Microfossil Biostratigraphy: Main geologic-time technique for hydrocarbon exploration and fundamental research

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Summary

Biostratigraphy predates other techniques of age identification like radiometric dating and magnetostratigraphy by over a century (Smith 1815), yet microfossils remain a leading tool for the age identification due to their small size, widespread distribution, abundance in rocks, and fast evolution. Many groups of microfossils evolved rapidly through time, thus aiding a very fine stratigraphic resolution. A brief overview of major biostratigraphically important microfossil taxa throughout the Phanerozoic is provided below. A case study of the Albian-Cenomanian (mid-Cretaceous) chalk-dominated succession from the Eastern Mediterranean provides an example of high-resolution geochronology using calcareous nannofossils, foraminifers, and on $^{40}Ar/^{39}Ar$ and K-Ar ages from basic effusives (Ovechkina et al., 2019).

Microfossil biostratigraphy in Phanerozoic strata: Overview

Microfossils are tiny (mainly 50–500 µm) remains of organisms comprising microzoofossils (Foraminifera, Radiolaria, Ostracoda), microphytofossils (calcareous nannofossils, diatoms, dinoflagellates, silicoflagellates), plant reproductive organs (spores, pollen, seeds)), minute representatives of larger organisms like Mollusca, Brachiopoda, Echinodermata, Graptolithina, problematics (Acritarcha, Chitinozoa, Hydroconozoa), and microcoprofossils. All these groups save for microcoprofossils are crucial for biostratigraphy of various time intervals and types of sedimentary rocks (Fig. 1).

Stratigraphically important calcareous microfossils include Foraminifera, Ostracoda and calcareous nannofossils (nannoplankton). Benthic foraminifera, which enter the fossil record in the Cambrian, and planktonic foraminifera, which enter in the Toarcian (Jurassic), have been successfully used in biostratigraphy of the Upper Palaeozoic and younger sequences. These are single-celled organisms were sometimes extremely abundant in limestone-dominated strata, *e.g.* Pennsylvanian–Permian fusulinid limestones and the Tertiary nummulitic limestones.

The tiny unicellular Haptophyte algae, which are referred to as calcareous nannoplankton or calcareous nannofossils, are known from the Triassic. Many calcareous nannofossil species are restricted to very narrow stratigraphic intervals, thus being extremely important for high-resolution biostratigraphy of the Late Mesozoic and Cenozoic strata, and this presentation provides a case study for their utility.

Ostracoda are minute crustaceans with the bivalved calcified carapace that live in all aquatic environments, from oceans to estuaries, lagoons, freshwater ponds and even in moist soils. This group is used for relative age identification from the Ordovician up the section.

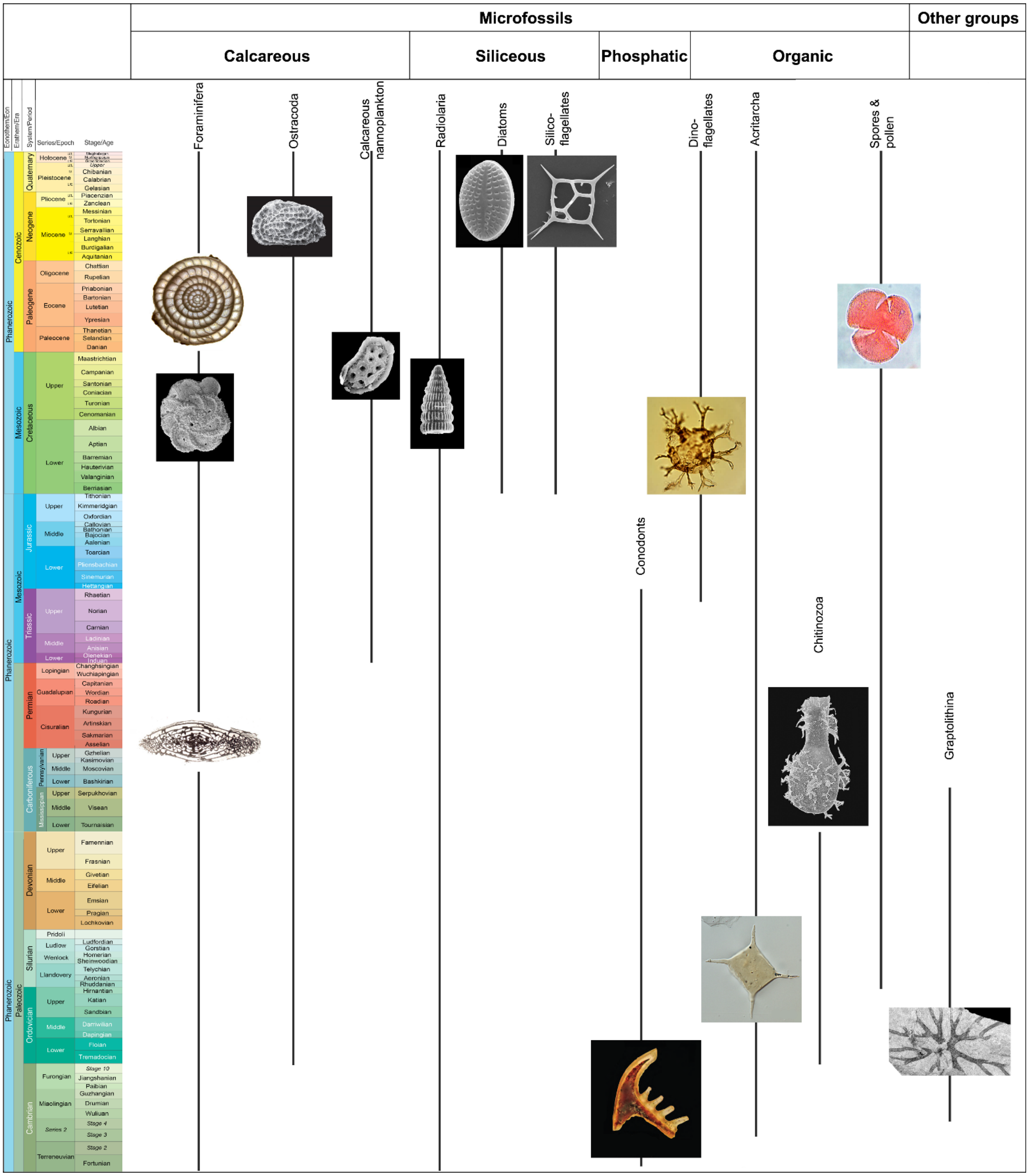

Figure 1. The stratigraphic distribution of the main microfossil groups and graptolites. Benthic Foraminifera: *Leptotriticites wetherensis* Thompson, Lower Permian (Asselian) (Wahlman & West 2010); *Nummulites striatoreticulatus* Rutten, Middle Eocene (Torres-Silva et al. 2018). Planktic Foraminifera: *Marginotruncana coronata* (Bolli), Upper Turonian–Lower Coniacian (Ovechkina et al. 2021). Ostracoda: *Tenedocythere cruciata* Bonaduce,

Ruggieri & Russo, Middle Miocene (Filipescu et al. 2014). Calcareous nannofossils: *Nephrolithus frequens* Górka, Upper Maastrichtian (Ovechkina et al. 2021). Radiolaria: *Dictyomitra densicostata* Pessagno, Upper Santonian (Ovechkina et al. 2021). Diatoms: *Navicula tenelloides* Hustedt, Recent (Kopyrina et al. 2020). Silicoflagellates: *Dictyocha stapedii* Haeckel, Recent (Rigual-Hernández et al. 2016). Conodonts: *Cordylodus andresi* Viira & Sergeyeva in Kaljo et al. 1986, Cambrian (Miller et al. 2015). Dinoflagellates: *Cymososphaeridium validum* Davey, Lower Cretaceous (Vašíček et al. 2020). Acritarcha: *Veryhachium lairdii* Deflandre ex Loeblich, Late Ordovician – Lower Silurian (Le Hérissé et al. 2015). Chitinozoa: *Ramochitina* sp., Lower Givetian (Gaugris & Grahn 2006). Pollen: *Tricolpites reticulatus* Cookson, Neogene (Riding & Dettmann 2014). Graptolites: *Paradelograptus norvegicus* (Monsen), Lower Ordovician (Gutiérrez-Marco & Martin 2016).

Siliceous microfossils include radiolaria, diatoms and silicoflagellates. Radiolaria are instrumental for dating and correlating basinal strata. Radiolaria first appeared in the Cambrian and are still extant. Many radiolaria species are restricted to quite narrow stratigraphic intervals, which makes them useful for high-resolution biostratigraphical schemes. Diatoms are algae that occur in both marine and freshwater sediments of the Cretaceous to Recent. They are particularly useful for the Miocene–Holocene biostratigraphy. Silicoflagellates—unicellular chrysophyte algae—enter the fossil record in the Cretaceous and are useful in the correlation of deep-sea sediments.

Organic-walled microfossils include Dinoflagellata, Acritarcha, Chitinozoa, and spores and pollen. Cysts of the unicellular dinoflagellate algae are recorded form the Late Triassic, becoming more common in the Jurassic and younger sediments. This group is important for biostratigraphy of the marine, lagoonal and lacustrine deposits. Acritarchs have uncertain biological affinity and evolved in the Precambrian (~3.2 billion years ago) with their acme in the Ordovician. This group is important for biostratigraphy of the Palaeozoic; however, they are also useful in younger deposits. In addition to biostratigraphy, acritarchs are useful in deciphering the maturity of hydrocarbon source rocks. Chitinozoans also have uncertain biological affinity, first appeared in the Early Ordovician and became extinct in the Devonian.

The reproductive organs of higher plants—spores and pollen—are not mineralized, but their sporopollenin walls are durable and well preserved in sediments. The earliest spores are known from the Silurian; the pollen appeared in the Devonian and diversified in the Carboniferous. The angiosperm pollen became abundant from the Cretaceous onwards. Although the distribution of spores and pollen is influenced by the ecology of their parent plants, these microfossils disperse in sediments widely, from terrestrial to freshwater, brackish and marine, which makes them instrumental for correlation between marine and non-marine sequences.

The phosphatic microfossils—conodonts—are widely distributed and important for biostratigraphy of the Palaeozoic from the Cambrian up to the Triassic. In addition to their biostratigraphic significance, it should be noted that the chemical alteration of the conodont elements, expressed as the "conodont colour alteration index", is an indicator of the thermal maturity of a basin, and hence is useful in the basin analysis for the purpose of the hydrocarbon exploration.

There are also some microfossil groups comprised of the detached skeletal elements of large-sized organisms that are difficult to identify without a microscope, such as sponge spicules, plates of corals, echinoderm spines, graptolites *etc.* Graptolites are colonial and are believed to belong to the Pterobranchia, small worm-shaped animals that still dwell in the modern ocean. Graptolites are a critically important stratigraphic group from the Middle Cambrian to the mid-Emsian stage of the Devonian. Due to the sporadic nature of graptolite distribution, graptolite biozones are a theoretical concept and are defined locally in lithological sections and have to be seen in relation with the older and younger strata or graptolite biozones. During the Early Ordovician, multiramous graptolites were most important, providing the majority of the index fossils (Maletz 2017).

Besides geologic time utility, microfossils, due to their color change with progressive heating, are used in petroleum geology as indicators of thermal maturation (*e.g.,* chitinozoans, graptolites, conodonts).

Case study: Mid-Cretaceous microfossil biostratigraphy

Recent discoveries of significant hydrocarbon deposits in the Eastern Mediterranean call for a robust tectonostructural, sedimentological and stratigraphic models to assist in hydrocarbon exploration. One of the most significant gravity-magnetic anomalies in the central Levant continental margin is located in Israel in the Carmel Region, and a thorough biostratigraphical study of this area is mandatory (Fig. 2).

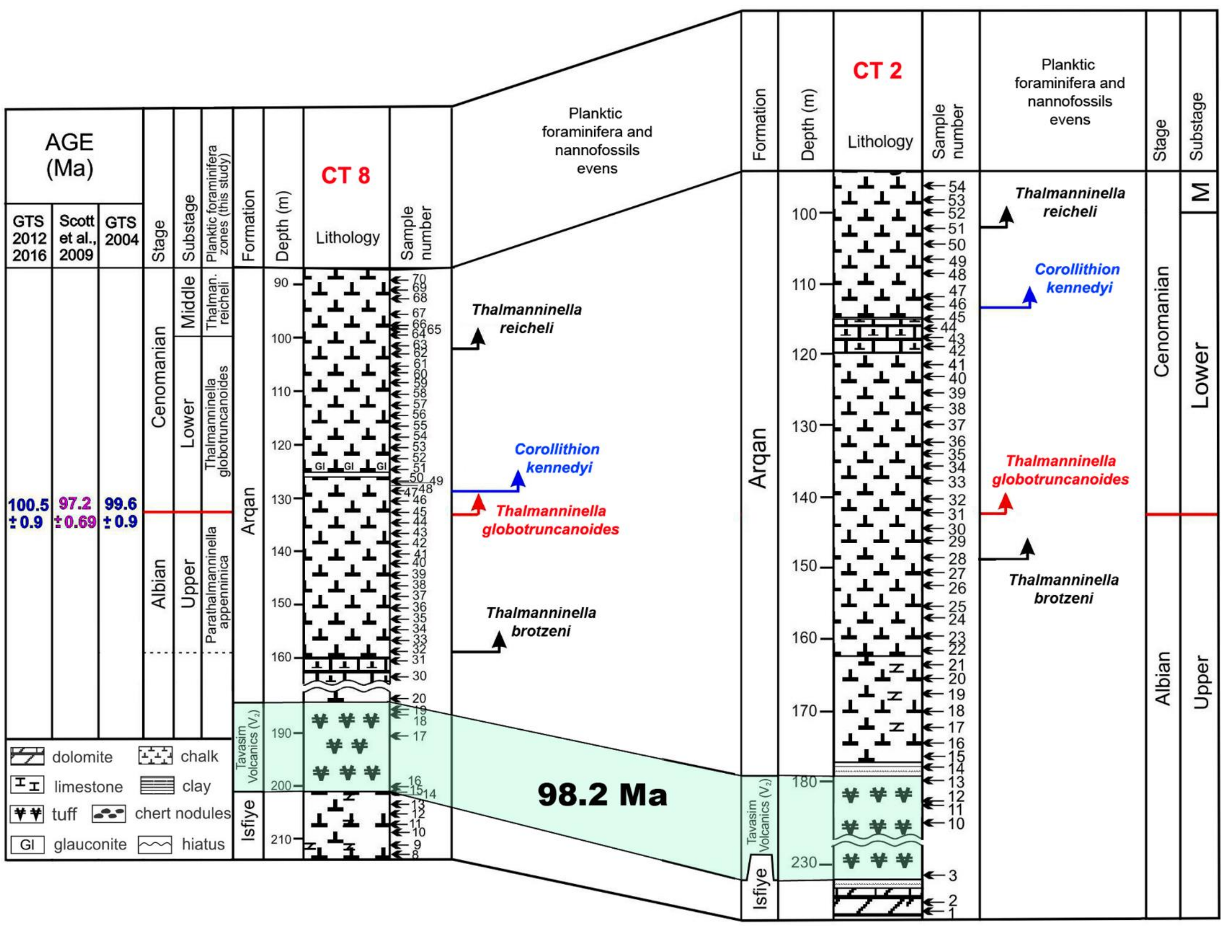

Figure 2. The correlation of boreholes CT8 and CT2 in the Mount Carmel Region, NW Israel.

The biostratigraphic analysis is based on the study of the calcareous nannofossils and planktic foraminifera from two boreholes in the Mount Carmel Region, NW Israel, CT8 (225 m deep) and CT2 (237.6 m deep) drilled ca. 2 km apart and penetrating the Isfiye, Tavasim Tuff and Arqan formations. The entire succession belongs to (sub)zones NC9b, NC9b & UC0a–b, UC0a–b (all Upper Albian), UC0c (Upper Albian – Lower Cenomanian), UC1, UC2 (both Lower Cenomanian), and UC3 (Middle – Upper Cenomanian) (Ovechkina et al., 2019). The FOs of *Thalmanninella globotruncanoides*, *Thalmanninella brotzeni* and *Corollithion kennedyi* place the Albian–Cenomanian boundary in the Isfiye Fm. (CT2, ca. 85.5 m above Tavasim Tuff) and in lower part of the Arqan Fm. (CT8, ca. 52 m above Tavasim Tuff). The 98.2±1.1 Ma age of Tavasim Tuff at the bottom third of Arqan Fm. and 96.7 Ma age of Raqefet Basalt at the center of Arqan Fm. (based on $^{40}Ar/^{39}Ar$ and K-Ar ages of fresh amphibole megacrysts and basalt samples) constrain the age of the Albian–Cenomanian boundary at 97.2 Ma.

Concluding remarks

Besides being a mandatory component in geological surveys and subsurface resource exploration, microfossils are extensively used in studying the ocean-floor stratigraphy and reconstructing the Earth depositional history. Biostratigraphic data of different groups should be aligned with other stratigraphic approaches. This contribution offers an example of the importance of microfossils (foraminifers and coccoliths) along with radiometric data across the Albian–Cenomanian boundary, an important event during a protracted "super-greenhouse" epoch.

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