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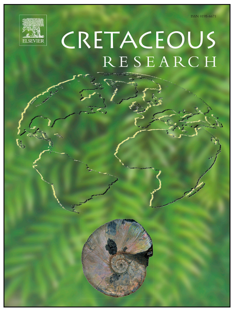


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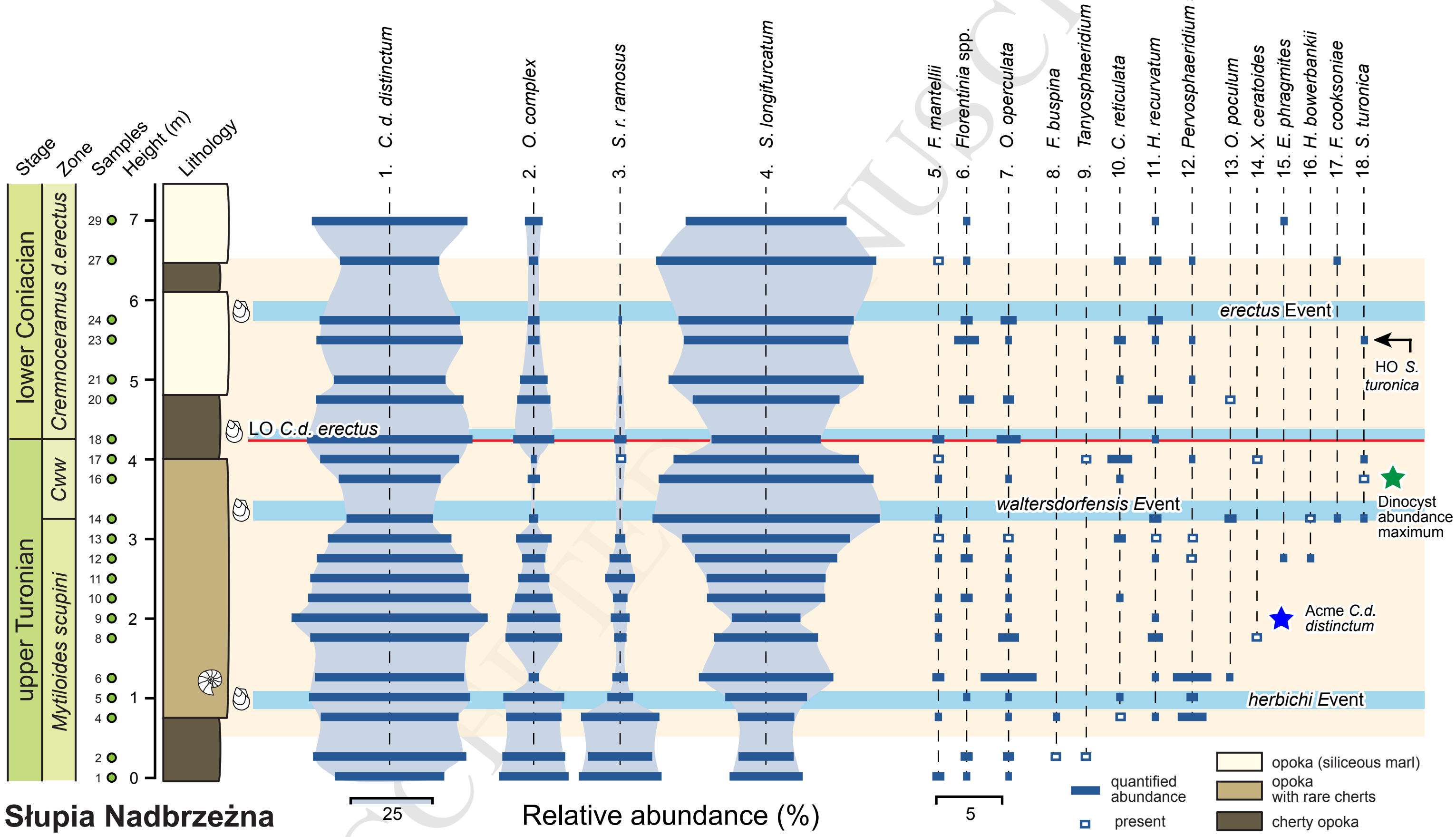
PII: S0195-6671(16)30068-4
DOI: 10.1016/j.cretres.2016.04.010
Reference: YCRES 3388

To appear in: *Cretaceous Research*

Received Date: 2 July 2015
Revised Date: 31 March 2016
Accepted Date: 15 April 2016

Please cite this article as: Olde, K., Jarvis, I., Pearce, M., Walaszczyk, I., Tocher, B., Organic-walled dinoflagellate cyst records from a prospective Turonian – Coniacian (Upper Cretaceous) GSSP, Słupia Nadbrzeżna, Poland, *Cretaceous Research* (2016), doi: 10.1016/j.cretres.2016.04.010.




Olde et al. Fig. 4

# Organic-walled dinoflagellate cyst records from a prospective Turonian – Coniacian (Upper Cretaceous) GSSP, Słupia Nadbrzeżna, Poland

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*Keywords:* Turonian, Coniacian, GSSP, Palynology, Dinoflagellate cyst

**ABSTRACT**

A river section at Słupia Nadbrzeżna, central Poland, has been proposed as a candidate Turonian – Coniacian (Cretaceous) GSSP, in combination with the Salzgitter-Salder quarry section of Lower Saxony, Germany. Results of a high-resolution (25 cm) palynological study of the boundary interval in the Słupia Nadbrzeżna section are presented. Terrestrial palynomorphs are rare; marine organic-walled dinoflagellate cysts dominate the palynological assemblage. The dinoflagellate cyst assemblage has a low species richness (5 – 11 per sample; total of 18 species recorded) and diversity (Shannon index $H$ = 0.8 – 1.4), dominated by four taxa: *Circulodinium distinctum* subsp. *distinctum; Oligosphaeridium complex; Spiniferites ramosus* subsp. *ramosus; Surculosphaeridium longifurcatum*. Declining proportions of *O. complex* and *S. ramosus* subsp. *ramosus* characterise the uppermost

Turonian, with an increased dominance of *S. longifurcatum* in the lower Coniacian. The Turonian – Coniacian boundary interval includes an acme of *C. distinctum* subsp. *distinctum* in the upper *Mytiloides scupini* Zone, a dinoflagellate cyst abundance maximum in the *Cremnoceramus walterdorfensis walterdorfensis* Zone, and the highest occurrence of *Senoniasphaera turonica* in the basal Coniacian lower *Cremnoceramus deformis erectus* Zone. Most previously reported Turonian – Coniacian boundary dinoflagellate cyst marker species are absent; a shallow-water oligotrophic epicontinental depositional setting, remote from terrestrial influence, likely limited species diversity and excluded many taxa of biostratigraphic value.

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## 1. Introduction

The Słupia Nadbrzeżna river cliff section, central Poland, combined with the Salzgitter-Salder quarry of Lower Saxony, Germany, has been proposed as a composite Global Boundary Stratotype Section and Point (GSSP) for the base of the Coniacian Stage at 89.75 Ma (Walaszczyk and Wood, 1998; Walaszczyk et al., 2010; Ogg et al., 2012).

During the Late Cretaceous, Słupia Nadbrzeżna was located in a pelagic carbonate setting on the eastern margin of the Central European epicontinental basins system (Voigt et al., 2008; Fig. 1). The section forms part of the expanded Upper Cretaceous succession of the Middle Wisła (Vistula) River, and is exposed in the western Wisła river cliff in the village of Słupia Nadbrzeżna (50.9501°N, 21.8078°E), situated 150 km SSE of Warsaw. The exposure exists in a poor state, requiring excavation before study (Walaszczyk et al., 2010), but yields well-preserved inoceramid bivalve assemblages. The approximately 10 m section consists of opoka (siliceous marl) facies with varying proportions of chert (Fig. 2).

The Słupia Nadbrzeżna section spans the upper Turonian uppermost *Mytiloides scupini* Zone to the lower Coniacian lowest *Cremnoceramus deformis erectus* Zone, and provides an expanded and more complete Turonian – Coniacian boundary record than the better-exposed Salzgitter-Salder section (Wood et al., 2004; Walaszczyk et al., 2010), which was proposed as the base Coniacian GSSP by the Coniacian Working Group of the Subcommission on Cretaceous Stratigraphy (Kauffman et al., 1996). The proposed base of the Coniacian is taken at the lowest occurrence of the inoceramid bivalve *Cremnoceramus deformis erectus* (Meek, 1877) [= *C. rotundatus* (*sensu* Tröger, 1967 *non* Fiege, 1930)]. This lies above the lowest occurrence of the ammonite *Forresteria (Harleites) petrocoriensis* (Coquand, 1859), traditionally used as a Coniacian marker in the stratotype area of the Aquitaine Basin (Kennedy and Walaszczyk, 2004; Fig. 3). Inoceramid records indicate condensation and a minor hiatus at the stage boundary in the stratigraphically more extensive section at Salzgitter-Salder (Wood et al., 2004; Walaszczyk et al., 2010); this hiatus provides the rationale for using the two sections as a composite GSSP.

The lithostratigraphy, macrofossil, foraminiferal and nannofossil biostratigraphy and carbon stable-isotope chemostratigraphy of Słupia Nadbrzeżna and Salzgitter-Salder have been described by Walaszczyk and Peryt (1998), Walaszczyk and Wood (1998), Kennedy and Walaszczyk (2004), Wood et al. (2004), Lees (2008) and Walaszczyk et al. (2010). In terms of carbon stable isotopes, the Turonian – Coniacian boundary lies at an inflection point from long-term falling to rising $\delta^{13}C$ values (Voigt and Hilbrecht, 1997; Wiese, 1999; Jarvis et al., 2006). Most of the succession at Słupia Nadbrzeżna represents the upper part of the broad $\delta^{13}C$ minimum that occurs globally at the Turonian – Coniacian boundary (Wendler, 2013; Jarvis et al., 2015), the Navigation Carbon Isotope Event (CIE; Fig. 2) of Jarvis et al. (2006). However, carbon and oxygen stable-isotope values from Słupia Nadbrzeżna show high-amplitude variation with lithology (Figs. 2, 3), indicating that the section has likely been affected by diagenesis (cf. Walaszczyk et al., 2010). Carbon stable-isotope values are around 1 ‰ lower than those found at an equivalent level in Salzgitter-Salder (Fig. 2), offering further evidence of a diagenetic overprint.

## 2. Materials and Methods

Twenty-one samples from the Słupia Nadbrzeżna section that had been collected for stable-isotope analysis (Walaszczyk et al., 2010) were selected for palynological preparation. Splits (20 g) of chipped samples were processed for quantitative palynological analysis. Palynomorphs >15 μm were concentrated by a commercial processing company (PLS Ltd, Holyhead, UK) using the HCl-HF method of Lignum (2009), modified from Lignum et al. (2008, 'Company B' methodology). Oxidation of the samples was unnecessary due to the low concentration of amorphous organic matter present. All samples were spiked with tablets containing the modern spore *Lycopodium* to allow statistically valid quantitative analysis (dinoflagellate cysts per gram, dpg).

Palynomorph identification and counting was undertaken using a Leitz Laborlux S light microscope with a 40x objective. Three hundred organic walled dinoflagellate cysts (dinocysts) were identified per sample. Broken or partial specimens were added to the count only if there was more than half of the specimen present. Unidentifiable specimens were recorded as 'indeterminate', and were not included in the count of 300, but were included when calculating total palynomorphs per gram. Following this count, the remainder of the slide was scanned to identify any additional species, which were marked as 'present', but in abundances too low to be recorded among the 300. The presence of any other palynomorphs such as pollen grains, spores, acritarchs and foraminiferal test linings was also noted.

All materials used in this study are held by the Department of Geography and Geology, Kingston University London (London, UK).

## 3. Results and discussion

Dinoflagellate cysts recovered from Słupia Nadbrzeżna are well preserved, but the assemblage exhibits a low species richness (18 species recorded), with between 5 and 11 species identified in each sample (Fig. 3; Appendix A, B). Dinoflagellate cysts are numerous (up to ~1500 dinoflagellate cysts per gram of sediment; Fig. 3) and at least 300 specimens were identified in all samples. Species diversity is low with Shannon (Shannon–Wiener) index values of $H = 0.8 – 1.4$ (Fig. 3). Approximately 90 % of the assemblage throughout the section is made up of four species: *Circulodinium distinctum* subsp. *distinctum*, *Oligosphaeridium complex*, *Spiniferites ramosus* subsp. *ramosus* and *Surculosphaeridium longifurcatum* (Figs. 4, 5.4 – 5.7). Approaching the stage boundary, *O. complex* and *S. ramosus* subsp. *ramosus* decline in relative abundance, while *S. longifurcatum* increases, showing a particular peak around the *waltersdorfensis* inoceramid Event.

Dinoflagellate cyst abundance does not display a consistent long-term trend but peaks immediately above the *waltersdorfensis* Event, in the mid-*C. w. waltersdorfensis* Zone (Fig. 3). Diversity shows a progressive smooth decline through the section, but with a pronounced trough in the uppermost Turonian coincident with the abundance maximum. Other diversity and dominance indices (not plotted; see Appendix B) closely follow the Shannon index trend. Domination of the assemblage by *S. longifurcatum* accounts for low Shannon index diversity values over this interval (Figs. 3, 4). A sharp recovery of diversity occurs at the stage boundary, followed by continuing falling values above.

Terrestrial palynomorphs occur sporadically in low abundance through the section, generally with < 10 bisaccate pollen grains per gram (< 1 % of the palynomorphs counted), with the exception of the lowest sample, in which 27 bisaccate pollen grains per gram were recorded. Pollen grains occur consistently only in the lowest metre of the section (Fig. 3).

### *3.1. Dinoflagellate cyst biostratigraphy*

*Surculosphaeridium longifurcatum*, which was used by Williams (1977) to define an acme zone representing the Turonian, is a frequent component of the Słupia Nadbrzeżna Turonian – Coniacian boundary assemblage (Figs. 4, 5.6). However, *S. longifurcatum* is a long-ranging species, from upper Barremian (Prössl, 1990) to Campanian (Williams and Bujak, 1985; Kirsch, 1991; Williams et al., 1993; Pearce, 2000). At Słupia Nadbrzeżna, it is most abundant (40 – 68 % of the assemblage) higher in the section, in the uppermost Turonian – basal Coniacian. A comparable trend has been observed in the Bch-1 core near Prague, Czech Republic (Olde et al., 2015a, b). Here, *Surculosphaeridium longifurcatum* occurs throughout the uppermost Cenomanian – lower Coniacian, but it is only common in the uppermost Cenomanian – basal middle Turonian and then again in the uppermost upper Turonian *M. scupini* Zone to lower Coniacian, including a peak around the Navigation CIE.

*Circulodinium distinctum* subsp. *distinctum* constitutes ~40% of the dinoflagellate cysts assemblage throughout the Słupia Nadbrzeżna section (Figs. 4, 5.8). Turonian acmes of *C. distinctum* subsp. *distinctum* have been found to have biostratigraphic significance in other European sections (FitzPatrick, 1995; Pearce, 2000; Pearce et al., 2003; Olde et al., 2015a) but, to our knowledge, an acme at the Turonian – Coniacian boundary has not been recorded elsewhere.

*Senoniasphaera turonica*, a characteristic Turonian species (Pearce et al., 2011), was identified in 4 samples from the Słupia Nadbrzeżna section (Figs. 4, 5.2). Its highest occurrence (HO) is at 5.5 m in the lower Coniacian *C. erectus* Zone, below the *erectus* Event. The highest occurrence of this species has been recorded near the Turonian – Coniacian boundary elsewhere, extending into the basal Coniacian in the English Chalk (Pearce, 2000; Pearce et al., 2003, 2011). In the Czech Republic Bch-1 well, the HO of this species occurs in the mid-*S. neptuni* Zone (upper Turonian), below the Hitch Wood CIE (Olde et al., 2015a).

The HO of *Oligosphaeridium poculum* occurs in the lower Coniacian at Słupia Nadbrzeżna (Fig. 4). The HO of this species was considered to be lower Turonian by Williams et al. (2004). However, in NW Europe, a regional reoccurrence datum level for the species occurs in lower to middle Turonian (Pearce, 2000; Pearce et al., 2009, Olde et al., 2015a), and it is recorded sporadically above this, ranging into the Coniacian in the Trunch borehole of eastern England (Pearce, 2000) and in the Běchary Bch-1 borehole of the Czech Republic (Olde et al., 2015a). Our records from Słupia Nadbrzeżna support an extended range for this taxon.

The main Turonian – Coniacian boundary dinoflagellate cyst events observed in the Czech Republic and elsewhere (Olde et al., 2015a) have not been recorded at Słupia Nadbrzeżna; for example, the lowest occurrences of *Surculosphaeridium belowii* and *Cribroperidium wilsonii*, and the lowest common occurrence of *Oligosphaeridium pulcherimum*, are unrepresented due to an absence of the index species. Additionally, other key boundary datum levels, such as the highest common occurrence of *Cauveridinium membraniphorum* immediately below the Navigation CIE in the uppermost Turonian, and the HO *Kiokansium unituberculatum* immediately above the Navigation CIE in the lower Coniacian (Olde et al., 2015a) are unrepresented, perhaps due to the very limited stratigraphic range of the Polish section, which is largely confined to the Navigation CIE interval (Fig. 2).

### *3.2. Palaeoenvironmental interpretation*

The dinoflagellate cyst assemblages at Słupia Nadbrzeżna are characterised by low abundances, low species richness and diversity, and an absence of peridinioid taxa, which typify environments with elevated nutrient levels (Jacobsen and Anderson, 1986; cf. Olde et al., 2015b). The dinoflagellate cyst taxon *C. distinctum* subsp. *distinctum* is placed within the Areoligeraceae, a family that is usually considered to have inner-neritic and reduced salinity environmental affinities (e.g. Batten, 1982; Harker et al., 1990; Wilpshaar and Leereveld, 1994; Leereveld, 1995; Pearce, 2000). *Surculosphaeridium longifurcatum* has also been previously attributed an inner-neritic affinity (Pearce, 2000; Pearce et al., 2003).

Foraminiferal assemblages at Słupia Nadbrzeżna show a dominance of benthic species (~80 %) in the upper Turonian (Fig. 3), with a short (one sample) increase in planktonic taxa at the Turonian – Coniacian boundary (~45 %), above which planktonic forms become even rarer, making up less than 10 % of foraminiferal specimens in the Coniacian (Walaszczyk and Peryt, 1998; Walaszczyk et al., 2010). This contrasts strongly with the Salzgitter-Salder succession, where planktonic taxa constitute >50 % of the foraminiferal assemblage in the uppermost Turonian, increasing through the *M. scupini* Zone to ~90 % across the stage boundary and throughout the lower Coniacian *C. erectus* Zone (Walaszczyk et al., 2010). Low planktonic/benthic ratios at Słupia Nadbrzeżna support an inner-neritic setting for the area at that time.

The Słupia Nadbrzeżna section is poorly exposed and weathered, offering the possibility that the observed palynological and calcareous microfossil assemblages are not solely a product of the depositional environment, but may have been modified by diagenesis and/or weathering. Different dinoflagellate cyst species respond differently to oxidation, with some being very sensitive and others being very resistant (Zonneveld et al., 1997). Modern dinoflagellate cysts most vulnerable to degradation are often produced by heterotrophic peridinioid species (Zonneveld et al., 1997, 2008). The absence of peridinioid cysts could therefore be an artefact of preservation: most recovered forms identified are large and robust. However, Zonneveld et al.'s (1997, 2008) studies focussed on Cenozoic peridinioid cysts within the Congruentidiaceae family; there is little evidence to suggest that this selective preservation applies equally to Late Cretaceous peridinioids. On balance, the lack of peridinioid specimens in the Słupia Nadbrzeżna section is considered to most likely reflect the depositional environment.

The combination of low dinoflagellate cyst species richness and diversity, and an absence of peridinioid forms suggest stressed palaeoenvironmental conditions. The lack of peridinioids, in particular, indicates an oligotrophic depositional environment. The prevalence of *C. distinctum* subsp. *distinctum* and benthic foraminifera suggests a relatively shallow-water 'inner-shelf' setting for Słupia Nadbrzeżna during the late Turonian. However, the lack of terrestrial palynomorphs is not typical of such an environment. The most likely interpretation therefore is of a shoal setting within an extensive shallow epicontinental sea. Rising sea levels accompanying the Turonian eustatic highstand limited siliciclastic sedimentation in Poland to the margins of Fennoscandia (Krassowska, 1997; Walaszczyk in Voigt et al., 2008), in the vicinity of Gdańsk (Fig. 1). Słupia Nadbrzeżna, situated more than 300 km to the SE, was sufficiently far from any landmass to account for the lack of terrestrial palynomorphs.

The influx of *S. longifurcatum* over the *C. waltersdorfensis* Event is coincident with a minor negative $\delta^{13}C$ excursion that may be indicative of a short-term sea-level fall at this level. This suggests that the relative abundance of *S. longifurcatum* is negatively correlated with local sea level (i.e., it becomes more abundant during times of lowered sea level). The subsequent ~0.5 ‰ positive-$\delta^{13}C$ excursion is coupled with a *S. longifurcatum* minimum, and peaks in foraminifera planktonic/benthic ratio and dinoflagellate cyst diversity (Fig. 3). These features likely reflect a short-term transgression coincident with the base Coniacian, as noted also in the Czech Republic (Uličný, et al. 2014; Jarvis et al., 2015; Olde et al., 2015b).

## 4. Conclusions

Palynological investigations of the prospective Turonian – Coniacian GSSP at Słupia Nadbrzeżna reveal an assemblage dominated by well-preserved organic walled dinoflagellate cysts, though abundance, species richness and diversity are low. Due to the paucity of palynomorph species, few datum levels are of biostratigraphic utility. These include the highest occurrence of *Senoniasphaera turonica* in the lowest Coniacian *Cremnocermaus deformis erectus* Zone and, potentially, a dinoflagellate cyst abundance maximum in the uppermost Turonian *Cremnocermaus walterdorfensis walterdorfensis* Zone.

Palynological results suggest a relatively shallow-water pelagic environment for the Słupia Nadbrzeżna Turonian – Coniacian boundary sediments, though diagenetic overprinting or weathering evidenced by stable-isotope results may also have affected the assemblages. Oligotrophic conditions in a distal epicontinental sea, remote from terrestrial influence, are indicated by the low dinoflagellate cyst diversity, an absence of peridinioid species, and a paucity of terrestrial palynomorphs.

**Acknowledgments**

Kate Olde acknowledges receipt of a Kingston University London PhD studentship and support by Statoil Petroleum AS contract 4501936147. Przemysław Gedl (Polish Academy of Sciences), two anonymous referees, and editor Eduardo Koutsoukos provided valuable critical reviews.

**Appendix A. Species list**

List of dinoflagellate cyst species identified from Turonian – Coniacian boundary interval in the Słupia Nadbrzeżna section. Numbers refer to order of species plotted in Fig. 4. Selected species are illustrated in Fig. 5. Numerical data are listed in Appendix B. Taxonomic references are given in Fensome et al. (2008) and Pearce et al. (2011).

10. *Cassiculosphaeridia reticulata* Davey, 1969

1. *Circulodinium distinctum* subsp. *distinctum* (Deflandre and Cookson, 1955) Jansonius, 1986

15. *Exochosphaeridium phragmites* Davey et al., 1966

8. *Florentinia buspina* (Davey and Verdier, 1976) Duxbury, 1980

17. *Florentinia cooksoniae* (Singh, 1971) Duxbury, 1980; emend. Duxbury, 1980

5. *Florentinia mantellii* (Davey and Williams, 1966) Davey and Verdier, 1973

6. *Florentinia* spp.

16. *Hystrichosphaeridium bowerbankii* Davey and Williams, 1966

11. *Hystrichosphaeridium recurvatum* (White, 1842) Lejeune-Carpentier, 1940

7. *Odontochitina operculata* (Wetzel, 1933) Deflandre and Cookson, 1955

2. *Oligosphaeridium complex* (White, 1842) Davey and Williams, 1966

13. *Oligosphaeridium poculum* Jain, 1977

12. *Pervosphaeridium* spp.

18. *Senoniasphaera turonica* (Prössl, 1990 ex Prössl, 1992) Pearce et al., 2011

3. *Spiniferites ramosus* subsp. *ramosus* (Ehrenberg, 1838) Mantell, 1854

4. *Surculosphaeridium? longifurcatum* (Firtion, 1952) Davey et al., 1966

9. *Tanyosphaeridium* spp.

14. *Xenascus ceratioides* (Deflandre, 1937) Lentin and Williams, 1973

**Appendix B.** Numerical palynological data from the Turonian – Coniacian boundary interval at Słupia Nadbrzeżna.

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## Figure Captions

**Fig. 1.** Location of the Słupia Nadbrzeżna and Salzgitter-Salder candidate GSSP sections and Turonian palaeogeography of central Europe. Map compiled from Voigt et al. (2008).

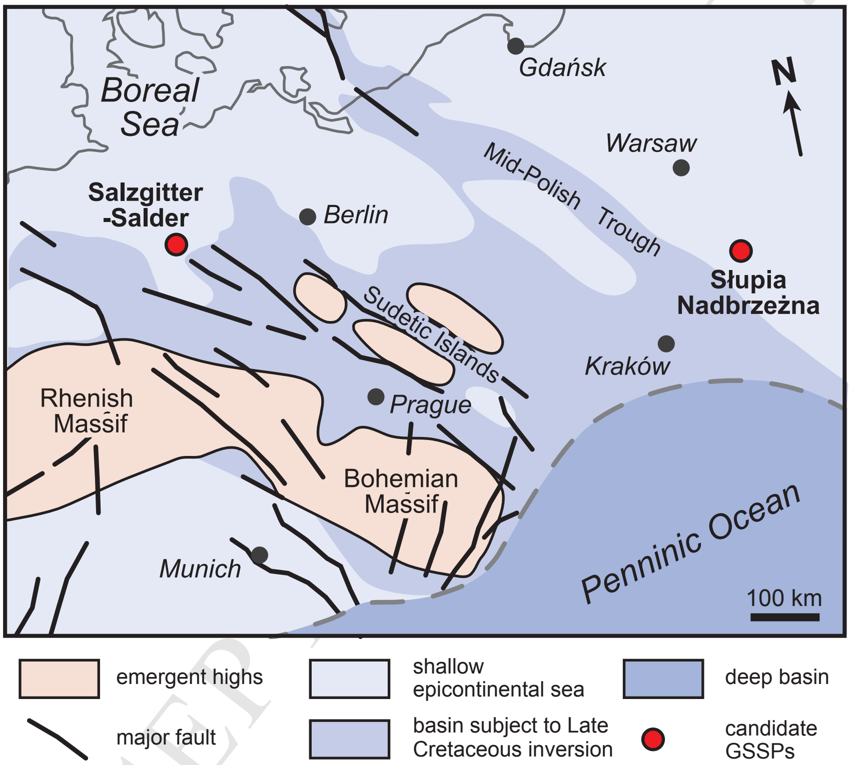
**Fig. 2.** Stratigraphy, key inoceramid bivalve ranges, macrofossil events, unsmoothed carbon stable-isotope profiles, and correlation of the Turonian – Coniacian boundary interval between the Salzgitter-Salder (Germany) and Słupia Nadbrzeżna (Poland) sections. *Cww* = *Cremoceramus walterdorfensis walterdorfensis*. LO = lowest occurrence. Compiled from Walaszczyk et al. (2010).

**Fig. 3.** Carbon and oxygen stable-isotope profiles, foraminifera planktonic / benthic (P/B) ratio, and organic walled dinoflagellate cyst abundance, species richness and diversity through the Turonian – Coniacian boundary interval at Słupia Nadbrzeżna. Cream band indicates extent of the Navigation Carbon Isotope Event (CIE) of Jarvis et al. (2006); blue bands are inoceramid bivalve events. The recorded position of the ammonite *Forresteria (Harleites) petrocoriensis* is indicated (arrow). Numbered circles indicate positions of stable-isotope samples; filled circles are samples that were additionally processed for palynology. Coloured dots and thin joining lines show data values; thicker coloured lines are three-point moving averages (except for lower resolution foraminifera data). LO = lowest occurrence. Lithology and biostratigraphy after Walaszczyk and Wood (1998), Kennedy and Walaszczyk (2004) and Walaszczyk et al. (2010).

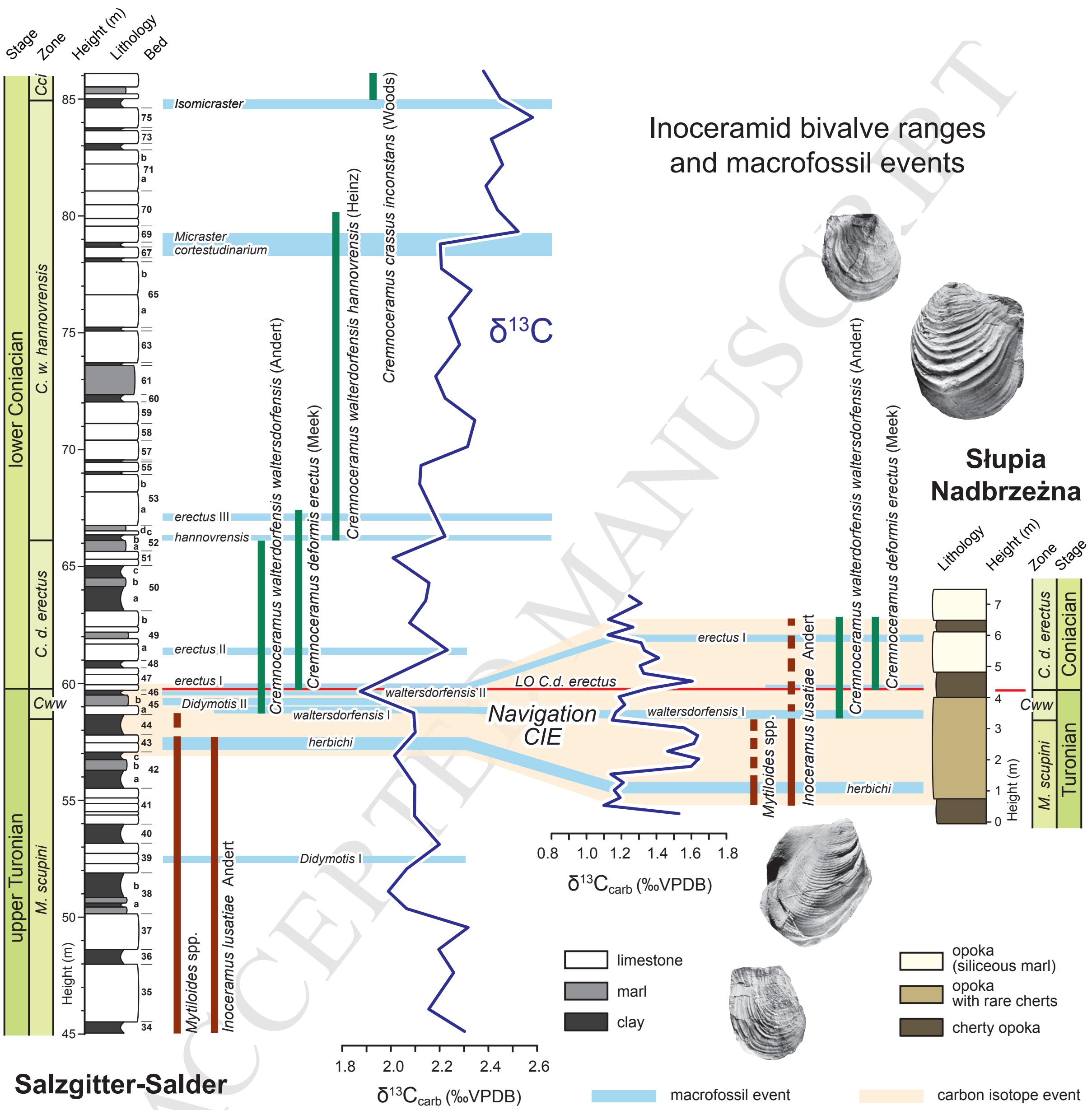
**Fig. 4.** Range chart of dinoflagellate cyst species identified in the Słupia Nadbrzeżna Turonian – Coniacian boundary section. Dinoflagellate cyst relative abundances are given as a percentage of specimens of each species in a sample. Note the different abundance scales used for the four dominant taxa (blue shaded profiles; left) and other species (right). Potentially significant dinoflagellate cyst biostratigraphic datum levels are indicated. Cream

band indicates extend of the Navigation CIE; blue bands are inoceramid bivalve events. LO = lowest occurrence; HO = highest occurrence. Lithology and inoceramid biostratigraphy after Walaszczyk et al. (2010). Selected species are illustrated in Fig. 5.

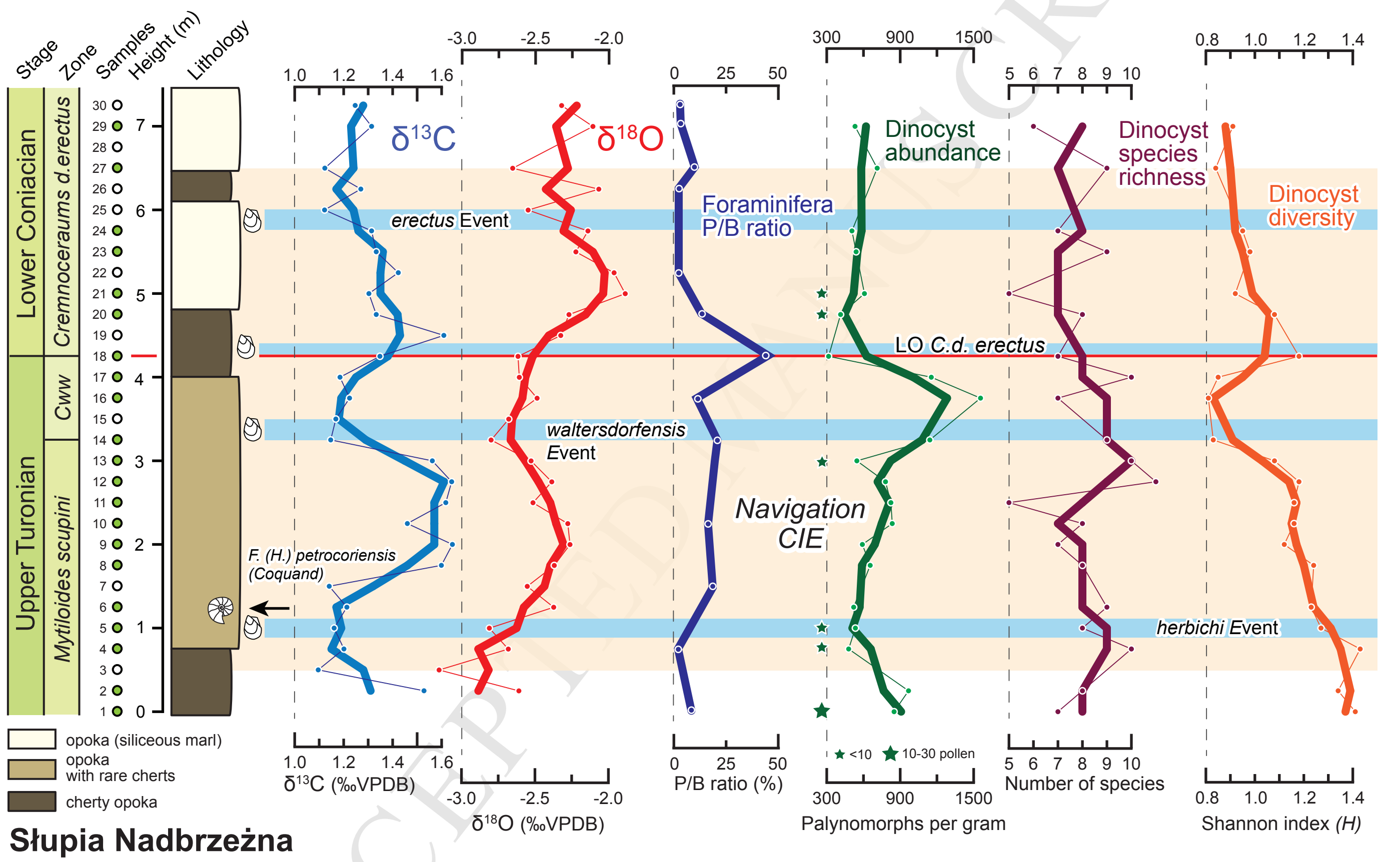
**Fig. 5.** Selected dinoflagellate cyst species identified from the Turonian – Coniacian boundary interval at Słupia Nadbrzeżna. 1, *Tanyosphaeridium* sp., sample 2, 0.25 m. 2, *Senoniasphaera turonica*, sample 16, 3.75 m. 3, *Florentinia mantellii* sample 1, 0 m. 4, *Oligosphaeridium complex*, sample 4, 0.75 m. 5, *Surculosphaeridium longifurcatum*, sample 14, 3.25 m. 6, *Spiniferites ramosus* subsp. *ramosus*, sample 17, 4.0 m. 7, *Circulodinium distinctum* subsp. *distinctum*, sample 16, 3.75 m. 8, *Cassiculosphaeridia reticulata*, sample 4, 0.75 m. 9, *Oligosphaeridium poculum,* sample 20, 4.75 m. 10, *Pervosphaeridium* sp., sample 12, 2.75 m. 11, *Odontochitina operculata*, sample 1, 0 m. 20 μm scale-bar is used for all photos.



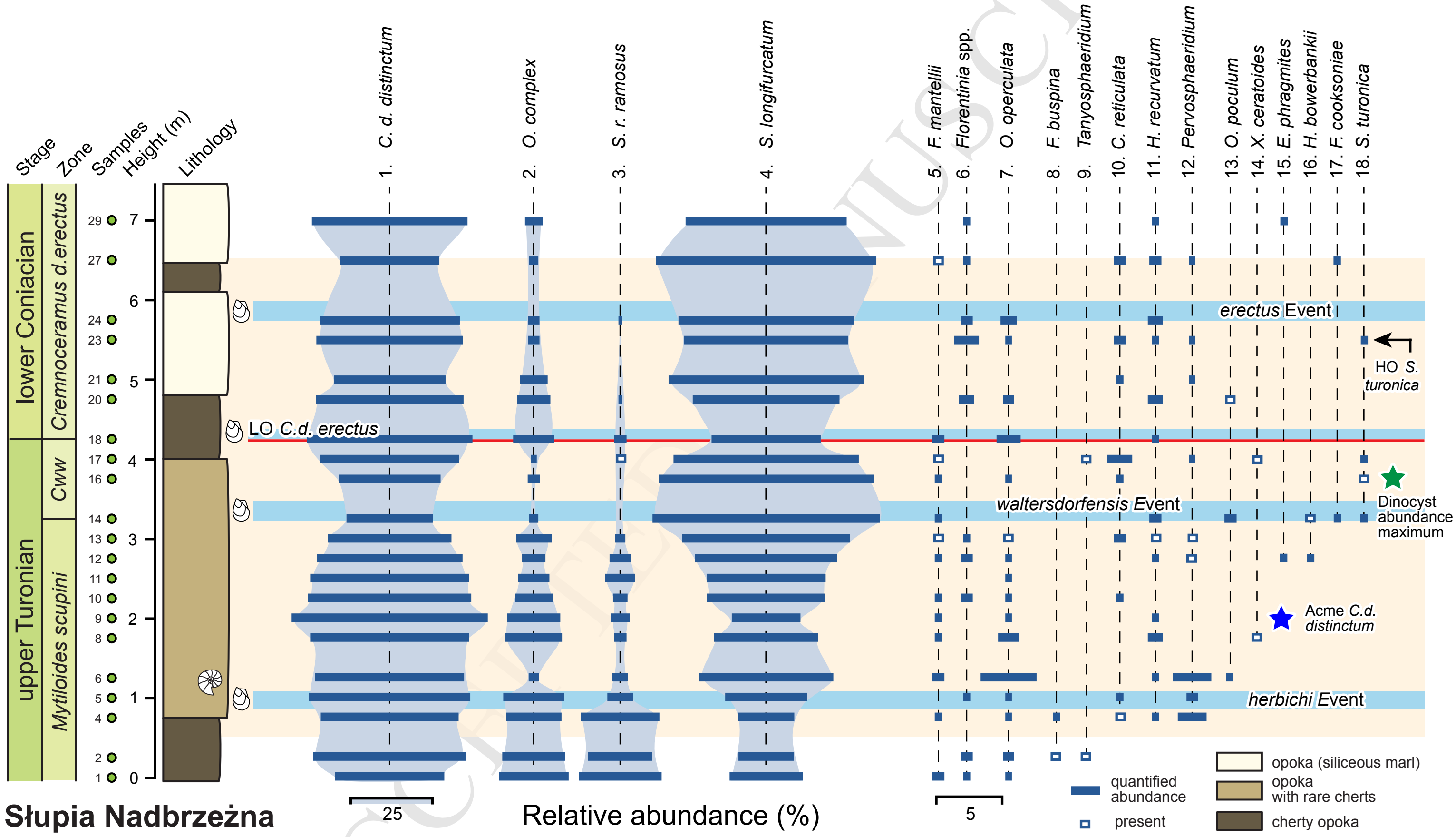

Olde et al. Fig. 1



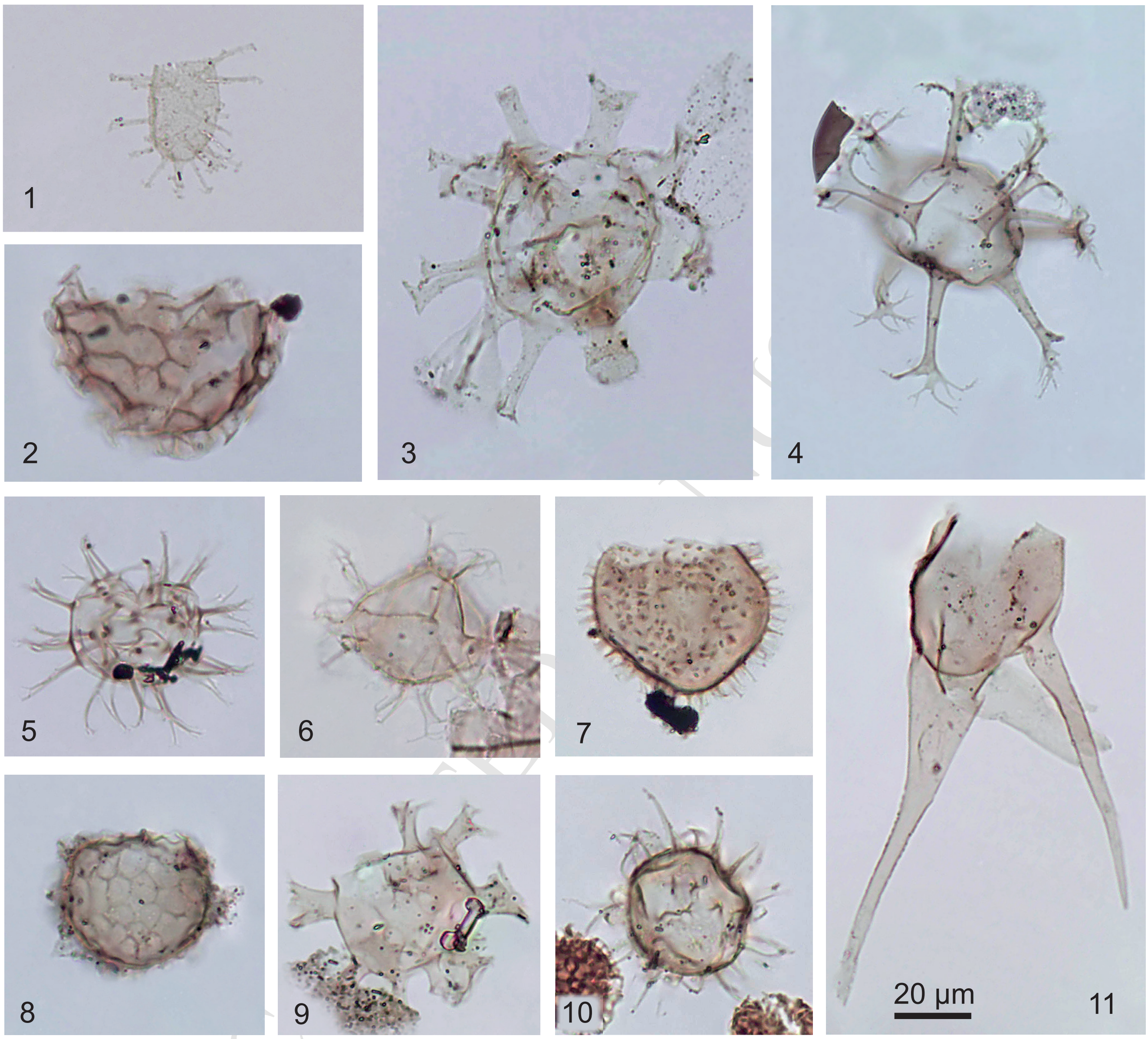

Olde et al. Fig. 2




Olde et al. Fig. 3




Olde et al. Fig. 4




Olde et al. Fig. 5

Organic-walled dinoflagellate cysts have been recovered from the Turonian – Coniacian candidate GSSP

All samples yielded abundant well-preserved specimens enabling quantitative analysis

Assemblages have low species richness and diversity, and are dominated by four taxa; they include few biostratigraphic marker species

Terrestrial palynomorphs are poorly represented

Deposition occurred in a relatively shallow water pelagic environment in the Eastern European epicontinental sea