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Fossil phytoplankton: importance in palaeoceanography

K. P. Jain

Birbal Sahni Institute of Palaeobotany, Lucknow 226 007, India

Fossil phytoplankton in marine sedimentary rocks cover a wide range of algal plant protist remains that are represented by organic walled cysts and biogenic mineral calcareous shells and siliceous skeletons. Their distribution through the Phanerozoic indicates maximum development during Mesozoic and Cenozoic, though acritarchs were dominant during the Early Palaeozoic times. The significance of phytoplankton lies in their minute size, diversity, morphological complexity, rapid evolution, abundance and wide geographic distribution. These have made them a tool in resolving the problems of palaeoceanography and oil exploration through high-resolution biostratigraphy, correlation of strata, age of the sedimentary sequences, palaeoecology, palaeogeography and palaeoenvironment. Phytoplankton are major maiine contributors of organic matter that are accumulated and buried in the sediments on continental margins and contribute much to the genesis of hydrocarbons. These microfossils have great potential in Indian palaeoceanographic and oil exploration programmmes.

BIRBAL Sahni was amongst the pioneers who introduced the study of plant microfossils in India. He stated: 'In India the scope of palynology is as wide as anywhere. The material is vast, but specially trained workers are lacking, here more than in other countries.'[1] The rapidly expanding circumscription of palynology confirms this perception in the modern context. It has almost acquired the dimension of micropalaeobotany, covering not only spores and pollen of terrestrial plants, but also marine phytoplankton and even finely dispersed organic matter, though there are diverse opinions about such a wide encompass, specially the inclusion of non-acid resistant calcareous and siliceous biogenic microfossils. Phytoplanktonology, an important branch of micropalaeobotany, has recently been undertaken in India to resolve problems of palaeoceanography, parallel to micropalaentology (micropalaeozoology).

The marine microplankton essentially comprise the protists, the unicellular plants and animals. The algal plant protists in general are called phytoplankton and are dense free-floating populations in oceans, though some also occur in freshwater bodies. These microscopic organisms are biflagellate (except non-flagellate diatoms), mostly autotrophic (photosynthetic), fixing more carbon than does the entire plant kingdom[2]. It has been estimated that the atmospheric carbon dioxide and oxygen balance is governed by phytoplankton photosynthesis since the early Precambrian time[3]. They constitute 90% of the marine food chain and are the main primary producers of organic matter. Their productivity is mainly controlled by the factors of incident effective radiation, temperature, salinity, minor and major nutrients, water depth, and hydrodynamics in the photic zone. They bloom on continental shelf and slope which provide optimum of these requirements. Phytoplankton play a major role in oil genesis. They alone contribute more than 50% to the undegraded organic matter biomass in marine sediments. Phytoplankton organic matter is mainly composed of variable amounts of proteins (up to 50% or more), lipids (between 5 and 25%) and carbohydrates (40% or less) and is more of aliphatic or alicyclic nature. The diatoms and dinoflagellates are very rich in these chemical constitutents, especially the latter which have a relatively very high total lipid fraction (2 to 10%) containing 3 to 14% hydrocarbons[2,4]. Amongst all groups that constitute phytoplankton, viz. blue green algae, dinoflagellates, coccolithophorides, diatoms and silicoflagellates, only the blue-green algae are prokaryotes.

All others, except dinoflagellates, are eukaryotes. The dinoflagellate nucleus possesses mixed features of both prokaryotes and eukaryotes, and thus dinoflagellates are referred to as mesokaryotes.

In the fossil state, the phytoplankton do not represent the complete assemblage as only the hard and resistant parts are preserved, representing but a stage in the life cycle. The common fossil phytoplankton groups that are mostly buried and preserved in the sediments are organic walled cysts of dinoflagellates and acritarchs; plates of coccolithophores and extinct discoasters and other calcareous nannoplankton; dispersed frustules (single valve) of diatoms, and the skeletons of silicoflagellates and ebridians.

The fossil dinoflagellates are the empty resting cysts that are abandoned after excystment of protoplasm during a stage in the life cycle. Each cyst is a nonmotile single unit, ranging in size from 5 to 2000 μm, having one or more wall layers. The wall is composed of sporopollenin, that makes them acid-resistant. Apart from these, there are some fossil records of calcareous (*Thoracosphaera*, comparable to the extant genus *Calciodinellum*) and siliceous (*Peridinites*) dinoflagellate cysts.

The acritarchs include many hystrichospheres that are not dinoflagellates and their affinities remain uncertain. These are single-celled cysts of some algal group of phytoplankton composed of organic cell wall similar to dinoflagellate cysts, and spores and pollen, possibly composed of sporopollenin. They range in size from 5 to 500 μm. The excystment opening or the aperture is the simplest and most primitive type. In wall ultrastructure the *Tasmanites*, *Cymatiosphaera* and *Baltisphaeridium* groups compare closely with recent Prasinophycean cysts and cells.

The extant diatom frustule is a siliceous bipartite structure, having two unequal halves (the valves) overlapping each other like a box of pills and range in size from 0.75 to 2000 μm. The frustules are composed of pure amorphous silica in part hydrated (opaline) and are not solid. These are generally distinguished into two groups, the Centrales and the Pennales. The former may be circular, triangular, quadrangular or oblong in outline, with surface markings radiating from a central area, whereas the latter are elongate in shape having surface markings at right angles to the long axis. These marine diatoms at cyst stage in the life cycle release the frustule valves which are preserved as fossils. The majority of marine planktonic diatoms are centric, whereas the benthos is constituted of pennate forms.

Silicoflagellates are small single-celled organisms having siliceous skeleton around the cytoplasm, ranging in size from 20 to 200 μm. The skeleton is symmetrical, tubular with hollow rods having radial short projections, and is composed of opaline silica. In the fossil state, these skeletons occur in siliceous sediments associated with diatoms. Like silicoflagellates, the ebridians are also siliceous skeletons with solid rods and triradial or tetraxial symmetry.

The calcareous nannoplankton is a diverse group of tiny calcareous microfossils generally 1–50 μm in size that includes coccoliths, and several associated, probably related or unrelated forms that are collectively termed nannoliths. The nannoliths include morphologically quite dissimilar groups of calcareous nannoplankton such as discoasters, nannoconids, pithonellids, schizosphaerellids, braarudosphaerids, thoracosphaerids, ceratolithids and many other calcite crystallites of specific shapes/designs.

Palaeoceanography is a vast interdisciplinary branch of marine geology that implies the evolution of ocean systems through time or the development of geological history of ocean basins leading to the development of modern oceans[4]. Various aspects of basin analysis mainly relate to the study of marine sedimentary sequences that contain past marine biota in the form of fossils, which generate possible data for correlation and age determination of the strata, environment of deposition, palaeoclimate, palaeosalinity, palaeotemperature, palaeocurrents, palaeobathymetry, palaeogeography and palaeobiography, etc., consequently also helping exploration of hydrocarbon resources.

The fossil phytoplankton cysts are affiliated to one or the other living microalgal plant groups, and are useful in drawing reasonable inferences about oceanic physical conditions of the past. Since phytoplankton cyst assemblages do not represent the complete life assemblage, it is worthwhile to follow a multidisciplinary approach in interpreting the palaeoceanogrphic data to arrive at precise biostratigraphic conclusions. The significance of these microfossils further lies in their abundance, minute size, diversity, complexity of structures, wide geographical distribution, and rapid evolution through time, which have made them an indispensable tool for biostratigraphic and palaeoecologic interpretations and palaeoceanographic modelling.

The fundamental aspect of biostratigraphy is evolution and extinction of taxa or a group that has time connotation and is used to subdivide the strata. The phytoplankton have a long evolutionary history. The Cynophycean algae and acritarchs are the only known marine phytoplankton that dominated the Late Precambrian to Early Palaeozoic. In recent years, the Mesozoic and Cenozoic phytoplankton biozonational schemes have been proposed considering the concept of *datum levels*, which is based on the evolutionary first appearance (FAD) and last appearance (LAD) of a taxon in a sedimentary sequence[5]. This covers wide range correlation and age determination of sedimentary strata establishing distinctive phytoplankton events through time. The phytoplankton results have also been well corroborated with palaeontological, oxygen isotope and palaeomagnetic data for developing high resolution biostratigraphy. The species diversity of every phytoplankton group, through time, is variable and in many cases useful to demarcate time boundaries, besides palaeoclimatic and palaeoecological derivations.

The Mesozoic era is significant in phytoplankton evolution, as all the major groups, viz. dinoflagellates, coccolithophorides, diatoms and silicoflagellates appeared then. The known pre-Triassic records of dinoflagellates and coccolithophorides are doubtful. Their primitive nucleus (mesokaryotic) would suggest the early evolution of dinoflagellates. Their doubtful sporadic records in Palaeozoic might have been due to the non-preservable cysts produced then. The dinoflagellates and coccolithophorides and other calcareous nannoplankton have earliest fossil records in Early and Late Triassic, respectively. The siliceous phytoplankton evolved much later, in Middle Cretaceous. Discoasters evolved in Late Palaeocene and became extinct at the Plio–Pleistocene boundary (Figure 1).

The applicability of fossil phytoplankton depends upon the data available on geographic distribution of extant phytoplankton related to their physical oceanic

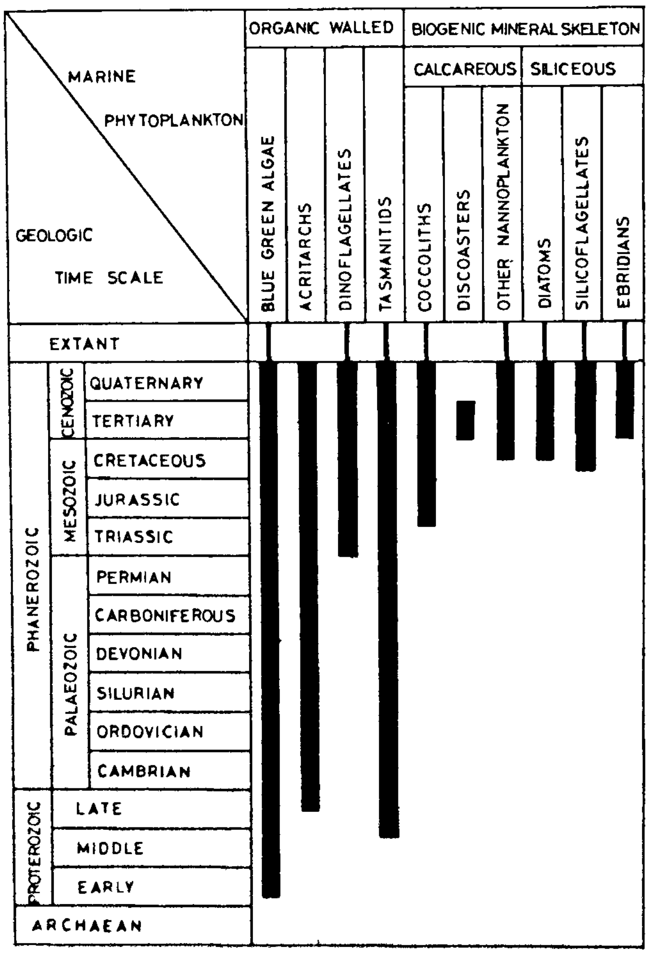

Figure 1. Distribution of fossil phytoplankton through time.

conditions. A comparison of fossil and living assemblages permits precise assessment of the palaeoconditions. Thus Miocene to Pleistocene fossil phytoplankton assemblages have better interpretative potential than that of Pre-Miocene period. A study of Pliocene silicoflagellates from the Antarctic indicates that the Pliocene temperature in surface water was about 10°C higher than the present[6]. These conclusions are based on the abundance ratio analysis of *Dictyocha* and *Distephanus*, which also identified oceanographic boundaries and water masses through Late Cenozoic. The silicoflagellates and ebridians are important constitutents of higher latitude (polar) and deeper waters, where calcareous nannofossils are either scarce or totally absent. The distribution of marine diatoms is controlled by temperature and salinity, and is a more reliable indicator for Neogene sediments. The diatoms tolerate a wide range of environments, and are important indicators of palaeocurrents, particularly the bottom currents. Characteristic dinoflagellate cyst species associations have been utilized to interpret alternating temperate and subarctic or colder–water conditions in a Pleistocene subsurface section of England[7].

Dinoflagellate cyst data are significantly used to indicate palaeoenvironments. Thick-walled dinoflagellate cysts are generally indicative of littoral zone and thin-walled forms are mostly restricted to open marine environment[8]. The single-species dominance in a fossil dinoflagellate assemblage indicates low salinity. The near-shore environment is inferred from the presence of reworked palynomorphs and also through the analysis of spore-pollen and dinoflagellate cyst ratio[9]. Higher percentage of dinoflagellate cysts in an assemblage indicates an environment away from the shore line. Transgressive and regressive phases have also been recognized, based on stratigraphical distribution of different dinoflagellate cyst and acritarch associations, indicating littoral, lagoonal and open marine environment in early Eocene[10]. The distribution of calcareous nannofossils during Quaternary period in North Atlantic and subantarctic regions shows large-scale migration of surface waters related to a palaeoclimatic changes[11].

The use of fossil phytoplankton in global high resolution biostratigraphy is linked to deep-sea drilling programmes, which have also greatly helped in oil exploration activities. This vital parameter has recently proved very significant for dating, biozonation and correlation of sedimentary sequences, including resolution of time boundaries in India. The most significant results of phytoplankton study have been in the precise delineation of the Cretaceous-Tertiary time boundary in an outcrop section (Umsohrengkew river) of Meghalaya. The discovery of marker species, viz. *Micula murus* and *M. prinsii* of latest Maestrichtian calcareous nannoplankton Zone CC26 is significant coinciding with the extinction of dinoflagellate cyst genus *Dinogymnium* below the iridium-rich clay layer that marks the end of the Cretaceous period. The occurrence of marker dinoflagellate cyst species *Danea californica* in the overlying samples marks the beginning of Early Danian[12]. The phytoplankton zones near the boundary integrated with the known planktonic foraminiferal zones[13] and geochemical data[14] indicate the potential for basinal and intrabasinal correlation[12].

Through fossil dinoflagellate discovery in Siang district of Arunachal Pradesh, Eocene marine sediments have been recognized, suggesting the extension of Tethys sea in that area[15]. Further, the oldest marine sediments in the Krishna–Godavari and Palar basins have been identified to be Hauterivian–Barremian in age. This has palaeogeographic implications[16]. The integration of Late Jurassic dinoflagellate and ammonoid assemblage zones of Spiti Shale succession (Oxfordian-Valanginian) reveal close correspondance[17]. The top two dinoflagellate cyst assemblages in the sequence have been compared with those of boreal ammonite *Pectinatus* zone, and are further equated with Tethyan ammonite *Himalayites–Corongoceras–Aulacosphinctes* assemblage zone of early Upper Tithonian[17,18].

The Upper Palaeocene sediments in subsurface and outcrop sequences of the Cauvery basin and South Shillong Plateau, respectively, have been dated and correlated on the evidence of index dinoflagellate cyst taxa of *Apectodinium* plexus[19,20]. The dinoflagellate data of the Cauvery basin have also been well integrated with calcareous nannoplankton *Discoaster multiradiatus* NP9 zone recovered from the same sequence[20,21]. The dinoflagellate biozones proposed for Middle Eocene (Lutetian) succession in southwestern Kutch closely corroborates with the larger foraminiferal zones[22]. In another section, in the same area, calcareous nannoplankton zones NP16 and NP 17 of Bartonian age have been documented[23].

In view of the above the significance of fossil phytoplankton in geologic exploration is self-evident and has a tremendous future for high resolution biostratigraphy and other palaeoceanographic reconstructions. India has a great potential for phytoplankton research because of the development of thick marine Mesozoic and Cenozoic sedimentary deposits in different onshore and offshore sedimentary basins.

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