ACTA PALAEONTOLOGICA ROMANIAE V. 7 (2011), P. 239-248

HOLOCENE CALCAREOUS NANNOPLANKTON IN THE INNER SHELF OF THE NW BLACK SEA

MIHAELA C. MELINTE-DOBRINESCU[1] & ANDREI BRICEAG[1]

Abstract. During the Holocene, the Black Sea experienced a shift from a brackish environment to a marine one, similar to that of modern times. This change is well reflected in the composition and fluctuation pattern of calcareous nannoplankton, a planktonic group of unicellular marine algae that is very sensitive to environmental changes. This paper is focussed on the calcareous nannoplankton assemblages, which were identified in the Holocene deposits intercepted by several cores located in the inner shelf of the Romanian Black Sea. In general, the nannofloral assemblages are dominated by the species *Emiliania huxleyi*, which is accompanied by the less frequent *Braarudosphaera bigelowii*. The quantitative analyses led to the identification, in the investigated Holocene deposits, of several intervals (youngest first): **Nannofloral Interval I**, dominated by *E. huxleyi* of very high abundance, over 1.400 specimens/mm^2; *B. bigelowii* is present with a very low frequency or even absent; **Nannofloral Interval II**, which is also dominated by *E. huxleyi*, that decreases in amount as the depth increases, from around 800 specimens/mm^2 down to less than 100 specimens/mm^2, while *B. bigelowii* continuously increases with depth, always yielding a negative correlation with *E. huxleyi*; **Nannofloral Interval III**, which is characterized by the occurrence of assemblages exclusively containing *B. bigelowii*, and **Nannofloral Interval IV** that contains no nannofloras either *in situ* or reworked. Based on calcareous nannoplankton fluctuation, a scenario of an abrupt salinity increase related to a rapid sea-level rise in the Romanian inner shelf at around 7.500 y BP could be assumed. This assumption is also supported by the sudden replacement, in the studied area, of the brackish deposits with *Dreissena* mollusc assemblages by marine sediments with marine *Mytilus* and *Modiolus* mollusc associations.

Keywords: calcareous nannoplankton fluctuation; nannofloral intervals; ecobiostratigraphy; palaeoenvironment; Romanian inner shelf of the Black Sea.

INTRODUCTION

The evolution of the Black Sea from a lacustrine palaeoenvironment to a marine one during Holocene times is still a matter of debate in the world scientific community. There are two main hypotheses regarding the sea-level rising of the Holocene Black Sea: catastrophic and gradual. The scenario concerning the catastrophic flooding of the Black Sea was published by Ryan et al. (1997), attracting the greatest attention and arousing a great deal of controversy and further research. The other scenario, based on a huge amount of collected data (for a synthesis see Yanko-Hombach et al., 2007a), indicates that no catastrophic flooding occurred. On the contrary, the Neoeuxinian Lake gradually transformed into a marine basin. The above-mentioned hypothesis is supported by the findings of many scientists (Winguth et al., 2000; Aksu et al., 2002; Kaminski et al., 2002; Strechie-Sliwinski, 2007; Yanko-Hombach et al., 2007b, among many others).

The planktonic organisms are very useful in deciphering palaeoenvironmental fluctuations in general, and changes that took place during the Holocene in the Black Sea in particular. For instance, the foraminifers and the calcareous nannoplankton are very sensitive to biogeographic and environmental fluctuations, being affected both by oceanic and atmosphere modifications.

The calcareous nannoplankton, the group of organisms that we focus on in this paper, is a major component of the oceanic phytoplankton. Nowadays, coccolithophores are abundant throughout the world ocean and can be found from tropical to sub-arctic waters with temperatures dropping below 0^0C. The life of these unicellular algae is related to the photic zone, their maximum abundance being recorded up to 50 m in depth (Tappan, 1980). The calcareous nannoplankton, as most of the marine planktonic organisms, reflects environmental changes such as fluctuations in light, salinity, temperature, sea-level, ocean productivity, nutrients and water pollution with high fidelity.

The calcareous nannoplankton is - as most groups of marine organisms, very sensitive to salinity fluctuations. Although typical marine taxa, a few coccolithophores live in brackish waters and even in fresh ones. In modern times, coccoliths seem to be adapted to very high salinity fluctuations. For instance, *Coccolithus pelagicus* has been found in the Dead Sea, which is of 250‰ salinity (Tappan, 1980), while *Emiliania huxleyi* lives in the Black Sea, at salinity below 20 ‰ (Bukry, 1974). Notably, the first common appearance of *Emiliania huxleyi* in the Black Sea, indicating the instauration of a stable normal marine regime, was approximated at 3,000 y BP (Bukry, 1974). Recently, Giunta et al. (2007) used calcareous nannofossil assemblages to investigate the Late Quaternary evolution of the Black Sea. The above-mentioned authors identified several calcareous nannoplankton ecozones within the Upper Holocene deposits of the Black Sea based on which they traced palaeoenvironmental changes.

This paper focuses on the calcareous nannofossil fluctuations in composition and abundance in the Holocene deposits of the NW Black Sea. It also provides comparison between the ecobiostratigraphy of the studied interval and the results of Giunta et al. (2007), as well as highlights a palaeoenvironmental approach.

MATERIALS AND METHODS

The calcareous nannofossil assemblages were studied in several inner shelf cores from the Romanian Black Sea (Fig. 1), placed at various water depths, as follows: 12 m in the MN 07-03 Site, 20 m in the PO 02 Site, 27.50 m in the PO 03 Site, 42 m in the PO 04 Site, 28.15 m in the EF 08-01 Site, and 66 m in the BS 08-055 Site. The sediment recovery for each core is given in Fig. 2. The lithology of the six investigated cores was recently

[1] National Institute of Marine Geology and Geo-ecology (GEOECOMAR), 23-25 Dimitrie Onciul Street, RO-024053 Bucharest, Romania, melinte@geoecomar.ro; andrei.briceag@geoecomar.ro

published (Oaie & Melinte-Dobrinescu, 2010). In general, the Upper Holocene intercepted sediments are composed of muds interbedded with coquina levels. Alternating sequences of mud, clay and silt were also observed. Towards the bottom of some studied sites (i.e., PO 04, EF 08-01 and BS 08-055) compact yellowish-grey clay was observed, overlain by a coquina containing mixed fresh-water and marine macro faunal assemblages (Oaie & Melinte-Dobrinescu, 2010).

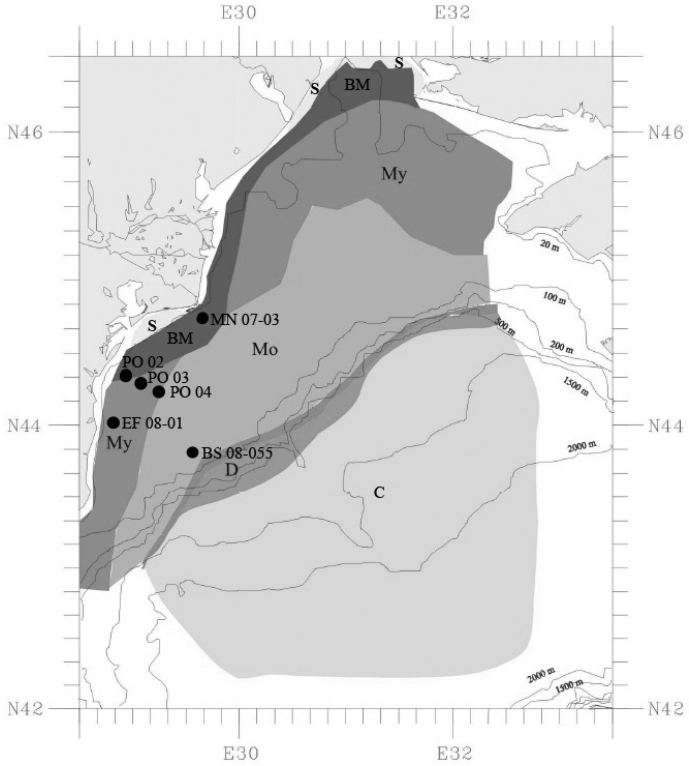


Fig. 1 – Location of the investigated cores MN 07-03, PO 02, PO 03, PO 04, EF 08-01 and BS 08-055 on the inner shelf of the NW part of the Black Sea. BM-black mud; S-sands; My–mud with *Mytilus*; Mo–mud with *Modiolus*; D-mud with *Dreissena*; C-coccolith mud. Repartition of the lithostratigraphical units on the sea floor is after Silviu Rădan (unpublished data).

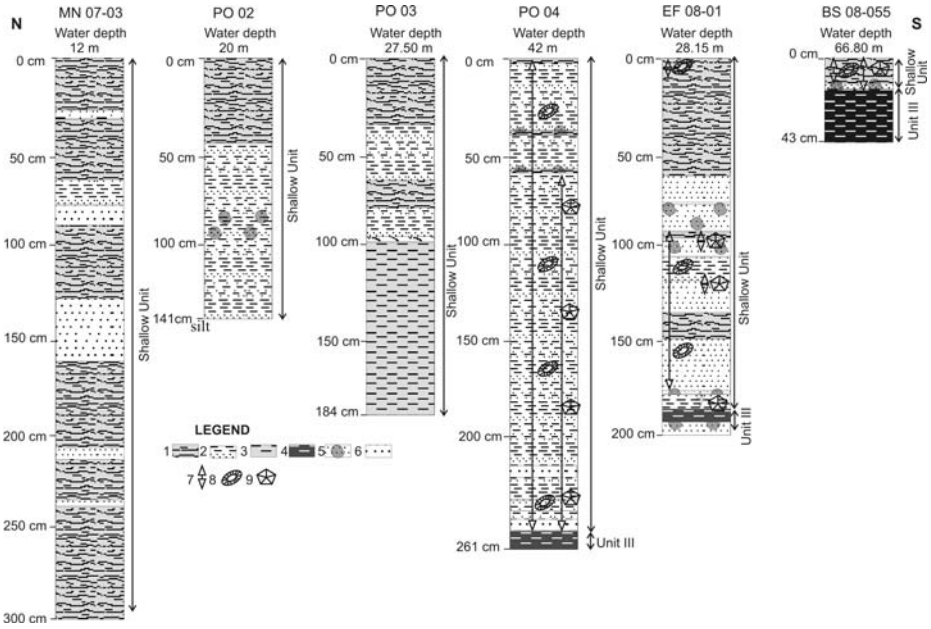


Fig. 2 – Lithology and calcareous nannofossil fluctuation in the investigated cores. Lithology after Oaie & Melinte-Dobrinescu (2010). Legend: 1-mud; 2-clay; 3-silt; 4-compact clay; 5-coquina levels; 6-sand; 7-interval of occurrence; 8-*Emiliania huxleyi*; 9-*Braarudosphaera bigelowii*.

To perform calcareous nannoplankton analyses, samples have been collected from each site at intervals of 5 centimetres. Smear-slides were prepared from the untreated material, in order to preserve the original composition. Examinations were carried out by using LM (light microscope) at a magnification of x1200 and SEM (scanning electron microscope). Both qualitative and quantitative nannofloral studies were performed. We used the following criteria in order to estimate species' abundance:

0 specimen= absent
1-5 specimens at 50 fields of view= very rare
1-5 specimens at 10 fields of view=rare
5-10 specimens each field of view=common
10-20 specimens each field of view = abundant
>30 specimens each field of view = very abundant

The relative abundance of *Emiliania huxleyi* (expressed as %) was determined on a total sum of at least 350 specimens. For sub-dominant species (*Braarudosphaera bigelowii*), counting was continued until the 350 specimens total was reached.

Additionally, counting in a fixed area corresponding to 75.5 fields of view were performed. The results were converted into population density (number/mm^2) by using the formula given by Giunta et al. (2007) for calcareous nannoplankton studies of the Black Sea Holocene deposits: number of individuals observed/field of view number*field of view area.

CALCAREOUS NANNOPLANKTON ASSEMBLAGES

In sites that are located in a very shallow environment, close to the shoreline in the vicinity of the Sahalin Island and in front of the Razelm-Sinoe lagoonal complex (Gura Portiţa area), such as MN 07-03, PO 02 and PO 03 (Fig. 1), the calcareous nannoplankton assemblages contain only reworked taxa from Mesozoic-Tertiary deposits (Fig. 2). Most of reworked taxa (80 %) are well preserved Tertiary nannofossils. The rest (20 %) is composed of Mesozoic (mainly Cretaceous) species, which yield dissolution and overgrowth. No typical Holocene *in situ* calcareous nannoplankton taxa, such as *Emiliania huxleyi*, were observed.

In the EF 08-01 Site, placed in front of the Eforie N beach, the youngest 5 cm of the core contain monospecific calcareous nannoplankton assemblages with *Emiliania huxleyi* (Fig. 3). Even if *E. huxleyi* represents 100 % of the encountered assemblages, its abundance (< 250 specimens/mm^2) is low in comparison with other investigated sites from the Romanian Black Sea inner shelf (Fig. 4). Besides, within the above-mentioned interval, rare reworked Tertiary nannofossils, usually well preserved, were observed (Plate 1). Within the sedimentary depth interval of 5-100 cm, no calcareous assemblages *in situ* were found, only Tertiary nannofossils being observed (Plate 1). In the sedimentary interval of -100/-170 cm, *in situ* calcareous nannoplankton assemblages contain mainly *Emiliania huxleyi*, representing between 95-98 % of all nannofloras, and a small amount of *Braarudosphaera bigelowii*, representing between 2-6 % (Fig. 3). The abundance of *E. huxleyi* in the top layer is around 750 specimens/mm^2 and it continuously decreases (< 150 specimens/mm^2). In the same interval, the abundance of *B. bigelowii* is much lower, from 1.4 specimens/mm^2 to 14 specimens/mm^2. A negative correlation could be observed between *E. huxleyi* and *B. bigelowii* throughout the studied interval. The sediment sample of -180/-185 cm contains monospecific assemblages with *B. bigelowii*, in amounts of 22.4 specimens/mm^2. The bottom sediments of the EF 08-01 Site (i.e., the interval of -185/-200 cm sediment depth) contain no nannofloras, *in situ* or reworked (Figs. 3 and 4).

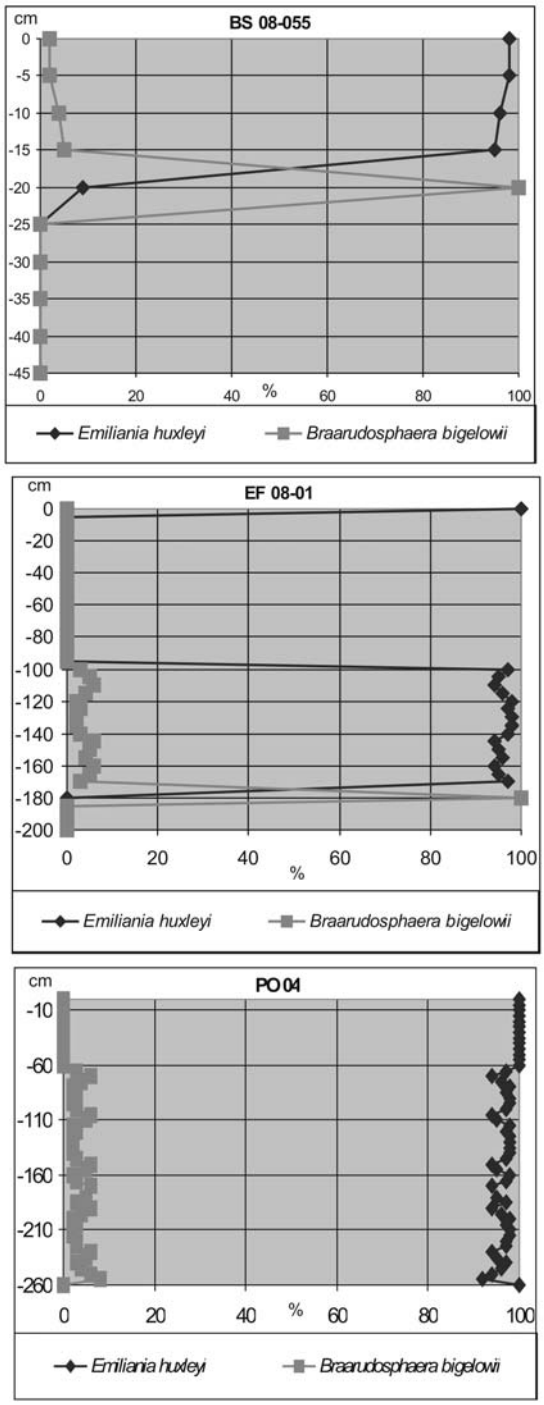


Fig. 3 – Fluctuation in abundance (%) of calcareous nannoplankton taxa *Emiliania huxleyi* and *Braarudosphaera bigelowii* in the Holocene deposits of the Black Sea Romanian inner shelf (Sites BS 08-055, EF 08-01 and PO 04).

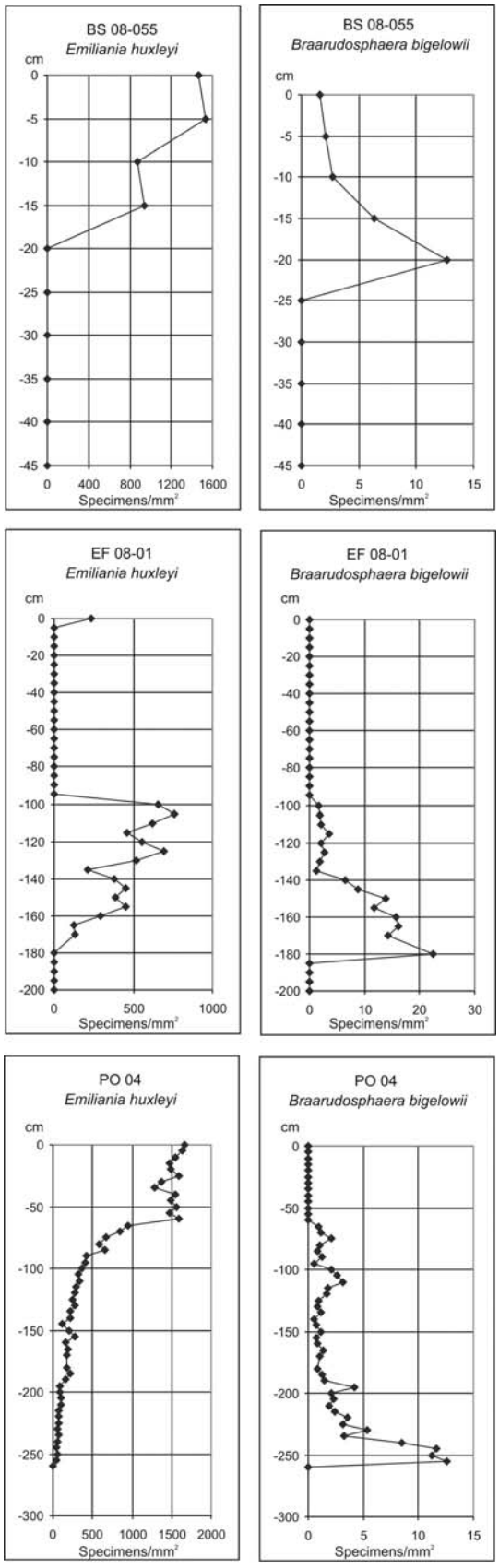


Fig. 4 – Fluctuation in abundance (specimens/mm^2) of calcareous nannoplankton taxa *Emiliania huxleyi* and *Braarudosphaera bigelowii* in the Holocene deposits of the Black Sea Romanian inner shelf (Sites BS 08-055, EF 08-01 and PO 04).

The youngest 60 cm of the PO 04 Site contain monospecific assemblages with *Emiliania huxleyi* (Plate 1) of a very high amount in the investigated Holocene deposits, between 1250-1470 specimens/mm^2 (Fig. 4). The sedimentary interval of -65/-255 cm contains *in situ* assemblages dominated by *E*. *huxleyi* (always representing more than 90 % of all nannofloras), the rest being represented by *B. bigelowii*. Additionally, in the sedimentary interval of -195/-255 cm, the abundance of *E*. *huxleyi* is low (less than 100 specimens/mm^2) and continuously decreases towards the bottom of the core (Table 1). The oldest cored interval (i.e., of -245/-255 cm), contains a significant decreasing iin abundance of *E*. *huxleyi* (less than 70 specimens/mm^2) and an increasing of *B*. *bigelowii* (more than 11 specimens/mm^2), but the abundance of *E*. *huxleyi,* clearly indicates a dominance of this taxon (92 % of all *in situ* assemblages). The oldest 5 cm (-255/-260) of the PO 04 core contain no nannofloras *in situ* nor reworked.

In the BS 08-055 Site, the youngest cored 15 cm are characterized, from a calcareous nannoplankton point of view, by the dominance of *E*. *huxleyi* (over 95 %), the rest being represented by *B*. *bigelowii*. The youngest 10 cm contain a high abundance of *E*. *huxleyi* (over 1450 specimens/mm^2), while in the lowermost 10 cm its abundance declines (Table 1). At a depth of 20 cm, *E*. *huxleyi* is no longer found; the calcareous nannoplankton assemblages are only composed of *B*. *bigelowii* (Plate 1). Below 25 cm in depth, no calcareous nannoplankton either *in situ* or reworked was remarked.

ECOBIOSTRATIGRAPHY

The above-presented data allow us to recognize, based on calcareous nannoplankton fluctuations in the investigated Romanian inner shelf sites from the Black Sea, four nannofloral intervals (Table 1), from youngest to oldest:

- **Nannofloral Interval I** is characterized by a very high abundance in *E*. *huxleyi*, between 1.450 and 1.650 specimens/mm^2 and by a very low abundance (up to 2 specimens/mm^2) or even by the absence of *B*. *bigelowii* (Table 1). This is characteristic for Holocene sediments of the studied sites, located more than 40 m water depth, and it is not the case for the EF 08-01 Site (water depth around 28 m). As far as *E*. *huxleyi* is concerned, there is no positive correlation between number of specimens and depth. Rare reworked Mesozoic-Tertiary calcareous nannofossils are also present.

- **Nannofloral Interval II** is characterized by a common occurrence of *E*. *huxleyi* of an abundance < 950 specimens/mm^2, as well as by the continuous, although rare, presence of *B*. *bigelowii* with a variable abundance from < 1 specimens/mm^2 up to > 16 specimens/mm^2. Notably, from the top to the base of this interval, the number of *E*. *huxleyi* specimens continuously decreases, from 800-900 specimens/mm^2, representing half of the specimens found in the younger Nannofloral Interval 1, down to < 100 specimens/mm^2. The abundance of *B*. *bigelowii* continuously increases from the top to the base of this interval. Therefore, a negative correlation exists between the number of *E*. *huxleyi* specimens and that of *B*. *bigelowii* specimens. A few reworked Mesozoic-Tertiary taxa were also encountered.

Table 1 – Abundance (specimens/mm^2) of *Emiliania huxleyi* and *Braarudosphaera bigelowii* in the investigated cores of the Black Sea Romanian inner shelf.

BS 08-055 depth cm	*E. huxleyi*	*B. bigelowii*	EF 08-01 depth cm	*E. huxleyi*	*B. bigelowii*	PO 04 depth cm	*E. huxleyi*	*B. bigelowii*
0	1470,7	1,6	0	235,6	0	0	1670,2	0
-5	1532,5	2,1	-5	0	0	-5	1640,7	0
-10	871,3	2,7	-10	0	0	-10	1550,3	0
-15	935,1	6,3	-15	0	0	-15	1470,2	0
-20	0	12,7	-20	0	0	-20	1489,1	0
-25	0	0	-25	0	0	-25	1591,5	0
-30	0	0	-30	0	0	-30	1377,5	0
-35	0	0	-35	0	0	-35	1279,1	0
-40	0	0	-40	0	0	-40	1544,8	0
-45	0	0	-45	0	0	-45	1488,7	0
			-50	0	0	-50	1566,2	0
			-55	0	0	-55	1480,5	0
			-60	0	0	-60	1590,2	0
			-65	0	0	-65	950,4	0,9
			-70	0	0	-70	850,3	1,2
			-75	0	0	-75	665,3	2,1
			-80	0	0	-80	590,1	1,1
			-85	0	0	-85	663,2	0,8
			-90	0	0	-90	425,8	1,3
			-95	0	0	-95	413,2	0.5
			-100	653,8	1.7	-100	367,9	2,1
			-105	759,6	1,9	-105	326,9	2,6
			-110	621,9	2,2	-110	331,2	3,1
			-115	458,2	3,5	-115	289,3	1,8
			-120	551,5	2,1	-120	278,2	1,7
			-125	693,2	2,7	-125	251,2	0,9
			-130	516,6	1,9	-130	278,1	0,8
			-135	212,9	1,3	-135	223,3	1,2
			-140	379,2	6,5	-140	221.1	0,5
			-145	455,8	8,9	-145	123,2	0,7
			-150	385,9	13,8	-150	199.3	1,2
			-155	456,2	11,7	-155	275,6	0,7
			-160	289,5	15,7	-160	167,2	0,8
			-165	122,3	16,2	-165	189,4	1.4
			-170	127,9	14,2	-170	177,3	1,1
			-180	0	22.4	-180	178,3	0,8
			-185	0	0	-185	213,5	1,3
			-190	0	0	-190	158,5	1,5
			-195	0	0	-195	89,4	4,2
			-200	0	0	-200	91,2	2,1
						-205	95,4	2,3
						-210	98,4	1,9
						-215	74,3	2,4
						-220	75,3	3,6
						-225	71,2	3,1
						-230	56,4	5,4
						-235	67,9	3,2
						-240	61,2	8,5
						-245	48,9	11,6
						-250	59,2	11,2
						-255	43,2	12,6
						-260	0	0

LEGEND

Interval 1
Interval 2
Interval 3
Interval 4

- **Nannofloral Interval III** is characterized by monospecific assemblages with *B. bigelowii* that reaches values as high as 22 specimens/mm^2. Within this interval, reworked nannofloras were observed only sporadically. This interval was detected only in two sites located at a water depth below 40 m, while the peak of *B. bigelowii* is present in only 5-6 cm of sediment cores. Even if a biozone, which was determined by analyzing merely a few samples, is difficult to define, the peak for *B. bigelowii* could be used as a significant tool in ecobiostratigraphy, being placed in the Romanian inner shelf of the Black Sea just above the top of Unit 3 described by Ross & Degens (1974).

- **Nannofloral Interval IV** is present towards the base of the studied sites. No calcareous nannoplankton, either *in situ* or reworked, was remarked. Therefore, it was described as being a barren interval.

Recently, studies conducted on the calcareous nannoplankton fluctuation, from basinal and shallow settings of the Black Sea, were published (Giunta et al., 2007). In all the investigated sites of the western part of the Black Sea, Giunta et al. (2007) identified, from top to bottom, three nannofloral intervals (ecozones), as follows: (i) **Ecozone 1** that is characterized by a very high abundance of *E. huxleyi* (up to 1600 specimens/mm^2), the continuous presence of *B. bigelowii* (up to 13 specimens/mm^2) and few Cretaceous

and Cenozoic reworked taxa; (ii) **Ecozone 2** that is marked by the continuous occurrence of *E. huxleyi*, but in lower numbers than in the younger Ecozone 1 (a maximum of 800 specimens/mm^2) and *B. bigelowii* (a maximum of 20 specimens/mm^2), as well as numerous Cretaceous and Cenozoic reworked taxa, and (iii) **Ecozone 3** that contains scattered and small-sized specimens of *Emiliania huxleyi*, a significant amount of reworked taxa, but no *Braarudosphaera bigelowii* (Fig. 5). The boundary between Ecozones 1 and 2 corresponds to the lithological boundary between Units 1 and 2 described by Ross & Degens (1974), while the boundary between Ecozones 2 and 3 approximates the boundary between Units 2 and 3 described by Ross & Degens (1974).

A correlation can be established between nannofloral intervals presented herein and ecozones identified by Giunta et al. (2007), particularly for the youngest Holocene deposits of the Black Sea, described as the Shallow Unit. Nonetheless, the 'classical' Holocene units of Ross & Degens (1974) could not be identified in a shallow setting such as the Romanian inner shelf of the Black Sea.

The units identified by Ross & Degens (1974), from youngest to oldest: (i) Unit 1 (the microlaminated coccolith ooze, a pelagic sediment deposited under recent marine conditions, associated with the full invasion of the coccolithophore species *Emiliania huxleyi*), (ii) Unit 2 (the sapropel mud, corresponding to a brackish, anoxic phase), and (iii) Unit 3 (the lacustrine lutite deposited during the freshwater or oligohaline stage), could be found only in basinal parts (at a water depth below 200 m) of the Black Sea (Fig. 5).

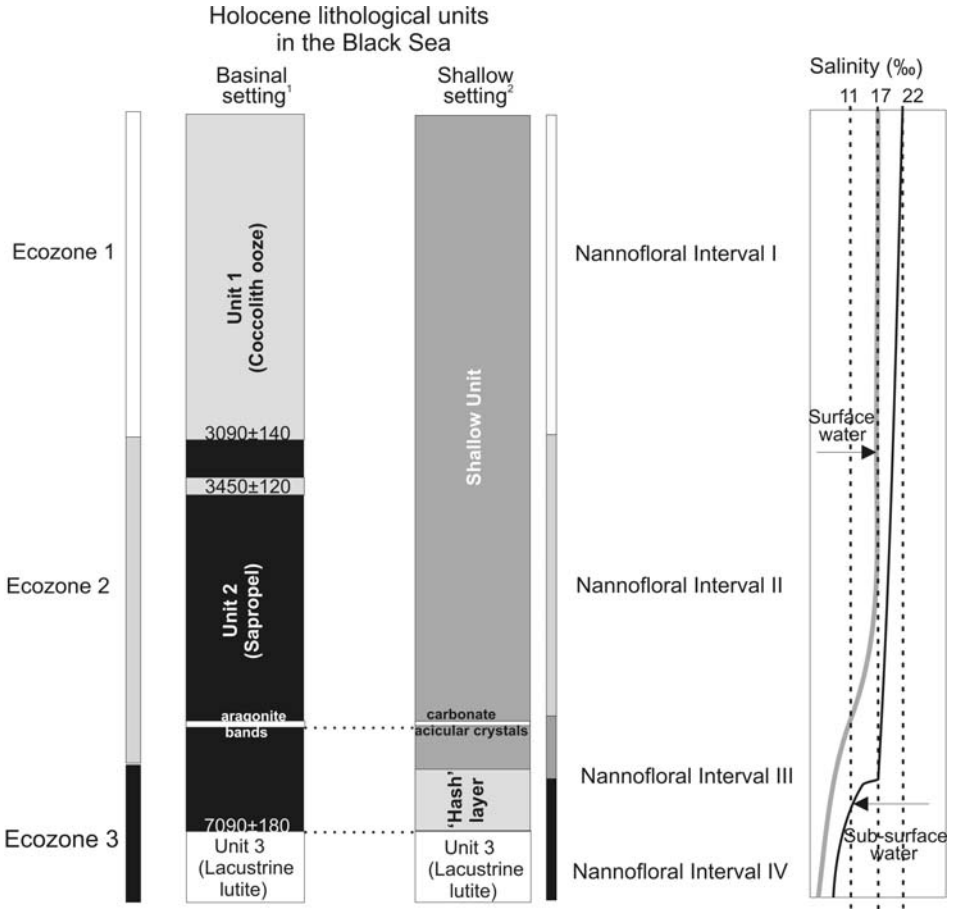


Fig. 5 – Holocene lithological units and identified calcareous nannoplankton intervals (ecozones) in the Black Sea. (1) Basinal setting: lithological units after Ross and Degens (1974); ecozones after Giunta et al., 2007 (Site MD04 2754 from the SE Black Sea, placed at 453 m water depth); absolute age after Jones and Gagnon (1994). (2) Shallow setting of Romanian inner shelf: lithological units after Oaie and Melinte-Dobrinescu (2010); Nannofloral Intervals described in this study; surface and subsurface water salinity according to data in this paper.

In the Romanian inner shelf of the Black Sea, Oaie & Melinte-Dobrinescu (2010) identified the Shallow Unit as being the youngest Holocene lithological one (*sensu* Giunta et al., 2007), rich in marine mollusc faunas, which they assumed to be the shallower correspondent of basinal Units 1 and 2 described by Ross & Degens (1974). From the calcareous nannoplankton point of view, the stratigraphic interval covered by the Shallow Unit is characterized by the development of Nannofloral Intervals I and II.

We suppose that Nannofloral Interval I corresponds to Ecozone 1 identified by Giunta et al. (2007), both ecobiozones being characterized by a very high abundance of *Emiliania huxleyi* (up to 1600 specimens/mm^2). However, there is a difference between the two units in the fluctuation pattern of

Braarudosphaera bigelowii. In the Ecozone 1, described by Giunta et al. (2007), *B. bigelowii* occurs continuously, but in very small amounts. Its occurrence in Nannofloral Interval 1 is discontinuous and in small amounts. This difference may reflect episodes of lowering salinity below the surviving limit for *B*. *bigelowii* during the deposition of the upper part of the Shallow Unit in the Black Sea Romanian inner shelf (Table 2).

Table 2 – Recent distribution of *Emiliania huxleyi* and *Braarudosphaera bigelowii* in various marine settings (after Bukry, 1974; Giunta et al., 2007).

	Sea of Azov 11 ‰	Black Sea 17-18 ‰	Atlantic Ocean 35 ‰	Red Sea 37-41 ‰
Emiliania huxleyi				
Braarudosphaera bigelowii				

The identified Nannofloral Interval II probably corresponds to the Ecozone 2 described by Giunta et al. (2007). According to the above-mentioned authors, this ecozone extends within the sapropel mud (Unit 2 as indicated by Ross & Degens, 2007), except for the lower part of this lithological unit. In the studied cores, Nannofloral Interval II extends within the lower part of the Shallow Unit. Within the Nannofloral Interval II, the abundance of *Emiliania huxleyi* drops abruptly and significantly, representing half of the *E*. *huxleyi* abundance recorded in Nannofloral Interval 1 (i.e., from more than 1.500 specimens/mm^2 to less than 800 specimens/mm^2 – Table 1). The abundance of *E*. *huxleyi* continuously decreases within this interval to < 100 specimens/mm^2. Nevertheless, *E*. *huxleyi* is always present. By contrast, *E*. *huxleyi* appears discontinuously in Ecozone 2, described by Giunta et al. (2007), from 800 specimens/mm^2 down to < 1 specimens/mm^2. There is no correlation between its fluctuation pattern and the depth (Table 1 by Giunta et al., 2007).

In the investigated sediments from the Romanian inner shelf of the Black Sea, towards the base of the Shallow Unit, there is a particular level rich in carbonate acicular crystals (Plate 1). This level probably corresponds to the inorganic aragonite bands deposited in deep parts of the Black Sea towards the base of the sapropel mud labelled Unit 2 by Ross & Degens, 1974 (Fig. 5). Underneath the carbonate acicular crystals level, at the base of the Shallow Unit, a 'shell hash-layer' made by coquinas with sandy matrix containing marine molluscs (i.e., *Mytilus galloprovincialis* and *Cardium spp*.) and freshwater ones (i.e., *Dreissena spp*. and *Monodacna spp.*) was observed in the investigated cores. The depositional interval comprised between the upper part of the 'shell hash-layer' and the lower part of the Shallow Unit, containing a high abundance of carbonate acicular crystals, is characterized as being the Nannofloral Interval III, containing only assemblages with *B*. *bigelowii*.

Samples rich in *B*. *bigelowii* were previously observed by Giunta et al. (2007) from the Holocene deposits of the Black Sea, placed towards the upper part of Ecozone 2 within Unit 2 (i.e., the sapropel mud). In cores situated in the Romanian shelf of the Black Sea, Giunta et al. (2007) located the peak for *B*. *bigelowii* slightly above the deposition of the 'shell hash-layer'. However, *E*. *huxleyi* is still present in these assemblages.

Nannofloral Interval IV corresponds to Unit 3 (i.e., the lacustrine lutite), which is the only Black Sea Holocene unit from a basinal setting that can also be found in the Romanian inner shelf of the Black Sea, according to Oaie & Melinte-Dobrinescu (2010) – Fig. 5. No nannofloras, either *in situ* or reworked, were observed within this interval. However, Giunta et al (2007) identified *E*. *huxleyi* in the lacustrine lutite sediments of Unit 3 described by Ross & Degens (1974), both in the shallow and the deep parts of the Black Sea, but with a rare and discontinuous occurrence.

PALAEOENVIRONMENTAL IMPLICATIONS

Holocene calcareous nannoplankton assemblages are absent from the sites located seaward near the Danube Delta (i.e., MN 07-03, PO 01 and PO 02 sites). This fact is linked to the evolution of the Danube Delta during Holocene times, including changes of the coastline position. The MN 07-03 site is located in the Saint George II Palaeodelta, while the PO 01 and PO 02 sites are placed in the area of the Coşna-Sinoe Palaeodelta (Panin, 1998) that has formed around 3,500 y BP (Panin, 1997; Panin & Jipa, 2002). Hence, we may suppose that the low surface water salinity of this area did not allow the flourishing of coccolithophore algae.

In the other studied sites (i.e., PO 04, EF, 08-01 and BS 08-055 – Fig. 1), the calcareous nannoplankton assemblages are present in the youngest cored Holocene deposits (i.e., the Shallow Unit), but not in the older Unit 3 (corresponding to Nannofloral Interval IV). The absence of any nannofloras in Interval IV indicates a very low palaeosalinity of surface waters during the deposition of Unit 3 (i.e., the lacustrine lutite depicted by Ross & Degens, 1974). Possibly, the palaeosalinity was below 11 ‰ (the lowest value for surface waters at which *Emiliania huxleyi* still survives – Table 2).

On the other hand, Giunta et al. (2007) identified *E*. *huxleyi* also in Unit 3 described by Ross & Degens (1974). The encountered specimens of *E*. *huxleyi* are extremely rare and have a smaller size than normal. To justify this finding, the above-mentioned authors advanced two hypotheses: (1) *E*. *huxleyi* specimens are reworked from outcrops of previous sea level highstands, but this assumption does not explain why only this extremely fragile coccolith was reworked, and (2) *E*. *huxleyi* specimens derived from the transport of waters from the Mediterranean to the Black Sea during short connection events.

Taking the latest scenario into account, we may assume that influxes from the Mediterranean penetrating the Black Sea basin did not reach the Romanian inner

shelf during the deposition of Unit 3, its uppermost portion dating to 7,000 y BP, after Giunta et al. (2007) and around 7,920 y BP, after Strechie-Sliwinski (2007). This assumption is also supported by data obtained by Lericolais et al. (2009, 2010), indicating a low-stand period for the NW Black Sea (including the Romanian shelf), from 11,000 y BP to 8,000 y BP. According to the above-mentioned authors, this time interval was characterized by dry climatic conditions, being accompanied by the formation of dunes at around 8,500 y BP on the desiccated NW Black Sea shelf.

Nannofloral Interval III, which we identified in the Romanian inner shelf of the Black Sea, composed of monospecific assemblages with *B*. *bigelowii* and a high concentration in carbonate acicular crystals, is of great interest for palaeoenvironmental reconstructions. Probably, the thin carbonate crystal levels were formed in a calcite-saturated lake environment, where there was an infiltration of marine sulphate (Lericolais et al., 2009). If so, the assemblages containing *B*. *bigelowii* exclusively represent a palaeobiotical evidence sustaining the idea of a shift from a lacustrine-brackish palaeoenvironment to a marine one, with a sudden increase in salinity from below 11 ‰ to above 17 ‰.

The identified Nannofloral Intervals II and I correspond to a marine setting of the Romanian Black Sea inner shelf. The salinity of surface waters was probably already established at values close to those of modern times, as both *E*. *huxleyi* and *B*. *bigelowii* are present.

CONCLUSIONS

The fluctuation pattern of the calcareous nannoplankton species *Emiliania huxleyi* and *Braarudosphaera bigelowii* from the investigated sites of the Romanian inner shelf allow us to identify palaeoenvironmental changes of the NW Black Sea during Holocene times. The youngest studied Holocene deposits (i.e., the upper part of the Shallow Unit) are characterized by the Nannofloral Interval I that contains a very high abundance of *E*. *huxleyi* and a low abundance of *B*. *bigelowii*, indicating full marine conditions, with a salinity around 17-18 ‰, close to nowadays values for the Black Sea. The extremely high abundance of *E*. *huxleyi* is possibly linked to high nutrient input in the inner shelf area of the NW Black Sea. The origin of Nannofloral Interval I is probably related to the transgression placed towards the upper part of the Subboreal climate stage, at around 3,500 y BP (Shuisky, 2007).

The lower part of the Shallow Unit is characterized by the Nannofloral Interval II, with high abundance of *E*. *huxleyi* and moderate abundance of *B*. *bigelowii*. Within this interval, the abundance of *E*. *huxleyi* decreases, while that of *B*. *bigelowii* increases with depth. There is a negative correlation between the two above-mentioned taxa throughout the whole studied Holocene intervals. We assume that the upper part of the Nannofloral Interval II corresponds to a time-span comprised between the last invasion of *E*. *huxleyi* (placed in basinal parts of the Black Sea at the base of Unit 1, 'finely laminated coccolithic ooze') and the first invasion of *E*. *huxleyi* in the Black Sea, situated in basinal parts at the top of Unit 2, 'the sapropel muds'.

The Nannofloral Interval III, composed of monospecific assemblages with *B*. *bigelowii*, is placed at the boundary between the Shallow Unit (at the top) and the Unit 3 (at the base). We may suppose that, within this interval, a first rapid and significant increase in salinity took place. Some authors (Kelly et al., 2003) assumed that braarudospherid depositional events as "subsurface blooms" took place in the lower photic zone, where these taxa are usually found. By contrast, *E*. *huxleyi* mostly inhabited the upper photic zone. Hence, a scenario implicating that the salinity was higher in the lower photic zone than in the upper one could be advanced. This idea could explain why blooms of *B*. *bigelowii* are present in Nannofloral Interval III, while *E*. *huxleyi*, which is most tolerant to a lower salinity, was not found.

The oldest Nannofloral Interval IV (corresponding to the lithological Unit 3, which is the lacustrine lutite as described by Ross & Degens, 1974) contains no nannofloras. This fact reflects a lower salinity of both surface and subsurface waters, probably below 11 ‰ (the minimum value required for the survival and growth of *E*. *huxleyi* – Bukry, 1974), in an earlier period than 7.500 y BP.

The changes in calcareous nannoplankton composition and abundance indicate that salinity increased during Holocene times in the NW Black Sea, from a brackish setting to a marine one, similar to the one found in modern times. Taking into account the fluctuation pattern of nannofloras, a sudden increase in salinity could be assumed for deeper parts of the Romanian shelf (i.e., below 40 m of water depth) while a gradually progressive one could be supposed for extremely shallow areas.

Acknowledgments

The authors acknowledge the financial support the Grant – Programme type EUROCORES ESF nr. 2/2008. We are grateful to the crew of the Romanian research vessel *Mare Nigrum* (owner GEOECOMAR), for their assistance during the scientific cruises. We are also thankful to Philippe Münch (Departement Géologie des Systèmes Carbonatés, Université de Provence, Marseille, France), for providing support related to SEM studies and microphotographs of the calcareous nannoplankton. We are grateful to the reviewers Alessandra Negri and Gheorghe Popescu; their comments and suggestions significantly improved this paper.

REFERENCES

Aksu, A.E., Mudie, P.J., Rochon, A., Kaminski, M.A., Abrajano, T. & Yasar, D. 2002. Persistent Holocene outflow from the Black Sea to the Eastern Mediterranean contradicts Noah's flood hypothesis. *Geotimes* 12: 4-10.

Bukry, D. 1974. Coccoliths as paleosalinity indicators - evidence from Black Sea. In: Degens, E.T. & Ross, D.A. (eds.), The Black Sea - Geology, Chemistry and Biology. *AAPG Memoirs*, 20**:** 353-363.

Giunta S., Morigi, C., Negri, A., Guichard F. & Lericolais, G., 2007. Holocene biostratigraphy and paleoenvironmental changes in the Black Sea based on calcareous nannoplankton. *Marine Micropaleontology,* 63: 91-110.

Kaminski, M.A., Aksu, A., Box, M., Hiscott, R.N., Filipescu, S. & Al-Salameen, M. 2002. Late Glacial to Holocene benthic foraminifera in the Marmara Sea: implications for Black Sea-Mediterranean Sea connections following the last deglaciation. *Marine Geology*, 190 (1-2): 165-202.

Kelly, D.C., Norris, R.D. & Zachos, J.C., 2003. Deciphering the paleoceanographic significance of Early Oligocene

Braarudosphaera chalks in the South Atlantic. *Marine Micropaleontology* 49, 1-2: 49-63.

Lericolais, G., Bulois, C., Gillet, H. & Guichard, F. 2009. High frequency sea level fluctuations recorded in the Black Sea since the LGM. *Global and Planetary Change*, 66: 65-75.

Lericolais, G., Guichard, F., Morigi, C., Minereau, A., Popescu, I. & Rădan, S. 2010. A post Younger Dryas Black Sea regression identified from sequence stratigraphy correlated to core analysis and dating. *Quaternary International*: doi: 10.1016/j.quaint.2010.02.003

Oaie, G. & Melinte, M.C., 2010. Holocene litho- and biostratigraphy of the NW Black Sea (Romanian shelf). *Quaternary International*: doi:10.1016/j.quaint.2009.12.014.

Panin, N. 1997. On the geomorphologic and geologic evolution of the River Danube-Black Sea interaction zone. *Geoecomarina* 2: 31-40.

Panin, N. 1999. Danube Delta: Geology, Sedimentology, Evolution. *Association des Sedimentologistes Français,* Maison de la Géologie, Paris: 66.

Panin, N. & Jipa, D. 2002. Danube river sediment input and its interaction with the northwestern Black Sea. *Estuarine Coastline Shelf Science*, 54: 551-562.

Ross, D.A. & Degens, E.T. 1974. Recent sediments of the Black Sea. In: Degens E.T. and Ross D.A. (Eds.), The Black Sea: Geology, Chemistry, and Biology. *American Association of Petroleum Geologists*: 183-199.

Ryan, W.B.F., Pitman, W.C., Major, C.O., Shimkus, K., Moskalenko, V., Jones, G.A., Dimitrov, P., Görür, N., Sakinç, M. & Yücel, H. 1997. An abrupt drowning of the Black Sea shelf. *Marine Geology*: 138: 119-126.

Shuisky, Y. 2007. Climate dynamics, sea-level change, and shoreline migration in the Ukraine sector of the Circum-Pontic region. In: Yanko-Hombach, V., Gilbert, A.S., Panin, N. & Dolukhanov, P.M. (Eds.), *The Black Sea Flood Question: Changes in Coastline, Climate and Human Settlement*. Springer, Dordrecht: 149-205.

Strechie-Sliwinski, C. 2007. Changements environmentaux récents dans la zone de Nord-Ouest de la Mer Noire. *Geoecomarina* 13, Special Publication 1: 270 pp.

Tappan, H. 1980. Haptophyta, Coccolithophores and other calcareous nannoplankton. The Paleobiology of Palnt Protista. *Freeman San Francisco Publishing House*: 678-803.

Winguth, C., Wong, H.K., Panin, N., Dinu, C., Georgescu, P., Ungureanu, G., Krugliakov, V.V. & Podshuveit, V. 2000. Upper Quaternary water level history and sedimentation in the north-western Black Sea. *Marine Geology* 167: 127-146.

Yanko-Hombach, V., Gilbert, A.S., Panin, N. & Dolukhanov, P.M. (Eds.), 2007a. *The Black Sea Flood Question: Changes in Coastline, Climate and Human Settlement*. Springer, Dordrecht*:* 971 pp.

Yanko-Hombach, V., Gilbert, A. S. & Dolukhanov, P. 2007b. Controversy over the great flood hypotheses in the Black Sea in light of geological, paleontological and archaeological evidence. *Quaternary International* 167-168: 91-113.

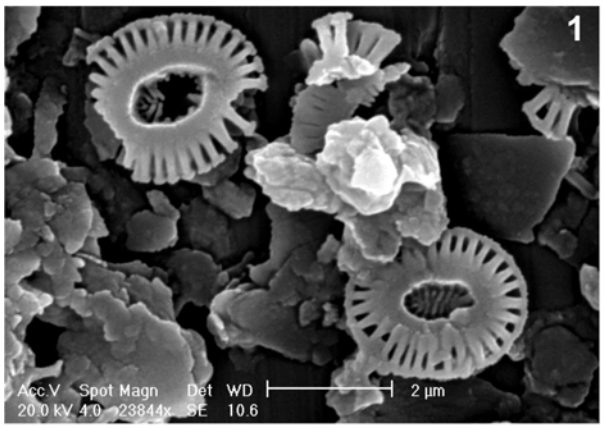
PLATE CAPTIONS

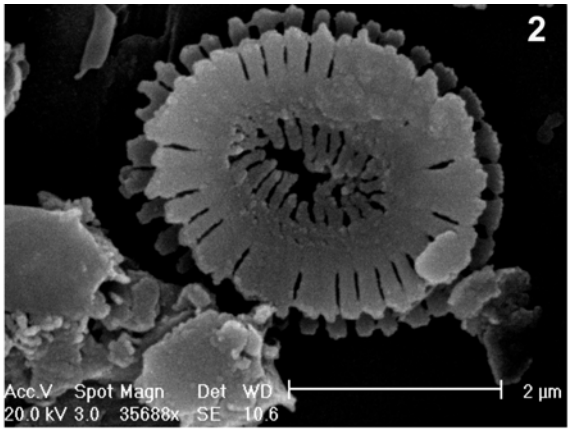
PLATE I

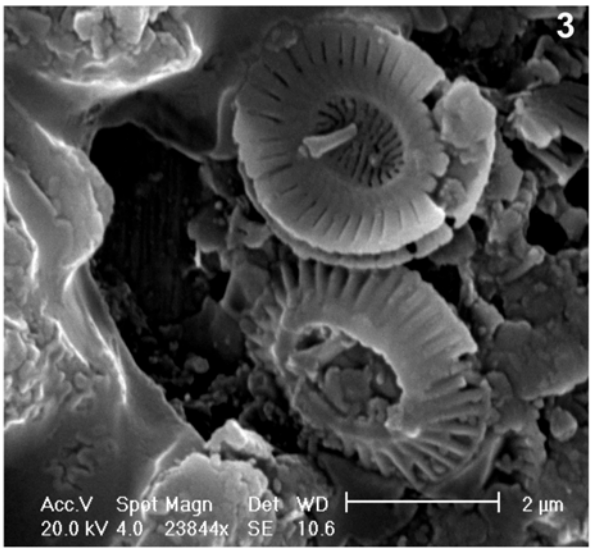
SEM microphotographs, except Figs. 5 and 6 that are LM microphotographs, crossed-nicols.
Scale bar in microns.

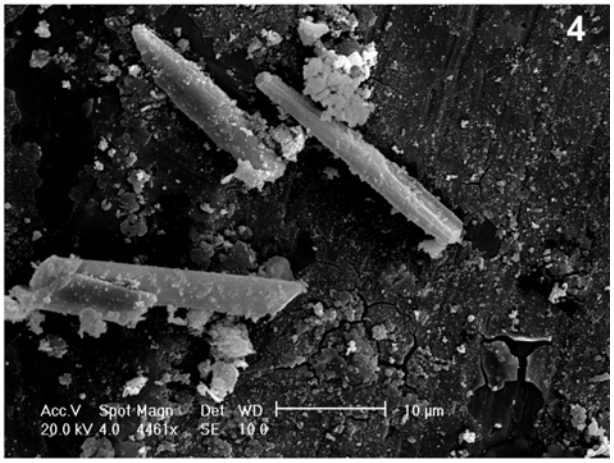
1- Bloom of *Emiliania huxleyi* (Lohmann, 1902) Hay and Mohler *in* Hay et al. 1967, 0-5 cm, Site BS 08-055.
2- Specimen of *Emiliania huxleyi* (Lohmann, 1902) Hay and Mohler *in* Hay et al. 1967 (down) and reworked specimen of *Reticulofenestra* sp. (up), 0-5 cm, Site EF 08-01.
3- Tertiary reworked calcareous nannoplankton, 195-200 cm, Site EF 08-055.
4- Acicular carbonate crystals, 0-5 cm, Site BS 08-055.
5- High abundance of *Emiliania huxleyi* (Lohmann, 1902) Hay and Mohler *in* Hay et al. 1967, 55-60 cm, Site PO 04.
6- *Braarudosphaera bigelowii* (Gran and Braarud, 1935) Deflandre 1947, 15-20 cm, Site BS 08-055.

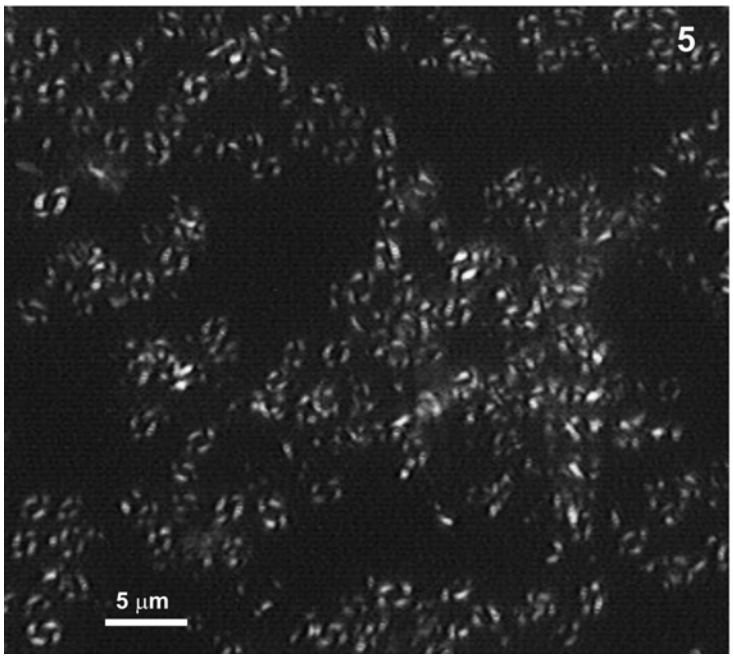
PLATE I

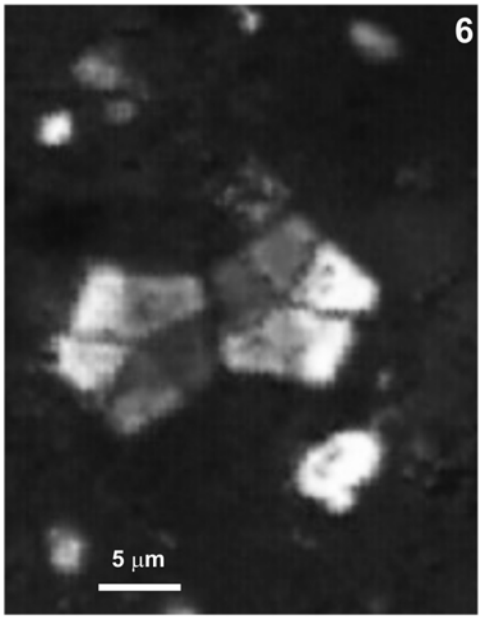

1
Acc.V Spot Magn Det WD 2 µm
20.0 kV 4.0 23844x SE 10.6


2
Acc.V Spot Magn Det WD 2 µm
20.0 kV 3.0 35688x SE 10.6


3
Acc.V Spot Magn Det WD 2 µm
20.0 kV 4.0 23844x SE 10.6


4
Acc.V Spot Magn Det WD 10 µm
20.0 kV 4.0 4461x SE 10.0


5
5 µm


6
5 µm