Fossil Focus: Calcareous nannofossils: the best things are microscopic

by Amy P. Jones[1]

Introduction:

Calcareous nannofossils — words that are, perhaps, unfamiliar to you. You might never have stumbled upon them before … So what are they? They are the fossil remains of coccolithophores: single-celled marine algae from the phylum Haptophyta and division Prymnesiophyceae. They exist in great abundance around the world in the oceans, and have done for over 200 million years. They are also known as the grass of the sea, and are regarded as one of the most important phytoplankton groups in the oceans owing to their relationship with the carbon cycle. They provide valuable proxies to help us understand conditions throughout geological history, because their evolution shows consistent and resilient patterns.

Nannofossils are composed of calcium carbonate, also called calcite ($CaCO_3$), and are typically less than 30 micrometres across A single nannofossil is called a coccosphere, and is covered in many calcite plates (usually between 5 and 10 micrometres across) known as coccoliths (Fig. 1). The shapes of the coccoliths define different nannofossil species. For example, some have spines, diverse central areas or distinctive rim shapes (Fig. 2). Even the slightest variation can denote a different species. The coccosphere housed the coccolithophore cell in life. After death, some may fall apart and descend as 'marine snow' to the sea bed, where they settle before being preserved. They are often found with similar structures of unknown origin, which are known as nannoliths. These also come in a wide range of unique shapes.

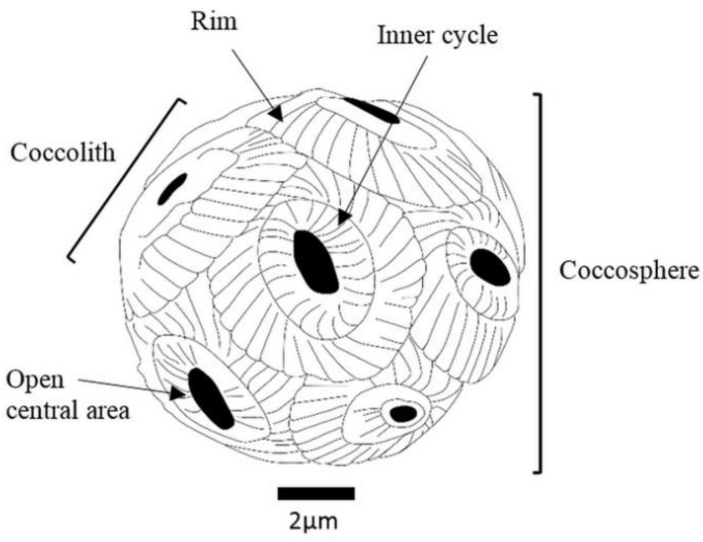

Figure 1 — Key external features of a calcareous nannofossil.

History of study:

The word 'coccoliths' was first used in 1836 by German naturalist Christian Ehrenberg, in a study conducted on chalk from the Baltic Sea. It wasn't until the latter half of the nineteenth century that British biologist George Charles Wallich proposed that coccoliths joined together to form the organic outer walls of coccospheres. Few people contested this, and it was later proved correct after the HMS *Challenger* expedition of 1872, the first global marine-research expedition. It was on this voyage that coccospheres were determined to be the skeletons of calcareous algae. From the 1960s onwards, revolutionary discoveries on coccolithophore biology, systematics and the fossil record have increased exponentially. Research into calcareous nannofossils has grown because these fossils provide information on the ages of the rocks in which they are found, which is valuable to both industry and the academic community owing to international drilling expeditions such as the Deep Sea Drilling Project, the Ocean Drilling Program and the International Ocean Discovery Program. Today, nannofossils are commonly used for quick and accurate determination of the age of rock samples, largely because they are very abundant, they have an extensive fossil record and samples can be prepared quickly.

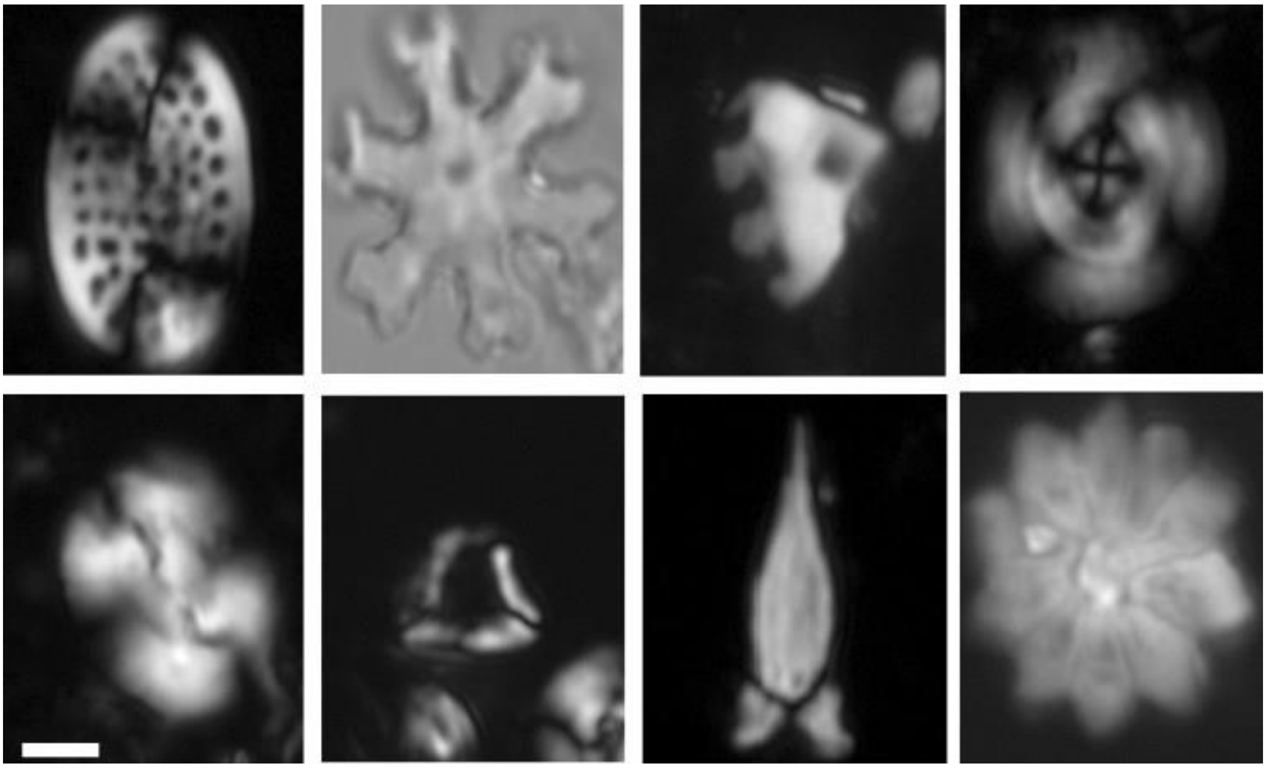

Figure 2 — Individual nannofossils from the Nanggulan Formation in Java, Indonesia. Scale bar represents 3 micrometres. Top row (left to right): *Pontosphaera multipora*, *Discoaster distinctus*, *Pemma papillatum*, *Reticulofenestra reticulata*. Bottom row (left to right): *Reticulofenestra bisecta*, *Lanternithus minutus*, *Sphenolthus obtusus* and *Discoaster barbadiensis*. All images from Jones & Dunkley Jones (in preparation).

Observation:

Sometimes, under exceptional preservation, you can retrieve whole coccospheres in samples. However, exceptional preservation is rare, so when it comes to looking at nannofossils we usually record the species of individual coccoliths. To observe these tiny fossils, you need a high-powered transmitted-light microscope, capable of reaching a magnification of ×1000 or ×1250. Another way of viewing nannofossils is to use a scanning electron microscope (SEM). This scans the sample surfaces with a beam of focused electrons and enables you to image the specimens at magnifications greater than ×6000. This method of imaging, however, is expensive and takes much longer than using a transmitted-light microscope. It is not regularly used unless the study requires a very detailed view of the specimens.

Unlike 'normal' body fossils in palaeontology, which you can pick up or look at with the naked eye, nannofossils in micropalaeontology can be observed only in 2D. You are unable to flip them over or see them at an angle of your choosing. Although we can sometimes see top views and even side views of different species, it all depends on how the nannofossils settle on the slide when you prepare the sample. This is down to luck, because individual coccoliths are so minute that it is impossible to manipulate one.

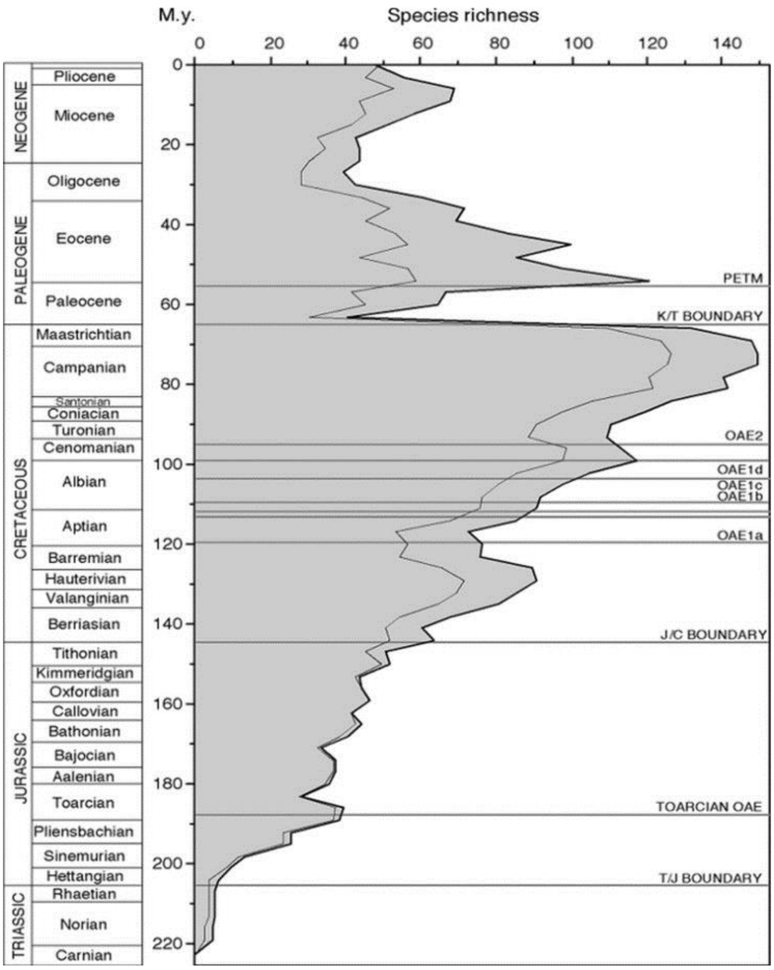

Figure 3 — Calcareous nannofossil species richness through time. Coccolithophore (light line) and total nannofossil (dark line) diversity plotted at 3-million-year intervals. From Bown et al. (2004).

Geological history:

Through time, the diversity, morphologies and abundance of calcareous nannofossils have varied greatly, usually due to: changes in global climate, the arrangement of continents and plate-tectonic movement, newly formed ocean circulation patterns or the amount of carbon dioxide in the atmosphere. The earliest calcareous nannofossils are found from the late Triassic period (around 225 million years ago). It is thought that this was the first time that planktonic organisms inhabiting open oceans would export $CaCO_3$ into the deep ocean via their calcareous skeletons, which is important for the biogeochemical cycle. The emergence of calcareous nannofossils in the late Triassic started at low latitudes (near the equator) with low diversity and abundance (Fig. 3). Then, at the boundary between the Triassic and Jurassic periods (201 million years ago), all species of coccolithophore except *Crucirhabdus primulus* went extinct.

After this extinction event, diversity began to re-establish quickly with nannofossils rapidly taking new forms; this led to the origination of most major families in the late early Jurassic (ca. 180 million years ago). Nannofossils seized the opportunity to adapt, colonize and flourish in almost all marine niches. In the early Jurassic, nannofossils diversified continuously, bringing a sustained increase in diversity into the Cretaceous period (starting 146 million years ago); peak diversity occurred in the Maastrichtian age (72 million to 66 million years ago). Nearing the end of the Maastrichtian, however, a sharp decrease in diversity is recorded, bringing extinction to 90% of all calcareous nannofossil species over the infamous K–Pg boundary — the extinction event that also killed the dinosaurs (Fig. 3).

A minimal number of small, simple species survived the catastrophic event, including *Neobiscutum* spp.. However, diversity recovered speedily, with the maximum diversity of species for the Cenozoic era (66 million years ago to the present day) transpiring around 10 million years after K–Pg event, during a time known as the Palaeocene–Eocene Thermal Maximum. Radiation of Cenozoic nannofossils bought about new families, some vastly different to those seen in the Triassic, Jurassic and Cretaceous, such as the *Discoasterales* (Fig. 2). There were almost as many species as are observed in the Maastrichtian. This peak, however, was short-lived. Slowly but surely, the number of nannofossil species began to decrease as the global climate cooled; this continued up to the present day (Fig. 4).

The diversity records of nannofossils through the Cenozoic are closely related to changes in climate: warmer intervals see higher diversity, whereas cooler periods see a decline in diversity. Recovery of species diversity can be traced during ‘warm intervals’, events such as the Middle-Eocene Climatic Optimum or the Middle-Miocene Climatic Optimum, further supported by the abundance of species with few offspring (K-selected taxa), for example the Discoasters. Cooler climates, however, saw the proliferation of mesotrophic groups (those that live in water with moderate amounts of nutrients) and eutrophic groups (those that live in water with lots of nutrients), for example the Isochrysidales. Since the middle to late Eocene epoch (ca. 40 million years ago), nannofossil diversity has continued to fall as extinctions have outnumbered the origination of new species; this has happened at the same time as a fall in the ratio of oxygen-18 to oxygen-16 isotopes found in the shells of the fossils, which shows that the planet was cooling (Fig. 5).

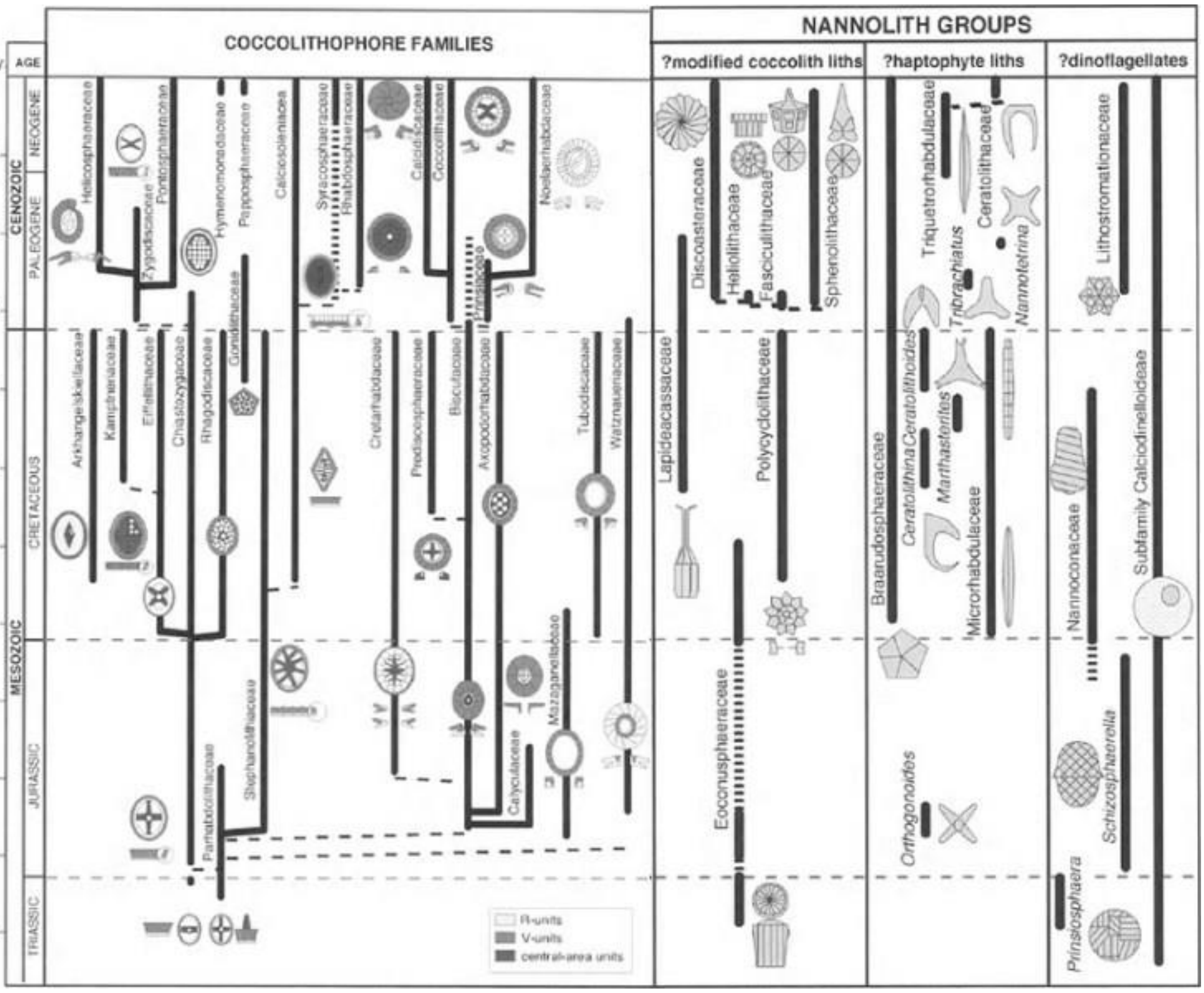

Figure 4 — Coccolithophore and nannolith families through time, from their first appearance, extinction and to the present day. Modified from Bown et al. (2004).

Fossil significance and biostratigraphy:

Calcareous nannofossils are found all over the world (dependant on a species' environmental tolerance), are abundant throughout geological history and evolve rapidly. This makes them a valuable fossil group and they have a number of applications. For example, they are useful for biostratigraphy, the process of dating rock layers and assigning them relative ages by identifying the fossils present. Some species of nannofossil have short evolutionary ranges, meaning that their occurrence in geological history may last for only a couple of million years. A short-ranging species is biostratigraphically important, because it provides a short time interval, making the dating precise. A long-ranging species might occur for tens of millions of years, which is less useful in biostratigraphy, because researchers want to know the date as precisely as possible.

The preservation of nannofossils can severely alter the ability to date rock samples effectively. Some nannofossils might be exquisitely preserved, whereas others might have been severely damaged when they dissolved in sea water, making it difficult to identify their species and therefore almost impossible to use them for dating. Coccoliths are phenomenally abundant on the sea floor, especially those that exist above the calcite compensation depth. Below this depth, dissolution preferentially removes calcite and therefore damages the coccoliths. This is just one form of bad preservation potential for coccoliths. Others include: bioturbation (disturbance of the remains and sediments by living organisms), diagenesis (physical and chemical changes while the sediments turn into rock) and reworking of sediments.

Despite this, nannofossils are often very abundant in small rock samples and provide plenty of observable material, which is easy to transport, store and prepare for study on oil or gas drilling platforms. Biostratigraphy is most commonly used in the oil and gas industry. During drilling, small rock chippings are brought back to the surface and given to nannopalaeontologists so that they can estimate the age of the rocks that are being drilled. This can help to guide and even locate the rock that will hopefully contain oil or gas. This can be incredibly important — you wouldn't want to guide the drill wrongly and miss the target section!

Microfossils are regarded as the best fossil group to use in biostratigraphy. This is not limited to nannofossils: other organisms, including foraminifera, dinoflagellates and even pollen and spores can be used. This has led to the creation of biozonation schemes for all microfossil groups (Fig. 6), in which geological layers are classified according to the microfossils that are found in them. Schemes have been formulated for different areas of the world at different latitudes, across seas and even geological periods, some depicting specific important events. Biozones can be defined by the beginning or extinction of a species, the point at which a species is at its peak, or even the beginning or end of a common occurrence of a species — these can also be known as markers and help to determine the ages of rock samples as precisely as possible. Biozone scheme helps to keep dating consistent in both industry and academia.

Academic research:

The use of biostratigraphy is not restricted to the oil and gas industry: it is also common in academic research. Micropalaeontologists use the technique as a standard dating method. It is also used where other dating tools, such as radiometric dating, are not available. Fieldwork for research projects involving calcareous nannofossils is often done on outcrops of land onshore, rather than during drilling expeditions at sea, and samples are dated using biostratigraphy. Nannofossils and modern living coccolithophores are studied to broaden knowledge of past and present forms of these creatures. Studies can include topics such as: the relationships between species, patterns of diversity through time and modelling past climates. Studies such as these help to build understanding of evolution, diversity in relation to global climate shifts, and even asteroid-impact events. By comparing ancient forms with living species and other data, we can produce a detailed and robust record.

Comparisons are not made just between living and extinct forms of one fossil group, but across a variety of time periods, long or short, and with other fossil groups. This helps to resolve past events by making the data more reliable, especially if patterns occur in multiple fossil groups.

Nannofossil research is still growing as new discoveries and projects piece together and reconstruct past events. Research on samples worldwide and across geological history helps to paint a bigger picture of past climates, oceans and even atmospheric interactions, but there is still so much more to uncover.

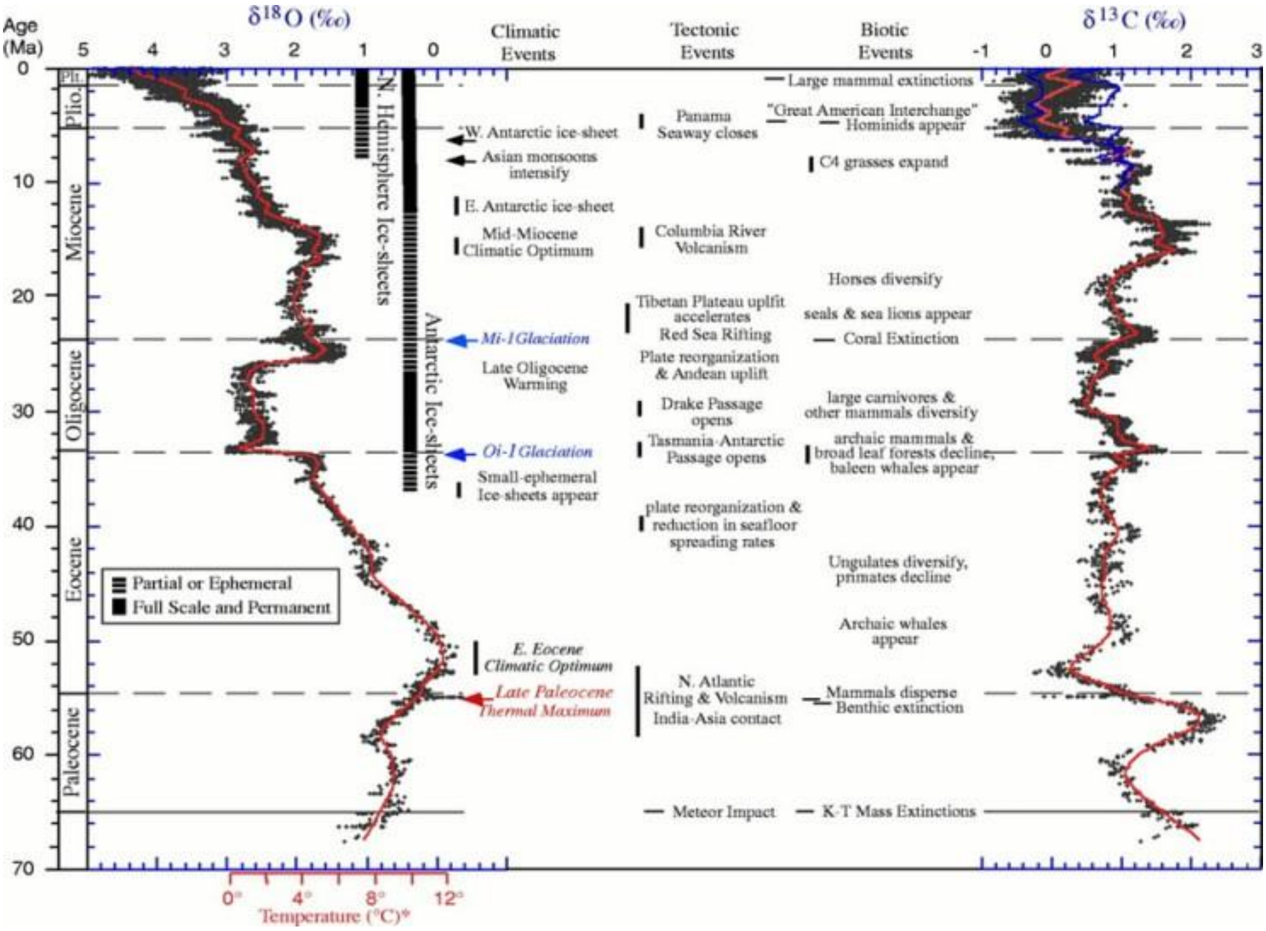

Figure 5 — Global deep-sea oxygen and carbon isotope records that span the entire Cenozoic era (66 million years ago to the present day). The curve on the left indicates temperature through time, whereas the curve on the right signifies productivity. Important climatic, tectonic and biotic events are listed between the curves. Modified from Zachos et al. (2001).

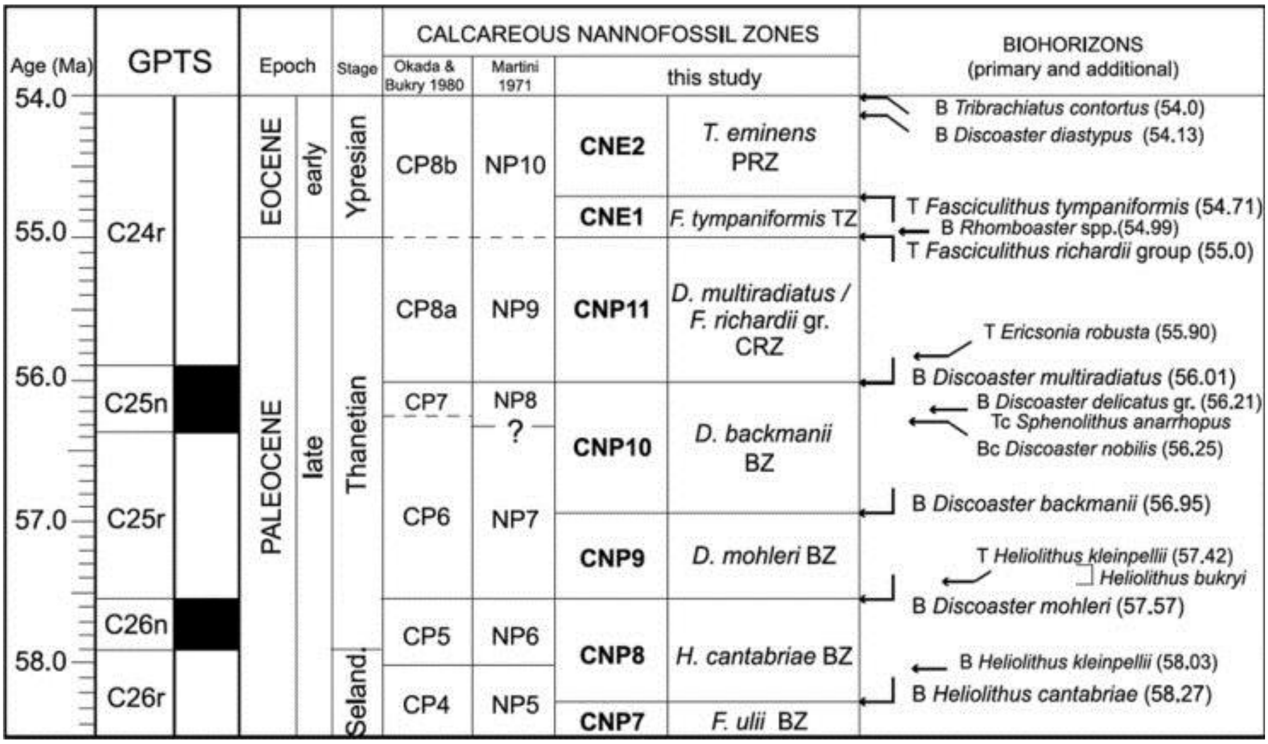

Figure 6 — An example of a biozonation scheme, taken from Agnini et al. (2014). Note the different biozone schemes by Martini (1971) and Okada & Bukry (1980) to display variation in species occurrences at different latitudes. This particular scheme is for low and middle latitudes.

Summary:

Calcareous nannofossils, nannofossils, nannoplankton and coccolithophores: all names that represent single-celled marine phytoplankton. Some extinct and others living, these organisms contribute vastly to the oxygen and carbon dioxide exchange in our atmosphere. Their fossil record, stretching back tens to hundreds of millions of years, gives us a detailed view of changes in the climate and the oceans of the past, due to the organisms' high sensitivity to changes in environments, their extraordinary abundance, global availability and extensive fossil record. This makes them some of the best fossils to use in multiple-proxy reconstructions of Earth history. Even though few people know what a coccolithophore is, they have immense applications in modern and palaeontological studies.

Suggestions for further reading:

Agnini, C., Fornaciari, E., Raffi, I., Catanzariti, R., Pälike, H., Backman, J. & Rio, D. Biozonation and biochronology of Palaeogene Calcareous nannofossils from low and middle latitudes. *Newsletters on Stratigraphy* **47**, 131–181 (2014). DOI: 10.1127/0078-0421/2014/0042

Bolli, M. H., Saunders, J. B. & Perch-Neilsen, K. *Plankton Stratigraphy: Volume 1, Planktic Foraminifera, Calcareous Nannofossils and Calpionellids* (Cambridge University Press, 1989).

Bown, P. R. (eds) *Calcareous Nannofossil Biostratigraphy* (Chapman & Hall, 1998).

Bown, P. R. Calcareous nannoplankton evolution: A tale of two oceans. *Micropaleontology* **51**, 299–308 (2005). DOI: 10.2113/gsmicropal.51.4.299

Bown, P. R., Lees, J. A. & Young. J. R. in *Coccolithophores: From Molecular Processes to Global Impact* (eds Thierstein, H. R. & Young, J. R.) 481–508 (Springer, 2004).

Zachos, J., Pagani, M., Sloan, L., Thomas, E. & Billups, K. Trends, rhythms, and aberrations in global climate 65Ma to present. *Science* **292**, 686–693 (2001). DOI: 10.1126/science.1059412

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[1]School of Geography, Earth & Environmental Sciences, University of Birmingham, UK.