

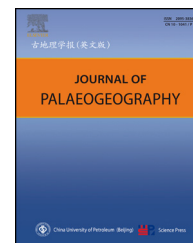
HOSTED BY



ELSEVIER

Available online at www.sciencedirect.com

ScienceDirect

journal homepage: <http://www.journals.elsevier.com/journal-of-palaeogeography/>

Calcareous nannoplankton dating of the Late Quaternary deposits in Greece and the eastern Mediterranean: Case studies from terrestrial and marine sites

Maria V. Triantaphyllou

Faculty of Geology and Geoenvironment, University of Athens, Panepistimioupolis Zografou, 157-84 Athens, Greece

ARTICLE INFO

Article history:

Received 17 December 2014

Accepted 20 January 2015

Available online 21 September 2015

Keywords:

Emiliania huxleyi

Biostratigraphy

Palaeoclimatic conditions

Greece

Eastern Mediterranean

ABSTRACT

The distribution and abundance of *Emiliania huxleyi* (*E. huxleyi*) assemblages in the marine sediments of the Aravonitsa Plateau, Greece, and from the eastern Mediterranean are used (1) to evaluate the calcareous nannoplankton NN21a and NN21b biozones and the NN21a/NN21b boundary, and (2) to analyze the palaeoenvironmental and palaeoclimatic conditions prevailing in this interval. The sediment succession displays varied *E. huxleyi* assemblages and these are interpreted as reflecting climatic variability during marine isotope stages MIS 1–8.

© 2015 The Author. Production and hosting by Elsevier B.V. on behalf of China University of Petroleum (Beijing). This is an open access article under the CC BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/4.0/>).

1. Introduction

Emiliania huxleyi (*E. huxleyi*) is by far the most abundant and widespread coccolithophore in the world's oceans (Winter et al., 1994; Young, 1994). It was first identified using light microscopy (Lohmann, 1902) whereas the complicated structure of the coccolith was initially described by Black and Barnes (1961), Braarud et al. (1952), and Deflandre and Fert (1954), using Electron Microscopy. Three types (A, B and C) of *E. huxleyi* are distinguished (Young and Westbroek, 1991), based on heterococcolith morphology, and it was demonstrated that the size of the different morphotypes is influenced by ecophenotypic and genotypic factors. The phylogenetic origins of *E. huxleyi* are documented in the fossil

record by Gallagher (1989), Perch-Nielsen (1985), Romein (1979) and Young et al. (1992). The monospecific genus *Emiliania* is considered to have evolved from the genus *Prinsius* through *Toweius*, *Reticulofenestra* and *Gephyrocapsa* (Perch-Nielsen, 1985; Samtleben, 1980; Young et al., 1992).

Amongst the extant coccolithophores, *E. huxleyi* has the widest distribution, dominating the living assemblages. It occasionally forms massive blooms, when water conditions are favorable, e.g. high light, limited silicate and high carbonate saturation (Tyrrell and Merico, 2004). Under certain environmental conditions it sheds coccoliths (Paasche, 2001). Variation in the coccolith size and morphology of *E. huxleyi* is frequent (Young and Westbroek, 1991), being usually associated with temperature, salinity and available nutrients (e.g., Bollmann and Herrle, 2007; Paasche, 1998, 2001; Watabe and

E-mail address: mtriant@geol.uoa.gr.

Peer review under responsibility of China University of Petroleum (Beijing).

<http://dx.doi.org/10.1016/j.jop.2015.01.001>

2095-3836/© 2015 The Author. Production and hosting by Elsevier B.V. on behalf of China University of Petroleum (Beijing). This is an open access article under the CC BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/4.0/>).

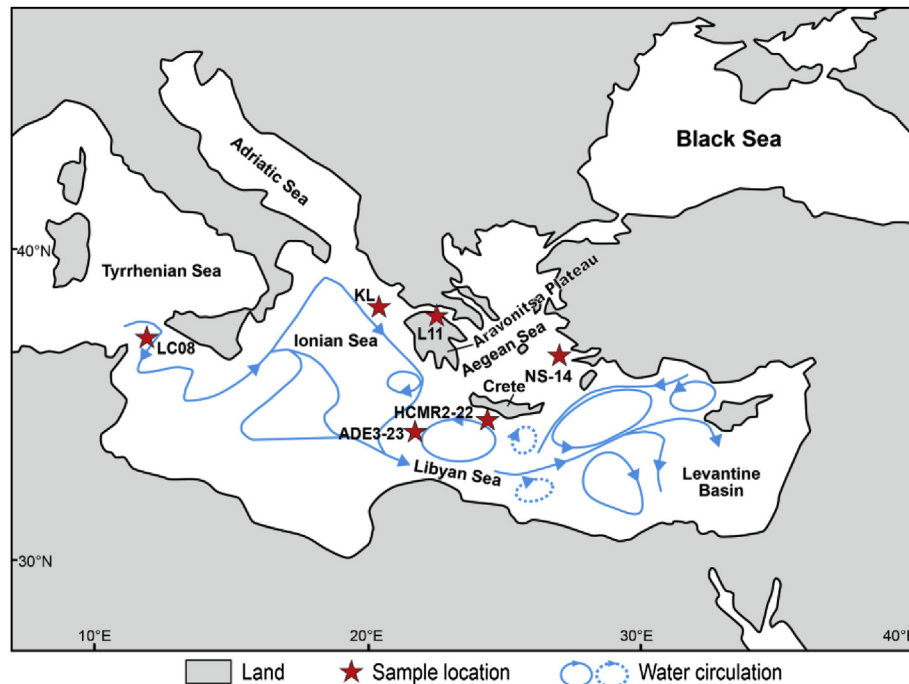


Fig. 1 – Location of the reviewed on-land and marine records in the eastern Mediterranean. The general circulation pattern is modified from [Malanotte-Rizzoli et al. \(1997\)](#).

[Wilbur, 1966](#)). The increase in atmospheric CO₂ partial pressure and the consequent changes in the seawater carbonate chemistry can cause a decrease in its cellular particulate inorganic carbon (PIC)/particulate organic carbon (POC) ratio as well as malformations of the coccoliths ([Riebesell et al., 2000](#)) – these might have opposing effects on the marine carbon cycle ([Rost and Riebesell, 2004](#)). Recently, the morphological variability of *E. huxleyi* var. *huxleyi* (= *E. huxleyi* type A) has been demonstrated in the modern Aegean Sea, in respect to the environmental parameters of the water column, providing strong evidence for seasonal variation in *E. huxleyi* coccoliths ([Triantaphyllou et al., 2010b](#)). A consistent pattern of increase in the size and calcification of coccoliths and coccospheres has been observed, including the thickness of the inner tube elements in the winter and spring and low sea-surface temperature and moderate productivity when compared with summer time, high temperature and low productivity ([Triantaphyllou et al., 2010b](#)).

The first appearance datum (FAD) of *E. huxleyi* in the geological records is used as a biostratigraphic marker and marks the base of the NN21 calcareous nannofossil biozone (NN21a; [Martini, 1971](#)). It has been dated at ~270 ka using correlation with planktonic foraminiferal $\delta^{18}\text{O}$ records ([Gartner and Emiliani, 1976](#)), at ~268 ka, late in the cold marine isotopic stage 8 (MIS 8; [Thierstein et al., 1977](#)), at ~285 ka (Pacific ocean; [Ahagon et al., 1993](#)), and at ~230 ka ([Hills and Thierstein, 1989](#)). According to [Kroon et al. \(1998\)](#), this event is placed at 260 ka in the eastern Mediterranean, whereas the astronomically tuned biozone timescale of [Lourens et al. \(2005\)](#) dates the lowest occurrence of *E. huxleyi* and subsequently the base of the calcareous nannofossil biozone MNN21a ([Raffi, 2002; Rio et al., 1990](#)), (= NN21a; [Martini, 1971](#)) at 270 ka (265 ka according to [Raffi et al., 2006](#)).

The blooming life-style of *E. huxleyi* started in warm time-spans between ~80 ka at the end of MIS 5 and 50 ka (MIS 3) ([Kroon et al., 1998](#)), and is associated with the *E. huxleyi* Acme Zone (NN21b; [Martini, 1971](#)) in the fossil record. In shallow marginal and inland seas the *E. huxleyi* Acme Zone began later; in these areas *Gephyrocapsa* spp. are generally more dominant (e.g., [Okada and Honjo, 1975](#)). The base of NN21b is followed by the top of the *Gephyrocapsa muelleriae* Acme Zone at 45.7 ka ([Flores et al., 1997; Incarbona et al., 2009](#)), characterized by a dramatic and continuous reduction in *G. muelleriae*, which suggests that *E. huxleyi* may have taken over an ecological niche formerly dominated by *Gephyrocapsa* spp.

At the present day *E. huxleyi* type A, characterized by moderately elevated distal shield, robust distal shield elements and a central area covered by curved rod-like elements ([Young et al., 2003](#)), is abundant in the Mediterranean Sea. It dominates particularly the winter coccolithophore assemblages of the Aegean Sea. Overall, high cell densities are

Table 1 – Aravonitsa samples: Quantitative SEM analysis of 300 coccoliths.

Species %	Samples	
	W146A	W146B
<i>Emiliana huxleyi</i>	1	1
Small <i>Reticulofenestra</i> spp.	34	12
Small <i>Gephyrocapsa</i> spp.	60	80
<i>Syracosphaera pulchra</i>	1	1
<i>Gephyrocapsa oceanica</i>	3	2
<i>G. protohuxleyi</i>		3
<i>Calcidicus leptoporus</i>	0.7	0.6
<i>Umbilicosphaera sibogae</i>	0.3	0.4

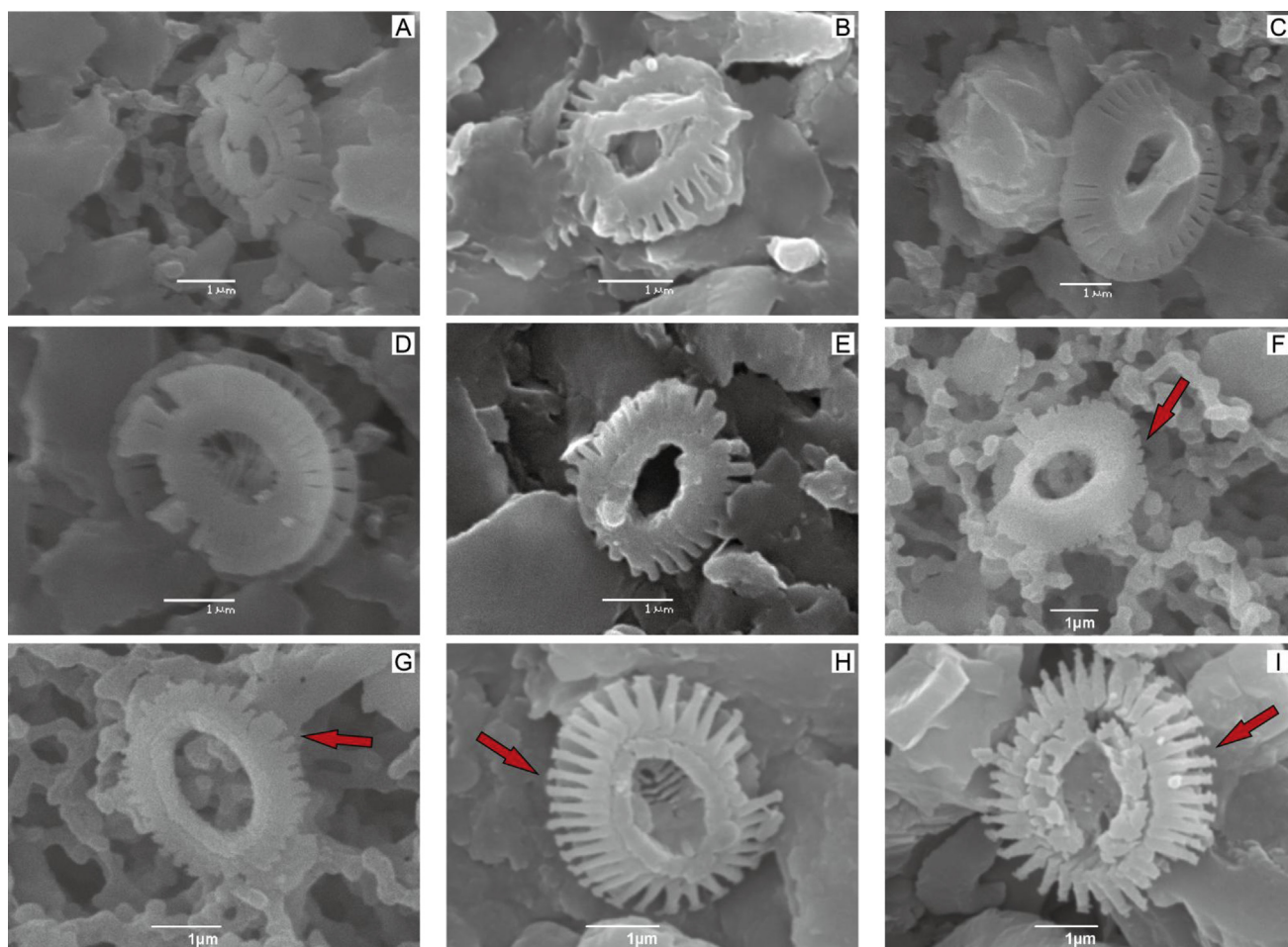


Fig. 2 – A–E–*Gephyrocapsa protohuxleyi* specimens possessing a bridge or the remains of the bases of a bridge; F–G–Small *Reticulofenestra* specimens that have undergone etching resulting in separation of the ends of the elements (arrows); H–I–*Emiliana huxleyi* with etching and/or incomplete shield formation (arrows). All samples from the on-land record of Aravonitsa Plateau, location L11.

observed in winter and early spring during phases of higher-nutrient, well-mixed waters (Jan.: 34×10^3 cells/dm³, March: 23×10^3 cells/dm³), whereas densities are lower in the summer–early autumn oligotrophic and highly stratified water column (Aug.–Sept.: 2×10^3 cells/dm³; Dimiza et al., 2008; Triantaphyllou et al., 2010a). The analysis of sediment trap samples has shown that *E. huxleyi* largely dominates the total coccolith flux in the modern Aegean Sea and the eastern

Mediterranean (Malinverno et al., 2009, 2014; Triantaphyllou et al., 2004; Ziveri et al., 2000).

This study is based on the analysis of the coccolithophore assemblages occurring in marine sediments belonging to the NN21a and NN21b biozones that have been recovered from the eastern Mediterranean and from mainland Greece. Particular attention has been given to the variations in the pattern of *E. huxleyi* assemblages and their use both as a

Table 2 – Piston core LC08, sample LC08-3 (40–100 cm): Quantitative SEM analysis of 300 coccoliths.

Species %	Samples						
	LC08-3 –40 cm	LC08-3 –50 cm	LC08-3 –60 cm	LC08-3 –70 cm	LC08-3 –80 cm	LC08-3 –95 cm	LC08-3 –100 cm
<i>E. huxleyi</i>	45	29.4	5.5	7.4	3.9	2.1	6.3
<i>Gephyrocapsa muelleriae</i>	31.1	48.2	47.9	47.6	57.1	86.1	74.4
Small <i>Reticulofenestra</i> spp.	11.8	5.7	38.9	39.6	31.9	8.9	16.7
<i>Syracosphaera pulchra</i>	3.6	6.3	1.4	2.9	2.8	2.1	0.4
<i>Helicosphaera carteri</i>	3.2	3.3	1.9	0.3	1.7	0.6	1.6
<i>Calcidicus leptoporus</i>	3.2	2.7	3.9	1.2	1.8	0.3	0.4
Biozone	NN21b		NN21a				

biostratigraphic tool and as a means to evaluate the palaeoenvironmental and palaeoclimatic conditions prevailing in these biozones.

2. Samples and methods

The locations of the sample sites are shown in Fig. 1. The single mainland site is on the Aravonitsa Plateau, northern Peloponnese (location L11, Palyvos et al., 2010). There are deep sea gravity cores from the Libyan Sea (ADE3-23: Triantaphyllou et al., 2010a), the southeastern Aegean Sea (NS-14: Triantaphyllou et al., 2009), and the southern Crete margin (HCMR2-22: Ioakim et al., 2009; Katsouras et al., 2010) as well as a long piston core from the Pantelleria Trough (LC08: Anastasakis and Pe-Piper, 2006).

Samples of fine-grained marine sediments were examined by scanning electron and light microscopy for their content of calcareous nannoplankton using standard methods with counts of 300 coccolith specimens (Negri and Giunta, 2001; Perch-Nielsen, 1985; Thierstein et al., 1977). The definition of the *E. huxleyi* NN21a biozone is based on the first appearance

of specimens of the species, that is the midpoint of the slope of the initial increase of the species in counts of 300 coccoliths (FAD of *E. huxleyi*; Rio et al., 1990; Thierstein et al., 1977), whereas the *E. huxleyi* Acme Zone (MNN21b) is defined as the interval where the frequency of *E. huxleyi* in the coccolith population exceeds 40% level (Castradori, 1993; Rio et al., 1990).

3. Results

3.1. Terrestrial records

The sedimentary successions of fine-grained shallow marine deposits on the Aravonitsa Plateau are remnants preserved on a flat depositional geomorphic surface now at 500–520 m above sea level. They were discovered during the investigation of the Pleistocene coastal uplift in the westernmost part of the Corinth Gulf (Palyvos et al., 2010). Two samples of these fine-grained terrigenous sediments (location L11, samples W146A, W146B; Palyvos et al., 2010) yielded sparse nannoplankton assemblages. These contained abundant small

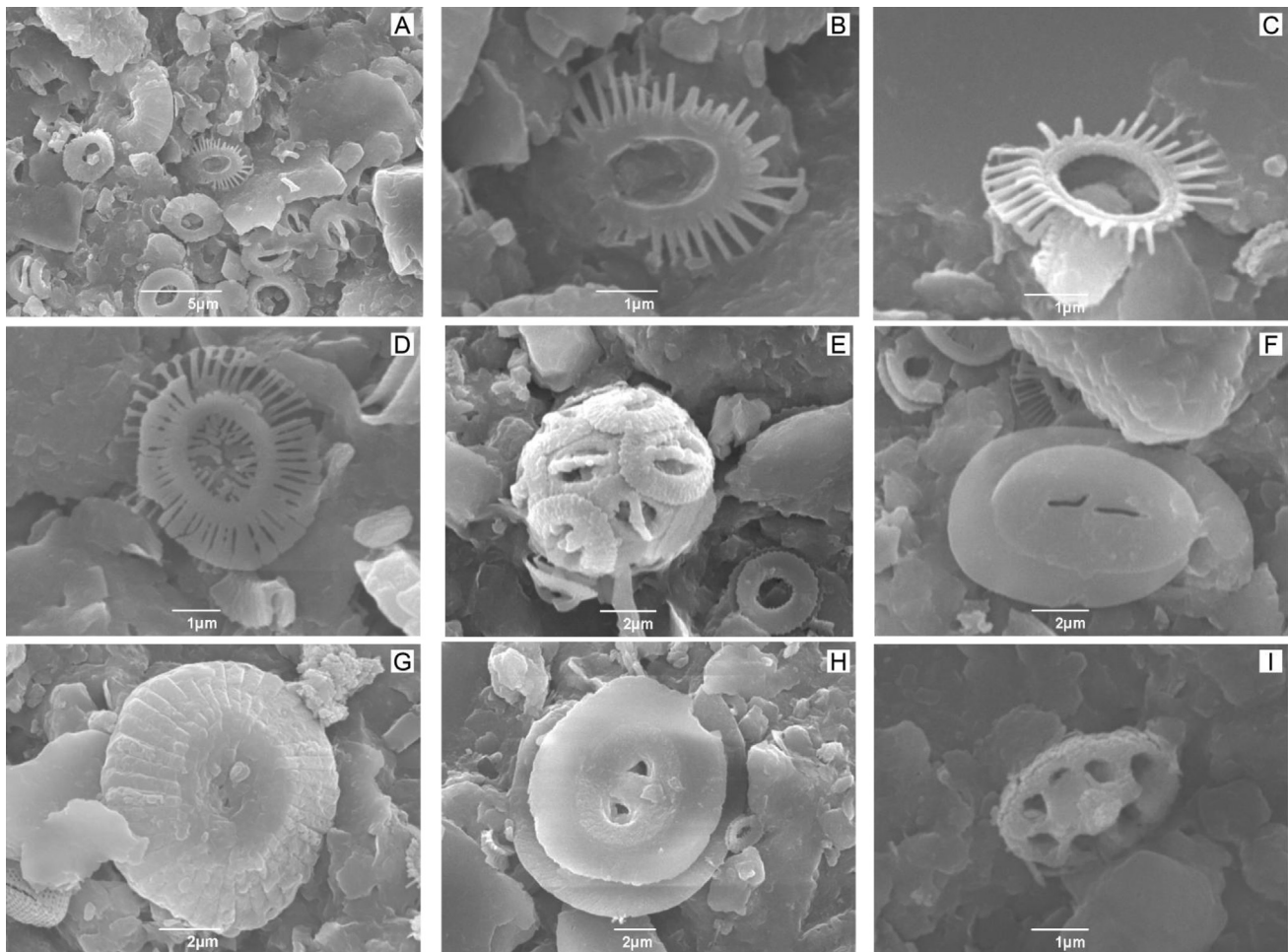


Fig. 3 – A–NN21a biozone assemblage, sample LC08-3–100 cm; B–*E. huxleyi* distal, sample LC08-3–100 cm; C–*E. huxleyi* distal, sample LC08-3–60 cm; D–*E. huxleyi* proximal, sample LC08-3–40 cm; E–*Gephyrocapsa muellerae* coccosphere, sample LC08-3–60 cm; F–*Helicosphaera carteri* proximal view, sample LC08-3–60 cm; G–H–*Coccolithus pelagicus* distal and proximal, sample LC08-3–60 cm; I–*Helicosphaera carteri* HOL (*Syracolithus confusus*), sample LC08-3–60 cm, from piston core LC08.

Gephyrocapsa spp. (Table 1) including *Gephyrocapsa protohuxleyi*. The *G. protohuxleyi* specimens possess a bridge or the remains of the bases of a bridge (Fig. 2A–E). It is also clear in each of these specimens that the distal shield elements are more or less tube-like with parallel sides, and there is some evidence in each instance that these had expanded ends (hammer heads) although most elements have lost at least part of their ends. In addition, small coccoliths resembling *E. huxleyi* occur very occasionally, and these bear platy distal shield elements in contact for much of their length and do not show any trace of hammer-heads. They have been identified as small specimens of *Reticulofenestra* spp. which have undergone etching resulting in separation of the ends of the elements (Fig. 2F–G). Exhaustive microscopic analysis revealed the presence of rare (approximately 1%) true representatives of *E. huxleyi* with etching and/or incomplete shield formation (Table 1, Fig. 2H–I).

The very low abundance of *E. huxleyi* in these samples could suggest correlation with the basal part of NN21a within the cold MIS 8 stage. Apparently, the lowest occurrence of *E. huxleyi* (at 270 ka) in the stratigraphic record of the eastern Mediterranean falls within the cold MIS 8, a phase of low sea levels based on sea-level curves (e.g., Shackleton and Pisias, 1985; Siddall et al., 2007). However, during this phase, the Corinth Gulf developed as a lake, isolated from the sea by a sill (e.g., Palyvos et al., 2010). Depending on the elevation of the sill at the time, the lowest occurrence of *E. huxleyi* in the Corinth Gulf is therefore expected to be more or less close to the MIS 7e highstand (i.e. a few ka before 240 ka), because only then sea

water had the chance to enter the gulf (Palyvos et al., 2010). Therefore these marine deposits from the Aravonitsa Plateau (location L11) most probably belong to the warm MIS 7e stage at approx. 240 ka, otherwise *E. huxleyi* would have been more abundant.

This is one of the very rare records of this marine biozone preserved in Greece. Another suggested terrestrial occurrence of this marine biozone has been described from a borehole drilled in the shallow valley of Livadi separating Kefallonia from its western peninsula, Paliki, during the search for Homer's Ithaca (Underhill, 2006, 2008). Very well preserved specimens of *E. huxleyi* have been recorded in the top 40 m of sediment of this borehole. It is suggested that these very young deposits may not represent *in situ* sedimentation, but can be considered as consistent with the impact of a catastrophic landslide on a marine channel. This would have ejected a large volume of water out of the channel and saturated the infill material. This interpretation has been favored, because it was thought that *E. huxleyi* could not have reached this location earlier than about 6000 years ago, when rising global sea levels penetrated the shallow gulf of Livadi for the first time (Underhill, 2008).

3.2. Marine cores

In the present study, a very clear transition between the NN21a and NN21b biozones is documented from the lower part of the long piston core LC08 in the Pantelleria Trough, Sicily Channel. This part of the core is dominated by the

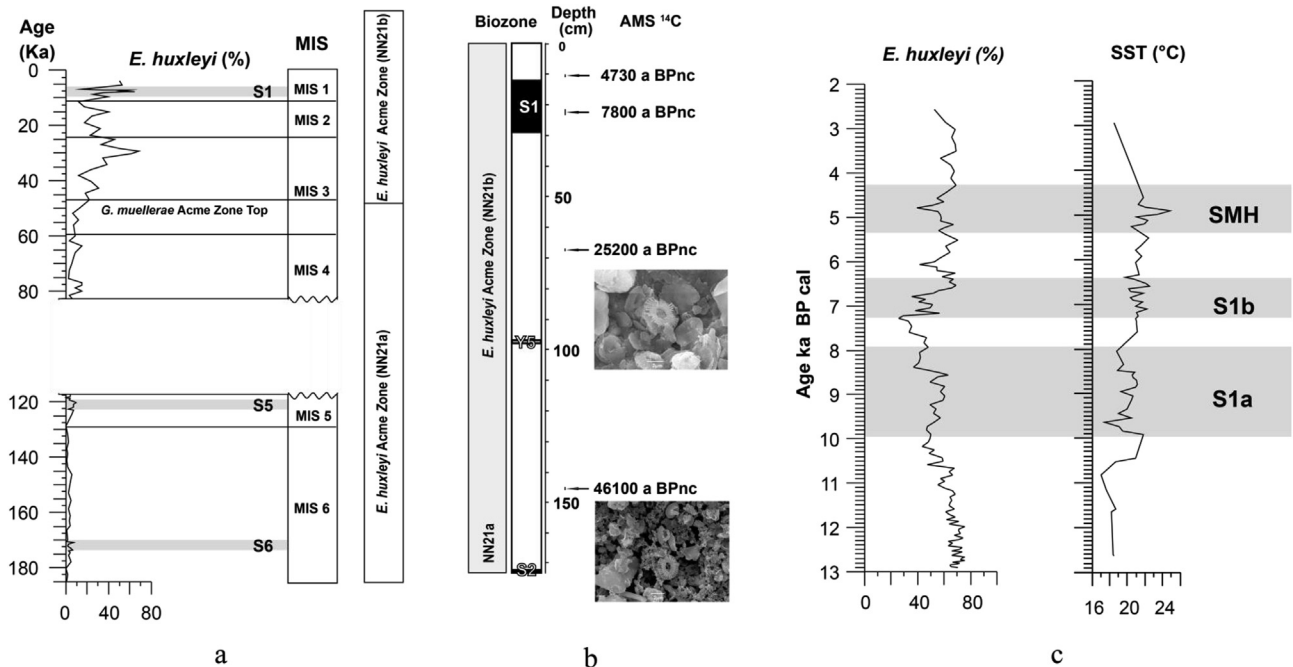


Fig. 4 – a–Stratigraphy, MIS stages and biozonation with core ADE3-23 from the Libyan Sea. The distribution of *E. huxleyi* and the top of *G. muelleriae* Acme Zone are shown (modified from Triantaphyllou et al., 2010a); b–Stratigraphy, AMS ages and biozonal assignment of core HCMR2-22 from the southern Crete margin; c–The distribution of *E. huxleyi* and sea surface temperature (SST) pattern within the MIS 1 stage core NS-14 from southeastern Aegean Sea (modified from Triantaphyllou et al., 2009). S1a = The lower part of sapropel S1 layer; S1b = The upper part of sapropel S1 layer; SMH = Sapropel Mid Holocene layer.

presence of a thick volcanoclastic interval deposited from a large gravitational flow during the Green Tuff eruption (Anastasakis and Pe-Piper, 2006). The lower hemipelagic marls, immediately below the base of the volcanoclastic interval, have been examined for their nannofossil content. *E. huxleyi* is present in amounts of below 10% in the lower parts of this interval, and this rapidly increases upwards to 40% and more (Table 2, Fig. 3). The presence of *G. muellerae* has been constantly recorded as more than 40%. A sample of marl from the hemipelagic interval yielded an accelerator mass spectrometry conventional radiocarbon age of 41190 ± 1090 a BP (Beta 198833) with a calibrated radiocarbon age of $43\text{--}47 \pm 2$ ka (Anastasakis and Pe-Piper, 2006). Although radiocarbon dates older than 40–45 ka are questionable, the calcareous nannofossil assemblages confirm the biostratigraphic correlation of this interval (sample LC08-3–40 cm) with biozone NN21b, providing a unique chance to calibrate the base of this zone in the Mediterranean with an AMS radiocarbon age.

A case study involving the definition of NN21a/NN21b boundary has been documented in the gravity core ADE3-23, located SW of Crete ($34^{\circ}45.000'$ N, $21^{\circ}52.800'$ E), at 2459 m water depth. The core recovered 3.49 m of gray hemipelagic mud and silty mud interlayered with three distinct dark gray

sapropelic layers, i.e., S6, S5 and S1, and a hiatus of approximately 35 ka between ~83 ka and ~118 ka (Triantaphyllou et al., 2010a). *E. huxleyi* displays values well below 20% (Fig. 4a) during the cold MIS 6 and MIS 4 stages, although during the latter, values are comparably higher. It just exceeds 10% during the warm MIS 5 (sapropel S5 depositional interval). Apparently the lower part of the core ADE3-23 corresponds to the NN21a biozone. The increase in abundance of *E. huxleyi*, although never reaching 20% as previously reported (e.g., Castradori, 1993; Corselli et al., 2002; Violanti et al., 1991), suggests higher fertility in the surface waters in the middle part of S5, corresponding to the timing of relaxation in the northward penetration of the African monsoon already recorded within S5 in the southeastern Mediterranean area (Rohling et al., 2002). The definition of the NN21a/NN21b boundary is marked by the increase of *E. huxleyi* within MIS 3 at 50 ka. This event is shortly followed in core ADE3-23 by the top of the *Gephyrocapsa muellerae* Acme Zone, characterized by a dramatic and continuous reduction in *G. muellerae*, which points to an age of 45.7 ka (Triantaphyllou et al., 2010a). A further increase of *E. huxleyi* is recorded within MIS 1 (Fig. 4a).

The top of the *G. muellerae* Acme Zone (45.7 ka BP) has also been recognized in the lower part of one additional sediment

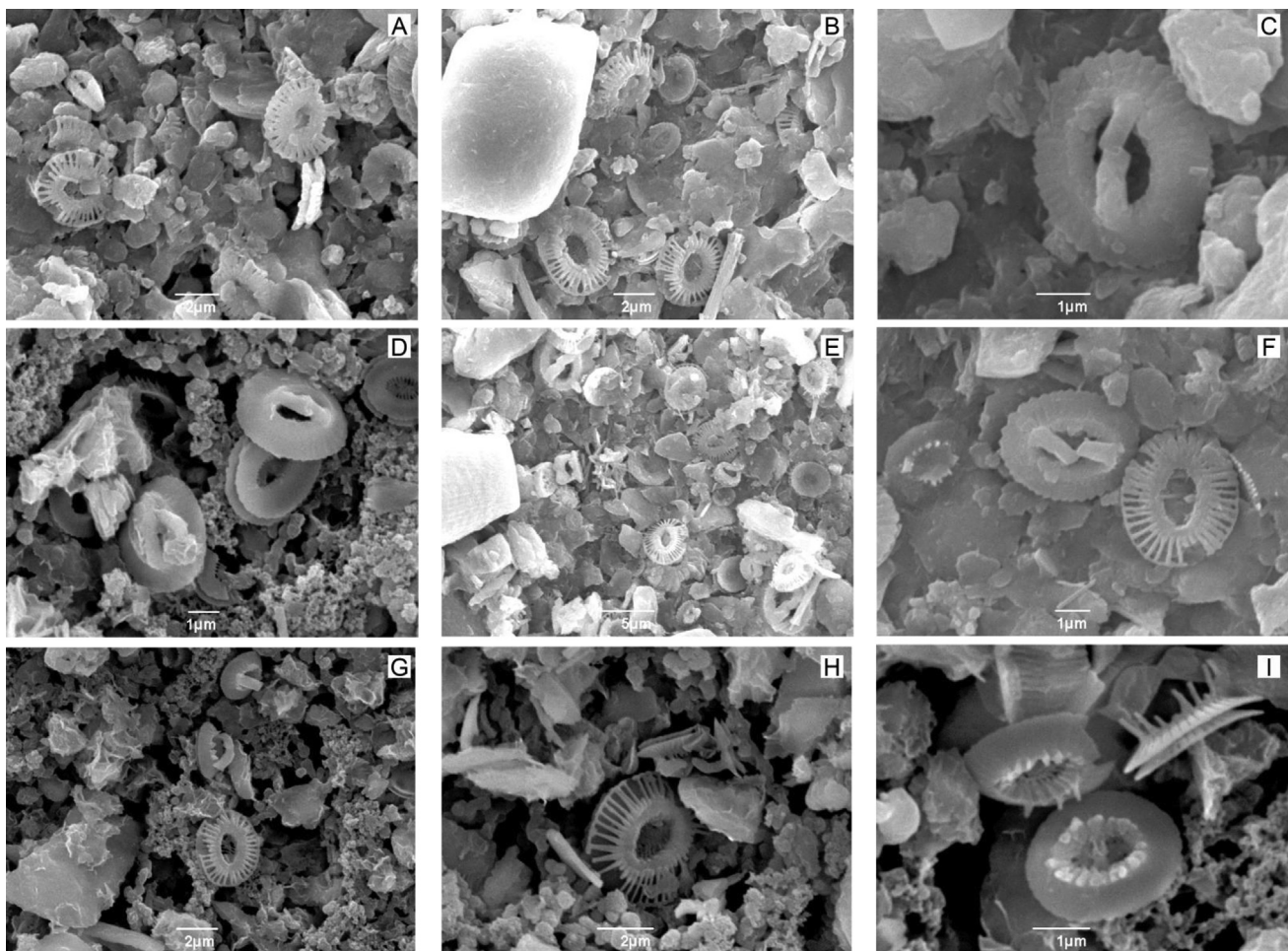


Fig. 5 – A–B–E. *huxleyi* Acme Zone assemblage, sample 67–68 cm; C–*Gephyrocapsa muellerae*, *G. muellerae* Acme Zone, samples 145–146 cm, and 173–174 cm; D–H–*G. muellerae* Acme Zone assemblage, samples 118–119 cm, 145–146 cm, and 173–174 cm; I–Small *Reticulofenestra* spp., sample 173–174 cm. Samples from gravity core HCMR2-22.

succession from gravity core HCMR2-22 (34°33.968' N, 24°53.770' E, water depth 2211 m, length 175 cm) from the southern Crete margin (Ioakim et al., 2009; Katsouras et al., 2010). Based on calcareous nannofossil biostratigraphy, most of this sedimentary succession has been proved to span the last approximately 50 ka and can be correlated with the *E. huxleyi* Acme Zone NN21b (Figs. 4b and 5).

Very detailed information for the distribution of *E. huxleyi* during the Late Glacial–Holocene interval in the warm MIS 1 is provided from a high-resolution record in the southeastern Aegean Sea (gravity core NS14; Triantaphyllou et al., 2009). The high surface nutrient indicator *E. huxleyi* (Young, 1994) is the most abundant placolith within the coccolithophore assemblages from ~13 to 10.6 ka BP (Fig. 4c; Triantaphyllou et al., 2009). This points to cool surface-water conditions, as *E. huxleyi* is a species that prevails in the Aegean surface waters mainly in winter (Dimiza et al., 2008) and displays more heavily calcified *E. huxleyi* morphotypes (Triantaphyllou et al., 2010b). Following this interval, *E. huxleyi* decreases during the warm and wet phase during the deposition of sapropel S1. There is a prominent reduction starting at 8.5 ka BP with minimum values of 25% at the base of the upper part of sapropel S1 (S1b), implying low surface productivity and strong stratification of the water column (Triantaphyllou et al., 2009). *E. huxleyi* increases again from 7.3 ka BP presenting three main negative shifts at ~6.8, 6.0 and 4.8 ka BP within the Sapropel Mid Holocene layer (SMH; Triantaphyllou et al., 2009, 2014) associated with fluctuating sea-surface temperatures. (Fig. 4c; Triantaphyllou et al., 2009).

4. Conclusions

The sediment records reveal variations in the *E. huxleyi* assemblages during marine isotope stages MIS 1–8. These appear to be linked with climatic variability.

In particular, based on *E. huxleyi* assemblages:

- 1) The *E. huxleyi* assemblage from the lowermost part of biozone NN21a is described from the Aravonitsa Plateau in the northern Peloponnese and most probably represents the warm phase MIS 7e at approx. 240 ka. This is the first marine representative of this biozone onshore. The *E. huxleyi* coccoliths in the Kefallonia deposits are considered to be redeposited material.
- 2) The lower part of the long piston core LC08 from the Pantelleria Trough, Sicily Channel, displays the transition from biozone NN21a to NN21b. A radiocarbon (AMS) age of 41190 ± 1090 a BP from this core provides a temporal calibration for the basal part of biozone NN21b in the eastern Mediterranean.
- 3) *E. huxleyi* displays values well below 20% of the total nannofossil assemblage during the cold stages MIS 6 and MIS 4 in the marine core ADE3-23 from the Libyan Sea, although during the latter stage, values are comparably higher. They exceed slightly 10% during the middle part of sapropel S5, within the warm MIS 5.
- 4) The biozone NN21a/NN21b boundary is marked by an abrupt increase of *E. huxleyi* within the relatively warm stage MIS 3 at 50 ka. Overlying this boundary in core ADE3-23 from the eastern Mediterranean is the top of the *Gephyrocapsa muelleriae* Acme Zone at 45.7 ka; this has also been recognized in the lower part of the succession in core HCMR2-22 from the southern Crete margin.
- 5) A further increase and considerable fluctuations in *E. huxleyi* are recognized within warm stage MIS 1 in the core NS-14 from the southeastern Aegean Sea. This is thought to reflect continuous climate variability during this stage in the Late Glacial–Holocene.

Acknowledgements

G. Anastasakis is kindly thanked for providing the study material of piston core LC08. The manuscript benefited by the criticism of Christopher Jeans and two anonymous reviewers.

REFERENCES

- Ahagon, N., Tanaka, Y., Ujiie, H., 1993. *Florisphaera profunda*, a possible nannoplankton indicator of Late Quaternary changes in sea-water turbidity at the northwestern margin of the Pacific. *Mar. Micropaleontol.* 22 (3), 255–273.
- Anastasakis, G., Pe-Piper, G., 2006. An 18 m thick volcanoclastic interval in Pantelleria Trough, Sicily Channel, deposited from a large gravitative flow during the Green Tuff eruption. *Mar. Geol.* 231 (1–4), 201–219.
- Black, M., Barnes, B., 1961. Coccoliths and discoasters from the floor of the South Atlantic Ocean. *J. R. Microsc. Soc.* 80 (2), 137–147.
- Bollmann, J., Herrle, J.O., 2007. Morphological variation of *Emiliania huxleyi* and sea surface salinity. *Earth Planet. Sci. Lett.* 255 (3–4), 273–288.
- Braarud, T., Gaarder, K.R., Markali, J., Nordli, E., 1952. Coccolithophorids studied in the electron microscope. Observations on *Coccolithus huxleyi* and *Syracosphaera carterae*. *Nytt Magasin Botanikk* 1, 129–134.
- Castradori, D., 1993. Calcareous nannofossil biostratigraphy and biochronology in eastern Mediterranean deep-sea cores. *Riv. Ital. Paleontol. Stratigr.* 99 (1), 107–126.
- Corseili, C., Principato, M.S., Maffioli, P., Crudeli, D., 2002. Changes in planktonic assemblages during sapropel S5 deposition: evidence from Urania Basin area, eastern Mediterranean. *Paleoceanography* 17 (3), 1–30.
- Deflandre, G., Fert, C., 1954. Observations sur les coccolithophoridés actuels et fossiles en microscopie ordinaire et électronique. *Ann. Paléontologie* 40, 115–176 (in French).
- Dimiza, M.D., Triantaphyllou, M.V., Dermitzakis, M.D., 2008. Seasonality and ecology of living coccolithophores in eastern Mediterranean coastal environment (Andros Island, Middle Aegean Sea). *Micropaleontology* 54 (2), 159–175.
- Flores, J.A., Sierro, F.J., Francés, G., Vázquez, A., Zamarréno, I., 1997. The last 100,000 years in the western Mediterranean: sea surface water and frontal dynamics as revealed by coccolithophores. *Mar. Micropaleontol.* 29 (3–4), 351–366.
- Gallagher, L., 1989. *Reticulofenestra*: a critical review of taxonomy, structure and evolution. In: Crux, J.A., van Heck, S.E. (Eds.), *Nannofossils and Their Applications*. Ellis Horwood Ltd., Chichester, pp. 41–75.

- Gartner, S., Emiliani, C., 1976. Nannofossil biostratigraphy and climatic stages of Pleistocene Brunhes Epoch. *AAPG Bull.* 60 (9), 1562–1564.
- Hills, S.J., Thierstein, H.R., 1989. Plio-Pleistocene calcareous plankton biochronology. *Mar. Micropaleontol.* 14 (1–3), 67–96.
- Incarbona, A., Di Stefano, E., Bonomo, S., 2009. Calcareous nannofossil biostratigraphy of the central Mediterranean Basin during the last 430 000 years. *Stratigraphy* 6, 33–44.
- Ioakim, C., Triantaphyllou, M., Tsaila-Monopolis, S., Geraga, M., Dimiza, M., Lykousis, V., 2009. New micropalaeontological records of eastern Mediterranean marine sequences recovered offshore of Crete, during HERMES cruise and their palaeoclimatic-palaeoceanographic significance. *Acta Nat. "L'Ateneo parmense"* 45, 152.
- Katsouras, G., Gogou, A., Bouloubassi, I., Emeis, K.C., Triantaphyllou, M., Roussakis, G., Lykousis, V., 2010. Organic carbon distribution and isotopic composition in three records from the eastern Mediterranean Sea during the Holocene. *Org. Geochem.* 41 (9), 935–939.
- Kroon, D., Alexander, I., Little, M., Lourens, L.J., Matthewson, A., Robertson, A.H.F., Sakamoto, T., 1998. Oxygen isotope and sapropel stratigraphy in the eastern Mediterranean during the last 3.2 million years. *Proceedings of the Ocean Drilling Program. Sci. Results* 160, 181–189 (Chapter 14).
- Lohmann, H., 1902. Die Coccolithophoridae: eine Monographie der Coccolithen bildenden Flagellaten, zugleich ein Beitrag zur Kenntnis des Mittelmeerauftriebs. *Arch. für Protistenkd.* 1, 89–165 (in German).
- Lourens, L., Hilgen, F., Shackleton, N.J., Laskar, J., Wilson, D., 2005. The Neogene Period. In: Gradstein, F.M., Ogg, J.G., Smith, A.G. (Eds.), *A Geologic Time Scale 2004*. Cambridge University Press, Cambridge, pp. 409–440.
- Malanotte-Rizzoli, P., Manca, B.B., D'Alcalà, M.R., Theocharis, A., Bergamasco, A., Bregant, D., Budillon, G., Civitarese, G., Georgopoulos, D., Michelato, A., Sansone, E., Scarazzato, P., Souvermezoglou, E., 1997. A synthesis of the Ionian Sea hydrography, circulation and water mass pathways during POEM-Phase I. *Prog. Oceanogr.* 39 (3), 153–204.
- Malinverno, E., Triantaphyllou, M.V., Stavrakakis, S., Ziveri, P., Lykousis, V., 2009. Seasonal and spatial variability of coccolithophore export production at the south-western margin of Crete (eastern Mediterranean). *Mar. Micropaleontol.* 71 (3), 131–147.
- Malinverno, E., Maffioli, P., Corselli, C., De Lange, G.J., 2014. Present-day fluxes of coccolithophores and diatoms in the pelagic Ionian Sea. *J. Mar. Syst.* 132, 13–27.
- Martini, E., 1971. Standard Tertiary and Quaternary calcareous nannoplankton zonation. In: Farinacci, A. (Ed.), *Proceedings of the Second Planktonic Conference*. Technoscienza, Roma, pp. 739–785.
- Negri, A., Giunta, S., 2001. Calcareous nannofossil paleoecology in the sapropel S1 of the eastern Ionian Sea: Paleoceanographic implications. *Palaeoecology, Palaoclimatology. Palaeoecology* 169 (1–2), 101–112.
- Okada, H., Honjo, S., 1975. Distribution of coccolithophores in marginal seas along the western Pacific Ocean and in the Red Sea. *Mar. Biol.* 31 (3), 271–285.
- Paasche, E., 1998. Roles of nitrogen and phosphorus in coccolith formation in *Emiliania huxleyi* (Prymnesiophyceae). *Eur. J. Phycol.* 33 (1), 33–42.
- Paasche, E., 2001. A review of the coccolithophorid *Emiliania huxleyi* (Prymnesiophyceae), with particular reference to growth, coccolith formation, and calcification-photosynthesis interactions. *Phycologia* 40 (6), 503–529.
- Palyvos, N., Mancini, M., Sorel, D., Lemeille, F., Pantosti, D., Julia, R., Triantaphyllou, M., De Martini, P.M., 2010. Geomorphological, stratigraphic and geochronological evidence of fast Pleistocene coastal uplift in the westernmost part of the Corinth Gulf Rift (Greece). *Geol. J.* 45 (1), 78–104.
- Perch-Nielsen, K., 1985. Cenozoic calcareous nannofossils. In: Bolli, H.M., Saunders, J.B., Perch-Nielsen, K. (Eds.), *Plankton Stratigraphy*. Cambridge University Press, Cambridge, pp. 427–554.
- Raffi, I., 2002. Revision of the Early–Middle Pleistocene calcareous nannofossil biochronology (1.75–0.85 Ma). *Mar. Micropaleontol.* 45 (1), 25–55.
- Raffi, I., Backman, J., Fornaciari, E., Pälke, H., Rio, D., Lourens, L., Hilgen, F., 2006. A review of calcareous nannofossil astrobiochronology encompassing the past 25 million years. *Quat. Sci. Rev.* 25 (23), 3113–3137.
- Riebesell, U., Zondervan, I., Rost, B., Tortell, P.D., Zeebe, R.E., Morel, F.M., 2000. Reduced calcification of marine plankton in response to increased atmospheric CO₂. *Nature* 407 (6802), 364–367.
- Rio, D., Raffi, I., Villa, G., 1990. Pliocene–Pleistocene calcareous nannofossil distribution patterns in the western Mediterranean. *Proceedings of the Ocean Drilling Program. Sci. Results* 107, 513–533.
- Rohling, E.J., Cane, T.R., Cooke, S., Sprovieri, M., Bouloubassi, I., Emeis, K.C., Schiebel, R., Kroon, D., Jorissen, F.J., Lorre, A., Kemp, A.E.S., 2002. African monsoon variability during the previous interglacial maximum. *Earth Planet. Sci. Lett.* 202 (1), 61–75.
- Romein, A.J.T., 1979. Lineages in Early Paleogene calcareous nannoplankton. *Utrecht Micropaleontol. Bull.* 22, 1–231.
- Rost, B., Riebesell, U., 2004. Coccolithophores and the biological pump: Responses to environmental changes. In: Thierstein, H.R., Young, J.R. (Eds.), *Coccolithophores: from Molecular Processes to Global Impact*. Springer, Berlin, pp. 99–125.
- Samtleben, C., 1980. Die Evolution der Coccolithophoriden-Gattung *Gephyrocapsa* nach Befunden im Atlantik. *Paläontologische Z.* 54 (1–2), 91–127 (in German).
- Shackleton, N.J., Pisias, N.G., 1985. Atmospheric carbon dioxide, orbital forcing, and climate. In: Sundquist, E.T., Broecker, W.S. (Eds.), *The Carbon Cycle and Atmospheric CO₂: Natural Variations Archean to Present*, American Geophysical Union Geophysical Monograph Series, vol. 32, pp. 303–317.
- Siddall, M., Chappell, J., Potter, E.K., 2007. Eustatic sea level during past interglacials. In: Sirocko, F., Claussen, M., Sanchez-Goni, M.F., Litt, T. (Eds.), *The Climate of Past Interglacials, Developments in Quaternary Sciences*, vol. 7, pp. 75–92.
- Thierstein, H.R., Geitzenauer, K.R., Molino, B., Shackleton, N.J., 1977. Global synchronicity of Late Quaternary coccolith datum levels validation by oxygen isotopes. *Geology* 5 (7), 400–404.
- Triantaphyllou, M.V., Ziveri, P., Tselepidis, A., 2004. Coccolithophore export production and response to seasonal surface water variability in the oligotrophic Cretan Sea (NE Mediterranean). *Micropaleontology* 50 (1), 127–144.
- Triantaphyllou, M.V., Ziveri, P., Gogou, A., Marino, G., Lykousis, V., Bouloubassi, I., Emeis, K.C., Kouli, K., Dimiza, M., Rosell-Melé, A., Papanikolaou, M., Katsouras, G., Nunez, N., 2009. Late Glacial–Holocene climate variability at the south-eastern margin of the Aegean Sea. *Mar. Geol.* 266 (1–4), 182–197.
- Triantaphyllou, M.V., Antonarakou, A., Dimiza, M., Anagnostou, C., 2010a. Calcareous nannofossil and planktonic foraminiferal distributional patterns during deposition of sapropels S6, S5 and S1 in the Libyan Sea (eastern Mediterranean). *Geo-Marine Lett.* 30 (1), 1–13.
- Triantaphyllou, M.V., Dimiza, M., Krasakopoulou, E., Malinverno, E., Lianou, V., Souvermezoglou, E., 2010b. Seasonal variation in *Emiliania huxleyi* coccolith morphology and calcification in the Aegean Sea (eastern Mediterranean). *Geobios* 43 (1), 99–110.

- Triantaphyllou, M.V., Gogou, A., Bouloubassi, I., Dimiza, M., Kouli, K., Rousakis, G., Kotthoff, U., Emeis, K.C., Papanikolaou, M., Athanasiou, M., 2014. Evidence for a warm and humid Mid-Holocene episode in the Aegean and northern Levantine Seas (Greece, NE Mediterranean). *Reg. Environ. Change* 14 (5), 1697–1712.
- Tyrrell, T., Merico, A., 2004. *Emiliana huxleyi*: bloom observations and the conditions that induce them. In: Thierstein, H.R., Young, J.R. (Eds.), *Coccolithophores: from Molecular Processes to Global Impact*. Springer, Berlin, pp. 75–97.
- Underhill, J.R., 2006. Quest for Ithaca. *Geoscientist* 16 (9), 4–29.
- Underhill, J.R., 2008. Testing classical enigmas. *Geoscientist* 18 (9), 20–27.
- Violanti, D., Grecchi, G., Castradori, D., 1991. Paleoenvironmental interpretation of Core BAN88-11GC (eastern Mediterranean, Pleistocene–Holocene) on the grounds of Foraminifera, Thecosomata and calcareous nannofossils. *Il Quat.* 4 (1a), 13–39.
- Watabe, N., Wilbur, K.M., 1966. Effects of temperature on growth, calcification, and coccolith form in *Coccolithus huxleyi* (Coccolithineae). *Limnol. Oceanogr.* 11 (4), 567–575.
- Winter, A., Jordan, R.W., Roth, P.H., 1994. Biogeography of living coccolithophores in ocean waters. In: Winter, A., Siesser, W.G. (Eds.), *Coccolithophores*. Cambridge University Press, Cambridge, pp. 161–177.
- Young, J.R., 1994. Functions of coccoliths. In: Winter, A., Siesser, W.G. (Eds.), *Coccolithophores*. Cambridge University Press, Cambridge, pp. 63–82.
- Young, J.R., Westbroek, P., 1991. Genotypic variation in the coccolithophorid species *Emiliana huxleyi*. *Mar. Micropaleontol.* 18 (1), 5–23.
- Young, J.R., Didymus, J.M., Brown, P.R., Prins, B., Mann, S., 1992. Crystal assembly and phylogenetic evolution in heterococcoliths. *Nature* 356 (6369), 516–518.
- Young, J.R., Geisen, M., Cros, L., Kleijne, A., Sprengel, C., Probert, I., Østergaard, J.B., 2003. A guide to extant calcareous nanoplankton taxonomy. *J. Nanoplankt. Res. (Special Issue 1)*, 1–125.
- Ziveri, P., Rutten, A., de Lange, G.J., Thomson, J., Corselli, C., 2000. Present-day coccolith fluxes recorded in central eastern Mediterranean sediment traps and surface sediments. *Palaeogeogr. Palaeoclimatol. Palaeoecol.* 158 (3–4), 175–195.