Dinoflagellate biostratigraphy at the Campanian-Maastrichtian boundary in Zumaia, northern Spain

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Abstract

Dinoflagellate cyst assemblages from a well-exposed uppermost Cretaceous section at Zumaia (northern Spain) provide a basis for comparison with previous biostratigraphical and magnetostratigraphic studies on the problematic location of the Campanian-Maastrichtian boundary in the section. The position of the last occurrence of *Corradinisphaeridium horridum* and first common occurrence of *Alterbidinium* cf *acutulum*, correspond well with the bioevents defining the Campanian-Maastrichtian boundary in the Global boundary Stratotype Section and Point of Tercis les Bains (130 km to the North). Together with other age-diagnostic dinoflagellate cyst bioevents, we suggest that the boundary should be placed between 239.75 and 224.75 m below the Cretaceous-Palaeogene boundary, about 46 meters lower than previously based on the first occurrence of the planktonic foraminifer *Pseudoguembelina palpebra* and the last occurrence of the nannofossils *Broinsonia parca* subsp. *constricta*. A conspicuous acme of the dinoflagellate cyst *Thalassiphora* cf. *delicata* is encountered around the lower-upper Maastrichtian boundary (placed by foraminiferal, calcareous nannoplankton and magnetic polarity data), which may prove to be a useful correlatable event.

Keywords: Campanian-Maastrichtian boundary, dinoflagellate cysts, planktonic foraminifera, Zumaia, northern Spain

1. Introduction

The studied coastal outcrop is located in Zumaia, Basque Country, northern Spain. It represents one of the best known and intensely studied Palaeogene intervals due to the good accessibility of the section, completeness, thickness and absence of structural complexity. However, dinoflagellate cysts from the Upper Cretaceous interval at Zumaia have not been studied in a biostratigraphical mean. A confident high-resolution calibration of micropalaeontological data with magnetostratigraphic record for the Campanian-Maastrichtian boundary (CMB) interval remains inconclusive at Zumaia (Pérez-Rodríguez et al., 2012), and the placement of the CMB is contested. The aim of this study is to describe the palynological assemblages and suggest the position of the CMB at Zumaia based on the first and last stratigraphic occurrence (FO and LO) of dinoflagellates and correlation of key markers with Time-equivalent sections in Europe.

2. Previous study

Biostratigraphical study of the Upper Cretaceous section based on dinoflagellate cysts has not been previously undertaken, despite the use of dinocysts as excellent markers for the Global boundary Stratotype Section and Point (GSSP) for the Campanian-Maastrichtian stage boundary at Tercis les Bains in southern France (Odin et al., 2001). The dinoflagellate cysts from Zumaia outcrop were only analyzed to obtain palaeoenvironmental results (Davies et al., 1991).

Other uppermost Cretaceous microfossils, particularly planktonic foraminifera and calcareous nannofossils, have been previously analysed by Herm (1965), Lamolda (1983), Burnett et al. (1992), Lamolda and Gorostidi (1994), Arz and Molina (2002), Batenburg et al., (2012), Pérez-Rodríguez et al. (2012) and Pérez-Rodríguez (2013).

Macropalaeontological investigations of the Zumaia section are numerous and are focused on ammonites and inoceramids (MacLeod and Orr, 1993; Ward and Kennedy, 1993; Ward et al., 1991; Wiedmann, 1988).

Previous palynological analyses of younger section in Zumaia yielded excellent results and allowed for establishment of GSSP for the bases of the Selandian and Thanetian stages.

3. Regional setting

The Zumaia section (43º17’56’’N, 2º16’04’’W) is located in the Gipuzkoa province of Basque Country, Spain. The uppermost Cretaceous outcrop is exposed in the southwestern part of the Punta Aitzgorri cliff, close to the village of Zumaia. Geologically, the section is located in the domains of the Basque arc within the Basque-Cantabrian Basin (Fig. 1) and is represented by thick marine pelagic and turbiditic deposits (Martín-Chivelet et al., 2002).

Please, insert Fig. 1 around here

The uppermost Campanian and Maastrichtian strata of Zumaia were deposited at an estimated water depth of 800–1500 m, based on benthic foraminifera (Schwentke and Kuhnt, 1992). The Zumaia section represents the deepest part of the Basque-Cantabrian basin, which borders a marine carbonate platform to the north that is represented by the Tercis section (Fig. 2). The Basque-Cantabrian Basin was an interplate trough with a complex tectonic evolution history related to kinematic relationships between the Iberian and European plates, as well as opening of the North Atlantic and Bay of Biscay (García-Mondéjar, 1996; Rat, 1988). After a riftingspreading stage during the Aptian to early Campanian, the Pyrenean orogeny was initiated, as the Iberian plate moved north-westward, resulting in the convergence between Iberia and Europe (Schwentke and Kuhnt, 1992). This movement created the trough by the enlargement and connection of precursor sub-basins of the spreading stage (Pujalte et al., 1998).

Please, insert Fig. 2 around here

The studied interval comprises two geological formations: Aguinaga and Zumaia-Algorri, both defined by Mathey (1982). At Zumaia, these two formations are separated by the Pikote Azpia fault system located near a waterfall (Figs 3, 4). The age of the Aguinaga Formation is early Campanian (Baceta et al., 2010) to early Maastrichtian (this work). It is consists of thin and medium bedded sandstone turbidites alternated with marls. This formation unit was deposited during an interval of increased differential subsidence (Pujalte et al., 1998) and at Zumaia it reaches 1500 m thickness (Baceta et al., 2010). The Zumaia-Algorri Formation age is of early Maastrichtian to latest Maastrichtian age. It consists rhythmic alternations of hemipelagic limestone and marlstone, with some intercalations of thin bedded sandy turbidites. It reaches a thickness of approximate 200 m at Zumaia. This unit was deposited during an interval of slight subsidence and relative tectonic stability. This was reflected in the basin by a strong reduction of siliciclastic input and sedimentation rates (Pujalte et al., 1998).

Please, insert figures 3 and 4 around here

4. Material and methods

A total of 34 rock samples were collected through 312.78 m of the section (thickness of vertical section was measured). The samples were preferentially collected from the soft marly beds as a preliminary investigation determined more favorable abundances. They were collected starting from 398.75 m and continuing up to 85.97 m below the Cretaceous-Paleogene boundary (Figs 3, 4). The sampled interval spans Unit 1 to Unit 7 described previously by Wiedmann (1988). Unit 1 is represented by the top of the Aguinaga Formation and consist of a turbiditic sequence composed of an alternation of thin to medium bedded sandstone turbidites (from 5 to 60 cm approximately) and marls of similar thickness. The other units belong to Zumaia-Algorri Formation. Unit 2 comprises: 33.40 m of grey marly limestone beds with grey marls with occasional thin decimeter or centimeter sandstone turbidites. It is separated from unit 1 by the Pikote Azpia fault system. Unit 3: 18.6 m of grey limestones and marls of similar thickness with occasional thin sandstone turbidites which decrease towards the top of the unit. Unit 4: 10.4 m of grey limestones and marls, with only a few laminated turbiditic sandstone layers. Unit 5: 7.2 m of grey marly limestone with marls and a few centimeter turbiditic layers. Unit 6: 13.7 m of grey micritic limestones with a very few marly and turbiditic layers. Unit 7: 28.9 m of red marls with grey interbeds and a few centimeter sandstone turbidites.

The palynological samples were processed at the Polish Academy of Sciences, Laboratory of the Geological Sciences Institute, Kraków. The applied procedure included 38% HCl and 40% HF acid treatments, separation by heavy-liquid ($ZnCl_2$+HCL; density 2.0 g cm^{-3}) and sieving through a nylon sieve (10 μm mesh). Weight of the processed rock was 40.0 g for each sample. Palynological slides were made with addition of glycerin jelly. Slides were studied under Zeiss Axioscope 50. Up to 200 dinoflagellate cysts were counted from each sample when possible (Table 1). In case of low dinoflagellate cyst frequency (less than 200 specimens), a scan of second slide was made and included in Tab. 1. The rock samples, palynological residues and slides are stored in the collection of the Institute of Geological Sciences, Polish Academy of Sciences, Kraków.

5. Results

Relatively common and diverse assemblages of dinoflagellate cysts from the Zumaia section provided a basis for a palynostratigraphic framework and establishment of the CMB. The species *Cannosphaeropsis utinensis*, recorded within the whole section, is indicative for a terminal Santonian to late Maastrichtian age (Begouën et al., 1990; Williams et al., 2004). The FO of *C. diebelii* suggests the upper Campanian (Antonescu et al., 2001; Slimani et al., 2001, 2011). The *C. horridum* is used to define the uppermost Campanian in Tercis les Bains (Fig. 5, Antonescu et al., 2001). The LO of *Raetiaedinium truncigerum* present 5 m above the LO of *C. horridum* is located in the lower Maastrichtian at Tercis les Bains (Antonescu et al., 2001). The same event has been recorded in the uppermost Campanian (Slimani et al., 2001) and upper Campanian (Slimani et al., 2011). The FO of *Alterbidinium acutulum* co-occuring with the LO of *R. truncigerum* indicates an early Maastrichtian (Nøhr-Hansen, 2012) or an early Campanian (Slimani et al., 2001, 2011). Antonescu et al. (2001) regarded the first common occurrence (FCO) of *Alterbidinium* sp. (cf. *acutulum*) as indicative of the lowermost Maastrichtian at the Tercis les Bains section. The FCO of *A. acutulum* in Zumaia was recorded at the depth of 224.75 m, above the LO of *R. truncigerum*. The presence of *Trithyrodinium quinqueangulare* above the LO of *R. truncigerum* and below the FCO of *A. acutulum* also indicates the early Maastrichtian age (Marheinecke, 1992; Nøhr-Hansen, 2012; Schiøler and Wilson, 1993). Because of age discrepancies involving such events as LO of *R. truncigerum* and FO of *A. acutulum*, the confident CMB is placed between the LO of the *C. horridum* (239.75 m) and FCO of the *A. acutulum* (224.75 m).

Please insert Fig. 5 around here.

Several dinoflagellate cyst bioevents recorded above the FCO of *A. acutulum* support the Maastrichtian age: LO of *A. acutulum* (Nøhr-Hansen, 2012; Schiøler and Wilson, 1993; Slimani et al., 2001, 2011), FO of *Thalassiphora* cf. *delicata* (De Coninck and Smit, 1982), FO of *Rottnestia wetzelii* (Schiøler et al., 1997), LO of *Flandrecysta furcata* (Antonescu et al., 2001; Schiøler and Wilson, 2001; Slimani, 1994; Slimani et al., 2001), LO of *Florentinia mayi* (Williams et al., 2004), LO of *Tanyosphaeridium variecalamum* (Begouën, 1993; Foucher, 1979) and LO of *Pervosphaeridium pseudhystrichodinium* (Antonescu et al., 2001; Roncaglia and Corradini, 1997; Schiøler and Wilson, 2001; Skupien and Mohamed, 2008). The additional presence of *Cannosphaeropsis utinensis* in the youngest collected sample suggests that the studied interval is no younger than the late Maastrichtian (Schiøler et al., 1997; Schiøler and Wilson, 1993; Slimani et al., 2001, 2011; Williams et al., 2004).

6. Discussion and conclusions

Differences between the micropalaeontological data from Zumaia and those from the Tercis boundary stratotype section in France suggest that the selected criteria used to identify the CMB are problematic (Pérez-Rodríguez et al., 2012) and that the proposed foraminiferal biostratigraphy is not sufficient for establishing the boundary

(Gardin et al., 2012; Pérez-Rodríguez et al., 2012; Robaszynski and Mzoughi, 2010). The FO of the ammonite *Pachydiscus neubergicus*, that has been chosen as a marker for the CMB, also shows limited biostratigraphical application in Zumaia, as it has been found within the Unit 2 of Wiedmann (Ward and Kennedy, 1993), about 55 m above the CMB boundary according to this study. This discrepancy may be caused by a scarcity of these taxa at Zumaia outcrop, causing that this marker may be unreliable for establishing the CMB in the region.

Regarding the magnetostratigraphy of the CMB, there is a consensus about its position at Chron C32n.2n (Gardin et al., 2012; Husson et al., 2011; Odin, 2001; Voigt et al., 2012). It indicates that in Zumaia section the CMB should be located lower than suggested before by Dinarès-Turell et al. (2013) and Pérez-Rodríguez et al. (2012), who tentatively placed it at the magnetochron C31r. Based on the dinoflagellate bioevent stratigraphy at Tercis les Bains (Antonescu et al., 2001), we suggest that the CMB at Zumaia should be placed between 239.75 m and 224.75 m below the Cretaceous/Paleogene boundary (Fig. 6), between the LO of C*orradinisphaeridium horridum* and the FCO *of A. acutulum*.

Please insert Fig. 6 around here.

The Zumaia section has been proposed as a potential substage boundary stratotype for lower-upper Maastrichtian (Odin et al., 1996) but a practical definition of the boundary is still pending. Our dinoflagellate cyst study has unfortunately not yielded bioevents for the placement of the lower-upper Maastrichtian boundary. The LO of *Alterbidinium acutulum* which may indicate the boundary (Schiøler and Wilson, 1993; Slimani et al., 2001, 2011) similarly as *Hystrichodinium pulchrum* subsp. *pulchrum*

(Kirsch, 1991; Schiøler et al., 1997; Schiøler and Wilson, 1993; Slimani et al., 2001) are both located below the LOs of the *Tanyosphaeridium variecalamum* and *Pervosphaeridium pseudhystrichodinium*. The LO of *T. variecalamum* has been previously recorded from the lower Maastrichtian (Foucher, 1975; Tocher and Jarvis, 1987). The LO of *P. pseudhystrichodinium* also indicates the age not younger than the early Maastrichtian (Schiøler and Wilson, 1993). In addition the LO of *Florentinia mayi* located between the LO of *Alterbidinium acutulum* and *Hystrichodinium pulchrum* indicates the earliest early Maastrichtian (Williams et al., 2004). Thus we find the establishment of the lower-upper Maastrichtian boundary problematic.

The other potential markers for the lower-upper Maastrichtian include the extinction of rudist reefs, virtual extinction of inoceramids, the FOs of calcareous nannofossils and the ammonite *Pachydiscus fresvillensis*. More recently, Pérez-Rodríguez et al. (2012) suggested the FO of the planktonic foraminifera *Racemiguembelina fructicosa*, the FO of nannofossils *Lithraphidites quadratus*, and the C31r/C31n magnetic polarity reversal as potential markers. The latter event occurs within the Unit 6 in Zumaia, where a conspicuous acme of the dinoflagellate cyst *Thalassiphora* cf. *delicata* (Fig. 6) has been recorded. The species dominates the samples at 125.9 to 111.6 m by reaching 90 to 99 % of the assemblage. The presence of *T*. cf. *delicata* has been previously recorded from the Maastrichtian of southern Spain by de Coninck and Smit (1982), but without an obvious acme. Therefore, additional studies are required to determine the usefulness of *T*. cf. *delicata* as a potential (local?) marker for the lower-upper Maastrichtian boundary.

Please, insert figs. 7 to 9 around here.

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Systematic palynology

Dinoflagellate cyst species recorded in this study and listed alphabetically. Details and references not provided are given in Fensome and Williams (2004), Fensome et al. (2008; 2009). Selected species are illustrated in Figs. 7 to 9.

Achomosphaera spp.

Adnatosphaeridium spp.

Alterbidinium acutulum (Wilson, 1967) Lentin and Williams, 1985

Cannosphaeropsis utinensis Wetzel, 1933

Cassiculosphaeridia reticulata Davey, 1969

Cerodinium diebelii (Alberti, 1959) Lentin and Williams, 1987

Cerodinium spp.

Chlamydophorella? *grossa* Manum and Cookson, 1964

Circulodinium distinctum (Deflandre and Cookson, 1955) Jansonius, 1986

Circulodinium spp.

Cleistosphaeridium spp.

Cordosphaeridium fibrospinosum Davey and Williams, 1966

Cordosphaeridium spp.

Corradinisphaeridium horridum (Deflandre, 1937) Masure, 1986

Cribroperidinium spp.

Cyclonephelium spp.

Dinopterygium cladoides Deflandre, 1935

Exochosphaeridium spp.

Fibrocysta spp.

Flandrecysta furcata Slimani, 1994

Florentinia mayi Kirsch, 1991

Florentinia spp.

Foraminiferal test linings

Glaphyrocysta spp.

Heterosphaeridium spp.

Hystrichodinium pulchrum Deflandre, 1935

Hystrichosphaeridium spp.

Hystrichosphaeridium tubiferum (Ehrenberg, 1838) Deflandre, 1937

Isabelidinium spp.

Kleithriasphaeridium loffrense Davey and Verdier, 1976

Rigaudella apenninica (Corradini, 1973) Below, 1982

Oligosphaeridium complex (White, 1842) Davey and Williams, 1966

Oligosphaeridium spp.

Ovoidinium spp.

Palaeocystodinium australinum (Cookson, 1965) Lentin and Williams, 1976 – *bulliforme* Ioannides, 1986 complex

Palambages morulosa (algae)

Pervosphaeridium pseudhystrichodinium (Deflandre, 1937) Yun Hyesu, 1981

Pervosphaeridium spp.

Phelodinium spp.

Pterodinium spp.

Raetiaedinium truncigerum (Deflandre, 1937) Kirsch, 1991

Rottnestia wetzelii (Deflandre, 1937) Slimani, 1994

Spinidinium echinoideum (Cookson and Eisenack, 1960) Lentin and Williams, 1976

Spiniferites ramosus (Ehrenberg, 1838) Mantell, 1854 Group

Tanyosphaeridium spp.

Tanyosphaeridium variecalamum Davey and Williams, 1966

Thalassiphora cf. *delicata* (Fig. 10)

Proximate, dorsoventrally flattened dinoflagellate cyst with the general outlook resembling the *Thalassiphora delicata.* Transparent, typically smooth periphragm and endophragm separated from each other by pericoel, being in contact only in mid-dorsal area, similarly as in the *T. delicata*. Periphragm dorsoventrally flattened, fenestrate appearance typical for the *T. delicata* not observed. The recorded specimens are strongly deformed, so the paratabulation and distribution of the plates are not possible to record. The typical precingular archaeopyle, processes and fibrous structures characteristic for the genus are not visible.

Trithyrodinium quinqueangulare Marheinecke, 1992

Please, insert Tab. 1 around here.

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Figure 1. A, location of the Basque-Cantabrian Basin. B, schematic division of the Basque-Cantabrian Basin in its three geological domains and the Upper Cretaceous outcrops. Modified after Martín-Chivelet et al. (2002) and Vera (2004). C, location of Zumaia village and the studied outcrop.

Figure 2. Palaeogeographical reconstruction of the Pyrenean area showing the distribution of the different depositional settings during the Maastrichtian, modified after Plaziat (1981) and Dinarès-Turell et al. (2013).

Figure 3. Panoramic view of the outcrop in the Punta Aitzgorri cliffs, showing the lithological units U1 to U8 of Wiedmann (1988) and location of the palynological

samples. The top and base of the units based on Wiedmann (1988) and Dinarès-Turell et al. (2013).

Figure 4. Panoramic view of the outcrop in the Punta Aitzgorri cliffs, showing location of palynological samples and the Campanian-Maastrichtian boundary according to dinoflagellate cyst data. U1 = Unit 1 of Wiedmann (1988).

Figure 5. Simplified scheme showing selected dinoflagellate cyst events as they occur from the Tercis section in France. Modified after Antonescu et al. (2001).

Figure 6. Summary of the dinoflagellate cyst and other microfossil data from the upper Campanian and Maastrichtian of the Zumaia section. The foraminiferal biostratigraphy of the section is based on previous study of the Aguinaga Fm. (Arz and Molina, 2002) and the Zumaia-Algorri Fm. (Pérez-Rodríguez, 2013).

Figure 7

1. *Alterbidinium acutulum*, 229.75 m
2. *Cannosphaeropsis utinensis*, 398.75 m
3. *Cassiculosphaeridia reticulata*, 398.75 m
4. *Cerodinium diebelii*, 398.75 m
5. *Circulodinium distinctum*, 274.75 m
6. *Cordosphaeridium fibrospinosum*, 368.75 m
7. *Corradinisphaeridium horridum*, 398.75 m
8. *Corradinisphaeridium horridum*, 398.75 m
9. *Dinopterygium cladoides*, 239.75 m

10. *Flandrecysta furcata*, 204.75 m

11. *Florentinia mayi*, 224.75 m

Figure 8.

1. *Florentinia* sp., 190.75 m

2. *Hystrichodinium pulchrum*, 244.75 m

3. *Hystrichosphaeridium tubiferum*, 182.4 m

4. *Kleithriasphaeridium loffrense*, 178.75 m

5. *Rigaudella apenninica*, 209.75 m

6. *Oligosphaeridium* sp., 165.7 m

7. *Palaeocystodinium australinum-bulliforme*, 190.75 m

8. *Pervosphaeridium pseudhystrichodinium*, 398.75 m

9. *Pervosphaeridium pseudhystrichodinium*, 398.75 m

10. *Pterodinium* sp., 239.75 m

11. *Raetiaedinium truncigerum*, 308.75 m

Figure 9.

1. *Rottnestia wetzelii*, 182.4 m

2. *Spinidinium echinoideum*, 244.75 m

3. *Spiniferites membranaceus*, 239.75 m

4. *Spiniferites* sp., 274.75 m

5. *Spiniferites* cf. *ramosus*, 204.75 m

6. *Tanyosphaeridium variecalamum*, 398.75 m

7. *Thalassiphora* cf. *delicata*, 182.4 m

8. *Trithyrodinium quinqueangulare*, 191.02 m

9. *Trithyrodinium quinqueangulare*, 229.75 m

10. *Trithyrodinium suspectum*, 214.75 m

11. Foraminiferal test lining, 239.75 m

12. *Palambages morulosa* (algae), 175.65 m

Table 1. Distribution of palynomorphs in the upper Campanian and Maastrichtian Zumaia section.