# Radiolaria as tracers of ocean–climate history

*V. Sharma and J. Daneshian*

*Radiolaria, siliceous protozoan marine planktons, though reported since long from rocks and recent oceanic sediments, have proved as potential tools in the last three decades in understanding geological history as well as in getting better insight into the oceanographic processes. This has particularly been possible with the availability of deep-sea cores as a result of Deep Sea Drilling Project. As constituents of modern surface sediments and as fossils, radiolarians occur in sediments deposited normally at greater depths. Because of this characteristic, they are significant for studies on sequences deposited below the carbonate compensation depth, where calcareous fossils are rare or absent. Besides being important in biostratigraphic studies, usefulness of radiolarians is increasingly being recognized for unravelling the oceanographic and climatic history.*

RADIOLARIA is one of the protozoan groups that have been described and illustrated for over one hundred and fifty years in studies conducted on rock samples as well as on sediments collected during various oceanographic expeditions. With the availability of enormous data and samples from deep sea sediment cores recovered as a result of the Deep Sea Drilling Project (DSDP) and Ocean Drilling Program (ODP), radiolarians have been, and are, being studied extensively. Deep sea drilling provided cores from low-to-high latitudes, ranging from Late Mesozoic to Recent, thus have given an unprecedented opportunity to study radiolaria from different oceanic regions.

Stratigraphic importance of radiolaria was not firmly established until the beginning of DSDP. The present knowledge on biostratigraphy, taxonomy and evolution of this group is largely based upon the DSDP cores. Examination of continuous sequences of sediment cores, containing well-preserved radiolaria and foraminifera and their geomagnetic reversal records, has led to the establishment of radiolarian zones that can be correlated to zones based on other microfossil groups, and also to determine stage boundaries and radiometric ages with increasing accuracy.

In the 1970s a detailed zonation for low-latitude areas was already in use, dividing the whole of Cenozoic (except Paleocene) into twenty-nine zones[1]. Further refinement in a part of the zonal scheme took place in later years, dividing the Pliocene–Pleistocene interval into eleven zones[3,4]. Identification of a number of radiolarian datum levels or 'events' (first, last and evolutionary appearances of a species) was also possible as a result of availability of uninterrupted marine deep sea sequences recovered by DSDP and ODP[5–9].

The authors are in the Department of Geology, University of Delhi, Delhi 110 007, India.

Biochronology, which deals with the succession of bioevents during a time interval, plays a significant role in proper placement of a stratigraphic sequence in the geological column. Recent years have witnessed multidisciplinary work, including radiometric and paleomagnetic studies of the sequences obtained from DSDP and ODP. Consequently, age assignment to radiolarian datums became possible, and now there is fairly good understanding of these datums in absolute ages[9–13]. Radiolarian biochronology with estimated ages of datums is of immense value in dating and correlation of inter-oceanic sequences and in calibrating geological events.

## Radiolaria: General

Radiolaria are exclusively marine planktons with siliceous tests (= skeletons) made of amorphous (opaline) silica. A radiolarian test is microscopic, usually made of a network of 'bars', which are elongate elements connected at both the ends; and 'spines', which are elongate elements connected at one end only[14]. Of the two groups to which Radiolaria are divided, Phaeodaria usually have delicate skeletons composed of organic and siliceous matrix, or hollow skeletal tubes, and are rarely preserved in sediments as they require favourable condition of rapid rate of accumulation of sediments with high-silica content[1,2]. As a result, they are practically absent in sedimentary sequences. However, they can be seen in good numbers in modern plankton samples.

The tests of members of the other group, Polycystina, are made of solid skeletal bars and are abundantly preserved in sediments. Polycystines are further divided into two major groups: (i) Spumellaria – usually spherical, single or multiple concentric, ellipsoidal, discoidal, or coiled; and (ii) Nassellaria – usually characterized by axial symmetry, although modifications are seen in this fundamental shape[14] (Figure 1). Radiolarian workers are almost exclusively concerned with polycystine radiolaria.

Radiolaria are studied either by preparing thin sections of rocks or by separation technique. While thin sections are prepared when the rocks are hard, separation technique is used to free radiolaria from unconsolidated deep-sea cores, surface sediments or from rocks, for which various chemical and mechanical methods are

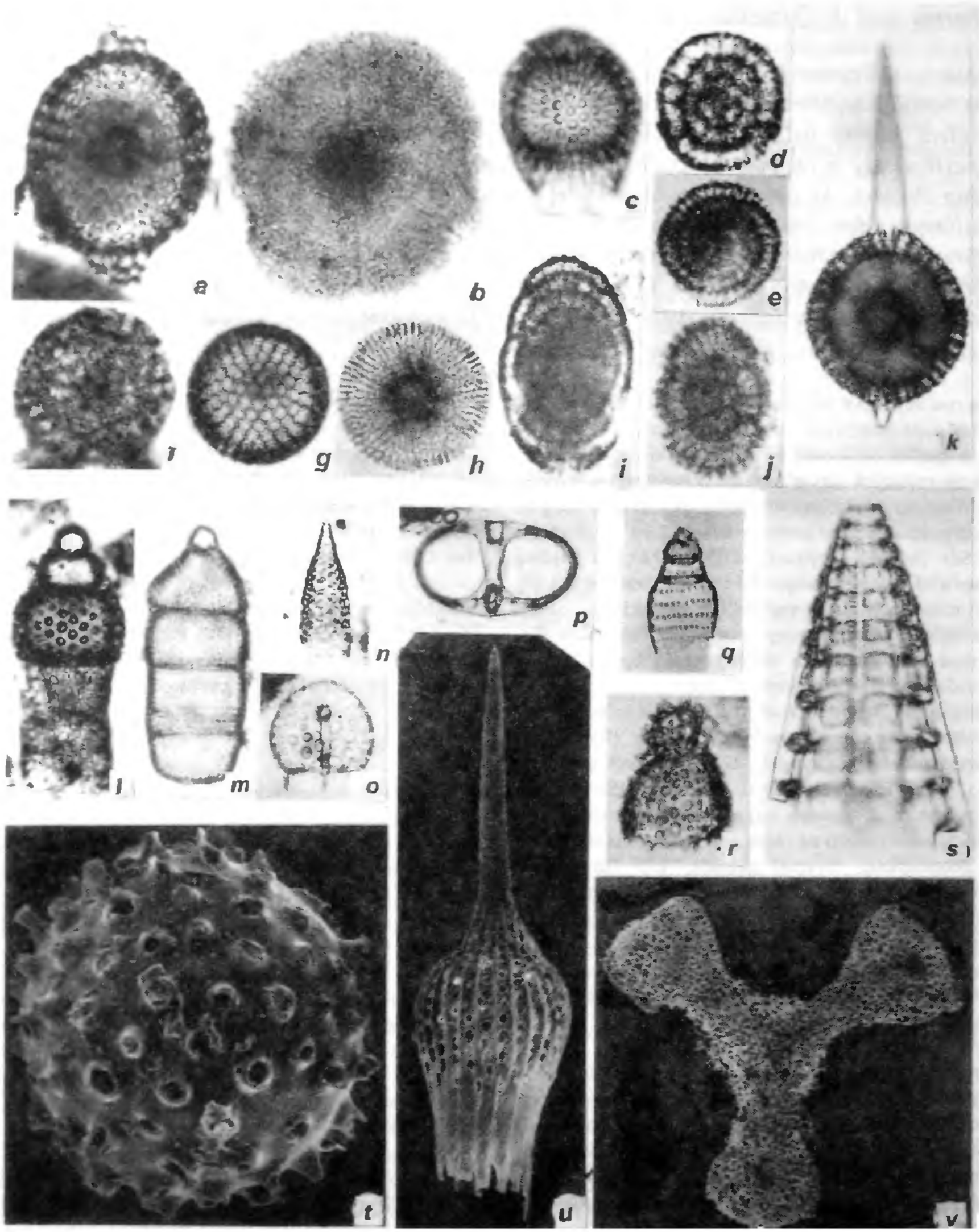


**Figure 1.** Morphological variations in polycystine radiolaria, *a–k*, Spumellarians; *l–s*, Nassellarians (definition in the text), photographed in transmitted light. *t–v*, scanning electron micrographs showing enlarged external features of Spumellarians (*t*, *v*) and a Nassellarian shell (*u*). Magnification used for: *a–d*, *i–m*, *p*, *r*, *s* (×250); *e*, *o* (×200); *f–h*, *n*, *q*, *v* (×150); *t* (×270); *u* (×185).

available. Separated radiolaria are mounted on glass slides to study them under microscope. In case of cherts, which are very hard and may contain abundant radiolaria, the usual method of study is by preparation of the slides. However, sometimes separation techniques can be used as well. Separation of radiolaria from cherts which are also siliceous, requires experience in order to free them by dissolving cherty (silica) matrix by hydrofluoric acid without much dissolving the siliceous skeletons of the radiolarians[15].

Radiolaria are best studied under microscope. The transmitted light of a microscope allows examination of external as well as internal features of radiolarian skeletons. Scanning Electron Microscope (SEM) is employed to study the finer surface ultrastructural details. The relationship between the radiolarian surface ultrastructure and oceanographic parameters is yet not fully understood and may be a challenging area for future research.

### *Distribution of living radiolaria*

Radiolaria are widely distributed in the oceans and are found on the surface of the ocean as well up to depths of hundreds of metres. A general homogeneity in radiolarian assemblages, parallel to latitudes; and heterogeneity, across the latitudes, indicate that temperature plays a major role in their distribution. Within this general framework of distribution, variations in assemblages can occur depending upon the presence of a water body having different physical, chemical, and biological parameters, i.e. presence of a different water mass. Such water masses are maintained by currents and carry their own characteristic assemblage. Kuroshio Current in the Western Pacific, for example, can carry a distinct tropical assemblage polewards[14]. This tropical assemblage can reach as far as off the northern Japan. Vertical distribution of radiolaria too is dependent on water masses at depths.

### *Radiolaria in oceanic sediments and rocks*

In the oceanic sediments, accumulation of radiolarian tests is consequent to their sinking from the overlying water after the death of organisms. What is preserved in the sediments is a fraction of the living population, as the silica-deficient sea water dissolves the skeletons while they are sinking or at the water–sediment interface at the sea-bottom before their burial. In the water column, a rapid rate of dissolution is observed nearer the sea surface than at greater depths, because sea water is more deficient in silica nearer its surface[16].

Radiolaria are abundant in deep sea sediments, particularly in equatorial regions where productivity is high in the overlying water column. Higher abundance of radiolaria also occurs in high latitude areas in the North Pacific and around Antarctica[14]. Their high abundance in sediments gives rise to a radiolarian ooze, the deposition of which is usually suggestive of slower rate of sediment accumulation, high surface productivity, deposition at great depth particularly below the carbonate compensation depth, and low dissolution of radiolarian tests. Radiolarians occur in cherts as well, some of which may be associated with ophiolites.

## Radiolaria in ocean-climate history reconstruction

Since the pioneering work of Ernst Haeckel in the late nineteenth century on radiolaria from ocean floor samples collected by HMS *Challenger*, this protozoan group today has attained great importance. Once considered unreliable for age determination and inter-oceanic correlation, they now have the potential to unravel climatic and oceanographic changes; both for long and short term.

The oceans and the atmosphere are in direct contact with each other, therefore atmospheric changes are also reflected in the oceans. Climatic cooling and warming affect earth's surface, including the oceans. Such thermal changes result in production of thermal gradients from equator to poles. These gradients in turn result in provincialism in the distribution of radiolaria, as well as in giving rise to different radiolarian assemblages which are characteristic of different water masses. Steeper the thermal gradient, stronger the provincialism.

In the geological past, variation in climate and oceanic circulation gave rise to different assemblages, evidences of which can be found in deep sea sediment cores from the various oceans. The radiolarian assemblages thus preserve the signatures of oceanic and climatic changes of the past. Since radiolaria, unlike calcareous fossils, can be preserved in deep sea sediments independent of carbonate compensation depth (CCD), they have greater potentiality to be used as tools in such studies, especially where calcareous fossils are absent due to their dissolution.

The basic assumption in using radiolarians (and other fossil groups) in understanding the oceanic and climatic history of the earth is that similar relationship between radiolarian assemblages and oceanic parameters existed in the past, as it does today. Studies carried out to understand relationship between the watermass and radiolarian distribution in modern oceans are of immense value in understanding paleoclimatic (usually paleotemperature) change and paleoceanographic conditions, like, changes in surface water circulation, and upwelling[17–25]. Best records for such studies are, as already pointed out, available in deep sea cores, wherein uninterrupted sedimentary sequences spanning long intervals exist. Land-based sequences, which usually represent a smaller duration of time, nevertheless, have also been successfully investigated.

Using radiolarians, paleotemperature fluctuations have been determined by Keany[19], and Moore and Lombari[26]. Keany[19] used *Antarctissa strelkovi* (Figure 1 *r*), a high latitude species found in the Antarctic waters. Distribution of its tests in surface sediments corresponds with its presence in the Antarctic waters[18]. Any change in the temperature of water affects its abundance; fluctuations in percentage frequency of which can be a measure of change in temperature. By plotting percentage frequency of *A. strelkovi* in the Pliocene–Pleistocene samples from paleomagnetically dated drill cores from Antarctic and subantarctic waters in the Southern Ocean (South of Australia and from Central South Pacific), a 'paleoclimatic curve' was obtained[19]. A high frequency of *A. strelkovi* indicates a cooler condition. It was suggested that Matuyama was, in general, cooler than the Brunhes in the area of study. The results obtained in this investigation are in agreement with the earlier studies based on foraminifera[27,28].

Regression analysis of radiolarian assemblages has been successfully used to interpret paleotemperatures. By regression analysis, modern distribution of radiolarians in surface sediments can be related to modern sea surface temperature. The technique can be applied to all the marine microfossil groups. Radiolaria, however, have an advantage over other microfossil groups because of their greater diversity in modern oceans and long geological range of many of its species. Because of long range of radiolarian species, a number of species common to both fossil and modern assemblages are available for the analysis. Census data of modern radiolarian assemblages are first related to modern sea surface temperature. Using fossil assemblages, this relationship is then applied to estimate sea surface temperature changes in the past. Moore and Lombari[26] used regression analysis on Late Miocene radiolarian assemblages from sites located between equator and 40°N lat. in the North Pacific for paleotemperature estimation. The estimated temperatures of sea water indicate an overall cooling trend throughout the examined time interval, with several distinct increased cooling events which corroborated the earlier findings on the paleotemperature estimation[29,30].

The oceanic phenomenon of upwelling leaves its imprints on the radiolarian assemblages. Waxing and waning of upwelling results in the fluctuation of 'upwelled species' of radiolaria in the indigenous assemblage of an area. By identifying the upwelled species in the assemblage, upwelling regions can be demarcated. Relative intensity of upwelling can be interpreted by recording the fluctuation in percentage of the upwelled species. Principal component analysis on the radiolarian distributional data in samples from land-based Miocene – Early Pliocene Monterey Formation, California indicated that in the Late Miocene there was an increase in relative abundance of cold water taxa which continued to dominate in the Early Pliocene[31]. This is considered as a result of the increased upwelling in the Late Miocene due to cooler oceanographic conditions of high latitudes. These Late Miocene cooling episodes have been corroborated by isotopic records as well[32,33]. The result is in agreement with that obtained by lithologic data of Ingle[34] and diatom data of Barron and Keller[35] for the Monterey Formation.

Similar study, on the Quaternary cores in the eastern tropical Pacific, using factor analysis on radiolarian assemblage, revealed intensified coastal upwelling during the Last Glacial (between about 33,000 and 11,000 years ago) than during the Present[23]. In an another study, in the time span from about 11 Ma to the Present, increase and decrease in the intensity of upwelling are recognized in the northwest Arabian Sea[36]. By identifying certain species of modern radiolaria as belonging to 'upwelling assemblage' and applying the data to the radiolarian assemblages from cores, Nigrini[36] observed strengthening of the upwelling mechanism at about 4.7 Ma followed by another, though less obvious, near Pliocene/Pleistocene boundary (at about 1.5 Ma).

Evolution of oceanic circulation in the equatorial and North Pacific during the Miocene, from about 23 Ma to 5 Ma, was determined by Romine and Lombari[37], using radiolaria from DSDP site 289, in the western tropical Pacific. The paleogeographic changes that occurred during the Miocene had great influence on the oceanic circulation patterns, the record of which are preserved in the radiolarian assemblages. The three significant events in the Miocene, viz. formation of East Antarctic ice sheet (15–13 Ma), closure of equatorial Indo-Pacific passage (12–10 Ma), and the Messinian episode of the Mediterranean gave rise to changes in circulation pattern in the Pacific, which were identified by incorporating evidences from other studies with the radiolarian evidences. For example, a major increase in western transitional radiolarian assemblage, a decrease in the abundance of certain radiolarian species (*Stichocorys delmontensis*, *S. wolffii*, and *S. peregrina*), and an increase in silica dissolution are observed in the Late Middle Miocene at 12–10 Ma, which suggest development or intensification of North Pacific transitional water mass due to an increased transport in the subtropical gyre[37]. The closure of Indo-Pacific passage at about 12–10 Ma gave rise to intensification of subtropical gyre, as westward equatorial flow in the Pacific was diverted towards the poles[38].

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ACKNOWLEDGEMENTS. We thank Prof. M. S. Srinivasan, Department of Geology, Banaras Hindu University, for critical reviews and helpful suggestions. Financial assistance from the CSIR to V.S. in the form of a project is gratefully acknowledged.

Received 6 April 1998; accepted 9 September 1998

# Side effects of some medicinal plants

*L. M. Gupta and R. Raina**

*Herbal drugs are playing an important role in health care programmes worldwide, especially in developing countries. This is primarily due to the general belief that herbal drugs are without any side effects besides being cheap and locally available. The article gives an account of 21 medicinal plant species which are being used, on large scale, for treatment of particular diseases, reported to be having serious side effects. Medicinal plants, before being allowed to be used as drugs, should also be tested for side effects, if any.*

LATELY, there is a resurgence of interest in herbal medicines for treatment of various ailments chiefly because of prohibitive cost of allopathic drugs, unavailability in remote areas and also due to popular belief that herbal medicines are without any adverse side effects. Moreover, as is well known, the herbal medicine system has originated as a result of continuous trial and use of various plants/plant parts by people inhabiting areas rich in floral wealth and the information so

The authors are in the Department of Forest Products, Dr Y. S. Parmar University of Horticulture and Forestry, Nauni, Solan 173 230, India
*For correspondence. (e-mail: fpu@yspuf.hp.nic.in)