EMILIANIA HUXLEYI AND *BRAARUDOSPHAERA BIGELOWII* FLUCTUATIONS IN QUATERNARY SEDIMENTS OF THE WESTERN BLACK SEA

Eliza ANTON[1], Gabriel ION[1], Andrei BRICEAG[1], Vlad APOTROSOAEI[1,2], Constantin LAZĂR[1,2], Florin PITEA[1]

[1]*National Institute of Marine Geology and Geo-Ecology (GeoEcoMar), 23-25 Dimitrie Onciul St., 024053 Bucharest, Romania*
e-mail: antoneliza@geoecomar.ro
[2]*University of Bucharest, Doctoral School of Geology, 1 Nicolae Bălcescu Blvd., Bucharest, Romania*

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Abstract. This paper presents the fluctuation of the calcareous nannoplankton species *Emiliania huxleyi* and *Braarudosphaera bigelowii* identified in four cores sampled from the NW Black Sea, at various water depths, between 160.9 and 1.031 m. Unit 1 (Coccolith Mud) and 3 (Lacustrine Lutite) are present in all studied cores, the former showing a variable thickness. Unit 2 (Sapropel Mud) was not observed in the shallowest studied cores, i.e., above 200 m water depth. At the deepest levels of the studied cores, a red-brownish succession, composed of clays and muds, was identified. Calcareous nannoplankton assemblages *in situ* are present only in the youngest Holocene units 1 and 2, being composed of *Emiliania huxleyi* and *Braarudosphaera bigelowii*. These two calcareous nannoplankton species, very abundant especially in Unit 1, show a negative correlation in their abundance pattern.

Key words: calcareous nannofossils, fluctuation, gravitational cores, Black Sea basin

1. INTRODUCTION

During the Last Glacial Maximum (LGM), the Black Sea became a giant freshwater lake, being isolated from the ocean. Following the deglaciation, the reconnection of the Black Sea with the Mediterranean took place and the salted Mediterranean waters entered the Black Sea, *via* the Marmara Sea - Bosphorus Sill (Ryan *et al.*, 1997; Hiscott and Aksu, 2002; Yanko-Hombach, 2004; Ryan, 2007; Lericolais *et al.*, 2009; Soulet *et al.*, 2011; Yanchilina *et al.*, 2017; Ion *et al.*, 2022, among many others). The reconnection between the Black Sea and the Marmara Sea is marked by the deposition of coccolith ooze (Black, 1973; Arthur and Dean, 1998), which consists in blooms of the marine algae *Coccolithophores*.

During the Quaternary, the calcareous nannoplankton represents one of the most important marine primary producers amongst the unicellular algae. As planktonic organisms, they are very sensitive to environmental changes, such as salinity, surface-water temperature, pH, dissolved CO_2, and nutrient input. One of the most widespread cosmopolitan species is *Emiliania huxleyi,* which shows nowadays a high abundance in all the oceans and seas of our planet, including the Black Sea, where 1 litre collected from the surface water contains around 40-50 million of *Emiliania huxleyi* cells (Lancelot *et al.*, 2002). Presently, in the intra- and intercontinental seas, *E. huxleyi* can be found in the surface-waters of the Sea of Azov at approximately 11‰ salinity, but also in the Red Sea at salinity up to 41‰ (Bukry, 1974; Ross and Degens, 1974; Paavola *et al.*, 2005).

The calcareous nannoplankton species *Emiliania huxleyi* firstly occurred in the Mediterranean Sea approximately 300.000 years ago (Young, 1998 and references included), but its first consistent appearance in the Black Sea was assumed to be at around 3.000 years BP (Before Present), according to Bukry (1974) and Giunta *et al.* (2007). Recent studies (Ion *et al.*, 2022) identified its presence from the top of Unit 3, i.e., the Lacustrine Lutite as described by Ross and Degens (1974). This event probably indicates an increase in salinity up to 11‰ (which is the minimum salinity needed for this species to survive) and might be coeval with the first invasion of salty Mediterranean waters, at about 9.000 years BP (Soulet *et al.*, 2011).

In the Holocene deposits of the NW Black Sea the calcareous nannoplankton species *Braarudosphaera bigelowii* is also present. Nowadays, this taxon occurs in the high salinity surface waters of the Red Sea, but not in the Sea of Azov (Paavola *et al.*, 2005). The minimum salinity where *B. bigelowii* can be found is approximately 17‰ (Bukry, 1974; Oaie and Melinte-Dobrinescu, 2012; Melinte-Dobrinescu & Ion, 2013).

The aim of this study is to identify calcareous nannoplankton fluctuations in the NW Black Sea, based on the abundance pattern of *E. huxleyi* and *B. bigelowii*. According to their fluctuation framework, a paleosetting approach is also presented.

2. MATERIAL AND METHODS

We have sampled 4 gravity cores from various water depths (11_GC_1 from 160.9 m, 13_GC_1 from 171.4 m, 6_GC_1 from 648.5 m, and 4_GC_4 from 1.031 m) located in the NW Black Sea (Fig. 1). These cores were taken in 2019 and 2020 by the team of the National Institute of Marine Geology and Geo-ecology (GeoEcoMar), in the frame of the uBiogas Project (24PCCDI/2018), financed by UEFISCDI, with the research vessel *Mare Nigrum* (owned by GeoEcoMar). Recently, lithostratigraphy and absolute ages were published for 11 cores collected in 2019, along with biostratigraphy, mainly based on ostracods and calcareous nannoplankton and geochemistry of 3 cores (Ion *et al.*, 2022). In addition, absolute ages made by Nagavciuc *et al.* (2021) were reinterpreted and placed in the lithological context.

The study of the 4 gravity cores presented in this paper was based on lithological and sedimentological investigations, along with a detailed sampling (every 3 cm for Units 1 and 2 and every 5 cm for Unit 3 - units defined by Ross and Degens, 1974). The length of the cores is comprised between 348 and 396 cm (Fig. 2).

The calcareous nannoplankton studies were carried out using an Olympus LM (light microscope), with x1200 magnification. Both qualitative and semiquantitative investigations have been performed. The nannoplankton taxa were counted in longitudinal traverses, randomly distributed, in at least 300 FOVs (field of view). The number of *Emiliania huxleyi* and *Braarudosphaera bigelowii* specimens were quantified in percentages for each studied sample.

3. RESULTS

3.1. Lithostratigraphy

All the three units described by Ross and Degens (1974), Unit 1 - The Coccolith Mud, Unit 2 – The Sapropel Mud and Unit 3 – The Lacustrine Lutite, have been identified in the studied cores. Unit 3 is made of green-greyish clays, rich in black stains of organic matter. In the deepest three cores investigated (13_GC_1 from 171.4 m, 6_GC_1 from 648.5 m, and 4_GC_4 from 1.031 m) a succession of red-brownish clays and muds was observed (Fig. 3).

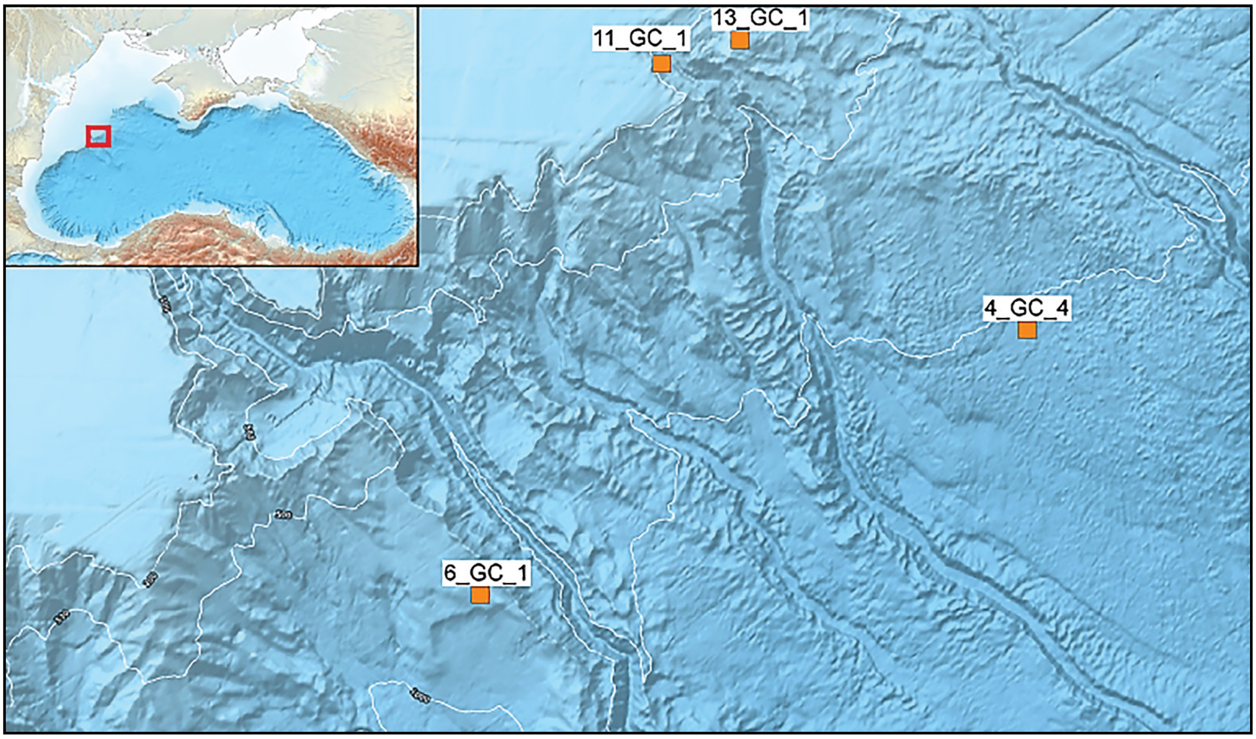

Fig. 1. Location of the investigated gravity cores in the NW Black Sea. Bathymetry data from https://tiles.emodnet-bathymetry.eu/preview.html and the National Institute of Marine Geology and Geo-ecology (GeoEcoMar) (modified after Ion *et al.*, 2022).

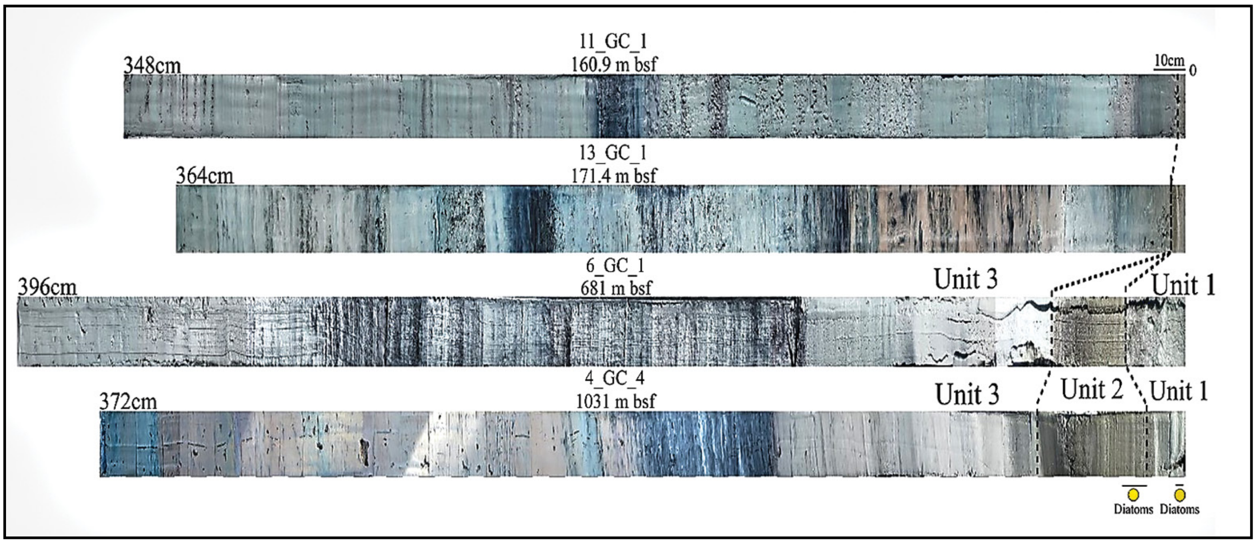

Fig. 2. Photographs of the investigated gravity cores. *Legend*: **Unit 1** – The Laminated Coccolith Muds; **Unit 2** – The Sapropel Muds; **Unit 3** – The Neoeuxinic Muds or `Lacustrine Lutites`.

These red beds were not encountered in the shallowest studied core 11_GC_1, taken from 160.9 m water depth. In the cores located up to 200 m water depth, for instance, 11_GC_1 and 13_GC_1, cm-thick sand levels are present within the lower half of the Unit 3. In the core 13_GC_1, a 12 cm-thick coquina layer, composed of brackish and fresh-water mollusk fragments, was identified, below the red clays and mud succession. Mollusk fragments or entire shells are present at several levels of Units 3, not only in the sands, but also in the grey-greenish mud and clays from the deeper part of the basin, i.e., below 600 m water depth. (Figs. 2 and 3).

Unit 3 is followed by Unit 2 – The Sapropel Mud in the deepest studied cores that are 6_GC_1 (648.5 m bsf – below sea floor) and 4_GC_4 (1.031 m bsf). The lithology of Unit 2 is characterized by the presence of fine-grained brownish-blackish muds, displaying millimeter-scale coccolith laminae at its base. This feature was also noticed at the top of Unit 2 in the deepest studied core, 4_GC_4 (Fig. 3).

The youngest Holocene Unit 1 – The Coccolith Mud, composed of light greyish silty clays, interbedded with mm-thick coccolith laminae, occur in all the studied cores. Its thickness decreases from the deeper parts of the basin, where it averages from 18 cm to only a few cm in the shallow setting (i.e., 6 cm at 171.4 m bsf and 3 cm at 160.9 m bsf).

3.2. Calcareous nannoplankton

In the studied samples from the top of Unit 3 only reworked taxa from older deposits, such as Cretaceous to Miocene in age, were encountered. In the other units (Coccolith Mud and Sapropel Mud), we observed only the calcareous nannoplankton species *Emiliania huxleyi* and *Braarudosphaera bigelowii*, considered to be *in situ*.

The oldest bloom of *E. huxleyi*, found at the base of Unit 2 (Sapropel Mud) is well represented in both deepest cores 4_GC_4 and 6_GC_1 (Fig. 3). This bioevent is followed by a remarkable increase in *B. bigelowii* specimens and a substantial decrease of *E. huxleyi* ones (Fig. 4).

For instance, in the deepest studied core, 4_GC_4 (1.031 water depth), the 0-3 cm bsf depositional interval contains 83% *E. huxleyi* and 17% *B. bigelowii*. Between 6 to 14 cm bsf, *E. huxleyi* shows very high percentages (83-100%), while *B. bigelowii* percentages slightly fluctuate (averaging 10%). In the interval 14-17 cm bsf, both species show similar percentage values (approximately 50%). Between 17 to 26 cm bsf, a very important shift of *B. bigelowii* that increases to an average of 76% was observed, along with the decrease of *E. huxleyi* to 24% (Figs. 4 and 5).

In a few samples from the 4_GC_4 core, we noted a distinct feature: the presence of diatoms. They were encountered in the youngest sample from the top of Unit 1 (0-3 cm bsf) and in the youngest 2 samples collected from Unit 2 (17-23 cm bsf), being represented by taxa from the centric group.

Concerning the calcareous nannoplankton of Core 6_GC_1, the youngest 5 samples (0-15 cm bsf) contain the highest content of *E. huxleyi* (an average of 98%), whereas *B. bigelowii* is present only in 2% from the total assemblage. From 18 to 21 cm, a significant decrease in abundance of *E. huxleyi* (32%) and a remarkable increase in *B. bigelowii* (68%) was observed. The 21-24 cm bsf interval is marked by a new increase in *E. huxleyi* abundance (up to 88%) and an abrupt decrease in *B. bigelowii* (12%). The 24-30 cm bsf samples show another increase to 22% of *B. bigelowii*, along with a high abundance of *E. huxleyi* (78%). From 27 to 30 cm bsf a gradual decrease in both species can be observed. The 30 to 33 cm bsf interval is barren. Between 33-39 cm bsf a remarkable bloom of *E. huxleyi* specimens was observed, while no *B. bigelowii* specimens were encountered (Fig. 3).

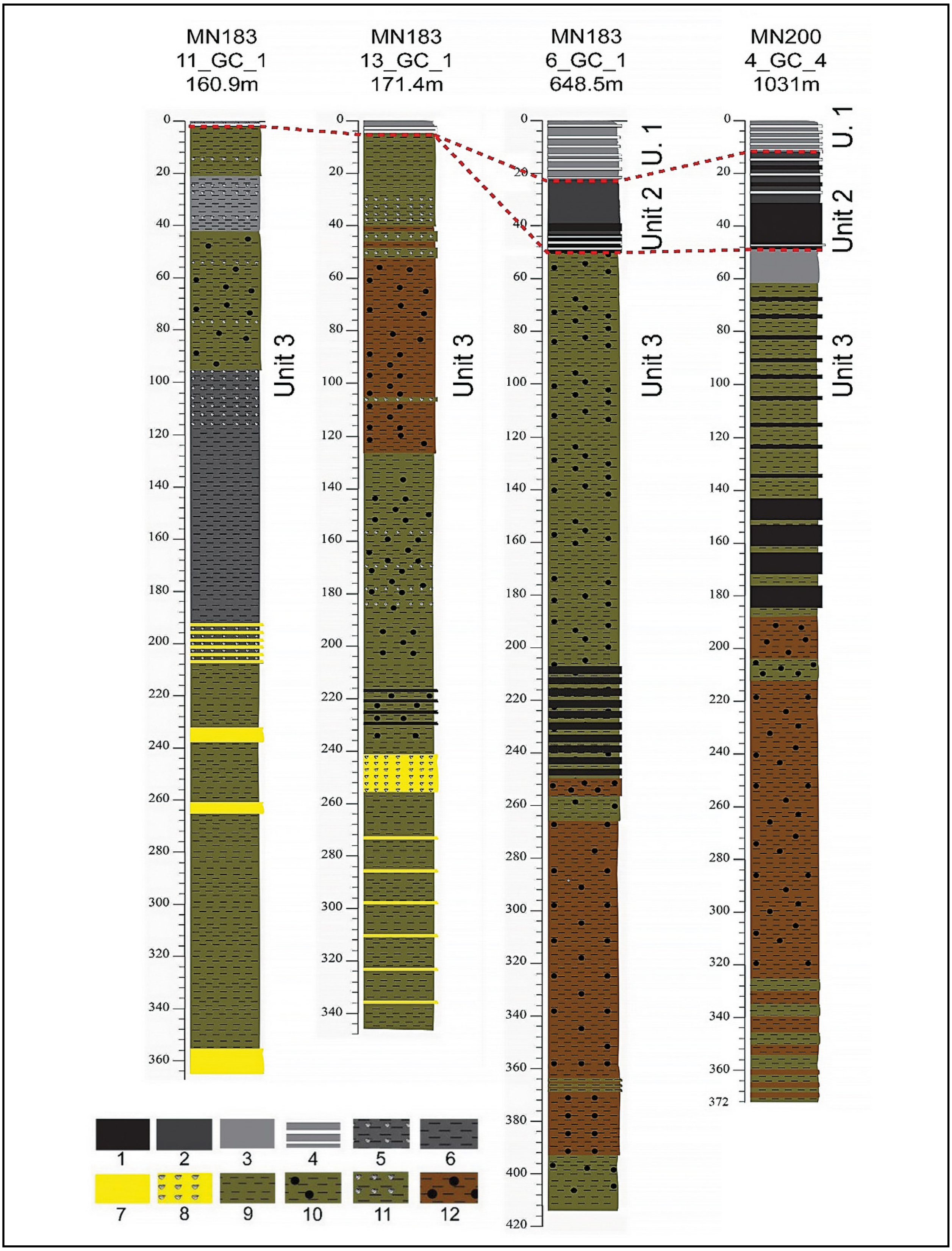

Fig. 3. Lithostratigraphy of the investigated cores (11_GC_1, 13_GC_1, 6_GC_1 and 4_GC_4) and the correlation between the main units described by Ross & Degens (1974) in the Black Sea basin. *Legend for lithology*: **1** – black mud; **2** – grey-blackish mud; **3** – grey mud; **4** – coccolith mud; **5** – grey mud with mollusks; **6** – grey mud and clays; **7** – sands; **8** – coquinas; **9** – grey-greenish mud and clays; **10** – grey-greenish mud and clays with organic matter; **11**– grey-greenish mud and clays with coquinas; **12** – red-brownish clays and muds with organic matter (modified after Ion *et al*., 2022).

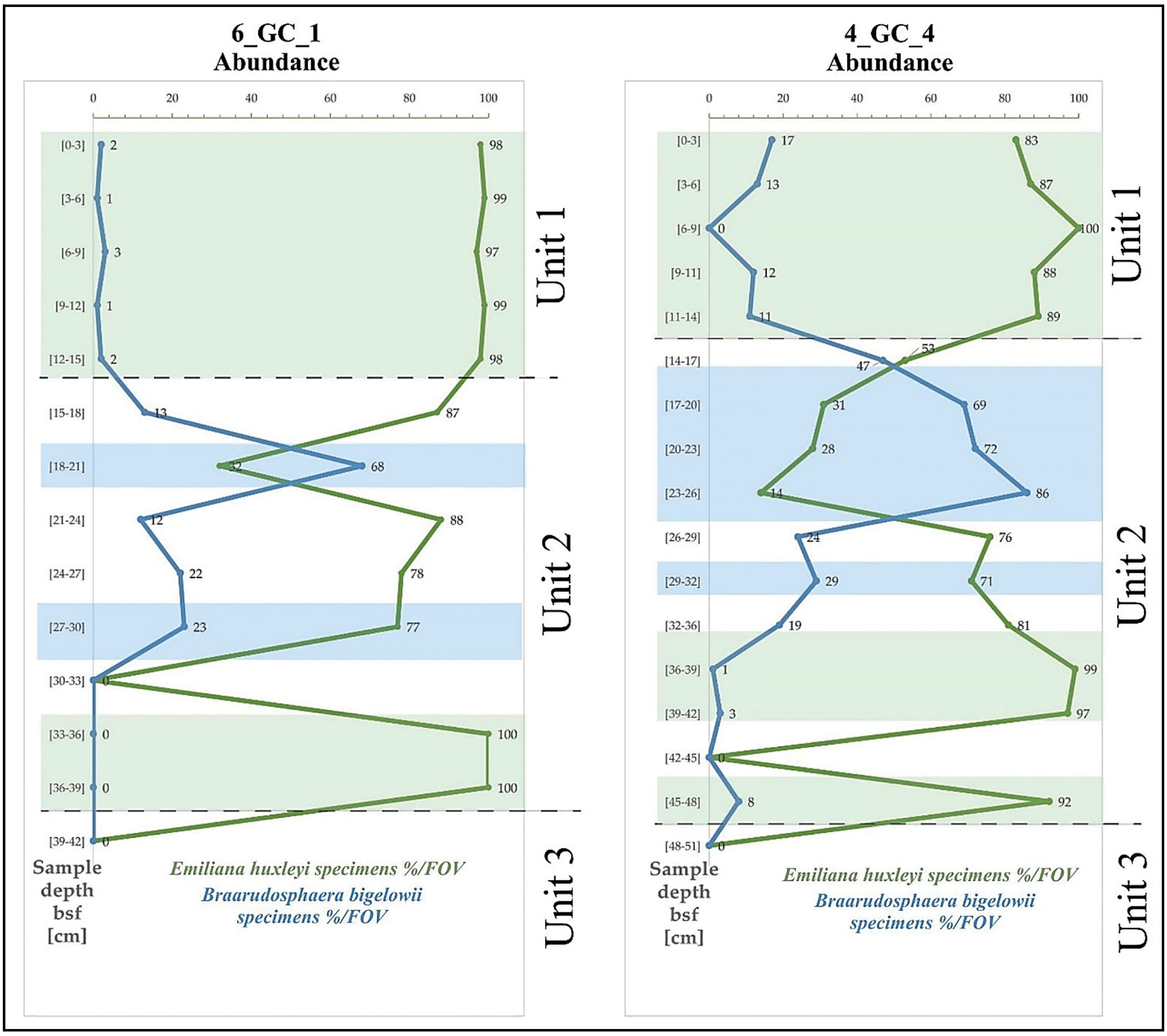

Fig. 4. Quantitative analyses on *Emiliania huxleyi* and *Braarudosphaera bigelowii* calcareous nannoplankton species. **FOV**: Field of View; **bsf**: below sea floor.

In the core 11_GC_1 we analyzed the top 3 cm bsf (representing Unit 1 – Coccolith Mud), which contained *E. huxleyi* blooms (100%). *B. bigelowii* has not been observed. In 13_GC_1 core, the top 6 cm bsf contain monospecific *in situ* assemblage with *E. huxleyi*.

4. DISCUSSION AND SUMMARY

The study of four cores collected from the NW Black Sea at various water depths revealed the significant paleoenvironmental changes that took place since LGM. The Lacustrine Lutite, Unit 3, was deposited everywhere in the basin, in both the shallow setting and the deep one, however lithological differences exist. The shallowest studied core, located at a water depth less than 200 m, frequently contain sandy depositional intervals and coquina layers made by fresh- to brackish-water mollusks. The above-mentioned lithology is probably linked to the Late Pleistocene-Early Holocene glacial and meltwater sediments, mirrored in a higher frequency of sandy intercalations and shell detritus, possibly reflecting a littoral and/or partly emerged area.

The red-brownish depositional intervals of Unit 3, covering the upper part of Heinrich Stadial 1 and the lower part of the warmer Bølling–Allerød interval (Briceag *et al.*, 2019; Nagavciuc *et al.*, 2021; Ion *et al.*, 2022), are not encountered in the shallow setting of Core 11_GC_1 (160.9 m bsf), being present in the other three investigated cores, i.e., 13_GC_1 at 171.4 m bsf, 6_GC_1 at 648.5 m, and 4_GC_4 at 1.031 m bsf. Previous studies (Ion *et al.*, 2022) reported the presence, in some deep setting cores of NW Black Sea, i.e., below 600 m bsf, of two distinct red-brownish layers, separated by the grey-greenish clays and muds of Unit 3.

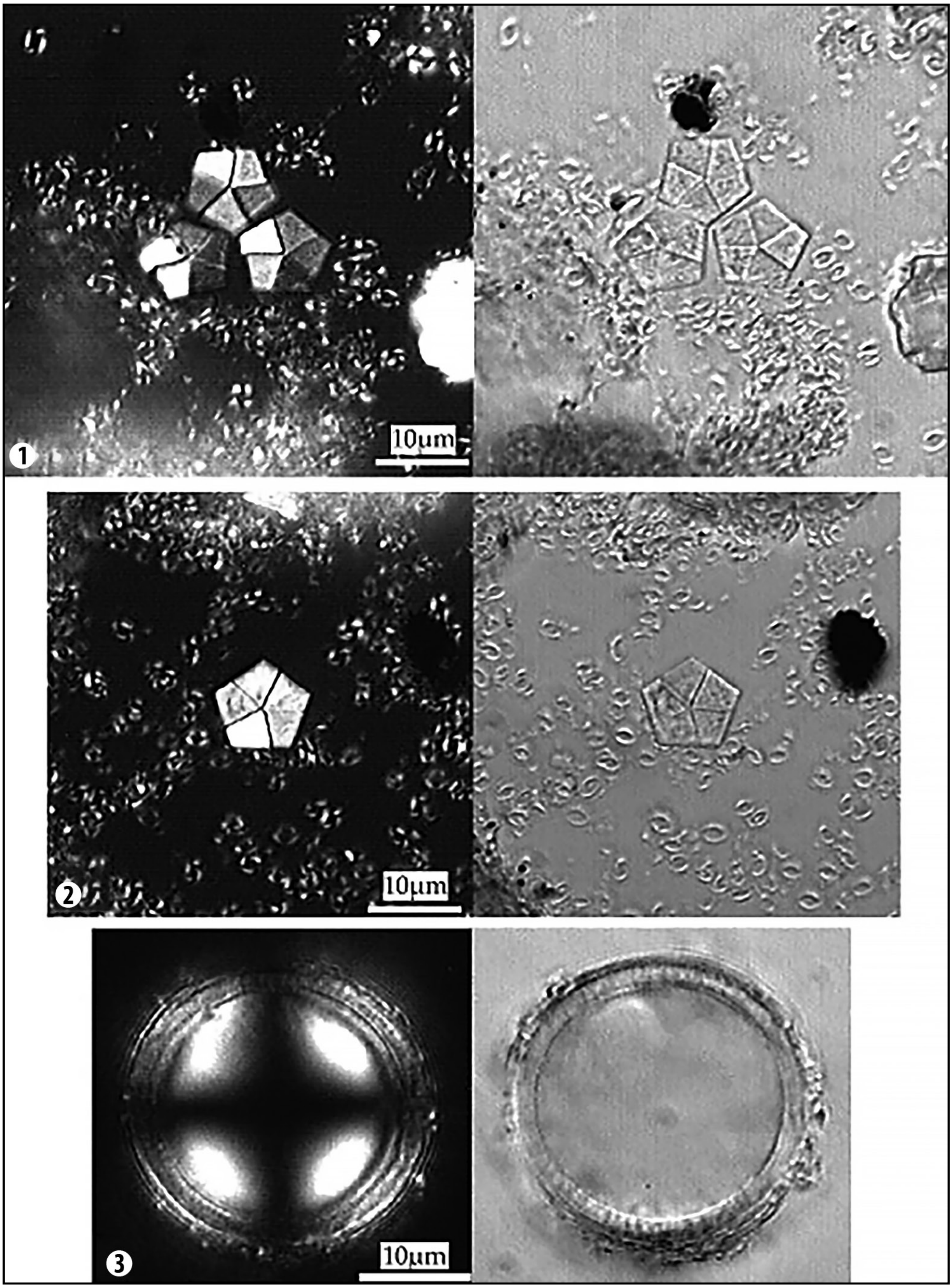

Fig. 5. Microphotographs of calcareous nannoplankton and diatoms taken at LM (light microscope); 1, 2, 3 left in crossed nicols; 1, 2, 3 right – transmitted light; **1, 2** – *Braarudosphaera bigelowii* (Gran and Braarud, 1935) Deflandre, 1947 surrounded by specimens of *Emiliania huxleyi* (Lohmann 1902) Hay and Mohler, in Hay *et al.*, 1967 (core 4_GC_4, sample 23-26 cm bsf); **3** – centric diatoms (core 4_GC_4, sample 17-20 cm bsf).

The authors hypothesized that the occurrence of repetitive red-brownish successions could be linked to the paleotopography, such as the location on the sites of NW Black Sea canyon, allowing a facies recurrence. In the cores we studied, only one consistent red-brownish level was encountered, thicker, i.e., over 1.2 m, in the deep paleosetting, and thinner, up 0.8 m, in the shallow core 13_GC_1 at 171.4 m bsf.

Concerning the presence of the Sapropel Mud (Unit 2), this was encountered only in the deep paleosetting, as remarked by many authors (Ryan *et al.*, 1997; Arthur and Dean, 1998; Hiscott and Aksu, 2002; Bahr *et al.*, 2005; Briceag and Ion, 2014; Goldberg *et al.*, 2016; Yanchilina *et al.*, 2017; Ion *et al.*, 2022, among many others). The presence of *E. huxleyi*, showing a sudden bloom at the base of Unit 2, is most probably indicative for a very rapid event linked to the increase salinity in the Black Sea basin, once it was reconnected with the Mediterranean Sea. To note that *B. bigelowii* is absent at the base of Unit 2, showing that the salinity was no more than 17‰. Presently, *E. huxleyi* was found in the surface waters at salinity of 8-9‰, in front of the Danube Delta (Melinte-Dobrinescu and Ion, 2013). The co-occurrence of *E. huxleyi* and *B. bigelowii* in the upper part of Unit 2 indicates that the salinity was already >17‰ shortly after the reconnection between the Black Sea and the Mediterranean. Full marine environmental conditions have settled in Unit 1 (Coccolith Mud), when both the two calcareous nannoplankton species *E. huxleyi* and *B. bigelowii* are blooming.

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