Fossil diatoms and their significance

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Chandra A 1992. Fossil diatoms and their significance. *Palaeobotanist* **40** : 429-467.

A brief introduction to diatoms, an important group of siliceous organisms, is presented. This includes the history of diatom study, their classification and morphology, cell structure, ecology, nutrition and reproduction, palaeogeography and evolutionary history. Association of diatoms with volcanism and silica dissolution and overgrowth of fossil diatoms are also provided. Significance of fossil diatoms in palaeoecology and biostratigraphy including palaeoceanography is highlighted. Fossil diatoms known from India and a few DSDP sites of the Indian Ocean are listed alongwith their geological horizon. In India, reports of marine and freshwater diatoms were made from the Miocene rocks of Nancowry Island (Ehrenberg, 1851) and from the Karewa Formation of Kashmir (Lundquist, 1936), respectively.

Key-words—Fossil diatoms, Biostratigraphy, Palaeoecology, Andaman and Nicobar Islands, Kashmir.

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साराँश

अश्मित डाएटम एवं इनका महत्व

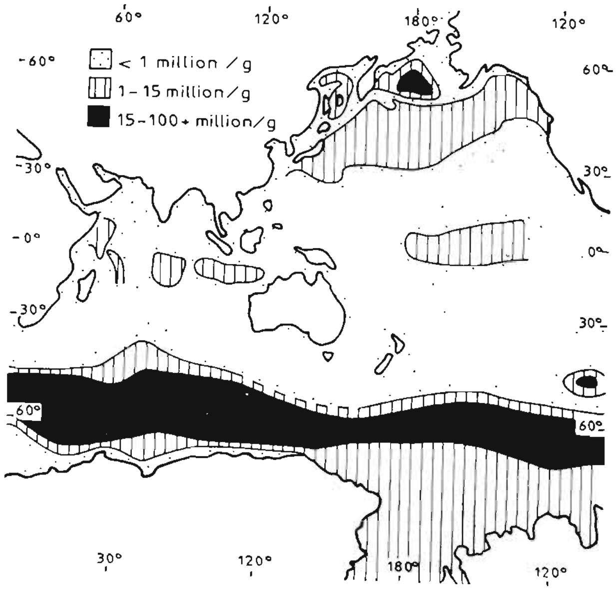
अनिल चन्द्रा

अश्मित डाएटमों के विषय में इस शोध-पत्र में विवेचना की गई है। इस विवेचना में डाएटमों के अध्ययन का इतिहास, उनका वर्गीकरण एवं आकारिकी, कोशिका संरचना, पारिस्थितिकी, पोषण एवं प्रजनन, पुराभौगोलिकी एवं वैकासिक इतिहास सम्मिलित हैं। ज्वालामुखीयता एवं सिलिका घुलन से डाएटमों का साहचर्य तथा अश्मित डाएटमों की अधिक वृद्धि की भी समीक्षा की गई है। डाएटमों की पुरापारिस्थिति, जैव-स्तरविन्यास एवं पुरासमुद्रविज्ञान में उपयोगिता पर भी प्रकाश डाला गया है। भारत से तथा हिन्दमहासागर में कुछ स्थानों से विदित अश्मित डाएटमों की सूची बनाई गई है। भारत में नैनकॉवरी द्वीप (अहरनबर्ग, 1851) की मध्यनूतन कालीन चट्टानों तथा काश्मीर के करेवा शैल-समूह (लनक्विस्ट, 1936) से क्रमशः समुद्री एवं स्वच्छ जलीय डाएटमों के अभिलेख हैं।

DIATOMS are the most abundant siliceous organisms in suspension. Radiolarians occupy the second place of importance followed by the silicoflagellates. The diatoms are microscopic, single celled, golden brown algae. They possess a typical external box-like skeleton or frustule of opaline silica (SiO_2 n. H_2O) which is the basic unit of their life cycle. The frustule is composed of two mirror image valves that enclose and protect the soft protoplasm of the cell. Different types and patterns of surface ornamentation of frustules form the basis of diatom classification. In size, diatoms are less than 1 μm to over 1000 μm, e.g., *Chaetoceros galvestonensis* Collier & Murphy (Collier & Murphy, 1962), *Cylindropyrix profunda* Hendey (Hendey *et al.*, 1969) and *Ethmodiscus rex* (Wallich in Rattray) Hendey in Weisman and Hendey (McHugh, 1954) have a diameter of 0.75 μm, 1.8 μm to 2.00 μm and 2.00 mm, respectively. Majority of them, however, have a 10 to 100 μm size range. Chains of colonial species may be more than 7 cm in length.

Diatoms are distributed in all lighted water bodies both marine and freshwater. They are found in a variety of modern environments from freshwater to hypersaline lakes, hot springs, melt water pools on icebergs and soils. They may be free floating or attached to rocks and other substrates (pebbles in streams, sea weed or even whales) within the spray or the splash zones near water. The diatoms may be benthic or planktonic, single or colonial and a few are endosymbiotic. Amongst the approximately 175 living and fossil diatom genera, 70 per cent are exclusively marine, 17 per cent are freshwater and

Four Decades of Indian Palaeobotany
Editors : B. S. Venkatachala & H P Singh
Publisher Birbal Sahni Institute of Palaeobotany, Lucknow



Text-figure 1—Distribution of diatom frustules in surface sediments of the Indian and Pacific oceans in Millions per gram of sediment (after Brasier, 1980).

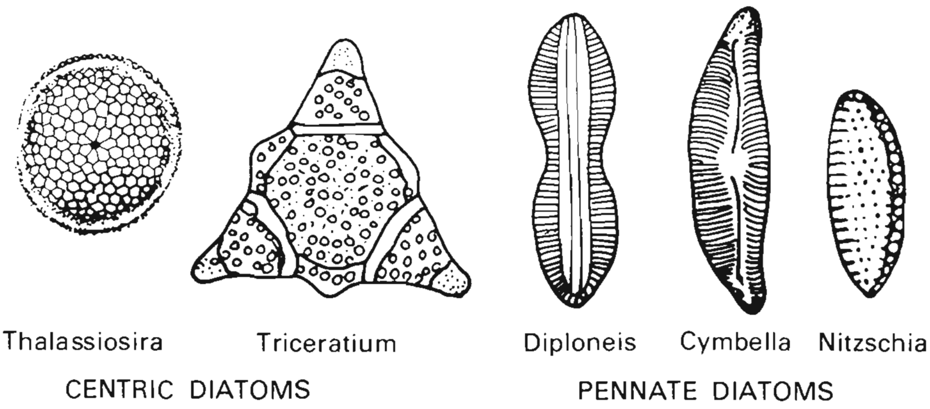
the remaining 13 per cent are either predominantly marine or freshwater with only a few species crossing from one habitat to the other (Round & Sims, 1981). Brasier (1980) has shown the distribution of diatom frustules in surface sediments of the Indian and Pacific oceans in million per gram of sediment (Text-figure 1).

Diatoms form an important base for the food chain in marine and freshwater environments. And so, they are also known as 'grass of the sea'. They are the most important primary producers in modern oceans and their abundance characterizes the most fertile areas of the oceans. Beneath these fertile waters, sea floor sediments consist of abundant frustules of diatoms which are commonly known as Diatom Oozes. These oozes become diatomites (rocks) after lithification. Diatomaceous earth is soft and friable. In the ocean's photic zone diatoms are widely distributed (water depth typically less than 100 m) and adopt various benthic life styles. At higher latitudes they may be very abundant and diverse in contrast to calcareous microfossils. They either live singly or form colonies. Many diatoms secrete a mucilagenous substance which covers the siliceous wall and serves to attach the cells in colonies. It also attaches the benthic diatoms to a substrate, and helps their propulsion along a substrate.

HISTORY OF DIATOM STUDY

Taxonomical work on diatoms was initiated during the laterhalf of the nineteenth century. This came in the form of monographic publications by various workers like Ehrenberg (1838), Schmidt *et al.* (1874-1959), Van Heurck (1880-1885) and many others which comprise numerous hand-drawn illustrations of diatoms. One of the most famous publications amongst these is by Schmidt *et al.* (1874-1959) which covers both marine and non-marine diatoms. Diatom biostratigraphical study was started in the early twentieth century by Hanna and Lohman who described many marine diatom assemblages from the Cretaceous to Pliocene sediments of the North American continent. Hustedt (1927-1966) started a compilation of diatom taxonomy which is still treated as an ideal reference for diatom study. Detailed stratigraphical study of diatoms was initiated by Kanaya (1957). Significance of marine diatoms in biostratigraphy and palaeoecology was realized only after the collection of deep sea cores by the Oceanographic Institutions and the Deep Sea Drilling Project in 1960 and 1970 respectively. The real momentum in the study of diatom morphology was gained through the aid of the Scanning Electron Microscopy and this has resulted in various changes at generic and higher levels of diatom taxonomy.

First report of marine fossil diatoms in India was made by Ehrenberg in 1851 from the Miocene rocks of the Nancowry Island while the first report of freshwater fossil diatoms is from the Karewa Formation (Late Pliocene) of Kashmir by Lundquist (1936). These microfossils from Nancowry were later worked out by Grunow (1867), Van Heurck (1880-1885), Cleve (1883, 1894, 1895), Pentocsek (1889), Schmidt (1885-1944-illustrations), Cleve and Moller (1878), Tempere and Peragallo (1915), and Rattray (1890). Further contributions on fossil diatoms up to 1950 have been made by De Terra and Paterson (1939)—freshwater, Iyengar and Subrahmanyan (1943)—freshwater, and Ghosh and Maitra (1947)—marine. A large number of publications on fossil diatoms of India appeared during the last four decades and these are by Jacob and Shrivastava (1952 : marine), Desikachary and Maheshwari (1958 : marine), Das (1961 : freshwater), Rao and Awasthi (1963 : freshwater), Roy 1971, 1974, 1975, 1979, 1982, 1984, 1988 : freshwater), Singh and Vimal (1973, 1976 : marine); Singh, Vimal and Nautiyal (1978 : marine), Singh (1979 : marine), Srinivasan and Srivastava (1972, 1977 : marine); Mathur (1973, 1981, 1985, 1987 : marine), Mohan (1987, 1988a, 1988b, 1989, 1990 : freshwater), Mohan, Gandhi and Vora (1982 : freshwater), Mohan and Vora (1986, 1987, 1987a, 1987b, 1988 : freshwater), Gandhi and Mohan (1983 : freshwater), Gandhi, Mohan and Vora (1984, 1986 : freshwater), Gandhi, Vora and Mohan (1984,



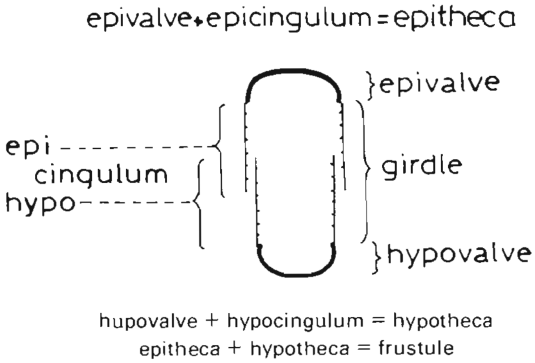
Text-figure 2—Two basic groups of diatoms. Centric-radial symmetry and Pennate-bilateral symmetry (after Barron, 1987).

1985a, 1985b : freshwater), Gupta and Khandelwal (1984, 1986 : freshwater), Khandelwal and Gupta (1989 : freshwater), and Desikachary and Ranjitha Devi (1986 : marine). Fossil diatoms from the sediment cores of the Indian Ocean region were perhaps first described by Kolbe (1957). This was followed by the contributions of Bukry (1974), Schrader (1974), Desikachary, Latha and Ranjitha Devi (1984), Desikachary, Gowthaman and Latha (1987), Desikachary (1989), Gowthaman and Desikachary (1989) and Prema and Desikachary (1989) from the DSDP samples of the Indian Ocean region. Gupta (1974) listed the fossil diatoms from India followed by Roy (1988).

CLASSIFICATION AND MORPHOLOGY

The classification of diatoms is based on the form and sculpture of the frustule. Hustedt (1930) has elevated this algal group to an independent division—the Bacillariophyta. However Hendey (1964) prefers their accommodation in a separate class—the Bacillariophyceae under the division Chrysophyta alongwith Chrysophyceae and Xanthiophyceae. Taxa belonging to these classes have similar endoplasmic cysts, which secrete silica, store oil and possess a bipartite cell wall (Tappan, 1980). Both divisions—the Chrysophyta and the Bacillariophyta belong to the Kingdom Protista. Diatoms have been further divided (Hendey, 1964) into two orders namely the Centrales and Pennales. The Centrales or the centric diatoms have a radial symmetry (Text-figure 2) where the surface markings radiate from some central or near central point. The centric forms are circular, hemi-circular, triangular, quadrangular or oblong. The Pennales or the pennate diatoms have a bilateral symmetry (Text-figure 2) where the structural centre is formed by a line. Pennate forms are elongate with major structures at approximately right angles from a median line which runs parallel to the long axis.

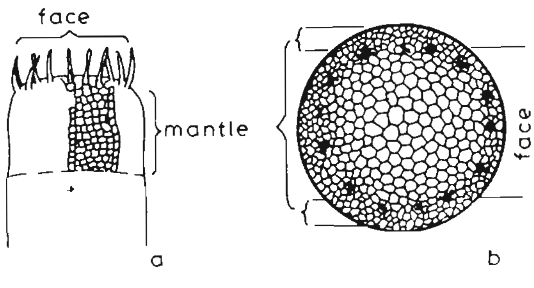
Standardization of diatom terminology, which is quite complicated yet clear, has been proposed by Annonymous (1975) and Ross *et al.* (1979). This has been done by the International Committees through the International Society for Diatom Research. About 95 per cent cell wall of diatoms is impregnated with opaline silica and this siliceous element forms the frustule and the girdle of a diatom. Components of a frustule include two valves (Text-figure 3) which are known as epivalve (larger one) and the hypovalve (smaller one). These two valves are usually connected by a thin circular band which is known as girdle (Text-figure 3). The girdle occupies the area between the epivalve and hypovalve and is usually present in fossil records without any stratigraphical significance. The valve mantle is the junction of valve margin and girdle. Valve face (Text-figure 4) is the part of the valve surrounded by mantle. A study of diatom frustule under two views (valve and girdle) helps in the identification although most diatom taxonomy is based upon the valve view. The girdle (Text-figure 2) consists of epicingulum and hypocingulum. The epivalve and epicingulum are derived from the parent cell and overlap the hypovalve and hypocingulum. Hypovalve and hypocingulum are formed internally during the vegetative division. Epivalve and epicingulum together are known as epitheca (Text-figure 2). Similarly, hypovalve and hypocingulum are jointly known as hypotheca (Text-figure 2). Epitheca and hypotheca constitute a diatom frustule. The siliceous valve wall may be of two types (Hendey, 1964). A single laminar wall is composed of a single layer of silica. Another more complex, the locular wall consists of a double layer of silica separated by vertical silica 'slats'. Some pennate diatoms like *Surirella* and *Entopyla* have transverse thickenings of



Text-figure 3—Components of a frustule (after V. Stosch).

the valve wall known as costae (Text-figure 5). The costae are useful in taxonomy. A honey-comb like cross section with chambered pores is seen in the double layered valve wall. These pores are known as areolae. Usually the areolae are covered by a finely perforated plate which is known as sieve plate. The ornamentations (Text-figure 6) on the valve face of diatom frustule include pores (areolae), processes, marginal and sub-marginal spines, hyaline areas (areas of clear structureless silica) and other specialized structures.

The frustules of the pennate diatoms (Text-figure 7) are elliptical or rectangular in valve view with bilateral symmetrical sculptures. The sculpture includes a longitudinal unsilicified groove known as raphe. It runs down the middle or the centre of each valve parallel to the apical axis with rows of punctae arranged at right angles on either side (Text-figure 7). Raphe is a longitudinal V-shaped slit or a pair of slits which usually looks like a narrow line under the light microscope. It is usually present on both valves of a pennate diatom. However, in some genera like *Achnanthes* and *Cocconeis* (Text-figure 5) the raphe is present only on one valve. In such cases, the other valve has hyaline axial area which is free of any structure (punctae). This structureless hyaline area is known as pseudoraphe (Text-figure 5). The extrusion of mucilagenous material through the raphe helps in the movement of diatoms along a substrate (Tappan, 1980). A central nodule is present at the middle point of the valve face and divides the raphe into two (Text-figure 7). Polar nodules may also be present at both the extremities on the valve face of a pennate diatom (Text-figure 7). Presence of raphe or pseudoraphe on one or both valves is used in further sub-dividing the pennate diatoms. Valve shape, presence of raphe, the areolar pattern and pattern of any other specialized structure (spine or process) on the apices are the important features in describing a pennate diatom.



Text-figure 4—Valve face and mantle *Stephanopyxis* (from Cupp.).

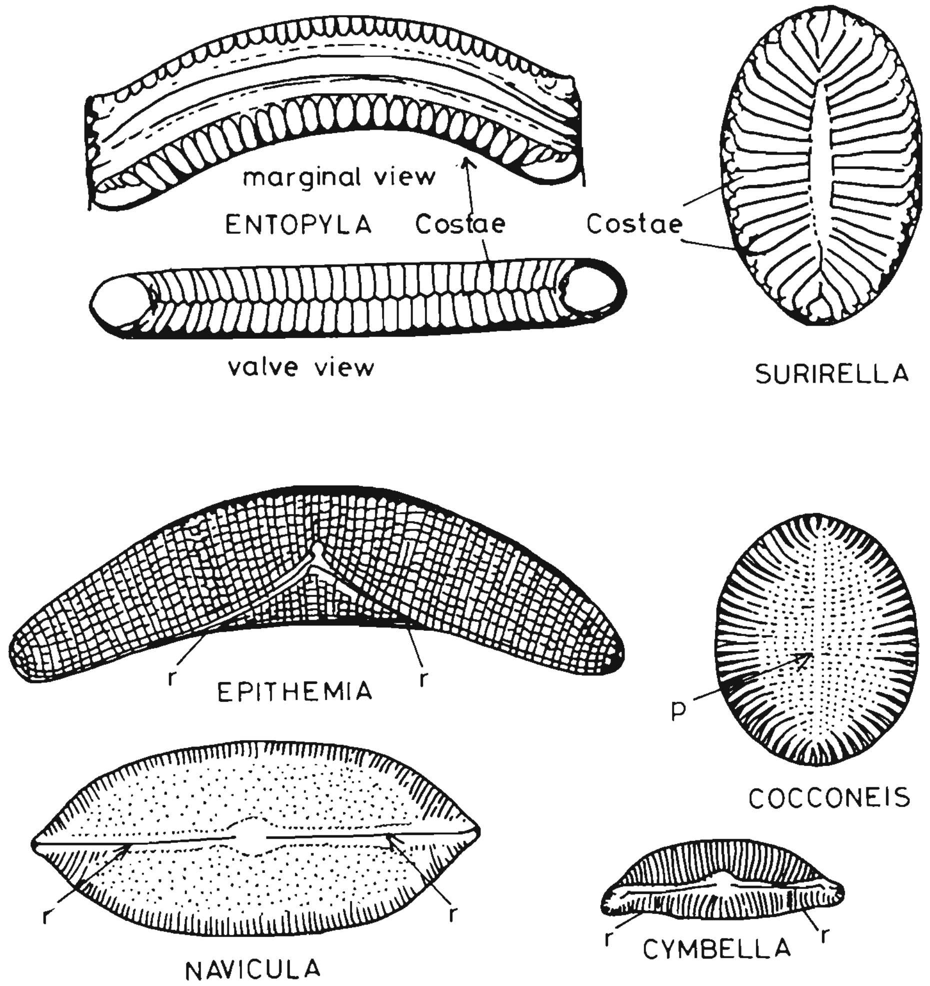
The frustules of centric diatoms are circular, triangular or quadrate in valve view and rectangular or ovate in girdle view. They do not possess any raphe or pseudoraphe for mostly they are planktonic and non-motile. Presence, type and number of any process, spines or specialized structures, type of areolar pattern (radial or tangential areolation, Text-figures 8A, B), the number of areolae (Text-figure 9) per 10 μm, any variation in this number along the valve diameter and any interuption to the areolar pattern by raised or lowered region or by hyaline areas are included in the description a centric diatom.

Diatom symmetry (Text-figure 10) is usually related to three axes : the apical axis which is parallel to the long dimension of valve, the transapical axis which is at right angles to the apical axis, and the prevalvar axis which runs through the centre of two valves. Normally a complete frustule is not found in fossil state and thus fossil diatoms are typically described with reference to apical and transapical axes.

Detailed morphological studies have been possible through the use of Scanning Electron Microscopy for refinement of the existing diatom taxonomy. Determination of number, distribution and type of labiate processes have been found to be important in sub-dividing the diatoms at the sub-order and family levels. In India, Desikachary (1952, 1954a,b,c, 1956), Desikachary and Bahadur (1954a,b,c), Gandhi, Mohan and Vora (1984), Mohan and Vora (1986) and others have studied the diatoms by SEM.

DIATOM CELL, ECOLOGY, NUTRITION AND REPRODUCTION

The protoplasm of a diatom cell consists of a cytoplasmic layer which lines the interior of the frustule and surrounds a large central vacuole. A diploid nucleus, usually small, displaced to one side and variously shaped is present within the cytoplasmic layer. Smaller bodies—the nucleoli, are



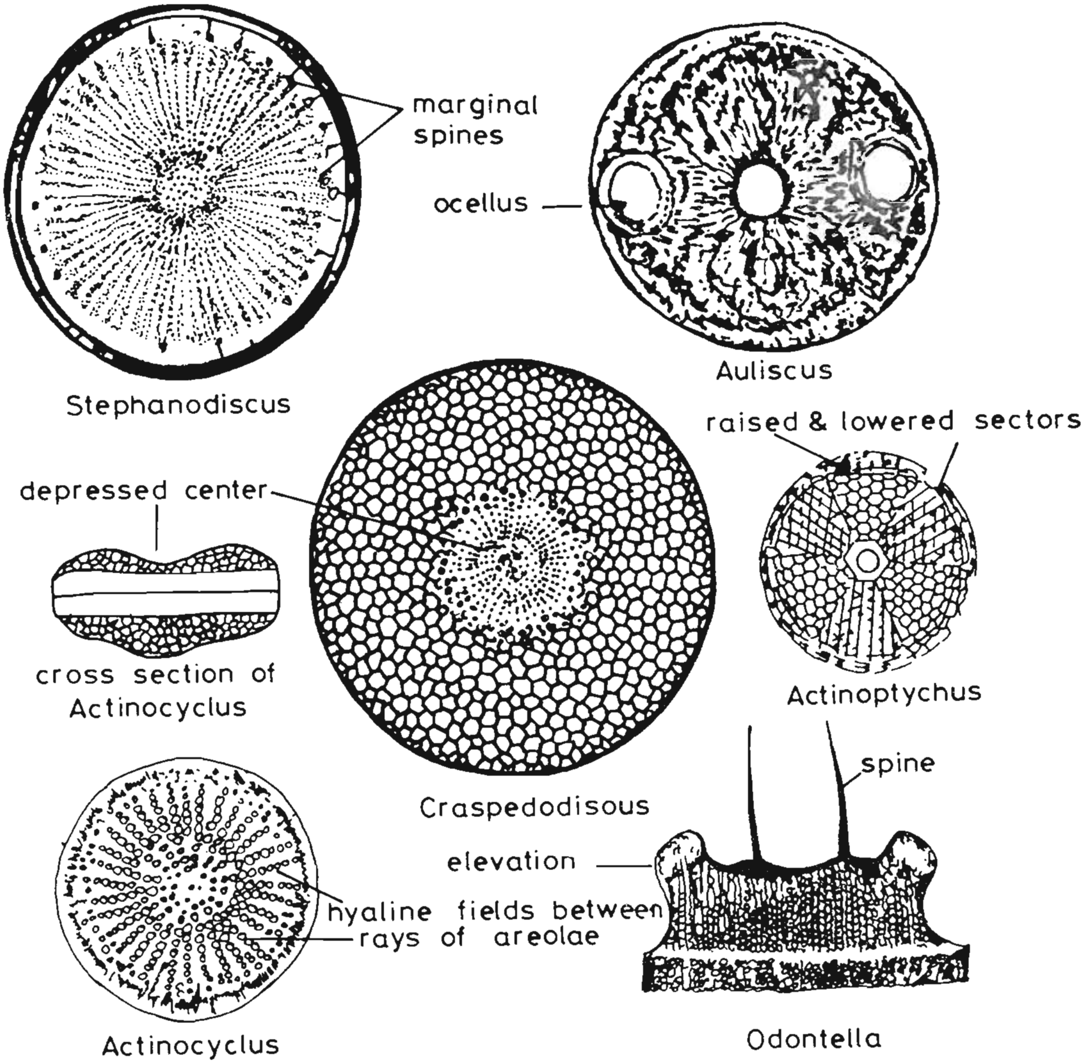
Text-figure 5—Examples of raphes (r)—longitudinal slits through the valve wall, a pseudoraphe (p) and costae in pennate diatoms (after Barron, 1987).

present within the nucleus. There are two to several pigment-bearing plastids surrounding the nucleus. The plastids are the sites of photosynthesis and their pigments contain chlorophyll a, C1, C2, carotenoids and xanthophylls.

Diatoms are found both in marine and freshwater environments. Different species occupy benthic and planktonic niches in ponds, lakes, rivers, salt marshes, lagoons and oceans while some live in the soil or attached to rocks and plants as well as in bottom muds. Pennate diatoms dominate the freshwater, soil and epiphytic niches although they also thrive in benthic marine waters, especially at subpolar and temperate latitudes. Distinct plankton assemblages are known to dwell in nearshore, neritic and oceanic environments. They can also occur as plankton in freshwater bodies.

Two broad habitats of diatoms are identified in the marine environments. The first one benthic diatoms (adopted to live on sea bottom) may be vagile (free moving) or sessile (passive as attached). The second one, i.e., planktonic diatoms (free floating), are considered as part of the oceanic (deep sea) or neritic (shallow sea) plankton. Hendey (1964) has divided the neritic plankton into three categories—holoplanktonic, meroplanktonic, and tychopelagic (Text-figure 11).

Nitrate, phosphorus and silica are important limiting factors for their growth, reproduction and distribution. Areas of higher concentration of phosphate in the surface waters of the oceans show abundance of diatoms. Apart from the nutrient supply, there are additional requirements like carbon dioxide and light for the growth and reproduction of the diatoms. They are photosynthetic although a few are heterotrophs and can grow and reproduce in dark or light without carbon dioxide by using the stored organic compounds. Individual diatom species has specific salinity, acidity, oxygen and temperature tolerances. Elements like sulphur, boron, barium, manganese, cobalamin (vitamin B_{12}) and thiamin (vitamin B_1)

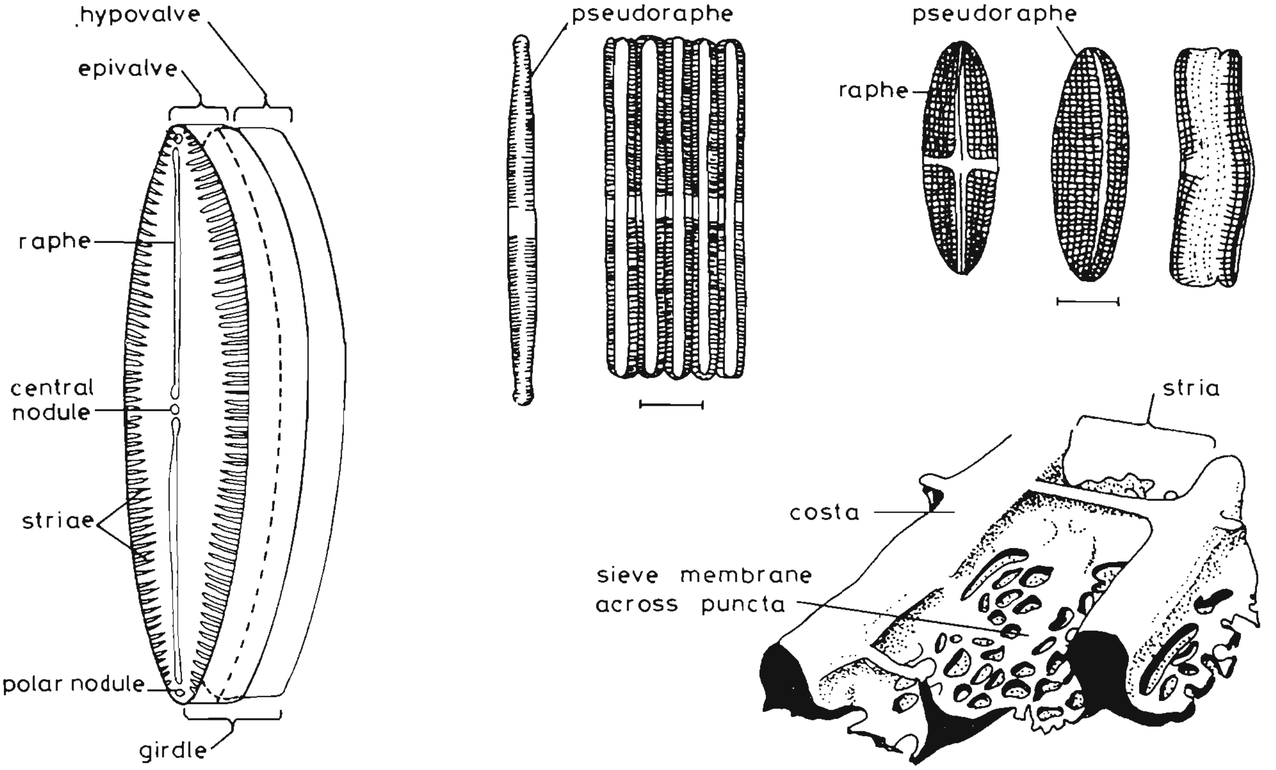


Text-figure 6—Specialized structures and variation of the valve face of centric diatoms which are used in descriptions (after Barron, 1987).

are necessary for the growth of different species. Various species respond to trace elements in the water.

Diatom reproduction is complex and includes asexual and sexual generations as well as spore formation. Simple binary fission is controlled by the intensity and duration of light and nutrient concentration. Just before the fission, the epitheca and hypotheca (Text-figure 12) move slightly away from each other resulting in the separation of two valves. Two new silica valves (daughters) are formed on the exposed protoplasm from the central area outwards within the confines of the parent valve. Each parent valve becomes an epivalve for the daughter cells while each newly formed daughter valve becomes a hypovalve for the daughter cells. Thus, both the original valves become epitheca in new individuals. One can thus visualize a mean size decrease in valve diameter with successive divisions (Text-figure 12). Eventually, however, a viable limit to the size is reached when original size is attained through sexual reproduction and formation of specialized cells known as auxospores. Auxospores are zygotes formed from the sexual fusion of male and female gametes. The female gametes are non-motile and the male gametes are uniflagellate in centric diatoms, while they are morphologically alike and non-flagellate in pennate diatoms (Drebes, 1977).

Many neritic planktonic diatoms have a dimorphic life cycle. The normal planktonic vegetative form alternates seasonally with a thicker walled resting form or cyst or statospore. These statospores may remain within the parent cell or get isolated from it. Restoration of the proper environmental conditions causes the statospore to



Text-figure 7—Pennate diatoms **(a)** *Pinnularia*—oblique view with raphe (after Seagel *et al.*, 1965), **(b)** *Fragilaria*—valve view with pseudoraphe (left and girdle view of colony (right) (after van der Werff & Huls, 1957-63), **(c)** *Achnanthes*—hypovalve view with raphe (left), epivalve view with pseudoraphe (centre) and girdle view (right) (after van der Werff & Huls, 1957-63), **(d)** details of diatom punctae (after Chapman & Chapman, 1973 from Fott.).

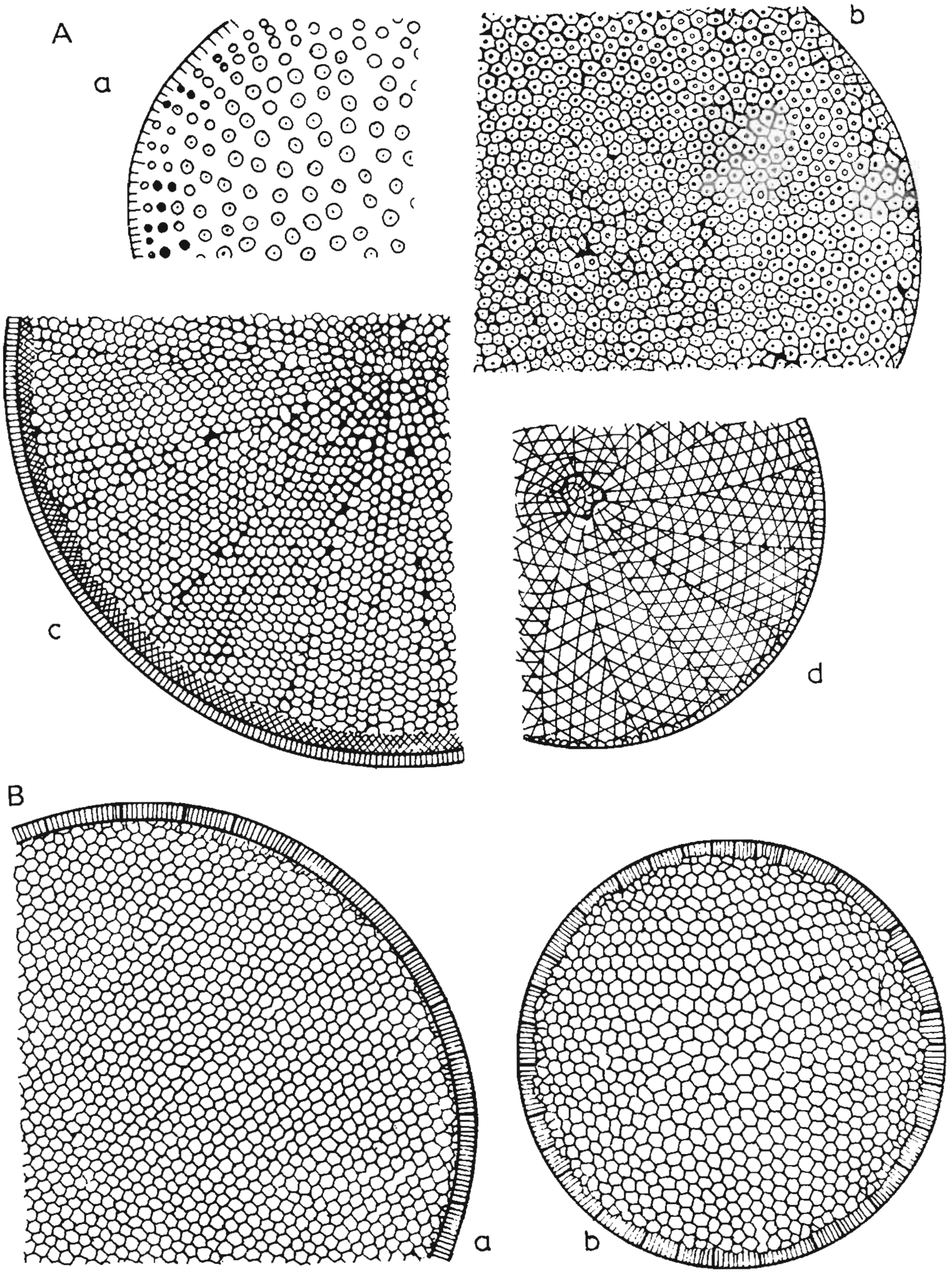
germinate when the cell returns to its normal vegetative stage.

Intense bloom of selected species may be caused by seasonal upwelling. The upwelling enriches the surface water with nutrients within the photic zone. The nutrients otherwise, are normally entrained in deeper waters. The abundance of diatoms may increase one hundred fold in a given volume of sea during blooms which last for two-three weeks and then are terminated at the depletion of the available nutrient supply. This causes a rapid decrease in the abundance of the blooming species. These species then commonly form abundant resting spores. Other species which can survive lower nutrient concentrations increase in abundance. Further changes occur in succession in the local diatom assemblage due to seasonal changes in the local oceanographic conditions. For example, an offshore oceanic assemblage may move into the coastal areas as upwelling conditions and seasonal coastal currents diminish. Freshwater diatoms also experience seasonal blooms when seasonal winds or temperature changes cause mixing of stratified lakes. This brings the nutrients to the surface, where they can be utilized by planktonic diatoms.

PALAEOGEOGRAPHY

Marine diatoms have a similar biogeography as that of radiolarians in the open oceans. High production of diatoms is seen in those areas of oceans where phosphate and nitrate concentration is high (Text-figure 13). Diatoms are most abundant in the areas of upwelling (wind enhanced) where these nutrients (including silica) are brought to the surface from the deep waters. Upwelling, which causes high diatom productivity, may also be caused by diverging surface currents such as in eastern equatorial Pacific. In colder areas of the oceans (near Antarctica and north Pacific, north of about 40°N and south of about 55°S), there is constant nutrient supply due to weak thermocline (surface and deep water temperatures more or less same) resulting again in high diatom productivity.

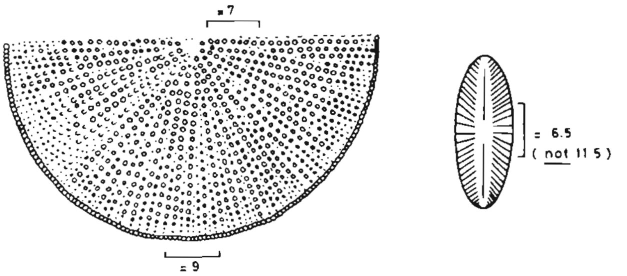
Three major belts of diatomaceous sediments are recognized in the modern oceans: (i) a southern belt encircling the globe between 45°S and 65°S, (ii) a northern belt within the Pacific including Okhotsk, Japan and Bering seas (also developed somewhat in Norwegian sea), and (iii) equatorial belt which is well defined in the Pacific and Indian Oceans and less well defined in the Atlantic (Text-



Text-figure 8—Areolation in Centrales. **A,** radial areolation: **a.** radial, single areolae, **b.** with secondary rows in spirals, **c, d.** radial fasciculate, **d.** curvatulus type; **B,** tangential areolation: **a.** straight row (lineata type, **b.** rows concave towards margin (eccentrica type from Hustedt).

figure 14; Lisitzin, 1972). Distinct planktonic assemblages are found in regions of differing water masses. Within the North Pacific, Kanaya and Koizumi (1966) have described equatorial, subtropical, sub-arctic, northwest marginal and transitional diatom assemblages which reflect different water masses indicating differences in their temperature and salinities.

Non-marine diatoms have similar nutrient (nitrate, phosphate and silica) requirements as those of marine diatoms for their growth and reproduction. They are found practically in all environments having moisture and sunlight. Lakes and ponds (quiet water) are characterized by the planktonic diatoms, while rivers and streams have generally pennate benthic diatoms as the dominant

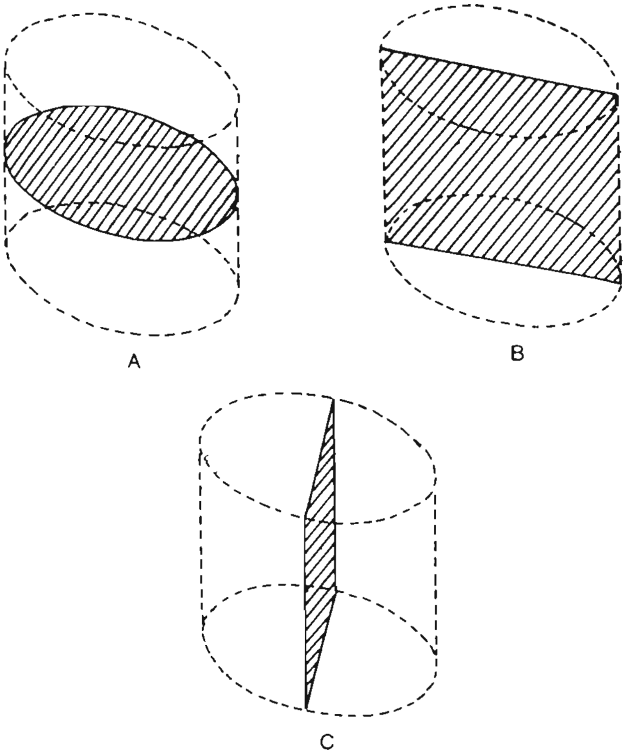


Text-figure 9—Measurement of areolae and striae in centric and pennate diatoms (from Hustedt).

constituent of the assemblage. Non-marine diatomaceous sediments are typically lacustrine in origin.

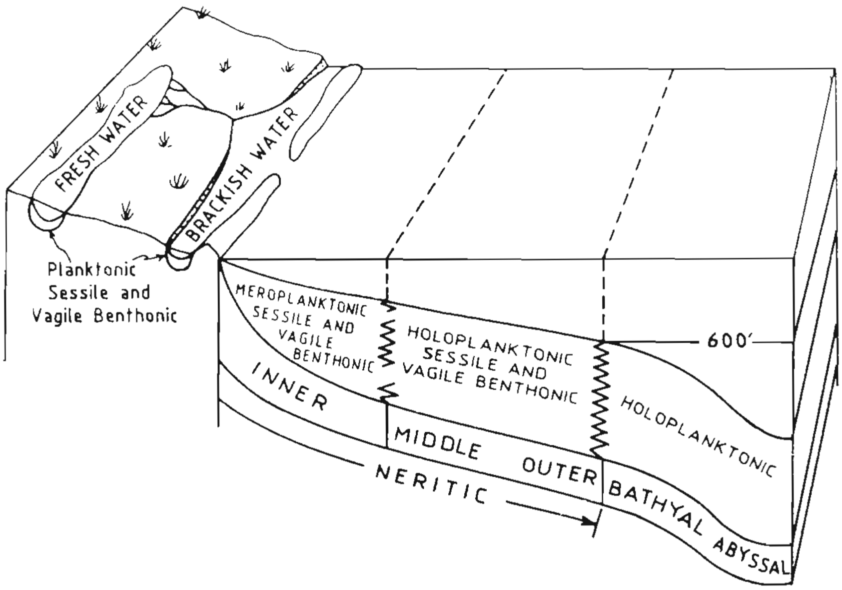
EVOLUTIONARY HISTORY

The oldest reliable records of diatoms are two marine species of *Pyxidicula* from the Early Jurassic (Toarcian Stage) of Germany (Rothpletz, 1896). Diatoms reported from older rocks like Precambrian, Devonian and Carboniferous are contamination (Fenner, 1985). The earliest record of abundant and well preserved diatoms from Campanian is diversified in relation to genera and complex morphology. One would naturally think that they evolved much earlier. Round and Crawford (1981) postulate a much older (before Toarcian) evolution of diatoms and think that the earliest diatoms were spherical in shape and possessed siliceous scales without any siliceous cell wall. Such scales are found in the division Chrysophyta. Round and Crawford (1981) further add that similar scales have been observed in the auxospores of some centric diatoms. Morphology of these spherical diatoms (without any siliceous cell wall) is similar to that of the simplest valve of centric diatoms. These spherical diatoms? either existed as naked protoplasm or were not fossilized at all. Thus the susceptibility of opal-A of diatoms to dissolution and absence of properly developed siliceous frustule (without any siliceous cell wall) explains the missing evidence of the existence of diatoms from the older periods. Fenner (1985) notes three pre-conditions necessary for the preservation of diatoms older than Campanian (Late Cretaceous). These are shallow burial, low heat flow, and sealing off from the dissolution process (e.g., in concretions) early in the rock's diagenetic history.



Text-figure 10—Diatom symmetry. Oblique view showing both the valve and girdle views. **A.** Valvar plane, **B.** Apical plane, **C.** Transapical plane.

Diatom generic extinction rate (23 per cent) at the Cretaceous-Tertiary boundary is very low in comparison to those of coccolithospherids (73 per cent), radiolarians (85 per cent) and planktonic foraminifera (92 per cent) according to the estimates of Kitchell *et al.* (1986). They further observe that many Late Cretaceous diatoms formed non-planktonic resting spore stages and might have the ability to survive short lived catastrophic events such as the global darkening which is postulated at the Cretaceous-Tertiary boundary. Mass extinction of marine diatoms has not been observed during the Cenozoic. However, times of relatively rapid turnover (gradual extinction of many species and their replacement by newly evolved ones) occur in the marine diatom assemblage near the Early Eocene-Middle Eocene boundary, in the middle part of the Oligocene and in the middle part of the Middle Miocene (Fenner, 1985; Barron, 1986). Other periods of changes (abrupt abundance changes of the dominant species of low latitude assemblages) are observed at the end of the Middle Eocene and Oligocene-Eocene boundary (Fenner, 1985). She also observed the increasing provincialism in the Late Eocene to earliest Oligocene which made it difficult to correlate the high and low-latitude assemblages. Latest Miocene (6.5 Ma) was another time of major change when a number of species of *Thalassiosira* evolved, later to characterize the Pliocene (Barron, 1985). Planktonic non-marine diatoms also show major changes in the latest Miocene with the appearance of *Stephanodiscus* and



Text-figure 11—Marine and freshwater environments occupied by diatoms (from Wornardt, 1969).

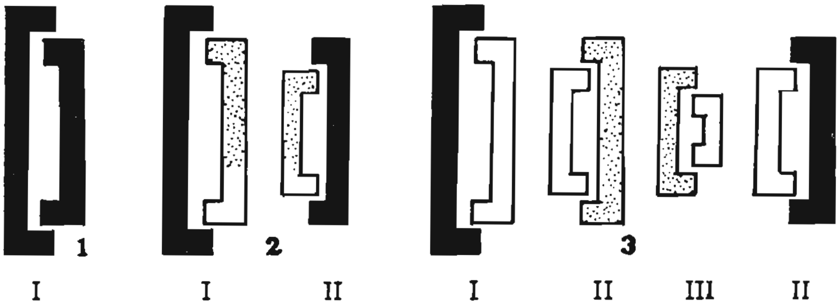
Cyclostephanos which later radiated in the Pliocene and Pleistocene (Krebs *et al.* in Barron, 1987). The latest Pliocene and Pleistocene are characterized by the diatom assemblages which are more or less identical with modern assemblages.

The earliest freshwater diatoms are pennates which were described from the Palaeocene of USSR by Proshkina-Lavrenko (1968). Round and Sims (1981) suggested a separate evolutionary history of freshwater diatoms, different from that of marine diatoms since at least the Cretaceous. They feel that poor taxonomic studies and lack of fossil diatoms in marginal environments make it difficult to understand the origin of freshwater diatoms. According to Round and Sims (1981), invasion of freshwater environment by the diatoms required mutation as no single diatom species is found in both freshwater and marine environments. Freshwater diatoms first diversified during Oligocene (Tappan, 1980). Planktonic freshwater diatoms exhibited expansion during Middle Miocene and Pliocene-Pleistocene (Krebs *et al.* in Barron, 1987). Radiation of freshwater diatoms during the Middle Miocene might have been caused by the increased volcanism which in turn supplied silica for diatom growth and raised the global sea level. This might have eased the invasion of *Actinocyclus* (Krebs in Barron, 1987) into the non-marine environments. Increased Middle Miocene volcanism also created favourable conditions for the preservation of non-marine diatoms in isolated basins (see also 'Association with volcanism' in this paper). Diversification of planktonic freshwater diatoms in the Pliocene-Pleistocene is largely confined to the family Thalassiosiraceae and it may reflect increased seasonality and ability of this group of diatoms to form resting spores to survive changing physical-chemical conditions in the lakes (Barron, 1987).

Numerous evolutionary lineages of the diatom are presented by Small (1944/1945, 1950) for the number of genera and species (both Centrales and Pennales), Simonsen (1972) for the suborders and families of Centrales, Makarova (1975) for the genus *Thalassiosira* and allied Centrales genera and Schrader (1969) for the Pennales.

ASSOCIATION WITH VOLCANISM

Association of diatomaceous rocks with volcanism and volcanic rocks was realized by Taliaferro (1933) and Bramlette (1946) who felt that necessary silica for diatom growth was supplied by volcanism. They substantiated their observations by giving many examples of the association of diatomaceous sediments and volcanic rocks both in marine and non-marine environments throughout the world. However, it is now well known that high production of marine diatoms occurs in the areas of upwelling regardless of the presence or absence of volcanism (Listizin, 1972; Calvert, 1974; Heath, 1974). Heath (1974) on the basis of Calvert's (1966) studies (Gulf of California) suggested that a series of closed basins were formed due to tectonism (divergence and transform faultings along the boundary between the Pacific and North American



Text-figure 12—Girdle views of diatom valves through several reproductive phases. Note the progressive decrease in size of some forms (from Burckle, 1978).

plates). These basins form the site of deposition of modern diatomaceous sediments. This tectonism is associated with Late Cenozoic volcanism and so mixtures of volcanic ash and diatomite are found in the closed basins. Volcanism therefore is indirectly related to the high production of diatoms in the Gulf of California.

The association of non-marine diatomaceous deposits with the volcanic rocks may be more direct. Lacustrine diatomites are typically found in volcanic terrain (Cleveland, 1966) and silica necessary for diatom growth is supplied by volcanic activities. On the other hand, Paasche (1980) feels that silica is rarely a limiting nutrient for diatom growth in lakes. This is supported by the fact that diatoms thrive in numerous lakes which were not associated with volcanism.

SILICA DISSOLUTION AND OVERGROWTH OF FOSSIL DIATOMS

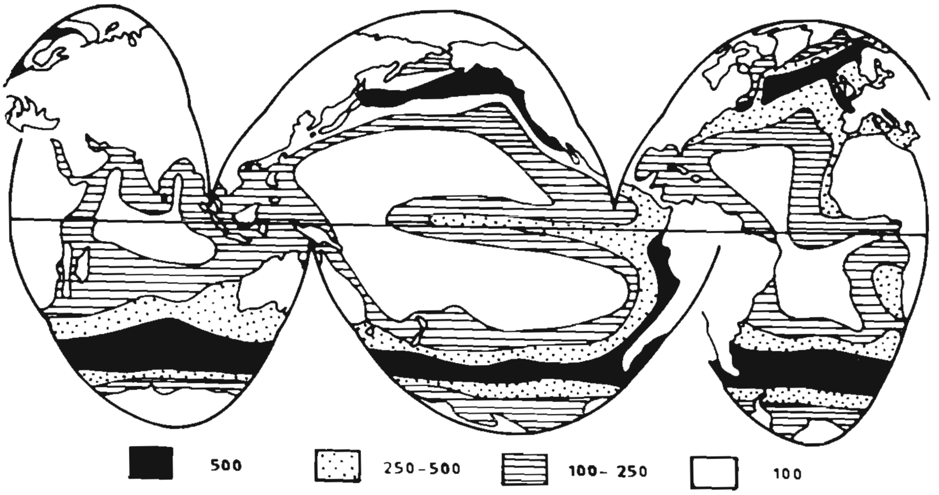
Stratigraphical and palaeoecological interpretations have been given more importance in the study of fossil diatoms. On the other hand, their preservational aspect (silica dissolution and overgrowth) of equal significance has not received due consideration and attention. The highest concentration of diatoms is seen in the upwelling areas of the modern oceans. And we very well know that dissolved silica from oceanic water is incorporated into the diatom valves. This silica (diatom skeleton) is quickly recycled, as 90 to 99 per cent of the diatom valves produced are dissolved before reaching the sediment—water interphase (Lisitzin, 1971). In fact, the fossil diatom assemblage found in the sediments represents only 1-5 per cent of the original living assemblage (Barron, 1985). Incorporation of diatom frustules into copepod fecal pellets in the surface waters is an effective way of saving them from dissolution which also speeds up their descent to the sea floor (Schrader, 1971).

No systematic information of dissolution sequences of different diatom species has been published except the observations made by Lewin (1961) and Schrader (1971, 1972). Work connected with diagenesis has been done by Wise *et al.* (1972 : diatom), Adelseck *et al.* (1973 : siliceous microfossils) and Hein *et al.* (1976 : diatoms).

First report of silica precipitation and overgrowth on diatoms was made by Mikkelsen (1977). She observed the dissolution effects (such as etching, loss of delicate structures and areolar enlargements) by exposing the cleaned fossil diatoms to natural sea water in the laboratory. A small group of species, however, shows overgrowths which were not present in the original assemblage. Mikkelsen (1977) also noticed different degrees of overgrowth on the valve of *Hemidiscus cuneiformis* Wallich which apparently initiated around the areolae of the valve surface. There is thus experimental evidence for the simultaneous occurrence of silica dissolution and overgrowth in diatom diagenesis. According to Mikkelsen (1977) differential dissolution is the chief process which alters the morphology of diatoms and diatom assemblages. Schrader (1972) also observed the alteration of diatom assemblages by dissolution. Thus interpretations of fossil diatom assemblage can be strongly biased due to differential diagenesis of the original assemblages.

PALAEOECOLOGY

Fossil diatoms are used as reliable indicators of palaeoecology and palaeotemperature. The distribution of various living species exactly reflects the difference in temperatures, nutrients, salinity and other physico-chemical parameters of the environments. For better preservation of diatom frustules, it is necessary that they are buried quickly, the burial temperature should not be more than 50°C and the pH less than 7. Sea water as we know,



Text-figure 13—Global variation of the extraction of dissolved silica (g $SiO2$ per m per yr) by phytoplankton in near-surface ocean waters. This represents a good picture of relative diatom production in near-surface waters, because diatoms are the overwhelmingly dominant siliceous phytoplankton group in the oceans (after Calvert, 1974).

is undersaturated with regard to silica. Dissolution of frustules (silica) begins after the death of a diatom. In other words, the longer a diatom frustule is exposed to sea, the more likely it is to be dissolved. It has already been mentioned that only 1-5 per cent of biocoenose (living assemblage) is represented by thanatocoenose (death assemblage) in the sea floor sediments. Frustules preserved in the sediments were either robust or had settled quickly through the water column by settling in aggregates (marine snow) or by inclusion into the fecal pellets (Barron, 1987). Quaternary palaeoecological study combines factor analysis of the modern assemblages with correlation of the factored assemblages to modern temperature and salinity conditions. Pre-Quaternary palaeoecological studies typically involve the quantitative analysis of the diatom assemblages and require interpretation of environmental tolerances of the extinct species.

Ratio of warm to cold water diatoms are used to interpret the palaeotemperature (Kanaya & Koizumi, 1966). Quantitative studies are made down core to determine the fluctuations in diatom assemblages through time and a palaeoceanographic model is developed. This can explain changes in the water mass distribution through time and may allow the estimation of palaeotemperature (Sancetta & Silvestri, 1986).

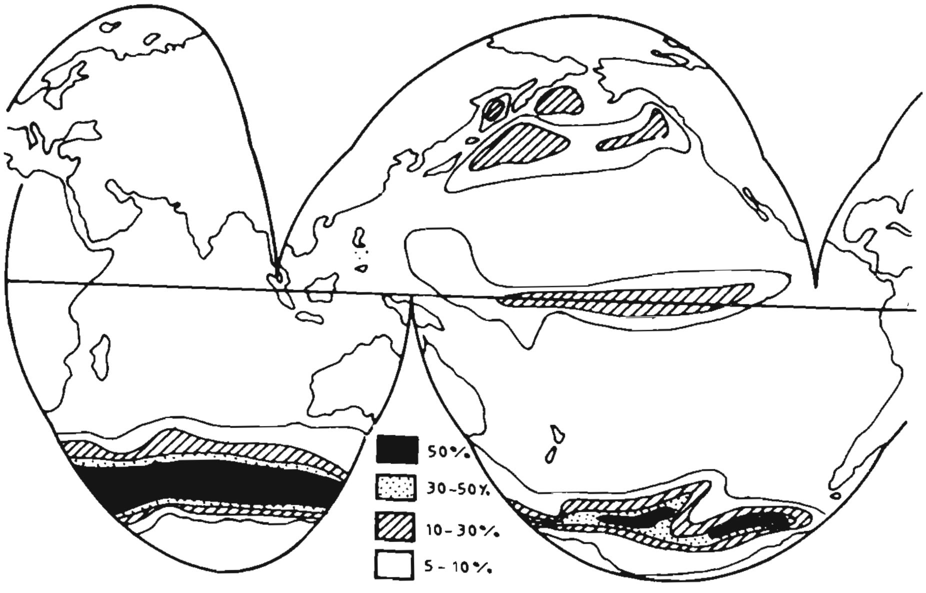
Fossil diatoms may also be used to estimate the palaeosalinity, track the distribution of sea ice in the Antarctic and Arctic, recognize glacial or interglacial bottom currents (identified by the presence of endemic Antarctic diatoms) in the South Atlantic and Indian Oceans (Burckle, 1978). Non-marine diatoms are blown hundred of kilometers into the North Atlantic from dry lake beds of northwest Africa and their presence in marine cores records fluctuations in the degree of aridity in northwest Africa as well as the strength and distribution of the winds.

Palaeolimnological interpretations are also made through the study of fossil diatom assemblages. Changes in lacustrine diatom assemblages exactly indicate the past environmental changes in lakes. Varved lake sediments give a year to year records so that human settlement and industrialization on lake conditions can be monitored through diatom studies (Bradbury, 1975).

Diatoms have too little scope to be used as palaeodepth indicators for they are photosynthetic and live within the photic zone (water depth less than 100 m). Nevertheless, a transect from the strand line to the open ocean meets the assemblage dominated by benthic diatoms through the assemblage dominated by tychopelagic diatoms to the neritic planktonic assemblage and finally to open ocean assemblage. Consequently, it is possible to estimate relative distance to the strand line by analyzing fossil assemblages provided one gives allowances for variations in the down slope transport.

BIOSTRATIGRAPHY

The fundamental principle of biostratigraphy is the evolution and extinction of the species at specific time and this is applied to subdivide the strata on the basis of particular species. Fossil diatoms, in contrast to other microfossils, have many advantages in biostratigraphical interpretations. It is relatively easy to process fossil diatoms that are



Text-figure 14—Distribution and concentration of biogenous opal in surface sediments of the Pacific and Indian oceans on a $CaCo_3$ free basis. Diatoms dominate in the high latitude areas whereas radiolarians dominate by weight per cent in the tropics (after Calvert, 1974).

normally present in large numbers in small quantity of sample. Diatoms are abundant and diverse at higher latitudes where calcareous microfossils are comparatively sparse or low in diversity. They, therefore, serve as primary tool of correlating high latitude deep-sea sediments. Furthermore, the siliceous diatom frustule, as different from calcareous microfossils, is not effected by silica compensation depth and may be preserved in sediments deposited in 6,000 m depth of water.

Tremendous progress in diatom stratigraphy has been made since the Deep Sea Drilling Project (DSDP) started drilling along the continental margin and in high latitudes. DSDP is now known as Ocean Drilling Program (ODP). A more or less complete Tertiary biostratigraphy could be established through the study of deep sea cores which have comparatively less detritus with minimum diagenetic effects. It is difficult to obtain such samples from land based sections for establishing composite biostratigraphy. We have sufficient material (DSDP) with wide geographical distribution from Neogene and Quaternary. This has therefore resulted in the establishment of more refined biostratigraphy for Neogene and Quaternary than that of Late Cretaceous and Palaeocene. Further, many Neogene and Quaternary biostratigraphic events (appearances and extinctions of species) have been correlated directly to the magnetic stratigraphy which in turn makes it possible to correlate the diatom biochronologies beyond the palaeogeographic boundaries. The dichroneity of the appearances and disappearances of species across the latitude can be determined by magnetic stratigraphy. This makes it possible to distinguish the migrational events from the evolutionary ones.

Diatom stratigraphic zonations from Middle Eocene to Oligocene of both low and high latitudes (high northern and southern latitudes) have been proposed by Fenner (1985). Her proposal includes 12 diatom zones for low latitudes, 10 diatom zones for high northern latitudes (Norwegian Sea) and 6 diatom zones for high southern latitudes (Southern Ocean) alongwith their correlation to each other. The paucity of reference sections makes it difficult to correlate different palaeogeographic provinces. Palaeocene to Early Eocene and Campanian-Maastrichtian diatom stratigraphics have been summarized by Fenner (1985). In general, Cretaceous to Early Eocene diatom biostratigraphy is in developing stage. The recovery of Late Cretaceous diatomaceous sediment sequences (long, continuous reference sections) are not frequent. This makes it difficult to assess the palaeoecology of species ranges.

The appearance of the benthic diatoms like any other benthic organism can be time transgressive. Therefore true time stratigraphical correlations are best interpreted on the basis of the planktonic diatoms. Holoplanktonic (open ocean) diatoms are more wide-spread in their distribution in comparison to the benthic or the neritic ones. They are, therefore, widely used for marine diatom biostratigraphy. Nevertheless, application of neritic and benthic diatoms as marker species becomes necessary in shallow water deposits for establishing local diatom zonations in the absence of holoplanktonic diatoms. Correlation of these zonations from shallow water deposits with open ocean zonations therefore becomes a little difficult.

Diatom zonations from low and high latitudes are utilized for biostratigraphical inferences for they are abundant in both climatic regions. Further, there is a great degree of provincialism in these assemblages from different climatic regions particularly in post-Eocene deposits. In low latitudes, abundant diatoms are restricted to more fertile regions of the oceans (e.g., the eastern equatorial Pacific) and are not used as extensively as calcareous microfossils (coccoliths and planktonic foraminifera) for biostratigraphy. All the same, Late Cenozoic low latitude diatom stratigraphy is as refined as calcareous microfossil biostratigraphy and is well correlated to magnetic stratigraphy (Burckle, 1978; Barron, 1985).

Diatoms are particularly useful for correlation in the Southern Ocean and in the North Pacific, north of 40°N. This is for the fact that the calcareous microfossils are scarce or less diverse while well developed radiolarian biostratigraphy is missing in these regions. Many diatom species have bipolar distribution yet only a few show synchronous appearances and extinctions between the Northern and Southern Hemispheres. On the other hand, a number of species are endemic to one or the other region specially since the latest Miocene (ca 6 Ma).

Late Cenozoic (Miocene to Holocene) diatom stratigraphic studies have been concentrated in three main areas of oceans (i) low latitude regions (particularly eastern equatorial Pacific and Indian Oceans), (ii) the middle to high latitude circum-North Pacific, and (iii) the Southern Ocean (Antarctic and sub-Antarctic). Each of these regions has mostly endemic Late Cenozoic diatom assemblage and is represented by separate diatom zonations (Burckle & Opdyke, 1977). Pliocene and Quaternary diatom assemblages of these areas are quite distinct.

In the Late Cenozoic of low latitude four diatom zonations are known (Burckle's, 1972; Schrader's, 1974; Kazarina's, 1975). Barron (1985) summarized the low-latitude zones and sub-zones and proposed 17 zones. A prefix NTD for Neogene Tropical Diatom zone is used, e.g., *Rossiella paleacea* Zone (NTD1), *Craspedodiscus elegans* Zone (NTD2) and so on. Similarly, 12 Neogene North Pacific Diatom zones (NNPD1-NNPD12) and 16 Neogene Southern Ocean Diatom zones (NSD1-NSD16) were proposed for North Pacific and Southern Ocean respectively.

Recent trend in diatom biostratigraphy includes the use of quantitative data as a biostratigraphical tool. Quantitative diatom stratigraphy is more commonly employed in Quaternary, where abundance changes in detailed sample intervals are referenced to oxygen isotope stratigraphy, palaeomagnetic stratigraphy or ^{14}C dating (Sancetta & Silvestri, 1986). Within a palaeoceanographic province, abundant changes may be induced by abrupt and widespread environmental changes which may approach isochroniety. It has been suggested (Burckle *et al.*, 1981) that changes in size in tropical Pacific diatom, *Azpeitia nodulifer* can be used to recognize the last glacial maximum (oxygen isotope stage 2) and preceeding major glacial event (oxygen isotope stage 5e). The development of non-marine diatom biostratigraphy has remained far behind than that of marine diatom biostratigraphy due to many reasons. Some of these are (i) the non-marine deposits normally have limited areal extent which makes it rather difficult to compare the patterns of succession, (ii) these deposits generally are poorly dated by other microfossils (one would not expect to get silicoflagellates, foraminifera or nannoplankton in non-marine sediments), (iii) individual non-marine deposits represent comparatively short period of geological time, and (iv) there were a few specialists who were studying non-marine diatoms (Krebs *et al.* in Barron, 1987). They further think that centric diatoms are more reliable in non-marine diatom biostratigraphy and that periods of diversification of centric non-marine diatoms occurred during the Early Miocene, early Late Miocene and Pliocene.

FOSSIL DIATOMS IN INDIA

Fossil diatoms are known in India since the second half of the nineteenth century almost contemporaneous with the initiation of diatom research in other parts of the world. The first report of the marine fossil diatoms in India is by Ehrenberg (1851) from the Miocene rocks of the Nancoori (now known as Nancowry) Island of the Andaman and Nicobar group of Islands. These rocks containing diatoms from Nancowry were termed as 'Polycystine rocks' by Ehrenberg (1851). Many species of diatoms were described from the same locality of Nancowry (Grunow, 1867; van Heurck, 1880-85; Cleve 1883, Pentocsek, 1889). A few more diatom species from the Nancowry material are included in Schmidt's atlas (1885-1944). 20 to 25 forms were added to the Nancowry diatom assemblage on the examination of the slides of Moller (1868) and Cleve and Moller (1878) respectively (in Desikachary and Ranjitha Devi, 1986). Tempere and Peragallo (1910) have listed 17 diatom species from the Nancowry material. In addition, accounts or original records of diatom from Nancowry are also available in Rattray (1890) and Cleve (1894, 1895). Ghosh and Maitra (1947) reported 27 forms from Nicobar Islands (Miocene Formation) belonging to 14 genera. These are *Navicula, Anomoeneis, Diploneis, Rhaphoneis, Campyloneis, Cocconeis, Cymbella, Auliscus, Triceratium, Stricta, Coscinodiscus, Arachnoidiscus, Actinoptychus* and *Craspedodiscus*. Jacob and Shrivastava (1952) have reported the presence of fossil diatoms from the Miocene rocks of Colebrook Island and other islands of Ritchie's Archipelago without any description or photograph. Desikachary and Maheshwari (1958) made detailed study of diatoms from the Miocene deposits of Colebrook Island which includes 20 forms belonging to 14 genera. Seven species of this assemblage were new records to the known fossil diatoms from the Andaman and Nicobar Islands. Desikachary and Maheshwari (1958) also listed 133 species of diatoms known till then from the Nancowry deposits. Srinivasan and Srivastava (1972) gave stereoscan illustrations of *Annellus californicus* Tempere in Tempere and Peragallo from the Middle Miocene of Nancowry Island. Srinivasan and Srivastava (1977) also described a new species of *Annellus—A. saturnulus* from the Middle Miocene of the Nancowry Island. Desikachary and Ranjitha Devi (1984) reported the occurrence of *Rossiella* Desikachary & Maheshwari from Nancowry deposits. Mathur (1973) reported 15 forms of diatoms belonging to 9 genera from the Round Formation and Strait Sandstone Formation (Early Miocene) of Havelock Island of Richie's Archipelago of Andaman Islands. Perhaps this is the first record of diatoms from well established stratigraphic horizon of Andaman and Nicobar region. Mathur (1981) described 10 species of diatoms belonging to 7 genera from the Strait Sandstone Formation exposed at South Point in Outram Island of Richie's Archipelago which she correlated with *Craspedodiscus coscinodiscus* Zone (Middle Miocene). Subsequently, he (1985) described 27 diatom species belonging to 18 genera including one new species of *Liostephania—L. ovalis* from the Middle Miocene of Nicholson Island of the Richie's Archipelago Group of Islands and found them to represent *Cestodiscus peplum* Zone of early Middle Miocene age. Singh and Vimal (1973) listed 7 diatom species belonging to 5 genera from the Early Pliocene of Neill Island of South Andaman. Singh and Vimal (1976) studied the fossil diatoms in detail from the Sawai Bay Mudstone Formation (Late Miocene—Early Pliocene) of Neill Island by describing 25 forms belonging to 12 genera from the lower part (greyish white) and 8 forms belonging to 7 genera from the upper part (grey coloured) of the Sawai Bay Mudstone Formation. *Coscinodiscus* in the lower part is represented by 8 species. Singh, Vimal and Nautiyal (1978) described 30 species of diatoms belonging to 13 genera from the Early Pliocene of Neill Island, South Andaman. Three species from this assemblage were described as new. Singh (1979) reported additional diatom taxa (30 species belonging to 19 genera) from the Early Pliocene of Neill Island, South Andaman.

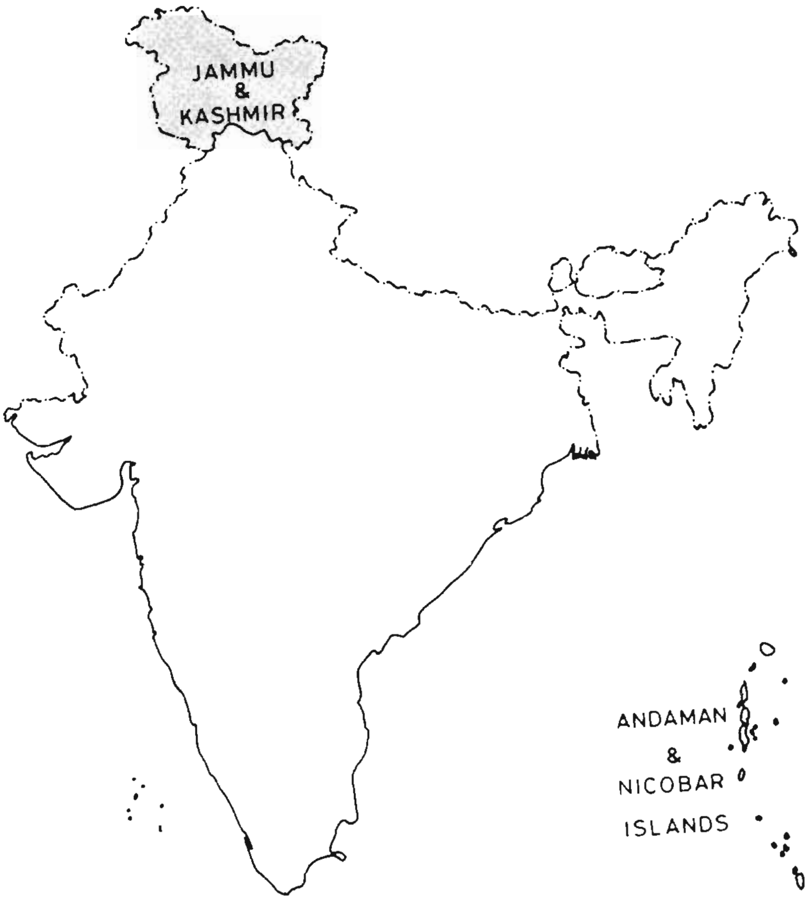
The earliest record of freshwater fossil diatoms in India is from the Lower Karewa Formation (Late Pliocene) of Kashmir by Lundquist (1936). Fossil diatoms from Karewa Formation were subsequently worked out by many others. Cogner in De Terra and Paterson (1939) recorded the occurrence of some species of fossil diatoms from the Karewa beds of Kashmir. In this assemblage, the centric diatoms are represented by two species of *Cyclotella* namely *C. comta* (Ehrenberg) Kutzing and its varieties and *C. kutzingiana* Thwaites from Tatrot Stage of Upper Siwalik Formation (Early Pleistocene) of Naushahra. Iyengar and Subrahmanyan (1943) described 15 species of diatoms from Karewa beds of Kashmir. The centric diatoms in this assemblage are represented by *Cyclotella meneghiniana* Kutzing and *Melosira distans* (Ehrenberg) Kutzing from Gulmarg. Rao and Awasthi (1963) described only centric diatoms from the Pleistocene deposits of Laredura in Kashmir. These are *Melosira* (4 species, 3 varieties new), *Cyclotella* (4 species, one species and one variety new) and *Stephanodiscus* (2 species—one variety new). Roy (1971) listed a rich assemblage of fossil diatoms from the Karewa Formation of Botapathri, Sochalpathri, Baramula and other localities of Kashmir. The centric diatoms in this assemblage are *Coscinodiscus* (1 sp.), *Cyclotella* (3 spp.), *Melosira* (3 spp.) and *Stephanodiscus* (1 sp.), while the pennates are *Achnanthes* (2 spp.), *Amphora* (1 sp.), *Caloneis* (2 spp.), *Cocconeis* (1 sp.), *Cymbella* (9 spp.), *Diatoma, Diploneis*, (2 spp. each), *Epithemia* (5 spp.), *Eunotia* (3 spp.), *Fragilaria* (2 spp.), *Gomphonema* (8 spp.), *Hantzchia* (1 sp.), *Licmophora* (1 sp.), *Navicula* (5 spp.), *Nitzschia* (1 sp.), *Opephora* (1 sp.), *Pinnularia* (5 spp.), *Pleurosigma* (1 sp.), *Rhoicosphenia* (1 sp.), *Rhopalodia* (2 spp.), *Stauroneis* (2 spp.), *Surirella* (1 sp.), *Synedra* (3 spp.), *Tabellaria* (2 spp.) and *Tetracyclus* (1 sp.). Roy (1974) on the basis of fossil diatoms recovered from various localities divided the Karewa Group of

Kashmir into three biostratigraphic zones. These zones were named as Zone-A (Centrales Assemblage Zone), Zone-B (Pennales Assemblage Zone) and Zone-C (devoid of any diatom). He further subdivided the lower Zone-A into *Cyclotella* Subzone and *Melosira* Subzone and the Upper Zone-B (Pennales Assemblage Zone) into *Fragilaria* Subzone, *Cocconeis* Subzone, *Synedra* Subzone, *Cymbella* Subzone, *Eunotia* Subzone, *Tetracyclus* Subzone and *Epithemia* Subzone. Mio-Pliocene age to the Lower Karewa Formation of Kashmir was suggested by Roy (1974) on the basis of fossil diatoms which is questionable (Gandhi, Vora & Mohan, 1985). Roy (1975) examined about 1,000 samples from 32 measured sections of various localities of Karewa Formation of Kashmir for diatom study. Roy (1988) discussed the distribution of fossil diatoms in India and their relationship with the present. He (1988) listed fossil and living diatoms (freshwater and marine) from India known till then. A number of papers were also published dealing with fossil diatoms reported from new localities, their importance in palaeoclimatic and stratigraphic interpretations from the Karewa Formation of Kashmir (Mohan, 1987, 1988a, 1988b, 1989, 1990; Mohan, Gandhi & Vora, 1982; Mohan & Vora, 1986, 1987, 1987a, 1987b, 1988; Gandhi & Mohan, 1983; Gandhi, Mohan & Vora, 1984, 1986; Gandhi, Vora & Mohan, 1984, 1985a, 1985b).

Kolbe (1957) described Quaternary marine diatoms from 23 selected sediment cores comprising 75 samples from the Indian Ocean (off Java, East Indian Ocean, off Ceylon, off Maldives, West Indian Ocean, off Seychelles and off African coast) under the Swedesh Deep-Sea Expedition (1947-48). The maximum core length was 97 m. This is perhaps the first comprehensive report of fossil diatoms from the deep sea sediments of the Indian Ocean. This was followed by contributions by Bukry (1974), Schrader (1974), Desikachary, Latha and Ranjitha Devi (1984), Desikachary, Gowthaman and Latha (1987). Recently Gowthaman and Desikachary (1989) reported some new and interesting fossil diatoms from the DSDP samples of the Indian Ocean region. These are *Craspedodiscus undulatus* Gombos A.M. Jr. from DSDP 24-236 (Upper Oligocene), *Isthmia squinaboli* Forti A. from DSDP 24-237 (Middle Eocene), *Triceratium kanayae* var. *trilobata* Fenner from DSDP 24-236 (Lower Oligocene) and *Triceratium kanayae* var. *quadriloba* Fenner from DSDP 24-236 (Lower Oligocene). A new genus *Quadrodiscus* was instituted by Prema and Desikachary (1989) from the DSDP samples of the Indian Ocean. The proposed species of this genus are *Q. indicus* from the DSDP 22-217 (Oligocene) and *Q. gombosii* (= *Coscinodiscus lewisianus* Grev. f. *concavus* Gombos 1983) of Late Oligocene. Other new taxa described by Prema and Desikachary (1989) are *Porodiscus minor* from the DSDP 22-217 (Oligocene) and *Porodiscus venkataramanii* from the DSDP 22-217 (Oligocene).

It is thus seen that rich, diverse and well preserved fossil diatoms are known from two main areas of India. Out of these, the freshwater diatoms are from the Karewa Formation (Lower Pliocene) of Kashmir while the marine diatoms are from the Neogene Formation of the Andaman and Nicobar group of islands (Text-figure 15). Different localities of Kashmir from where freshwater fossil diatoms are reported include Ara, Baltal, Hirpur, Nadial, Upper Ningle Valley-Botapathri-Sochalpathri-Hakarpathri region, Baramula, Nichahom, Raithan, Narigund, Keach, Arigam, Handwor, Laredura, Liddermarg, Danider, Anchar Lake (Pandach), Arijal, Dainzeb, Tsanam, Badrish nala section, Taundus, Faquirbagh, Wogur and Sangarwain. Various islands of Andaman and Nicobar region from where fossil marine diatoms are known include Neill (Pliocene—Singh & Vimal, 1973, 1976; Singh, Vimal & Nautiyal, 1978; Singh, 1979; Desikachary & Ranjitha Devi, 1986); Nancowry (Miocene—Ehrenberg, 1851, 1954-56; Ghosh & Maitra, 1947; Woodward, 1967; Wornardt, 1971; Desikachary & Ranjitha Devi, 1986; Ranjitha Devi & Desikachary, 1987); Colebrook (Miocene—Jacob & Shrivastava, 1952; Desikachary & Ranjitha Devi, 1986; Ranjitha Devi & Desikachary, 1987); Outram (Middle Miocene—Mathur, 1981); Nicholson (Miocene—Mathur, 1985); Kamorta (Miocene—Desikachary & Ranjitha Devi, 1986); Round (Pliocene—Desikachary & Ranjitha Devi, 1986) and Little Andaman (Desikachary & Ranjitha Devi, 1986). Jacob and Shrivastava (1952) reported the presence of fossil diatoms in the Miocene rocks of Colebrook, Neill, Havelock, John Lawrence, Henry Lawrence and Outram Island without naming any taxa. Fossil diatoms known from the Indian Ocean region come from DSDP Leg 22, sites 211, 213, 215, 216, 217; DSDP Leg 23, sites 220, 221, 223, 225; DSDP Leg 24, sites 232, 233, 236, 237, 238 and DSDP 26, sites 251, 252 (Text-figure 16) in addition to those described by Kolbe (1957) from the sediment cores. The oldest sediment having diatoms from the Indian Ocean region is Lower Eocene. Desikachary (1989) recorded *Nitzschia kanayai* (Desikachary & Gowthaman in Desikachary from this horizon (DSDP 24-237-38-1, level 7-8 cm).

Besides Kashmir region, freshwater diatoms have also been described from the Bengal Delta (Das, 1961), Holocene sediments of Sankrail, Bengal Basin (Gupta & Khandelwal, 1984) and the

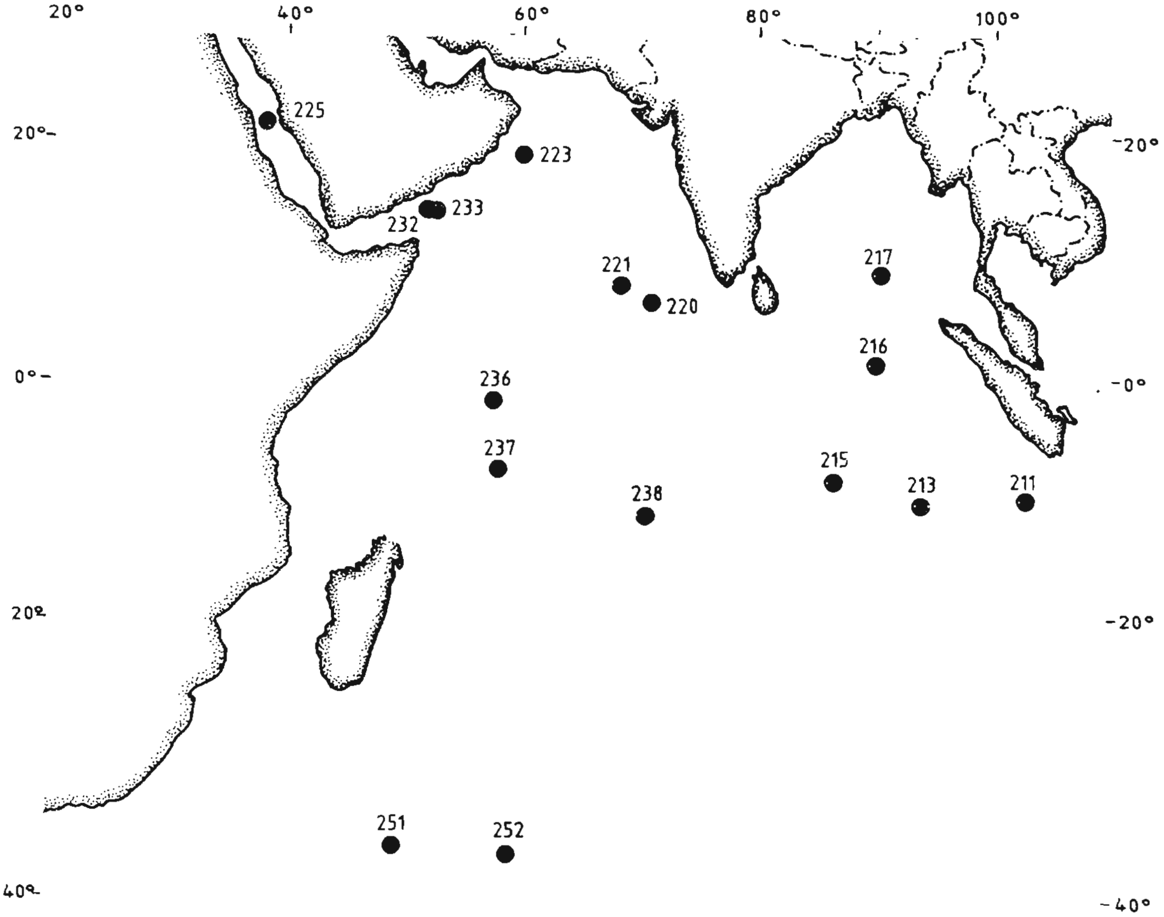


Text-figure 15—Map of India showing two main areas of fossil diatoms.

Holocene sediments of Kua Tal, Nainital (Khandelwal & Gupta, 1989). Roy (1988) identified a number of freshwater diatoms genera from the Godavari delta alluvium and also reported the sporadic occurrence of diatoms in parts of Guntur District, Andhra Pradesh, Santhal Parganas of Bihar, Birbhum and 24 Parganas District, West Bengal and Jodhpur District, Rajasthan.

Similarly apart from Andaman and Nicobar Islands, sporadic occurrence of a few diatom genera from the Quaternary marine sediments of Kerala is reported by Roy (1988). He (1988) also mentioned the occurrence of diatoms from the marine sediments of Meghalaya, Tamil Nadu, etc.

The present paper gives the geological distribution of fossil diatom taxa reported up to 1990 from India with additional and similar information about the diatom taxa known from the DSDP sites of the Indian Ocean region (Table 1). Types of the deposit (freshwater or marine) containing these microfossils are also provided. In marine deposits, the land-based and DSDP sections have been distinguished. The generic distribution of fossil diatoms from India and Indian Ocean region is given (Table 2) which shows the total number of taxa known for a genus in brackets. This is followed by a number (outside the bracket) showing the firmly identified taxa. The non-specifically recognised forms and doubtful taxa like *Achnanthes, Achnanthes* sp., Diatom *indet.*, etc. have been eliminated. Finally total number of diatom genera known from India and Indian Ocean region is provided (Table 3). This comes to 110, out of which only 99 diatom genera are represented by well defined species. Out of 25 genera known from freshwater deposits and 65 from the marine deposits only 19 and 60 are validly represented, respectively. This shows that the ratio of diatom genera from freshwater and marine deposits in India including Indian Ocean region is about 1:3. In the marine deposits, 30 genera are known from land-based sections, while 14 are from the DSDP sections. Valid representation of marine diatom genera from land-based and DSDP sections is 27 and 12 respectively which brings the ratio of diatom genera from land-based and DSDP sections to about 2:1. This invites more investigations on different DSDP sites of the Indian Ocean region for obtaining more number of diatom genera. 21 genera



Text-figure 16—Map showing the location of different DSDP sites of the Indian Ocean from where fossil diatoms are known.

Table 1—Geological distribution of fossil diatom taxa in India and Indian Ocean

TAXA	EOCENE			OLIGOCENE		MIOCENE			PLIOCENE		QUATERNARY		FRESH	MARINE	
	Early	Middle	Late	Early	Late	Early	Middle	Late	Early	Late	Pleistocene	Holocene	WATER	Land sect.	DSDP sect.
Achnanthes exigua											******		******		
A. lanceolata										******			******		
A. lanceolata & varieties										******			******		
A. lanceolata var. *dubia*											******		******		
A. lanceolata var. *elliptica*										******			******		
A. paragalli										******			******		
Achnanthes sp.										******			******		
Achnanthes sp.										******			******		
Achnanthes										******			******		
Actinocyclus cubitus								******							******
A. divisus											******				******
A. ehrenbergii							******	******						******	******
A. ehrenbergii var. *tennella*											******				******
A. ellipticus							******	******			******			******	******
A. ellipticus var. *Elongatus*								******							******
A. ellipticus var. *Janvanicus*							******	******						******	******
A. ellipticus, cf. *Lanceolata*								******							******
A. ellipticus forma							******							******	
A. ellipticus var. *Moronensis?*									******					******	
A. ellipticus sp. 1								******							******
A. elongatus											******	******			******
A. giennensis								******						******	

Contd.

Table 1—Contd.

TAXA	EOCENE			OLIGOCENE		MIOCENE			PLIOCENE		QUATERNARY		FRESH WATER	MARINE	
	Early	Middle	Late	Early	Late	Early	Middle	Late	Early	Late	Pleistocene	Holocene		Land sect.	DSDP sect.
A. ingens								******							******
A. kutzingii									******	******					******
A. moronensis								******	******	******	******			******	******
A. octonarius var. *Tenellus*										******					******
A. ovalis							******							******	
A. peplum							******							******	
A. peplum, Malformations of							******							******	
A. roperii							******							******	
A. srinivasanii							******							******	
Actinocyclus sp. 1							******								******
Actinodictyon weissflogii							******							******	
Actinodictyon sp.									******					******	
Actinoptychus capensis							******							******	
A. sp. cf. *A. chenevierei*						******								******	
A. pulchellus							******							******	
A. senarius							******				******	******		******	******
A. splendens							******							******	
A. sp. cf. *A. splendens* var. *Solisi*						******								******	
A. undulatus						******	******	******	******					******	
A. wittianus							******							******	
Actinoptychus sp.							******							******	
Amphipleura pellucida											******	******	******		
Amphora ovalis										******	******	******	******		
A. ovalis var. *affinis*											******		******		
A. ovalis var. *Baltica*											******		******		
A. ovalis var. *Libyca*										******	******	******	******		
A. ovalis var. *Lyrica*											******				
A. ovalis var. *Pediculus*										******	******	******	******		
Amphora sp.										******			******		
Amphora sp.										******			******		
Amphora									******	******	******	******	******	******	
Anaulus sp. 1								******							******
Annellus californicus							******							******	
A. saturnulus							******							******	
Anomoeoneis sculpta											******		******		
A. sphaerophora											******		******		
Archnoidiscus cibdelus							******							******	
A. ehrenbergii							******		******					******	
A. ehrenbergii var. *nankoorensis*							******							******	
A. indicus							******							******	
A. gungaricus							******							******	
A. sp. cf. *A. mannii*						******								******	
A. ornatus							******							******	
A. rajui									******					******	
A. sastryi									******					******	
A. talukdarii									******					******	
Archnoidiscus sp.									******					******	
Asterolampra acutiloba								******							******
A. affinis							******	******						******	******
A. ambigua							******							******	
A. dubia							******							******	
A. grevillei							******		******	******				******	******
A. marylandica							******		******	******				******	******
A. nankoorensis							******							******	
A. nicobarica							******							******	
A. punctifera						******								******	
Asterolampra, Liostephenia, Stage of									******	******					******
Asterolampra sp.						******								******	
Asteromphalus arachne											******	******			******

Contd.

Table 1—Contd.

TAXA	EOCENE			OLIGOCENE		MIOCENE			PLIOCENE		QUATERNARY		FRESH WATER	MARINE	
	Early	Middle	Late	Early	Late	Early	Middle	Late	Early	Late	Pleistocene	Holocene		Land sect.	DSDP sect.
A. brookei											******				******
A. elegans							******				******			******	******
A. flabellatus							******				******			******	******
A. flabellatus forma							******							******	
A. heptactis									******	******					******
A. hiltonianus				?											******
A. hookeri											******				******
A. imbricatus											******	******			******
Asteromphalus ? marylandica									******					******	
A. moronensis								******							******
A. nankoorensis							******							******	
A. petersonii											******				******
A. robustus											******				******
A. shadboltianus				?											******
A. variabilis							******							******	
Asteromphalus, Liostephania, Stage of									******	******	******				******
Asteromphalus sp. 1									******	******					******
Asteromphalus sp.								******	******					******	
Asteromphalus sp. 1									******					******	
Asteromphalus sp. 2									******					******	
Aulacodiscus amoenus							******							******	
A. angulatus							******							******	
A. argus							******							******	
A. bonei							******							******	
A. crux							******							******	
A. kittoni							******							******	
A. kittoni var. *johnsonii*							******							******	
A. macereaenus							******							******	
A. orientalis							******							******	
A. parvulus							******							******	
A. patulus							******							******	
A. petersii							******							******	
A scaber							******							******	
Auliscus caelatus							******							******	
A. caelatus var. *Major*							******							******	
A. caelatus var. *Rhipis*							******							******	
A. pruinusus							******							******	
A. pruinosus var. *Nankoorensis*							******							******	
A. rhipis							******							******	
A. sculptus var. *Major*							******							******	
A. sculptus var. *Nankoorensis*							******							******	
A. stoeckhardtii							******							******	
Auliscus sp.									******					******	
Azpeitia neocrenulata									******	******					******
A. nodulifer							******							******	
Bacteriastrum spp.									******	******	******				******
? *Bacterosira* sp.									******					******	
Biddulphia infundibuloides									******						******
B. moholensis								******							******
B. tridens									******						******
B. tuomeyi									******					******	
? *Biddulphia* sp.									******					******	
Brunia mirabilis								******							******
Caloneis schumanniana										******			******		
C. schumanniana var. *biconstricta*										******	******		******		
C. schumanniana var. *biconstricta* *f. brevistriata*											******		******		
C. silicula										******		******	******		

Contd.

Table 1—Contd.

TAXA	EOCENE			OLIGOCENE		MIOCENE			PLIOCENE		QUATERNARY		FRESH WATER	MARINE	
	Early	Middle	Late	Early	Late	Early	Middle	Late	Early	Late	Pleistocene	Holocene		Land sect.	DSDP sect.
Caloneis										******			******		
Campylodiscus grevillei									******						******
C. latus							******							******	
C. nankoorensis							******							******	
C. samoensis									******					******	
? *Campylodiscus* sp.									******					******	
Campyloneis grevillei							******							******	
Campyloneis sp.									******					******	
Ceratoneis sp.?											******		******		
Cestodiscus peplum							******							******	
C. pulchellum							******							******	
Chaetoceros compressus							?								******
C. messanensis							?								******
C. peruvianus							?								******
Chaetoceros spp.							?								******
Cladogramma sp.									******					******	
Climacosira mirifica							******							******	
Cocconeis dirupta var. *Sigma*							******							******	
C. disculus										******			******		
C. distans										******			******		
C. lanzii							******							******	
C. pellucida							******							******	
C. pellucida var. *Nankoorensis*							******							******	
C. placentula										******	******	******	******		
C. placentula var. *Euglypta*										******	******	******	******		
C. placentula var. *Lineata*										******	******		******		
C. punctatissima							******							******	
Cocconeis ? *Punctatissima*									******					******	
C. sigma							******							******	
Cocconeis sp.												******	******		
Cocconeis sp. 1									******					******	
Cocconeis sp. 2									******					******	
Cocconeis										******	******		******		
Coscinodiscus aeginensis								******							******
C. africanus									******	******	******				******
C. argus											******	******			******
C. asteromphalus							******		******					******	
C. asteromphalus var. *hybrida*							******							******	
C. asteromphalus var. *omphalanthus*									******					******	
C. sp. cf. *C. asteromaphalus*						******								******	
C. biangulatus							******							******	
C. crenulatus											******				******
C. cribrosus											******	******			******
C. curvatulus							******				******	******		******	******
C. curvatulus var. *minor*							******							******	
C. ellipticus							******							******	
C. endoi							******	******						******	******
C. excentricus							******		******	******	******	******	******	******	******
C. excentricus var. *leasareolatus*									******					******	
C. gigas							******							******	
C. gigas var. *diorama*							******				******			******	******
C. grunowii var. *minor*							******							******	
C. interlineatus							******							******	
C. jonesianus							******					******	******	******	
C. leptolus							******							******	
C. lewisianus							******							******	
C. sp. cf. *C. lewisianus*						******								******	
C. lineatus							******	******	******		******	******		******	******

Contd.

Table 1—Contd.

TAXA	EOCENE			OLIGOCENE		MIOCENE			PLIOCENE		QUATERNARY		FRESH WATER	MARINE	
	Early	Middle	Late	Early	Late	Early	Middle	Late	Early	Late	Pleistocene	Holocene		Land sect.	DSDP sect.
C. lineatus var *ellipticus*											******				******
C. marginatus							******	******	******	******	******	******	******	******	******
C. sp. cf. *C. marginatus*							******							******	
C. minor							******							******	
C. moelleri											******	******			******
C. moronensis										******			******		
C. nankoorensis							******							******	
C. nitidus				?											******
C. nodulifer							******		******		******	******		******	******
C. obscurus							******	******	******	******	******	******	******	******	******
Coscinodiscus ? *oculus-iridis*									******					******	
C. oculus-iridis							******							******	
C. odontodiscus var. *subtilis*							******							******	
C. ovalis							******							******	
C. pacificus									******					******	
C. paleaceus							******	******						******	******
C. partitus							******							******	
C. planiusculus											******	******			******
C. plicatus							******	******	******	******				******	******
C. plicatus group 1									******	******					******
C. plicatus group 2								******							******
C. plicatus group 3								******							******
C. plicatus group 4											******				******
C. plicatus group 5											******				******
C. plicatus group 6											******				******
C. punctatus							******							******	
C. radiatus							******				******			******	******
C. radiatus var. *minor*							******							******	
C. rex							******							******	
C. robustus							******							******	
C. rothii									******					******	
C. rothi var. *subsalsa*												******	******		
C. salisburianus											******	******			******
C. simbirskianus											******	******			******
C. sublineatus							******							******	
C. subtilis							******							******	
C. subtilis var. *scabra*							******							******	
C. superbus							******							******	
C. symbolophorus							******								******
C. symmetricus											******	******			******
C. tabularis var. *egregius*								******	******	******	******				******
C. tabularis var. *egregius*, Liostephania Stage of									******	******	******	******			******
C. temperei									******	******					******
C. turgidus											******	******			******
C. vetustissimus							******		******	******				******	******
C. yabei								******							******
Coscinodiscus spp.												******	******		
Coscinodiscus spp.							******							******	
Coscinodiscus sp.				******										******	
Coscinodiscus spp.				******										******	
Coscinodiscus sp. 1									******					******	
Coscinodiscus sp. 2									******					* ***	
Coscinodiscus sp. 3									******					******	
Coscinodiscus sp.											******	******			******
Coscinodiscus										******	******	******	******	******	
Craspedodiscus coscinodiscus							******							******	
C. coscinodiscus var. *nankoorensis*							******							******	

Contd.

Table 1—Contd.

TAXA	EOCENE			OLIGOCENE		MIOCENE			PLIOCENE		QUATERNARY		FRESH WATER	MARINE	
	Early	Middle	Late	Early	Late	Early	Middle	Late	Early	Late	Pleistocene	Holocene		Land sect.	DSDP sect.
C. insignis							••••••							••••••	
C. nankoorensis							••••••							••••••	
C. nicobaricus							••••••							••••••	
C. undulatus					••••••										••••••
Craspedodiscus sp.							••••••							••••••	
Cussia lancettula								••••••	••••••	••••••					••••••
C. paleacea							••••••	••••••						••••••	••••••
C. praepaleacea								••••••							••••••
C. tatsunokuchiensis				?											••••••
Cussia sp. 1											••••••				••••••
Cussia sp.									••••••					••••••	
Cyclotella catenata											••••••		••••••		
C. comensis										••••••			••••••		
C. comta										••••••	••••••	••••••	••••••		
C. comta ?											••••••		••••••		
C. comta var. *affinis*											••••••		••••••		
C. glomerata												••••••	••••••		
C. iris									••••••	••••••	••••••		••••••		
C. iris & varieties									••••••	••••••	••••••		••••••		
C. iris var. *ovalis*									••••••	••••••	••••••		••••••		
C. iyengaria											••••••		••••••		
C. kutzingiana									••••••	••••••	••••••		••••••		
C. kutzingiana var. *ambigua*										••••••			••••••		
C. kutzingiana var. *planetophora*										••••••	••••••		••••••		
C. kutzingiana var. *radiosa*										••••••	••••••		••••••		
C. meneghiniana										••••••	••••••	••••••	••••••		
C. meneghiniana var. *genuina*												••••••	••••••		
C. ocellata											••••••		••••••		
C. stelligera										••••••			••••••		
C. striata											••••••	••••••			••••••
C. transilvanica										••••••			••••••		
Cyclotella sp.										••••••			••••••		
Cyclotella sp. II										••••••			••••••		
Cyclotella sp. II										••••••			••••••		
Cyclotella sp.								••••••	••••••					••••••	
Cyclotella sp.									••••••					••••••	
Cyclotella sp. 1										••••••			••••••		
Cyclotella sp. 2										••••••			••••••		
Cyclotella									••••••	••••••	••••••	••••••	••••••	••••••	
Cymatopleura elliptica							••••••							••••••	
C. solea							••••••							••••••	
Cymatopleura										••••••			••••••		
Cymbella affinis											••••••		••••••		
C. aspera										••••••	••••••	••••••	••••••		
C. cesatii											••••••	••••••	••••••		
C. cistula											••••••	••••••	••••••		
C. cuspidata										••••••	••••••		••••••		
C. cymbiformis									••••••	••••••	••••••		••••••		
C. ehrenbergii										••••••	••••••	••••••	••••••		
C. gracilis										••••••			••••••		
C. hustedtii											••••••		••••••		
C. lanceolata										••••••	••••••	••••••	••••••		
C. lata										••••••			••••••		
C. leptoceros										••••••	••••••		••••••		
C. leptoceros var. *rostrata*											••••••		••••••		
C. minuta											••••••		••••••		
C. naviculiformis										••••••			••••••		
C. parva							••••••			••••••	••••••		••••••	••••••	

Contd.

Table 1—Contd.

TAXA	EOCENE			OLIGOCENE		MIOCENE			PLIOCENE		QUATERNARY		FRESH WATER	MARINE	
	Early	Middle	Late	Early	Late	Early	Middle	Late	Early	Late	Pleistocene	Holocene		Land sect.	DSDP sect.
C. prostrata											••••••	••••••	••••••		
C. radiosa										••••••			••••••		
C. reinhardtii ?										••••••			••••••		
C. tumida										••••••			••••••		
C. turgida										••••••	••••••	••••••	••••••		
C. turgidula										••••••			••••••		
C. ventricosa										••••••	••••••	••••••	••••••		
Cymbella sp.							••••••							••••••	
Cymbella sp.											••••••		••••••		
Cymbella										••••••	••••••	••••••	••••••		
Denticula hustedtii							••••••	••••••						••••••	••••••
D. lauta									?						••••••
D. sp. cf. *D. lauta*							••••••							••••••	
D. nicobarica							••••••		?					••••••	••••••
D. punctata var. *hustedtii*							••••••								••••••
Denticula sp.									••••••				••••••		
Denticula sp.						••••••								••••••	
Denticulopsis hustedtii							••••••							••••••	
D. nicobarica							••••••							••••••	
Diatom, gen. et sp. indet.									••••••					••••••	
Diatom, unidentified taxon										••••••			••••••		
Diatom, unidentified form										••••••			••••••		
Diatoma vulgare											••••••		••••••		
Diatoma spp.										••••••			••••••		
Diatoma										••••••		••••••	••••••		
Diploneis beyrichiana							••••••							••••••	
D. bombus							••••••							••••••	
B. campylodiscus							••••••							••••••	
D. carabro							••••••	••••••	••••••					••••••	
Diploneis ? crabro									••••••					••••••	
D. crabro var. *pandura*							••••••							••••••	
D. elliptica										••••••			••••••		
D. elliptica var. *elongata*										••••••			••••••		
D. elliptica var. *ladogensis* ?										••••••			••••••		
D. interrupta							••••••							••••••	
D. nicobarica							••••••							••••••	
D. nitescens							••••••							••••••	
D. ovalis							••••••			••••••			••••••	••••••	
D. prisca							••••••							••••••	
D. smithii							••••••			••••••			••••••	••••••	
D. subcincta									••••••					••••••	
D. suborbiculis							••••••							••••••	
D. subovalis											••••••		••••••		
D. subovalis var. *ovata*										••••••			••••••		
D. taschenbergeri									••••••					••••••	
Diploneis spp.									••••••					••••••	
Diploneis sp.							••••••							••••••	
Diploneis									••••••	••••••	••••••	••••••	••••••		
Endictya oceanica							••••••							••••••	
E. robustus							••••••							••••••	
Epithemia argus									••••••	••••••	••••••	••••••	••••••		
E. hyndmanii										••••••	••••••		••••••		
E. sorex										••••••	••••••	••••••	••••••		
E. sorex var. *gracilis*											••••••		••••••		
E. turgida										••••••	••••••	••••••	••••••		
E. zebra										••••••	••••••	••••••	••••••		
E. zebra var. *frickei*										••••••			••••••		
E. zebra var. *porcellus*										••••••	••••••	••••••	••••••		
E. zebra var. *saxonica*										••••••			••••••		

Contd.

Table 1—Contd.

TAXA	EOCENE			OLIGOCENE		MIOCENE			PLIOCENE		QUATERNARY		FRESH WATER	MARINE	
	Early	Middle	Late	Early	Late	Early	Middle	Late	Early	Late	Pleistocene	Holocene		Land sect.	DSDP sect.
E. zebra var. *subcapitata*										••••••			••••••		
Epithemia										••••••			••••••		
Ethmodiscus rex									••••••	••••••	••••••	••••••		••••••	••••••
Euodia gibba							••••••							••••••	
Eunotia alpina										••••••			••••••		
E. flexuosa										••••••			••••••		
E. grunowii										••••••			••••••		
E. jogensis										••••••			••••••		
E. lunaris										••••••			••••••		
E. major										••••••			••••••		
E. monodon										••••••			••••••		
E. pectinalis										••••••		••••••	••••••		
e. pectinalis var. *neglecta*												••••••	••••••		
E. pectinalis var. *undulata*										••••••			••••••		
E. praerupta var. *muscicola*											••••••		••••••		
E. pseudo-pectinalis var. *robusta*										••••••			••••••		
E. robusta										••••••	••••••		••••••		
E. tschirchiana										••••••			••••••		
E. valida										••••••	••••••		••••••		
Eunotia sp.										••••••			••••••		
Eunotia sp.											••••••		••••••		
Eunotia										••••••	••••••	••••••	••••••	••••••	
Eupodiscus junesianus							••••••							••••••	
Fragilaria capucina											••••••	••••••	••••••		
F. construens										••••••	••••••	••••••	••••••		
F. construens var. *baltalensis*										••••••			••••••		
F. construens var. *binodis*										••••••			••••••		
F. construens var. *elliptica*										••••••			••••••		
F. construens var. *subsolina*										••••••			••••••		
F. construens var. *venter*										••••••			••••••		
F. inflata										••••••			••••••		
F. intermedia							••••••							••••••	
F. leptostauron									••••••	••••••	••••••		••••••		
F. leptostauron var. *amphitetras*									••••••	••••••	••••••		••••••		
F. leptostauron var. *dubia*									••••••	••••••	••••••		••••••		
F. leptostauron var. *trigona*										••••••			••••••		
Fragilaria ?nankoorensis							••••••							••••••	
F. pinnata										••••••			••••••		
F. pinnata var. *elliptica*										••••••			••••••		
F. pinnata var. *lancettula*										••••••	••••••		••••••		
F. rumpens var. *familaris*											••••••		••••••		
F. virescens										••••••			••••••		
F. virescens var. *carpitata*										••••••			••••••		
F. virescens var. *lanceolata*										••••••			••••••		
F. virescens var. *mesolepta*										••••••			••••••		
Fragilaria sp.										••••••			••••••		
Fragilaria sp.										••••••			••••••		
Fragilaria									••••••	••••••	••••••	••••••	••••••	••••••	
Frustulia										••••••			••••••		
Gephyria media									••••••					••••••	
G. media var. *ornata*								••••••						••••••	
Glyphodesmis nancoorense								••••••						••••••	
Gomphonema acuminatum										••••••	••••••	••••••	••••••		
G. aequatorialis										••••••			••••••		
G. augur										••••••	••••••		••••••		
G. capitatum										••••••	••••••	••••••	••••••		
G. clavatoides										••••••			••••••		
G. clevatum										••••••			••••••		

Contd.

Table 1—Contd.

TAXA	EOCENE			OLIGOCENE		MIOCENE			PLIOCENE		QUATERNARY		FRESH WATER	MARINE	
	Early	Middle	Late	Early	Late	Early	Middle	Late	Early	Late	Pleistocene	Holocene		Land sect.	DSDP sect.
G. clevei										******	******		******		
G. constrictum										******	******	******	******		
G. constrictum var. *capitata*.											******		******		
G. constrictum var. *capitatum*												******	******		
G. geminatum var. *hybrida*											******	******	******		
G. gracile										******			******		
G. grovei									******	******	******		******		
G. grovei & varieties										******			******		
G. grovei var. *conspicua*									******	******	******		******		
G. grovei var. *lanceolata*									******	******	******		******		
G. grovei var. *rhomboidea*									******	******	******		******		
G. intricatum										******	******	******	******		
G. intricatum var. *dichotomum*										******	******		******		
G. lanceolatum										******			******		
G. longiceps										******			******		
G. montanum											******		******		
G. montanum var. *acuminata*												******	******		
G. olivaceum ?										******			******		
G. parvulum										******			******		
G. sphaerophorum										******			******		
G. subelavatum										******			******		
Gomphonema									******	******	******	******	******		
Grammatophora angulosa var. *islandica*						******							******		
G. hungarica							******							******	
G. longissima							******							******	
G. lyrata							******							******	
G. marina					******				******						******
G. sp. cf. *G. maxima*						******								******	
G. merletta							******							******	
G. robusta					******										******
G. serpentina															******
G. undulata							******							******	
Grammatophora spp.								******							******
Grammatophora spp.									******					******	
Grammatophora											******	******		******	
Gyrosigma acuminatum												******	******		
G. attenuatum											******		******		
Gyrosigma sp.										******			******		
Gyrosigma										******			******		
Hantzschia amphioxys										******	******	******	******		
H. amphioxys var. *densistriata*										******			******		
H. amphioxys var.?										******			******		
Hantzschia									******	******	******		******		
Hemiaulus ambiguus							******							******	
H. ornithocephalus f. *nicobaricus*							******							******	
H. polymorphus							******							******	
Hemidiscus cuneiformis							******	******	******	******	******	******		******	******
H. cuneiformis f. *gibba*							******							******	
H. simplicissimus							******	******	******	******	******				******
Hyalodiscus nobilis							******							******	
H. subtilis							******							******	
Isthmia enervis							******							******	
I. enervis var. *nankoorensis*							******							******	
I. squinaboli		******													******
Licmaphora abbreviata										******			******		
Licmaphora										******			******		
Liostephania ovalis							******							******	
Liostephania, Stages of									******	******					******

Contd.

Table 1—Contd.

TAXA	EOCENE			OLIGOCENE		MIOCENE			PLIOCENE		QUATERNARY		FRESH WATER	MARINE	
	Early	Middle	Late	Early	Late	Early	Middle	Late	Early	Late	Pleistocene	Holocene		Land sect.	DSDP sect.
Liradiscus										******			******		
Mastagloia splendida							******		******		******			******	******
Mastagloia spp.											******				******
Mastagloia										******			******		
Melosira ambigua										******			******		
M. ambigua var. *desikacharya*											******		******		
M. ambigua var. *krishna*											******		******		
M. ambigua var. *laredura*										******	******		******		
M. Arenaria										******	******		******		
M. distans										******	******		******		
M. granulata									******	******	******		******		
M. granulata var. *muzzanensis*											******		******		
M. sulcata							******	******	******	******				******	******
Melosira sp.										******			******		
Melosira sp.												******	******		
Melosira sp.												******	******		
Melosira									******	******	******	******	******	******	
Meridion sp.										******			******		
Navicula ambigua											******	******	******		
N. americana										******			******		
N. amphiphynchus											******	******	******		
N. amphisbaena											******	******	******		
N. anglica										******			******		
N. bacilliformis									******	******	******		******		
N. bacilliformis var. *signata*										******			******		
N. bacillum										******	******		******		
M. borealis											******	******	******		
N. cari var. *angusta*											******		******		
N. cuspidata										******	******	******	******		
N. cuspidata var. *ambigua*												******	******		
N. decussis										******			******		
N. dicephala										******			******		
N. digitoradiata										******			******		
N. elongata										******			******		
N. exigua										******			******		
N. sp. cf. *N. exigua*										******			******		
N. forcipata var. *nankoorensis*							******							******	
N. formosa							******							******	
N. gastrum										******			******		
N. gastrum var. *signata*										******			******		
N. gemmata var. *biseriata*							******							******	
N. graciloites												******	******		
N. hasta							******			******			******	******	
N. hendeyi							******							******	
N. iridis											******		******		
N. lanceolata											******		******		
N. limosa											******	******	******		
Navicula ?lyra									******					******	
N. lyra							******							******	
N. major											******	******	******		
N. mutica										******			******		
N. mutica var. *undulata*										******			******		
N. nebulosa							******							******	
N. oblonga											******	******	******		
N. pelliculosa ?										******			******		
N. peregrina ?										******			******		
N. placentula										******			******		
N. placentula var. *rostrata*											******		******		

Contd.

Table 1—Contd.

TAXA	EOCENE			OLIGOCENE		MIOCENE			PLIOCENE		QUATERNARY		FRESH WATER	MARINE	
	Early	Middle	Late	Early	Late	Early	Middle	Late	Early	Late	Pleistocene	Holocene		Land sect.	DSDP sect.
N. praetexia							••••••							••••••	
N. polygramma											••••••	••••••	••••••		
N. prisca							••••••							••••••	
N. protrecta										••••••			••••••		
N. pseudoscutiformis											••••••		••••••		
N. pupula										••••••			••••••		
N. pupula var. *elliptica*										••••••			••••••		
N. pupula var. *rectangularis*										••••••			••••••		
N. pusilla							••••••							••••••	
N. radiosa											••••••	••••••	••••••		
N. renharti										••••••	••••••		••••••		
N. rhyncocephala var. *amphiceros*												••••••	••••••		
N. schonfeldii										••••••			••••••		
N. scutelloides										••••••	••••••		••••••		
N. sphaerophora											••••••	••••••	••••••		
N. viridis											••••••	••••••	••••••		
N. zanzibarica							••••••							••••••	
Navicula sp.									••••••					••••••	
Navicula sp.												••••••	••••••		
Navicula sp. 1										••••••			••••••		
Navicula sp. 2										••••••			••••••		
Navicula sp. 3										••••••			••••••		
Navicula sp. 4										••••••			••••••		
Navicula sp. 5										••••••			••••••		
Navicula sp.											••••••		••••••		
Navicula										••••••	••••••	••••••	••••••	••••••	
Neidium kozlowi											••••••	••••••	••••••		
N. obliques-striatum var. *parallela*												••••••	••••••		
Neidium										••••••			••••••		
Nitzschia aequatorialis											••••••				••••••
N. amphibia											••••••		••••••		
N. angustata											••••••	••••••	••••••		
N. antarctica							••••••				••••••	••••••		••••••	••••••
N. bacillum											••••••				••••••
N. cylindrica								••••••	••••••	••••••					••••••
N. cylindrica-fossilis											••••••	••••••			••••••
N. cylindrica-fossilis group								••••••							••••••
N. fossilis									••••••	••••••	••••••			••••••	••••••
N. sp. cf. *N. fossilis*									••••••	••••••					••••••
N. hungarica											••••••	••••••	••••••		
N. indica								••••••							••••••
N. interrupta									••••••	••••••	••••••				••••••
N. sp. cf. *N. interrupta*								••••••							••••••
N. jouseae								••••••	••••••	••••••	••••••				••••••
N. kanayai	••••••	••••••	••••••					••••••	••••••	••••••	••••••	••••••			••••••
N. kerguelensis							••••••				••••••			••••••	••••••
N. kolaczeckii										••••••	••••••				••••••
N. macilenta							••••••							••••••	
N. marina								••••••	••••••		••••••	••••••		••••••	••••••
N. sp. cf. *N. marina*								••••••							••••••
N. marina-miocenica group								••••••							••••••
N. miocenica								••••••							••••••
N. moissocensis										••••••			••••••		
N. nicobarica							••••••							••••••	
N. obtusa										••••••		••••••	••••••		
N. palea											••••••	••••••	••••••		
N. palea var. *debillis*										••••••			••••••		
N. porteri								••••••							••••••

Contd.

Table 1—Contd.

TAXA	EOCENE			OLIGOCENE		MIOCENE			PLIOCENE		QUATERNARY		FRESH WATER	MARINE	
	Early	Middle	Late	Early	Late	Early	Middle	Late	Early	Late	Pleistocene	Holocene		Land sect.	DSDP sect.
N. praereinholdii									••••••	••••••					••••••
N. praereinholdii-fossilis group									••••••	••••••					••••••
N. praereinholdii-jouseae group									••••••	••••••					••••••
N. princeps							••••••							••••••	
N. reinholdii								••••••	••••••	••••••	••••••	••••••		••••••	••••••
N. rhombica												••••••	••••••		
N. sigmoidea											••••••	••••••	••••••		
N. seriata										••••••					••••••
Nitzschia sp. 2								••••••							••••••
Nitzschia sp. 4								••••••	••••••	••••••					••••••
Nitzschia sp. 8								••••••	••••••	••••••					••••••
Nitzschia sp. 13								••••••	••••••	••••••					••••••
Nitzschia spp.									••••••					••••••	
Nitzschia sp.												••••••	••••••		
Nitzschia, 2-3 species of										••••••			••••••		
Nitzschia sp. 1										••••••			••••••		
Nitzschia sp. 2										••••••			••••••		
Nitzschia sp. 3										••••••			••••••		
Nitzschia sp. 4										••••••			••••••		
Nitzschia sp. 5										••••••			••••••		
Nitzschia sp. 6										••••••			••••••		
Nitzschia sp. 7										••••••			••••••		
Nitzschia sp. 8										••••••			••••••		
Nitzschia sp.								••••••							••••••
Nitzschia									••••••	••••••	••••••	••••••	••••••	••••••	
Opephora martyi										••••••	••••••		••••••		
O. robusta										••••••			••••••		
Opephora									••••••	••••••	••••••		••••••		
Orthoneis barbapensis var. *nankoorensis*							••••••							••••••	
Paralia sulcata							••••••							••••••	
Pinnularia brevissonii										••••••			••••••		
P. dactylus										••••••			••••••		
P. dactylus var. *hyalina*										••••••	••••••		••••••		
P. dairiana										••••••			••••••		
P. divergens										••••••			••••••		
P. eburnea										••••••			••••••		
P. gentilis										••••••			••••••		
P. gibba										••••••	••••••	••••••	••••••		
P. gibba var. *mesogongyla*										••••••			••••••		
P. lacunarum										••••••			••••••		
P. legumen var. *florentina*										••••••			••••••		
P. major										••••••			••••••		
P. microstauron										••••••			••••••		
P. stauroptera var. *minuta*										••••••			••••••		
P. viridis											••••••		••••••		
Pinnularia sp.										••••••		••••••	••••••		
Pinnularia										••••••	••••••	••••••	••••••	••••••	
Plagiogramma nankoorensis							••••••							••••••	
P. polygibbum							••••••							••••••	
P. sulcatum							••••••							••••••	
P. tessellatum							••••••							••••••	
Planktoniella sol.											••••••				••••••
Pleurosigma angulatum							••••••						••••••		
P. attenuatum										••••••	••••••	••••••	••••••		
P. balticum							••••••							••••••	
P. kutzingii											••••••	••••••	••••••		
P. nicobaricum							••••••							••••••	

Contd.

Table 1—Contd.

TAXA	EOCENE			OLIGOCENE		MIOCENE			PLIOCENE		QUATERNARY		FRESH WATER	MARINE	
	Early	Middle	Late	Early	Late	Early	Middle	Late	Early	Late	Pleistocene	Holocene		Land sect.	DSDP sect.
Pleurosigma sp.												******	******		
Pleurosigma species									******	******	******				******
Pleurosigma sp.										******			******		
Pleurosigma										******			******		
Podocystis javanica							******							******	
P. spathulata							******							******	
Podosira argus							******							******	
Porodiscus minor				******	******										******
P. venkataramanii				******	******										******
Psammodiscus nitidus							******							******	
Pseudoeunotia doliolis									******		******	******		******	******
Pseudostictodiscus eulensteinii							******							******	
Pseudotriceratium obscurum							******							******	
P. punctatum							******					******		******	******
Pyxidicula minuta												******	******		
Pyxidicula reniformis							******							******	
Pyxidicula ?sp.												******	******		
Pyxilla baltica								******	******	******					******
Quadrodiscus indicus				******	******										******
Q. minutus				******	******										******
Rhaphoneis amphiceros							******							******	
R. sp. cf. *R. amphiceros*						******								******	
R. amphiceros var. *antarctica*							******							******	
R. amphiceros var. *elongata*									******					******	
R. amphiceros var. *gemmifera*									******					******	
R. cocconeisformis							******							******	
R. elegans							******							******	
R. sp. cf. *R. elegans*							******							******	
R. gemmifera							******							******	
R. miocenica							******							******	
Rhaphoneis sp.							******							******	
Rhaphoneis sp.									******					******	
Rhaphoneis										******	******	******	******	******	
Rhizosolenia bergonii											******	******			******
R. curvirostris											******	******			******
R. firma											******				******
R. hebetata f. *hiemalis*								******			******	******			******
R. praebergonii									******	******	******	******			******
R. styliformis											******	******			******
Rhoicosphenia curvata										******	******	******	******		
Rhoicosphenia										******			******		
Rhopalodia gibba										******	******	******	******		
R. gibba var. *ventricosa*											******	******	******		
R. parallera										******			******		
Rhopalodia sp.										******			******		
Rhopalodia										******	******	******	******	******	
Roperia praetesselata								******							******
R. tesselata											******	******			******
R. tesselata var. *coscinodiscoides*								?							******
R. tesselata var. *ovata*											******				******
Rossiella paleacea							******							******	
R. sp. cf. *R. paleacea*						******								******	
R. praepaleacea										******					******
R. tatsunokuchiensis									******						******
Rouxia californica								******							******
R. moholensis								******							******
R. naviculoides									******	******					******
Stauroneis acuta var. *tenuis*										******			******		

Contd.

Table 1—Contd.

TAXA	EOCENE			OLIGOCENE		MIOCENE			PLIOCENE		QUATERNARY		FRESH WATER	MARINE	
	Early	Middle	Late	Early	Late	Early	Middle	Late	Early	Late	Pleistocene	Holocene		Land sect.	DSDP sect.
S. anceps										******	******	******	******		
S. legumen										******			******		
S. phoenicenteron										******	******	******	******		
Stauroneis									******	******	******	******	******		
Stephanodiscus astraea										******	******	******	******		
S. astraea var. *bizonata*											******		******		
S. astraea var. *minutula*										******			******		
S. hantzschii										******			******		
Stephanodiscus									******	******	******	******	******	******	
Stephanogonia actinoptychus							******							******	
Stephanopyxis minuta							******							******	
S. nankoorensis							******							******	
S. pandura							******							******	
S. turris							******				******			******	******
S. turris var. *cylindrus*											******	******			******
S. turris var. *intermedia*										******	******	******			******
Stictodiscus argus							******			******				******	******
S. californicus							******							******	
S. californicus var. *aggegata*							******							******	
S. johnsonianus var. *trigona*							******							******	
S. nankoorensis							******							******	
S. sp. cf. *S. nankoorensis*						******								******	
S. novarae							******							******	
S. parallelus							******							******	
S. rota							******							******	
Stictodiscus sp.									******					******	
Stictodiscus sp.										******					******
Strangulonema barbadense							******								******
Surirella biformis										******			******		
S. bifrons											******	******	******		
S. nankoorensis							******							******	
S. ovata											******	******	******		
S. pandura							******							******	
S. patens							******							******	
S. robusta										******	******		******		
Surirella sp.												******	******		
Surirella sp.										******			******		
Surirella sp.												******	******		
Surirella sp.										******			******		
Surirella, 1-2 species of										******			******		
Surirella									******	******	******	******	******	******	
Synedra acus												******	******		
S. capitata										******	******	******	******		
S. crystallina										******			******		
S. formosa					******										******
S. gaillonii											******	******	******		
S. goulardii												******	******		
S. obtusa											******	******	******		
S. jouseana							******							******	******
S. pulchella										******	******	******	******		
S. rumpens var. *meneghiniana*											******		******		
S. ulna									******	******	******	******	******		
S. ulna var. *amphirhynchus*										******			******		
S. ulna var. *biceps*										******	******		******		
S. ulna var. *danica*										******	******		******		
S. ulna var. *oxyrhynchus*							******							******	
S. vitrea											******	******	******		
Synedra sp.										******			******		
Synedra sp.										******			******		

Contd.

Table 1—Contd.

TAXA	EOCENE			OLIGOCENE		MIOCENE			PLIOCENE		QUATERNARY		FRESH WATER	MARINE	
	Early	Middle	Late	Early	Late	Early	Middle	Late	Early	Late	Pleistocene	Holocene		Land sect.	DSDP sect.
Synedra									••••••	••••••	••••••		••••••		
Syringidium americanum							••••••							••••••	
Tabellaria fenestrata										••••••	••••••		••••••		
T. flocculosa										••••••	••••••		••••••		
Tabellaria sp.											••••••		••••••		
Tabellaria										••••••	••••••		••••••		
Tetracyclus emerginata										••••••			••••••		
T. imaginata										••••••			••••••		
T. japonica										••••••	••••••		••••••		
T. lacustris									••••••	••••••	••••••		••••••		
Tetracyclus									••••••	••••••	••••••		••••••		
Thalassionema lineatum											••••••				••••••
T. nitzschioides							••••••	••••••	••••••					••••••	••••••
Thalassiosira antarctica									••••••	••••••	••••••	••••••			••••••
T. burckliana								••••••							••••••
T. convexa									••••••	••••••					••••••
T. convexa S. ampl.								••••••							••••••
T. convexa ?									••••••					••••••	
T. convexa var. *aspinosa*								••••••							••••••
T. excentrica											••••••				••••••
T. sp. cf. *T. excentrica*								••••••							••••••
T gravida											••••••				••••••
T. lineata							••••••							••••••	
T miocenica								••••••	••••••	••••••					••••••
T. nativasensu								••••••	••••••	••••••					••••••
T. oestrupii								••••••	••••••	••••••	••••••				••••••
T. plicata									••••••	••••••	••••••				••••••
T. symbolophora											••••••				••••••
Thalassiosira sp.											••••••				••••••
Thalassiosira sp.												••••••	••••••		
Thalassiosira sp. I								••••••							••••••
Thalassiosira sp. II									••••••	••••••					••••••
Thalassiosira sp. III								••••••	••••••	••••••					••••••
Thalassiosira sp. VI											••••••				••••••
Thalassiosira sp. VII								••••••	••••••	••••••					••••••
Thalassiosira sp.									••••••					••••••	
Thalassiosira spp.							••••••							••••••	
Thalassiothrix frauenfeldii											••••••				••••••
T. longissima											••••••	••••••			••••••
T. monospina								••••••							••••••
Thalassiothrix sp.											••••••	••••••			••••••
Thalassiothrix sp.									••••••					••••••	
Thalassiothrix sp.											••••••	••••••			••••••
Triceratium antedeluvianum							••••••							••••••	
T. arcticum							••••••							••••••	
T. arcticum var. *pentagona*							••••••							••••••	
T. arcticum var. *trigona*							••••••							••••••	
T. broeckii							••••••							••••••	
T. cancellatum						••••••	••••••							••••••	
T. cellulosum var. *japonicum*								••••••	••••••		••••••			••••••	••••••
T. cinnamomeum							••••••							••••••	
T. cinnamomeum var. *minor*											••••••	••••••			••••••
T. cinnamomeum f. *quadrangulata*									••••••	••••••					••••••
T cinnamomeum forma 1								••••••							••••••
T. concinum							••••••							••••••	
T. distinctum						••••••	••••••							••••••	
T. favus							••••••	••••••	••••••					••••••	
T. fimbriatum							••••••							••••••	

Contd.

Table 1—Contd.

TAXA	EOCENE			OLIGOCENE		MIOCENE			PLIOCENE		QUATERNARY		FRESH WATER	MARINE	
	Early	Middle	Late	Early	Late	Early	Middle	Late	Early	Late	Pleistocene	Holocene		Land sect.	DSDP sect.
T grande							******							******	
T. kanayae var. *quadriloba*				******											******
T kanayae var. *trilobata*				******											******
T. madagascarense							******							******	
T megastomum							******							******	
T mucronatum ?									******					******	
T nankoorensis							******							******	
T. nicobaricum							******							******	
T obscurum							******							******	
T. obtusum							******							******	
T pentacrinus f. *quadratum*									******						******
T quinquelobatum							******							******	
T. receptum							******							******	
T. reticulatum							******							******	
Triceratium sp.									******					******	
Triceratium sp.									******					******	
Triceratium											******	******		******	
Trigonium arcticum var. *arcticum*							******							******	
T. arcticum var. *kerguelense*							******							******	
T arcticum var. *quinquelobatum*							******							******	
T. moronense var *nicobarica*							******							******	
Trinacria excavata							******								******
T regina							******								******
Xanthiopyxis oblonga							******							******	

Table 2—Geological distribution of fossil diatoms (generic) in India and Indian Ocean

TAXA	EOCENE			OLIGOCENE		MIOCENE			PLIOCENE		QUATERNARY		FRESH WATER	MARINE	
	Early	Middle	Late	Early	Late	Early	Middle	Late	Early	Late	Pleistocene	Holocene		Land sect.	Dsdp sect.
Achnanthes (9) 5										******	******		******		
Actinocyclus (22) 18							******	******	******	******	******	******		(7) 3	(12)
Actinodictyon (2) 1							******		******					******	
Actinoptychus (9) 6						******	******	******	******		******	******		(8) 1	******
Amphipleura (1)											******		******		
Amphora (9) 6										******	******	******	******		
Anaulus (1)								******							******
Annellus (2)							******							******	
Anomoeoneis (2)											******		******		
Archnoidiscus (11) 9						******	******		******					******	
Asterolampra (11) 9						******	******	******	******	******				(6) 3	(2)
Asteromphalus (21) 14						******	******	******	******	******	******	******		(7) 2	(12)
Aulacodiscus (13)							******							******	
Auliscus (10) 9							******		******					******	
Azpeitia (2)							******		******	******				(1)	(1)
Bacteriastrum (1)									******	******	******				******
?Bacterosira (1)									******					******	
Biddulphia (5) 4								******	******					(2)	(3)
Brunia (1)								******							******
Caloneis (5) 4										******	******	******	******		
Campylodiscus (5) 4							******		******					(4)	(1)
Campyloneis (2) 1							******		******					******	
Ceratoneis (1)											******		******		
Cestodiscus (2)							******							******	
Chaetoceros (4) 3															******
Cladogramma (1)									******					******	
Climacosira (1)							******							******	

Contd.

Table 2—Contd.

TAXA	EOCENE			OLIGOCENE		MIOCENE			PLIOCENE		QUATERNARY		FRESH WATER	MARINE	
	Early	Middle	Late	Early	Late	Early	Middle	Late	Early	Late	Pleistocene	Holocene		Land sect.	Dsdp sect.
Cocconeis (16) 11							••••••		••••••	••••••	••••••	••••••	(7)	(9)	
Coscinodiscus (78) 60						••••••	••••••	••••••	••••••	••••••	••••••	••••••	(1) 3	(37) 9	(28)
Craspedodiscus (7) 6					••••••		••••••							(6)	(1)
Cussia (6) 4							••••••	••••••	••••••	••••••	••••••			(1) 1	(4)
Cyclotella (27) 18								••••••	••••••	••••••	••••••	••••••	(24)	(2)	(1)
Cymatopleura (3) 2							••••••			••••••			(1)	(2)	
Cymbella (26) 22							••••••			••••••	••••••	••••••	(24) 1	(1)	
Denticula (7) 4						••••••	••••••	••••••		••••••			(1)	(2) 1	(3)
Denticulopsis (2)							••••••							••••••	
Diatom, gen. et sp. indet. (1)									••••••					••••••	
Diatom, Unidentified taxon (1)										••••••			••••••		
Diatom, Unidentified form (1)										••••••			••••••		
Diatoma (3) 1										••••••	••••••	••••••	••••••		
Diploneis (22) 18							••••••	••••••	••••••	••••••	••••••	••••••	(6) 2	(14)	
Endictya (2)							••••••							••••••	
Epithemia (11) 10										••••••	••••••	••••••	••••••		
Ethmodiscus (1)									••••••	••••••	••••••	••••••			••••••
Euodia (1)							••••••							••••••	
Eunotia (18) 15										••••••	••••••	••••••	••••••		
Eupodiscus (1)							••••••							••••••	
Fragilaria (25) 21							••••••			••••••	••••••		(22) 1		
Frustulia (1)										••••••			••••••		
Gephyria (2)							••••••							••••••	
Glyphodesmis (1)							••••••							••••••	
Gomphonema (28) 25										••••••	••••••	••••••	••••••		
Grammatophora (13) 9					••••••	••••••	••••••		••••••		••••••	••••••			
Gyrosigma (4) 2										••••••	••••••	••••••	••••••		
Hantzschia (4) 2									••••••	••••••	••••••	••••••	••••••		
Hemiaulus (3)							••••••							••••••	
Hemidiscus (3)							••••••	••••••	••••••	••••••	••••••	••••••		(1)	(2)
Hyalodiscus (2)							••••••							••••••	
Isthmia (3)		••••••					••••••							(2)	(1)
Licmaphora (2) 1										••••••			••••••		
Liostephania (2) 1							••••••		••••••	••••••				(1)	(1)
Liradiscus (1)										••••••			••••••		
Mastagloia (3) 1							••••••		••••••	••••••	••••••		(1)	•••••• 1	(1)
Melosira (13) 9							••••••	••••••	••••••	••••••	••••••	••••••	(12)	•••••• 1	
Meridion (1)										••••••			••••••		
Navicula (65) 53							••••••		••••••	••••••	••••••	••••••	(51) 3	(12)	
Neidium (3) 2										••••••	••••••	••••••	••••••		
Nitzschia (54) 29	••••••	••••••	••••••				••••••	••••••	••••••	••••••	••••••	••••••	(20) 1	(3) 5	(25)
Opephora (3) 2									••••••	••••••	••••••	••••••	••••••		
Orthoneis (1)							••••••							••••••	
Paralia (1)							••••••							••••••	
Pinnularia (17) 15										••••••	••••••	••••••	••••••		
Plagiogramma (4)							••••••							••••••	
Planktoniella (1)											••••••				••••••
Pleurosigma (9) 5							••••••			••••••	••••••	••••••	(4)	(4)	(1)
Podocystis (2)							••••••							••••••	
Podosira (1)							••••••							••••••	
Porodiscus (2)				••••••	••••••										••••••
Psammodiscus (1)							••••••							••••••	
Pseudoeunotia (1)									••••••		••••••	••••••		••••••	••••••
Pseudostictodiscus (1)							••••••							••••••	
Pseudotriceratium (2)							••••••					••••••		(1)	(1)
Pyxidicula (3) 2							••••••					••••••	(2)	(1)	
Pyxilla (1)								••••••	••••••	••••••					••••••
Quadrodiscus (2)				••••••	••••••										••••••
Rhaphoneis (13) 8							••••••		••••••	••••••	••••••	••••••	••••••	(12)	

Contd.

Table 2—Contd.

TAXA	EOCENE Early	EOCENE Middle	EOCENE Late	OLIGOCENE Early	OLIGOCENE Late	MIOCENE Early	MIOCENE Middle	MIOCENE Late	PLIOCENE Early	PLIOCENE Late	QUATERNARY Pleis-tocene	QUATERNARY Holo-cene	FRESH WATER	MARINE Land sect.	MARINE Dsdp sect.
Rhizosolenia (6)								••••••	••••••	••••••	••••••	••••••			••••••
Rhoicosphenia (2) 1										••••••	••••••	••••••	••••••		
Rhopalodia (5) 3										••••••	••••••	••••••	(4) 1	••••••	
Roperia (4)							••••••				••••••	••••••			••••••
Rossiella (4) 3						••••••	••••••		••••••	••••••				(2)	(2)
Rouxia (3)								••••••	••••••	••••••					••••••
Stauroneis (5) 4									••••••	••••••	••••••	••••••	••••••		
Stephanodiscus (5) 4									••••••	••••••	••••••	••••••	(3)	(1)	
Stephanogonia (1)							••••••							••••••	
Stephanopyxis (6)							••••••			••••••	••••••	••••••		(3) 1	(2)
Stictodiscus (11) 8						••••••	••••••	••••••	••••••	••••••	••••••			1	(9) (1
Strangulonema (1)							••••••								••••••
Surirella (13) 7							••••••			••••••	••••••	••••••	(9) 1	(3)	
Synedra (19) 16					••••••		••••••		••••••	••••••	••••••	••••••	(16)	(1) 1	(1)
Syringidium (1)							••••••							••••••	
Tabellaria (4) 2									••••••	••••••	••••••		••••••		
Tetracyclus (5) 4									••••••	••••••	••••••		••••••		
Thalassionema (2)							••••••	••••••	••••••		••••••			•••••• 1	(1)
Thalassiosira (22) 12							••••••	••••••	••••••	••••••	••••••	••••••	(1)	(4)	(17)
Thalassiothrix (6) 3								••••••	••••••		••••••	••••••		(1)	(5)
Triceratium (32) 27				••••••		••••••	••••••	••••••	••••••	••••••	••••••	••••••		(25) 1	(6)
Trigonium (4)							••••••							••••••	
Trinacria (2)							••••••								••••••
Xanthiopyxis (1)							••••••							••••••	

Table 3—Total number of fossil diatom genera known from India and Indian Ocean

FROM FRESHWATER DEPOSITS
(25) 19

FROM MARINE DEPOSITS
(65) 60

FROM LAND SECTIONS
(30) 27

COMMON
(21)

FROM DSDP SECTIONS
(14) 12

GENERA COMMON TO FRESHWATER AND MARINE DEPOSITS (LAND & DSDP) ------ (9)

GENERA COMMON TO FRESHWATER AND MARINE (LAND) DEPOSITS ------ (11)

GENERA COMMON TO FRESHWATER AND MARINE (DSDP) DEPOSITS ------ (NONE)

are common to land-based and DSDP sections, 9 genera are common to freshwater and marine deposits (land-based and DSDP sections) while 11 genera are common to freshwater and marine land sections (Table 2 and 3). No genera have been found to be common in freshwater and marine DSDP sections (Table 2 and 3).

CONCLUSION

Application of fossil diatoms in palaeoecology, biostratigraphy and palaeoceanography is firmly established particularly after the initiation of diatom studies on DSDP and ODP sections. Fossil diatoms have been found to be as reliable as any other group of microfossils in correlation and dating of the rocks. In India, as has already been said, fossil diatoms are known from two main regions—namely Kashmir (Lower Pliocene—freshwater deposits) and Andaman and Nicobar group of Islands (Neogene—marine deposits). It is, therefore, necessary to attempt the recovery of fossil diatoms by expanding the studies both geologically and geographically. We have no records of fossil diatoms from Cretaceous and Palaeogene rocks of India. Therefore it should be interesting to look for these microfossils in these rocks which are well developed in Andaman and Nicobar region. Diatoms from Cretaceous may be helpful in understanding their evolutionary history. Rocks of similar age from the DSDP/ODP sections of the Indian Ocean particularly the deep wells of the Andaman Basin should also be studied. Fossil diatoms from the Palaeogene (Eocene and Oligocene) of the Indian Ocean region are, however, reported by Prema and Desikachary (1989) and Gowthaman and Desikachary (1989).

Some of the new lines of diatom research to be taken up in India should include (i) the use of size changes of diatom valve as a biostratigraphical tool (large-sized individuals measuring more than 60 μm of *Coscinodiscus (Azpeitia) nodulifer* are more abundant during glacial interval—Burckle, Shackleton and Bromble 1981), (ii) shape and size variations of an endemic diatom species and their palaeoceanographic significance, (iii) quantitative diatom assemblage analysis for refining the stratigraphic resolutions between the datum (Gombos & Ciesielski, 1983), (iv) quantitative studies to determine the biogenic siliceous components (diatoms—freshwater and marine, silicoflagellates, radiolarians, sponge spicules, archaeomonadaceae, spermatogonia, ebridians, asterionella and phytoliths) per gram of the sediment, (v) Neogene history of upwelling in Andaman and Nicobar region on the basis of diatoms, and (vi) silica dissolution and overgrowth of fossil diatoms.

ACKNOWLEDGEMENTS

The author is thankful to Dr B. S. Venkatachala, Director and Dr H. P. Singh, Deputy Director of the Sahni Institute for critically going through the manuscript and offering helpful suggestions during the preparation of this paper.

REFERENCES

Adelseck CG, Geehan GW & Roth PH 1973. Experimental evidence for the selective dissolution and overgrowth of calcareous nannofossils during diagenesis. *Geol. Soc. Am. Bull.* **84**(8) : 2755-2762.

Annonymous 1975. Proposals for a standardization of diatom terminology and diagnoses. *Nova Hedwigia Beih.* **53** : 323-354.

Barron JA 1985. Miocene to Holocene planktic diatoms. *In* Bolli HM *et al.* (editors)—*Plankton stratigraphy* : 763-809. Cambridge University Press, Cambridge.

Barron JA 1986. Response of equatorial Pacific diatoms to polar cooling during the Middle Miocene. *In* Ricard M (Editor)—*Proc. 8th int. Diatom Symposium on Recent and fossil diatoms, Paris (1984)* : 591-600. Koeltz Scientific Books, Koenigstein, W. Germany.

Barron JA 1987. Diatoms. *In* Broadhead TW (Editor)—*Fossil prokaryotes and protists, Notes for a short course. Studies in Geol.* **18** : 128-147 University of Tennessee, Department of Geological Sciences.

Bradbury JP 1975. Diatom stratigraphy and human settlement in Minnesota. *Geol. Soc. Am. Spec. Pap.* **171** : 1-74.

Bramlette MN 1946. The Monterey Formation of California and the origin of its siliceous rocks. *U.S. Geol. Surv. Prof. Paper* **212** : 1-57.

Brasier MD 1980. *Microfossils.* George Allen & Unwin Ltd., London.

Bukry D 1974. Coccolith and silicoflagellate stratigraphy, eastern Indian Ocean, Deep Sea Drilling Project, Leg 22. *In* von der Borch CC *et al.* (editors)—*Initial Rep. Deep Sea Drilling Project* **22** : 601-607. U.S. Government Printing Office, Washington.

Burckle LH 1972. Late Cenozoic planktonic diatom zones in equatorial Pacific sediments. *Abstr. Geol. Soc. Am.* **7** : 24.

Burckle LH 1978. Marine diatoms. *In* Haq BU & Boersma A (editors)—*Introduction to marine micropalaeontology*: 245-266. Elsevier North Holland, Inc., New York.

Burckle LH & Opdlyke ND 1977. Late Neogene diatom correlations in the Circum-Pacific. *In Proc. 1st int. Congr. Pac. Neogene Stratigr., Tokyo 1976* : 255-284. Kaiyo Shuppan Co. Ltd., Tokyo.

Burckle LH, Shackleton NJ & Bromble SL 1981. Late Quaternary stratigraphy for the equatorial Pacific based upon the diatom *Coscinodiscus nodulifer. Micropalaeontology* **27** : 352-355.

Calvert SE 1966. Accumulation of diatomaceous silica in the sediment of the Gulf of California. *Geol. Soc. Am. Bull.* **77**(6) : 569-596.

Calvert SE 1974. Deposition and diagenesis of silica in marine sediment. *Spec. Publ. int. Assoc. Sedimentol.* **1** : 273-299.

Chandra A 1991. *A catalogue of fossil plants from India.* Pt. **8**. *Diatoms and silicoflagellates.* Birbal Sahni Institute of Palaeobotany, Lucknow.

Cleve PT 1983. Diatoms collected during the expedition of the *"Vega" Ur Vega-Expeditionens Vetenskepliga iakttagelser* **3** : 457-517

Cleve PT 1894-95. Synopsis of the Naviculoid diatoms. *K. svenska VetenskAkad. Handl.* **26**(2) : 194; **27** : 1-219.

Cleve PT & Möller JD 1877-1882. Diatoms (exsiccata). Uppsala Slides : 1-48 (1877); 49-108 (1878); 109-168 (1878); 169-216 (1879); 217-276 (1881); 277-324 (1882). Esatas Edquists Boktryckeri.

Cleveland GB 1966. Diatomite in mineral and water resources of California. *California Div. Mines and Geol. Bull.* **191** : 151-158.

Collier A & Murphy A 1962. Very small diatoms : preliminary notes and description of *Chaetoceros galvestonensis. Science* **136** : 780-781.

Das P 1961. Recent microscopic flora from the Bengal Delta, India. *Micropalaeontology* **7**(1) : 87-94.

Desikachary TV 1952. Electron microscope study of the diatom wall structure. *J. scient. industr. Res.* **11B** : 491-500.

Desikachary TV 1954a. Electron microscope study of the diatom wall structure-III. *Amer. J. Bot.* **41**(8) : 616-619.

Desikachary TV 1954b. Electron microscope study of the diatom wall structure-VI. *Mikroskopie* **9**(5/6) : 168-178.

Desikachary TV 1954c. The structure of the areolae in diatoms. *8th Congress int. Bot. Paris. Rapp. & Comm. Sect.* **17** : 126.

Desikachary TV 1956. Electron microscope studies of diatoms. *J. R. Micr. Soc.* **76** : 9-36.

Desikachary TV 1989. Marine diatoms of the Indian Ocean region. *In* Desikachary TV (Editor)—*Atlas of diatoms, Fascicle VI* : 1-13. Madras Science Foundation, Madras.

Desikachary TV & Bahadur K 1954a. Electron microscope study of diatom wall structure-II. Genus *Chaetoceros* Ehrenberg. *J. scient. industr. Res.* **13B** : 92-94.

Desikachary TV & Bahadur K 1954b. Electron microscope study of diatom wall structure-IV *J. scient. industr. Res.* **13B**(4) :

240-243.

Desikachary TV & Bahadur K 1954c. Electron microscope study of diatom structure-V. *Trans. Am. micros. Soc.* **73** : 274-277

Desikachary TV, Gowthaman S & Latha Y 1987. Diatom flora of some sediments from the Indian Ocean region. *In* Desikachary TV (Editor)—*Atlas of diatoms, Fascicle* **11** : 1-10. Madras Science Foundation, Madras.

Desikachary TV, Latha Y & Ranjitha Devi KA 1984. *Rossiella* and *Bogorovia* : two fossil diatom genera. *Palaeobotanist* **32** : 337-340.

Desikachary TV & Maheshwari CL 1958. Fossil diatoms from Colebrook Island. *J. Indian bot. Soc.* **37**(1) : 27-41.

Desikachary TV & Ranjitha Devi KA 1986. Marine fossil diatoms from India and Indian Ocean region. *In* Desikachary TV (Editor)—*Atlas of diatoms, Fascicle* **1** : 1-8 Madras Science Foundation, Madras.

De Terra H & Paterson TT 1939. *Studies on the ice age in India and associated human cultures.* Carnegie Instn., Washington.

Drebes G 1977. Sexuality. *In* Werner D (Editor)—*The biology of diatoms : botanical monograph no.* **13** : 250-283. University of California Press, Berkeley & Los Angeles.

Ehrenberg CG 1838. *Die Infusionsthiereben als Vollkommende Organismen. Ein Blick in das teifere Organische Leben der Natur,* p. i-xvii, 1-548, Atlas, pl. 1-64. Leopold Voss, Leipzig.

Ehrenberg CG 1851. On the extensive rock formation of siliceous *Polycystina* from the Nicobar Island. *Berlin Monatsbericht* : 476-478.

Ehrenberg CG 1854-1856. *Microgeologie. Das Erden und Felsen Schaffende Wirken des unsichtbar Kleinen selbstandigen Lebens auf der Erde.* Leopold Voss, Leipzig, Texte 3745. (1854). Atlas, 40 Tafeln (1854). Furtsetzung 1885 (1856).

Fenner J 1985. Late Cretaceous to Oligocene planktonic diatoms. *In* Bolli HM *et al.* (editors)—*Plankton stratigraphy* : 713-762. Cambridge Univ. Press, Cambridge.

Gandhi HP & Mohan DJ 1983. Fossil diatoms from Baltal, Kashmir. *Man Environment* **7** : 154-156.

Gandhi HP, Mohan DJ & Vora AB 1984. Preliminary observation on Baltal and Ara sediments, Kashmir. *In* Badve RM *et al.* (editors) —*Proc. 10th Indian Colloq. Micropalaeont. Stratigr., Pune 1982* : 555-570. Maharashtra Association for the Cultivation of Science, Pune.

Gandhi HP, Mohan DJ & Vora AB 1986. Ecology of diatoms from the Karewa beds of the Baltal area, Kashmir, India. *Bull. geol. Min. metall. Soc. India* **54** : 159-161.

Gandhi HP, Vora AB & Mohan DJ 1984. Diatoms as one of the important parameters to ascertain geological age of sedimentary rocks and palaeoeconomical and palaeoclimatic conditions. *4th Annual Conf. Indian Geograph., Ahmedabad 1984* : 26-27. Gujarat University, Ahmedabad (Abst.).

Gandhi HP, Vora AB & Mohan DJ 1985a. Fossil diatoms from Baltal, Karewa beds of Kashmir. *Curr. Trends in Geology (Climate and Geology of Kashmir)* **6** : 61-69.

Gandhi HP, Vora AB & Mohan DJ 1985b. Review of the fossil diatom flora of the Karewa beds of Kashmir. *Curr. Trends in Geology (Climate and Geology)* **6** : 57-60.

Ghosh AK & Maitra SC 1947. On the occurrence of diatomaceous earth in the Nicobar Islands. *Trans. natn. Inst. Sci. India* **2** : 441-450.

Gombos AM Jr 1983. Survey of diatoms in the Upper Oligocene and Lower Miocene in Holes 515B and 516F. *In* Barker PF & Carlson RL *et al.* (editors)—*Initial Rep. Deep Sea Drilling Project* **72** : 565-581. U.S. Government Printing Office, Washington.

Gombos AM Jr & Ciesielski PF 1983. Late Eocene to Early Miocene diatoms from the southwest Atlantic. *In* Ludwig WJ, Krasherinitov VA *et al.* (editors)—*Initial Rep. Deep Sea Drilling Project* **71** : 583-634. U.S. Government Printing Office, Washington.

Gowthaman S & Desikachary TV 1989. Some new and interesting fossil diatoms. *Phykos* **28**(1-2) : 132-135.

Grunow A 1867. Algae Reise sciener Majestat Fregatte "Novara" um die Erde in den Jahren, 1857, 1858, 1859. *Bot. Teil.* **1** : 1-104.

Gupta HP 1974. Indian fossil diatoms. *In* Surange KR, Lakhanpal RN & Bharadwaj DC (editors)—*Aspects & appraisal of Indian palaeobotany* : 29-37. Birbal Sahni Institute of Palaeobotany, Lucknow.

Gupta HP & Khandelwal A 1984. Holocene diatoms from Sankrail, Bengal Basin, India. *In* Tiwari RS *et al.* (editors)—*Proc. 5th Indian geophytol. Conf., Lucknow (1983) Spl. Publ.* : 355-358. Palaeobotanical Society, Lucknow.

Gupta HP & Khandelwal A 1986. Diatom analysis of Hirpur Locality-III (Lower Karewa), Kashmir Valley. *Palaeobotanist* **35** : 357-362.

Heath GR 1974. Dissolved silica and deep-sea sediments. *In* Hay WW (Editor)—*Studies in palaeoceanography, Soc. Econ. Palaeontol. Min. Spec. Publ.* **20** : 77-93.

Hein JR, Scholl DW & Gutmacher CE 1976. Diagenesis of Neogene diatomaceous sediment from the far northwest Pacific and Southern Bering Sea. *Geol. Soc. Am. Abst. with Programs* **8** : 379-380.

Hendey NI 1964. *An introductory account of the smaller algae of British coastal waters, Part V : Bacillariophyceae (Diatoms).* Ministry of Agriculture, Fisheries and Food, Fisheries Investigations.

Hendey NI, von Stosch HA & Kowallik K 1969. The fine structure of the frustules of *Cylindropyxis profunda* Hendey 1964, Coscinodiscaceae, a very small centric marine diatom. *Nova Hedwegia, Beih.* **18** : 175-180.

Hustedt F 1927-1966. Die Kieselalgen in Deutschlands. Osterreichs und der Schweiz. *In* Rabenhorst L. (Editor)—*Kryptogamen Flora von Deutschland, Osterreich und der Schweiz* **7** : 1-920, figs. 1-542, 1927-1930; 2 : 1-845, figs. 543-1179, 1931-1959; 3 : 1-816, figs. 1180-1788, 1962-1966, Akademie Verhasges, Leipzig.

Iyengar MOP & Subrahmanyan R 1943. Fossil diatoms from the Karewa beds of Kashmir. *Proc. natn. Acad. Sci. India* **13**(4) : 225-237.

Jacob K & Shrivastava RN 1952. Fossil radiolaria and silicoflagellata from the Tertiary clays of Colebrook Island and the Ritchie's Archipelago, Andaman Islands. *Sci. Cult.* **17** : 346-348.

Kanaya T 1957. Eocene diatom assemblages from the Kellog and 'Sidney' Shales, Mt. Diablo area, California. *Sci. Rep. Tohoku Univ.*, ser. 2, *Geol.* **28** : 27-124.

Kanaya T & Koizumi J 1966. Interpretation of diatom thanatocoenoses from the North Pacific applied to a study of core V 20-130 (Studies of a Deep Sea Core V 20-130, part IV). *Sci. Rep. Tohoku Univ.*, ser 2, *Geol.* **37** : 89-130.

Kazarina GK 1975. Diatom zones in the sediments of the eastern tropical region of the Indian Ocean. *Okednol. Akad. Nauk.* **15** : 1073-1078 (in Russian).

Khandelwal A & Gupta HP 1989. Fresh water diatoms from Kua Tal, district Nainital, Kumaon Himalaya, Uttar Pradesh. *Palaeobotanist* **37** : 180-184.

Kitchell JA, Clark DL & Gombos AM Jr 1986. Biological selectivity of extinction. *Palaios* **1** : 504-511.

Kolbe RW 1957. Diatoms from equatorial Indian Ocean. *Swedish Deep Sea Expd. (1947-48) Rept.* **9**. *Sediment Cores from the Indian Ocean* **1** : 55. Goteberg.

Lewin JC 1961. The dissolution of silica from diatom walls. *Geochim. Cosmochim Acta* **21** : 182-198.

Lisitzin AP 1971. Distribution of siliceous microfossils in suspension and in bottom sediments. *In* Funnel BM & Reid WR (editors)—*The Micropalaeontology of Oceans* : 223-230. Cambridge University Press, Cambridge.

Lisitzin AP 1972. Sedimentation in World Ocean. *Soc. Econ. Palaeontol. Min. Spec. Publ.* **17** : 218.

Lundquist E 1936. Hochasiatisch Binnensee sedimente. *Connecticut Acad. Arts Sci. Mem.* **10** : 193-238.

Markarova IV 1975. On the taxonomic position of the genus *Thalassiosira* Cleve and the phylogeny of the family Thalassiosiraceae Lebour emend. Hasle (Bacillariophyta) (In Russian). *Bot. J.* **60** : 1413-1420.

Mathur K 1973. Studies in the fossil microflora of Andaman Islands-2 : fossil diatoms from Havelock Island. *Geophytology* **3** : 103-134.

Mathur K 1981. Silicoflagellates, diatoms and other fossils from Outram Island, Andaman Sea, Andaman, India. *Geosci. J.* **2**(1) : 31-42.

Mathur K 1985. Middle Miocene diatoms from Nicholson Island, Andaman Sea, India *Geosci. J.* **6**(1) : 81-94.

Mathur K 1987 Studies on the Neogene diatoms, silicoflagellates and nannoplankton of Havelock Island, Andaman Sea, India. *Int Symp. on Phycology, Madras (1987).* Centre of Advanced Study in Botany, Madras University, Madras (Abst.) : 41.

McHugh JL 1954. Distribution and abundance of the diatom *Ethmodiscus rex* off the west coast of North America. *Deep Sea Res.* **1** . 216-222.

Mikkelsen N 1977 Silica dissolution and overgrowth of fossil diatoms. *Micropalaeontology* **23**(2) : 223-226.

Mohan DJ 1987 Diatoms as markers of changes in palaeoclimatic and palaeoenvironment of Karewa beds, Kashmir, India. *Int. Phycotalk Symp., Varanasi (1987).* Centre of Advanced Study in Botany, Banaras Hindu University, Varanasi (Abst.) : 18.

Mohan DJ 1988a. Climato-diatomological investigations of Karewa beds, Kashmir, India. *In* Patel MP *et al.* (editors)—*Proc. natn. Sem. Rec. Quat. Studies, Baroda (1988)* : 211-223. Geology Department, Maharaja Sayajirao University, Vadodara.

Mohan DJ 1988b. Diatoms and the palaeoclimate, palaeoenvironment and stratigraphy of Kashmir sedimentary sequences. *The Neogene of Karakoram and Himalayas (1988).* University of Leicester, Leicester, London (Abst.).

Mohan DJ 1989. Climato-diatomological results from Baltal-Lower Karewa beds, Kashmir, India. *Curr. Sci.* **58**(6) : 294-300.

Mohan DJ 1990. Known and unknown fossil diatoms from Karewa Deposits, Kashmir, India. *In* Rajarao VN (Editor)—*Perspective in phycology (Prof. M.O.P. Iyenger Centenary Celebration Volume), Int. Symp. on Phycology (1987).* Centre of Advanced Study in Botany, Madras University, Madras.

Mohan DJ, Gandhi HP & Vora AB 1982. Fossil diatoms from Baltal, Karewa beds of Kashmir. *Int. Workshop on the Late Cenozoic palaeoclimatic changes in Kashmir and Central Asia, Ahmedabad (1982).* Physical Research Laboratory, Ahmedabad (Abst.).

Mohan DJ & Vora AB 1986. Pleistocene diatoms from Karewa beds, Kashmir, India. *In* Biradar NV (Editor)—*Proc. Spl. Indian geophytol. Conf., Pune (1986)* : 109-112.

Mohan DJ & Vora AB 1987. Ecology of fossil diatoms from Ara, Karewa beds of Kashmir (India). *Curr. Sci.* **56**(19) : 995-998.

Mohan DJ & Vora AB 1987a. Living and sub-fossil diatoms of Anchar Lake (Pandach), Kashmir, India. *All India Seminar on Advances in Botanical Res. in India during the last ten years, Bikaner (1976-1986)* : 4. Department of Botany, Dungar College, Bikaner (Abst.).

Mohan DJ & Vora AB 1987b. Palaeoecological studies of Karewa sediments, Kashmir with reference to diatoms. *2nd All India Applied Phycol. Congr., Delhi (1987)* 12-13. Maitreyi College, Delhi University, Delhi (Abst.).

Mohan DJ & Vora AB 1988. Preliminary diatomological investigations of Nadial bog (Wular Lake), Kashmir, India. *Proc. Indian natn. Sci. Acad.* **54A** : 490-496.

Paasche E 1980. Silicon. *In* Morris I. (Editor)—*The Physiological Ecology of Phytoplankton, Studies in Ecology* **7** : 259-284. University of California Press, Berkeley.

Pentocsek J 1889. *Beitrage zur Kenntniss der fossilen Bacillarien Ungarns. II Teil, Barckwasser Bacillarien, Anhang: Analyse de marinen depots von Bory, Bremia, Nagy-kurtos in* Ungarn; Ananino und Kusnetzk in Russland. Nagy-Tapolosany, Hungary (Julius Platzko).

Prema P & Desikachary TV 1989. New and interesting fossil diatoms from the Indian Ocean. *Phykos* **28**(1-2) : 127-131.

Proshkina-Lavrenko AI 1968. K evolyutaii diatomovykh vodorosley (on the evolution of diatoms). *Byulleten Moskoba Obshchi Ispytan Prirodo, Otdel Biologichekich* **65**(5) : 52-62.

Ranjitha Devi KA & Desikachary TV 1987. Fossil diatoms from Andaman and Nicobar Islands. *Int. Symp. on Phycology, Madras (1987)* : 43. Centre of Advanced Study in Botany, Madras University, Madras (Abst.).

Rao AR & Awasthi P 1963. Diatoms from the Pleistocene deposits of Kashmir (India). Part-I. Centric diatoms. *Palaeobotanist* **11** 82-91.

Rattray J 1890. A revision of the genus *Coscinodiscus* Ehr. and some allied genera. *Proc. R. Soc. Edinb.* **16** : 449-692.

Ross R, Cox EJ, Karayeva NI, Mann DG, Paddock TBB, Simonsen R & Sims PA 1979. An amended terminology for the siliceous components of the diatom cell. *Nova Hedwigia.Beih* **64** : 613-633.

Rothpletz A 1896. Uber die Flysch Fucoiden und einige andere fossile Algen, Sowie uber liassische diatomeenfuhrende Hornschwamme. *Z. Deutsch. geol. Ges.* **48** : 854-914.

Round FE & Crawford RM 1981. The lines of evolution of the Bacillariophyta 1. Origin. *Proc. R. Soc. Lond.* **B211** : 237-260.

Round FE & Sims PA 1981. The distribution of diatom genera in marine and freshwater environments and some evolutionary considerations. *In* Ross R. (Editor)—*Proc. 6th int. Symp. on Recent and fossil diatoms, Budapest, (1980)* : 301-320. Koeltz, Koenigstein, West Germany.

Roy DK 1971. Fossil diatoms from the Karewas of Kashmir. *Indian Min.* **24**(3) : 307-309.

Roy DK 1974. Fossil diatoms and biostratigraphy of the Lower Karewa Formation of Kashmir. *Palaeobotanist* **21** : 113-120.

Roy DK 1975. Stratigraphy and palaeontology of the Karewa Group of Kashmir. *Geol. Surv. India, Misc. Publ.* **24**(1) : 204-221.

Roy DK 1979. Diatoms and Plio-Pleistocene boundary in Kashmir. *In* Bharadwaj DC *et al.* (editors)—*Proc. IV int. palynol. Conf., Lucknow (1976-1977)* **2** : 735-744. Birbal Sahni Institute of Palaeobotany, Lucknow.

Roy DK 1982. Reclassification of the Karewa Group of Kashmir. *Rec. geol. Surv. India* **111**(2) : 187-194.

Roy DK 1984. Biostratigraphy of Karewa Group of Kashmir. *In* Sharma AK *et al.* (editors)—*Proc. Symp. on Evolutionary botany and biostratigraphy, Calcutta (1979)* : *AK Ghosh Commem. Vol., Curr. Trends in Life Sci.* **10** : 633-643.

Roy DK 1988. Fossil diatoms of India. *Geol. Surv. India Spl. Publ.* **11**(2) : 133-146.

Sancetta C & Silvestri CM 1986. Pliocene-Pleistocene evolution of the North Pacific Ocean-atmospheric system, interpreted from fossil. *Palaeoceanography* **1** : 163-180.

Schmidt A *et al.* 1874-1959. *Atlas der Diatomaceenkunde.* 472 Plates. Leipzig: R. Reisland. Ascherleben.

Schrader HJ 1969. Die pennaten Diatomeen aus dem obereozan Von Oamaru, Neu Seeland. *Nova Hedwigia Beih.* **28** : 1-124.

Schrader HJ 1971. Fecal pellets : role in sedimentation of pelagic diatoms. *Science* **174** : 55-57.

Schrader HJ 1972. Kieselsaure-Skelette in Sedimenten des ibero-marokkanischen Kontinentalrandes und angrenzender Tiefs ee-Ebenen, "Meteor" *Forsch.-Ergebn.*, ser. C, **8** 10-36.

Schrader HJ 1974. Cenozoic marine planktonic diatom stratigraphy of the tropical Indian Ocean. *In* Fischer RL *et al.* (editors)—*Initial Rep. Deep Sea Drilling Project* **24** : 887-967. U.S. Government Printing Office, Washington.

Simonsen R 1972. Ideas for a more natural system of the centric diatom. *Nova Hedwigia Beih.* **39** : 37-54.

Singh P 1979. Additional Early Pliocene diatoms and silicoflagellates from Neill Island, South Andaman, India. *Curr. Sci.* **48**(13) : 593-594.

Singh P & Vimal KP 1973. A note on the geology and micropalaeontology of Neill Island, South Andaman. *Curr. Sci.* **42**(7) : 239-241.

Singh P & Vimal KP 1976. Origin and geology of Neill Island, South Andaman, India. *J. palaeont. Soc. India* **19** : 28-36.

Singh P, Vimal KP & Nautiyal DD 1978. Early Pliocene diatoms and silicoflagellates from Neill Island, South Andaman, India. *J. palaeont. Soc. India* **21, 22** : 49-59.

Small J 1944/1945. Tables to illustrate the geological history of species in diatoms. *Proc. R. Irish. Acad.* **1** : 295-309.

Small J 1950. Quantitative evolution. XVI. Increase of species number in diatoms. *Annals Bot.* **14**(n.s.) : 91-113.

Srinivasan MS & Srivastava SS 1972. Foraminifera from Nancowry and Kamorta Islands, Bay of Bengal and some aspects of Early Neogene orogeny. *Indian Bull. Earth Sci.* **1** : 27-35.

Srinivasan MS & Srivastava SS 1977. A new fossil diatom (*Annellus*) from Nicobar Islands, Bay of Bengal. *In* Venkatachala BS & Sastri VV (editors)—*Proc. 4th Colloq. Indian Micropalaeont. Stratigr., Dehradun (1974-75)* : 193-195. Institute of Petroleum Exploration, Oil & Natural Gas Commission, Dehradun.

Taliaferro NL 1933. The relation of volcanism to diatomaceous and associated siliceous sediments. *California Univ. Pubs. Geol. Sci.* **23**(1) : 1-56.

Tappan HN 1980. Diatoms. *In* Tappan HN (Editor)—*The Palaeobiology of plant protist* : 567-677. W.H. Freeman and Company, San Francisco.

Tempere J & Peragallo H 1907-1915. Les Diatomees du monde entier, Tables with slides and Text, 2nd ed., Chez J. Tempere, Villa Andree-Lucie a Arachon, Gironde, 480 + 68 pp.

van Heurck H 1880-85. *Synopsis des diatomees de Belgique.* Atlas, pl. 1-30 (1880); pl. 31-77 (1881); pl. 78-103 (1882); pl. 104-132 (1883); pls. A, B, C (1884), Texte. Mtin, Browers Co. Anvers, 235 (1885), Decaju & Cie, Anvers. Table Alphabetique (Index) J.F. Dieltjens. Rop (1885).

Wise SW, Buie BF & Weaver FM 1972. Chemically precipitated sedimentary cristobalite and the origin of chert. *Ecologae Geol. Helv.* **65**(1) : 157-163.

Woodward JB 1967. A new *Aulacodiscus* from Nancowry, Nicobar Island. *Microscopy J. Quekett. micr. Club* **30** : 307-308.

Wornnardt WW Jr 1969. Diatoms : Past, present, future. *In* Bronnimann P & Renz HH (editors)—*Proc. 1st int. Conf. planktonic microfossils. Geneva-II (1967)* : 690-714. Leiden, Netherlands.

Wornardt WW Jr 1971. Eocene, Miocene and Pliocene marine diatoms and silicoflagellates studied with the Scanning Electron Microscope. *In* Farinacii A (Editor)—*Proc. 2nd Planktonic Conference, Rome* **2** : 1277-1300.