CALCAREOUS NANNOPLANKTON, A TOOL TO ASSIGN ENVIRONMENTAL CHANGES

Mihaela Carmen MELINTE

National Institute of Marine Geology and Geoecology (*GEOECOMAR*), 23-25 Dimitrie Onciul str., 024053 Bucharest, Romania
melinte@geoecomar.ro

Abstract. Main taxonomical and biostratigraphical features of the calcareous nannoplankton, algae widespread in all the marine environments are discussed. The biostratigraphy and the distribution of this group of organisms for the last 225 Ma are also presented. The calcareous nannoplankton, as most of the planktonic organisms, reflects with high fidelity environmental changes, such as fluctuations of light, salinity, temperature, sea-level changes, ocean productivity, nutrients and water pollution. The key role of the calcareous nannoplankton in reconstructing palaeoecological changes, in identifying global and regional environmental modifications and in advancing climatic predictions is argued.

Key words: calcareous nannoplankton, morphology, taxonomy, biostratigraphy, environmental fluctuations.

INTRODUCTION

The calcareous nannoplankton represents a major component of oceanic phytoplankton. The evolution pattern of this group of marine organisms and its present-day distribution all over the marine world are extremely useful in various research domains, as: marine biology, marine geology, biogeochemistry and palaeontology.
Since its discovery, in the middle of the XIXth Century, the calcareous nannoplankton proved important for paleontological studies (for testing the evolutionary hypothesis) and for biostratigraphical studies (for accurately dating sedimentary marine successions), being intensively used nowadays for palaeoecological and palaeogeographical reconstructions. As the calcareous nannoplankton represents a group of living organisms, one of the most diversified and widespread in the marine phytoplankton world, it is also used for marine biology and marine geology investigations, in marine environmental analysis and predictions, as well.
In order to debate the key role played by the calcareous nannoplankton in reconstructing palaeoecological changes, in identifying global and regional environmental modifications and in advancing climatic predictions, we need to answer two essential questions:

- What is the calcareous nannoplankton?
- Why use calcareous nannoplankton investigations for a better understanding of the marine environment?

TAXONOMY AND MORPHOLOGY

The calcareous nannoplankton includes calcite-secreting haptophyte algae. The living organisms belong to *coccolithophores*, which include all haptophyte algae possessing calcified scales (*coccoliths*) at some stage in their life. They are widespread today in all the marine environments on our planet. Of the approximately 300 haptophytes in modern oceans, about 200 are coccolithophores (Jordan & Chamberlain, 1997). They are classified as follows:

CLASSIFICATION (by Young & Bown, 1997; Edvardsen et al., 2000)
DIVISION: *Haptophyta*
CLASS: *Prymnesiophyceae*
Order:

- *Isochrysidales* - 1 Family
- *Zygodiscales* - 2 Families
- *Syracosphaerales* - 4 Families
- *Coccolithales* - 6 Families
- *Incertae sedis* - 1 Family

The average size of the calcareous nannoplankton is between 5-15 microns, but larger or smaller specimens are also common. A more restrictive definition (Tappan, 1980) considers the nannoplankton size of less than 2 µm, and defined as ultramicroplankton those between 2-20 µm. The fossils of calcareous nannoplankton are defined as calcareous nannofossils (or simply nannofossils). The term of nannofloras is also in use. The study of the calcareous nannoplankton is performed under optical microscope (LM) and under Scanning Electronic Microscope (SEM) (Fig.1).

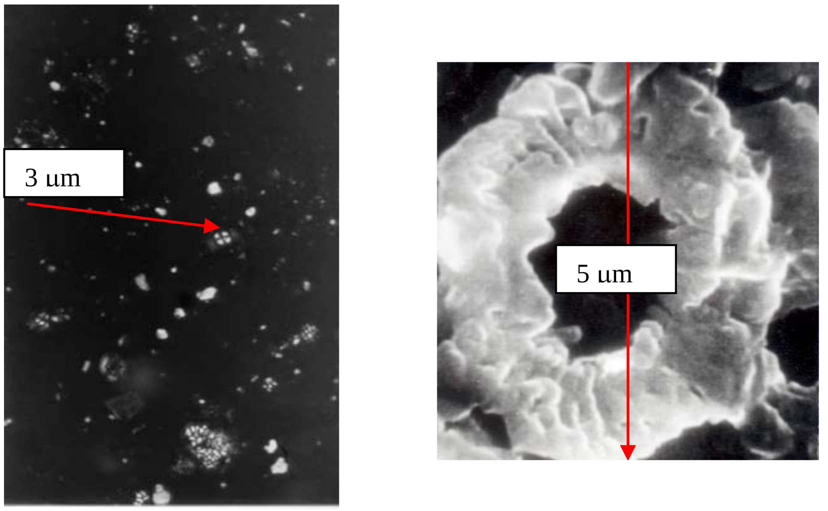

Fig. 1 Field of view with coccoliths under LM, crossed-nicols (left) and coccolith at SEM (right)

During the fossilization processes, most often only isolated calcite plates (named coccoliths) are preserved, but sometimes, complete coccosphaeres could be found (Fig. 2).

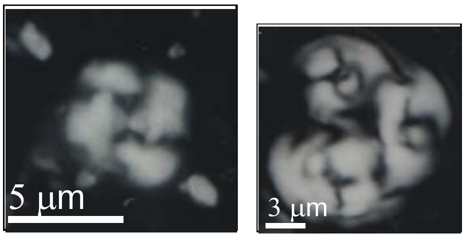

Fig.2 Coccolith - *Reticulofenestra lockeri* (left) and coccosphaere of *Dictyococcites bisectus* (right), LM, N+

The coccoliths are formed by numerous crystals of calcite, which may take various forms as prismatic, tabular, rhomboedric, or even a combination of forms (Fig. 3). Due to the high double refraction of the calcium carbonate, a pattern of the interference, and a specifical extinction position of the calcite elements characterize (under petrological microscope, in crossed-nicols) each coccolith species.

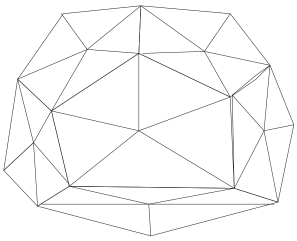

Fig. 3 Coccosphaere of *Braarudosphaera bigelowii* (penthaliths)

SAMPLING AND PREPARATION METHODS

The samples for calcareous nannoplankton studies are collected from sediments (outcrops and cores) and from sea waters. Very small samples are needed (in 1g of sediments thousands of nannofossils could be found).
Coccolithophores are present in every liter of water samples everywhere on the surface of the world ocean. Samples of waters are collected in a clean PVC bottle into the surface water or at different depths, using Niskin bottles. After the sample is collected, a concentration of the microalgal content is realized by filtration through a membrane filter or sieves, of 5 mm pore up to 63µm size. The samples are deposited and transported at or below the temperature of collection.
The preparation technique of smear-slides for calcareous nannoplankton analyses is one of the simplest and the cheapest used in micropalaeontological investigations. No chemicals are necessary, except distilled water. The most

accurate preparation technique in use for qualitative and quantitative studies follows the method described by Lamolda *et al*. (1994): 0.02 g of sample are dispersed in 10 ml distilled water and agitated as suspension, then 0.2 ml of suspension is spread over a slide, which is allowed to dry on a hot-plate and mounted with Canada Balsam. The smear-slides for calcareous nannoplankton investigations are analysed with a petrological microscope, with 1000 magnification, by using an immersion objective. For accurate quantitative studies, at least 300 specimens are counted in longitudinal transverses, randomly distributed.

Due to the low quantity of sample required for coccolith analyses (a few grams), and to the very simple and cheap preparation technique, the calcareous nannofossils are widely used in applied micropaleontology (e.g. to accurately and rapidly determine the age of sedimentary successions encountered by drills).

However, their micronic size led to same disadvantages of the method. The calcareous nannofossils are easily reworked in the sedimentary sequences. This could lead to reporting erroneous ages for the coccolith assemblages and even to claim continental sediments to be marine ones. Contaminations of the samples/smear slides during the preparation technique must also be avoided. Due to the fact that the calcareous nannoplankton consists of calcite, processes related to overgrowth of secondary calcite and dissolution of taxa may be encountered. In this way, the specific identification could be hindered.

BIOSTRATIGRAPHY

The first record of the calcareous nannoplankton in geological time is placed in the Upper Triassic (Carnian) marine sediments of the Southern Alps, Italy, an interval containing a maximum of five nannofossil species (Bown, 1998). An evolutionary radiation of this group of phytoplankton already took place in the Jurassic. Almost 60 species are known from the Jurassic/Cretaceous boundary interval. The radiation of this microalgal group continued throughout the Cretaceous. The maximum diversity of the calcareous nannoplankton in all its evolutionary history was reached in the Upper Cretaceous (Perch-Nielsen, 1985), when up to 150 different nannofloral species have been recorded in the nannofossil assemblages. The chalk deposits of the Upper Cretaceous (giving the name of this period) resulted from the accumulation of coccoliths.

The calcareous nannoplankton was strongly affected, as other marine planktonic organisms, by the Cretaceous/Tertiary boundary event. A mass extinction was recorded around 65 Ma ago, which led to the extinction of over 90% of the total nannofloral taxa (Melinte *et al*., 2003). A recovery of the calcareous nannoplankton took place during the Paleocene, when the diversity (around 60-70 species across the Paleocene/Eocene boundary; Perch-Nielsen, 1985) was comparable with that of Jurassic/Cretaceous boundary interval. During the Eocene, an important evolutionary radiation of this group of phytoplankton took place, the total number of species being around 120. A rapid nannofloral diversity shift is recorded during the Oligocene (up to 40 calcareous nannoplankton species), probably related to the climatic deterioration (Aubry, 1992). During the Miocene and the Pliocene, a new specific radiation took place, a maximum of 65 taxa being recorded in the Middle Miocene. The trend of nannofloral diversity since the Quaternary is in continuous decline (Figure 4).

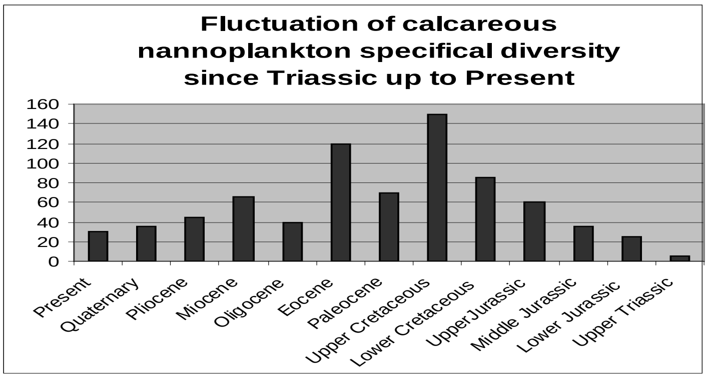

Figure 4 Calcareous nannoplankton Species Diversity from Triassic up to the Present

Taking into account the evolution of calcareous nannofloras during the Mesozoic and Cenozoic, it seems that the absence of ice-caps, a warm climatic mode and slight latitudinal gradients were favorable to the diversification of the calcareous nannoplankton, while the presence, around the poles, of ice caps, accompanied by the instauration of cooler climatic modes, determined significant shifts in the species richness.

The biostratigraphy based on calcareous nannoplankton is one of high resolution, throughout the last 225 million years, from the Upper Triassic (the Carnian stage) up to Present. Numerous calcareous nannoplankton events (first appearances, extinctions, blooms) led to the identification of nannofossil zones characterizing each stage of the Mesozoic (from the Upper Triassic) and of the Cenozoic.

The average time-span of one Calcareous Nannoplankton Zone is 2 Ma. Some biozones cover larger intervals (e.g. in Oligocene over 3 Ma) or more reduced ones (the Emiliana huxleyi Calcareous Nannoplankton Zone, the youngest in the Earth history, covers the last 200.000 years – Berggren *et al*., 1995). Moreover, the calcareous nannofossils are good proxy for major palaeobiological, paleoclimatic and paleogeographical events: Triassic/Jurassic Boundary Extinction Event, Jurassic/Cretaceous Boundary Palaeobiological Turnover, Upper Cretaceous maximum diversity, K/T mass extinction of marine planktonic organisms, (together with other marine and continental faunas and floras), Eocene Maximum Thermal Event, Oligocene Cooling (followed by the separation of the Tethys Ocean in European semi-isolated basins), rapid and strong salinity fluctuations in Neogene, abrupt sea-level changes in Quaternary, instauration of anoxic or oxic regimes in marine environments, etc.

ENVIRONMENT

Coccolithophores are abundant throughout the oceans today, and can be found from tropical to sub-arctic waters, even where the water temperature drops below 0°C. The coccolithophores life is related to the photic zone, the maximum abundance being recorded at 50 depth (Tappan, 1980).
The calcareous nannoplankton, as most of the planktonic organisms, reflects with high fidelity environmental changes, such as fluctuations of light, salinity, temperature, sea-level, ocean productivity, nutrients and water pollution.

Light

The coccolithophores play a key role in the carbon cycle: the formation of $CaCO_3$, by the calcifying life stages of this marine phytoplankton and its removal from water surface led to remarkable implications for the flux of inorganic carbon in the planetary ocean (Rost & Riebesell, 2004).
The deposition of calcium in coccolithophores seems to be strongly related to the photosynthesis processes, as cultures of most species ceased to grow, but also the production of coccoliths in culture is reduced or even inhibited by lower light intensity (Young, 1994).
The behaviour of calcareous nannoplankton species is not the same under light fluctuations. The growth of *Emiliana huxleyi* (the most widely distributed calcareous nannoplankton species at present) seems not to be very dependent on light. Even when the light intensity is lower than usual (e.g. 1000 µE/sm2 – Nanninga & Tyrrell, 1996) or, on the contrary, this taxon is exposed tot long photoperiods (Young, 1994), the rate growth of *Emiliana huxleyi* is not significantly disturbed. By contrast, the growth of some species, as *Calcidicus leptoporus*, is strongly inhibited by long photoperiods (Brand & Guillard, 1981).

Salinity

The calcareous nannoplankton is, as the most groups of marine organism, very sensitive to salinity fluctuations. Besides, although typical marine taxa, a few coccolithophores live in brackish waters and even in fresh ones.
At present, coccoliths seem to be adapted at very high salinity fluctuations: *Coccolithus pelagicus* has been found in the Dead Sea, at 250 ‰ (Tappan, 1980) and *Emiliana huxleyi* lives in the Black Sea, at salinity below 20‰ (Black, 1974; Aksu *et al*., 2002). In general, the oceanic species tolerate narrow fluctuations of salinity, while coastal species tolerate wider salinity changes (Brand & Guillard, 1981).
The first common appearance of *Emiliana huxleyi* in the Black Sea, indicating the instauration of a stable normal marine regime, is approximated at 3,000 years ago (Black, 1974). *Emiliana huxleyi* is still dominating the calcareous nannoplankton assemblages of the Black Sea (Morigi *et al.,* 2004), although this species is the most abundant living coccolithophore and seems to have broad ecological affinities.
In the Mediterranean Sea, the distribution pattern of living coccolithophores (Knappertsbush, 1993), indicates that highest frequencies of *Gephyrocapsa oceanica* (species more related to open marine environment) occur in regions of minimum salinity (37‰), with values 1.5-2‰ lower than normal salinity values of eastern Mediterranean surface waters. Most of the Quaternary sediments of the Black Sea lack *Gephyrocapsa oceanica*, or other typical oceanic species (*Calcidiscus leptoporus*, *Helicosphaera carteri*, *Umbilicosphaera tenuis* -Aksu *et al*., 2002), probably indicating salinities below the tolerance of most coccolithophores (Winter *et al*., 1994), but also unstable environmental conditions and low nutrient input.
The species *Braarudosphaera bigelowii*, a taxon confined mostly to shallow marine environment (first appearing in the Lower Cretaceous), is a good indicator of salinity fluctuations. In past geological records, blooms of *Braarudosphaera bigelowii* are known just above the Cretaceous/Tertiary boundary, but they probably have a more complex significance, indicating also the lack of nutrients and/or the absence of the competition with other planktonic organisms. Blooms of *B*. *bigelowii* were also identified in the Paleogene sediments of the Romanian Carpathians and the Transylvanian area, indicating a pronounced decrease in salinity, due to the isolation of the Paratethys region from the Tethys Realm (Mediterranean area).

Temperature and latitudinal distribution

Nowadays, the calcareous nannoplankton shows a clear latitudinal distribution, related to the specific tolerance at different temperatures. Some species are commonly found in low to middle latitudes, other are confined mostly to high ones.

A latitudinal distribution pattern of calcareous nannofossils was recognized throughout the Mesozoic and Cenozoic. The more pronounced latitudinal differences were recorded during the Early Cretaceous (Bown, 1998), interval for which different biostratigraphical nannofloral schemes are used for low-middle latitudes (the Tethys Realm) and for high ones (the Boreal Realm). A certain degree of provincialism of the nannofloras is maintained from the Mesozoic throughout Cenozoic, until today.

At present, six latitudinal surface water layers were recognized from north to south (Okada & Honjo, 1973): Subarctic, Temperate, Subtropical, Tropical and Subantarctic. From the living coccolithophores, *Syracosphaera pulchra* and *Helicosphaera carteri* are related to low-middle latitudes, *Calcidiscus leptoporus* is more common in the Temperate Zone, while *Coccolithus pelagicus* is confined mostly to high latitudes.

Nowadays, coccolithophores are very numerous in tropical/subtropical areas and less frequent in polar/subpolar ones. The obvious distinction between polar and low-latitude nannofloras indicates that these organisms are sensitive to temperature change of the water surface. Related to this latitudinal pattern, Tappan (1980) noted that ”the presence of calcareous nannoplankton in large numbers in rock implies a marine origin, deposition in the open sea, and a temperate or warm climate”. It is assumed that, originally, the calcareous nannoplankton appeared in tropic/subtropic areas, spreading later towards temperate and high latitudes.

The most widespread living calcareous nannoplankton species, *Emiliana huxleyi*, does not seem very affected by temperature fluctuations. This extremely cosmopolitan coccolithophore occurs today in all oceans, except the Arctic Ocean and the high-latitude Southern Ocean (Winter *et al*., 1994).

Blooms

Under specific environmental conditions, some remarkable development of calcareous nannoplankton taxa was recorded. The identified nannofloras could be characterized by monospecific assemblages or by a larger number of specimens, for a certain taxon, than usually recorded.

Blooms are known for almost all the history of this group of organisms. During the Early Cretaceous, the bloom of the *Nannoconus* genus in warm water of low to middle latitudes (the Tethyan Realm) led to the accumulation of carbonatic rocks, called nannomicrites. Blooms of *Braarudosphaera bigelowii*, a ‘‘disaster species” were associated with a drastic change in environmental conditions: e.g. in the Upper Cretaceous, around the Cenomanian/Turonian Anoxic Event; just above the Cretaceous/Tertiary Boundary, shortly after the mass palaeobiological extinction, and in the Oligocene deposits from the Carpathian area, when the salinity significantly decreased and anoxic sediments were deposited, etc.

Nowadays, the most studied blooms are those of *Emiliana huxleyi*. This living species of calcareous nannoplankton has an unusual behavior in the coccolithophore world: in certain environmental conditions it overproduced coccoliths, leading to the well-known blooms (Paasche, 2002).

According to Tyrrell & Merico (2004), blooms of *Emiliana huxleyi* should be considered only at cell concentration of at least 1,000,000 per liter. The highest bloom of this species, 115,000,000 cells per liter, was observed in the Norwegian fjord (*fide* Berge, 1962). Blooms of *Emiliana huxleyi* are recorded in many marine regions, among them also in the Black Sea, with a maximum of 10,000,000 cells/liter in 1992 (Mankovsky *et al*., 1996).

The coccolithic blooms produced “bright water” phenomenon (in satellite images), due to the light-scattering of the huge amount of coccoliths, or of “milky sea” (due to the turbid waters) as observed from the sea surface. These blooms have significant environmental impacts, consisting of increasing water albedo, large fluxes of calcium carbonate on the water surfaces, and a decrease in light and heat depth penetration (Tyrrell & Merico, 2004). Blooms of *Emiliania huxleyi* could act as an important source of dimethyl sulfide (DMS) and calcium carbonate, altering the optical properties of the surface mixed layer (Balch *et al*., 1991).

No significant bloom was recorded in the Black Sea between 1978-1986. Later, satellites captured images of widely distributed blooms of *Emiliana huxleyi* (Cokacar *et al*., 2001; Iglesias-Rodriguez *et al*., 2002 – Figure 5).

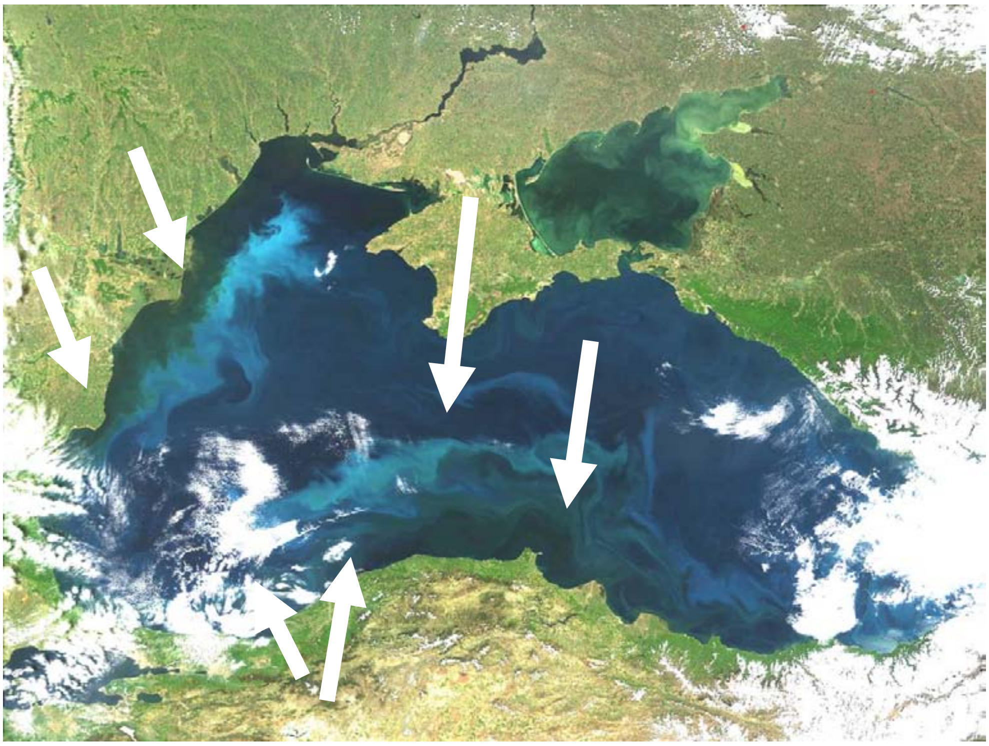

Fig. 5 Blooms of *Emiliana huxleyi* in the water surface of the Black Sea
(http://orbitnet.nesdis.noaa.gov/orad2/doc/ehux_www.html: Iglesias-Rodriguez *et al*., 2002)

Sea-level changes

The calcareous nannoplankton represents good proxy for the sea-level fluctuations. Based on the distribution pattern of calcareous nannofossils, palaeogeographical reconstructions could be obtained. Since, in the past and in the present, the nannofloras show a clear latitudinal distribution pattern, the “anomalous” presence of warm water forms in high latitudes, or vice-versa, suggests high-level stand intervals (Figure 6). The presence of mixed nannofloral assemblages (taxa of low-middle latitudes together with high ones) are indicative of the sea-level rise, while endemic assemblages characterize periods of low-stand sea level.

The absence of calcareous nannoplankton in the Black Sea during different intervals of the Holocene proved the existence of a brackish environment in this area. The first common *Emiliana huxleyi* recorded in the Black Sea, 3,000 years ago (Bukry, 1974), indicated a significant sea-level rise. However, that time *Emiliana huxleyi* was already spread in the Mediterranean area, dominating the coccolithic assemblages. Lericolais *et al*. (2004) noted that, during the Holocene, sea level fluctuations were different in the Black Sea compared to the rest of the world, prior to the reconnection of this giant lake with the Mediterranean Basin.

The investigations carried out on calcareous nannofossils allow for the identification of sea-level fluctuations, which are very important for deciphering the development history of such semi-isolated basins as the Black Sea.

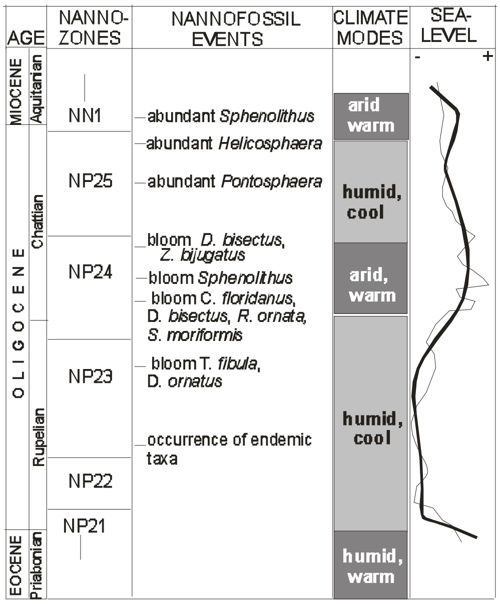

Figure 6 Climatic modes and sea-level fluctuations indicated by calcareous nannofossils of the Oligocene deposits from the Romanian Carpathians (after Melinte*, in press*)

Oxygen, Nitrogen and Phosphorus

The calcareous nannoplankton species have various levels of tolerance to the oxygen fluctuations. Some species need over 70% oxygen saturation for becoming abundant (Tappan, 1980; Paasche, 2002) and can not survive at levels below 40%, while some coccolithophores can live even below 20% oxygen saturation.

In the evolution of the calcareous nannoplankton, a significant shift in abundance (number of specimens) and in diversity (number of species) was observed during the instauration of anoxic regimes, while during oxic regimes the nannofloras indicated significant radiations.

The growth of calcareous nannoplankton requires nitrogen and phosphorus (Paasche, 2002). Coccolithophores can thrive when the nutrient phosphate is in short supply in the water, when light intensity is high, and when surface layers are well stratified. *Emiliana huxleyi* blooms require low level of phosphorus, but relatively high level of nitrogen (Rost & Riebesell, 2004). This species could use uric acid as a source of nitrogen (Tappan, 1980) and consequently they could grow intensively in polluted waters. Humborg *et al*., 1997 assumed that the presence of higher blooms in the Black Sea could be related to the construction, in the '70, of the Iron Gate Dam on the Danube River (which provide the majority of fresh-water supply into the Black Sea). The broad dissolved silicate of the river decreased, while the nitrogen increased. Consequently, the abundance of siliceous organisms (diatoms) shifted, while the abundance of marine organisms favored by high nitrogen supply (such as the coccolithophore *Emiliana huxleyi*) significantly increased (Mihnea, 1997).

Carbon

Coccolithophores take up carbon dioxide (CO_2) and other chemicals from sea water, to produce their calcium carbonate armor. At present, the large blooms of some coccolithophores (e.g. of *Emiliana huxleyi*) used most of the CO_2 of water surface.

The oceans absorb more CO_2 from the atmosphere, reducing in this way one agent of global warming. The marine food web processes the coccolithophores, subsequently pumping large volumes of organic matter and calcium carbonate into the deep ocean and to the ocean floor, where the calcium carbonate eventually ends up as marine sedimentary rocks. A small part of coccoliths attends the seafloor, becoming part of the sediments. Consequently, both the organic and inorganic coccolith remains provide key geochemical records for reconstructing the environmental conditions of the history of the Earth (e.g. cabonate deposition on different time-scales, composition of the surface waters, temperatures, etc. Hay, 2004).

CONCLUDING REMARKS

The calcareous nannoplankton represents an unique group of organisms in the biological evolution of our planet. These organisms provide indicators of palaeotemperatures, past dissolved and atmospheric CO_2 dissolution, carbon cycle, salinity and sea-level changes. Because they are living organisms, the hypothesis on the past geological record could be tested in the present, and allow us to predict the future of our planet.

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