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Macrofossil, planktonic foraminiferal and nannofossil zonation at the Campanian/Maastrichtian boundary

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with 6 figures

Abstract. Recent compilations and correlations of macrofossil, microfossil and nannofossil zonation across the Campanian/Maastrichtian boundary commonly correlate the base of a *Belemnella lanceolata* belemnite Zone, *Acanthoscaphites tridens* and *Pachydiscus neubergicus* ammonite Zones, the top of a *Globotruncanita calcarata* planktonic foraminiferal Zone and the base of a *Quadrum trifidum* nannofossil Zone. These horizons do not coincide. Of the various markers proposed for this boundary, the first occurrence of *Belemnella (Belemnella) lanceolata* (SCHLOTHEIM) is older than, progressively, the first occurrences of *Hoploscaphites constrictus* (J. SOWERBY), *Pachydiscus (P.) neubergicus* (HAUER) and *Acanthoscaphites tridens* (KNER), and the last occurrence of *Quadrum trifidum* (STRADNER) PRINS & PERCH-NIELSEN, and younger than the progressively older last and first occurrence of *Nostoceras (N.) hyatti* STEPHENSON, last occurrence of *Globotruncanita calcarata* (CUSHMAN), and first occurrence of *Globotruncana falsostuarti* SIGAL and *Quadrum trifidum* (STRADNER) PRINS & PERCH-NIELSEN. Rather than corresponding, as in published schemes, the base of the *Belemnella lanceolata* Zone lies in the upper part of the *Globotruncana falsostuarti* or *G. aegyptiaca* planktonic foraminiferal Zone of authors, and within the *Tranolithus phacelosus* (= *T. orionatus*) nannofossil Zone (CC23). What is regarded as Upper Campanian in macrofossil terms is regarded as Lower Maastrichtian in microfossil and nannofossil terms, even though the boundary defined by these groups is widely taken as synchronous by geochronologists, sequence stratigraphers and others.

1. Introduction

At the symposium on Cretaceous Stage Boundaries held in Copenhagen in October 1983, organised by the International Subcommission on Cretaceous Stratigraphy, a series of competing definitions were proposed for the bases of stages. These views were summarised by BIRKELUND, HANCOCK, HART, RAWSON, REMANE, ROBASZYNSKI & SURLYK (1984) and many of them were expounded upon in other contributions to the symposium volume (BIRKELUND & SURLYK, 1984). In the case of the Maastrichtian, no less than six possible datum-levels were considered, based upon nannofossils, planktonic foraminifera, ammonites and belemnites, although the relative positions of these levels were not stated by these authors. The last decade

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also saw publication of a series of reviews of such disparate subjects as geochronology and sequence stratigraphy with neat tabulations showing the relative positions of stage and zonal boundaries for the Upper Cretaceous, mostly without discussion or justification of the correlations made (Kaufmann, 1979; Berggren et al., 1983; Marks, 1984; Kent & Gradstein, 1985; Zachos & Arthur, 1986; Haq et al., 1987; Haq et al., 1988; Harland et al., 1990). These tabulations are highly misleading, in that they suggest to the non-specialist that the relative position of the boundaries of, say, Campanian/Maastrichtian belemnite, ammonite, planktonic foraminiferal and nannofossil zones are known with confidence and documented in detail such as to no longer be controversial and, indeed, that the position of stage boundaries is agreed by specialists in the field. Anyone who attended the 1983 meeting will recall that this was certainly not the case then, and so it remains. The International Commission has yet to rule on the position of Upper Cretaceous stage boundaries, and there is no 'agreed' or 'correct' definition of these boundaries. With some, a consensus may be emerging, although we cannot ourselves see this for the boundaries of any of the Cretaceous stages. We discuss here the evidence for the relative stratigraphical positions of the suggested markers for the boundary between the Campanian and Maastrichtian stages, and demonstrate for the first time the actual relative position of ammonite, belemnite, planktonic foraminiferal and nannofossil markers at this level in the Upper Cretaceous.

2. Campanian/Maastrichtian boundary definitions

Birkelund et al. (1984) listed six possible markers for the base of the Maastrichtian stage: (1) the first occurrence of the ammonite *Hoploscaphites constrictus* (J. Sowerby); (2) the first occurrence of the ammonite *Pachydiscus (Pachydiscus) neubergicus* (von Hauer); (3) the first occurrence of the belemnite *Belemnella (Belemnella) lanceolata* (Schlotheim); (4) the last occurrence of the planktonic foraminifer *Globotruncanita calcarata* (Cushman); (5) the first occurrence of the planktonic foraminifer *Globotruncana falsostuarti* Sigal; (6) the last occurrence of the nannofossil *Quadrum trifidum* (Stradner) Prins & Perch-Nielsen. Also widely mentioned, but not discussed, is the base of an *Acanthoscaphites tridens* ammonite Zone, while, as discussed below, the position of the heteromorph *Nostoceras (Nostoceras) hyatti* Stephenson is a critical marker for elucidating the relative positions of these potential boundary markers.

As to which of the datum-levels listed above marks the base of the Maastrichtian, we take, for the present discussion,the appearance of the belemnite *Belemnella lanceolata* as the reference point. There is a strong historical precedent for this, as discussed by Birkelund et al. (1984), Surlyk (1975), Schulz (1978) and others, while the base of a *B. lanceolata* Zone is shown as corresponding to the base of the Maastrichtian in macrofossil terms in many compilations (Jeletzky, 1951a, b, 1958; van Hinte, 1976; Berggren et al., 1983; Marks, 1984; Haq et al., 1987, 1988; Harland et al., 1990; Hancock, 1991, etc.).

3. The relative positions of Campanian/Maastrichtian boundary markers

Fig. 1 shows some of the zonal sequences currently recognised across the Campanian/Maastrichtian boundary in northwest Europe. Taking the first appearance of *Belemnella lanceolata*

<table>
<tr><th>SUBSTAGE</th><th>BLASZKIEWICZ, 1980</th><th>CHRISTENSEN, 1975</th><th>SCHULZ, 1979; SCHULZ et al, 1984</th></tr>
<tr><td rowspan="6">LOWER MAASTRICHTIAN</td><td rowspan="3">Belemnella occidentalis</td><td rowspan="3">Belemnella occidentalis</td><td>Belemnella fastigata</td></tr>
<tr><td>Belemnella cimbrica</td></tr>
<tr><td>Belemnella sumensis</td></tr>
<tr><td rowspan="3">Belemnella lanceolata lanceolata</td><td rowspan="3">Belemnella lanceolata</td><td>Belemnella obtusa</td></tr>
<tr><td>Belemnella pseudobtusa</td></tr>
<tr><td>Belemnella lanceolata</td></tr>
<tr><td rowspan="6">UPPER CAMPANIAN</td><td>Nostoceras pozaryskii</td><td rowspan="2">Belemnella langei
+
Belemnitella minor</td><td>Micraster grimmensis / Cardiaster granulosus</td></tr>
<tr><td>Didymoceras donezianum</td><td>Belemnitella langei</td></tr>
<tr><td rowspan="2">Bostrychoceras polyplocum</td><td rowspan="2">Belemnitella minor</td><td>Bostrychoceras polyplocum</td></tr>
<tr><td>Galerites vulgaris</td></tr>
<tr><td rowspan="2">Neancyloceras phaleratum</td><td rowspan="2">Belemnitella mucronata</td><td>Pachydiscus stobaei / Galeola papillosa</td></tr>
<tr><td>Echinocorys conica / B. mucronata senior</td></tr>
</table>

Fig. 1. Macrofossil zonation at the Campanian/Maastrichtian boundary in the European White Chalk succession. There is only an approximate equivalence between zonations in adjoining columns in the Upper Campanian.

as marking the base of the Maastrichtian, the observations of Schulz (1978) and others on the Chalk at Kronsmoor (see summary in Schulz, Ernst, Ernst & Schmid, 1984) allow us to place the first occurrence of *Hoploscaphites constrictus,* two specimens of which have been recorded from somewhere between 3.5 and 5 m (11.5 to 16.4 ft) above the lowest occurrence of *B. lanceolata.* The first occurrence of *Pachydiscus (P.) neubergicus* in Germany is in the upper part of the *Belemnella obtusa* Zone at Lüneburg (Schmid, 1955; Schulz et al., 1984), although the species ranges to the lower Upper Maastrichtian in Denmark (Birkelund, 1979; and in press). At Nagoryanȳ in the Ukraine, the species first occurs in association with *Belemnella (Pachybelemnella) inflata* (Arkhanguelsky), which occurs in the *lanceolata* to *pseudobtusa* Zones of Schulz (1979; see Christensen, 1987; Kennedy & Summesberger, 1987). In Poland, Blaskiewicz (1980) has *P. neubergicus* and subspecies occurring in both his zones of *B. lanceolata lanceolata* and *B. occidentalis.* The type occurrence of *P. (P.) neubergicus* is in equivalents of the middle part of the *sumensis* Zone of Schulz (1979) or younger, but probably no younger than the upper *sumensis* Zone (Kennedy & Summesberger, 1984). The oldest precisely dated *Acanthoscaphites tridens* (as interpreted by Kennedy & Summesberger, 1987) also occur at Nagoryanȳ and are thus somewhere in the *lanceolata* to *pseudobtusa* Zones sensu Schulz (1979). In Poland, it occurs in the zone of *B. lanceolata lanceolata* of Blas-

KIEWICZ (1980), and in the *obtusa* or lowermost *sumensis* Zone in Denmark (BIRKELUND, 1979, and in press).

The macrofossil sequence of first occurrences is thus *B. lanceolata* (oldest), *H. constrictus, P. (P.) neubergicus* and *A. tridens* (youngest). These can be linked to the last occurrence of the nannofossil *Quadrum trifidum* via the work of WAGREICH (1987), who showed that the Nagoryanȳ fauna with the oldest well-dated *P. (P.) neubergicus* and *A. tridens* belongs to nannofossil zone CC23B of SISSINGH (1977) and PERCH-NIELSEN (1985), that is to say, the upper part of the *Tranolithus phacelosus* Zone. *Q. trifidum* disappears at the top of this zone (as does *Tranolithus orionatus* (= *phacelosus*), a more reliable marker in the Boreal region), so that this is higher than any of the possible boundary markers discussed above.

The relative position of the last occurrence of the planktonic foraminifer *Globotruncanita calcarata* and the first occurrence of *Globotruncana falsostuarti* cannot be directly determined in relation to the markers discussed above, because the planktonic foraminifera and macrofossils have mutually exclusive geographic distributions. ROBASZYNSKI, CARON, GONZALEZ DONOSO & WONDERS (1984) show *G. calcarata* disappearing before the appearance of *G. falsostuarti,* although CARON (1985) shows *G. falsostuarti* appearing near the top of the range of *G. calcarata,* with an overlap interval; we have adopted the latter view on the advice of Professor F.T. BANNER.

These foraminiferal data can be linked to the macro- and nannofossil data via the occurrence of the heteromorph ammonite *Nostoceras (N.) hyatti* STEPHENSON. A taxonomic revision of this species is given in KENNEDY and COBBAN (in press). It defines a widely recognised ammonite zone in the United States Gulf Coast and Atlantic Seaboard, characterised by the following associated ammonites: *Pachydiscus (Pachydiscus) arkansanus* (STEPHENSON), *Pseudokossmaticeras galicianum* (FAVRE), *Nostoceras (Nostoceras) approximans* (CONRAD), *N. (N.) helicinum* (SHUMARD), *N. (N.) pauper* (WHITFIELD), *N. (N.) draconis* STEPHENSON, *N. (N.) colubriformis* STEPHENSON, *Didymoceras navarroense* (SHUMARD), *Lewyites oronensis* (LEWY), *Baculites undatus* STEPHENSON, *B. ovatus* SAY, *Hoploscaphites pumilis* (STEPHENSON) and *Jeletzykytes nodosus* (OWEN). The index species also occurs in the *Baculites jenseni* Zone in Colorado in the U.S. Western Interior. Two of us (WJK and JMH) have recently examined the type material and other specimens of *Nostoceras pozaryskii* BLASKIEWICZ (1980), from the Upper Campanian of the Vistula Valley, Poland. It is clear that the original of BLASKIEWICZ (1980, pl. 10, figs. 8, 9, 12, a paratype), is a synonym of *N. (N.) hyatti,* while the remaining paratypes and the holotype (BLASKIEWICZ 1980, pl. 10, figs. 1–5, 11, 13–15) are synonyms of *Nostoceras (N.) helicinum* (SHUMARD) (see revision in COBBAN, 1974). This confirms the view of COBBAN (1974, p.3), who noted the close resemblance between *Nostoceras (N.) hyatti* and what was subsequently described as *N. pozaryskii.* BLASKIEWICZ (1980, p. 14) carefully documented the occurrence of *N. (N.) hyatti* and *helicinum* (as *N. pozaryskii*), and this and our own observations show it to occur in the upper part of its eponymous zone (i.e. the *N. pozaryskii* Zone of BLASKIEWICZ), immediately below the first appearance of *Belemnella lanceolata.*

N. (N.) hyatti also occurs in the Biscay region of southwestern France and northern Spain. At Zumaya, *Cirroceras (Cirroceras) polyplocum zumayense* WIEDMANN (1962, p. 200, pl. 9, fig. 5) is based on a specimen of *N. (N.) hyatti* (WARD & KENNEDY, in press). WIEDMANN (1988) showed this species (as *Bostrychoceras zumayaense*) occurring about 400 m below the

Cretaceous/Tertiary boundary at Zumaya, in his *Pseudokossmaticeras tercense* Zone, which he correlated with a *Globotruncana falsostuarti* Zone. From data in HERM (1965, pl. 2, p. 326) this is 400 m above the top of the *G. calcarata* Zone, and below the base of HERM's *Globotruncana gansseri* Zone, although the precise distance below the base of the *gansseri* Zone, as used by HERM is unclear from the data in WIEDMANN.

Correlations for the Upper Campanian and Lower Maastrichtian have been developed by timing eustatic changes of sea-level (HANCOCK, 1990, in press). There is a major sea-level peak in the Late Campanian which can be dated in the U.K. as being near the base of the Portrush Chalk in County Antrim and in the middle of the Beeston Chalk in Norfolk. In the terms of the zonation of SCHULZ in Fig. 1, this lies near the top of the Zone of *Bostrychoceras polyplocum*, distinctly below the base of the Zone of *Belemnitella langei* in the German sense. In Mississippi/Alabama, this eustatic peak is represented by the maximum development of the Demopolis Chalk. This part of the Demopolis Chalk is exposed in the bottom 10 m of the Alexander Schoolhouse Road section in Oktibbeha County, Mississippi (RUSSELL, 1986, fig. 9), which forms the top part of the Zone of *G. calcarata* (SMITH & MANCINI, 1983). This indicates that the top part of the *G. calcarata* Zone corresponds to somewhere within the top part of the *polyplocum* Zone as used in Germany.

On this basis, the sequence of Campanian/Maastrichtian boundary markers is as follows (to which we have added the occurrence of *N. (N.) hyatti)*:

	(top)
last occurrence of	*Quadrum trifidum/Tranolithus phacelosus (= orionatus)*
first occurrence of	{ *Pachydiscus (P.) neubergicus*
	{ *Acanthoscaphites tridens*
first occurrence of	*Hoploscaphites constrictus*
first occurrence of	*Belemnella (B.) laceolata*
[first and last occurrence of	*Nostoceras (N.) hyatti]*
last occurrence of	*Globotruncanita calcarata*
first occurrence of	*Globotruncana falsostuarti*

These data, and the first and last occurrences of certain other key taxa, are summarised in Fig. 2.

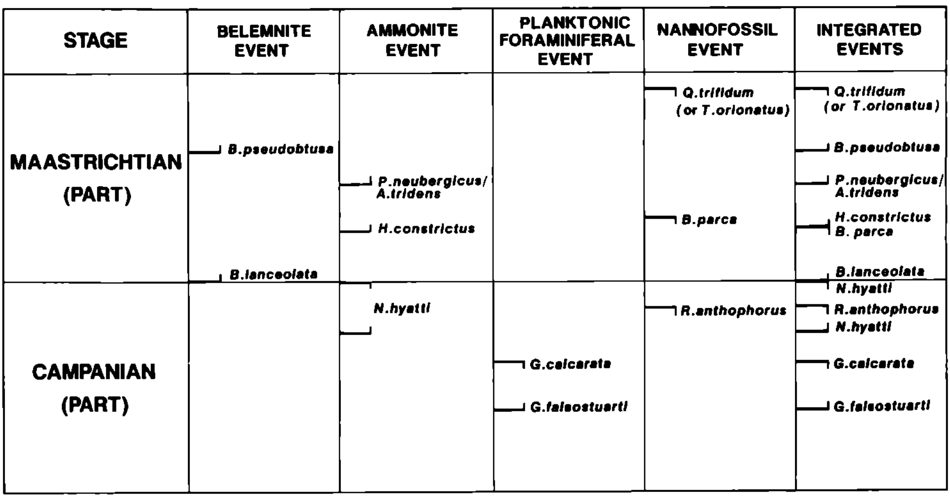


Fig. 2. The relative positions of certain macrofossil, microfossil and nannofossil first and last occurrences across the Campanian/Maastrichtian boundary.

4. Integrating macrofossil, microfossil and nannofossil zonations at the Campanian/Maastrichtian boundary

4.1 Previous work

VAN HINTE (1976), RAWSON et al. (1978), KAUFFMAN (1979), MARKS (1984), ROBASZYNSKI et al. (1984), HAQ et al. (1987, 1988) and many others show the base of a *Belemnella lanceolata* and / or *Acanthoscaphites tridens* Zone corresponding to the last occurrence of *Globotruncanita calcarata.* Quite where the base of the *lanceolata* Zone lies in terms of planktonic foraminiferal zonation cannot, in fact, be determined directly, since the relevant belemnites and foraminifera have mutually exclusive geographic occurrences. They can, however, be linked in that nannofossil and belemnite zones, and nannofossil and planktonic foraminiferal zonations can be integrated while *N. (N.) hyatti,* which disappears immediately below the base of the *lanceolata* Zone, can also be dated against macrofossil, planktonic foraminiferal and nannofossil zones.

4.2 Integration of planktonic foraminiferal and nannofossil zonations

Surprisingly few studies have integrated planktonic foraminiferal and nannofossil zonation schemes. Those discussed below are summarised in Fig. 3. (It should be noted that where SISSINGH's (1977) numerical zones have been subdivided (see PERCH-NIELSEN, 1985, fig. 6, p. 341), each of these subdivisions has been labelled A (oldest) to C (youngest) herein. Thus, for example, although PERCH-NIELSEN's fig. 7 (1985, p. 342) shows nannofossil zone CC22 to be divided into 22a and 22b, her fig. 6 (1985, p. 341) shows three subdivisions, herein labelled A, B and C). SMITH (1975), in re-evaluating the nannofloral zonation scheme of ČEPEK & HAY (1969), based on the Gulf Coast area of North America, integrated the aforementioned scheme with planktonic foraminiferal ranges, and discussed the results in a European context. He recognised a *Globotruncana calcarata* planktonic foraminifer Zone below the boundary and a *G. lapparenti* Zone above. Application of SISSINGH's (1977) and PERCH-NIELSEN's (1985) cosmopolitan nannofossil scheme to ČEPEK & HAY's (1969) zonation proved unhelpful, their *Tetralithus (= Ceratolithoides) aculeus* nannofossil Zone incorporating nannofossil Zones CC20 to CC23B–25A, this low degree of resolution being due to their non-recognition/ documentation or the non-preservation of now widely-used index species in their samples, and a reliance on local nannofossil ranges.

A diagram in SHUMENKO & STETSENKO (1978a) indicated that the Campanian/Maastrichtian boundary lay between a *Globotruncana morozovae* planktonic foraminifer Zone (Campanian) and a *G. stuarti* planktonic foraminifer Zone (Maastrichtian), and between a *Broinsonia parca (= Aspidolithus parcus* of authors) nannofossil Zone (Campanian) and a *Lithraphidites quadratus-Markalius nielsenae* nannofossil Zone (Maastrichtian). However, in their more detailed records (1978b) they indicated that *B. parca* (STRADNER) ranges into the Upper Maastrichtian; this latter view is not supported by our own observations.

Planktonic foraminiferal and nannofossil zonations of the West Carpathians were correlated by SALAJ & GASPARIKOVA (1979). They recognised a *Globotruncana arca rugosa* planktonic foraminifer Zone and a *Tetralithus (= Ceratolithoides) aculeus* nannofossil Zone below the boundary and a *G. falsostuarti* planktonic foraminifer Zone and *Tetralithus (= Quadrum) trifidum* nannofossil Zone above. In terms of the cosmopolitan nannofossil zonation scheme, this would place the Campanian/Maastrichtian boundary between zones CC21 and CC22, which is clearly unacceptable: PERCH-NIELSEN (1985) documented these zones as being of early Late to late Late Campanian age. Not enough nannofossil stratigraphical distribution data was published in SALAJ & GASPARIKOVA (1979) and thus their nannofloral zones cannot be resolved further in the context of the cosmopolitan scheme.

A correlation between the calcareous nannofossil and planktonic foraminiferal zonations of the much-studied Bottaccione section (near Gubbio, northern Italy) was effected by MONECHI & THIERSTEIN (1985). The last occurrence (LO) of the planktonic foraminifer *Globotruncanita calcarata* was used to define the Campanian/Maastrichtian boundary, whilst in nannofossil terms, the boundary was shown to lie between the first occurrence (FO) and LO of *Quadrum trifidum,* i.e. between nannofossil Subzones CC22A and CC23B. Application of the cosmopolitan nannofossil zonation scheme to the published nannofloral distribution data did allow further resolution of the placement of the boundary in nannofossil terms, although the results are still ambiguous: CC23A (defined as the interval between the LOs of *Reinhardtites anthophorus* (or *Eiffellithus eximius*) (base) and *Broinsonia parca* (top)) and CC22C (FO of *Reinhardtites levis* to the LO of *R. anthophorus*) could not strictly be applied because no distinction was made between *R. anthophorus* and its younger evolutionary successor, *R. levis;* both are apparently incorporated under '*Z. anthophorus*'. Thus, *E. eximius* (not a particularly reliable marker species) had to be substituted in order to apply the cosmopolitan scheme. In effect then, the boundary could feasibly lie in CC23A or CC22C. In addition, the FO of *Quadrum trifidum* usually occurs relatively lower than was found in the Italian study, and this datum could also be considered as unreliable in this region.

Taking the LO of the planktonic foraminifer *Globotruncanita calcarata* to indicate the Campanian/Maastrichtian boundary, RANOROARISOA, BELLIER, NEUMANN & LAMBERT (1987) apparently placed the boundary in nannofossil terms above the LO of *Bronsonia parca* and below the LO of *Quadrum trifidum,* within nannofossil Subzone CC23B. Elsewhere this subzone is known to be of Early Maastrichtian age in the sense used here.

SCHÖNFELD & BURNETT (1991) produced a direct correlation between planktonic foraminiferal and nannofossil zonation schemes around the Campanian/Maastrichtian boundary in the eastern North Atlantic Ocean (D.S.D.P. Hole 548A). Using the FO of *Globotruncana falsostuarti* as an approximation for the base of the Maastrichtian, it was found that, in nannofossil terms, the boundary lies within CC22C, in a Tethyan sense, that is to say *G.falsostuarti* has its first occurrence in nannofossil Subzone CC22C, which is Upper Campanian. This key correlation allows integration of Tethyan biostratigraphic sequences (containing the FO of *G. falsostuarti*/LO of *G. calcarata*) with Boreal ones.

4.3 Integration of nannofossil and belemnite zonations

We have made a direct integration of nannofossil and belemnite zones around the Campanian/Maastrichtian boundary from a composite section through the chalk in quarries at Lägerdorf and Kronsmoor, some 40 km north-west of Hamburg, south-western Holstein, north-western Germany. Nannofossil sample collection was made under the direction of Dr. J. SCHÖN-

FELD against the detailed stratigraphical logs of ERNST (1963) and SCHULZ (1978). Fig. 4 details the succession around the boundary. The base of the Maastrichtian here is taken at the base of the *Belemnella lanceolata* macrofossil Zone. The Campanian/Maastrichtian boundary thus falls within nannofossil Subzone CC23A, as described in detail by BURNETT & SCHÖNFELD (1991).

4.4 Nannofossil and planktonic foraminiferal dating of the *N. (N.) hyatti* Zone

The upper Upper Campanian *Nostoceras (N.) hyatti* Zone immediately underlies the *Belemnella lanceolata* Zone in Poland, where, as already noted, it corresponds to the *Nostoceras pozaryskii* Zone of BLASKIEWICZ (1980), although the index species is restricted to the upper part of the zone as used by BLASKIEWICZ. We examined samples from the *hyatti* Zone (=*pozaryskii* Zone) at Piotrawin in the Vistula Valley (Poland) (for locality details see BLASKIEWICZ, 1980, fig. 1). Thirty-four metres of microcavernous, chalky, siliceous 'opoka' facies without obvious marker beds are exposed, with *Belemnitella langei* throughout, and *N. (N.) hyatti* and *N. (N.) helicinum* present from 12 to 30 m above the base of the sequence. Belemnites collected at the top of the sequence are *Belemnitella langei,* so that the locality is entirely within the upper Upper Campanian. Nannofossil occurrences plotted, using the base of the workings in 1990 as the zero datum, are shown in Fig. 5. On this evidence, the *N. (N.) hyatti* Zone falls into the upper part of the *Quadrum trifidum* nannofossil Subzone (CC22C). GAZDZICKA (1978, fig. 2) showed the topmost Campanian and lowermost Maastrichtian to fall within a *Tetralithus (= Ceratolithoides) aculeus* nannofossil Zone (therein defined as the interval between the first occurrence of *C. aculeus* to the first occurrence of *Lithraphidites quadratus*). The zone equates to cosmopolitan zones CC20 to CC25B. However, she indicated that *Broinsonia parca* was present around the boundary at Piotrawin, and that *Reinhardtites anthophorus* (probably *R. anthophorus* and *R. levis* combined) became common below the Campanian/Maastrichtian boundary, so that the boundary would fall within Subzones CC22C or CC23A. It is not possible to further refine this without making a distinction between *R. levis* and *R. anthophorus. Eiffellithus eximius,* the last occurrence of which may sometimes be substituted as a marker for the base of Zone CC23, occurred (sparsely) only around the boundary according to GAZDZICKA (1978), and only in one sample in the *pozaryskii (= hyatti* herein) Zone at Piotrawin, according to that author, and was therefore considered to be unreliable. PEYRT (1980) studied planktonic foraminifera from this outcrop, and it is clear that her *Globigerinella multispinus* Zone spans the Campanian/Maastrichtian boundary, encompassing the *Neancyloceras phaleratum* to *Belemnella lanceolata lanceolata* Zones of BLASKIEWICZ (Fig. 1).

The *N. (N.) hyatti* Zone is well-represented in the Coon Creek Tongue of the Ripley Formation at its type locality on Coon Creek, Tennessee (WADE, 1926; SOHL, 1960, 1964; RUSSELL & PARKS, 1975; COBBAN & KENNEDY, in press). A sample from this locality was analysed for its nannofossil content, and yielded the following species: *Ahmuellerella octoradiata, A. regularis, Amphizygus brooksii, Biscutum ellipticum, B. magnum, Braarudosphaera bigelowii, Broinsonia parca, Calculites obscurus, Ceratolithoides aculeus, Chiastozygus bifarius, C. litterarius, Cribrocorona gallica, Cribrosphaerella ehrenbergii, Discorhabdus ignotus, Eiffellithus gorkae, Gartnerago obliquum, Gephyrorhabdus coronadventis, Kamp-*

tnerius magnifucus, Lithraphidites carniolensis, Lucianorhabdus cayeuxii, Microrhabdulus decoratus, M. undosus, Micula concava, M. cubiformis, M. praemurus?, M. staurophora, Octolithus multiplus, Placozygus fibuliformis, Prediscosphaera arkhangelskyi, P. cretacea, P. spinosa, Quadrum gothicum, Reinhardtites anthophorus, R. levis, Repagulum parvidentatum, Retecapsa crenulata, Staurolithites laffittei?, S. mielnicensis, Tranolithus orionatus, Watznaueria manivitae, Zeugrhabdotus compactus, Z. noeliae. The co-occurrence of *R. anthophorus* and *R. levis* indicate that the *Nostoceras (N.) hyatti* macrofossil Zone at this locality falls within nannofossil Subzone CC22C.

The *N. (N.) hyatti* Zone is also well-represented in the Saratoga Chalk in Arkansas (KENNEDY & COBBAN, in press). PESSAGNO (1969) referred the Saratoga Chalk in Arkansas to the upper part of the highest *Rugotruncana subcircumnodifer* Subzone (upper part of the *Globotruncana lapparenti* s.s. Zonule and lower part of *R. subpennyi* Zonule) of his *Globotruncana fornicata-stuartiformis* assemblage Zone. This corresponds to the upper part of the *G. falsostuarti* Zone of ROBASZYNSKI et al. (1984) and upper part of the *G. aegyptiaca* Zone of CARON (1985) and others (CARON, 1985, fig. 6). These data are thus wholly compatible with the occurrence of *N. (N.) hyatti* in the upper part of the *G. falsostuarti* Zone at Zumaya (see above). Samples from three localities yielding *N. (N.) hyatti* were examined for nannofossils, and results are summarised in Fig. 6. They show that localities D8008 and D8009 are within nannofossil Subzone CC22C, and locality D8010 within Subzone CC23A; the *N. (N.) hyatti* Zone thus spans the CC22C/CC23A nannofossil Zone boundary.

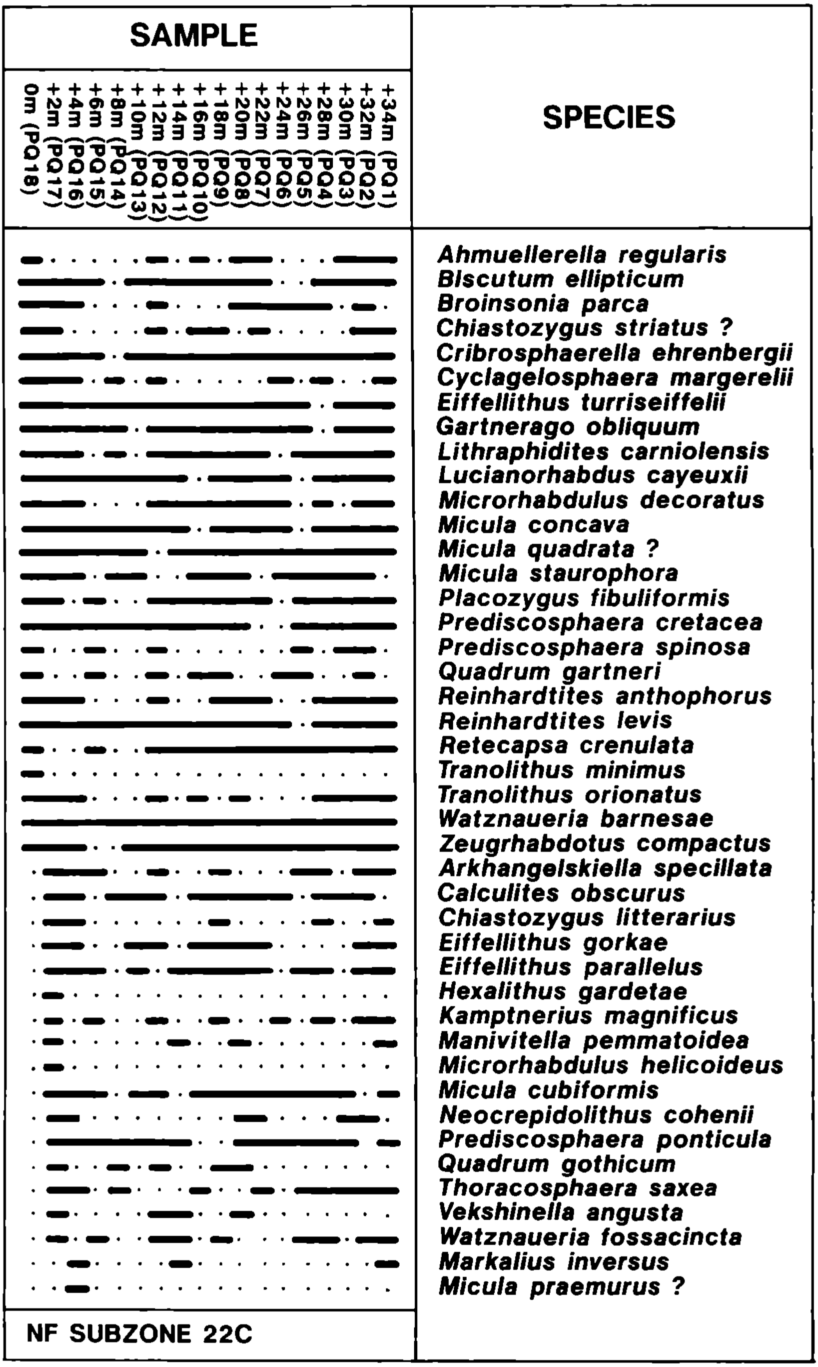
5. Conclusions

The first appearance of the belemnite *Belemnella lanceolata* is widely taken to indicate the base of the Maastrichtian stage, and is frequently taken to correspond to the extinction point of *Globotruncanita calcarata;* the latter correlation does not appear to be valid. Instead, the various putative markers for the Campanian/Maastrichtian boundary can be placed in sequence with key nannofossil events as follows:

(youngest)

- last occurrence of the nannofossil *Quadrum trifidum* [or *Tranolithus phacelosus* (= *orionatus*)]
- first occurrences of the ammonites *Pachydiscus (P.) neubergicus* and *Acanthoscaphites tridens.*
- last occurrence of the nannofossil *Broinsonia parca*
- first occurrence of the ammonite *Hoploscaphites constrictus*
- first occurrence of the belemnite *Belemnella (B.) lanceolata*
- last occurrence of the ammonite *Nostoceras (N.) hyatti*
- last occurrence of the nannofossil *Reinhardtites anthophorus* (or *Eiffellithus eximus*)
- first occurrence of the ammonite *Nostoceras (N.) hyatti*
- last occurrence of the planktonic foraminifer *Globotruncanita calcarata*
- first occurrence of the planktonic foraminifer *Globotruncana falsostuarti*
- first occurrence of the nannofossil *Reinhardtites levis*

(oldest)


SAMPLE
0m (PQ18)
+2m (PQ17)
+4m (PQ16)
+6m (PQ15)
+8m (PQ14)
+10m (PQ13)
+12m (PQ12)
+14m (PQ11)
+16m (PQ10)
+18m (PQ9)
+20m (PQ8)
+22m (PQ7)
+24m (PQ6)
+26m (PQ5)
+28m (PQ4)
+30m (PQ3)
+32m (PQ2)
+34m (PQ1)
SPECIES
Ahmuellerella regularis
Biscutum ellipticum
Broinsonia parca
Chiastozygus striatus ?
Cribrosphaerella ehrenbergii
Cyclagelosphaera margerelii
Eiffellithus turriseiffelii
Gartnerago obliquum
Lithraphidites carniolensis
Lucianorhabdus cayeuxii
Microrhabdulus decoratus
Micula concava
Micula quadrata ?
Micula staurophora
Placozygus fibuliformis
Prediscosphaera cretacea
Prediscosphaera spinosa
Quadrum gartneri
Reinhardtites anthophorus
Reinhardtites levis
Retecapsa crenulata
Tranolithus minimus
Tranolithus orionatus
Watznaueria barnesae
Zeugrhabdotus compactus
Arkhangelskiella specillata
Calculites obscurus
Chiastozygus litterarius
Eiffellithus gorkae
Eiffellithus parallelus
Hexalithus gardetae
Kamptnerius magnificus
Manivitella pemmatoidea
Microrhabdulus helicoideus
Micula cubiformis
Neocrepidolithus cohenii
Prediscosphaera ponticula
Quadrum gothicum
Thoracosphaera saxea
Vekshinella angusta
Watznaueria fossacincta
Markalius inversus
Micula praemurus ?
NF SUBZONE 22C

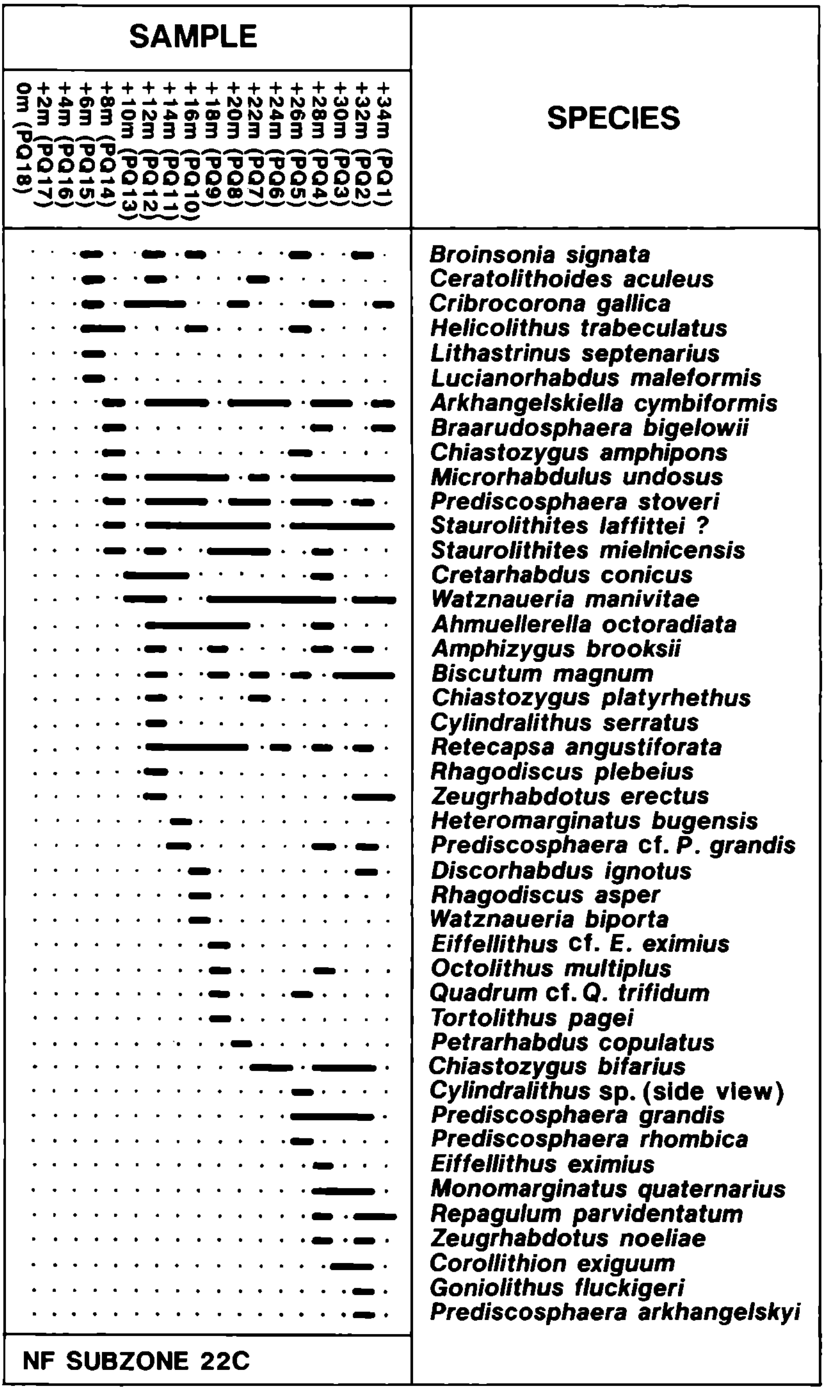


Fig. 5. Nannofossil distribution in the Upper Campanian *Nostoceras (N.) hyatti* Zone at Piotrawin in the Vistula Valley, Poland. No log is given for this section because it consists of monotonous microcavernous chalky siliceous 'opoka' facies without obvious marker beds. Nannofossil occurrences are plotted using the base of the workings in 1990 as the zero datum.

SPECIES	LOCALITY		
	D8008	D8009	D8010
Ahmuellerella octoradiata		●	
A. regularis	●	●	
Amphizygus brooksii		●	●
Arkhangelskiella cymbiformis	●	●	●
Biscutum dissimilis	●		
B. ellipticum	●	●	●
Braarudosphaera bigelowii	●		
Broinsonia enormis	●	●	
B. parca	●		●
Calculites obscurus	●	●	●
Chiastozygus litterarius	●		
C. tenuis		●	
Corollithion exiguum		●	
Cretarhabdus conicus			●
C. striatus			●
Cribrocorona gallica		●	
Cribrosphaerella ehrenbergii	●	●	●
Discorhabdus ignotus			●
Dodekapodorhabdus noeliae		●	
Eiffellithus gorkae		●	●
E. turriseiffelii	●	●	
Gartnerago obliquum		●	●
Helicolithus anceps		●	●
H. trabeculatus	●		
Lithraphidites carniolensis	●	●	●
L. praequadratus	?		
Lucianorhabdus cayeuxii	●		●
Microrhabdulus decoratus	●	●	●
M. helicoideus			●
Micula cubiformis			●
M. praemurus ?	●		
M. staurophora	●	●	●
M. swastica			●
Octolithus multiplus	●	●	●
Petrarhabdus copulatus		●	
Placozygus fibuliformis	●		
P. sigmoides			●
Prediscosphaera arkhangelskyi	●		
P. cretacea	●	●	●
P. grandis		●	
P. microrhabdulina			●
P. ponticula	●		●
P. stoveri	●		
Quadrum gothicum	●		●
Q. trifidum	●	●	
Reinhardtites anthophorus	●	●	
R. levis	●	●	●
Retecapsa angustiforata	●	●	●
R. crenulata	●	●	●
Rhagodiscus angustus			●
R. splendens	●	●	
Rucinolithus wisei		●	
Staurolithites laffittei ?	●	●	●
S. mielnicensis	●		●
Tranolithus minimus			●
T. orionatus	●	●	●
Watznaueria barnesae	●	●	●
W. manivitae	●		
Zeugrhabdotus compactus	●	●	●
Z. embergeri	●		
NANNOFOSSIL ZONE	**CC 22C**		**CC 23A**

The actual time interval that separates the extinction of *Globotruncana calcarata* and the appearance of *Belemnella lanceolata* cannot be determined with accuracy at this time, but the former is around the top of the Zone of *Bostrychoceras polyplocum* in the German sense and the occurrence of *Nostoceras (N.) hyatti* is within the upper part of the *Globotruncana falsostuarti* or *G. aegyptiaca* Zones of authors, and nannofossil Subzones CC22C (of *Quadrum trifidum*) and CC23A (of *Tranolithus orionatus*). The Campanian/Maastrichtian boundary, defined by the first appearance of *B. lanceolata*, lies within the *G. falsostuarti* (or *G. aegyptica*) planktonic foraminifer Zone and nannofossil Subzone CC23A.

It is quite clear that most recent integrated biostratigraphic schemes correlating zonal sequences across the Campanian/Maastrichtian boundary are in serious error, and that what is currently regarded as Upper Campanian in belemnite and ammonite terms is currently regarded as Lower Maastrichtian in nannofossil and planktonic foraminiferal terms.

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Fig. 6. Nannofossil occurrences in specimens of *Nostoceras (N.) hyatti* from the *Nostoceras (N.) hyatti* Zone Saratoga Chalk of Arkansas. Details of localities are as follows: USGS Mesozoic locality D8008: B.F. Clardy and W. Bush, collectors, 1971. Saratoga Chalk Road ditch along State Highway 4, 4.95 km (3 mi) north of Washington, in sec. 8, T. 11 S., R. 25 W., Hempstead County, Arkansas. USGS Mesozoic locality D8009: B. F. Clardy and W. Bush, collectors, 1971. Base of Saratoga Chalk. Road cuts along State Highways 355 and 73 east of Saratoga in sec. 33, T. 11 S., R. 27 W., Howard County, Arkansas. USGS Mesozoic locality D8010: B. F. Clardy and W. Bush, collectors, 1971. Saratoga Chalk. Cut along State Highway 355 N in Saratoga in sec. 32, T. 11 S., R. 27 W., Howard County, Arkansas.

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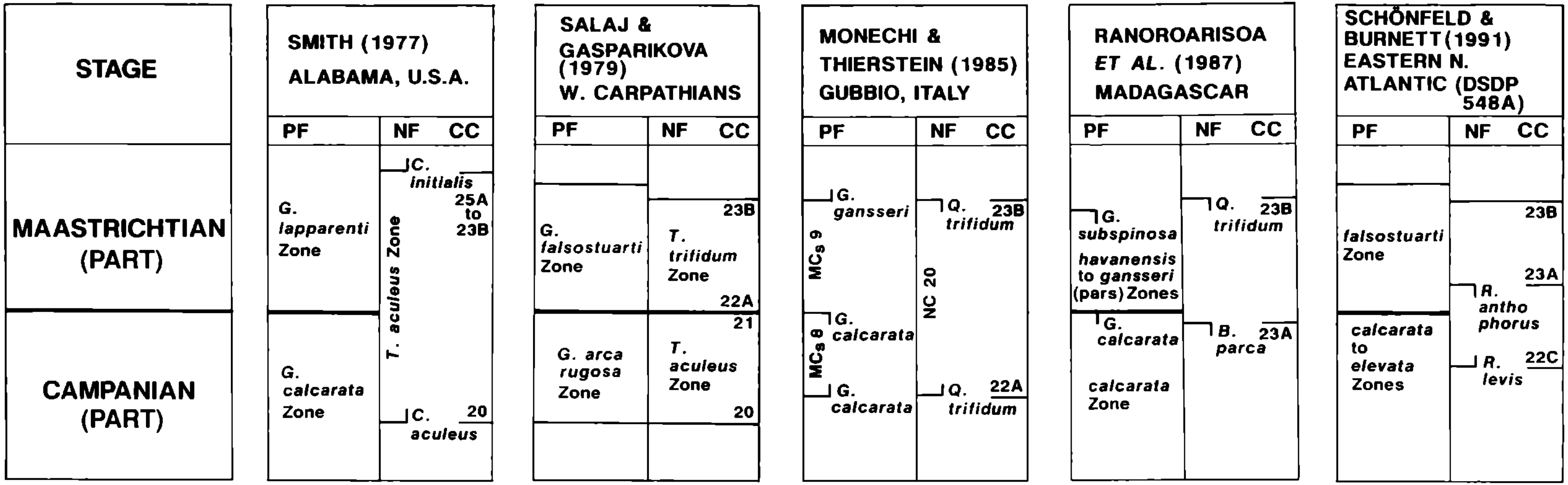

INDEX NANNOFOSSILS (NF)

Tetralithus (= Ceratolithoides) aculeus
Chiastozygus initialis
Tetralithus (= Quadrum) trifidum
Broinsonia parca
Reinhardtites anthophorus
Reinhardtites levis

INDEX PLANKTONIC FORAMINIFERA (PF)

Globotruncana lapparenti
Globotruncanita calcarata
Globotruncana falsostuarti
Globotruncana arca rugosa
Globotruncana gansseri
Globotruncana subspinosa
Globotruncana havanensis
Globotruncana elevata

Fig. 3. Summary of planktonic foraminiferal and nannofossil zonations at the Campanian/Maastrichtian boundary, as defined by the authors cited. No correlation between adjacent columns is intended or implied. CC refers to SISSINGH's (1977) and PERCH-NIELSEN's (1985) nannofossil (NF) Zones as referred to by the authors cited or as applied by the present authors herein, based on available data.

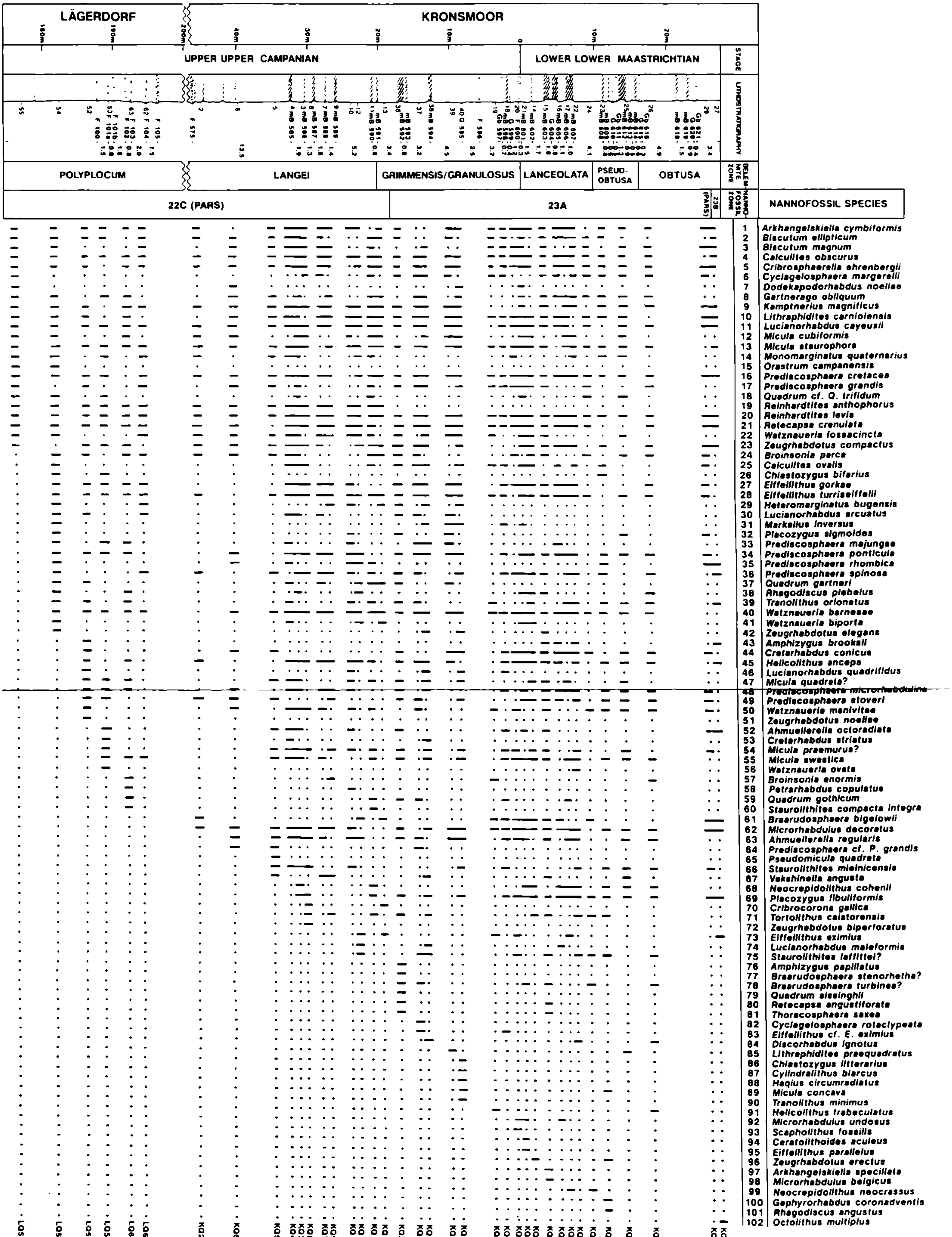

Fig. 4. Nannofossil zonation and distribution and macrofossil zonation across the Campanian/Maastrichtian boundary at Lägerdorf and Kronsmoor, Germany. Lithostratigraphy is from SCHULZ (1978).