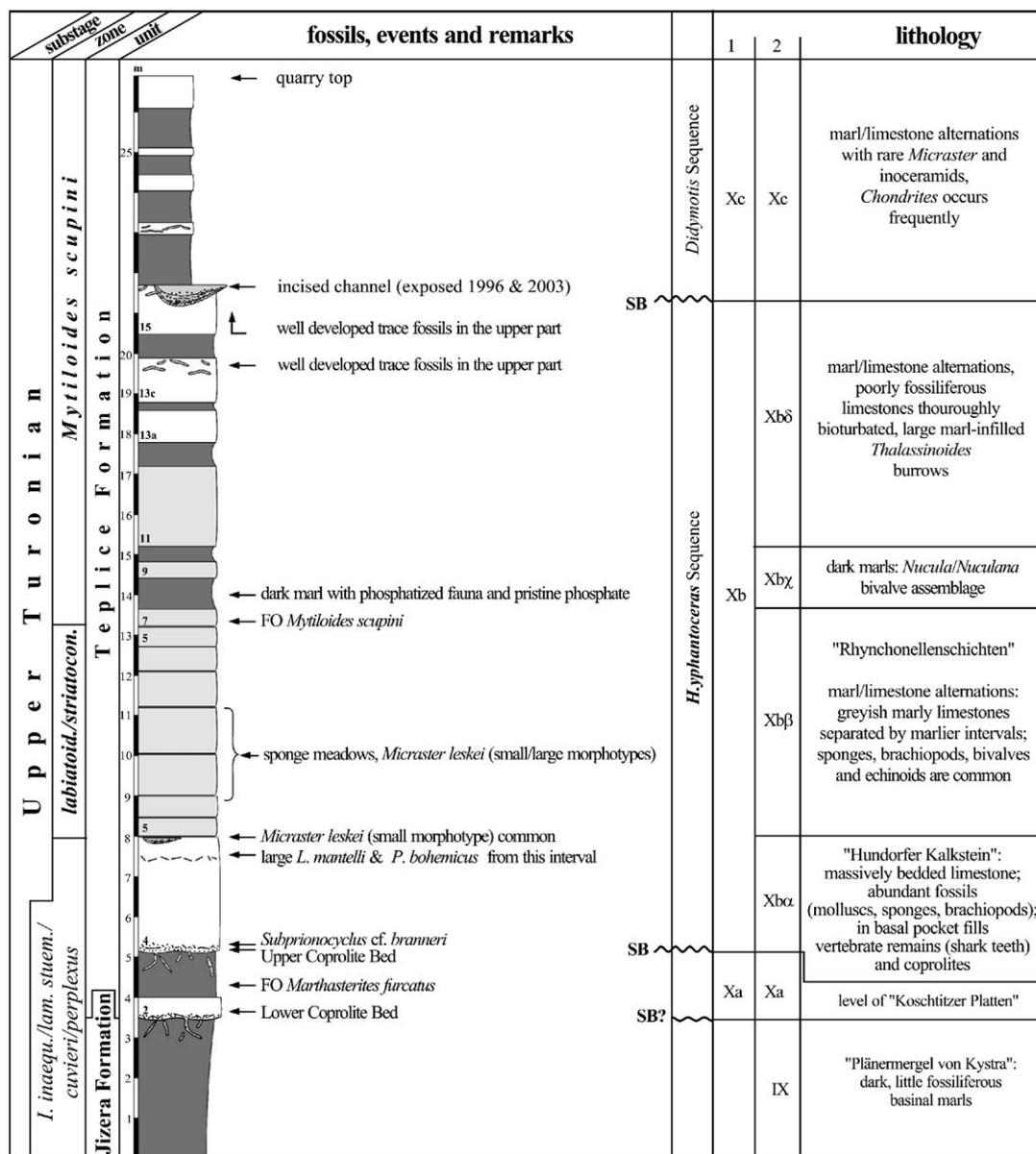


Fig. 2. Section of the upper Jizera and lower Teplice formations as exposed in the Úpohlavý working quarry. 1, Zahálka Beds (Zahálka, 1900a,b); 2, refined lithostratigraphic subdivision of Váně in Krutský et al. (1975). For sequence stratigraphic subdivision compare Fig. 8. Abbreviations in the figure: *labiatoid.*, *I. labiatoidiformis*; *striatocon.*, *I. striatoconcentricus*; *inaequ.*, *I. inaequivalvis*; *lam. stuem.*, *I. lamarcki stuemckei*.

lithostratigraphic subdivision of the exposed part of the Jizera and Teplice formations into four lithological units with some members is possible (IX, Xa, Xb<sub>α</sub>, Xb<sub>β</sub>, Xb<sub>γ</sub>, Xc; Fig. 2).

### 3.1. Lithounit IX (Bed 1)

The exposed part of lithounit IX (ca. 300 cm) represents the upper part of the Jizera Formation (“Plänmergel von Kystra” sensu Frič, 1889). It consists of dark, monotonous and poorly fossiliferous marls containing *Terebratulina lata* (R. Etheridge) and small *Pycnodonte*. No further description is required.

### 3.2. Lithounit Xa (bed 2–3)

**Lithology/microfacies.** The Lower Coprolite beds (20–30 cm) marks the base of Xa, which is also the basal boundary of the Teplice Formation. It is a glauconitic, bioclastic wackestone with an undulating base, suggesting erosive contact. Mm-sized quartz grains and partly large (bored) phosphatized clasts are common. It grades progressively into dark marls (Bed 2) which is accompanied by a gradual decrease in CaCO<sub>3</sub> content (Čech et al., 1996).

**Macrofauna (Fig. 3).** The base of Xa, the Lower Coprolite Bed (Bed 2), has a sharp and erosive base, which is accentuated by skeletal debris/siliciclastic

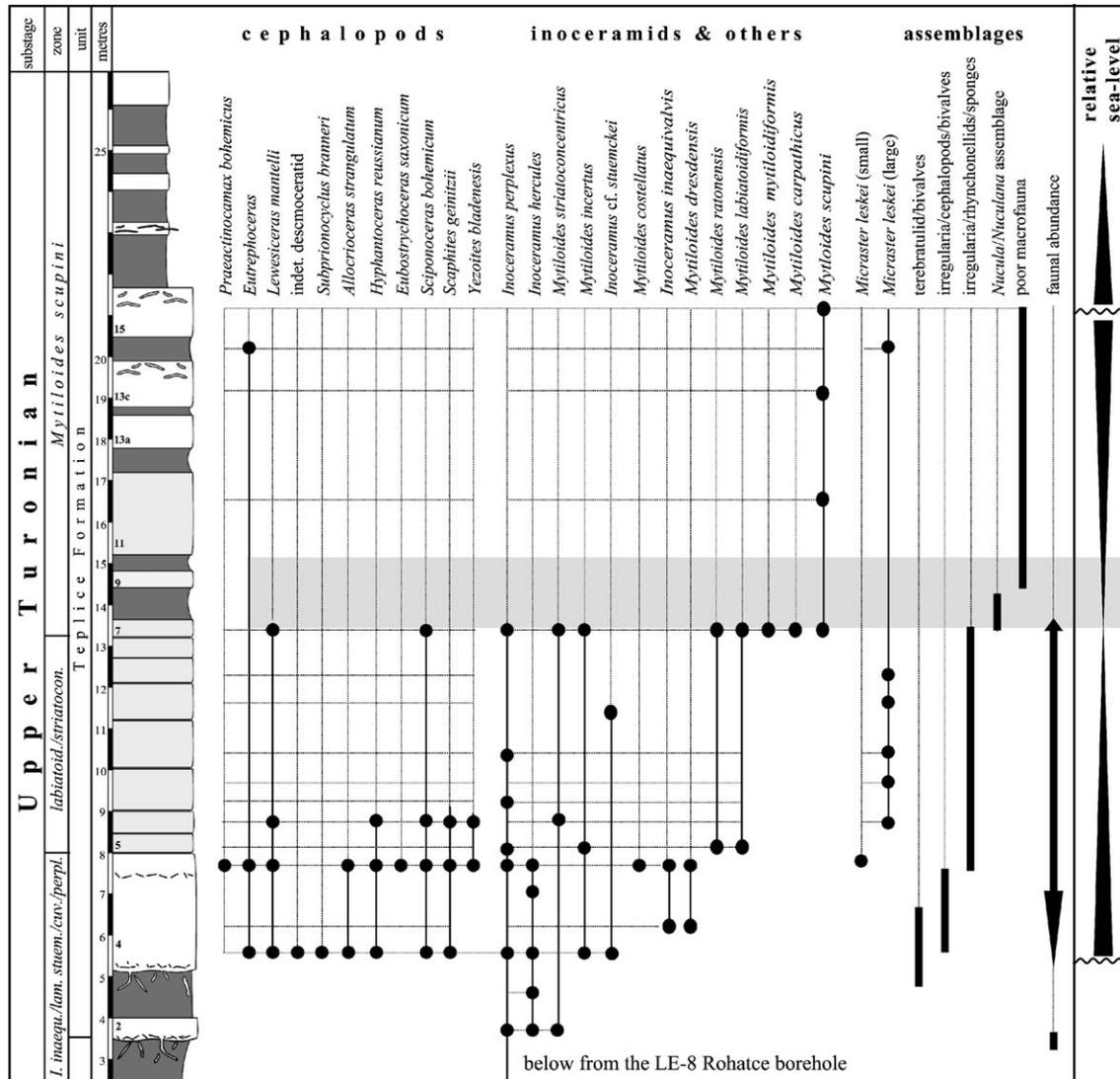
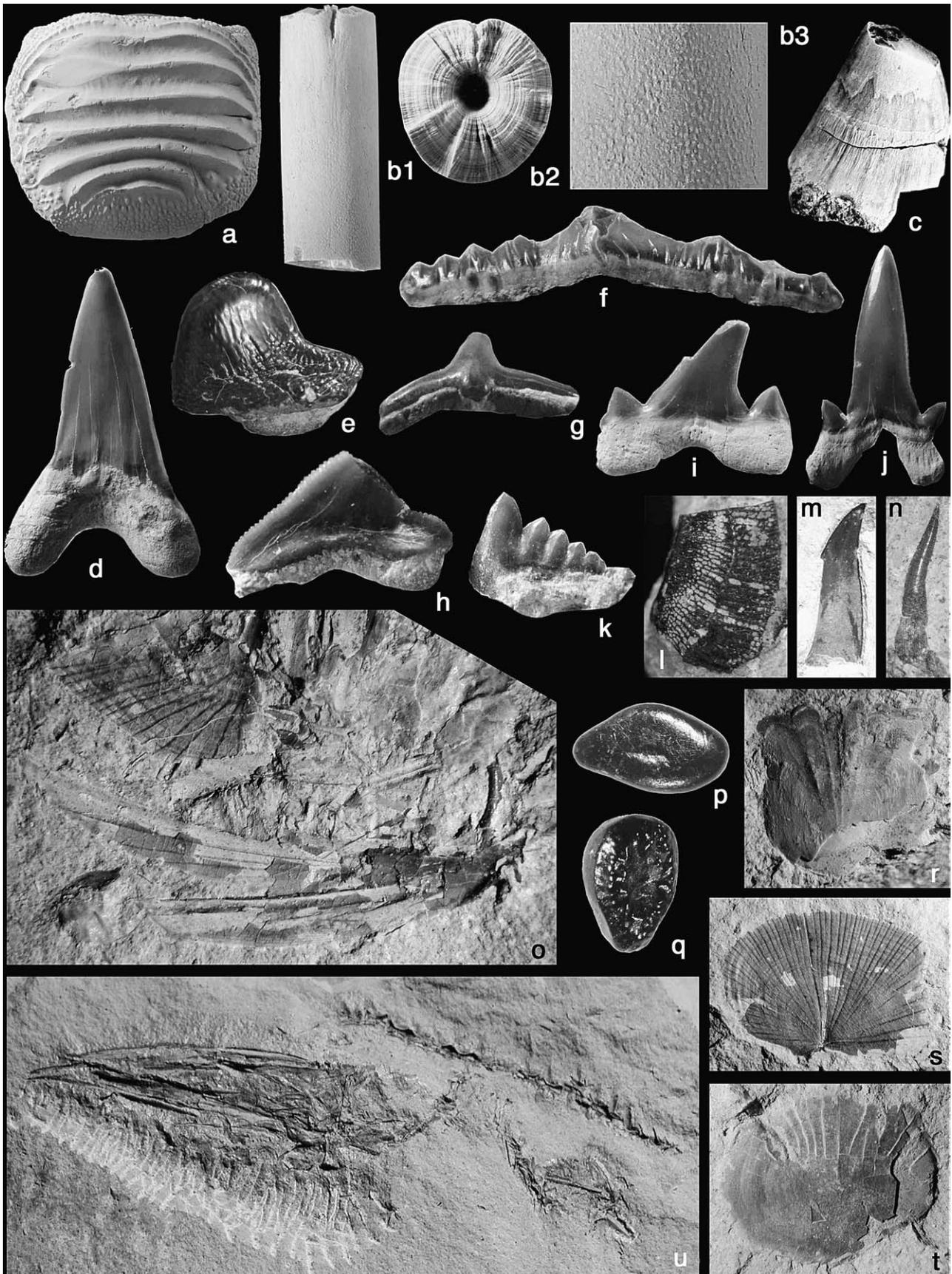


Fig. 3. Vertical ranges of selected macroinvertebrate groups and macrofaunal assemblages. Shaded interval: maximum flooding zone of the *Hyphantoceras* Sequence; compare Fig. 8.

infilled *Thalassinoides* burrows that pipe deeply down from Xa into the underlying Jizera Formation. Unit Xa itself is thoroughly bioturbated, although in the marlier intervals traces are less distinct due to compaction. The Lower Coprolite Bed is rich in fossil debris, notably common, very large *Inoceramus hercules* Heinz (Fig. 5d)

at the base of the bed. Phosphatized vertebrate remains and coprolites are enriched in pocket-like concentrations. Among fish, hybodont [*Hybodus cristatus* (Reuss) *Ptychodus mammillaris* Agassiz, *P. latissimus* Agassiz (Fig. 4a)] and lamniform sharks [*Isurus (Cretoxyrhina) mantelli* (Agassiz) (Fig. 4d), *Cretolamna subulata*

Fig. 4. (Abbreviations: NMP, National Museum, Prague). a, *Ptychodus latissimus* Agassiz; anterolateral tooth, occlusal view, PG Uy 1999/1 (CIGP), base Bed 4 ( $\times 2$ ). b, *Praeactinocamax bohemicus*, PG Uy 2002/1 (CIGP). b1, ventral view ( $\times 2$ ); b2, alveolar end ( $\times 3$ ); b3, detail of the granulated surface ( $\times 5$ ); upper part Bed 4. c, mosasaurid tooth, crown of the tooth, lateral view (private collection of Mr. J. Valiček); base Bed 4 ( $\times 3.5$ ). d, *Isurus (Cretoxyrhina) mantelli* (Agassiz), anterior tooth, lingual view (private collection of Mr. J. Valiček), base Bed 4 ( $\times 1.6$ ). e, *Ptychodus mammillaris* Agassiz, anterolateral tooth, lateral view (private collection of Mr. J. Valiček), base of Bed 4 ( $\times 3.6$ ). f, *Polyacrodus polydictios* (Reuss), lateral tooth, labial view (private collection of Mr. J. Valiček), base Bed 4 ( $\times 3$ ). g, *Squatina lobata* Reuss, lateral tooth, labial view (private collection of Mr. J. Valiček), base Bed 4 (ca.  $\times 6.5$ ). h, *Squalicorax heterodon* (Reuss), lateral tooth, lingual view (private collection of Mr. J. Valiček), base Bed 4 ( $\times 4.5$ ). i, *Cretodus simplicatus* (Münster in Agassiz), lateral tooth, lingual view (private collection of Mr. J. Valiček), base Bed 4 (ca.  $\times 2.2$ ). j, *Cretolamna subulata* (Agassiz), anterior tooth, lingual view (private collection of Mr. J. Valiček), base Bed 4 ( $2\times$ ). k, *Hexanchus (Notidanus)* sp., lateral tooth, lingual view (private collection of Mr. J. Valiček), base Bed 4 (ca.  $\times 7.5$ ). l, *Heterodontus (Gomphodus) agassizi* (Reuss), anterolateral tooth, occlusal view (private collection of Mr. J. Valiček), base Bed 4 (ca.  $\times 5$ ). m, *Cymolichthys* sp. (NMP Be-26), base Bed 4 (ca.  $\times 4$ ). n, *Enchodus* sp. (NMP Oc-465), upper part Bed 4 ( $\times 6.3$ ). o, *Enchodus* sp. (NMP Oc-469), upper part Bed 4 ( $\times 9.5$ ). p, pycnodont teeth (NMP Oc-464), base Bed 4 ( $\times 3.5$ ). q, pycnodont teeth (NMP Oc-463), base Bed 4 ( $\times 6.5$ ). r, *Osmeroides* sp. (NMP Oc-467), base Bed 4 ( $\times 3.8$ ). s, *Enchodus* sp. (NMP Oc-466), base Bed 4 ( $\times 3.2$ ). t, Ichthyodectiformes (NMP Oc-472), base Bed 4 ( $\times 5.4$ ). u, *Dercetis* cf. *elongatus* Agassiz (NMP Oc-452), base channel fill Bed 15 ( $\times 1.2$ ).



(Agassiz) (Fig. 4j), *C. acuminata* (Agassiz) *Squalicorax heterodon* (Reuss) (Fig. 4h), *S. appendiculatus* (Reuss)] are frequent. Small, unidentifiable fish remains occur in the coprolites. Inoceramids are very rare [*Inoceramus perplexus* Whitfield, *I. hercules* (Fig. 5f), *Mytiloides striatoconcentricus* (Gümbel) (Fig. 5g)]. The overall macrofossil content decreases in the upper, marly part of Xa (our Bed 3), but this interval is the lithostratigraphic position of the famous “Koschtitzer Platten” (Frič, 1889; Váně, 1945), patchy limestone plates with accumulations of siliciclastics and a high diversity micro- and mesofauna, in which disarticulated *Terebratulina lata* and small ostreids are numerous. The *Rusophycus*-like trace *Achilleum* also occurs. The preservation of this presumed cubichnion is due to a sudden infilling of a concave epirelief with coarse bioclastics, and is mostly associated with erosional truncation of the uppermost parts of the structure: small eroded structures are a concave, biscuit-like shape (*Achilleum bisquittiforme* Frič; Frič, 1889, p. 109, fig. 154); stronger truncation resulted in the preservation of the deeper parts of the trace, generating small *Rusophycus*-like structures (*Achilleum rugosum* Reuss; Frič, 1889, p. 108, fig. 153) in the deepest part of the trace. Although winnowing can result in debris accumulation, this mechanism cannot explain the sudden infilling of a concave epirelief. Therefore, a tempestitic origin for this preservation is inferred.

### 3.3. Lithounit Xb ( $Xb_{\alpha}$ , $Xb_{\beta}$ , $Xb_{\chi}$ , beds 4–15)

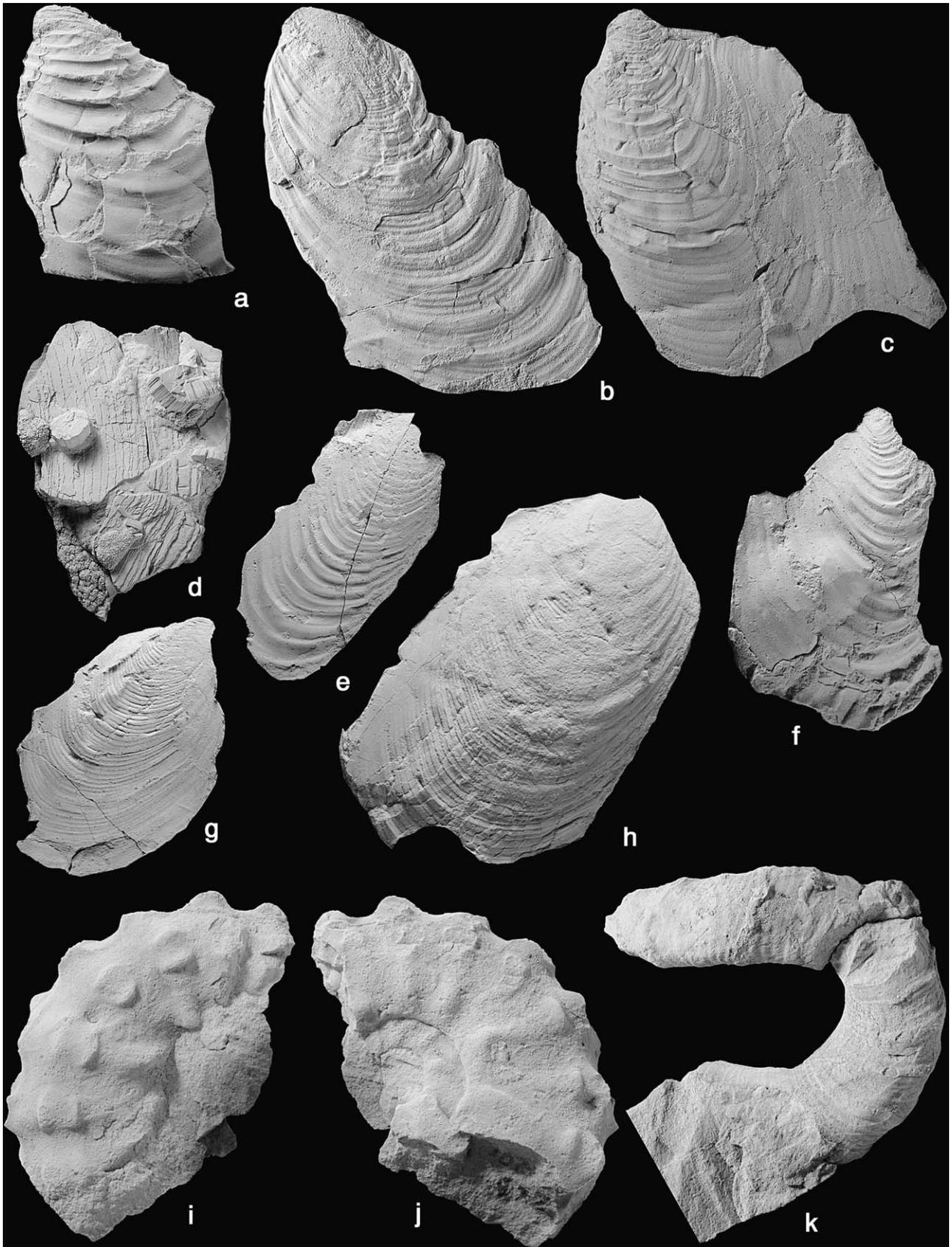
*Lithology/microfacies*  $Xb_{\alpha}$  (Bed 4; “Hundorfer Kalkstein” sensu Frič, 1889). The base of this unit is taken at the base of the Upper Coprolite bed, which is developed, like that of the Lower Coprolite Bed, with an undulating erosive base. It is also the base of Xb sensu Zahálka (Fig. 2). Data from regional prospecting drilling (Krutský, 1989) show that the erosional base cuts down 3–7 m into the underlying Bed Xa and Lithounit IX.  $Xb_{\alpha}$  reaches a thickness of 250–280 cm and corresponds to the “Hundorfer Kalkstein” (Limestone of Hundorf) of Frič (1889). It is an important lithostratigraphic marker for regional correlation within the Ohře Graben area (Fig. 1) and marks a significant and sudden increase in  $\text{CaCO}_3$  content (Krutský et al., 1975; Čech et al., 1996) that is mappable throughout the Bohemian Cretaceous Basin in both exposures and borehole logs;

it thus represents an important lithoevent for intra-basinal correlation.

The base of  $Xb_{\alpha}$  is an erosional surface. The overlying bed is a glauconitic, bioclastic wackestone that consists mainly of calcareous dinoflagellate cysts (c-dinocysts), globigerinoid planktonic foraminifera and inoceramid bioclasts. Debris of brachiopods, bryozoans, echinoderms, ostracods and benthic foraminifera (*Lenticulina*) are common. The base of the bed is marked by a concentration of coarse siliciclastics, phosphatized pebbles and fossil debris that partially fills vertical *Thalassinoides* shafts extending down some tens of centimetres into Xa. Up-section, the glauconite and quartz content decrease significantly and massively bedded limestones (bioclastic wackestones) with weak marl seams are developed. The grain size also decreases significantly, and the microfacies is dominated by a comparatively well-sorted bioclastic wackestone with some very fine-grained siliciclastics. Due to the lack of coarse bioclastics and c-dinocysts, the sediment is relatively enriched in fragments of planktonic foraminifera, ostracods and fine, very thin-shelled filaments (presumably referable to ostracods). Glauconite is rare. “Koschtitzer Platten”-like scours, infilled with a rich meso- and microfauna, occur scattered throughout Bed 4, and sharply based lenses (10–30 cm thick) were recently exposed at the top of the bed.

*Macrofauna*  $Xb_{\alpha}$ . In the Upper Coprolite Bed, vertebrate remains are very common. Amongst fish, teeth of pycnodonts (aff. *Anomoedus*, aff. *Coelodus*, aff. *Gyrodon*; Fig. 4p, q) and scarce scales and bones of teleosts occur. The shark fauna is even richer than that of the Lower Coprolite Bed: teeth of hybodont [*Hybodus cristatus*, *Acrodus* sp., *Acrodus affinis*, *Polyacrodus polydictios* (Fig. 4f), *Ptychodus mammillaris* (Fig. 4e), *P. latissimus*, *Ptychodus* sp.], hexanchiform [*Hexanchus* sp. (Fig. 4k), *Hexanchus (Notidanus) simplex* (Agassiz)], squatiniform (*Squatina lobata* Reuss; Fig. 4g), heterodontiform [*Heterodontus (Gomphodus) agassizi* (Reuss); Fig. 4l] and lamniform sharks [*Cretolamna subulata*, *C. acuminata*, *Cretodus semiplicatus* (Münster in Agassiz) (Fig. 4i), *Isurus (Cretoxyrhina) mantelli*, *Paranomotodon angustidens* (Reuss), *Scapanorhynchus raphiodon* (Agassiz), *Squalicorax heterodon*, *S. kaupii* (Agassiz) and *S. appendiculatus*] are frequent. Marine reptile remains (e.g., mosasaurids; Fig. 4c) are exclusively derived from the Upper Coprolite Bed (Bed 4). They consist of several

Fig. 5. (Abbreviations: CGS, Czech Geological Survey, Prague; CIGP, Institute of Geology and Palaeontology, Charles University, Prague). a, *Mytiloides scupini* (Heinz), coll. CGS (SC 1), Bed 8 ( $\times 1.3$ ). b, *Mytiloides mytiloidiformis* (Tröger), coll. CGS (SC 2), 0.4 m below top Bed 7 ( $\times 1$ ). c, *Mytiloides ratonensis* Walaszczyk and Cobban, coll. CGS (SC 3), Bed 6 ( $\times 1.3$ ). d, *Inoceramus hercules* Heinz, coll. CGS (SC 4), Bed 3 ( $\times 0.5$ ). e, *Mytiloides labiatoidiformis* (Tröger), coll. CGS (SC 5), Bed 7 ( $\times 1$ ). f, *Inoceramus perplexus* Whitfield, coll. CGS (SC 6), top Bed 4 ( $\times 1$ ). g, *Mytiloides striatoconcentricus* (Gümbel), coll. CGS (SC 10), Bed 5 ( $\times 0.9$ ). h, *Mytiloides incertus* (Jimbo), coll. CGS (SC 11), Bed 6 ( $\times 1$ ). i, j, *Subprionocyclus* cf. *branneri*, coll. CIGP (PG Uy 2000/A1), base Bed 4 ( $\times 1$ ). k, *Hyphantoceras reussianum*, coll. CIGP (PG Uy 2000/A2), base Bed 4 ( $\times 0.7$ ). All specimens coated with ammonium chloride.



strongly altered and thus imprecisely identified plesiosaurid and mosasaurid bones and teeth (Ekrt et al., 2001). Amongst invertebrates, inoceramids are common (see Section 4.3), and fragments of very large *I. hercules* in the form of broken, thick prismatic shell layers are frequent. These commonly show bioerosion by the boring sponge *Cliona*, expressed by the ichnogenus *Entobia*. Nautiloids [*Eutrephoceras* and rare *Deltocymatoceras*], ammonites [indet. desmoceratid, *Lewesiceras mantelli* Wright and Wright, *Subprionocyclus* cf. *branneri* (Anderson) (Fig. 5i, j), *Hyphantoceras reussianum* (d'Orbigny) (Fig. 5k), *Scaphites geinitzi* (d'Orbigny)], aptychii, and gastropods (*Bathrotomaria*) are common. Scaphopods are rare. The bivalve assemblage, comparatively rich in species and abundance [e.g., *Cardita tenuicostata* Sowerby, *Gryphaeostrea canaliculata* (J. Sowerby), *Plagiostoma hoperi* (Mantell), *Pycnodote canaliculata*, *Septifer lineatus* J. de C. Sowerby, *Spondylus spinosus* (J. Sowerby), *Lopha semiplana* (J. Sowerby), *Arca*], is a typical shelf assemblage consisting of endo- and epibenthic deposit- and suspension-feeding taxa. Valves of endobenthic taxa frequently exhibit *Oichnus*, here interpreted to result from endobenthic predating naticid gastropods. Brachiopods are represented by abundant *Terebratulina lata* and large *Gibbithyris semiglobosa* (J. Sowerby) (terebratulid/bivalve assemblage; Fig. 3). In the main body and uppermost part of Bed 4, terebratulids decrease significantly in numbers. Irregular echinoids [*Micraster leskei* Desmoulins, scattered debris of *Plesiocorys plana* (Mantell)] and ammonites [the same taxa as in the underlying beds, plus *Allocrioceras strangulatum* Wright, *Eubostrychoceras saxonicum* (Schlüter), and *Yezoites bladenensis* (Schlüter)] become more important, as do badly preserved hexactinellid sponges (irregularia/cephalopod/bivalve assemblage). Very large *L. mantelli* occur commonly in this interval here, and also in neighbouring localities (Frič, 1889; Houša, 1967). Two rostra of the belemnite *Praeactinocamax bohemicus* (Stolley) (Fig. 4b) were collected from the top of the main limestone body (Bed 4). Fragments of cirripedes are less frequent. Limonitized sponge remains, referable to *Ventriculites* and *Leptophragma*, occur scattered throughout the interval. Echinoderms are represented by rare fragments of the irregular echinoids *Micraster leskei* and *Plesiocorys plana*.

*Lithology/microfacies Xbβ*: (beds 5–7; “*Rhynchonellen-schichten*” sensu Frič, 1889). With Xbβ (beds 5–7; ca. 550 cm) the lithology changes markedly, and a marly, brittle and grey-weathering marl/limestone alternation develops. The amount of bioclasts decreases, as do c-dinocysts and planktonic foraminifera, indicative of a decreased CaCO<sub>3</sub> bioproductivity resulting in a relative enrichment of fine-grained siliciclastics. Towards the top of the unit, marls become more conspicuous and darker, while the CaCO<sub>3</sub> content in the limestone beds decreases progressively.

*Macrofauna Xbβ* (Fig. 3). The base of Xbβ marks a significant change in the macroinvertebrate assemblage. There is a sudden shift from a terebratulid (*Gibbithyris semiglobosa*) towards a diverse rhynchonellid brachiopod assemblage [*Cretirhynchia minor* Pettitt, *C. cuneiformis* Pettitt, *Orbirhynchia reedensis* (R. Etheridge)]. The associated faunal elements consist of hexactinellid sponges that form meadow-like accumulations [e.g., *Camerospongia fungiformis* (Goldfuss), *Tremabolites megastoma* (Roemer), *Ventriculites*] and large *Micraster leskei* (rhynchonellid/sponges/irregularia assemblage in Fig. 3). Large *Ventriculites* with well-developed and extensively branching roots indicate both decreased current activity and soup/softground conditions. The rich bivalve fauna from Bed 4 is rapidly replaced by an epifaunal assemblage dominated by abundant inoceramids (see Section 4.3) and soft-bottom reclining ostreids (*Gryphaeostrea canaliculata*). A single specimen of *Scapanorhynchus subulatus* was collected from Bed 5.

*Lithology/microfacies Xbγ* (beds 8–10). beds 8–10 consist of a single limestone bed sandwiched between two thick marls. The limestone appears to be no different lithologically from those of the underlying Bed 7; however, the overall CaCO<sub>3</sub> content has further decreased, resulting in a marly limestone. Lithologically, no differences from Bed 7 can be observed in the limestones; however, the overall CaCO<sub>3</sub> content has further decreased, resulting in a marly limestone. In the marls, pristine phosphate growth, phosphatized burrows and fossils (see below) are characteristically enriched.

*Macrofauna Xbγ* (Fig. 3). With Xbγ, macrofaunal diversity and abundance decreases abruptly and significantly (e.g., the sudden disappearance of rhynchonellids). The only common elements are small, in part bivalved, pyritized and phosphatized steinkerns of the endobenthic, sediment-feeding *Nucula/Nuculana* group (*Nucula/Nuculana* Assemblage) and unidentifiable gastropods. Remains of vertebrates (fishes) and sponges are not uncommon; isolated remains of *Osmeroides* (Fig. 4r), *Dercetis*, *Enchodus* (Fig. 4n, o, s), *Cymolichthys* (Fig. 4m), *Hoplopteryx* and ichthyodectiformes are derived from Bed 8.

*Lithology/microfacies Xbδ* (beds 11–15). With Xbδ (ca. 620 cm), a marl/limestone alternation develops, and the overall CaCO<sub>3</sub> content increases again. This corresponds to an increase in planktonic foraminifera, c-dinocysts and other skeletal debris (ostracods, filaments, rare inoceramids), as well as progressively to a more calcareous matrix. Towards the top of the unit, glauconite grains reappear, and the limestone can be slightly silicified. A large channel fill, cutting erosionally from Bed 15 into underlying sediments, was exposed in

1996 in the western part of the quarry, but this area is now backfilled and the channel is no longer visible (Uličný in Čech et al., 1996). Recently, a further (or parts of the same?) channel has been discovered in this interval. The channels are filled with coarse-grained bioclastic and siliciclastic sediments (quartz pebbles up to 2 cm); phosphatized pebbles and fossil fragments, as well as numerous vertebrate remains, are concentrated at the base (Čech et al., 1996).

*Macrofauna Xbδ* (Fig. 3). Although the limestones are more calcareous and resemble lithologically those at the top of Bed 4, the macrofauna remains extremely poor. No endobenthic bivalves occur, and only scattered *Spondylus spinosus*, *Micraster leskei* and sponges can be found. Inoceramids reappear but are represented only by *Mytiloides scupini* (Heinz) (beds 14 and 15; Fig. 5a). A single specimen of *Lewesiceras mantelli* was collected from Bed 13a and aptychii occur in Bed 15, as do remains of *Osmeroides*, *Dercetis*, *Enchodus* and undetermined ichthyolites. Brachiopods are represented by large *G. semiglobosa*. The tops of beds 13c and 15 are deeply burrowed by well-preserved, albeit compacted, *Thalassinoides* burrows. *Chondrites* and *Planolites* are well developed in the limestone bodies and are rendered conspicuous due to the strong colour contrast between the yellowish-grey limestones and the dark burrows. The observed ichnofauna assemblage is typical for Cretaceous pelagic carbonates (Ekdale and Bromley, 1991; Kedzierski and Uchmann, 2001). From the base of the channel fill (Fig. 2) an incomplete but articulated skeleton of *Dercetis* cf. *elongatus* (Fig. 4u) was collected.

### 3.4. Lithounit Xc (beds 16–23)

*Lithology/microfacies*. The base of lithounit Xc (ca. 600 cm) marks a sharp facies change towards marl-dominated and widely spaced marl/limestone alternations. Base and top show gradual bed contacts.

*Macrofauna* (Fig. 3). The exposed interval of Xc yields only a poor macrofauna, of which small *Nucula/Nuculana* and *Micraster leskei* are the most common taxa. Rare ex situ finds of advanced *Micraster* ex. gr. *praecursor* Rowe/*normanniae* Bucaille may derive from here. From the cored borehole Le-6 Sedlec, only 3 km west of Úpohlavý, a single *Prionocyclus germari* (Reuss) was collected from the base of the unit. In the marlstones, *Chondrites* is dominant.

## 4. Biostratigraphy

The biostratigraphic subdivision of the Bohemian Cretaceous suffered traditionally from the application of

the lithostratigraphic framework as biostratigraphically isochronous units, and most early stratigraphers did not strictly separate both litho and biostratigraphic concepts (see comments in Čech et al., 1980; Uličný, 2001). Recent biostratigraphic subdivisions of the Turonian and Coniacian in the Ohře area have mainly been presented by Čech (1989) and Čech and Švábenická (1992), who have shown the diachroneity of the formations in the Bohemian Cretaceous Basin. The first stratigraphic data for the Úpohlavý section were given by Čech et al. (1996), supplemented by Ekrt et al. (2001). Based on a literature review and new collecting, the Úpohlavý succession can be placed within the inoceramid bivalve zonal scheme that is applicable throughout northern Europe.

As the biostratigraphically relevant taxa of the Úpohlavý fauna are, to a large extent, identical to those from northwest Germany (Westphalia, Lower Saxony, Saxony-Anhalt) and Poland (Opole Basin), a high resolution stratigraphy and interbasinal correlation into the stratigraphically detailed northwest German framework (cf. Fig. 6) is attempted here.

### 4.1. Ammonites

The interval from Bed 1 to Bed 3 is an ammonite-barren interval. A poorly preserved ammonite fauna was collected approximately 20 cm above the Upper Coprolite Bed, in the lower part of Bed 4. The assemblage consists of *Lewesiceras mantelli*, *Hyphantoceras reussianum*, *Scaphites geinitzi* (common), *Allocioceras* and *Sciponoceras* sp. In addition, a specimen similar to that referred to *Jimboiceras planulatiforme* (Jimbo) by Wright and Kaplan (1988) was collected. Of stratigraphic significance is a single find of *Subprionocyclus* cf. *branneri*. Ammonites become more common in the interval from the upper part of Bed 4 to the lower part of Bed 5. *S. geinitzi* is by far the most abundant species. *Lewesiceras mantelli*, *Hyphantoceras reussianum*, *Eubostrychoceras saxonicum* and fragments of undetermined baculitids also occur. *Allocioceras strangulatum* is represented by two specimens only. The body-chamber of an ex situ, large *Lewesiceras* (diameter 70 cm) derived from the lower part of Bed 5 contained *H. reussianum*, *S. geinitzi*, *Yezoites bladenensis* and badly preserved baculitids. Above the base of Bed 5, the ammonite content decreases significantly and only rare fragments of *S. geinitzi* and *Lewesiceras mantelli* occur. Of stratigraphic importance is a find of *Prionocyclus germari* from an interval equating approximately with Bed 17 (lithounit Xc), collected from the cored borehole Le-6 Sedlec, only 3 km west of Úpohlavý.

*Discussion*. The ammonite assemblage of beds 4 and 5 is indicative of the so-called “*reussianum* Fauna” (named after the nostoceratid ammonite *Hyphantoceras*

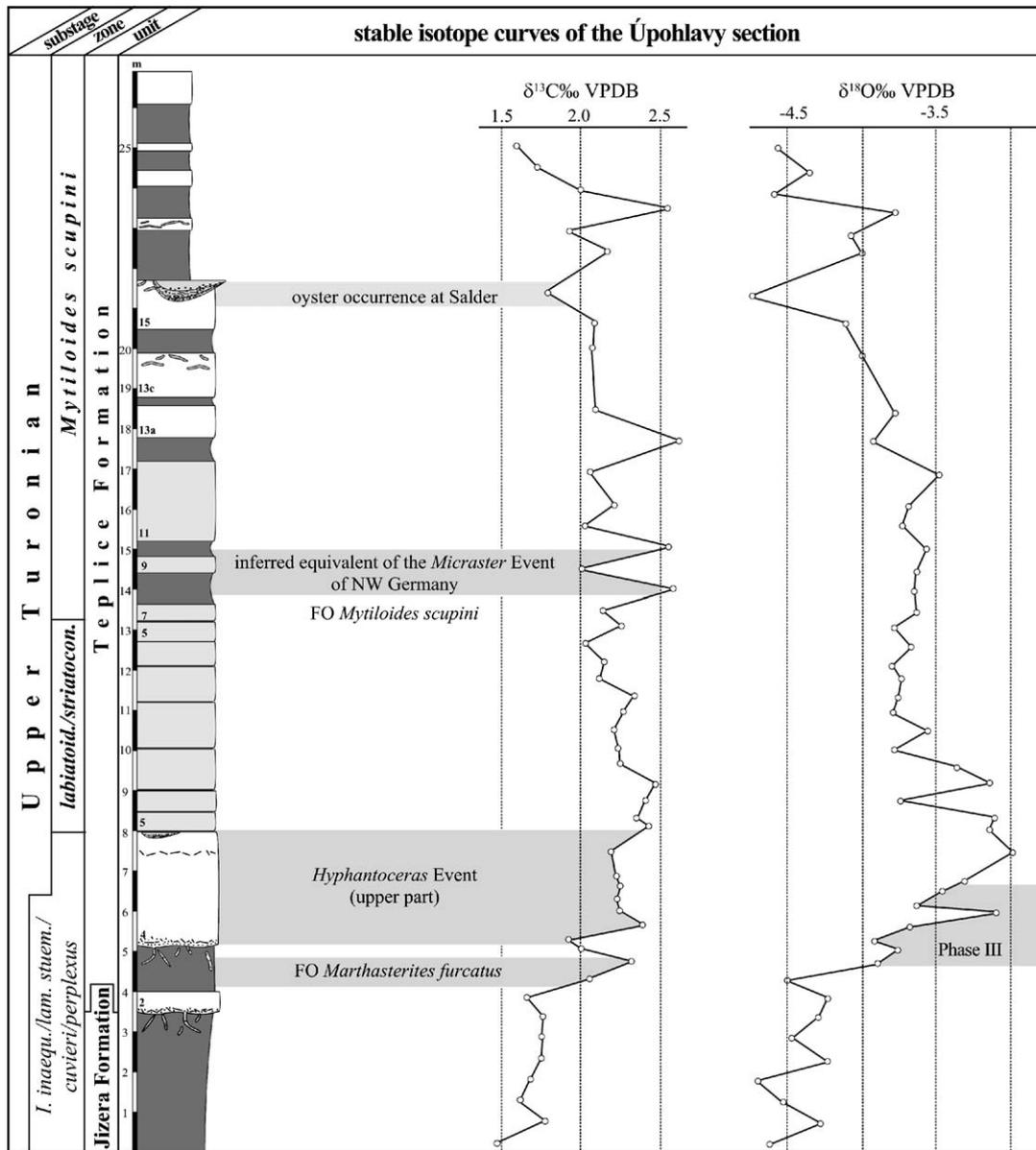


Fig. 6. Stable isotope curves ( $\delta^{13}\text{C}$ ,  $\delta^{18}\text{O}$ ) for the Upper Turonian section of the Úpohlavý working quarry. Shaded intervals  $\delta^{13}\text{C}$  curve: litho- and biomarker, in part inferred from interbasinal comparison with Salzgitter-Salder, northwestern Germany (Fig. 1). Shaded interval  $\delta^{18}\text{O}$ : Upper Turonian cooling Phase 3 of Voigt and Wiese (2000).

*reussianum*), which is known in comparable faunal composition from England, parts of France, Germany, Poland and, to some extent, Kazakhstan (e.g., Roman and Mazarán, 1913; Seifert, 1955; Tröger and Wolf, 1960; Wright, 1979; Dahmer and Ernst, 1986; Kaplan, 1986; Tarkowski, 1991; Metzendorf, 1992; Juignet and Breton, 1994; Marcinowski et al., 1996). This fauna falls into the upper part of the *Subprionocyclus neptuni* ammonite Zone, or into the uppermost part of the *perplexus/lamarcki stuemckei/inaequivalvis* inoceramid Assemblage Zone (see below). The *Hyphantoceras* Event is characterized by a succession of distinct ammonite assemblages (Kaplan, 1991; Kaplan and Kennedy, 1996), in ascending order: a lower collignoniceratid,

a middle nostoceratid and a succeeding desmoceratid assemblage. Based on the lateral distribution of ammonite morphotypes in the Münsterland Cretaceous Basin (allocrioceratid/collignoniceratid: proximal; nostoceratid: intermediate; desmoceratid: distal), this sequence of assemblages can be interpreted to reflect an overall transgressive development. Although not developed as the idealized sequence of assemblages figured by Kaplan and Kennedy (1996), the Úpohlavý fauna is characterized mainly by nostoceratids and scaphitids, with *Hyphantoceras* and *Scaphites* being the most common taxa. Very rare elements of the allocrioceratid/collignoniceratid assemblage occur: only two fragments of *Allocrioceras* and *Subprionocyclus* were collected.

The absence of an allocrioceratid/collignoniceratid assemblage in the Úpohlavý quarry may indicate that this assemblage is missing because of a hiatus, expressed here by the erosional contact of the Upper Coprolite Bed (base Bed 4) on the underlying marls. On the other hand, the distribution of the ammonite assemblages may also have been controlled by ecologic/palaeobiogeographic parameters that prevented the spread of allocrioceratids/collignoniceratids into the study area. In this context, it is interesting that, judging from ammonite material in the numerous collections visited by us (National Museum, Prague, and collections of Charles University and Czech Geological Survey, also Prague), taxa such as *Subprionocyclus neptuni* (Geinitz) and related species and *Allocrioceras* are rare throughout the entire Bohemian Cretaceous Basin. In neighbouring localities around Dresden (Dresden-Strehlen, Saxony, southeast Germany; Fig. 1), the same lithological change from marls to limestones can be observed (boundary between the marly Räcknitz Formation and the succeeding Strehlen Formation with its basal Strehlen Limestone). In this area, the allocrioceratid/collignoniceratid assemblage seems to be better developed, judging from numerous faunal lists (Seifert, 1955; Tröger and Wolf, 1960; Tröger, 1987) and the work of Geinitz (1872–1875).

It is difficult to estimate the extent of the stratigraphic hiatus between Xa and Xb. In Westphalia, the occurrence of *Subprionocyclus branneri* is stratigraphically restricted to the lower interval in the main *Hyphantoceras* Event (Kaplan and Kennedy, 1996); however, in Lower Saxony forms similar to *S. branneri* occur as high as the basal *scupini* Zone. The absence of the allocrioceratid/collignoniceratid assemblage may reflect ecologic or palaeobiogeographic factors instead of providing any stratigraphic signal. In this context, it is interesting to note that the distribution of allocrioceratids and collignoniceratids shows latitudinal limitations: these taxa decrease progressively towards the south (Wiese and Voigt, 2002) and play only a minor role in the intermediate faunas of northern Spain (Küchler, 1998). Thus, the palaeogeographic position of the Bohemian Cretaceous as a gateway from the Middle European shelf seas to the northern shelf of the Tethys may be responsible of these faunal characteristics.

The first occurrence (FO) of *P. germari* in the lowermost part of Xc marks the base of the terminal Turonian *Prionocyclus germari* ammonite Zone. This zone is well represented in the Bohemian Cretaceous Basin (Čech, 1989) and permits safe correlation with northwest Germany (Kaplan and Kennedy, 1996) and Spain (Küchler, 1998). The relationship between the European *germari* Zone and the Tunisian *germari* Zone (Robaszynski et al., 1990) is still unclear and is at the moment under investigation by one of us (Wiese).

According to Zahálka (1938), the FO of *Placentoceras d'obignyanum* is also located at the base of the Xc member in the nearby locality of Lenešice, making this taxon a possible additional marker for the basal *germari* Zone.

#### 4.2. *Belemnites*

Turonian belemnites are virtually absent from Central Europe and therefore cannot be used for biostratigraphic zonation. However, a belemnite incursion, presumably from the US Western Interior, reached Saxony and Bohemia in a stratigraphically narrow interval during deposition of the uppermost *Subprionocyclus neptuni*/lowermost *Mytiloides scupini* zones, expressed by scattered occurrences of *Praeactinocamax bohemicus* in the interval in question (Košťák and Wiese, 2002). In this context, two in situ finds of *P. bohemicus* (one with a well-preserved alveolar part, which permits precise specific determination; Fig. 4b) from the top of Bed 4 in the Úpohlavý working quarry are of great importance, since they constitute the first records of this taxon to have been accurately located stratigraphically for the last 100 years.

*Discussion.* The holotype of *P. bohemicus* comes from the upper *neptuni* Zone of Košice, Czech Republic. There are additional records from Nučnický near Lovosice and Vtelno near Mělník. Time-equivalent occurrences are several specimens from the Strehlen Limestone and one specimen from the Limestone of Weinböhla, an equivalent of the Strehlen Limestone (both Saxony, Germany), also from the *neptuni* Zone. Both limestones are stratigraphic equivalents of the upper part of the *Hyphantoceras* Event. Five specimens of *P. bohemicus* are recorded from the limestones of Hudcov (Hundorf) and Lahošť (Loosch) and one *P. aff. bohemicus* from Hudcov (Košťák, 1996) (both basal Teplice Formation). From the lower *germari* Zone of Lenešice near Louny comes one fragment of *P. bohemicus* and a pyritized alveolus, and a single find comes from Lány na Důlku near Pardubice. Although belemnites are rare, their repeated occurrence in the uppermost *neptuni*/lower *scupini* zones points to an immigration event of a stratigraphically limited duration. This immigration event can be seen in the context of an Upper Turonian cooling event and a shift of northern waters to the south (Voigt and Wiese, 2000).

#### 4.3. *Inoceramids*

At Úpohlavý, the uppermost Jizera Formation yielded no inoceramids; however, from the cored Le-8 Rohatce borehole nearby, a peak occurrence of *Inoceramus* ex gr. *perplexus* is located ca. 13 m below the Upper Coprolite Bed. One phosphatized steinkern of

*Inoceramus perplexus* together with fragments of *Inoceramus hercules* and *Mytiloides striatoconcentricus* was collected from the Lower Coprolite Bed at Úpohlavy. The succeeding marls (Bed 3) yielded only a poor inoceramid fauna. With Bed 4 (Xb $\alpha$ , “Hundurfer Kalkstein”), inoceramids become more numerous, and *I. perplexus*, *I. hercules*, *I. cf. stuemckei* Heinz, *I. inaequalis* Schlüter, *Mytiloides costellatus* (Woods) and *M. dresdensis* (Tröger) were collected. In the “Rhynchonellenschichten” (beds 5–7), *M. labiatoidiformis* (Tröger) (Fig. 5e), *M. ratonensis* Walaszczyk and Cobban (Fig. 5c), *M. incertus* (Jimbo) (Fig. 5h) and *M. striatoconcentricus* are common, with an acme of *M. mytiloidiformis* (Tröger) (Fig. 5b) and *M. carpathicus* (Simionescu) 0.4 m below the top of Bed 7 (Fig. 3). In Bed 7 (uppermost part of Xb $\beta$ ), *Mytiloides scupini* (Heinz) enters (see range chart, Fig. 3). Higher up-section, between beds 11 and 13, inoceramids become extremely rare.

**Discussion.** A refined inoceramid zonation for the uppermost part of the Jizera Formation is impossible due to the absence of inoceramids in the Úpohlavy section. However, the occurrence of a rich *perplexus* fauna (formerly referred to *I. costellatus*) some 13 m below the base of the Teplice Formation in the Rohatce borehole suggests that the Lower Coprolite Bed falls well into the Upper Turonian (Walaszczyk and Cobban, 2000). The assemblage from Bed 4 (Hundurfer Kalkstein) is indicative of the Upper Turonian *perplexus/lamarcki/stuemckei/inaequalis* Assemblage Zone as recognized in northern Germany (Wood et al., 1984). Furthermore, based on accurately horizoned collecting in northwest Germany, the FO of *Mytiloides incertus* ca. 10 cm above the base of the Upper Coprolite Bed suggests a position in the uppermost part of the assemblage zone, within or slightly above the stratigraphic equivalent of the *Hyphantoceras* Event (Keller, 1982). The different inoceramid assemblage from the “Rhynchonellenschichten” represents the middle Upper Turonian *M. labiatoidiformis/M. striatoconcentricus* Assemblage Zone (Ernst et al., 1983; Wood et al., 1984). The assemblages from the “Hundurfer Kalkstein” and “Rhynchonellenschichten” in Úpohlavy can be compared with those from the Strehlen (and Weinböhl) limestone of Saxony (Elbe valley in the vicinity of Dresden) (Tröger and Wolf, 1960; Tröger, 1969). The underlying Ränkitz Formation yielded *I. perplexus* (*I. costellatus* sensu Tröger and Wolf, 1960; *I. vancouverensis* sensu Tröger, 1967, 1969), indicating a stratigraphic equivalent of the Jizera Formation in the Ohře Graben. The stratigraphic level of the *costellatus/plana* Event of northwest Germany (lower Upper Turonian) therefore falls somewhere in the middle part of the Jizera Formation.

The FO of *Mytiloides scupini* in Bed 7 [formerly referred as *I. costellatus*, *I. frechi* (Flegel) or *I. kleini*

Müller by most Czech authors] defines the base of the *scupini* Zone. It represents an excellent marker for intra-basinal correlation within Europe, as it can be recognized, e.g., in Spain (Wiese and Wilmsen, 1999), Germany (Walaszczyk and Wood, 1999) and Poland (Walaszczyk and Cobban, 1998). The  $\delta^{13}\text{C}$  curves suggest that the FO of this taxon is virtually isochronous in an interbasinal context (Voigt and Hilbrecht, 1997; Wiese, 1999). Further correlation with the US Western Interior is possible (Walaszczyk, 2000). In comparison with the type locality of *M. scupini* in Waltersdorf, Saxony (Walaszczyk and Tröger, 1996), the Úpohlavy section in marly facies represents the lowermost part of the *scupini* Partial Range Zone, while at Waltersdorf (sandy facies), only the upper part of the zone is exposed. In the Ohře Graben (e.g., Čech, 1989), the bivalves *Didymotis costatus* (Frič), *Cremonoceras waltersdorfen-sis* (Andert) and *Cremonoceras ex gr. deformis* (Meek) (*Cr. erectus/rotundatus*), associated with *M. scupini* in Waltersdorf, appear stratigraphically somewhat higher in the upper part of Xc, which is not preserved in the Úpohlavy quarry.

#### 4.4. Irregular echinoids

*Micraster leskei* is common in the uppermost part of Bed 4, where the average specimens reach sizes rarely exceeding 4 cm. In the middle part of Bed 5, large *M. leskei* are frequent, and rare fragments of large *Plesiocorys* cf. *plana* occur. So far, no “advanced” *Micraster* of *M. ex gr. praecursor/normanniae* has been collected in situ, but very rare, ex situ finds indicate the FO to be located around beds 15–17.

**Discussion.** In the Boreal Turonian, zonation using irregular echinoids is only possible in some intervals. Specifically from the high Middle Turonian upwards, irregular echinoids have been used for zonation (e.g., the *plana* Zone of England and the succeeding *Micraster* zones). In the Upper Turonian, the evolution of *Micraster* and *Plesiocorys* has some stratigraphic potential (Ernst, 1970; Stokes, 1973; Fouray, 1981; Wiese, 1997; Smith and Wright, 2003). Of some significance is the typical and, in a geologic sense, rapid evolution of the *Micraster* succession in the terminal *neptuni* and the lowermost *scupini* zones of the Upper Turonian in three steps: (1) occurrence of small *M. leskei* in the uppermost *neptuni* Zone (Spain, France, England); (2) large *M. leskei* in the terminal *neptuni*/early *scupini* zones (Spain, France, England); (3) first occurrence (FO) of “advanced” *Micraster* in the lowermost *scupini* Zone (Spain, France, England, parts of Germany). However, the entry of “advanced” *Micraster*, previously suggested as a marker for the base of the “Senonian” or Coniacian, respectively (see discussion in Wood et al., 1984) is clearly diachronous in

an interbasinal context. The FO of advanced *M. ex gr. praecursor/normanniae* is approximately synchronous in basinal successions, while proximal settings are in part characterized up to the Early Coniacian either by *M. leskei* (Niebuhr et al., 1999) or by the virtual absence of the species (Ernst et al., 1997). Basinwide correlation of the FO of the new *Micraster* branch is thus of doubtful stratigraphic value.

At Úpohlavý, small *M. leskei* in Bed 4 are succeeded by large morphs in Bed 5, showing a similar stratigraphically separated size distribution development to that in Spain and the Anglo-Paris Basin of France and England. However it remains open to question whether or not these occurrences can be correlated: in Spain, the *Micraster leskei* (large) acme is located in the *scupini* Zone (Wiese, 1997) while at Úpohlavý *M. scupini* enters a bit higher. Thus, some stratigraphic fine-tuning is still needed. The absence of “advanced” *Micraster* immediately above Bed 5 is not necessarily surprising, as its occurrence may be facies-controlled as in other parts of the Turonian European shelf seas.

#### 4.5. Calcareous nannoplankton

The base of the Upper Cretaceous nannoplankton zone UC9a (Burnett, 1998), taken at the First Occurrence (FO) of *Lithastrinus septenarius* Forchheimer (nannozone CC 13 sensu Sissingh, 1977), is located in the marls succeeding the Lower Coprolite Bed, at the base of Bed 3 (Švábenická, 1999). It is noteworthy that there is a first, brief occurrence of *Marthasterites furcatus* (Deflandre) in Bed 3, followed by a barren interval and a re-entry of the taxon in Bed 16, well within the *scupini* Zone.

*Discussion.* The disjunct distribution pattern of *M. furcatus* has been inferred to be controlled by lithology (Švábenická, 1999), making it not an ideal stratigraphic marker, and Burnett (1998) suggested that its FO is diachronous on a global scale. However, the disjunct occurrence observed in the Úpohlavý quarry can also be seen elsewhere, e.g., in the Klement Formation of southern Moravia (Stráník et al., 1996). In southern England, a first occurrence of *M. furcatus* is located at an interval from just below Bridgewick Marl 1 to Bridgewick Marl 2 (Bailey et al., 1984) in the middle Upper Turonian. *M. furcatus* then reappears between the Navigation and Cliffe hardgrounds in the lowermost Coniacian. At Salzgitter-Salder, northern Germany, a first brief occurrence of *M. furcatus* is stratigraphically located around a distinct marl, Marl M<sub>E</sub>, which also falls within the middle Upper Turonian (Wood et al., 1984). Tephrostratigraphic (Wray, 1999) and  $\delta^{13}\text{C}$  correlations (Voigt and Hilbrecht, 1997) indicate that the two observed first occurrences in Germany and southern England are virtually isochronous. Judging

from the inoceramid and ammonite data (see above), a comparable position of the FO of *M. furcatus* in the Úpohlavý quarry is inferred, providing a further stratigraphic “nail” for interbasinal correlation.

## 5. Stable isotopes ( $\delta^{13}\text{C}$ , $\delta^{18}\text{O}$ )

A variety of Turonian stable isotope curves have been published from different European sites, which demonstrate the potential of carbon isotope stratigraphy for interbasinal correlation (e.g., Hilbrecht et al., 1986; Uličný et al., 1993; Jenkyns et al., 1994; Voigt and Hilbrecht, 1997; Wiese, 1999; Stoll and Schrag, 2000; Voigt, 2000a,b). In addition, oxygen stable isotope curves have been used to estimate relative palaeotemperature trends (Jenkyns et al., 1994; Schrag et al., 1995; Stoll and Schrag, 2000; Voigt and Wiese, 2000). For stable isotope stratigraphy, the Úpohlavý section was sampled at 50-cm intervals. Carbon and oxygen isotope measurements of bulk-rock samples were performed by off-line reaction of samples with 100% orthophosphoric acid at 40 °C and subsequent measurement of the CO<sub>2</sub> released with a Finnigan Delta S mass spectrometer (University of Cologne). The values are given as deviations from the VPDB standard and the reproducibility of repeated standard measurements was better than  $\pm 0.1\text{‰}$  for carbon and oxygen.

### 5.1. The $\delta^{13}\text{C}$ curve

The  $\delta^{13}\text{C}$  curve (Fig. 6) starts with slightly increasing values from 1.4 to 1.7‰ in the uppermost Jizera Formation, with no significant changes around the Lower Coprolite Bed. From Bed 3 to basal Bed 4 (lowermost Teplice Formation), the  $\delta^{13}\text{C}$  curve shows a distinct increase up to a first maximum (2.4‰) that is interrupted by a superimposed negative spike in the Upper Coprolite Bed. Carbon isotope values are stabilized within Bed 4 and increase towards a second maximum (2.5‰) in the lower part of Bed 5. This is the inflection point towards a decreasing course of the curve, reaching 2.0‰ in Bed 7. Above this level, the  $\delta^{13}\text{C}$  curve shows generally a decreasing trend with superimposed strong fluctuations between limestones and marls, with the marls being enriched in  $^{13}\text{C}$ . An abrupt decrease in values occurs in the uppermost part of the section.

*Discussion.* Previously published Turonian  $\delta^{13}\text{C}$  curves provide a sound basis for the integration of the Úpohlavý record into the existing intrabasinal  $\delta^{13}\text{C}$  stratigraphic framework (Jenkyns et al., 1994; Voigt and Hilbrecht, 1997; Wiese, 1999; Stoll and Schrag, 2000). In most expanded European sections (Salzgitter-Salder, Lower Saxony Basin; Liencres, North Cantabrian

Basin), the Upper Turonian  $\delta^{13}\text{C}$  curve is characterized by three minor variations around stable background values in its lower part (*Inoceramus perplexus* Zone), a long 1‰ increase and a maximum in the middle (*I. striatoconcentricus* Zone), and a long decrease in the upper part (*Mytiloides scupini* Zone) (Voigt and Hilbrecht, 1997; Wiese, 1999). It is difficult to recognize these features at a first glance at Úpohlavý. However, in relation to the biostratigraphic data, parts of the Upper Turonian  $\delta^{13}\text{C}$  record can be detected.

The occurrence of *I. ex gr. perplexus* in the Lower Coprolite Bed indicates a late Turonian age for the uppermost Jizera Formation. Since the base of the Lower Coprolite Bed marks an erosional surface, a hiatus of an unknown stratigraphic range must be assumed. Thus, it is not clear whether or not the low values below the Lower Coprolite Bed can be correlated with one of the small  $\delta^{13}\text{C}$  variations in the basal Upper Turonian (Fig. 6). The succeeding increase of the  $\delta^{13}\text{C}$  curve and its first maximum (beds 3 to 4 with the Upper Coprolite Bed in between) can be correlated with the long  $\delta^{13}\text{C}$  increase in the middle Upper Turonian. The first occurrence of *Marthasterites furcatus* within Bed 3 allows correlation with the marl layers around  $M_E$  in Lower Saxony and the Bridgewick Marls in southern England. The occurrence of ammonites in Bed 4, typical of the *neptuni* fauna, confirms the correlation with the *Hyphantoceras* Event in Lower Saxony. Based on the lithology of the Upper Coprolite Bed (erosional base) and the biostratigraphic data in this interval, we suggest that the Upper Coprolite Bed incorporates a hiatus, which corresponds to the stratigraphic equivalents of the horizon between  $M_E$  and the *Hyphantoceras* Event in Lower Saxony.

Higher up in the section, the Úpohlavý  $\delta^{13}\text{C}$  curve decreases towards the base of the *Mytiloides scupini* Zone, below the occurrence of the first *Micraster ex gr. normanniae*, which again marks a good correlation datum. This trend is consistent with Upper Turonian  $\delta^{13}\text{C}$  stratigraphies elsewhere. Above the FO of *M. scupini*, the  $\delta^{13}\text{C}$  values are more affected by lithological changes within the marl–limestone alternation than they reflect a general trend. Higher porosities within the limestones favoured the migration of  $^{12}\text{C}$ -rich pore fluids and caused the cemented limestones to be  $^{13}\text{C}$  depleted.

### 5.2. The $\delta^{18}\text{O}$ curve

In the Jizera Formation, the  $\delta^{18}\text{O}$  values (Fig. 7) fluctuate around  $-4.5\text{‰}$ , but increase sharply by  $1.5\text{‰}$  in the basal Teplice Formation from Bed 3 to the limestone above the Upper Coprolite Bed. A broad maximum with values of  $3.0\text{‰}$  is developed within Bed 4 and is followed by a  $0.7\text{‰}$  decrease and relatively stable values of  $-3.7\text{‰}$  between beds 5 and 11. It is noteworthy that the  $\delta^{18}\text{O}$  curve in this interval has a much more stable trend than the  $\delta^{13}\text{C}$  curve. Above Bed 11, through the uppermost part of the section, the oxygen isotope record decreases irregularly by almost  $1\text{‰}$ .

**Discussion.** The range of  $\delta^{18}\text{O}$  values between  $-4.7$  and  $-3.0\text{‰}$  shows a  $^{18}\text{O}$  depletion by  $1\text{--}2\text{‰}$  in comparison to pelagic chalk and limestone sections in southern England and northern Germany, and is typical of hemipelagic sediments in basin-margin settings. Lower contents of carbonate reduce the rock/fluid ratio

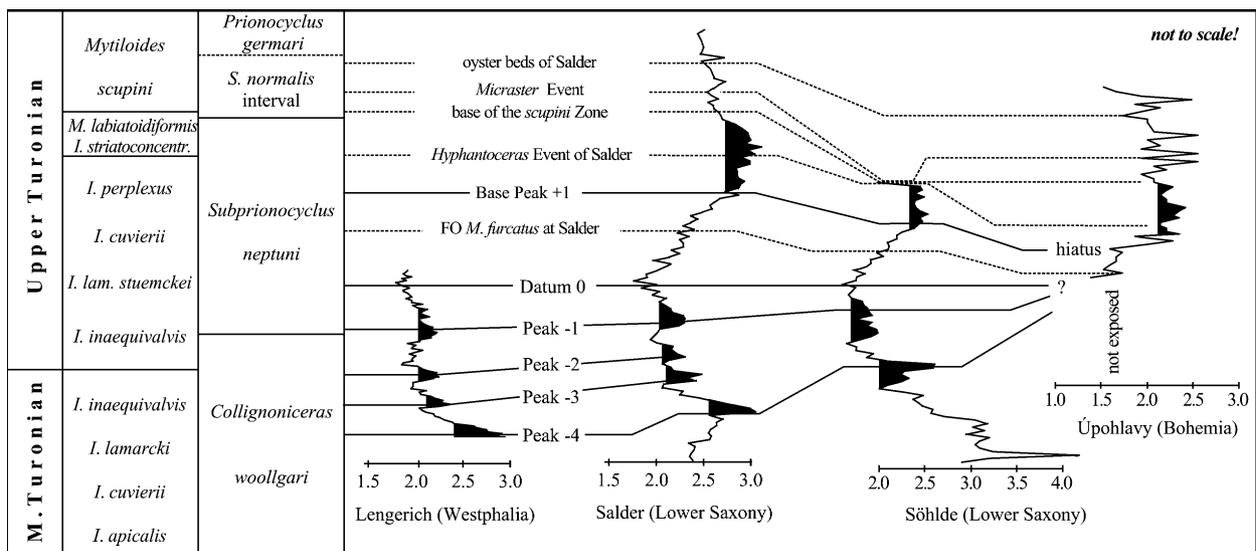


Fig. 7. Tentative correlation of the Úpohlavý  $\delta^{13}\text{C}$  curve with that of Lengerich, Westphalia (Wiese and Kaplan, 2001) and Salzgitter-Salder and Söhlde, Lower Saxony (Voigt and Hilbrecht, 1997). Numbering of individual positive peaks after Wiese (1999). Biostratigraphic subdivision modified after Ernst et al. (1983) and Kaplan (1986).

for oxygen, and favours enhanced diagenetic alteration of the oxygen isotopic composition during early and burial diagenesis. In the Úpohlavý section, this is reflected well by the broad  $\delta^{18}\text{O}$  maximum in Bed 4 that coincides with the highest carbonate contents of the succession. Furthermore, the sudden drop in oxygen isotope values at the top of Bed 14 correlates with the long-exposed first quarry floor, and reflects the influence of meteoric waters.

It is interesting to consider the 1.5‰ positive  $\delta^{18}\text{O}$  shift between beds 3 and 4 in more detail. About 0.8‰ of the shift occurs at the marl/limestone transition in the Upper Coprolite Bed and most probably can be attributed to diagenetic processes. However, 0.7‰ of the shift occurs within the Bed 3 marl, which does not show any significant changes in lithology. Within the given stratigraphic framework, this increase in the  $\delta^{18}\text{O}$  curve falls into the upper *neptuni* Zone, and occurs below the *Hyphantoceras* Event indicated by the *neptuni* fauna in Bed 4. This suggests a correlation with similar  $\delta^{18}\text{O}$  increases described from a variety of European sections in different depositional settings and facies, and interpreted to reflect a primary palaeotemperature signal (Phase III of Voigt and Wiese, 2000; Jenkyns et al., 1994; Stoll and Schrag, 2000). The Phase III oxygen isotope increase correlates with a concomitant southward spread of Boreal faunas (Voigt and Wiese, 2000) and can be recognized in well-preserved brachiopod shells as well (Voigt, 2000a,b). Therefore, a short-term (ca. 400 kyr) cooling event caused by global changes in oceanic circulation has been proposed as mechanism (Voigt and Wiese, 2000). This pulse is also recognized in the Bohemian Cretaceous Basin by the spread of a rich inoceramid fauna and an echinoid assemblage typical of the northern shelf seas of the Anglo-Paris Basin (pars), northwest Germany and the East European Platform areas. In addition, a Nerineacean warm-water gastropod assemblage of the Cenomanian–Middle Turonian (Kollmann et al., 1998) is replaced by a Boreal Pleurotomariacean fauna in the “Hundorfer Kalkstein”.

## 6. Sequence stratigraphy

### 6.1. Generalities

In the Bohemian Cretaceous Basin, the sudden development of pelagic boreal limestones at the base of the Teplice Formation, and an abrupt increase in the  $\text{CaCO}_3$  content, reflect a fundamental turnover in sedimentation from a siliciclastic-dominated setting towards a biosedimentary system. The latter is progressively influenced by in situ planktonic and benthic carbonate production (foraminifera, c-dinocysts, coccoliths, macrofossil debris), lithologically equivalent to the so-called Pläner Limestones of northwest Germany.

The Turonian palaeogeography and facies zonation on the European shelf seas (Tröger, 2000) shows the occurrence of the limestones in Bohemia to be the result of a southward shift of the Pläner Limestone facies, palaeoceanographically positioned between the siliciclastic-dominated nearshore settings close to ancient massifs (e.g., Bohemian Massif, Sudetic Island, Rhenish Massif) and the pelagic coccolith chalk *sensu stricto* (e.g., Anglo-Paris Basin, epicontinental chalk of the Russian Platform: mainly pelagic planktonic carbonate formed by coccolithophorids). While the pelagic Chalk *sensu stricto* shows little evidence of a response in terms of bioproductivity and accumulation rates to relative sea-level changes (Ehrmann, 1986; Ernst et al., 1996; Niebuhr, 1995), the Pläner Limestone facies behaves in a fundamentally different manner. Turonian successions of NW Germany show that among the carbonate producers c-dinocysts especially can occur in almost rock-forming quantities in geographically shifting belts of high carbonate bioproductivity and biosedimentation rates (Neumann, 1999; Wilmsen, 2003); this has also been observed elsewhere (Adams et al., 1967). The development of these belts, often associated with peak occurrences of invertebrate faunas, are mostly restricted to shallowing phases or near-swell settings (Neuweiler and Bollmann, 1991; Ernst et al., 1998; Neumann, 1999). A transgressive pulse in near-swell settings is always associated with a decrease in c-dinocyst abundance and macrofauna, resulting in a gradual shift from c-dinocyst wacke/packstones to marl/limestone alternations dominated by foraminiferal wackestone/mudstones, and an increase of marl beds respectively. Within this context, the gross sedimentary stacking pattern resembles that of siliciclastic systems: shallowing is accompanied mainly by coarsening- and, if sufficient accommodation space is available, thickening-up and facies progradation; transgressions are associated with a sudden breakdown of bioproductivity and the development of marlier intervals. Thus, bioproductivity and biosedimentation of the Pläner Limestones facies were intimately related in their response to relative sea-level changes, and lithological/compositional variations within the Pläner Limestones can be used as a reliable proxy for relative sea-level trends.

### 6.2. Tentative sequential interpretation and interbasinal discussion

An overview of the relative sea-level curve in the Bohemian Cretaceous was given by Valečka and Skoček (1991) and Krhovský (1991). Some data exist for selected Cenomanian intervals (Uličný et al., 1993, 1996, 1997), and Uličný (2001) presented a conceptual treatment of the Turonian/Coniacian nearshore shallow-marine depositional systems based both on outcrop and borehole data. A first sequence stratigraphy of the

Úpohlavy section was given by Uličný in Čech et al. (1996) and Svobodová et al. (2002).

As the best biostratigraphic compatibility is with the northwest German intrashelf basins, it will be attempted here to link the rocks described to the succession of sedimentary sequences observed in that area. For the interval in question, numerous high-resolution data are obtainable from the literature and provide a sound basis for interbasinal correlation (Ernst and Wood, 1995; Voigt and Hilbrecht, 1997; Wood and Ernst, 1997; Wiese et al., 2000). In order to facilitate a comparison with the Bohemian successions, we first present a synthesis of previously recognized relative sea-level cycles and our own field data from northwest Germany. We follow the suggestion of Hancock (2000) in naming sequences, and will apply and emend the provisional sequence terminology for the northwest German Turonian introduced by Wiese and Kröger (1998). Subdivision and intrabasinal correlation within northwest Germany is based mainly on the dating of hiatuses associated with sequence boundaries (“Lückenstratigraphie”, gap stratigraphy of Ernst et al., 1996) and the correlation of maximum flooding intervals (Galloway, 1989; genetic sequence model), which are mostly better developed and detectable over much wider areas. We also apply, where possible, the concept of a ‘Regressive Systems Tract’ to the

progradational part of the sequences. So far, five relative sea-level cycles have been observed in the terminal Middle Turonian–lowermost Coniacian interval in northwest Germany (Fig. 8). However, the precise positions of the sequence boundaries are still partly open to discussion as is the tentative sequence stratigraphic framework. The sequences observed so far (cf. Wiese and Kröger, 1998; Wiese et al., in press) are, in ascending order (Fig. 8): (1) *Inoceramus perplexus* Sequence I (associated maximum flooding zone in the lowermost Upper Turonian); (2) *Inoceramus perplexus* Sequence II (associated maximum flooding zone, the *costellatus/plana* Marls; Ernst and Wood, 1995); (3) un-named small brachiopod Sequence (associated maximum flooding zone, Marl M<sub>E</sub>); (4) *Hyphantoceras* Sequence (Wiese and Kröger, 1998) (associated maximum flooding zone, the *Micraster* Marls); (5) *Didymotis* Sequence (Wiese and Kröger, 1998) (associated maximum flooding zone, the lowermost part of the Grey and White Alternation).

Biostratigraphically, the succession investigated falls entirely within the Upper Turonian. An *Inoceramus perplexus* acme ca. 13 m below the Upper Coprolite Bed in the nearby Le-8 Rohatce borehole suggests an age well into the Late Turonian for the base of the interval investigated. However, only limited high-resolution stratigraphy makes a detailed sequence stratigraphic

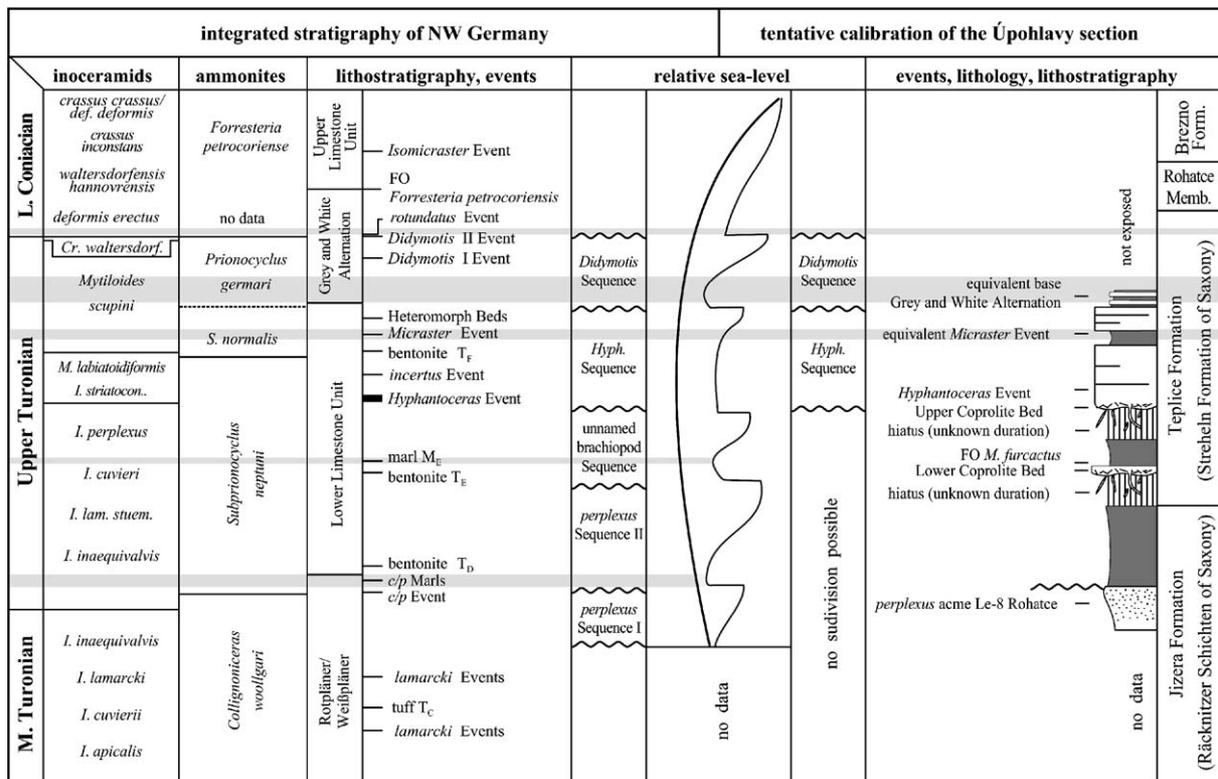


Fig. 8. Tentative calibration of the Úpohlavy section against the integrated stratigraphic framework of northwest Germany (compiled after Ernst et al., 1983; Kaplan, 1986; Wood et al., 1984); sequence stratigraphy based on partly unpublished data (FW). Turonian/Coniacian lithostratigraphic subdivision of Bohemia after Čech et al. (1980) (abbreviations: *Hyph.* = *Hyphantoceras*, *lam. stuem.* = *lamarcki stuemckeii*).

interpretation between the *I. perplexus* acme and the Lower Coprolite Bed and, thus, long-range correlation impossible. Both the sequence stratigraphic position (progradational unit of the siliciclastic system; regressive systems tract) and the evolutionary state of *I. perplexus* suggest a stratigraphic position equivalent to the *costellatus/plana* Event of northwest Germany (Fig. 6). However, the missing framework makes it impossible to relate this occurrence precisely to any of those recognized in northwest Germany. This is also true for the base of the Lower Coprolite Bed. Based on regional data, it is impossible to determine its significance as a possible sequence boundary (this bed was also recognized in the Weinböhla Limestones; Zahálka, 1924, p. 182). As high resolution biostratigraphy begins with Bed 4 (*Hyphantoceras* Event, middle Upper Turonian; Fig. 6), possible equivalents of the *Inoceramus perplexus* Sequence I, *Inoceramus perplexus* Sequence II and the unnamed brachiopod Sequence cannot be discriminated here. Within the given stratigraphic framework, only the *Hyphantoceras* and lower parts of the *Didymotis* sequences are recognized.

*Hyphantoceras* Sequence. The base of the Upper Coprolite Bed forms an important regional unconformity with massive erosion and an enrichment in coarse bioclastics, siliciclastics and phosphates. Stratigraphically, the SB is located well above the FO of *Marthasterites furcatus* and below the main body of the *Hyphantoceras* Event of northwest Germany. This stratigraphic framework permits precise dating of the sequence boundary and a safe correlation with the base of the *Hyphantoceras* Sequence of northwest Germany. The contact between the Upper Coprolite Bed is equivalent to the contact between the limestones of Weinböhla/Strehlen and the underlying marly Räcknitz Formation of Saxony (Prescher, 1981). Based on faunal assumptions (see above), large parts that are stratigraphically equivalent to an interval from above  $M_E$  to below the *Hyphantoceras* Event were either not deposited or were eroded. This interpretation is in accordance with the abrupt changes in the isotope curves. We interpret Bed 4, based on macrofaunal and sedimentological (gutter cast) evidence, to reflect a shallow, but overall transgressive development at a water depth close to storm wave base. Some influence of coastal waters is indicated by a higher content of terrestrial palynomorphs (Svobodová et al., 2002). The abundance of *Braarudosphaera* (calcareous nannoplankton) may indicate shifting salinities as inferred from the distribution of extant braarudosphaerids predominantly in nearshore, low-salinity marine waters (Bukry, 1974) (in open-ocean sites with normal salinities they occur only in very low numbers; (Okada and Honjo, 1973)).

Above Bed 4 (Rhynchonellenschichten, Xb $\beta$ ), an overall transgressive trend occurs, expressed by the

decrease in bioproductivity, grain size, faunal abundance and diversity, and the development of retrogradational marl/limestone alternations. The macrofaunal development is characterized by a change towards a rhynchonellid brachiopod assemblage and hexactinellid sponge meadows. The sudden decrease in species number and abundance amongst the ammonites (only scaphitids and *Lewesiceras*) is in accordance with data from large parts of northwest Germany at the same stratigraphic level (Kaplan, 1991; Kaplan and Kennedy, 1996), also reflecting transgressive development (Wiese and Kröger, 1998). Maximum flooding occurs in Bed 8 (Figs. 2, 8), accompanied by the almost exclusive occurrence of small nuculitid bivalves and gastropods and the absence of any other macrofauna. Above, the thickening-up development is indicative of progressive shallowing. However, the faunal abundance/diversity does not return to the previous structure as in Bed 4. The sequence boundary at the top of the regressive systems tract is taken at the top of Bed 15, from where a deep channel, cut into the underlying strata, was temporarily exposed until 1996 (Čech et al., 1996). We interpret this succession from the base of Bed 4 to the top of Bed 15 as a high-frequency, 3rd order, relative sea-level cycle, with the transgressive part from Bed 4 to Bed 7, the maximum flooding interval in Bed 8, and a regressive systems tract from Bed 9 to Bed 15. Biostratigraphically, this cycle shows excellent correlation with the interval from the upper *Hyphantoceras* Event to the base of the Grau-Weiße Wechselfolge of northwest Germany, with the *Micraster* Event as the maximum flooding interval (*Hyphantoceras* Sequence sensu Wiese and Kröger, 1998). A direct comparison between Salzgitter-Salder in northwest Germany and Úpohlavý shows the different regional subsidence/deposition histories: at Salder, the interval from the *costellatus/plana* Event to the *Hyphantoceras* Event is ca. 60 m thick (cf. Wood et al., 1984), while at Úpohlavý it is tentatively estimated at only 13 m. On the other hand, the interval from the top of the *Hyphantoceras* Event to the renewed transgression (base of the Grau-Weiße-Wechselfolge in Germany; Fig. 8) reaches ca. 20 m, at Úpohlavý ca. 17 m, providing an approximation of the sedimentary development. In addition, in both areas (which is also true for Westphalia and Saxony-Anhalt), the *Hyphantoceras* Event is transgressive and the *Hyphantoceras* Sequence shows a symmetrical geometry, indicating uniform tectono-sedimentary developments and sea-level effects in all areas.

Uličný (in Čech et al., 1996) interpreted the contact between Bed 3 and Bed 4 as a condensed section, Bed 4 (their Xb1) as a maximum transgression and the interval around Bed 8 as maximum regression. This interpretation is 180° out of phase with the approach attempted here (see above). Our interpretation may be further supported by the palynomorph/foraminiferal assemblage

(Svobodová et al., 2002, p. 252, fig. 2): from the top of the Jizera Formation, nonmarine palynomorphs decrease progressively. A first minimum occurs in the base of Bed 4. The further course of the palynomorph assemblage maps the symmetrical development of sea-level cycles. From Bed 4, the nonmarine assemblages decrease; there is major marine influence in Xb $\beta$ . With the regressive trend (beds 8–15), the amount of non-marine taxa increases again, indicating progressive coastal influence.

*Didymotis Sequence.* The contact of Bed 15 and Bed 16 forms a sequence boundary and likewise a transgressive surface. The deep channel incision described by Čech et al. (1996) cuts down from this level into the underlying strata. The age of the sequence boundary/flooding surface is stratigraphically exactly located in the lower *scupini* Zone, only a very little below the FO of *Prionocyclus germari*. In northern and south-eastern Bohemia it can easily be detected in all boreholes spanning this interval by the sudden decrease in carbonate content, pebble beds, glauconitic horizons or reworking. In an identical stratigraphic position, hardgrounds, prograding greensand bodies and turbidite fans are developed in northern Germany (Kaplan, 1994; Wiese and Kröger, 1998) as an expression of the same relative sea-level event. The succeeding flooding, presumably in the lowermost *germari* Zone, is of interbasinal relevance. It can be observed in the whole of northwest Germany (Grau-Weiße Wechselfolge) and is represented by a brief period of uniform Chalk development without hardgrounds (Cuilfail *Zoophycos*: Mortimore and Pomerol, 1991) at that level in the Anglo-Paris Basin.

## 7. Discussion

*Stratigraphic implications.* Although exposing only ca. 27 m, the section in the Úpohlavý working quarry is of interregional significance as a high resolution stratigraphic link between the Boreal pelagic biosedimentary system of northwest Germany and the siliclastic settings near the West Sudetic Island. There is good biostratigraphic correlation with northwest Germany, which permits a stratigraphic evaluation of the stable isotope curves. However, due to the incomplete sedimentary record, these curves can be correlated only to a limited extent in an interbasinal context. Specifically, the level of the *Hyphantoceras* Event (Peak +1), with its positive excursion, follows the trend observed in other areas, and the oxygen isotope record mirrors the widespread cooling event established within this level (Voigt and Wiese, 2000). However, owing to gaps in sedimentation, a detailed intra- and interbasinal correlation is impossible below Bed 4. This is also true for the

sequence stratigraphic subdivision; below Bed 4, no interbasinal sequential comparisons are possible. However, the *Hyphantoceras* Sequence and the base of the *Didymotis* Sequence can be correlated between Bohemia and northwest Germany within the biostratigraphic framework with a high degree of confidence. The elaboration of an integrated stratigraphic framework provides good potential for further correlation and calibration of regional lithostratigraphies. It likewise facilitates a fusion of physical subsurface data (Uličný, 2001) with outcrop stratigraphy and provides an important first stratigraphic “nail” to link a part of the Bohemian Upper Turonian successions to other, stratigraphically well-established successions of N/SW European Cretaceous basins.

*Palaeoceanographic implications.* The section is of particular importance as a key to palaeoceanographic changes within the Bohemian Cretaceous Basin in its palaeogeographic position as a gateway between the Tethys and the Boreal realm during late Turonian times. Having been influenced by siliclastic-dominated systems (sandstones, clays, marls, nearshore silty calcarenites and limestones), the sudden establishment of a (hemi-) pelagic limestone facies as exposed at Úpohlavý reflects both a fundamental change in biosedimentary dynamics and terrigenous input and the interplay between the two, as specifically expressed by a rapid vertical succession of the distinct faunal assemblages described above (Fig. 3). Diversity and population structure of both macro- and microbenthos is controlled by food availability (e.g., Sibuet et al., 1989; Blake and Hilbig, 1995; Rosenberg, 1995; Altenbach and Struck, 2001; Gooday et al., 2001), and Galeron et al. (2000) demonstrated that benthic metazoan diversity progressively decreased with a decrease in vertical nutrient flux. Based on extant bivalve assemblages, the terebratulid/bivalve assemblage is best interpreted to represent a ‘normal’ marine, mesotrophic benthic assemblage, consisting of epi- and endobenthic forms that represent both suspension and sediment feeders. The abundance peak of *Braarudosphaera* may indicate nutrient-rich (eutrophic?) surface waters. With the transgression during the TST of the *Hyphantoceras* Sequence, the development of hexactinellid sponge meadows (large surface, cup-shaped morphs dominate) and the decrease in bivalve abundance indicate the faunal response of suspension feeders to a reduction in bottom current activity (Krauter, 1998). As a lateral bottom current contributes 2–8 times more nutrients into the system than a vertical flux (Graf, 1992), this likewise is associated with a decrease in particle flux and nutrient availability. Consequently, a decrease in nutrients/suspension affected the suspension feeders and favoured the detritus-feeding *Nucula/Nuculana* group of Bed 8 (*Nucula/Nuculana* Assemblage). Furthermore,

a transgressive coastward shift of riverine nutrient-rich, plume-upwelling areas may have further decreased bioproductivity in the Úpohlavý area.

The main palaeoecologic change occurred, however, in the RST of the *Hyphantoceras* Sequence, when a (hemi-) pelagic biosedimentary system (lithologically comparable to the northwest German Pläner Limestones; see above) established for the first time in the BCB, in the form of c-dinocyst packstones. Obviously, bioproductivity of the main planktic carbonate constituents in Boreal pelagic systems (e.g., coccolithophorids, c-dinocysts) is controlled mainly by nutrient supply, relative water depth and temperature (Brand, 1994; Roth, 1994; Zügel, 1994; Zonneveld et al., 1999; Gale et al., 2000; Prauss, 2000; Vink et al., 2002, Wendler et al., 2002a). In relation to environmental changes, quantitative fluctuations among the main components fluctuate both on a small (orbitally driven) scale (Noel et al., 1995; Wendler et al., 2002b) and within 3rd order sedimentary sequences. Extant c-dinocyst abundances are sometimes described as occurring under eutrophic conditions (Wendler et al., 2002c), and Cenomanian c-dinocyst abundance peaks of *Pithonella sphaerica* and *P. ovalis* have been interpreted to indicate eutrophic surface-water conditions (Wendler et al., 2002b). Almost monospecific *P. sphaerica* packstones, as observed at Úpohlavý, are also very widespread in the Turonian Pläner Limestones of the wide, northwest German Turonian shelf sea, where they are, as in Bohemia, sometimes associated with a low diversity macrofauna, consisting mainly of inoceramids, brachiopods and sponges. Inferring eutrophic conditions as repeatedly suggested (see above), a high vertical nutrient flux must be assumed which, consequently, should result in a benthic faunal response in the form of a somewhat more diverse shelf fauna, as observed in the sections. Therefore, a discrepancy exists between the interpretation of *Pithonella sphaerica/ovalis* abundance as eutrophic and the low-diversity, shallow-water benthic invertebrate macrofauna, indicative of poor nutrient availability. In an open-ocean setting, progressive nutrient depletion occurs with depth, since within the upper hundreds of metres organic matter will be remineralized and does not reach the bottom (Galeron et al., 2000). However, such a scenario is hardly applicable to the Cretaceous shelf seas of Europe, because water depth fluctuated between storm wave base (tempestites) and ca. 100 m (see also discussion of the Cenomanian in Wilmsen, 2003). An unequivocal interpretation of the *P. sphaerica/ovalis* abundance peaks is also hindered by the poor understanding of the palaeobiology of this group: as there are no extant representative of these taxa, it is impossible to determine whether or not a cyst represents the normal stage during the life cycle or whether it represent a hypnozygote, indicative of unstable/unfavourable environmental con-

ditions (see discussion in Wendler et al., 2002b). Although extant species (*Thoracosphaera heimii*) can also form mass occurrences in eutrophic settings (Wendler et al., 2002b), it remains problematical to deduce nutrient demands for the *P. sphaerica/ovalis* group exclusively from this analogy without any further data from the associated fauna/flora: other c-dinocysts are inferred to be associated with oligotrophic conditions (Höll et al., 1998; Vink et al., 2000). It is proposed here that, particularly based on the positive correlation of an abundance of *P. sphaerica/ovalis* with a low-diversity macrofauna, these accumulations reflect nutrient depletion. This interpretation contradicts experiences from the Cenomanian (see above); hence, the palaeobiological feedback that led to high c-dinocyst production remains open to discussion.

In the context of a critical review of the Cenomanian–Turonian (C/T) Boundary Event, Gale et al. (2000) observed an early Turonian breakdown of macrofaunal diversity in the Anglo-Paris Basin comparable to that seen here. They suggested that this sudden diversity breakdown was result of the breakdown of the shelf break front (Hay, 1995) and a cessation of upwelling nutrients: oligotrophic oceanic waters shifted onto the northwest European shelf seas during the onset of transgression, resulting in stratified, oligotrophic surface waters. We believe that a comparable triggering mechanism, a change from mesotrophic to lower nutrient level (oligotrophic?) conditions, can basically explain the development observed at Úpohlavý. However, the reason for the establishment of the oligotrophic oceanic “blue water” system remains problematic: water depths associated with the Chalk Rock of England and parts of the Pläner Limestone facies may have been shallow (Chalk Rock hardground development) or close to, or even above, storm wave base, as indicated by the occurrence of tempestitic beds in some of the northwest German Turonian succession (Kott, 1985; Neuweiler and Bollmann, 1991). Despite the large coastal onlap onto the remaining emergent land areas within Europe during Turonian times (Haq et al., 1988), a Mid-Turonian shelf sea with water depths greater than 200 m cannot be recognized either in the northwest German Basin or the Bohemian Cretaceous Basin: instead, sedimentation kept pace. There is no evidence for water depths greater than 100–150 m; in several sections in northwest Germany water depths around and above storm wave base have been recognized. In other words, large parts of the European shelf seas were characterized by “normal” shelf water depths. Thus, a high relative sea-level that may have resulted in the vertical separation of shelf and oceanic water masses cannot have been the main triggering mechanism, and water mixing was at least periodically possible due to the comparatively low relative sea level.

Bioproductivity is controlled mainly by nutrient supply from upwelled waters (shelf break upwelling,

eddy upwelling, river plume upwelling), sediment load, depth of mixed layer and rate of loss (sedimentation of biomass) (see summary in Lalli and Parson, 1997). The palaeogeographic situation during Turonian times (Ziegler, 1988) indicates a shelf break hundreds of kilometres distant from the European shelf basins and thus only limited nutrients could have been supplied to the very expanded Turonian shelf seas via shelfbreak upwelling. The terrigenous and nutrient input from the remaining continental areas, on the other hand, must have been small, as indicated by the low content of clay minerals in the Chalk and Pläner limestones (Ehrmann, 1986) due, presumably, to a dramatic decrease in emergent regions in the northwest European area and a severe breakdown of nutrient input into the extended basinal areas. Riverine nutrient input is regarded here to have been insignificant; it would have been consumed in near-coast settings, as suggested by the rich and highly diverse benthic and nektonic invertebrate assemblages recorded in the literature (e.g., Geinitz, 1839–1842; Frič, 1889; Andert, 1934; Seifert, 1955). As a consequence, it is proposed here that the open shelf areas were at least partly cut off from any (except airborne) nutrient input. In this setting, coccolithophorids and dinoflagellates with affinities to oligotrophic conditions could bloom and, based on data from extant floras, light and water temperature were the factors limiting productivity (e.g., Mara et al., 2001). The southward shift of this oligotrophic shelfwater mass into the Bohemian Cretaceous Basin happened in the context of a reorganization of current systems (Voigt and Wiese, 2000), accompanied by a contemporaneous southward shift of northern faunas to the south (Wiese and Voigt, 2002). However, it must also be emphasized that this interpretation refers only to the stratigraphic interval and area considered.

## 8. Conclusion

The Úpohlavý section, ca. 27 m thick, was measured in detail and lithologically and stratigraphically investigated in order to link it to existing integrated stratigraphic frameworks. Biostratigraphic data show that the base of the Teplice Formation corresponds to the top of the Upper Turonian *Hyphantoceras* Event (*neptuni* Zone) of northwest Germany. Both biostratigraphic and stable isotope correlations show a significant hiatus between the Jizera Formation and the succeeding Teplice Formation. This hiatus is of regional development and also observed in Saxony. The base of the Teplice Formation (beds 4–15) represents a 3rd order sea-level cycle (*Hyphantoceras* Sequence in northwest Germany). The top of Bed 15 forms a sequence boundary/transgressive surface and marks the base of the *Didymotis* Sequence. In the section, a fundamental

palaeoceanographic turnover from a mesotrophic, faunistically diverse shelf setting to an oligotrophic, low-diversity system can be observed. As biosedimentary systems are highly sensitive to external agitations, the situation observed here can be applied to this area only for the time in question. The partly contradictory data in the literature indicates that more investigations are required in order to understand the biosedimentary dynamics of the Boreal pelagic systems in relation to benthic diversity. To determine the extent to which the surface waters of the Boreal pelagic carbonate system were enriched or depleted in nutrients, it is also necessary to consider macrobenthos in order to reconstruct vertical nutrient fluxes.

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