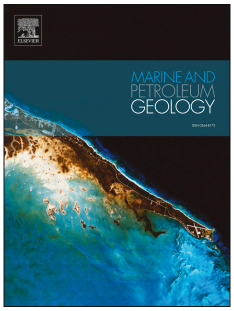

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PII: S0264-8172(19)30549-5

DOI: https://doi.org/10.1016/j.marpetgeo.2019.104107

Reference: JMPG 104107

To appear in: *Marine and Petroleum Geology*

Received Date: 7 August 2019

Revised Date: 21 October 2019

Accepted Date: 24 October 2019

Please cite this article as: Radmacher, Wiesł., Kobos, K., Tyszka, Jarosł., Jarzynka, A., Arz, José.Antonio., Palynological indicators of palaeoenvironmental perturbations in the Basque-Cantabrian Basin during the latest Cretaceous (Zumaia, northern Spain), *Marine and Petroleum Geology* (2019), doi: https://doi.org/10.1016/j.marpetgeo.2019.104107.

Palynological indicators of palaeoenvironmental perturbations in the Basque-Cantabrian Basin during the latest Cretaceous (Zumaia, northern Spain)

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Abstract

The latest Cretaceous palynological assemblages from the southern margin of the Basque-Cantabrian Basin (northern Spain, Zumaia) are dominated by black opaque equidimensional phytoclasts, black opaque blade shaped phytoclasts and translucent gold-orange to brown phytoclasts. Deep water dinoflagellate cysts *Cannosphaeridium utinensis* and *Pterodinium* spp. constitutes a part of the assemblages throughout the whole succession. This record and previous study suggest deposition of the Zumaia section in the marine bathyal conditions, in relative close proximity to the land. Palynofacies analyses yields increased abundance of *Leiosphaeridia* spp. and some changes in the palynomorph proportions just before the significant lithological change near the lower/upper Maastrichtian. This signal may either be primary and record an environmental change, or taphonomic. Nevertheless, environmental interpretation of the upper Maastrichtian palynological assemblage seems to be more consistent with the late Maastrichtian marine regression, and in consequence, a reduction of the distance from the nearby land. Such conditions may have caused transport of leiosphaerids from shallower water sites.

Keywords Campanian; Maastrichtian; palaeoenvironmental fluctuations; palynofacies, dinoflagellate cysts; *Leiosphaeridia* spp.

1. Introduction

The Cretaceous period (146 to 66 Ma) was a unique time of extremely warm climate conditions, high global sea-level, elevated atmospheric CO_2 and no significant ice at high latitudes (e.g. Frakes et al., 1992). The sea-level that could have been about a hundred meters higher than today (Hay, 2008) caused flooding of continental margins and interiors. Its fluctuations, as well as climate change, influenced phytoplankton evolution, ocean chemistry and organic carbon burial. The latest Cretaceous (Campanian and Maastrichtian) was a time of high variability of the palaeoenvironmental conditions (e.g. Barrera and Savin, 1999). The long-term global cooling interrupted by short-term warming and accelerated cooling episodes are proposed by Thibault and Gardin (2006), Linnert et al. (2014, 2016), Thibault et al. (2016a) and Chenot et al. (2016). Some of these episodes appear to be associated with fluctuation of sea-level, possible change in the nutrient supply, change in surface and bottom-water productivity, declining atmospheric $p\mathrm{CO}_2$ levels and negative carbon isotope anomalies (Jarvis et al., 2002, 2006; Friedrich et al., 2009; Linnert et al., 2014, 2018; Thibault et al., 2016; Engelke et al., 2017). Uppermost Cretaceous outcrops (especially these representing the Maastrichtian) are unfortunately rarely exposed in Europe. The coastal section in Zumaia, northern Spain, constitutes one of the best sedimentological records of this time interval. It represents about 240 m exposure of the Maastrichtian and much thicker, about 1100 m of Campanian (Mathey, 1982; Wiedmann, 1988), thus, being a unique material for detailed investigations. Among the marine micropaleontological proxies for environmental studies, palynofacies and dinoflagellate cysts constitute a valuable tool sensitive to changes of oceanic current dynamics, sea-level fluctuations (via proximal versus distal indicators), temperature and productivity of sea-surface waters (e.g. Brinkhuis et al., 1988; 1998; Dale and Fjellså, 1994; Götz et al., 2008; Sluijs et al., 2005; Tabara et al., 2017). Unfortunately, their application to reconstruct the latest Cretaceous in northern Spain is so far limited to only a few, mainly biostratigraphical studies (e.g. Radmacher et al., 2014). Thus, main aim of this study is to apply palynofacies and dinoflagellate cyst signal to provide a better insight into the palaeoenvironmental conditions of the Basque-Cantabrian Basin in the latest Mesozoic.

2. Geological setting

This study is focused on the Zumaia section located within the westernmost part of the Basque–Cantabrian Basin (BCB), Western Pyrenees, North Spain (Fig. 1). During the Cretaceous it was a rift-type SW European basin closely related to the history of the northern Iberian margin. The basin was opened westward towards the NE part of the Central Atlantic (Bay of Biscay), and in the east – towards the vanishing Western Tethys (Le Pichon and Sibuet, 1971; García-Mondéjar et al. 1996). It was surrounded by shallow shelf areas (Aquitania) and elevated platforms (Iberian, Ebro and Central massifs). The BCB extension was influenced by the opening of the North Atlantic Ocean and the Bay of Biscay (García-Mondéjar et al., 1996) and during the Jurassic and from the Albian to Santonian it was affected by inverse rotation of the Iberian Plate with respect to the European one (Olivet, 1996), and by clockwise motion of Africa (Smith, 1971; Blakey, 2008). This extensional basin originated in the Triassic and underwent rifting and subsequent spreading during the Cretaceous. From the Late Cretaceous, it was influenced by the Pyrenean Orogeny (Sibuet et al., 2004; Vergés et al., 2002) due to a collision between the microcontinent of Iberia and the southwestern part of the European Plate.

The uppermost Cretaceous succession of the BCB crops out along different coastal exposures. The thickest Maastrichtian exceeds 240 m and much thicker Campanian – about 1100 m of flysch deposits in Zumaia (Wiedmann, 1988). The age of Aguinaga Formation ranges from Campanian to lowermost Maastrichtian (see Mathey, 1982). This formation unit was deposited during increased subsidence of the basin (Pujalte et al., 1998). The Zumaia–Algorri Formation (lower to upper Maastrichtian) was deposited during an interval of slight subsidence and relative tectonic stability reflected in the basin by a reduction of siliclastic input and deposition rate (Pujalte et al., 1998). The division of Maastrichtian Zumaia–Algorri Formation (Mathey, 1982) is based on varying proportions of lithologies, including limestones and marls, clay-shales and thin to medium bedded turbidites. These lithological variations allowed the formal division into I–V members (Ward, 1988; Ward and Kennedy, 1993). The studied section includes Members I to IV that are further on divided into 8 informal lithological units (Wiedmann, 1988): (U1) turbiditic sequence with rare occurrence of macrofossils; (U2) marly limestone beds alternating with grey marls; (U3) pelagic grey limestones alternating with marls of similar thickness; U4: strongly burrowed grey limestones and marls with large inoceramids and *Zoophycos* trace fossils occurring abundantly on the upper bed surfaces. Also an increase of ammonite diversity was recorded in a part of this section; U5: grey marly limestones alternating with marls and a few laminated turbiditic layers with frequent ammonites, inoceramids and echinoids; U6: grey micritic limestones with no marly and turbiditic interlayers; U7: distinctive purple marls with grey interbeds with thin turbidites; U8: grey limestones alternating with grey, partly red marls. These units can be successfully recognised in geographically dispersed sections from northern Spain (Dinarès-Turell et al., 2013).

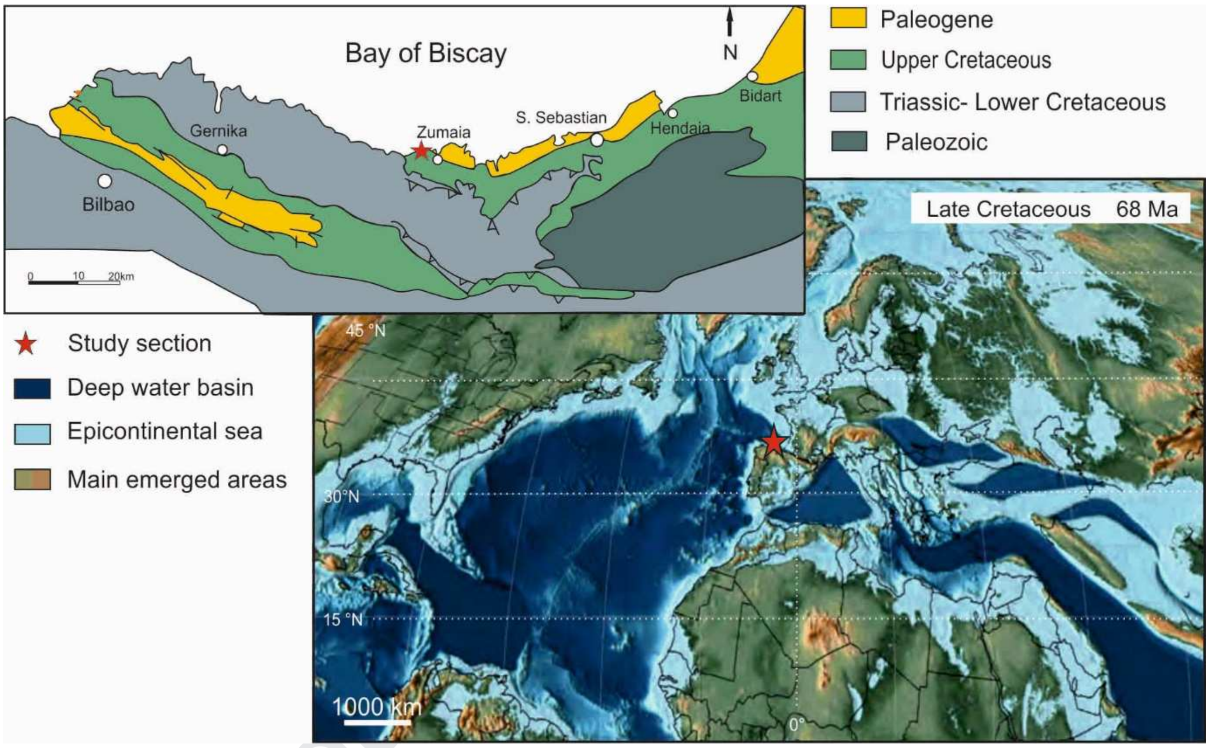


Fig. 1. Palaeogeographic location of the Basque–Cantabrian Basin with the location of the studied Zumaia site during the Late Cretaceous. Modified from Dinarès-Turell et al. (2013) and Scotese (2014).

3. Material and methods

The Zumaia section (43º17’56’’N, 2º16’04’’W) is exposed at the coastal Punta Aitzgorri cliff, west of the village of Zumaia, western part of the Guipuzkoa province (Fig. 1), belonging to the northernmost part of the so-called Zumaia syncline. The studied interval spans Unit 1 to 7 (Aguinaga and Zumaia–Algorri formations). The total of 34 samples were collected in year 2013 for biostratigraphical study (Radmacher et al., 2014), from 398.75 m up to 85.97 m below the Cretaceous/Paleogene (K/Pg) boundary. This is very important to collect the samples from specific lithologies, depending on the aim of the investigation and expected results. Samples from turbidite layers may contain completely different palynological assemblages, as represent material from more proximal conditions, subsequently transported by turbiditic currents into abyssal depths. Our aim was to date the sediment and reconstruct palaeoenvironmental conditions. Therefore, all of the samples were taken from soft marly intervals between the turbidite layers, to avoid redeposited material.

The samples were processed at the Polish Academy of Sciences, Institute of Geological Sciences, Cracow Research Centre. The weight of the processed rock was 40.0 gram per each sample. The methodology included removal of carbonates and silicates using 38% hydrochloric (HCl) and 40% hydrofluoric (HF) acids, removal of large particles by sieving with 250 μm and small particles with 10 μm mesh sieve and separation of organic material using heavy liquid ($ZnCl_2$ + HCl, density 2.0 g cm^{-3}). Slides were made with the addition of glycerine jelly and studied under the Zeiss Axioscope 50. Photographs were taken under a transmitted light microscope and Scanning Electron Microscope (SEM). Up to 1000 palynomorphs were counted from each sample under 40x magnification. Light photographs were taken by Zeiss Axioscope 50, under 40 to 100x magnification. The rock samples, palynological residues and slides are stored in the collection of the Institute of Geological Sciences, Polish Academy of Sciences, Kraków. Photographs of the key dinoflagellate cyst species discussed in this work as well as detailed biostratigraphic data are available in Radmacher et al. (2014).

A part of this study focuses on palynofacies analyses based on samples collected during the field trip to Zumaia in year 2013. Palynomorphs are divided into following categories: translucent gold-orange to brown phytoclasts, black opaque blade-shaped phytoclasts, black opaque equidimensional phytoclasts, spores and pollen; bisaccate pollen grains, amorphous organic matter (AOM), dinoflagellate cysts, microforaminiferal test linings (MFTL’s) and *Leiosphaeridia* spp. The relative richness of the

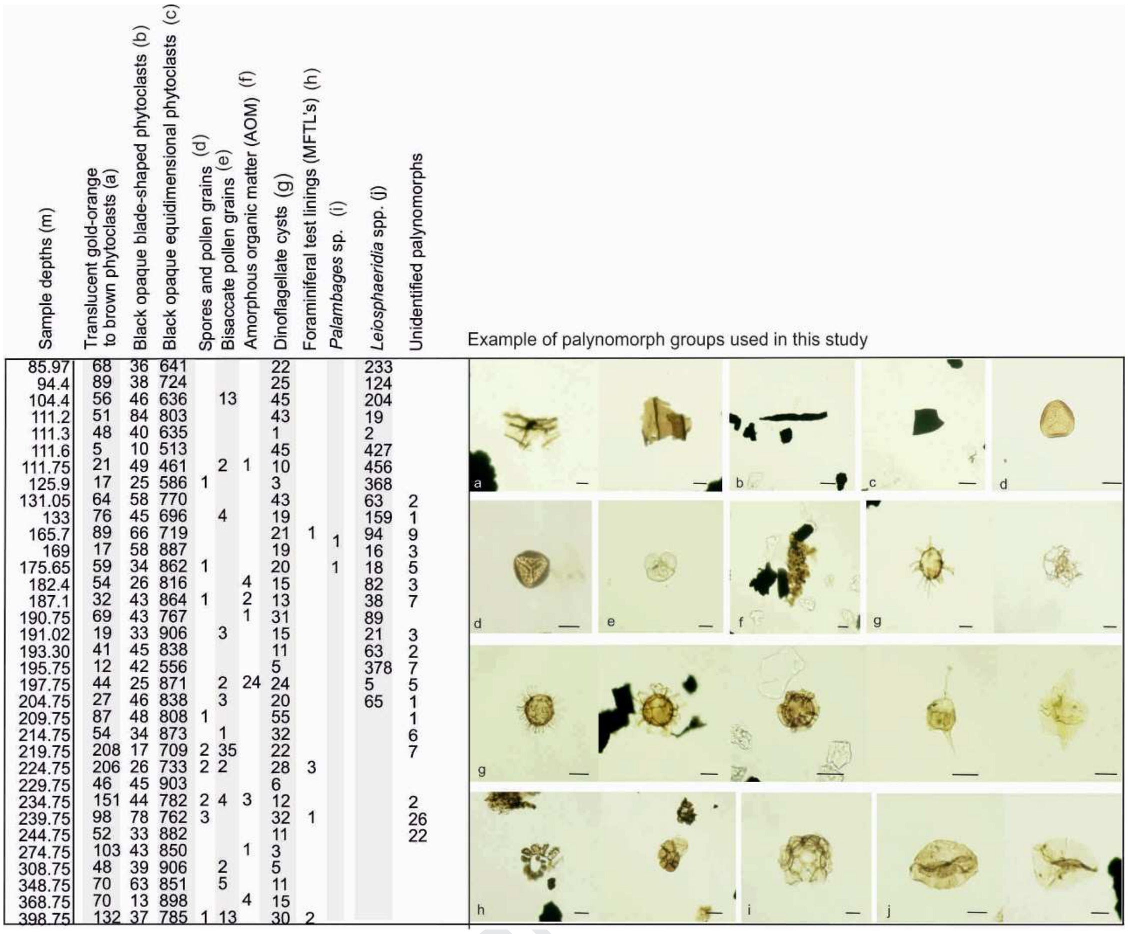
	GROUP	ORIGIN	DESCRIPTION	PALAEOENVIRONMENTAL SIGNIFICANCE WITHIN MARINE SETTINGS (this study)
TERRESTRIAL	Translucent gold-orange to brown phytoclasts	Tissues of terrestrial higher plants or fungi	Gold-orange to brown, translucent particles of wood tracheid, cellular sheets or epidermal tissues	Shallow sea/close distance to land
	Black opaque blade-shaped phytoclasts		Black particle of wood with long axis more than twice of the short axis	Shallow to deep sea/close to far distance from land
	Black opaque equidimensional phytoclasts		Black particle of wood with long axis less than twice of the short axis	Deep sea/far distance from land
	Spores and pollen grains	Terrestrial palynomorphs produced by Gymnosperm and Angiosperm plants, pteridophytes and fungi	Triangular, spherical to subspherical palynomorphs characterised by various ornamentation type. This group excludes bisaccate pollen grains	Vicinity of land
	Bisaccate pollen grains	Pollen grains of coniferous trees	Palynomorphs characterised by single central body with two attached bladders that enable the grains to travel long distances in the air	Vicinity of land. However, abundant occurrence of bisaccate pollen grains may indicate more distal conditions than other pollen grains and spores due to their easier transportation by wind/water currents
MARINE	Amorphous organic matter (AOM)	Organic matter of unknown affinity degraded by bacteria	Structureless, homogenous particles of brown to yellow colour, characterised by irregular to rounded (elongated) shape	High primary productivity, near-shore or upwelling zone
	Dinoflagellate cysts	Organic-walled microfossils of resting cysts produced by Dinophyceae during the sexual part of their life cycle	Palynomorphs that are distinguished from others by archaeopyle opening through which excystment occurs and paratabulation dividing the cyst into rectangular and polygonal plates. There are two main types characterised by different tabulation pattern: Gonyaulacoids (G) and Peridinioids (P)	Absence/presence of peridinioid-, gonyaulacoid type dinoflagellate cysts within sediment is controlled by primary conditions near the sea-surface (e.g. level of nutrients, sea-surface temperature, current directions), or syn- and post-depositional conditions related to bottom-water oxygenation and weathering, both hampering preservation of the cysts
	Microforaminiferal test linings (MFTL's)	Inner organic layers of calcareous foraminifers	Organic linings of brown colour with multiple chambers in spiral coiling	Shallow to deep marine conditions
	Palambages sp.	Chlorococcale colonial algae	Dark brown, globular, irregular, closely packed colonies	Enhanced fresh-water delivery
	Leiosphaeridia spp.	Organic-walled remnants of various planktic green algae/photosynthetic protists/other microorganisms of unknown affinities	Oblate, translucent spherical to elipsoidal in outline microfossil often wrinkled, with circular pylome located subapically. An equatorial line of folding or thickening across the body occurs in many of the observed specimens.	Stressed environmental conditions connected to marine regressive trend or longer sediment exposure to increased oxygen level.

Tab. 1. Classification of palynomorphs used in this study, including their origin, description and palaeoenvironmental significance within marine settings.

components is based on counting 1000 particles per slide. For more details see Table 1 and Figures 2A, 2B and 3. Further palaeoenvironmental reconstructions are supported by dinoflagellate cyst species diversity, and selected palaeoenvironmentaly important dinoflagellate cysts calculated according to data from Radmacher et al. (2014). Additional part of this paper includes synthesis of previously published palaeoenvironmental data from the BCB and adjacent areas.

4. Results

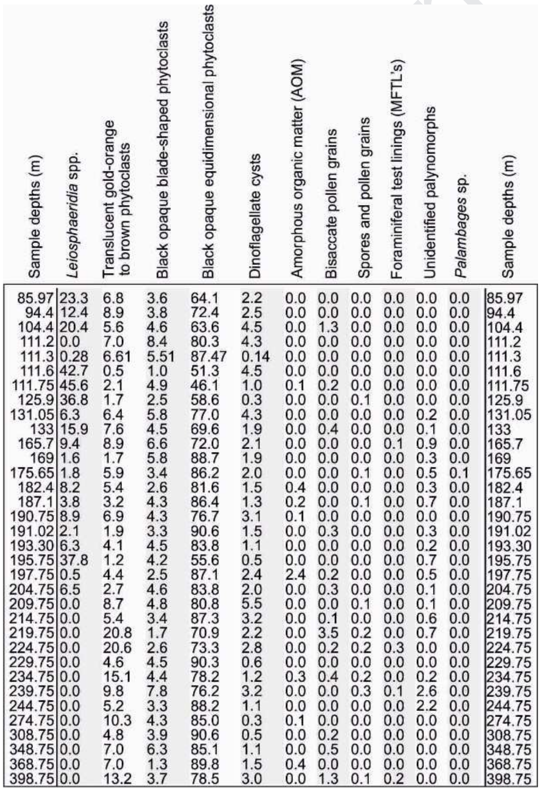
All studied samples yielded abundant occurrence of black opaque equidimensional phytoclasts (80% of the assemblage in average) and well-preserved dinoflagellate cysts (up to 5.5%). Black opaque blade-shaped phytoclasts are less abundant (up to 8.4%), and their number does not change significantly throughout the interval. Spores and pollen including bisaccate pollen, amorphous organic matter (AOM) and microforaminiferal test linings (MFTL's) occur in low number. *Leiosphaeridia* spp. appear within the uppermost part of the U1, in the lower Maastrichtian, and are continuously present towards the top of the studied interval, excluding two samples 111.30 and 111.20. They increase significantly in the sample 195.75 of U1; 125.90 (base of U6) and 111.75, 111.60 (top of U6). Excluding the sample 195.75, the *Leiosphaeridia* show gradual increase toward the top of U6. Strongest variations in the assemblage composition have been recorded within units 6 to 7. The black opaque equidimensional phytoclasts, black opaque blade-shaped phytoclasts and structural organic matter including translucent gold-orange to brown phytoclasts are recorded throughout the whole studied interval. The highest number of the translucent gold-orange to brown phytoclasts has been recorded in the upper part of the U1. Figure 2A, B and Table 1 present the total palynomorph abundance and their division scheme. It is worth to mention that the decreased trends in relative abundance of translucent gold orange to brown phytoclasts, black opaque blade-shaped phytoclasts and black opaque equidimensional phytoclasts from sample 204.75 upward constitute an artificial signal, due to a change in proportion caused by the appearance and of the *Leiosphaeridia* spp. Despite this, the dinoflagellate cysts in the upper part of the interval (sample 111.60 and above) become more abundant. In addition, according to our studies, the units U1 to U7 are dominated by *Spiniferites* spp. and this species occurs throughout the whole studied interval, together with *Pterodinium* spp. and *Cannosphaeropsis utinensis* (see Radmacher et al., 2014) that are not present only in few samples. Planktic foraminifera in the studied section are highly diversified and heterohelicids constitute the most dominant group during the Maastrichtian (Pérez-Rodríguez et al., 2013).



Sample depths (m)	Translucent gold-orange to brown phytoclasts (a)	Black opaque blade-shaped phytoclasts (b)	Black opaque equidimensional phytoclasts (c)	Spores and pollen grains (d)	Bisaccate pollen grains (e)	Amorphous organic matter (AOM) (f)	Dinoflagellate cysts (g)	Foraminiferal test linings (MFTL's) (h)	*Palambages* sp. (i)	*Leiosphaeridia* spp. (j)	Unidentified palynomorphs
85.97	68	36	641				22			233	
94.4	89	38	724				25			124	
104.4	56	46	636		13		45			204	
111.2	51	84	803				43			19	
111.3	48	40	635				1			2	
111.6	5	10	513				45			427	
111.75	21	49	461		2	1	10			456	
125.9	17	25	586	1			3			368	
131.05	64	58	770				43			63	2
133	76	45	696		4		19			159	1
165.7	89	66	719				21	1	1	94	9
169	17	58	887				19			16	3
175.65	59	34	862	1			20		1	18	5
182.4	54	26	816			4	15			82	3
187.1	32	43	864	1		2	13			38	7
190.75	69	43	767			1	31			89	
191.02	19	33	906		3		15			21	3
193.30	41	45	838				11			63	2
195.75	12	42	556				5			378	7
197.75	44	25	871		2	24	24			5	5
204.75	27	46	838		3		20			65	1
209.75	87	48	808	1			55				1
214.75	54	34	873		1		32				6
219.75	208	17	709	2	35		22				7
224.75	206	26	733	2	2		28	3			
229.75	46	45	903				6				
234.75	151	44	782	2	4	3	12				2
239.75	98	78	762	3			32	1			26
244.75	52	33	882				11				22
274.75	103	43	850			1	3				
308.75	48	39	906		2		5				
348.75	70	63	851		5		11				
368.75	70	13	898			4	15				
398.75	132	37	785	1	13		30	2			

Example of palynomorph groups used in this study

Fig. 2A. Absolute abundance of palynomorphs from the Zumaia section including their illustrations.



Sample depths (m)	*Leiosphaeridia* spp.	Translucent gold-orange to brown phytoclasts	Black opaque blade-shaped phytoclasts	Black opaque equidimensional phytoclasts	Dinoflagellate cysts	Amorphous organic matter (AOM)	Bisaccate pollen grains	Spores and pollen grains	Foraminiferal test linings (MFTL's)	Unidentified palynomorphs	*Palambages* sp.	Sample depths (m)
85.97	23.3	6.8	3.6	64.1	2.2	0.0	0.0	0.0	0.0	0.0	0.0	85.97
94.4	12.4	8.9	3.8	72.4	2.5	0.0	0.0	0.0	0.0	0.0	0.0	94.4
104.4	20.4	5.6	4.6	63.6	4.5	0.0	1.3	0.0	0.0	0.0	0.0	104.4
111.2	0.0	7.0	8.4	80.3	4.3	0.0	0.0	0.0	0.0	0.0	0.0	111.2
111.3	0.28	6.61	5.51	87.47	0.14	0.0	0.0	0.0	0.0	0.0	0.0	111.3
111.6	42.7	0.5	1.0	51.3	4.5	0.0	0.0	0.0	0.0	0.0	0.0	111.6
111.75	45.6	2.1	4.9	46.1	1.0	0.1	0.2	0.0	0.0	0.0	0.0	111.75
125.9	36.8	1.7	2.5	58.6	0.3	0.0	0.0	0.1	0.0	0.0	0.0	125.9
131.05	6.3	6.4	5.8	77.0	4.3	0.0	0.0	0.0	0.0	0.2	0.0	131.05
133	15.9	7.6	4.5	69.6	1.9	0.0	0.4	0.0	0.0	0.1	0.0	133
165.7	9.4	8.9	6.6	72.0	2.1	0.0	0.0	0.0	0.1	0.9	0.0	165.7
169	1.6	1.7	5.8	88.7	1.9	0.0	0.0	0.0	0.0	0.3	0.0	169
175.65	1.8	5.9	3.4	86.2	2.0	0.0	0.0	0.1	0.0	0.5	0.1	175.65
182.4	8.2	5.4	2.6	81.6	1.5	0.4	0.0	0.0	0.0	0.3	0.0	182.4
187.1	3.8	3.2	4.3	86.4	1.3	0.2	0.0	0.1	0.0	0.7	0.0	187.1
190.75	8.9	6.9	4.3	76.7	3.1	0.1	0.0	0.0	0.0	0.0	0.0	190.75
191.02	2.1	1.9	3.3	90.6	1.5	0.0	0.3	0.0	0.0	0.3	0.0	191.02
193.30	6.3	4.1	4.5	83.8	1.1	0.0	0.0	0.0	0.0	0.2	0.0	193.30
195.75	37.8	1.2	4.2	55.6	0.5	0.0	0.0	0.0	0.0	0.7	0.0	195.75
197.75	0.5	4.4	2.5	87.1	2.4	2.4	0.2	0.0	0.0	0.5	0.0	197.75
204.75	6.5	2.7	4.6	83.8	2.0	0.0	0.3	0.0	0.0	0.1	0.0	204.75
209.75	0.0	8.7	4.8	80.8	5.5	0.0	0.0	0.1	0.0	0.1	0.0	209.75
214.75	0.0	5.4	3.4	87.3	3.2	0.0	0.1	0.0	0.0	0.6	0.0	214.75
219.75	0.0	20.8	1.7	70.9	2.2	0.0	3.5	0.2	0.0	0.7	0.0	219.75
224.75	0.0	20.6	2.6	73.3	2.8	0.0	0.2	0.2	0.3	0.0	0.0	224.75
229.75	0.0	4.6	4.5	90.3	0.6	0.0	0.0	0.0	0.0	0.0	0.0	229.75
234.75	0.0	15.1	4.4	78.2	1.2	0.3	0.4	0.2	0.0	0.2	0.0	234.75
239.75	0.0	9.8	7.8	76.2	3.2	0.0	0.0	0.3	0.1	2.6	0.0	239.75
244.75	0.0	5.2	3.3	88.2	1.1	0.0	0.0	0.0	0.0	2.2	0.0	244.75
274.75	0.0	10.3	4.3	85.0	0.3	0.1	0.0	0.0	0.0	0.0	0.0	274.75
308.75	0.0	4.8	3.9	90.6	0.5	0.0	0.2	0.0	0.0	0.0	0.0	308.75
348.75	0.0	7.0	6.3	85.1	1.1	0.0	0.5	0.0	0.0	0.0	0.0	348.75
368.75	0.0	7.0	1.3	89.8	1.5	0.4	0.0	0.0	0.0	0.0	0.0	368.75
398.75	0.0	13.2	3.7	78.5	3.0	0.0	1.3	0.1	0.2	0.0	0.0	398.75

Fig. 2B. Abundance of palynomorphs from the Zumaia section expressed in percentages.

5. Discussion

5.1 Affinity and significance of *Leiosphaeridia* spp.

The palaeoenvironmental significance of the increase in *Leiosphaeridia* spp. is unclear and requires wider discussion. Leiosphaerids are considered to be algal cysts produced during dormant/reproductive stages in the life cycle, and this is supported by the presence of encystment opening, morphology and acid-resistant cell wall (Moczydłowska, 2008). The genus *Leiosphaeridia* known from Precambrian to present (Traverse, 2007) includes morphologically similar, spheroidal to ellipsoidal, organic-walled microfossils of various diameters and wall thickness. The single-celled *Leiosphaeridia* are produced by planktic algae (Chlorophyceans) alternating sexual/vegetative generations in their life cycle (Moczydłowska, 2008). Certain leiosphaerids are distinguished based on the ultrastructure of their multi- or single-layered cell-wall and biogeochemistry, and are assigned to green microalgae from the classes *Prasinophyceae* and *Chlorophyceae*, order *Chlorococcales* and *Volvocales* (Arouri et al., 1999, 2000; Talyzina and Moczydłowska, 2000; Javaux et al., 2004; Marshall et al., 2005; Moczydłowska and Willman, 2009; Moczydłowska et al., 2010; Moczydłowska, 2011). Thin-walled and single-layered leiosphaerids represent vegetative cell, which may grow an acanthomorphic reproductive cyst inside or may be transformed into a resting stage by secreting additional layers of different texture (Moczydłowska and Willman, 2009). Forms lacking distinguishable features that could allow for the detailed taxonomical assignment are grouped based on morphology. They are assumed to represent either various planktonic green algae species (Tappan, 1980; Guy-Ohlson, 1996; Moczydłowska, 2008a; Loron, 2016), or photosynthetic protists (Traverse, 2007) or other microorganisms of yet unknown affinities (Moczydłowska et al., 2010). The eukaryotic algal affinity of a few specimens of *Leiosphaeridia* has been supported by detailed studies of the cell wall (Talyzina and Moczydłowska, 2000; Arouri et al., 2000; Javaux et al., 2004). Such affinity has also been suggested based on morphology, size, cell-wall and palaeoecological distribution (Tappan, 1980; Colbath and Grenfell, 1995). As shown above, and suggested by some authors (Traverse, 2007; Moczydłowska, 2011) they should no longer be referred to acritarchs.

The specimens recorded from Zumaia (Plate 1) are represented by thin-walled large palynomorphs of 30 to 80 µm in average (25 specimens measured). It is worth to mention that some Ediacaran genera of *Leiosphaeridia* may achieve up to 230 µm (Moczydłowska, 2015). In microscopic view the wall is flattened, rugulate, often collapsed and folded in the middle. Circular pylome located subapically can be observed on selected specimens (see Plate 1A, 1B1-3).

Based on modern representatives of Chlorophyceae, Leiosphaeridia to be able to encyst require well-oxygenated open water conditions, easy access to the photic zone for photosynthesis (Tappan, 1980; Dorning, 1981a,b; Wicander and Playford, 1985; Moczydłowska, 2008) and periodic access to bottom sediment. However, palaeoenvironmental significance of the fossil *Leiosphaeridia* spp. are still controversial. According to Lebedeva (2008), their mass appearance may be typical of either deep-water, oxygen deficient environment or coastal, well freshened and oxygenated waters. Based on other studies, high abundance of the *Leiosphaeridia* spp. may be associated with shallow marine conditions, regressive phase/low sea-level and decreased salinity (Tahoun and Mohamed, 2015; Lebedeva and Nikitenko, 1999; Lebedeva, 2008; Moczydłowska, 2008; Pestchevitskaya, 2008; Eckart, 2010; Richardson, 1984).

The oxygen level is an important factor influencing the composition of palynological assemblage (e.g. Zonneveld et al., 1997; Pross, 2001; Radmacher and Uchman, 2019) and may cause a complete absence of organic-walled palynomorphs within the rock (Radmacher and Uchman, 2019). In contrast, it is likely that the *Leiosphaeridia* spp. may be more resistant to aerobic conditions that some dinoflagellate cysts (see Zonneveld et al., 1997) and may remain unaffected within deposits due to their better tolerance of oxygen (Nikitenko et al., 2008). It shows that the palaeoenvironmental interpretation of the signal provided by *Leiosphaeridia* needs to be carefully compared to other palaeontological and lithological data.

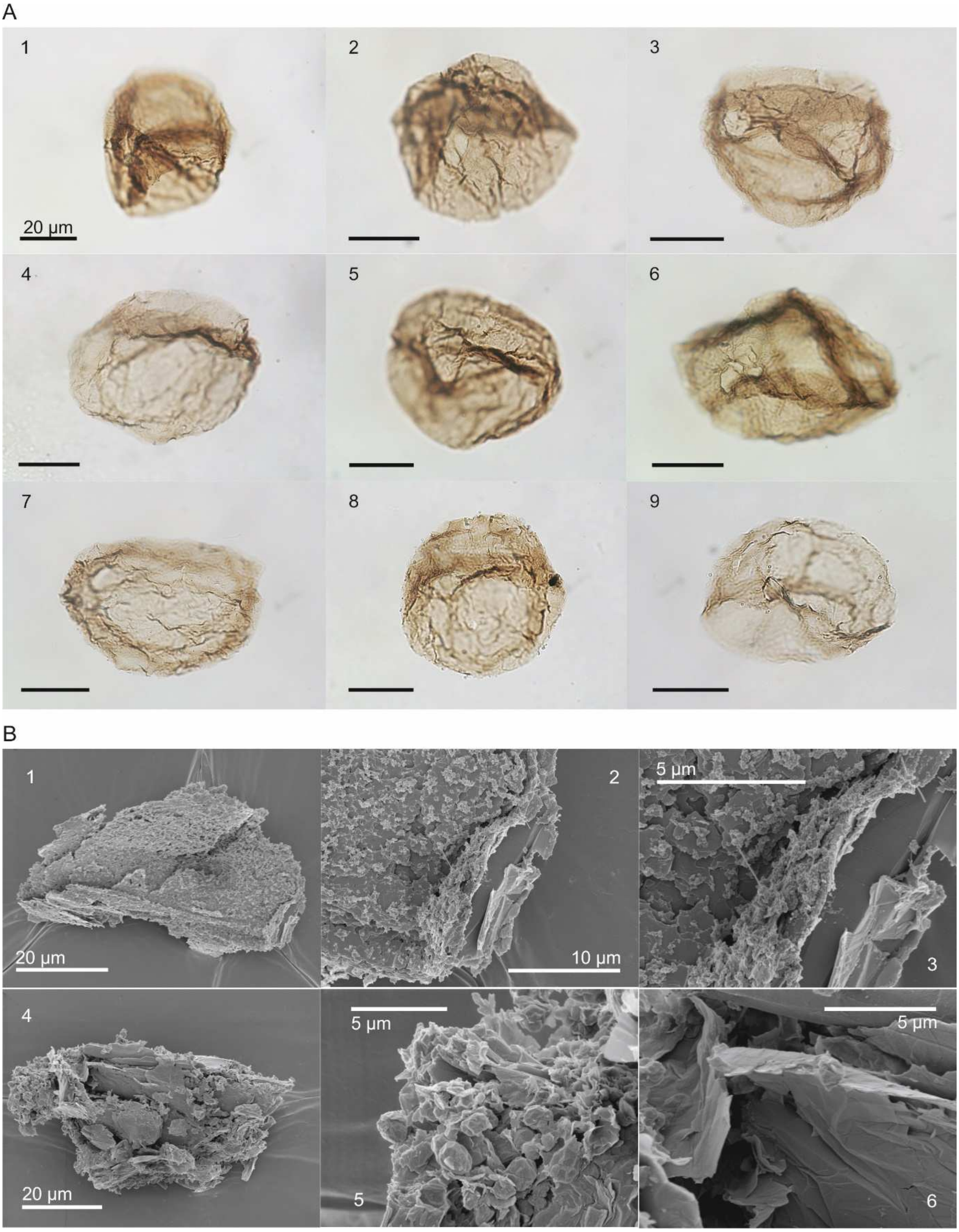


Plate 1. Various specimens of *Leiosphaeridia* spp. selected from Unit 6, sample 111.6, lower/upper Maastrichtian transition. A: Photographs taken under transmitted light microscope, visible circular pylome located subapically; B: Scanning Electron Microscope (SEM) photographs; B1-3 and B4-6 represent two different specimens. B2 and B3 show the circular pylome in details, B5 and B6 focus on the wall structure.

5.2. Palaeoenvironmental conditions in the Basque-Cantabrian region during the latest Cretaceous

The latest Cretaceous (Campanian and Maastrichtian) was a time of high variability of the palaeoenvironmental conditions (e.g. Barrera and Savin, 1999; Dubicka and Peryt, 2012). The long-term global cooling interrupted by short-term warming and accelerated cooling episodes are proposed by Thibault and Gardin (2006), Linnert et al. (2014, 2016), Thibault et al. (2016a) and Chenot et al. (2016). Some of these episodes appear to be associated with fluctuation of sea-level, possible change in the nutrient supply, change in surface and bottom-water productivity, declining atmospheric $p\mathrm{CO}_2$ levels and negative carbon isotope anomalies (Jarvis et al., 2002, 2006; Friedrich et al., 2009; Linnert et al., 2014, 2018; Thibault et al., 2016; Engelke et al., 2017). These global changes seem not to be clearly reflected in the latest Cretaceous sedimentological record of the Basque Cantabrian Basin (BCB). Different geological history of the region, influenced by regional tectonic processes (e.g. Sibuet et al., 2004; Vergés et al., 2002) hampers its palaeoenvironmental reconstruction.

The Campanian and Maastrichtian strata in the Zumaia section is represented by hemipelagic limestone/marl type of deposition with some turbiditic material transported from proximal part of the basin (Dinarès-Turell et al., 2013). It was deposited in the deep part of the BCB, where water depths ranged between 800–1500 m (Schwentke and Kuhnt, 1992; Kuhnt and Kaminski, 1993). The foraminiferal assemblages support bathyal settings (below the shelf edge) for the Zumaia site from Turonian onwards. Dinarès-Turell et al. (2013) describe the lower part of the upper Maastrichtian as deposited during the low-stand system tract. This is in agreement with Kuhnt and Kaminski (1993) and Schwentke and Kuhnt (1992) who based on benthic foraminiferal assemblages and subsidence history of the basin indicated middle bathyal water depths. Comparably, previous studies of the section yield diversified planktic foraminiferal assemblage indicative for stable normal salinity and open marine conditions, associated with an outer shelf to middle bathyal depths (Arz and Molina, 2002; Pérez-Rodríguez et al., 2012). According to depth ranges of Abramovich et al. (2003), early to late Maastrichtian planktic foraminiferal assemblages at Zumaia should be dominated by surface and subsurface dwellers, mostly represented by *Heterohelix, Pseudotextularia* and *Globigerinelloides* genera. Indeed, heterohelicids, characteristic for open ocean waters and mesotrophic to eutrophic conditions (Hart, 1999; Premoli Silva and Sliter, 1999), represent the most dominant element of all samples (Pérez-Rodríguez et al., 2012). Nevertheless, their co-occurrence with oligotrophic indicators

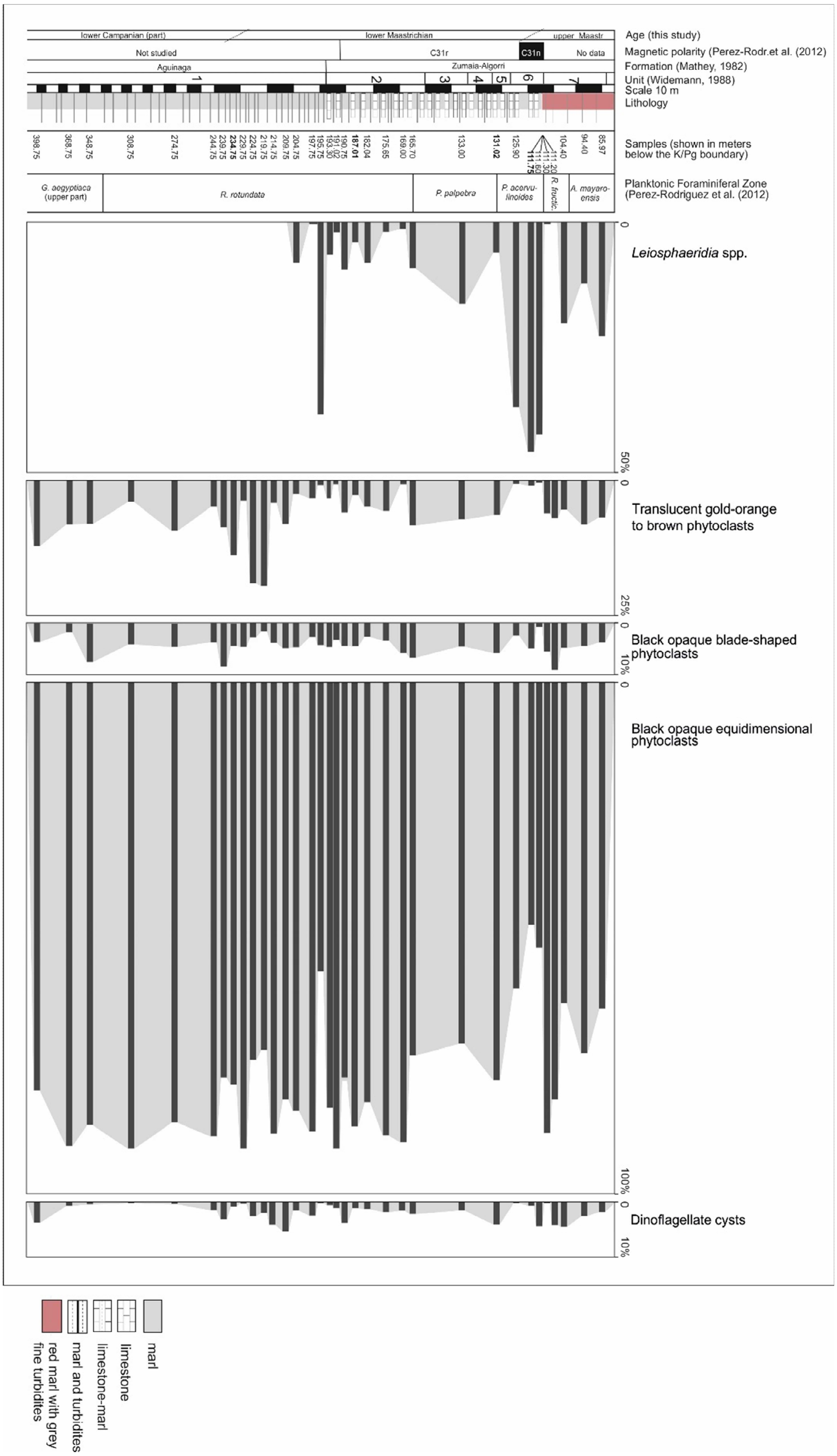
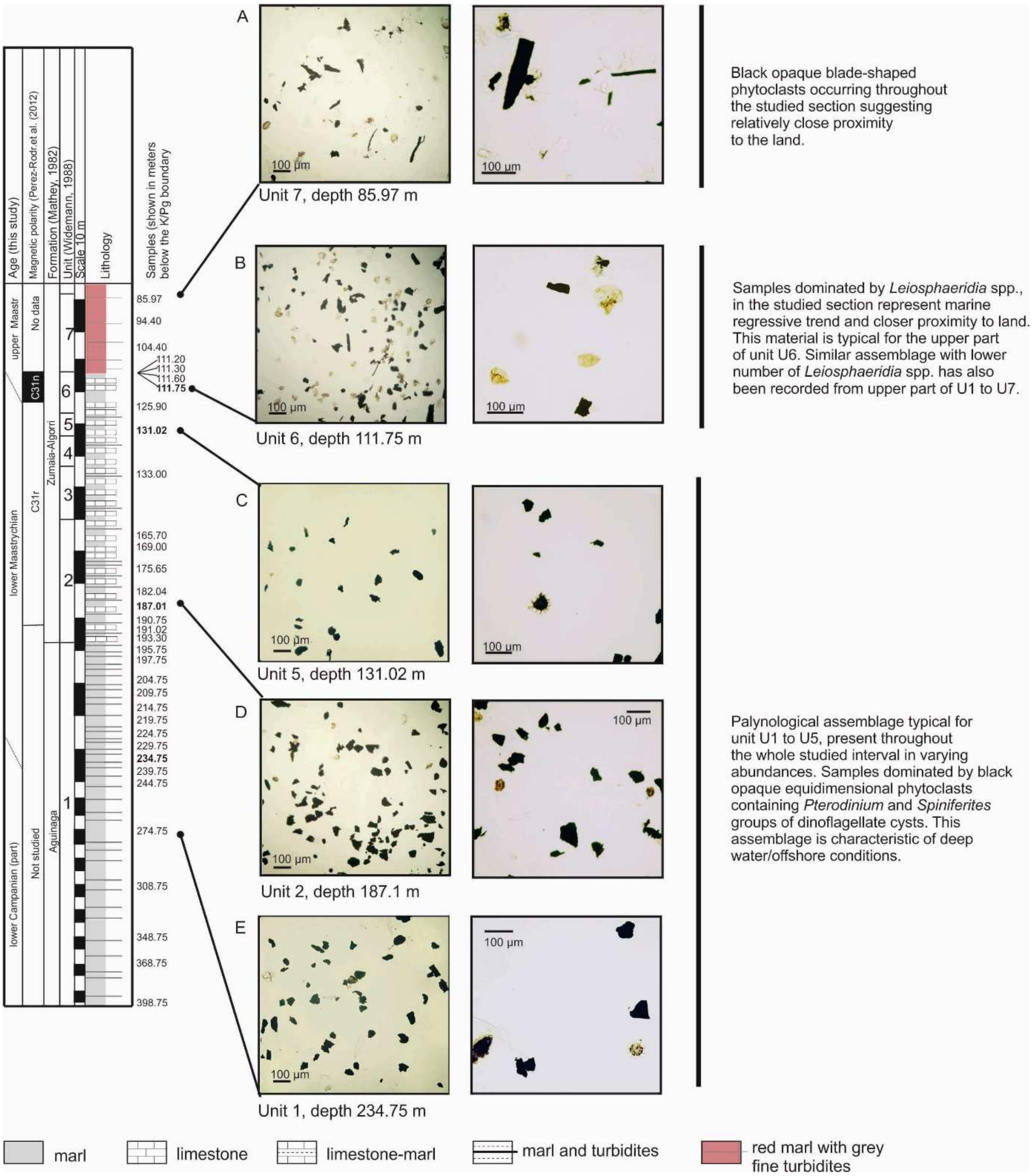


Fig. 3. Distribution of palynomorph groups diagnostic for various palaeoenvironmental conditions along the Zumaia section. Values are expressed in percentages.



Black opaque blade-shaped phytoclasts occurring throughout the studied section suggesting relatively close proximity to the land.

Samples dominated by *Leiosphaeridia* spp., in the studied section represent marine regressive trend and closer proximity to land. This material is typical for the upper part of unit U6. Similar assemblage with lower number of *Leiosphaeridia* spp. has also been recorded from upper part of U1 to U7.

Palynological assemblage typical for unit U1 to U5, present throughout the whole studied interval in varying abundances. Samples dominated by black opaque equidimensional phytoclasts containing *Pterodinium* and *Spiniferites* groups of dinoflagellate cysts. This assemblage is characteristic of deep water/offshore conditions.

Fig. 4. Lithological profile and palynofacies examples from various units of Zumaia section.

represented by frequent large and complex symbiotic taxa associated with well-oxygenated sediments suggests mesotrophic to oligotrophic conditions.

Dinoflagellate cyst record published by Radmacher et al. (2014) is in agreement with the foraminiferal data as indicates that the deposition of the whole studied sections took place in offshore settings. This is based on generally constant presence of oceanic dinoflagellate cysts throughout the section, including *Pterodinium* spp. and *Cannosphaeropsis utinensis*, that are typically oceanic species (Brinkhuis and Zachariasse, 1988; Pross and Brinkhuis, 2005; Tabara and Silmani, 2017). *Spiniferites* spp. represent a cosmopolitan group tolerant for a wide variety of environments from estuarine to offshore. Their abundant presence and co-occurrence with *Pterodinium* spp. and *C. utinensis,* supports deep offshore settings.

High abundance of black opaque equidimensional phytoclasts and offshore dinoflagellate cysts present throughout the whole section (Units 1- 7) suggest that the sediments could be deposited within the deep sea, offshore environment. Opaque phytoclasts, that develop mainly by oxidation of translucent phytoclasts, show a higher preservation potential (Tyson, 1993), supporting relatively distal conditions. However, constant presence of black opaque blade-shaped phytoclasts and translucent gold-orange to brown phytoclasts that constitute more proximal sediment, suggests proximity of the land (see Figs 3 and 4).

Some change in palynomorph proportion has been noticed near the lower/upper Maastrichtian boundary, where *Leiosphaeridia* spp. dominates the palynological record. According to previous studies, the high abundance of the *Leiosphaeridia* spp. may be associated with regressive phase/low sea-level and decreased salinity (Tahoun and Mohamed, 2015; Lebedeva and Nikitenko, 1999; Lebedeva, 2008; Pestchevitskaya, 2008; Eckart, 2010; Richardson, 1984). Other studies suggest that the *Leiosphaeridia* spp. may be more resistant to aerobic conditions than some dinoflagellate cysts (see Zonneveld et al., 1997) and may remain unaffected within deposits due to their better tolerance of oxygen (Nikitenko et al., 2008). The oxygen level is an important factor influencing the composition of palynological assemblage (Zonneveld et al., 1997) and may cause a reduction of organic-walled palynomorphs within the rock (Radmacher and Uchman, 2019; Zonneveld et al., 1997; Pross, 2001).

It is possible, that the increased number of Leiosphaeridia within the upper part of the Unit 6 (Fig. 3) is connected to gradual deepening of the basin, lower sedimentation rate and higher sedimentological condensation near the early/late Maastrichtian. This is in agreement with study of Pujalte et al. (1998), who described increased subsidence and relative tectonic stability reflected by a reduction of siliclastic input and deposition rate. Increased oxygen concentration near the basin bottom and/or longer exposure of the deep sea sediment to oxidation processes may explain the high abundance of the Leiosphaeridia that may be more resistant to oxygen then other palynomorphs. However, this explanation is not consistent with the onset of the red marl deposition (U7) characterised by still high but decreased abundance of Leiosphaeridia.

The significant lithological transition from limestone and marl to red marl typical to U7 may be connected to palaeoenvironmental changes on land, e.g. dryer, cooler climate, lower runoff and offshore progradation of red beds (Fig. 5). The marine regression and closer proximity of the studied section to the land in the late Maastrichtian is documented by previous (e.g. Dinarès-Turell et al., 2013) and this study. Decreasing number of black opaque equidimentional phytoclasts and higher abundance of translucent gold-orange to brown phytoclasts (Fig. 3) supports closer land proximity (as expressed on the map at Fig. 5A). Higher abundance of dinoflagellate cyst in the U7 possibly expresses shelf sea settings shallower than during the deposition of U6 (see also Schwentke and Kuhnt, 1992, Kuhnt and Kaminski, 2013, Dinarès-Turell et al., 2013). The increased abundance of Leiosphaeridia at the lower/upper Maastrichtian may be indeed connected to slower sedimentation rate and sedimentological condensation. In contrast, its decreased but still high abundance within the U7 is rather associated with stressed palaeoenvironmental conditions during the late Maastrichtian, most likely caused by marine regression and increased proximity to land. We cannot distinguish whether Leiosphaeridia bloomed offshore or in coastal waters. This signal may be coastal and express the regressive trend and followed closer distance from/to the coast, with Leiosphaeridia transported from shallower sites by oceanic currents and/or storms.

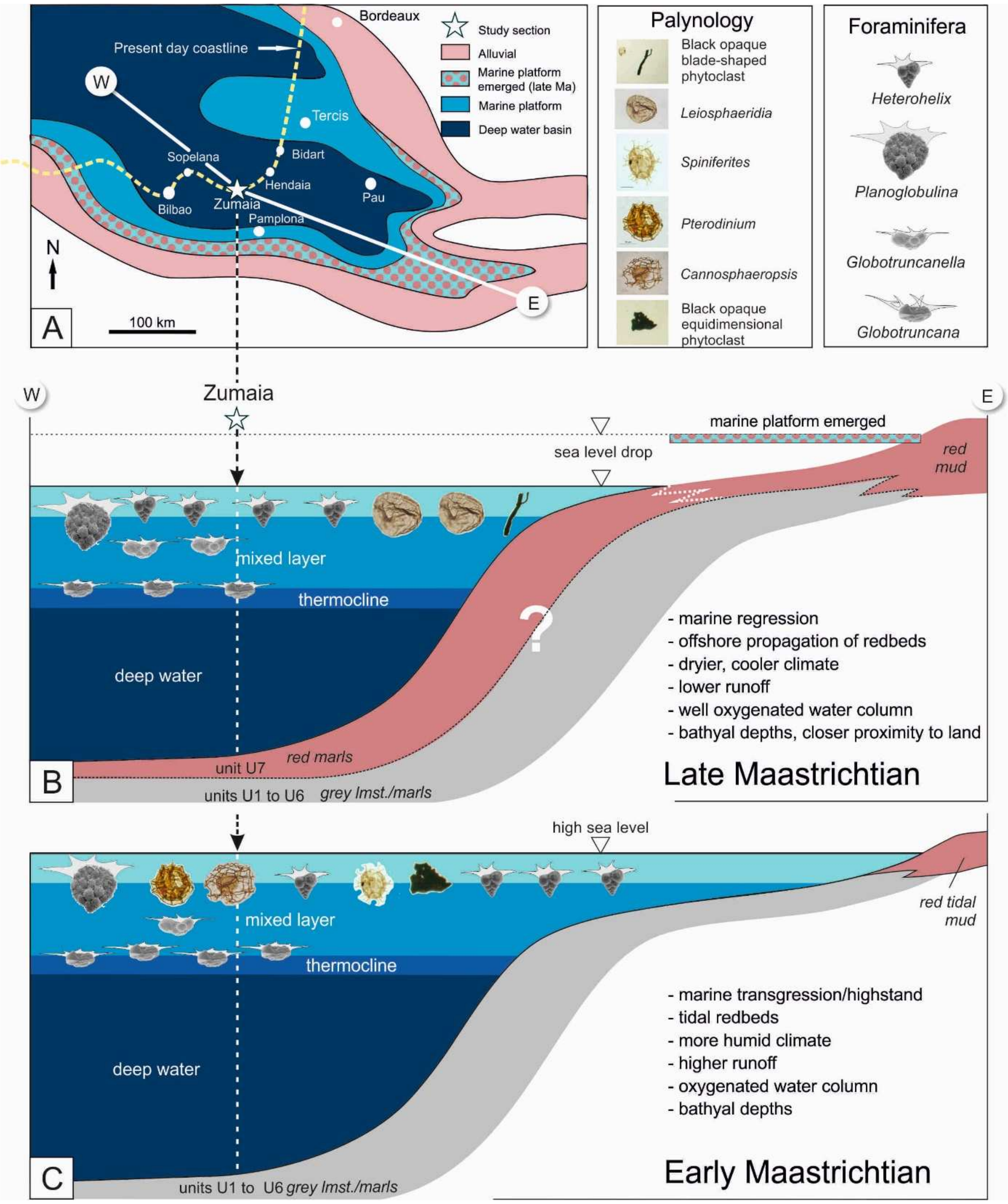


Fig. 5. (A) Palaeogeographic map of the Basque-Cantabrian Basin (modified from Plaziat, 1981 and Dinarès-Turell, 2013). Palaeoenvironmental models for the late Maastrichtian (B) and early Maastrichtian (C) in the Basque–Cantabrian Basin based on dinoflagellate cysts and foraminifera (logotypes of foraminiferal taxa are based on Pérez-Rodríguez et al., 2012, modified).

Conclusions

Palynological study of the coastal Campanian to Maastrichtian section from the southern margin of the Basque–Cantabrian Basin indicates marine conditions and relative close proximity to the land, while previous foraminiferal data from the same section suggest bathyal depths. Palynofacies are dominated by black opaque equidimensional phytoclasts, black opaque blade shaped phytoclasts, translucent gold-orange to brown phytoclasts and offshore dinoflagellate cysts, i.e. *Cannosphaeridium utinensis* and *Pterodinium* spp. No signal suggesting palaeoenvironmental change near the Campanian/Maastrichtian transition has been recorded. Lower Maastrichtian is characterised by appearance of *Leiosphaeridia* spp., which abundance increases near the lower/upper Maastrichtian, possibly due to decreased sedimentation rate and higher sedimentological condensation. Leiosphaeridia remaining relatively abundant within the upper Maastrichtian, along the lithological change from marl and limestones to red marl, indicate stressed environmental conditions most likely connected to marine regression. Different taphonomic conditions forced by more stable tectonic activity in the BCB, decreased sedimentation rate, higher sedimentological condensation and longer exposure to the near-bottom oxygen could also influence the upper Maastrichtian lithological and palynological variations. However, reduced distance from the nearby land resulting from marine regression seems to be better expressed by the obtained palynological record.

Acknowledgements

Authors would like to thank all the persons that have participated in the process of creating this manuscript, especially: Michał Radmacher for developing dedicated palynological software to process the data; Irene Pérez-Rodríguez for her company during the fieldwork and Asier Hilario for supporting the research. WR would also like to thank Gunn Mangerud and Martin A. Pearce for their long-lasting scientific guidance and continuous support during her PhD and later. We are grateful to Przemysław Gedl and other anonymous reviewer for helping to improve the initial concept of the manuscript. The research was financed by ING PAN scholarship for young scientists, by the ING PAN internal PALAEOCLIMATE projects and by MCIU/AEI/FEDER, UE (grant number PGC2018-093890-B-I00).

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Highlights

- Palynofacies are used for palaeoenvironmental study
- Lower/upper Maastrichtian in the Basque-Cantabrian Basin marked by abundant Leiosphaeridia spp.
- Upper Maastrichtian is marked by a marine regression and decreased land proximity
- *Leiosphaeridia* spp. are associated with the regressive phase

Declaration of interests

☒ The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

☐The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: