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The Salzgitter-Salder Quarry (Lower Saxony, Germany) and Słupia Nadbrzeżna river cliff section (central Poland): a proposed candidate composite Global Boundary Stratotype Section and Point for the Coniacian Stage (Upper Cretaceous)

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ABSTRACT:

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An integrated account of a candidate composite Global Boundary Stratotype Section and Point for the base of the Coniacian Stage, comprising the Salzgitter-Salder Quarry section (Lower Saxony, Germany) and the Słupia Nadbrzeżna river cliff section (central Poland), is provided. Documented are all the main biostratigraphically significant macrofossil and microfossil groups: ammonites, bivalves (inoceramids and the genus *Didymotis*), planktonic foraminifera and calcareous nannoplankton. Also provided are correlations based on stable carbon isotope curves.

The base of the Coniacian is defined by the first occurrence (FO) of the inoceramid bivalve *Cremnoceramus deformis erectus* (Meek, 1876), a cladogenetic successor of the *C. waltersdorfensis* (Andert, 1911) lineage. This event is well above the first appearance of the classic ammonite marker of this boundary, *Forresteria petrocoriensis* (Coquand, 1859), which is first noted high in the Upper Turonian *Mytiloides scupini* inoceramid bivalve Zone at Słupia Nadbrzeżna. The boundary at Salzgitter-Salder cannot be precisely defined by means of ammonites; however, there is an apparent local change in one scaphitid lineage a short distance below the boundary. In calcareous nannofossil terms, the boundary falls within the interval between the first occurrence of *Broinsonia parca parca* and the last occurrence (LO) of *Helicolithus turonicus*. At present, no planktonic species found in both sections can be used as a close proxy for the base of the Coniacian, as defined by the inoceramid bivalve marker. In terms of carbon stable isotopes, the Turonian–Coniacian Boundary lies in the inflection point from falling to rising $\delta^{13}C$ values. A comparison of the Salzgitter-Salder and Słupia Nadbrzeżna carbon isotope curves indicates a hiatus at the former locality.

The base of the Coniacian in the Salzgitter-Salder section is marked by a flood occurrence of *Cremnoceramus deformis erectus*, constituting the *deformis erectus* I Event. The boundary interval at Słupia Nadbrzeżna is expanded: here the first occurrence of *C. deformis erectus* is separated from both the terminal Turonian *C. waltersdorfensis waltersdorfensis* Event and the *C. deformis erectus* I Event, also indicating the existence of a hiatus at the boundary in the Salzgitter-Salder section. In view of this hiatus at the critical level, it is proposed that the two sections should constitute a candidate composite Coniacian GSSP.

Key words: GSSP; Upper Cretaceous; Coniacian; Composite stratotype section; Salzgitter-Salder–Słupia Nadbrzeżna sections; Stratigraphy.

INTRODUCTION

The Salzgitter-Salder Quarry section (Lower Saxony, Germany), was proposed as the main candidate Global Boundary Stratotype Section and Point (GSSP) for the base of the Coniacian Stage by the Coniacian Working Group of the Subcommission on Cretaceous Stratigraphy at its meeting during the Second International Symposium on Cretaceous Stage Boundaries in Brussels, September 8–16, 1995. As stated by Kauffman *et al*. (1996), in their report of the conclusions of the Coniacian Working Group, out of 19 votes of a ballot after the Brussels Symposium, 16 were in favour and 3 against the proposal (with no abstentions). In the formal recommendation, the Coniacian Working Group proposed (Kauffman *et al.* 1996) that the Turonian–Coniacian boundary at the Salzgitter-Salder Quarry be placed at the FO of the inoceramid bivalve *Cremnoceramus rotundatus* (*sensu* Tröger, *non* Fiege) [subsequently referred to *C. deformis erectus* (Meek) – see Walaszczyk and Cobban (1999, 2000); Walaszczyk and Wood (1999)]; at the base of the limestone bed MK 47 of the section described by Wood *et al.* (1984), above the *Didymotis* Ecoevent II and the flood occurrence of the inoceramid bivalve *Cremnoceramus*? *w. waltersdorfensis* (Andert) in limestone bed MK 45b. The main advantages of the Salzgitter-Salder section pointed out by the Working Group were as follows (Kauffman *et al*. 1996):

a. It is a thick, continuously exposed succession, without obvious hiatuses;
b. It is the best-studied of the proposed stratotypes, with exceptionally high-resolution stratigraphic data presented;
c. It contains one of the richest and most persistent records of inoceramid bivalves in Europe; and
d. It should be readily accessible at least in the foreseeable future.

The disadvantages indicated by the Working Group related to the diagenetic alteration of the carbonate, which causes difficulties in extraction of microfossils and the paucity of ammonites (Kauffman *et al.* 1996).

Subsequent studies of nannoplankton (Lees 2008) and planktonic foraminifera (Peryt, the present paper) from the Salzgitter-Salder section proved that, although there are indeed some difficulties in extraction of both nannofossils and microfossils, the record of both groups could be satisfactorily documented. However, study of the inoceramid bivalves (Walaszczyk and Wood 1999; Wood *et al*. 2004) revealed that the Salzgitter-Salder succession contained hiatuses within the boundary interval, with one hiatus directly below the base of the Coniacian, as proposed in Brussels. The latter hiatus was confirmed independently by comparison of the carbon stable isotope curve with the curve from the expanded Liencres section in northern Spain (Wiese 1999). Consequently, the proposal of the Salzgitter-Salder section as the main candidate GSSP for the Coniacian Stage has been strongly criticized in recent years.

A much more complete Turonian–Coniacian boundary interval succession is known from the Słupia Nadbrzeżna section in the river cliff on the left bank of the River Vistula in central Poland (for details see Walaszczyk and Wood 1999; Wood *et al.* 2004). [This section was also proposed informally as a candidate stratotype section in Brussels but because no formal proposal was made it was withdrawn by the Group from further consideration (see Kauffman *et al*. 1996)] This section possesses a high-resolution and a very well-preserved inoceramid bivalve record, and is apparently continuous within the boundary interval. Although its very poor exposure disqualifies it as an independent candidate basal boundary stratotype it well complements the Salzgitter-Salder section in the critical boundary interval. Consequently, a compromise proposal of a composite Coniacian basal boundary stratotype section, encompassing the Salzgitter-Salder and the Słupia Nadbrzeżna sections is now proposed. The proposal was first presented by two of the authors (IW and CJW) for discussion during the Cretaceous Subcommission meeting accompanying the 7th International Symposium on the Cretaceous at Neuchatel (September 2005), Switzerland, and subsequently at the Stratigraphical Commission and Subcommission meetings during the 33rd Geological Congress at Oslo in 2008 (Walaszczyk and Wood 2008). The concept was particularly well supported during the Oslo meeting. A presentation of the same proposal (prepared by IW) was given by CJW for discussion at the Cretaceous Subcommission meeting at the end of the 8th International Symposium on the Cretaceous in Plymouth, United Kingdom (September 2009). Comments received during and after both the Oslo and Plymouth meetings encouraged us to present the complete version of the proposal (herein) and, additionally, to prepare a formal report for the Cretaceous Subcommission.

Following the identification of hiatuses in the boundary interval of the Salzgitter–Salder section (Walaszczyk and Wood 1999; Wood *et al*. 2004), intensive work started on other Turonian–Coniacian boundary sections with the aim to find another possible candidate boundary stratotype. Among the sections studied in the greatest detail were the North American sections of Pueblo (Colorado), the Wagon Mound – Springer section (New exico) and, quite recently, the section of Hot Springs Trail in Texas. These studies have shown that none of them is superior to the Salzgitter-Salder–Słupia Nadbrzeżna composite section proposed herein.

The Pueblo section, Colorado, was actually suggested as a possible candidate Turonian–Coniacian boundary stratotype prior to the Brussels Meeting by William A. Cobban (US Geological Survey, Denver), but because it is relatively condensed and the shale intervals between the limestones yield a relatively depleted microbiota, it was withdrawn from serious consideration. Although this section is not as expanded as the Salzgitter-Salder section, it is apparently continuous and, in addition to having a very good inoceramid bivalve record it also yields relatively good ammonite data. The first detailed study of the section was presented by Scott and Cobban (1964). Subsequently, detailed descriptions of the ammonites (Kennedy and Cobban 1991) and inoceramid bivalves (Walaszczyk and Cobban 1999, 2000) were published. Additional stable isotope studies revealed, however, a strong diagenetic overprint of the isotopic signal, and further inoceramid bivalve studies demonstrated that there was a considerable stratigraphical gap very low in the Lower Coniacian (Walaszczyk, Plint and Cobban in prep.).

The Wagon Mound section was another favoured boundary candidate during the Brussels Meeting in 1995. Already in 1999 it was shown, however, that that succession did not range up to the level of the FO of *Cremnoceramus deformis erectus*, which disqualified it from a list of potential stratotype candidates for the base of the Coniacian (Walaszczyk and Cobban 1999, 2000). Nevertheless, Sikora *et al.* (2004), on the basis of microfossil studies, subsequently correlated the section exposed at Wagon Mound with the Turonian–Coniacian boundary succession at Salzgitter-Salder, and, more importantly, suggested the diachronous appearance of *C. deformis erectus*, thereby questioning its usefulness as a boundary marker. However, further study of the succession undertaken by some of us in 2005, after the publication of the Sikora *et al.* (1904) paper, revealed unequivocally that their entire discussion lacked any factual basis and stemmed from the methodological deficiencies inherent in their investigations. Because of the potential influence of their suggestions on the selection of a candidate GSSP, the results of this study of the Wagon Mound–Springer section are presented and discussed in a separate paper (Walaszczyk *et al*. in press).

A huge amount of work has also been done on the Salzgitter-Salder section, subsequent to its formal selection as the favoured candidate in Brussels, 1995 (Kauffman *et al.* 1996), and also on the Słupia Nadbrzeżna section. Our understanding of the inoceramid bivalve biostratigraphy and event stratigraphy of the Turonian–Coniacian boundary succession has improved markedly in recent years, and nannofossil and planktonic foraminiferal biozonations have since been established in both sections (Lees 2008, and this paper; Peryt, this paper). In addition, the carbon stable isotope curves now available (Voigt and Hilbrecht 1997; Voigt, this paper) demonstrate the high correlation potential of the sections. Moreover, the recent record of the traditional basal Coniacian zonal index ammonite *Forresteria petrocoriensis* from the Słupia Nadbrzeżna section (Kennedy and Walaszczyk 2004), enables a revised correlation between the ammonite and inoceramid bivalve zonal schemes.

BOUNDARY CRITERIA

Of the three boundary criteria discussed during the Brussels Meeting [(1) the FO of the ammonite *Forresteria petrocoriensis*; (2) the FO of the inoceramid bivalve species *Cremnoceramus deformis* and/or *C. schloenbachi*; and (3) the FO of *Cremnoceramus rotundatus* (*sensu* Tröger, *non* Fiege)] the one recommended by the Working Group was the FO of *C. rotundatus* (*sensu* Tröger, *non* Fiege). This taxon, which was shown later to be a younger synonym of the American species *Cremnoceramus deformis* and interpreted as its oldest chronosubspecies, *Cremnoceramus deformis erectus* (Meek, 1877) (see Walaszczyk and Wood 1999; Walaszczyk and Cobban 2000), has subsequently (with the exception of Sikora *et al.* 2004) been generally accepted as the basal boundary biomarker. However, the reasoning of the Working Group that this boundary definition preserved the original ammonite definition of the stage (Kauffman *et al*.. 1996), lying between the LO of the ammonite *Prionocyclus germari* (a latest Turonian species) and the FO of *F. petrocoriensis*, is no longer valid. As shown by Walaszczyk and Cobban (1998, 2000; see also Cobban *et al.* 2006), *C. deformis erectus* first appears well above the FO of *Forresteria peruana*, regarded an approximate equivalent of the European *F. petrocoriensis*. The same pattern was then also shown in Europe. The FO of *F. petrocoriensis* in the topmost part of the Upper Turonian *Mytiloides scupini* inoceramid bivalve Zone, well below the FO of *C. deformis erectus*, was demonstrated in the Słupia Nadbrzeżna section, central Poland (Kennedy and Walaszczyk 2004), and in the Aquitaine Basin, southwestern France (Diebold *et al*. 2010).

DESCRIPTION OF THE SALZGITTER-SALDER AND SŁUPIA NADBRZEŻNA SECTIONS

Both sections are located in Central Europe in the marginal portions of the Central European Basins System (see Scheck-Wenderoth *et al.*. 2008 for the Permian and Mesozoic evolution of this system); the Salzgitter-Salder section along its western margin and the Słupia Nadbrzeżna section on the eastern, about 1150 km apart (Text-fig. 1). Although both sections are located within the same basin system, they evolved within separate basins; the Salzgitter-Salder section in the NW–SE oriented Lower Saxony Basin and the Słupia Nadbrzeżna section in the similarly NW–SE oriented Mid-Polish Basin. Both basins were affected eventually by Late Cretaceous–Paleogene uplift (see Scheck-Wenderoth *et al.* 2008). Biogeographically the entire area of Central Europe belonged to the North European Province (according to Kauffman's 1973 biogeographic subdivision).

Salzgitter-Salder

Location

The quarry is located south of the motorway A39, between the town of Braunschweig and the Autobahn

Text-fig. 1. Location of the Salzgitter-Salder and Słupia Nadbrzeżna sections on a geological sketch-map of central Europe, with Cretaceous strata shown in green junction 'Salzgitter', near the exit to the village of Salzgitter-Salder (Lower Saxony, Germany). The quarry is situated in the southern, steeply dipping (c. 70º) flank of the asymmetrical Lesse Syncline, adjacent to the Lichtenberg structure (Text-fig. 2a). The asymmetry of the Lesse Syncline resulted from halokinetic movements of the Broistedt-Wendeburg salt-diapir and contemporaneous uplift of the Lichtenberg structure.

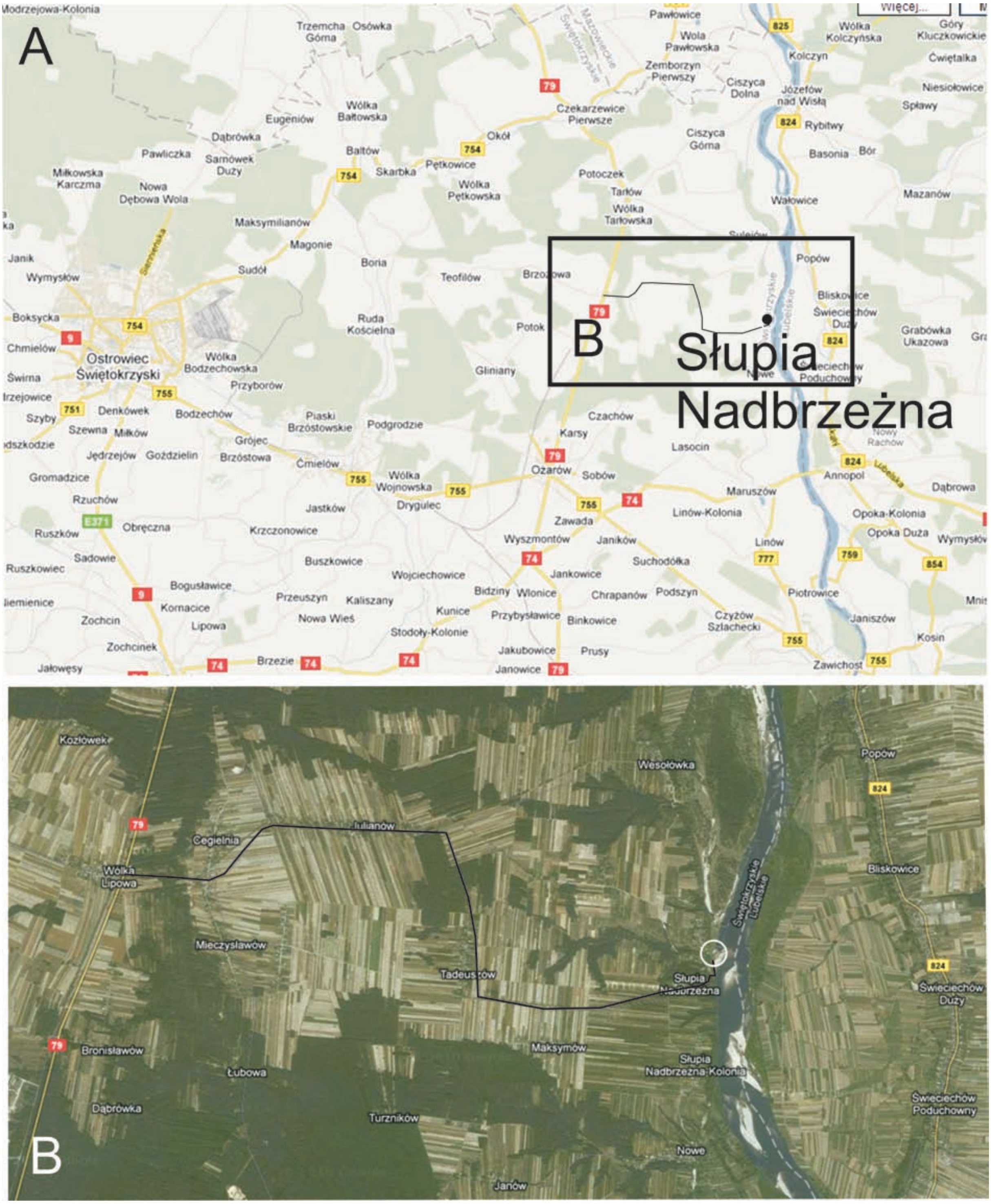
Litho- and event-stratigraphy

The 750 m long Salzgitter-Salder limestone quarry of Fels-Werke Peine Salzgitter GmbH lies parallel to the strike and exposes a c. 220 m thick Middle Turonian–Lower Coniacian succession of well-bedded carbonate rocks belonging to the Salder and Erwitte formations of the current lithostratigraphic framework (see Niebuhr *et al*. 2007, Wiese 2009). The Upper Turonian and Lower Coniacian part of the succession is subdivided, in ascending order, into four members: (1) Lower Limestone Member; (2) 'Grauweisse Wechselfolge' or Grey and White Alternation Member; (3) Upper Limestone Member; and (4) Transition Member. The succession can be additionally subdivided by means of numerous litho-, tephro- and eco-events, several of which occur throughout northwestern Germany (Ernst *et al.* 1983), with some ranging to England (Wood *et al.* 1984), Spain (Küchler and Ernst 1989; Wiese 1999) and even as far afield as western Kazakhstan (Marcinowski *et al*. 1996) and the US Western Interior (Walaszczyk and Cobban 1999, 2000; see also Walaszczyk 2000).

Turonian–Coniacian boundary

The Turonian–Coniacian boundary succession, as characterized herein, spans the middle and upper part of

Text-fig. 2. Locality maps of the Salzgitter-Salder (a) and Słupia Nadbrzeżna (b) sections the ‘Grauweisse Wechselfolge’ Member and the lower part of the overlying Upper Limestone Member. The discussion which follows focuses on the boundary interval, which embraces an inoceramid bivalve-dominated, fossil-rich interval, understood herein as ranging from Bed 39, the level of the *Didymotis* I Event, to Bed 53, the level of the *erectus* III Event (Text-fig. 3). Thus defined, it embraces a whole series of events characterizing the Turonian–Coniacian boundary in the Salzgitter-Salder section, including most of those referred to



Text-fig. 2. Locality maps of the Salzgitter-Salder (a) and Słupia Nadbrzeżna (b) sections when discussing the location of this boundary. The event succession was established and characterized by Ernst *et al.* (1983), Wood *et al.* (1984), Ernst and Wood (1995, 1998), Kauffman *et al.* 1996 and Walaszczyk and Wood (1999); the most recent update, correcting errors in some of the previous references, if that of Wood *et al.* (2004).

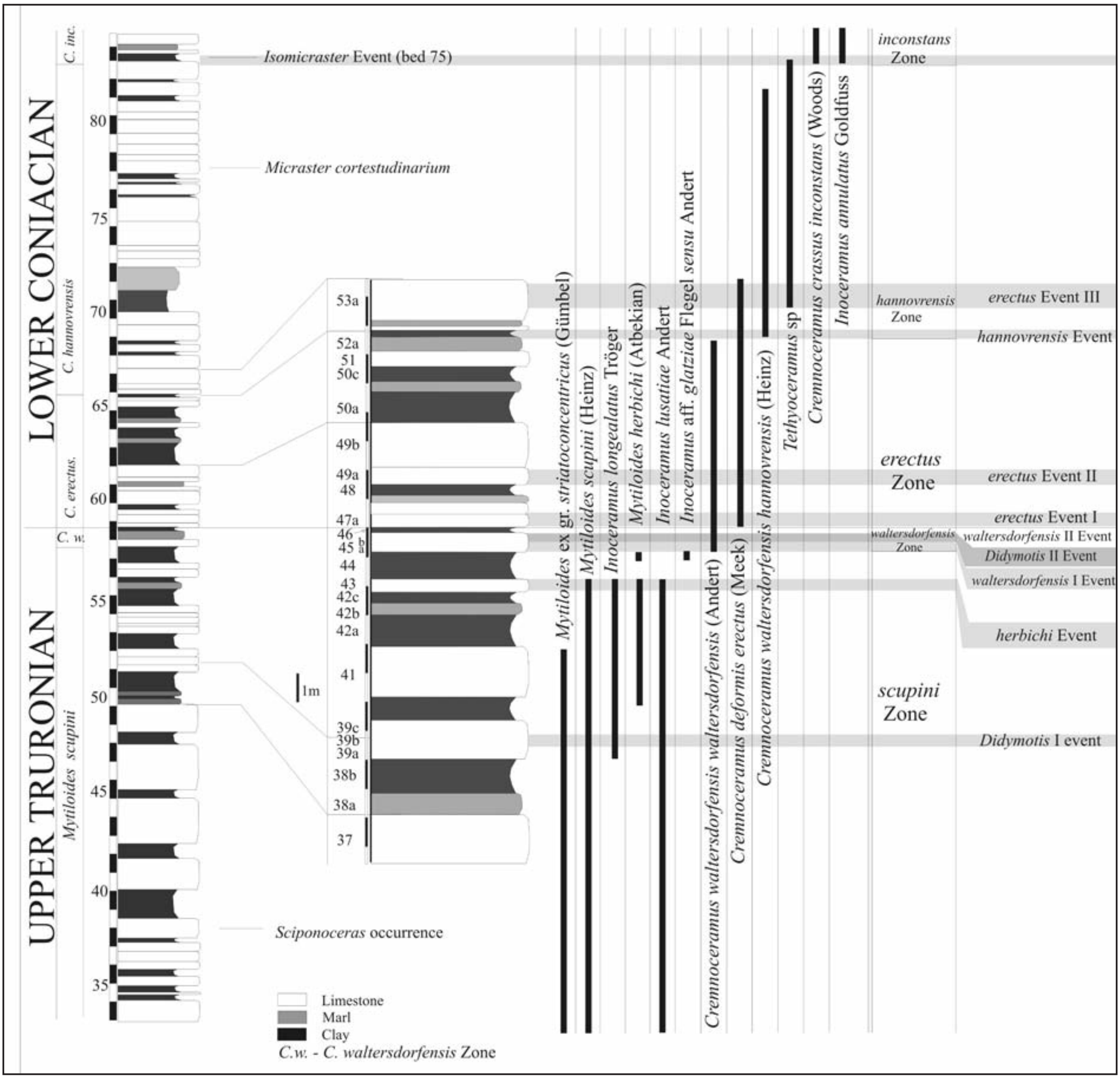
Słupia Nadbrzeżna

Location

The Słupia Nadbrzeżna Turonian–Coniacian boundary section forms part of the expanded Upper Cretaceous succession of the Middle Vistula River section, and is exposed in the western Vistula river cliff in the village of Słupia Nadbrzeżna, about 180 km south of Warsaw (Text-fig. 2b; see a;sp Walaszczyk 1992; Walaszczyk and Wood 1999). The section is a natural exposure, about 10 m high, immediately to the north of a small valley entering the Vistula valley in the village. The state of the exposure is poor and every visit requires some prior excavation before the succession can be studied.

Litho- and event-stratigraphy

No formal lithostratigraphy was proposed for this part of the Middle Vistula Upper Cretaceous succession. Informally, it is level *a* of Pożaryski (1938). The Tur-



Text-fig. 3. Litholog, bio- and event stratigraphy and inoceramid bivalve distribution of the Salzgiter-Salder section onian–Coniacian succession is marked by a series of bioevents, equivalent to those recognized in the Salzgitter-Salder section.

Turonian–Coniacian boundary

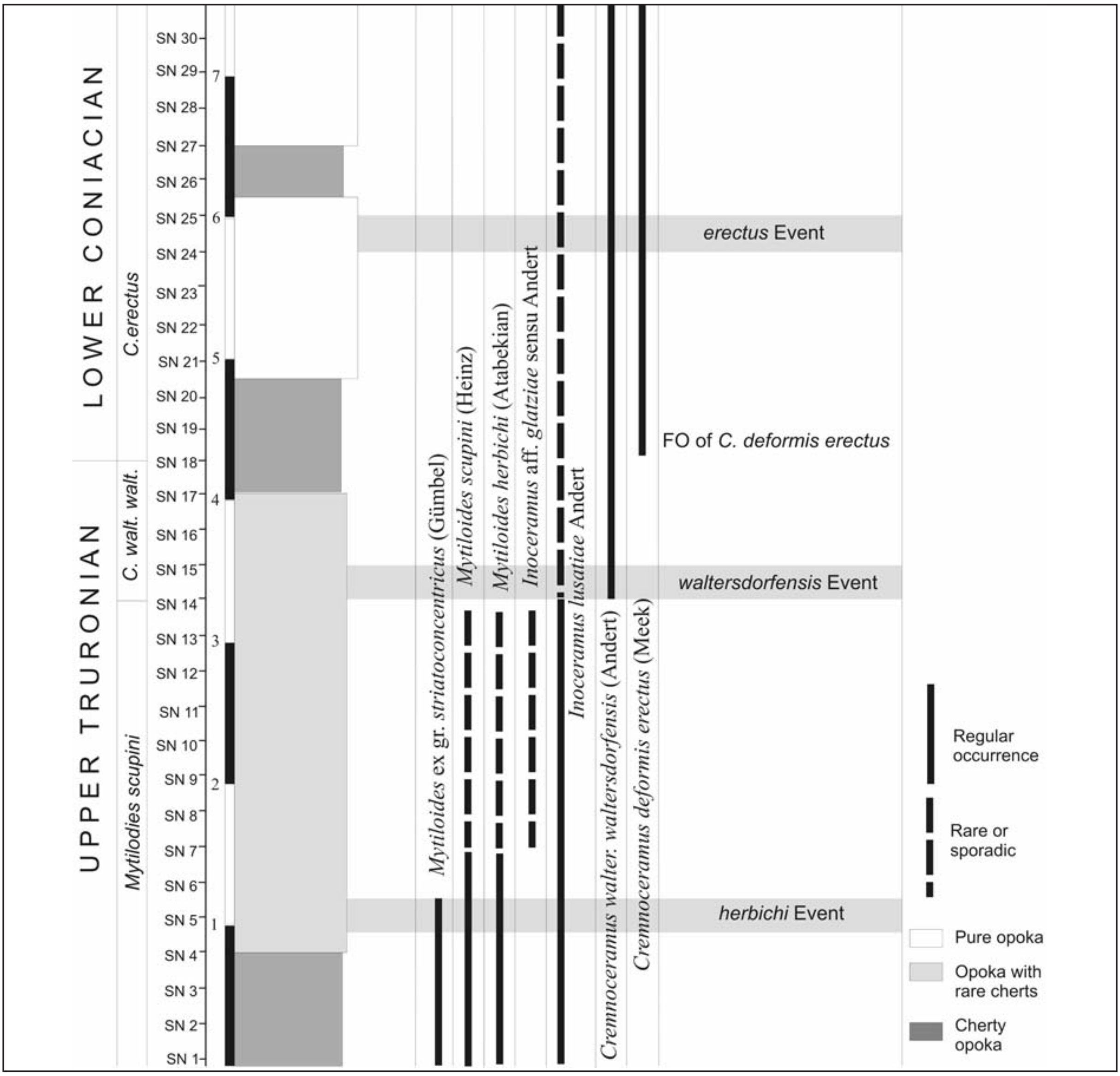
The Turonian–Coniacian boundary interval, easily accessible in the Słupia Nadbrzeżna section, ranges between the *Mytiloides herbichi* and *Cremnoceramus erectus* I events. The succession exposed complements the interval at Salzgitter-Salder where there is a hiatus between the *Cremnoceramus waltersdorfensis* II and *C. erectus* I events, and also the interval where there is a gap immediately below the *C. waltersdorfensis* I Event (Wood *et al.* 2004) (Text-fig. 4).

FOSSIL SUCCESSION

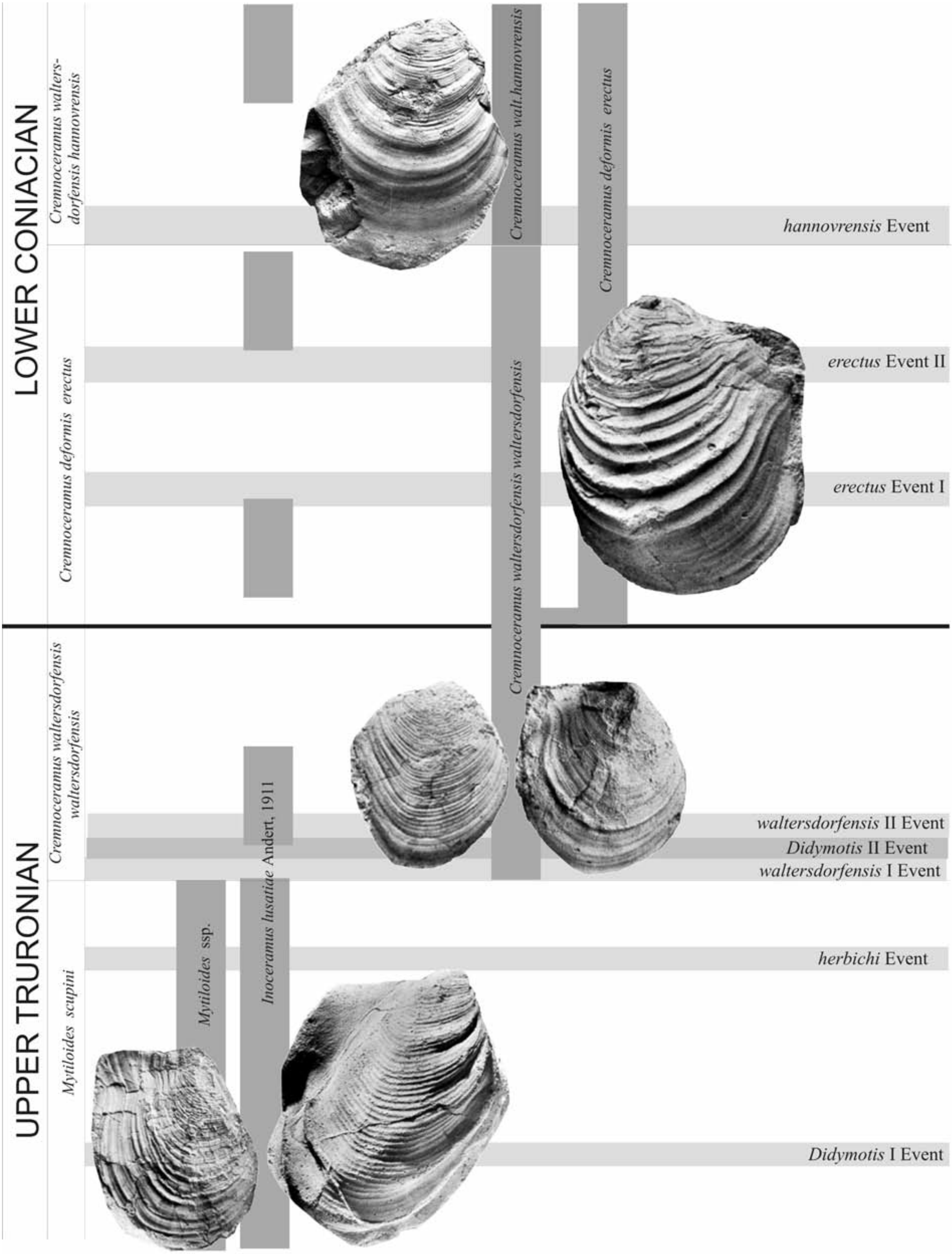
Inoceramid bivalves (I. Walaszczyk and C.J. Wood)

The study of inoceramid bivalves from the Salzgitter-Salder and Słupia Nadbrzeżna sections was presented earlier and the reader is referred to Walaszczyk and Wood (1999) and Wood *et al.* (2004) for details. The following brief summary of the inoceramid succession includes more recent observations and discusses the correlation potential of the group (Text-figs 3–5).

In the Salzgitter-Salder section, inoceramid bivalves occur in abundance, starting with Bed 39 in the 'Grauweisse Wechselfolge' Member and ranging to the top of the succession discussed above and below; below



Text-fig. 4. Litholog, bio- and event stratigraphy and inoceramid bivalve distribution of the Słupia Nadbrzeżna section



Text-fig. 5. Inoceramid and *Didymotis* bivalve succession across the Turonian–Coniacian boundary interval

Bed 39 the succession is relatively poorly fossiliferous. It is worthy of note that the interval below Bed 39 is the upper part of an expanded, c. 50 m thick, poorly fossiliferous succession spanning much of the upper Upper Turonian (Wood *et al.* 1984), and that correlatives of this interval are represented in the Słupia Nadbrzeżna section as well as in the US Western Interior (Walaszczyk and Cobban 1999, 2000).

The inoceramid record of the boundary interval is quite well known and mostly quite well understood. The lowermost part of the interval, Beds 39 to 43, is dominated by *Mytiloides scupini* (Heinz, 1930), *M. herbichi* (Atabekian, 1969) and *Inoceramus lusatiae* Andert, 1911, all of which are taxa characterizing the late Late Turonian *Mytiloides scupini* Zone. There is an abrupt turnover of the inoceramid bivalve fauna in limestone Bed 45a, with a total disappearance of *Mytiloides* and the mass appearance of *Cremnoceramus waltersdorfensis* (Andert, 1911), the zonal index of the terminal Turonian *Cremnoceramus waltersdorfensis waltersdorfensis* Zone. This taxon is the oldest representative of the *Cremnoceramus* clade, which then dominates the inoceramid fauna during most of the Early Coniacian.

In the Słupia Nadbrzeżna section between the *herbichi* and *waltersdorfensis* events there is a 2.5 m thick succession with at least two horizons with distinct inoceramid faunas (Wood *et al*. 2004). The lower one, approximately 0.3 m above the *herbichi* Event, is characterized by rare *M. herbichi*, *I. lusatiae* and a form which was referred to tentatively (Wood *et al*. 2004) as *Inoceramus* aff. *glatziae* sensu Andert, 1911. The higher horizon, c. 1 m above the *herbichi* Event, is characterized by common *I. lusatiae* and was referred to as the *lusatiae* Event (Wood *et al*. 2004). In the interval which follows, up to the *waltersdorfensis* Event, inoceramids are very rare.

It is noteworthy that the *Cremnoceramus* clade appears suddenly at this level, without any apparent ancestors in the underlying succession either at Salzgiter-Salder or in correlative successions elsewhere. *Cremnoceramus waltersdorfensis* shows very slow anagenetic change up to Bed 52, where a clear shift towards a more elongated morphotype is noted. Accordingly, two chronosubspecies of *C. waltersdorfensis* were distinguished, the older, nominative one, and *hannovrensis*, the younger. Beds 45a and the Marl Bed 46 actually contain monospecific accumulations of the older subspecies, *C. w. waltersdorfensis*, constituting the *waltersdorfensis* I and II events, respectively. The intervening limestone Bed 45b is virtually devoid of macrofossils apart from limonitised sponges.

For the boundary discussion, the most important event took place at the base of limestone Bed 47, the level of the FO of *Cremnoceramus deformis erectus*. The subspecies *erectus* is an older chronosubspecies of the *Cremnoceramus deformis* lineage (see Walaszczyk and Wood 1999; Walaszczyk and Cobban 2000), which is inferred to have branched off from the *waltersdorfensis* lineage relatively early in the history of the *Cremnoceramus* clade.

Comparison of the boundary record in the Salzgitter-Salder and Słupia Nadbrzeżna sections shows, however, that the direct succession of the *waltersdorfensis* II Event (Bed 46) and the *erectus* I event (Bed 47) in the former section results from condensation and/or a hiatus (Walaszczyk and Wood 1999; Wood *et al*. 2004). In the latter section, the *waltersdorfensis* and the *erectus* I events are separated by c. 2.0 m thick interval with the FO of *C. deformis erectus* about 0.7 m above the top of the *waltersdorfensis* Event, and its upper part dominated by C. *w. waltersdorfensis* accompanied by rare *C. deformis erectus*.

Another hiatus and/or condensation was shown to be associated with the top of the marl Bed 44 (Wood *et al.* 2004), which locally contains crushed specimens of the provisionally named *I.* aff. *glatziae* Flegel *sensu* Andert 1911, a form that has not been recorded from either below or above this level. Elsewhere in the quarry these inoceramids were apparently absent from this level, suggesting that perhaps they were locally preserved from erosion in depressions in the top of the otherwise apparently unfossiliferous Bed 44.

Didymotis **(C.J. Wood and I. Walaszczyk)**

The thin-shelled bivalve genus *Didymotis* is a significant component of the faunas across the Turonian–Coniacian boundary succession. It should be noted that, in well-preserved examples, the shell of this genus shows the same prismatic structure as is found in true inoceramid bivalves and it remains open to question whether or not *Didymotis* and its presumed precursor *Sergipia* should not be more correctly classified here. However, the thin shell in Salzgitter-Salder material is usually incompletely preserved at best, the majority of specimens constituting composite moulds.

Salzgitter-Salder

The lowest (rare) records of *Didymotis* from Salzgitter-Salder are from Bed 29 (Wood *et al.* 2004); these may equate with the *Didymotis* 0 Event identified at or near this level by Wiese and Kröger (1998).Despite intensive search, the latter horizon with this event occurrence of *Didymotis* has subsequently not been located. *Didymotis* occurs in relative abundance in Bed 39, where it is associated with three inoceramid bivalve taxa, *Inoceramus lusatiae*, *Mytiloides herbichi* and *M. scupini*. This occurrence constitutes the *Didymotis* I (DI) Event. The DI morphotype is characterized by broadly rounded, thick commarginal rugae, with relatively wide interspaces and little or no radial ornament; this, or a similar morphotype, is represented by the material collected from the *Didymotis* 0 Event (see Wiese and Kröger 1998) and subsequently studied by us. There is an apparent gap in the record from the DI event in Bed 39 up to the limestone Bed 45a, in which *Didymotis* occurs in abundance together with a monospecific occurrence of the inoceramid bivalve *Cremnoceramus w. waltersdorfensis*. This occurrence of *Didymotis* is coincident with the first occurrence of the genus *Cremnoceramus* and constitutes the DII event. In the original report of this event (Wood *et al.* 1984), it was suggested that the occurrence was restricted to a single bedding plane at the top of Bed 45 but subsequent, more detailed collecting has shown not only that this surface represented the top of Bed 45a, but that *Didymotis* occurs already at the base of this bed. It therefore appears that there is not a single horizon that can be called the DII event but instead this *Didymotis* event and the first *Cremnoceramus* flood event coincide in Bed 45a. The DII *Didymotis* morphotype is typically larger and posteriorly more elongate than the DI morphotype and is additionally characterized by finer, sharper and more closely spaced commarginal rugae that are crossed by a more or less strongly developed radial ribs. The DII morphotype is closely related to or conspecific with *Didymotis costatus* (Fritsch, 1893). At Salzgitter-Salder the DI and DII (*costatus*) morphotypes are relatively distinct and stratigraphically sharply separated but this appears not to be the case in Bohemia (Czech Republic), where *Didymotis* has a considerable stratigraphical range in the top Turonian and the two morphotypes are linked by transitional forms.

Above the DII Event, there are unconfirmed rare occurrences of *Didymotis* in the spongiferous but otherwise more or less barren limestone Bed 45b [IW]. The highest *Didymotis* record is a single large specimen from the topmost Turonian marl Bed 46 in the G. Ernst Collection. Wood (in Kauffman *et al.* 1996) additionally recorded rare *Didymotis* from the basal Coniacian Bed 47 but this Coniacian record remains to be substantiated. At Salzgitter-Salder there are no records of the undescribed giant form that is known from the Lower Coniacian of both Słupia Nadbrzeżna and the Sergipe Basin in Brazil.

Słupia Nadbrzeżna

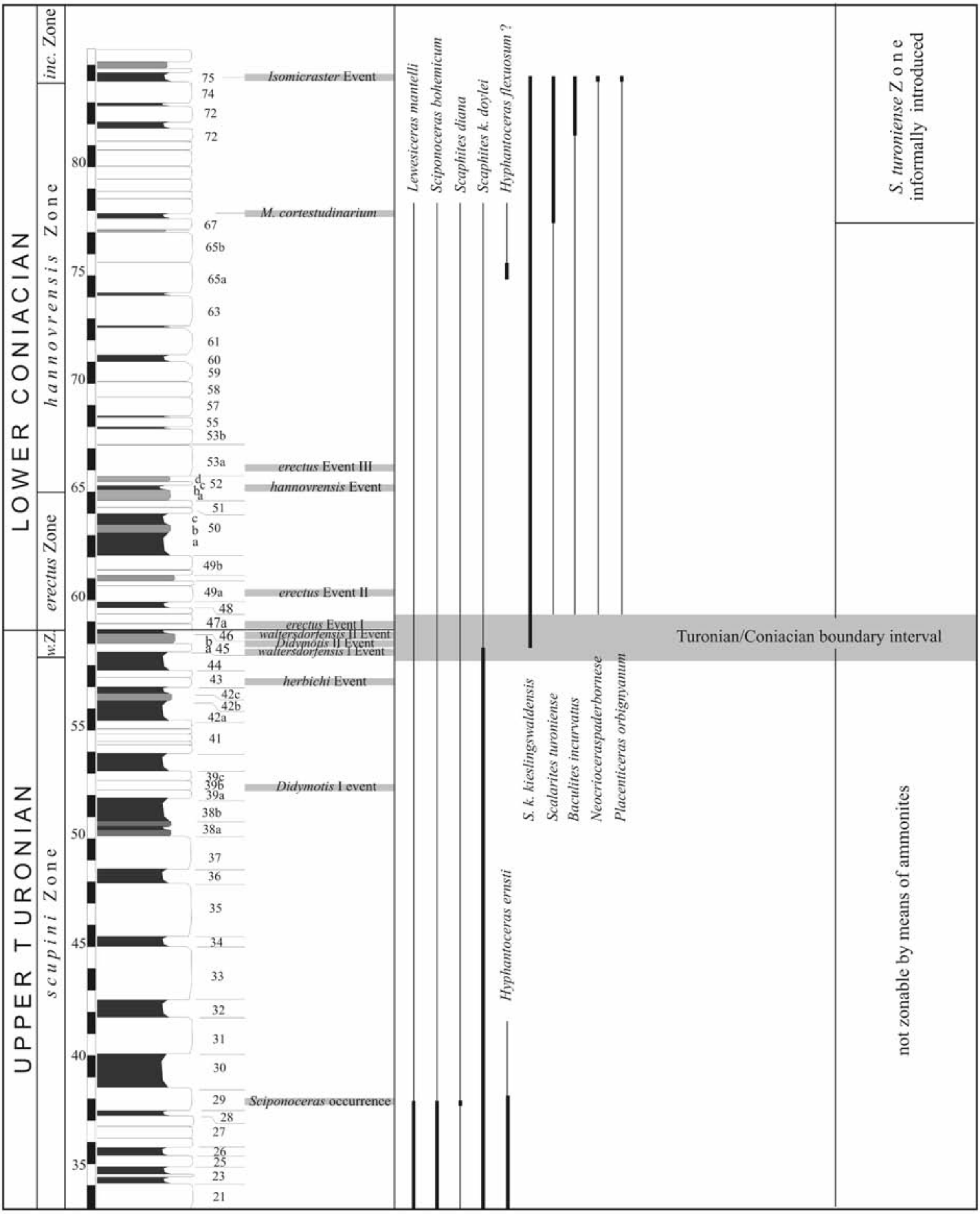
In the Słupia Nadbrzeżna section, *Didymotis* occurs in the succession below the bed with abundant *C. w. waltersdorfensis* that correlates with Bed 45 at Salzgitter-Salder. In contrast to Salzgitter-Salder, however, *Didymotis* at these levels shows both strong and weak to very weak radial ribbing, and there is no clear distinction between the DI and DII (*costatus*) morphotypes. *Didymotis* close to *D. costatus* occurs throughout the *waltersdofensis* Event bed in association with a monospecific occurrence of *C. w. waltersdorfensis*, as at Salzgitter-Salder. The undescribed Lower Coniacian giant form of *Didymotis* occurs in the topmost part of the *C. deformis erectus* Zone, where it appears to be limited to a single bed. There are no records of *Didymotis* in the intervening succession.

Ammonites (F. Wiese)

Ammonites are not particularly abundant throughout the Salzgitter-Salder section (Middle Turonian to Lower Coniacian), and only in some event beds (e.g. the *Hyphantoceras* Event) do ammonites occur in abundance (see Dahmer and Ernst 1986; Wood and Ernst 1998). This is typical of the entire Lower Saxony and Saxony-Anhalt areas, where Upper Turonian to Lower Coniacian strata are exposed in several sections but these have yielded only small numbers of ammonites. Consequently, there have been only few taxonomic and stratigraphic studies of Turonian–Coniacian ammonite faunas from these areas. In addition to Schlüter (1871–1876), Zimmermann (1914), Kaplan *et al.* (1987), Kaplan and Schmid (1988) and Wiese (2000) provided palaeontological accounts, while occurrences and stratigraphic ranges of Turonian–Coniacian ammonites from Lower Saxony were discussed by e.g. Wood *et al.* (1984), Ernst and Wood (1995) and Wood and Ernst (1998). The good inoceramid bivalve biostratigraphic and event-stratigraphic correlation to Westphalia (e.g. Wood *et al.* 1984) enables the application of the ammonite zonation established there on diverse ammonite assemblages (Kaplan 1986, 1988; Kaplan and Kennedy 1994, 1996) to the Lower Saxony and Saxony-Anhalt successions, and to the Salzgitter-Salder section in particular.

The ammonite ranges of the Salzgitter-Salder section have previously been published by Wood and Ernst (1998), but there exists no detailed and high- resolution bed-by-bed record of ammonites in the Turonian–Coniacian boundary interval. This is mainly due to the fact that ammonites are rare in this interval and, in addition, are difficult to extract from the hard and splintery limestones. Also, the main palaeontological focus has been on the inoceramid bivalves because of their high abundance. Ammonite preservation is often poor and fragmentary. Moreover, compression and pressure solution have commonly obscured morphological details so that identification, especially of scaphitids and baculitids, is often uncertain.

The data summarized here (Text-fig. 6) present a synthesis of ammonite records and ranges obtained from the literature (Wood and Ernst 1998; Wiese 2000), supplemented by some new finds, mostly collected from scree and thus not of immediate significance to the boundary discussion. However, these finds provide additional data on ammonite assemblages of the Salzgit-



Text-fig. 6. Ammonite distribution in the Turonian–Coniacian boundary interval of the Salzgiter-Salder section ter-Salder section and enable comparison with other localities. The G. Ernst Collection of the Salzgitter-Salder quarry, now housed at the Museum für Naturkunde, Berlin, has only recently been made accessible again. Well-labelled material in the collection is currently being reinvestigated in order to pinpoint individual ammonite occurrences in the boundary interval for future publication. In this overview, ranges of taxa are indicated by bars, providing a good impression of the ammonite succession and the LO/FO of species in the immediate boundary interval (Text-fig. 6).

Bed 29–Bed 46 (terminal *Mytiloides scupini* and *Cremnoceramus waltersdorfensis* inoceramid bivalve zones)

The Upper Turonian part of the boundary interval is characterized by a scaphitid/baculitid ammonite assemblage. *Scaphites geinitzii* (d'Orbigny, 1850) and *S. kieslingswaldesis doylei* (Wright, 1979) are recorded, but are not particularly common. Commoner, albeit not abundant, are poorly preserved fragments of baculitids, which probably belong mostly to *Sciponoceras bohemicum* (Fritsch, 1872). However, as *Baculites* enters the stratigraphic record in the Upper Turonian *Subprionocyclus neptuni* Zone (Wright 1979), a careful taxonomic reassessment of the baculitid material in the G. Ernst Collection may well reveal the occurrence of that genus, in addition to *Sciponoceras*. The *Sciponoceras* occurrence in Bed 29 yielded, apart from *S. bohemicum*, *Scaphites diana* (Wright, 1979) and *Hyphantoceras ernsti* Wiese, 2000. The LO of *Lewesiceras mantelli* (Wright and Wright, 1951) in the section falls in an interval between the *Sciponoceras* occurrence and *Didymotis* Event I (Bed 39), and *S.* cf. *diana* is recorded from the base of Bed 35 (Ernst and Wood 1995). *Scaphites k. kieslingswaldensis* Langenhan and Grundey, 1891 makes ist first appearance in Bed 45.

Base Bed 47a (Turonian–Coniacian boundary)

The Turonian/Coniacian boundary is taken at the FO of *Cremnoceramus deformis erectus in* Bed 47a (*erectus* Zone in Text-fig. 6; Walaszczyk and Wood 1999). From this bed, Ernst and Wood (1998) did not record any ammonites.

Bed 47–Bed 74 (*Cremnoceramus deformis erectus* and *C. waltersdorfensis hannovrensis* zones)

While no changes in the ammonite assemblages compared to those in the underlying beds can be seen in the *C. deformis erectus* Zone, a new ammonite assemblage becomes established progressively in the middle portion of the succeeding *hannovrensis* Zone. It consists of *Scaphites k.kieslingswaldensis*, *Scalarites turoniense* (Schlüter, 1872) (FO Bed 67) and *Neocrioceras paderbornensis* (Schlüter, 1872) (FO Bed 75). There is one specimen of *Placenticeras orbignyanum* (Geinitz, 1849) from the Ernst collection, labelled "4 m below *cortestudinarium* Event", which corresponds to a level around Bed 63. *Baculites brevicosta* Schlüter, 1876 has been collected loose below beds 72 and 75.

Hyphantoceras flexuosum (Schlüter, 1872) was recorded from Bed 65 by Wood and Ernst (1998), but the specimen on which this record is based has not been traced in the G. Ernst Collection. There is one specimen of *Hyphantoceras* from the Kahnstein area at Langelsheim, 20 km south of Salzgitter-Salder, in that collection (material from the diploma thesis of Liever 1980, labelled "Profil 11, Schicht 9"), which may represent something close to *H. flexuosum*. From this interval, Liever (1980) reported *Cremnoceramus* cf. *erectus* and *Cr. waltersdorfensis*, indicating an Early Coniacian age, which fits stratigraphically with the record from Salder. However, the specific identification remains problematic due to the poor preservation of the specimen. Given the great similarity of *H. ernsti* and *H. flexuosum* (see Wiese 2000), Lower Coniacian records of *H. flexuosum* should be treated with care. Stratigraphically well-constrained finds of *H. flexuosum* have so far been recorded exclusively from the lower *scupini* Zone in Lower Saxony (Wiese 2000). Specimens from Westphalia, identified as *H. flexuosum* (see Kaplan and Schmid 1988; Kaplan and Kennedy 1996) are in fact *H. ernsti* Wiese, 2000. The latter species is not uncommon in the *scupini* Zone of Lower Saxony; at Salzgitter-Salder it has been collected from beds 9, 13, 15, 21 and 29. The lectotype of *H. flexuosum* was labelled "*cuvieri*-Pläner of Windmühlenberg near Salzgitter" by Schlüter (1872). The locality name probably refers to one of a number of now filled quarries in Salzgitter-Bad. As the stratigraphic position of the *cuvieri*-Pläner covers an interval from the Upper Turonian *scupini* Zone into the Lower Coniacian, the horizon from which the lectotype was collected is impossible to reconstruct.

Ammonite zonations and the Turonian–Coniacian boundary at Salzgitter-Salder

In northern Germany, the uppermost Turonian can be defined by a *Prionocyclus germari* Zone (see discussion and interbasinal correlation in Kaplan and Kennedy 1996). However, the main occurrence of this taxon in northern Germany is largely restricted to the lower part of its range, corresponding to the lower but not lowermost part of the *Mytiloides scupini* Zone, from which only a single fragment has been collected to date at Salzgitter-Salder (Bed 17; Wiese 2009). A comparable range is recorded from the Western Interior of the USA (Walaszczyk and Cobban 2000). The distinction by Robaszynski *et al.* (1990) of a *germari* Zone, representing the entire Upper Turonian in the Kalaat-Senan area of Tunisia, might, therefore, be open to question. Only in the Czech Republic does *Prionocyclus germari* (Reuss, 1845) range as high as the base of the terminal Turonian *waltersdorfensis* Zone (Čech 1989; Čech and Švábenická 1992). A record of *P. germari* from the Turonian–Coniacian boundary interval in the Brzeżno area (central Poland) is doubt, because the specimen illustrated (Kaczorowski 2000, p. 245, fig. 3) is most likely not a *Prionocyclus* but a fragment of a desmoceratid.

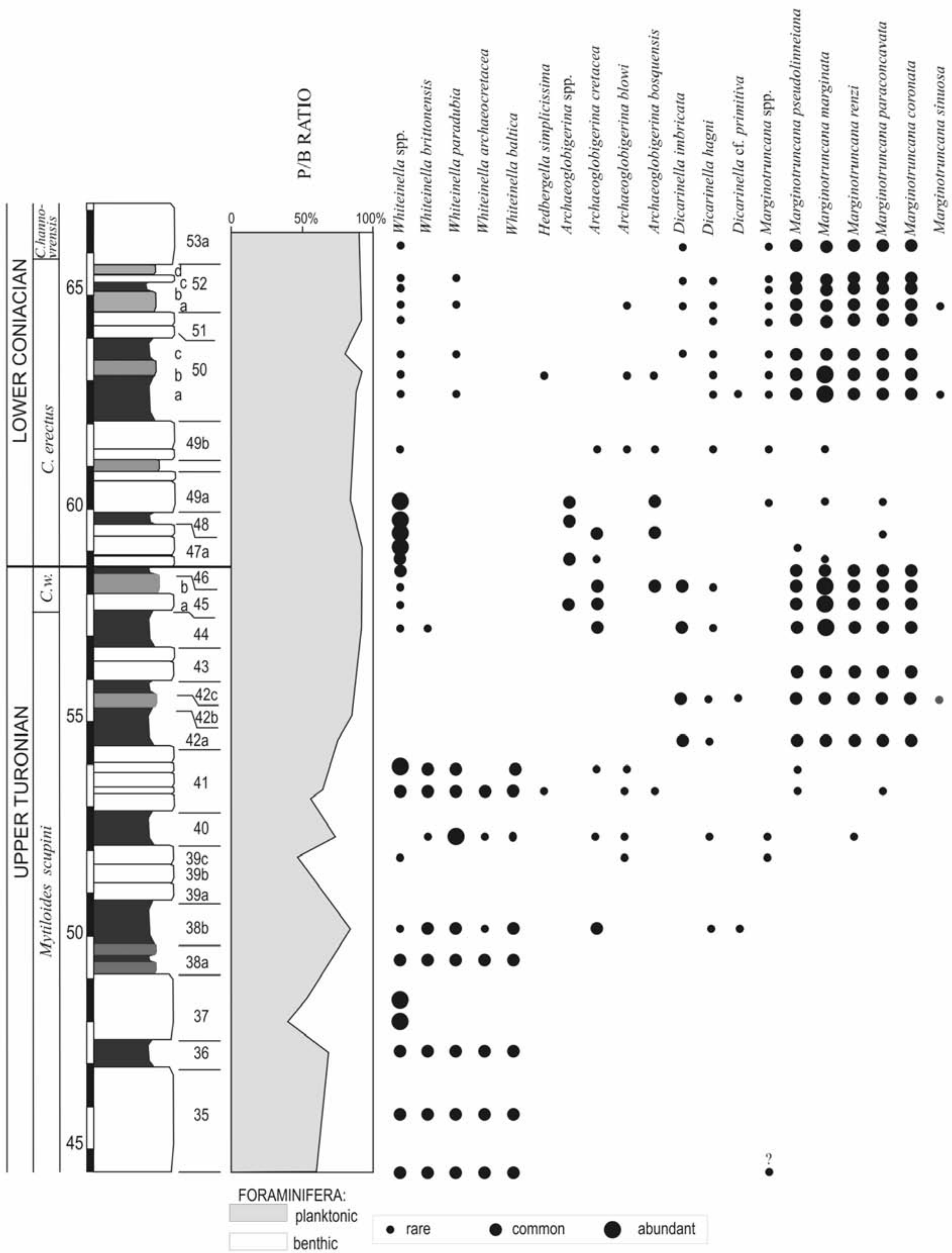
The base of the Coniacian has traditionally been placed at the FO of *Forresteria petrocoriensis* (see e.g. Kennedy 1984a, b; Kennedy *et al*. 1995), which falls in northern Germany and Spain in the *hannovrensis* Zone (e.g. Kaplan and Kennedy 1994, 1996; Küchler 1998). A detailed discussion of its stratigraphic position in northern Germany (Westphalia), in an interbasinal context, was provided by Kaplan and Kennedy (1996, fig. 26) (see also Kauffman *et al*. 1996). However, as recently shown by Kennedy and Walaszczyk (2004), the FO of *F. petrocoriensis* falls in the upper part of the *scupini* Zone and thus into the high, but not terminal, Upper Turonian in terms of inoceramid bivalve stratigraphy. This is also the case for other representatives of the genus (*F. peruana*, *F. brancoi*, and *F. hobsoni*), the first two of which occur in the US Western Interior in the *scupini*, while te last-named makes its first appearance in the *waltersdorfensis* Zone (Walaszczyk and Cobban 2000). This shows that, on a global scale, neither the species *F. petrocoriensis* nor the genus *Forresteria* can be used as a reliable boundary proxy. In conclusion, there is so far no reliable ammonite datum which can be used to define the base of the Coniacian at the approximate level of the boundary as defined by inoceramid bivalves. However, the upper Lower Coniacian *Peroniceras tridorsatum* Zone, inferred to be approximately time-equivalent with the *crassus*/*deformis* Zone (Kaplan and Kennedy 1994; Walaszczyk and Wood 1999), is an interval that is readily distinguishable in various basins of Europe (Kennedy 1984b; Hancock 1991; Kaplan and Kennedy 1994; Küchler 1998) and is, therefore, of value for correlation.

At Salzgitter-Salder, none of the typical Lower Coniacian *Forresteria* and *Peroniceras* known from Westphalia (Kaplan and Kennedy 1994) and other European basins (see references above) are represented, thus preventing any ammonite zonation of this interval. *Scaphites kieslingswaldensis* is recorded from the Upper Turonian *scupini* Zone and ranes well into the Lower Coniacian, and it is possible that the individual subspecies may have some chronostratigraphic significance. *Scaphites k. doylei* seems to be restricted to the Upper Turonian at Salzgitter-Salder. The last occurrences are recorded from just below the T/C boundary by Wood and Ernst (1998), from around Bed 45. The first *Scaphites* believed to represent true *S. k. kieslingswaldensis* comes from Bed 45, only a short distance below the T/C boundary. The last occurrence of S. *k. doylei* and the entry of the nominate subspecies may, therefore, be taken as proxies for the boundary at Salzgitter-Salder but not as definitive biomarkers. In the absence of *Forresteria*, the FO of *Scalarites turoniense* around Bed 67 (*hannovrensis* Zone) and the new ammonite assemblage that becomes progressively established above this level may indicate the assemblage that characterizes the *petrocoriensis* Zone as defined in Westphalia (Kaplan and Kennedy 1994). However, as noted above, the FO of the zonal index is in the Upper Turonian *scupini* Zone and consequently the concept of a *petrocoriense* Zone beginning well above the base of the Coniacian is no longer valid. In this context, it may prove worthwhile to establish a *Scalarites turoniense* ammonite Zone of merely regional significance (Westphalia, Lower Saxony), to span the interval from the lower *hannovrensis* Zone to the base of the *crassus*/*deformis* Zone.

The ammonite fauna of the Turonian–Coniacian boundary interval at Salzgitter-Salder is characterized by a scaphitid/baculitid ammonite assemblage and the total absence of any of the biostratigraphically significant representatives of the Collignoniceratidae used for zonation of terminal Turonian and Lower Coniacian successions elsewhere. Collignoniceratid ammonites can neither be used to delimit the base of the Coniacian precisely at Salzgitter-Salder nor to provide any ammonite-stratigraphic proxy for the boundary interval. In ca. 30 years of careful bed-by-bed collecting in the Salzgitter-Salder section, not a single collignoniceratid ammonite has been collected in and above the boundary interval. The absence of collignoniceratid ammonites in this interval may perhaps be attributable to a deeper-water setting at Salzgitter-Salder than that represented by the correlative ammonite-bearing strata in Westphalia. It is therefore unlikely that any collignoniceratid ammonites will be found by further intensive focused collecting in the context of the GSSP proposal.

Planktonic foraminifera (D. Peryt)

Planktonic foraminifera from the Słupia Nadbrzeżna section were discussed previsouly within the context of



Text-fig. 7. Stratigraphical distribution of planktonic foraminifera and P/B ratio in the Upper Turonian – lowermost Coniacian boundary interval in the Salzgitter-Salder section a wider study of an integrated inoceramid bivalve-foraminiferal biostratigraphy of the early Late Cretaceous of the Middle Vistula River section (Walaszczyk and Peryt 1998). The results of a study of a new set of samples from this locality are shown in Text-figs 11–15. This study enabled a revision of the ranges of some species. Also included in the range chart are taxa that were not listed in the 1998 report (*Dicarinella concavata*; *Archaeoglobigerina cretacea*, *Hedbergella delrioensis*, *Hedbergella simplex*, *Heterohelix globulosa*, *Whiteinella brittonensis*, and *Sigalitruncana sigali*). In addition, the P/B ratio (relative abundances of planktonic and benthic foraminifera in the assemblages) has been calculated for the interval studied. The following discussion concentrates thus on the Salzgitter-Salder section.

Salzgitter-Salder section

Thirty-two samples from a 21 m-thick sequence (Text-fig. 7) were studied for planktonic foraminifera. Washed residues were obtained by disaggregating the rocks with Na_2SO_4. 400–500 specimens from the >100 µm size fraction were picked and all species in each sample identified; P/B ratios were also calculated. The results are presented in Text-fig. 7. Selected species are illustrated in Text-figs 8–10. The classification used follows Robaszynski *et al*. (1979), Caron (1985), Loeblich and Tappan (1987) and Premoli Silva and Verga (2004). Material illustrated is housed at the Institute of Palaeobiology, Polish Academy of Sciences, Warsaw (abbreviation: ZPAL F. 60).

The Turonian–Coniacian boundary interval in the Salzgitter-Salder section yields abundant planktonic foraminifera. However, their preservation is poor due to diagenetic recrystallization which was extensive in the limestones and moderate in the marlstones. The P/B ratio in the lower part of the studied interval fluctuates significantly (40%–80%); in the upper part it is very high and almost stable (80%–90%). The planktonic foraminiferal assemblages are low to moderately diverse, with more than twenty species recorded (Text-fig. 7). They are represented mainly by cosmopolitan globigerine-shaped whiteinellids and double-keeled marginotruncanids, while other genera are minor constituents.

Whiteinella is common to abundant throughout the interval studied. It is represented by the following species: *W. brittonensis* (Loeblich and Tappan), *W. paradubia* (Sigal), *W. archaeocretacea* Pessagno, *W. aprica* (Loeblich and Tappan) and *W. baltica* Douglas and Rankin.

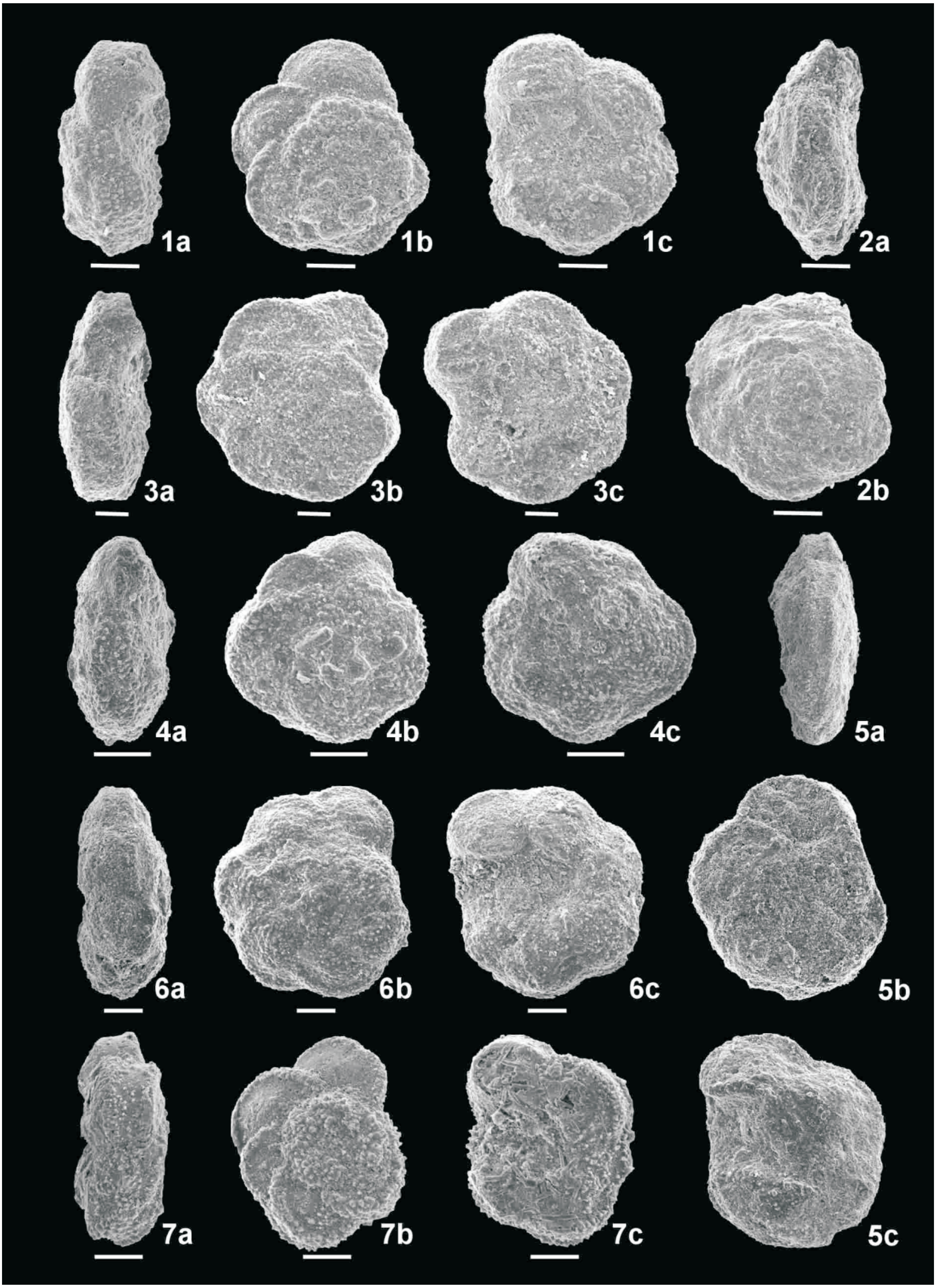
Marginotruncana marginata (Reuss) is the commonest representative of the genus. In the present study, the concept of Robaszynski *et al.* (1979) for *M. marginata* is followed, with *M. paraventricosa* Hofker considered a junior synonym. *Marginotruncana coronata* (Bolli), *M. pseudolinneiana* Pessagno, *M. renzi* (Gandolfi), *M. paraconcavata* Porthault and *M. sinuosa* Porthault are less common components of the assemblages. Single-keeled marginotruncanids were not recorded. The first rare and doubtful records of double-keeled marginotruncanids are from the base of Bed 35. Double-keeled marginotruncanids are abundant and dominate the assemblages in two intervals: from Bed 42 to Bed 46 and from Bed 50 to Bed 53. *Marginotruncana sinuosa* first appears in Bed 42b.

Archaeoglobigerina, represented by three species, *A. cretacea* (d'Orbigny)*, A. blowi* Pessagno and *A. bosquensis* Pessagno, is a rare to common contributor to the planktonic foraminiferal assemblages. It is recorded from the middle and upper part of the interval studied. *Dicarinella imbricata* (Mornod) and *D. hagni* (Scheibnerova) are found to occur more commonly in intervals where the planktonic foraminiferal assemblages are dominated by double-keeled marginotruncanids. *Dicarinella* cf. *primitiva* (Dalbiez) occurs sporadically in the upper part of the interval studied, while none of the samples yielded *D. concavata*.

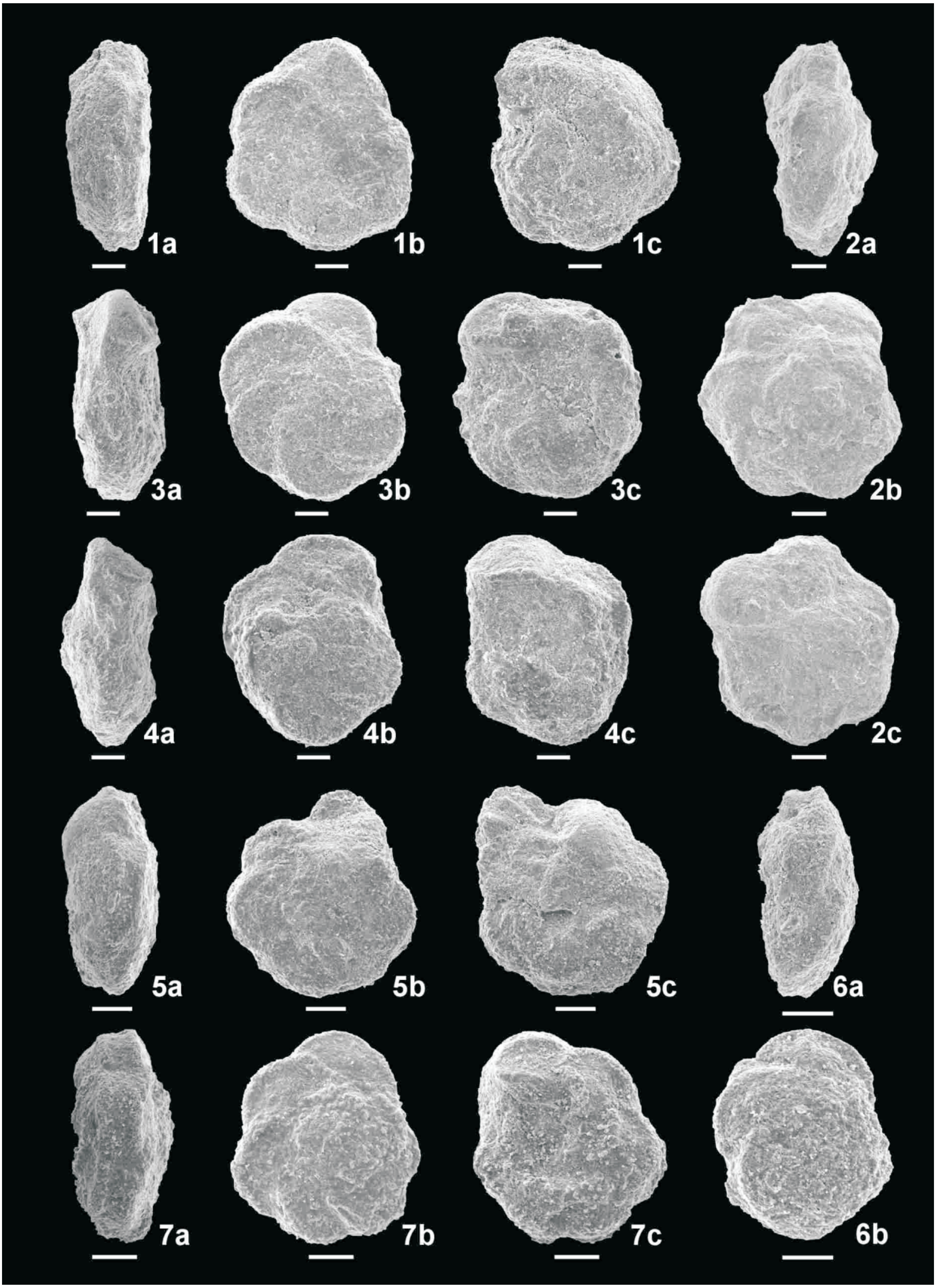
The planktonic foraminifera recovered from the Upper Turonian and Lower Coniacian parts of the Salzgitter-Salder section represent faunas characteristic of the Cretaceous Transitional or Temperate Province (e.g. Bailey and Hart 1979; Pożaryska and Peryt 1979; Caron 1985). They comprise mainly whiteinellids, archaeoglobigerinids and double-keeled marginotruncanids. Compared to coeval Tethyan faunas they are less diverse. Typical Tethyan umbilico-convex dicarinellids and single-keeled marginotruncanids with acute peripheries, biostratigraphically very important, are either very rare or absent.

In the most recent foraminiferal biostratigraphy, the Turonian–Coniacian boundary is placed within the *Dicarinella concavata* Zone, the base of which is placed in the Upper Turonian (Robaszynski *et al*. 1990; Premoli Silva and Sliter 1995; Robaszynski and Caron 1995; Ogg *et al*. 2004). *Dicarinella concavata* has not been recorded from the Salzgitter-Salder section. A Late Turonian–earliest Coniacian age for these strata is indicated, however, by the co-occurrence of whiteinellids and double-keeled marginotruncanids.

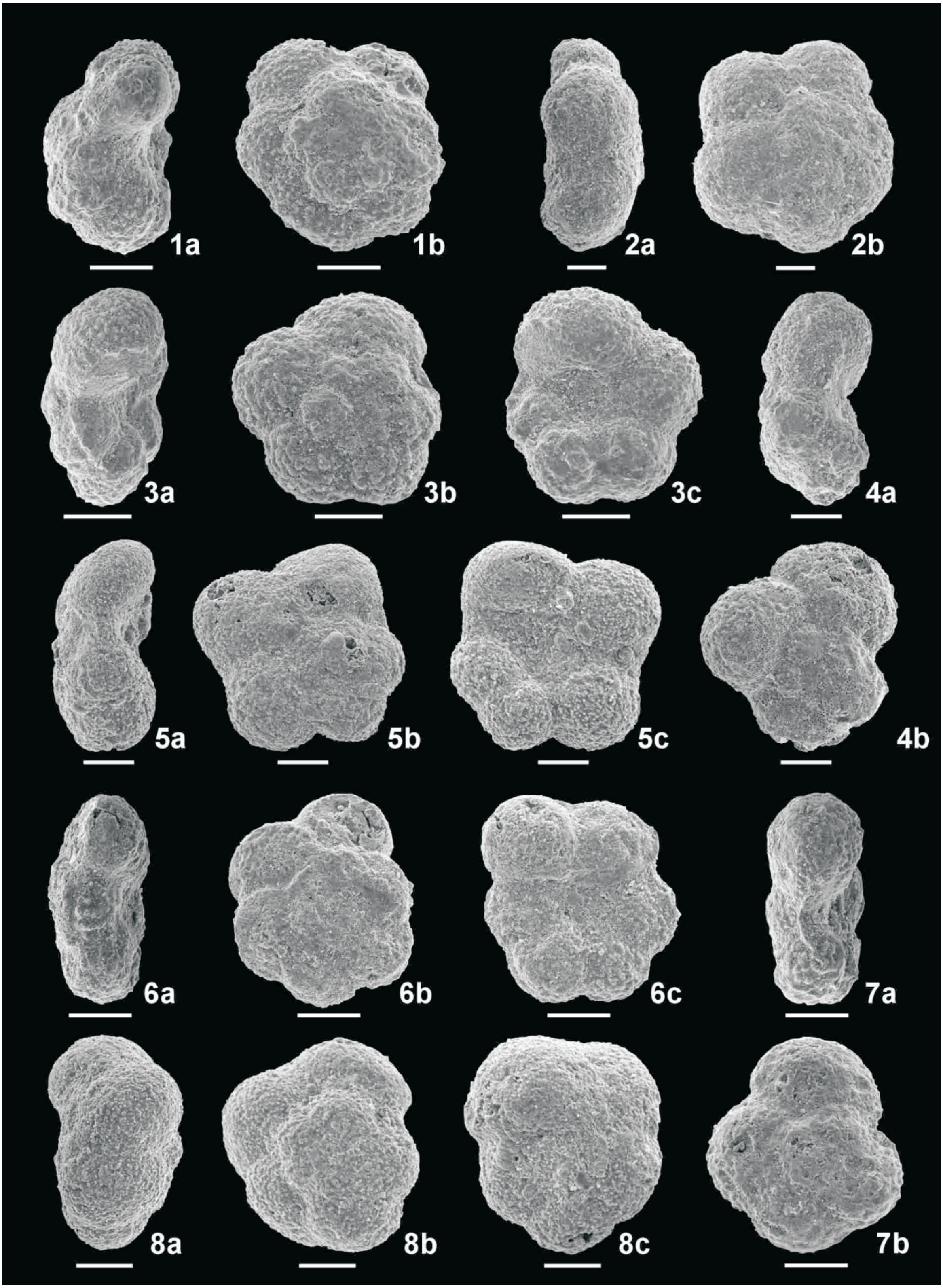
Alternations of planktonic foraminiferal assemblages dominated by whiteinellids with assemblages dominated by double-keeled marginotruncanids in the interval studied indicate environmentally controlled appearances of planktonic foraminifera in the area.



Text-fig. 8. 1a-c – *Marginotruncana marginata* (Reuss, 1845), sample 45b; 2a-b – *Marginotruncana sinuosa* Porthault, 1970, sample 42b; 3a-c – *Marginotruncana coronata* (Bolli, 1945), sample 50a; 4a-c – *Marginotruncana* sp, sample 49b; 5a-c – *Marginotruncana renzi* (Gandolfi, 1942), sample 42b; 6a-c – *Marginotruncana marginata* (Reuss, 1845), sample 42b; 7a-c – *Marginotruncana pseudolinneiana* Pessagno, 1967, sample 45b; scale bar = 100 μm



Text-fig. 9. 1a-c – *Marginotruncana paraconcavata* Porthault, 1970, sample 42b; 2a-c – *Dicarinella imbricata* (Mornod, 1950), sample 44b; 3a-c – *Marginotruncana pseudolinneiana* Pessagno, 1967, sample 50a; 4a-c – *Dicarinella* cf. *primitiva* (Dalbiez, 1955), sample 50a; 5a-c – *Dicarinella* cf. *hagni* (Scheibnerova, 1962), sample 42b; 6a-b – *Marginotruncana sinuosa* Porthault, 1970, sample 52a; 7a-c – *Marginotruncana renzi* (Gandolfi, 1942), sample 42; scale bar = 100 μm



Text-fig. 10. 1a-b – *Whiteinella paradubia* (Sigal, 1952), sample 41b; 2a-b – *Whiteinella aprica* (Loeblich and Tappan, 1961), sample 36; 3a-c – *Wheiteinella* cf. *brittonensis* (Loeblich and Tappan, 1961), sample 41b; 4a-b – *Whiteinella* sp., sample 41b; 5a-c – *Whiteinella aumalensis* (Sigal, 1952), sample 50b; 6a-c – *Marginotruncana* sp., sample 41b; 7a-b – *Wheiteinella baltica* Douglas and Rankin, 1969, sample 41b; 8a-c – *Archaeoglobigerina bosquensis* Pessagno, 1967, sample 50b2; scale bar = 100 µm

Conclusions

No planktonic species found in the Salzgitter-Salder succession can be used as a close proxy for the base of the Coniacian, as defined by the first appearance of the inoceramid bivalve *Cremnoceramus deformis erectus*. *Marginotruncana sinuosa*, indicated to be a good proxy for the base of the Coniacian by Walaszczyk and Peryt (1998), does not look convincing at present. In the Salzgitter-Salder section rare specimens of this species are noted from Beds 42b, 50 and 52, i.e. about 3 m below the base of the Coniacian. Tur *et al*. (2001) noted the first *M. sinuosa* in te nowetheastern Caucasus already quite low in the upper Upper Turonian from a level distinctly below the first appearance of *Dicarinella concavata*. In England *Marginotruncana* (=*Globotruncana*) *angusticarinata/sinuosa* was recorded from the highest Lower Coniacian (uppermost part of the *Micraster cortestudinarium* Zone) (Bailey and Hart 1979). The FO of *Marginotruncana renzi* (Gandolfi), documented from the base of the *C. waltersdorfensis* Zone in the

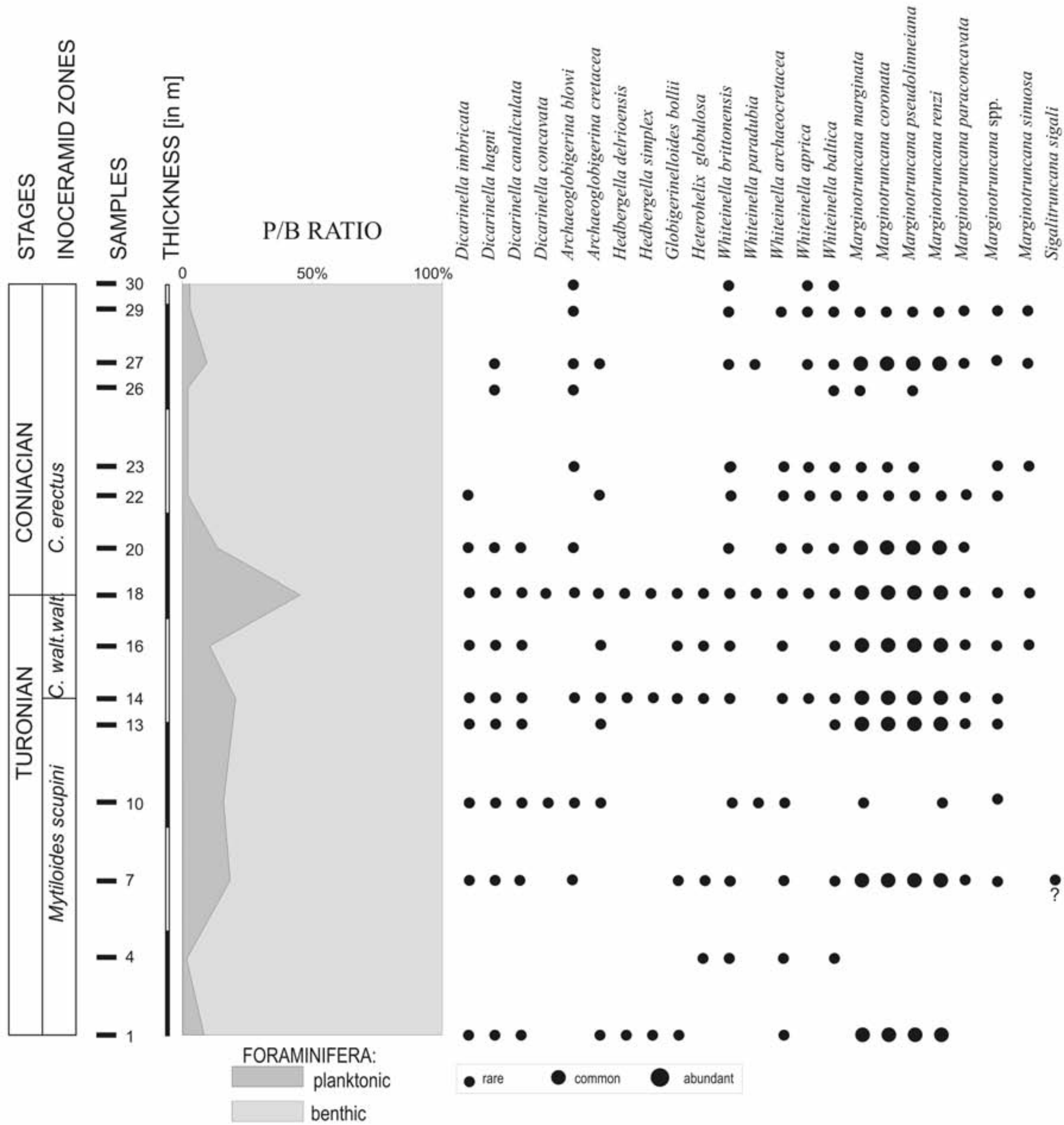


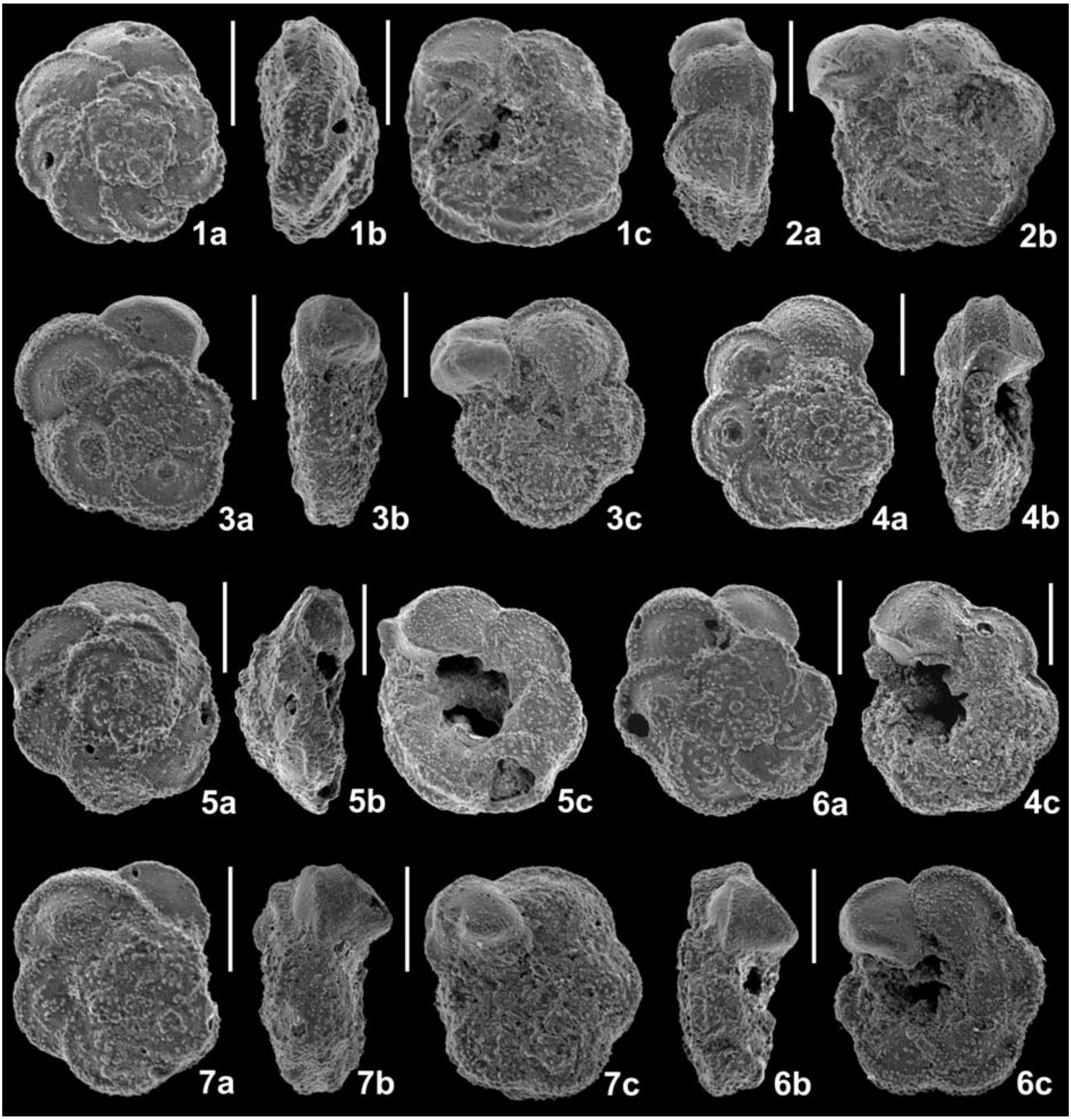
Fig. 11. Stratigraphical distribution of planktonic foraminifera in the Upper Turonian – lowermost Coniacian boundary interval in the Słupia Nadbrzeżna section

Briansk region (Central European Russia) by Walaszczyk *et al.* (2004), appears distinctly earlier both in the Salzgitter-Salder and Słupia Nadbrzeżna sections (see Text-figs 7, 11 and Walaszczyk and Peryt 1998).

Nannofossils (J.A. Lees)

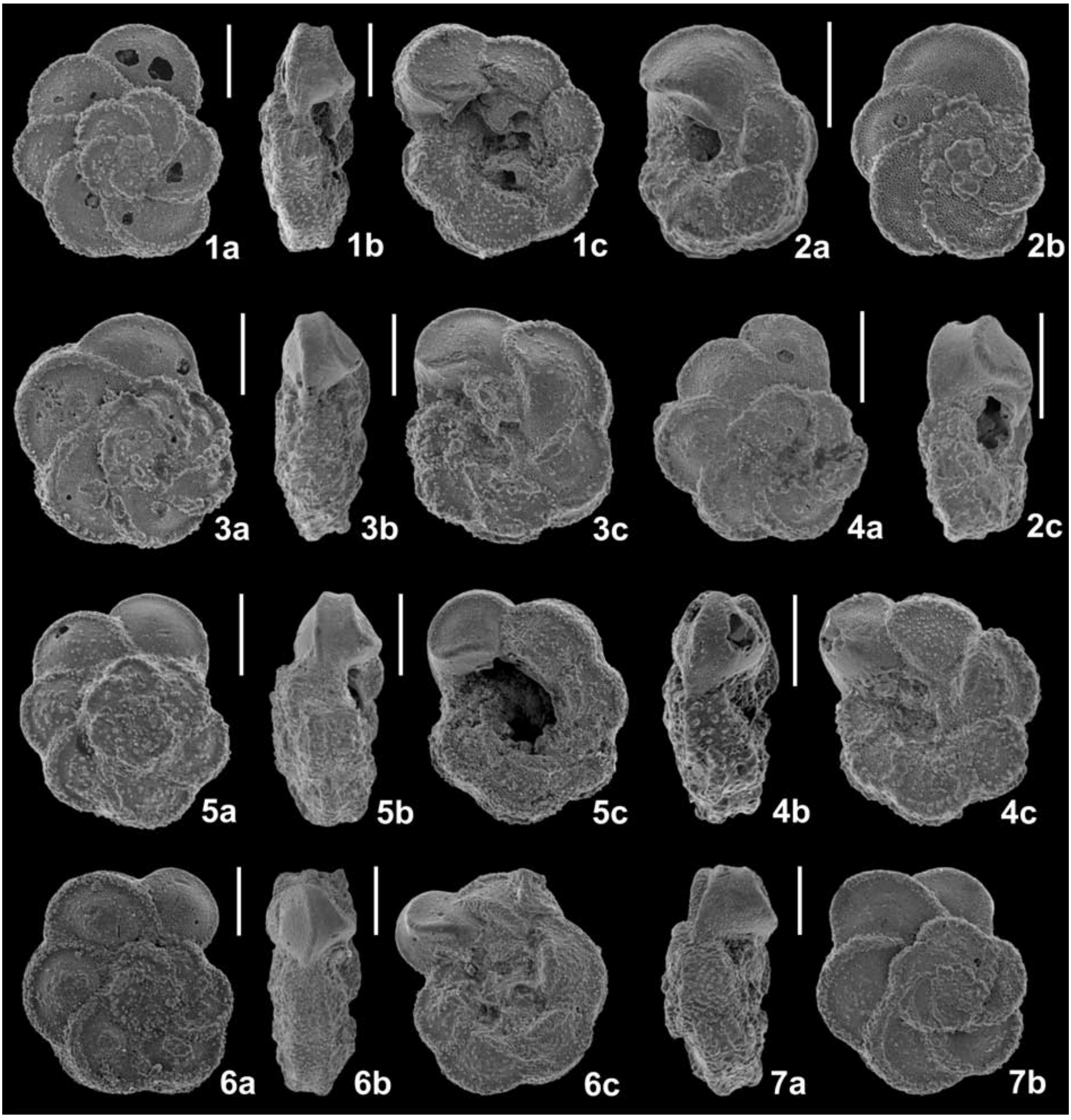
The calcareous nannofossil assemblages from both the Salzgitter-Salder and Słupia Nadbrzeżna sections have recently been studied by Lees (2008). The assemblages are quite rich taxonomically, being comparable to assemblages known from other coeval sections (see Lees 2008, table 6). Similarly, they are reasonably well preserved. This contradicts conclusions by Sikora *et al.* (2004), who claimed that the nannofloras from the Salzgitter-Salder section were too poorly preserved and depauperate taxonomically.

Documented in the Salzgitter-Salder section are

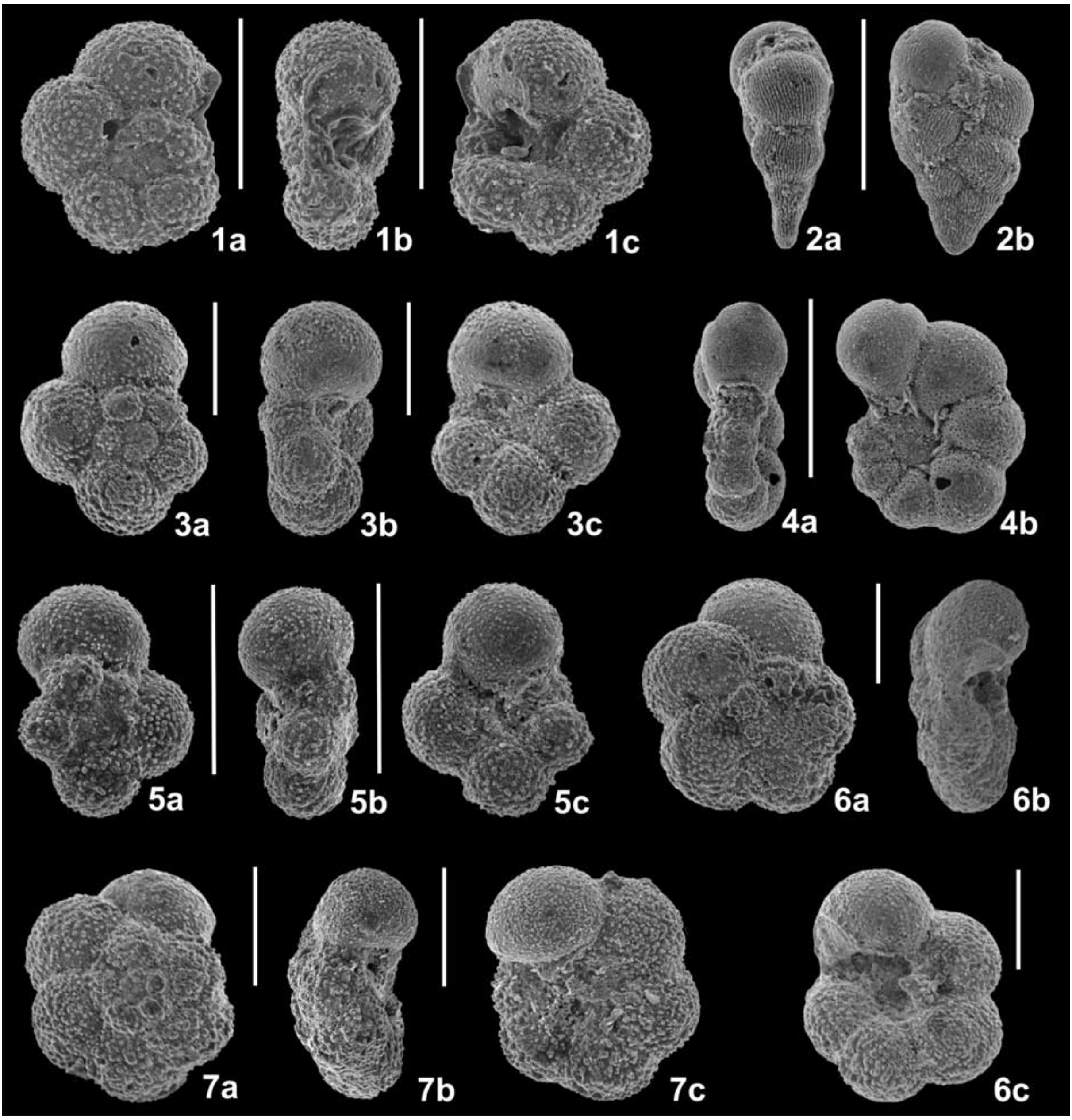


Text-fig. 12. 1a-c – *Marginotruncana sinuosa* Porthault, 1970; 2a-c – *Dicarinella concavata* (Brotzen, 1934); 3a-c. *Dicarinella hagni* (Scheibnerova, 1962); 4a-c – *Marginotruncana marginata* (Reuss, 1845); 5a-c – *Marginotruncana sinuosa* Porthault, 1970; 6a-c – *Dicarinella* cf. *canaliculata* (Reuss, 1854); 7a-c – *Dicarinella hagni* (Scheibnerova, 1962); scale bar = 200 µm calcareous nannofossils from Bed 21 to Bed 75. The whole interval represents Nannofossil Subzone UC9c, which is indicated by the continuous occurrence of *Broinsonia parca expansa*, the FO of which marks the base of the subzone, and the absence from the section of *Micula staurophora*, a nannofossil marker of Nannofossil Zone UC10. *Broinsonia parca expansa* first appears already in Bed 7, well below the interval discussed herein (Lees 2008). No significant nannofossil event was recognized in the studied interval below the Turonian/Coniacian boundary. The nannofossil event closest to the boundary is the LO of *Helicolithus turonicus*, which was found 30 cm below the top of Bed 52.

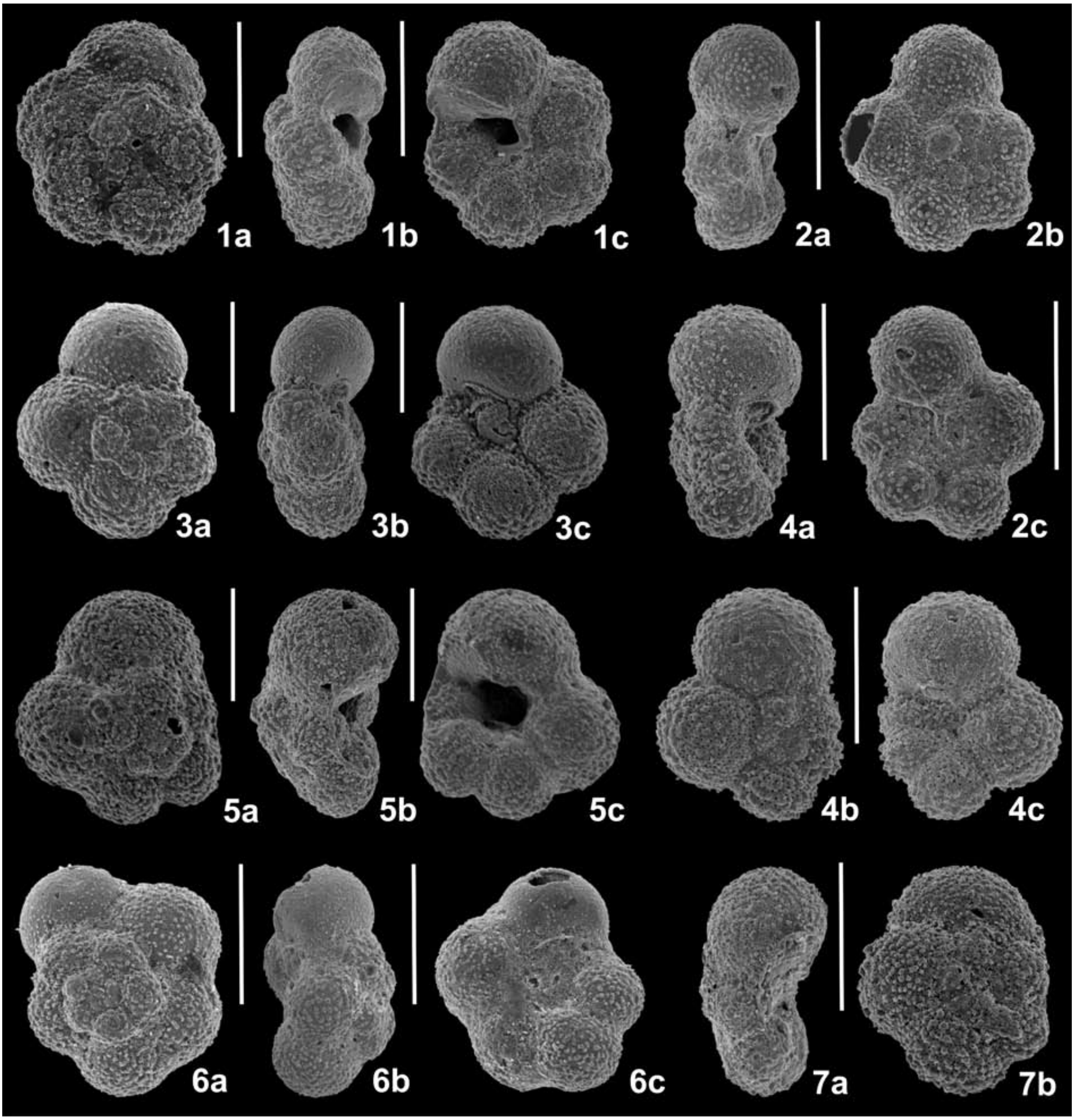
Similarly as in the Salzgitter-Salder section, the basal Coniacian boundary interval in the Słupia Nadbrzeżna section, as marked by the FO of *C. deformis erectus*, lies within Nannofossil Subzone UC9c, as



Text-fig. 13. 1a–c – *Marginotruncana coronata* (Bolli, 1945); 2a-b – *Marginotruncana pseudolinneiana* Pessagno, 1967; 3a-c – *Marginotruncana* sp.; 4a-c – *Marginotruncana pseudolinneiana* Pessagno, 1967; 5a-c – *Marginotruncana marginata* (Reuss, 1845); 6a-c – *Marginotruncana* cf. *coronata* (Bolli, 1945); 7a-b – *Marginotruncana pseudolinneiana* Pessagno, 1967; scale bar = 200 μm marked by the occurrence of *B. parca expansa*, which occurs first well below the boundary. It is interesting that the lowest sample from the Słupia Nadbrzeżna section contains *Zeugrhabdotus biperforatus* (along with *Lithastrinus septenarius* and *Marthasterites* spp.), indicating its location still within Nannofossil Subzone UC9b. As *Micula staurophora* is absent from the succession, Nannofossil Subzone UC9c extends to the top of the section. *Marthasterites furcatus* first appears 0.5 m above the base of the Słupia Nadbrzeżna section, below the oldest *B. parca expansa*; the species, however, is known from its sporadic occurrence, and thus it may actually start below the base of the section. Of importance is the last occurrence of *Helicolithus turonicus* just above the stage boundary, and a questionable first occurrence of *Micula adumbrata* noted 0.5 m above that level (see Lees 2008).



Text-fig. 14 1a-c – *Hedbergella delrioensis* (Plummer, 1940); 2a-c. *Heterohelix globulosa* (Ehrenberg, 1840); 3a-c. *Whiteinella baltica* Douglas and Rankin, 1969; 4a-c. *Globigerinelloides bollii* Pessagno, 1967; 5a-c. *Hedbergella simplex* (Morrow, 1934); 6a-c. *Archaeoglobigerina cretacea* (d'Orbigny, 1840); 7a-c. *Whiteinella aprica* (Loeblich and Tappan, 1961); scale bar = 200 µm



Text-fig. 15. 1a-b – *Whiteinella* cf. *aprica* (Loeblich and Tappan, 1961); 2a-b – *Hedbergella simplex* group (Morrow, 1934); 3a-c – *Whiteinella baltica* Douglas and Rankin, 1969; 4a-b – *Archaeoglobigerina* cf. *blowi* Pessagno, 1967; 5a-c – *Whiteinella* sp.; 6a-c – *Archaeoglobigerina bosquensis* Pessagno, 1967; 7a-c – *Whiteinella* cf. *archaeocretacea* Pessagno, 1967; scale bar = 200 µm

CARBON ISOTOPE STRATIGRAPHY (S. Voigt)

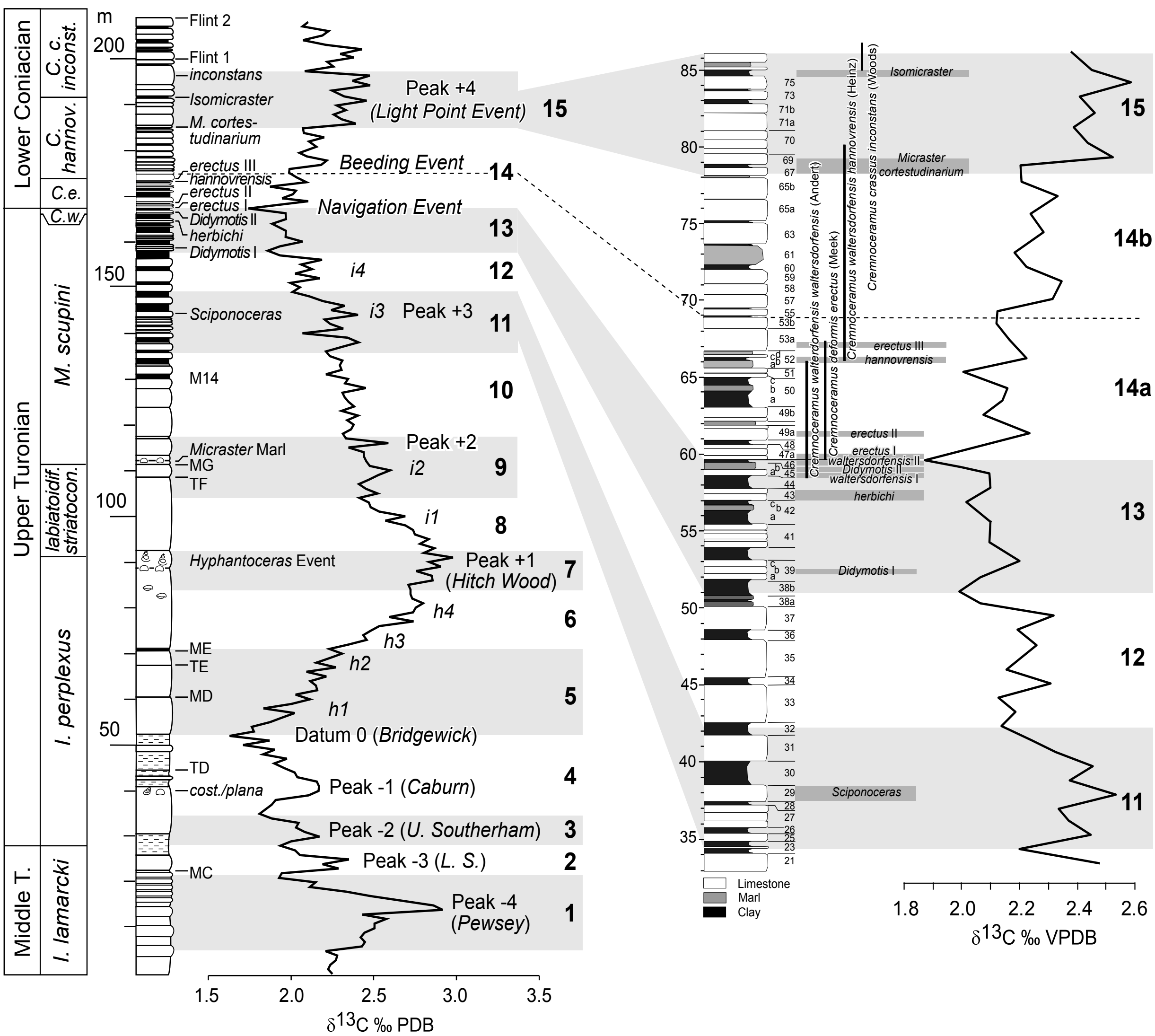
The Turonian–Coniacian carbon stable isotope curve displays a variety of distinct carbon isotope events which can be traced over long distances. The first Cenomanian–Santonian $\delta^{13}C$ curves of high temporal resolution were published for the English Chalk sections at Dover and the pelagic limestone succession at Gubbio in Italy (Jenkyns *et al.* 1994). Both curves can be correlated with high accuracy, and two positive $\delta^{13}C$ events occur in the Middle–Late Turonian interval.

Carbon isotope curve in Salzgitter-Salder

A detailed $\delta^{13}C$ curve of the Middle Turonian to Lower Coniacian limestone succession at Salzgitter-Salder was published by Voigt and Hilbrecht (1997). The main features of the $\delta^{13}C$ curve are a distinct positive excursion in the upper Middle Turonian (*Inoceramus lamarcki* Zone), followed by three small-scale positive events in the uppermost Middle and lowermost Upper Turonian (Text-fig. 16). The most prominent feature of the Upper Turonian carbon isotope curve is a broad positive $\delta^{13}C$ excursion (upper *I. perplexus* Zone), which has its local expression in the North German Basin as a carbonate maximum and an acme-occurrence of heteromorph ammonites, referred to as the *Hyphantoceras* Event (Ernst *et al.* 1983). Carbon isotope values show a long-term decline in the upper Upper Turonian (*Mytiloides labiatoidiformis–I. striatoconcentricus* and *M. scupini* zones) which is terminated by an inflection from falling to rising $\delta^{13}C$ values at the level of the Turonian–Coniacian Boundary. In the Lower Coniacian, carbon isotope values rise again towards the *Isomicraster* and *inconstans* events and decrease above this horizon.

All of these carbon isotope features are of interregional significance as proved by $\delta^{13}C$ curves from sections in northern Spain (Liencres; Wiese 1999), southern Spain (Santa Ines) and Italy (Contessa; Stoll and Schrag 2000). Even small-scale $\delta^{13}C$ variations can be traced between different biogeographic realms and provinces. Some of the Turonian $\delta^{13}C$ events are also recorded in terrestrial organic matter from the Hokkaido (Japan) and Sakhalin (Russia) islands in the Far East (Hasegawa 2003, Hasegawa *et al.* 2003).

Wiese (1999) introduced a labelling system for the positive $\delta^{13}C$ peaks in the Liencres section using the negative inflection in the lower Upper Turonian as a reference ("Datum 0"). Peaks below and above this datum are designated by negative and positive numbers respectively (Text-fig. 16). More recently, a new nomenclature of Cenomanian–Santonian $\delta^{13}C$ events was in-



Text-fig. 16. Stable carbon isotope curve for the Salzgitter-Salder section troduced for the English Chalk (Jarvis *et al.* 2006). The authors named positive and negative carbon isotope excursions after regional lithostratigraphic marker beds (names in italics in their fig. 1). Some of the $\delta^{13}C$ events in Jarvis *et al.* (2006) are identical to those of Wiese (1999), some of them are different and some have not been named so far. Small-scale $\delta^{13}C$ events/peaks differ in shape, magnitude and absolute value from section to section, which makes their precise definition difficult. Therefore, we consider the Turonian–Coniacian $\delta^{13}C$ curve in terms of intervals defined by background $\delta^{13}C$ trends (increases, decreases) and by small-scale cyclic variations. The boundary between two intervals is placed in the minimum between two maxima or in the inflection from slow rising/fast falling to fast rising/slow falling values (Text-fig. 16). The intervals are informally numbered and described below.

Intervals 1–4 are very distinctly developed in the carbonate successions of Europe and, therefore, easy to identify. Interval 1 represents the upper Middle Turonian positive $\delta^{13}C$ excursion with a magnitude of 0.7 ‰, which is named the Pewsey Event after a corresponding hardground in the English Chalk (Gale 1996) and Peak -4 by Wiese (1999). Whilst the definition of Peak -4 is limited to the horizon of highest $\delta^{13}C$ values, Interval 1 comprises rising and falling $\delta^{13}C$ values throughout the whole excursion. Interval 2 describes a small-scale positive excursion (0.2–0.3 ‰) and was named as Peak -3 and the Lower Southerham Event by Wiese (1999) and Jarvis *et al.* (2006), respectively. The top of Interval 2 corresponds to the occurrence of a bentonite layer in the English Chalk and northern Germany (Southerham Marl 1, T_{C2}; Wray 2000; Wiese *et al.* 2004a). Interval 3 represents a similar small-scale positive excursion to Interval 2 and corresponds to Peak -2 and the Upper Southerham Event. The inferred Middle/Upper Turonian Boundary lies between intervals 2 and 3 (Wiese and Kaplan 2001). Interval 4 comprises a third small-scale positive excursion (0.4 ‰) and a subsequent decrease in $\delta^{13}C$ values towards a minimum. The positive excursion corresponds to a fossiliferous horizon (*costellatus/plana* Event) and is named Peak -1 (Wiese 1999) or the Caburn Event (Jarvis *et al.* 2006). The bentonite T_D lies within the subsequent decrease in $\delta^{13}C$ values (Wray 2000). The upper boundary of Interval 4 is the Datum 0 horizon of Wiese (1999) or the Bridgewick Event of Jarvis *et al.* (2006). Both $\delta^{13}C$ events describe the prominent minimum in the Late Turonian $\delta^{13}C$ curve.

Intervals 5 and 6 encompass the increase in $\delta^{13}C$ values towards the Upper Turonian maximum. The discrimination of these two $\delta^{13}C$ intervals is justified by the varying steepness of the increase in $\delta^{13}C$ values. Both intervals are characterized by an initial steep rise in $\delta^{13}C$ values that becomes weaker in the upper part. Interval 5 terminates at the level of the prominent marl layer M_E, c. 3 m above the bentonite T_E, and Interval 5 ends at the level of an acme-occurrence of brachiopods. Jarvis *et al.* (2006) distinguished four subsidiary isotope dates, of which h1 and h2 are placed in Interval 5, and h3 and h4 in Interval 6. Interval 7 represents the $\delta^{13}C$ maximum (Peak +3, Hitch Wood Event) and is the most prominent feature of the Upper Turonian $\delta^{13}C$ curve. It is associated with the *Hyphantoceras* Event in Lower Saxony. Interval 8 represents the fast decline in $\delta^{13}C$ values after the $\delta^{13}C$ maximum. It is terminated by an inflection towards more slowly falling $\delta^{13}C$ values and corresponds to the horizon of an inferred acme-occurrence of *Mytiloides incertus* (Wiese *et al.* 2004b). Intervals 6–8 together encompass the positive Upper Turonian $\delta^{13}C$ excursion that was named the "Late Turonian Event" by Voigt *et al.* (2004).

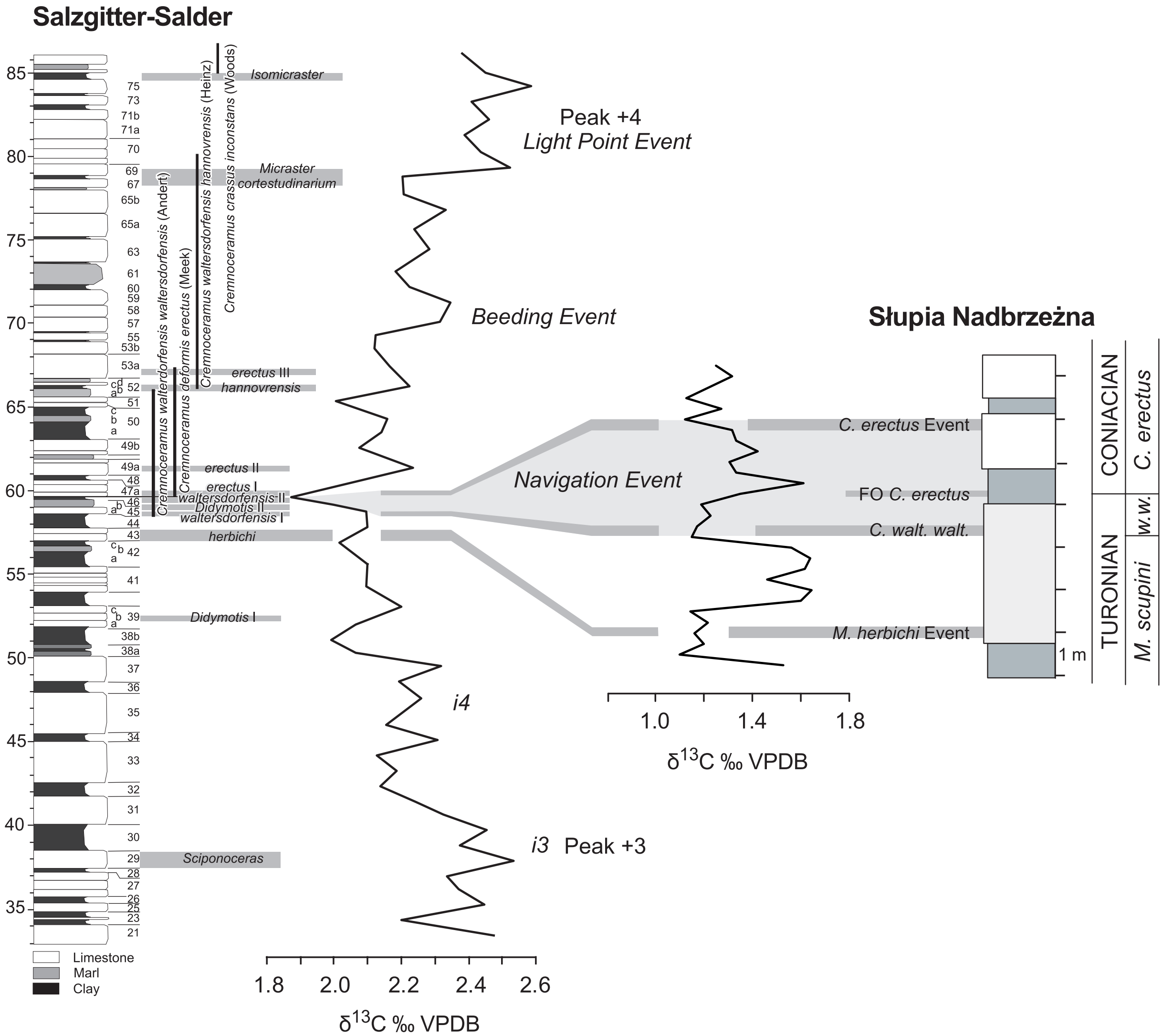
The upper Upper Turonian $\delta^{13}C$ curve is characterized by a long-term decrease in $\delta^{13}C$ values that is not steady but occurred in several steps interrupted by periods of more stable values. Interval 9 is characterized by the occurrence of some irregular small-scale positive peaks which together form a broader weak maximum. The lower small positive peak was related to the subsidiary isotope event i1 (Jarvis *et al.* 2006) and the upper one was named Peak +2 (Wiese 1999). A succession of marls comprising the bentonite T_F and an acme-occurrence of the echinoid *Micraster* is located in Interval 9. Interval 10 is mainly characterized by slowly falling $\delta^{13}C$ values without the occurrence of distinct small-scale events. The transition from pure limestones to a succession of alternating marls and limestones lies within this interval.

The slow and steady long-term decrease in background $\delta^{13}C$ values is terminated in Interval 11 by a weak positive excursion (Beds 18–32) that forms an inflection towards more rapidly falling $\delta^{13}C$ values (Text-fig. 16). The $\delta^{13}C$ maximum of Interval 11 lies within Bed 29, which yields a fauna with specimens of the ammonite genus *Sciponoceras*. A significant step towards lower $\delta^{13}C$ values occurs in the upper part of Interval 11 in Bed 31. Interval 12 represents the next weak positive excursion superimposed on the long-term $\delta^{13}C$ decrease (Beds 32–38). This horizon consists of three marl-limestone couplets with 1–2 m thick limestone beds. A renewed step towards lower background $\delta^{13}C$ values occurs at the transition between Beds 37 and 38. Interval 13 marks the last weak positive excursion (Beds 38b–46), which is superimposed on the uppermost Turonian $\delta^{13}C$ decrease. Several distinct fossiliferous horizons occur within this interval. The *Didymotis* I Event (Bed 39b) occurs in its lower part, and the bioevents of

Mytiloides herbichi (Bed 43), *Cremnoceramus w. waltersdorfensis* I (Bed 45a), *Didymotis* II (Bed 45a), and *C. w. waltersdorfensis* II (Bed 46) occur in the upper part (Wood *et al*. 2004). Altogether, Intervals 11–13 form three cycles of rising and falling $\delta^{13}C$ values superimposed on a background $\delta^{13}C$ decrease.

The $\delta^{13}C$ minimum between Intervals 13 and 14 marks the turning-point from falling to rising background $\delta^{13}C$ values and was named the Navigation Event by Jarvis *et al.* (2006). The $\delta^{13}C$ minimum is located in the uppermost Turonian at Salzgitter-Salder, although its precise position is not resolved because of the relatively low sample resolution (1m spacing). The $\delta^{13}C$ minimum occurs very close to the supposed Turonian–Coniacian boundary at Salzgitter-Salder, and is, therefore, a useful additional criterion for the identification of the boundary.

The Lower Coniacian $\delta^{13}C$ curve shows a long-term increase in background $\delta^{13}C$ values, and Intervals 14 and 15 are superimposed cycles on it. Interval 14 commences with a sharp increase in $\delta^{13}C$ values within Beds 47–49 that becomes weaker up to Bed 65b. Interval 14 could possibly be further divided into a lower and an upper cycle (14a and 14b), although the low sample resolution does not make this subdivision unambiguous. Interval 14a comprises again a series of bioevents with flood-occurrences of *C. deformis erectus* (Beds 47, Bed 49a, and Bed 53a) and *C. w. hannovrensis* (Bed 52b). Interval 14a marks the next weak positive $\delta^{13}C$ excursion that was named the Beeding Event in the English Chalk (Jarvis *et al.* 2006). This interval does not yield flood-occurrences of bivalves. The transition between Intervals 14a and 15 marks a sharp increase towards more positive $\delta^{13}C$ values and



Text-fig. 17. Stable carbon isotope correlation of the Turonian–Coniacian boundary interval between the Salzgitter-Salder and Słupia Nadbrzeżna sections

Interval 15 comprises a positive excursion between the bioevents of *Micraster cortestudinarium* (Bed 68) and *Cremnoceramus crassus inconstans* (Bed 75). The $\delta^{13}C$ maximum of this excursion was named Peak +4 by Wiese (1999) and the Light Point Event by Jarvis *et al.* (2006).

In summary, the Turonian–Coniacian Boundary Interval comprises six $\delta^{13}C$ cycles (Intervals 11–15), each of them 8–9 m thick. Three cycles occur in the latest Turonian, when background $\delta^{13}C$ values fell and three cycles occurred in the earliest Coniacian when background values rose. The Turonian/Coniacian Boundary lies in the inflection from falling to rising $\delta^{13}C$ values.

Lithologically, each cycle consists of 3–5 marl limestone couplets. The temporal resolution of the $\delta^{13}C$ record is too low to perform spectral analysis. However, assuming that these cycles correspond to the 100 kyr short eccentricity cycle, the average sedimentation rate at Salzgitter-Salder would be in the order of 8.3 cm/kyr. This unusually high value is confirmed by comparison of the Turonian $\delta^{13}C$ stratigraphy of Salzgitter-Salder with that of the Contessa section in Italy (Stoll and Schrag 2000). The sedimentation rate of the deep marine pelagic limestone succession at Contessa is an order of magnitude lower than that of Salzgitter-Salder and was estimated to be 0.98 cm/kyr (Voigt *et al*. 2004). The high rate of sediment accumulation at Salzgitter-Salder indicates a high rate of basin subsidence probably related to the onset of inversion tectonics in Central Europe.

Correlation to the Słupia Nadbrzeżna section

Both the carbon and oxygen stable isotope records from the Słupia Nadbrzeżna section show a strong variability with respect to lithology. This variability is more strongly developed than at Salzgitter-Salder and reflects some regional diagenetic overprint. However, the carbon curve is fine (Text-fig. 17).

Three $\delta^{13}C$ minima associated with the *M. herbichi*, *C. w. walterdorfensis* and *C. deformis erectus* events can be seen. Each of them has similar low $\delta^{13}C$ values. The greater part of the 7-m succession at Słupia Nadbrzeżna represents the upper part of the broad $\delta^{13}C$ minimum that occurs in Salzgitter-Salder between the *Didymotis* I and the *erectus* I events

The lower minimum at Słupia Nadbrzeżna can be correlated with a similar minimum in Salzgitter-Salder. The interval between the upper two minima at Słupia Nadbrzeżna falls into a small hiatus at Salzgitter-Salder, where the two minima are fused into a single minimum (Text-fig. 17).

GEOCHRONOLOGY

We have no direct absolute dates either from the Salzgitter-Salder section or the Słupia Nadbrzeżna section. The date for the base of the Coniacian as proposed herein has been calculated from dates obtained from bentonites bracketing the boundary level in the US Western Interior, and correlated biostratigraphically to the German section. In the Western Interior the $^{40}Ar/^{39}Ar$ ages were obtained from two bentonites: (1) a 15 cm-thick bentonite in the *Scaphites preventricosus* Zone of the Marias River Shale, Montana [number 15 in Obradovich's 1993 scheme] and (2) a thin bentonite 0.9 m from the *Prionocyclus macombi* Zone of the Juan Lopez Member of the Mancos Shale, New Mexico [number 16 in Obradovich's 1993 scheme]. The obtained dates are 88.34 and 90.21 Ma respectively. The younger date has recently been corrected to 88.55 Ma (Obradovich in Cobban *et al*. 2006). The dates for particular ammonite zones in the interval between were obtained by a subdivision of the difference between the two dates (1.66 myr) by the number of zones represented (8); the obtained result for the base of the *S. preventricosus* Zone, which is coeval with the base of the Coniacian in the US Western Interior ammonite scheme, is thus 88.75 Ma. This is distinctly younger that the one calculated for the base of the Coniacian by Ogg *et al.* (2004). The discrepancy stems from differences in the biostratigraphical correlation applied to the Turonian/Coniacian boundary. Instead of direct correlation of the base of the Coniacian by the FO of *Cremnoceramus deformis erectus,* Ogg *et al*. (2004) used as the primary datum the FO of the ammonite *Forresteria petrocoriensis*, which they regarded as the approximate equivalent of the FO of the North American species *Forresteria peruana*. However, the latter predates the basal Coniacian *S. preventricosus* Zone (Walaszczyk and Cobban 2000) and falls in the Upper Turonian *M. scupini* inoceramid bivalve Zone. Additionally, they added 0.2 myr to correct for the difference between the FOs of *C. deformis erectus* and the level of the lowest record of *F. petrocoriensis* in Westphalia. Their resultant date was 89.3 Ma (Ogg *et al*. 2004).

SUMMARY OF MAIN CONCLUSIONS

1. The succession at the Salzgitter-Salder Quarry (Lower Saxony, Germany), supplemented by data from the Słupia Nadbrzeżna river cliff section (Central Poland), constitutes the best record across the Turonian–Coniacian boundary currently available, offering a complete succession of bioevents, reco-

gnizable over much of the Euramerican biogeographic region. In the Salzgitter-Salder section, the Turonian–Coniacian boundary interval is part of an expanded Turonian to Lower Coniacian succession. Additionally, in spite of previous reservations based on observed diagenetic changes, the section offers a good record of calcareous nannofossils (Lees 2008, and this paper) and planktonic foraminifera (Peryt, this paper), enabling a reasonable correlation of the macrofaunal and microfaunal and nannofossil biostratigraphies with other sections, and contradicting recent criticisms by Sikora *et al*. (2004). Both sections provide a reliable carbon stable isotope curve (Voigt and Hilbrecht 1997; Voigt, this paper) with a high-resolution stratigraphical potential (see also Wiese 1999). The Słupia Nadbrzeżna section completes the record across the short-lived hiatuses in the boundary interval at Salzgitter-Salder as well as in sections elsewhere in Europe and in North America.

2. The base of the Coniacian Stage is placed at the FO of the inoceramid bivalve *Cremnoceramus deformis erectus*, which appears as a result of a cladogenetic (budding) event of the *Cremnoceramus waltersdorfensis* lineage. This event is well documented in the Słupia Nadbrzeżna succession; in the Salzgitter-Salder section it is missing due to an hiatus. The *Cremnoceramus deformis erectus* mass-occurrence Event in the Słupia Nadbrzeżna succession is located some distance above the base of the Coniacian.

   The suggestion of the diachronous appearance of *C. deformis erectus* and the consequent questioning of its usefulness as a boundary marker by Sikora *et al.* (2004) has been shown to be without foundation (see discussion in Walaszczyk *et al.*, in press).
3. As demonstrated in the Słupia Nadbrzeżna section, the FO of *Cremnoceramus deformis erectus* postdates that of *Forresteria petrocoriensis*, the traditional ammonite marker of the base of the Coniacian; *F. petrocoriensis* first appears in the topmost part of the *Mytiloides scupini* inoceramid bivalve Zone of the topmost Turonian.
4. The extended boundary interval is characterized at Salzgitter-Salder by a baculitid-scaphitid ammonite assemblage. The boundary itself cannot be precisely defined by ammonites; however, there is an apparent local change in one scaphitid lineage a short distance below the boundary. A progressive introduction of heteromorph taxa which characterize the *Forresteria petrocoriensis* Zone assemblage in Westphalia starts at Salzgitter-Salder within the *Cremnoceramus waltersdorfensis hannovrensis* Zone, with the FO of *Scalarites turonicus* around Bed 67.
5. The Turonian–Coniacian boundary lies within Nannofossil Subzone UC9c, the base of which is marked by the FO of *Broinsonia parca expansa*; in the Salzgitter-Salder section this zone spans the interval between beds 21 and 75 (Lees 2008). The nannofossil event closest to the boundary is the LO of *Helicolithus turonicus*, found 30 cm below the top of Bed 52 at Salzgitter-Salder, in the *C. waltersdorfensis hannovrensis* Zone, and a short distance above the boundary in the Słupia Nadbrzeżna section.
6. The base of the Coniacian lies within the zone of the planktonic foraminifer *Dicarinella concavata*. However, this species is absent from the Salzgitter-Salder and only rare specimens of this species are noted in the Słupia Nadbrzeżna section. In terms of planktonic foraminifera, a Late Turonian–earliest Coniacian age is indicated by the co-occurrence of whiteinellids and double-keeled marginotruncanids. *Marginotruncana sinuosa*, indicated earlier as a potential proxy for the base of the Coniacian (Walaszczyk and Peryt 1998), is known to appear distinctly earlier in the Late Turonian.
7. In the Salzgitter-Salder section, the Turonian–Coniacian Boundary Interval comprises six $\delta^{13}C$ cycles (Intervals 11–15), each of them 8–9 m thick. The base of the Coniacian lies in the inflection from falling to rising $\delta^{13}C$ values. Both the carbon and oxygen stable isotope records from the Słupia Nadbrzeżna section show a stronger variation than in the Salzgitter-Salder section and reflect some regional diagenetic overprint; however, its carbon curve is fine (Text-fig. 17). The greater part of the 7-m succession at Słupia Nadbrzeżna represents the upper part of the broad $\delta^{13}C$ minimum that occurs in the Salzgitter-Salder section between the *Didymotis* I and the *erectus* I events. The lower minimum at Słupia Nadbrzeżna can be correlated with a similar minimum in Salzgitter-Salder. The interval between the upper two minima at Słupia Nadbrzeżna is represented by a small hiatus at Salzgitter-Salder, where the two two minima are fused, forming a single minimum (Text-fig. 17).
8. The recent criticism of Sikora *et al.* (2004) of the Salzgitter-Salder section as a potential basal boundary stratotype, and of *C. deformis erectus* as a basal Coniacian biomarker, is rejected. Their discussion can be shown to have no factual basis and to stemmed from serious methodological deficiencies (see Walaszczyk *et al.*, in press).
9. The series of the most important ancillary marker events in the Salzgitter-Salder–Słupia Nadbrzeżna composite section and the location of the candidate GSSP are as follows (younger to older):

* The questionable first occurrence (at Słupia Nadbrzeżna) of the nannofossil *Micula adumbrata*

* ?The last occurrence of the nannofossil *Helicolithus turonicus*
* The mass-occurrence event of the inoceramid bivalve *Cremnoceramus waltersdorfensis hannovrensis*
* The mass-occurrence event of the inoceramid bivalve *C. deformis erectus*
* **The candidate GSSP: the first occurrence of the basal boundary biomarker, the inoceramid bivalve *Cremnoceramus deformis erectus*,** identifiable only at Słupia Nadbrzeżna
* The Navigation $\delta^{13}C$ carbon stable isotope event
* The mass-occurrence event of the inoceramid bivalve *Cremnoceramus waltersdorfensis waltersdorfensis* combined with the mass-occurrence of the thin-shelled bivalve *Didymotis* of the *Didymotis* II event
* The last occurrence of the inoceramid bivalve *Mytiloides scupini*
* The first occurrence (at Słupia Nadbrzeżna) of the ammonite *Forresteria petrocoriensis*
* The first occurrence of the planktonic foraminifer *Archaeoglobigerina blowi*
* The first occurrence of the planktonic foraminifer *Marginotruncana sinuosa*
* The first occurrence of the nannofossil *Broinsonia parca expansa*

CONCLUDING DISCUSSION AND RECOMMENDATION

At present, there is no suitable section available worldwide as Global Boundary Stratotype Section and Point for the base of the Coniacian Stage, defined by the currently accepted criterion, the first occurrence of the inoceramid bivalve *Cremnoceramus deformis erectus*. It is probable that in all sections that have been examined this datum is coincident with the mass-occurrence event of this inoceramid bivalve taxon, as is the case with the currently favoured and best available candidate Global boundary Stratotype Section, Salzgitter-Salder Quarry (Lower Saxony, Germany), where the terminal Turonian second *C. w. waltersdorfensisis* mass occurrence event is immediately followed by the first mass-occurrence event of *C. deformis erectus*. Only in the Słupia Nadbrzeżna river cliff section (central Poland) is the FO of *C. deformis erectus* separated from both these mass occurrence events, indicating that elsewhere the boundary is marked by a hiatus and/or condensation. Furthermore, the details of the carbon stable isotope curve from the boundary interval of the Słupia Nadbrzeżna section enable the portion of the curve missing (due to a hiatus) from the Salzgitter-Salder section to be complemented.

In the present absence of an alternative and better single-locality candidate, we propose a composite Global Boundary Stratotype Section and Point for the Coniacian Stage comprising the Salzgitter-Salder Quarry section (Lower Saxony, Germany) and the Słupia Nadbrzeżna river cliff section (central Poland). It is intended that this proposal will be formally submitted to the IUGS Cretaceous Subcommission and the Stratigraphical Commission for consideration.

Acknowledgements

We are particularly indebted to the late Professor Gundolf Ernst for his ground-breaking study of the Salzgitter-Salder section and recognition of a sequence of events over many years, as well as for his initiation and supervision of relevant research projects. This paper is dedicated to his memory. The warmest thanks are to journal referees, John W.M. Jagt and Isabella Premoli Silva, for their comments on the manuscript.

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