THE UBIQUITOUS DIATOM—A BRIEF SURVEY OF
THE PRESENT STATE OF KNOWLEDGE*

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ABSTRACT. Diatoms have distinctive and highly diversified tests or shells, similar to but not identical with opal in composition, accounting for their preservation as fossils in many kinds of sedimentary rocks and their importance to the geologist. The problem of unequivocally assigning diatoms and related minute unicellular or noncellular organisms to either the plant or the animal kingdom is increasingly being met by referring them to the Protista, which may be considered either as a separate kingdom of organisms or a confession of ignorance.

The earliest known large assemblage of marine diatoms occurs in rocks of Late Cretaceous age in California; the earliest known assemblage of nonmarine ones occurs in middle Oligocene rocks in Colorado. They are widespread over the globe, living today in virtually all non-toxic waters, occupying a wide variety of habitats. This wide distribution is explained by the ease with which these minute organisms may be transported over great distances in viable condition by means of water, wind, and attachment to larger organisms. The preservation of diatoms in sedimentary rocks is governed largely by the pH of the solutions penetrating the sediment, as the solubility of the diatom silica increases rapidly with increasing pH above 5. Even under such conditions diatoms may be preserved in calcareous concretions formed before the advent of the alkaline solutions.

The percentage of extinct species in any assemblage of diatoms increases with age of the enclosing sediment at rates comparable with those of mollusks, making them useful indicators of geologic time. The species in any assemblage still represented in living assemblages form the basis for paleoecological interpretations. The fact that large and representative assemblages of diatoms can be obtained from very small samples is of equal importance in both lines of investigation. The small size of the diatoms and their resulting ease of transportation introduces problems of reworking and contamination. The former is often difficult to evaluate; the latter can be virtually eliminated by systematic care and cleanliness in the collection and preparation of the samples.

INTRODUCTION

Diatoms are microscopic unicellular or noncellular organisms having a siliceous test or shell. At various times during the past hundred years they have been considered to be animals or plants, as they possess many of the attributes of both kingdoms. They are photosynthetic organisms possessing a combination of two dyes, diatomin and xanthophyll, which act in a manner similar to that of chlorophyll in higher plants in enabling them to synthesize complex carbon compounds from carbon dioxide and water through the action of sunlight. This constitutes one of their chief plant-like characteristics. On the other hand they store reserve food as lipoid fats and many have the power of independent movement, which constitute some of their animal-like characteristics. In view of these and other uncertainties, many students of these and other noncellular or unicellular organisms possessing this dual character have become uneasy about the arbitrary assignment of them to either the plant or animal kingdoms. Hogg (1860) early proposed the term Protoplasta for various organisms not clearly classifiable as either plants or animals. Haeckel, (1866) proposed the term Protista for the same group, and his shorter name has remained and gained substantial following by the establishment of the journal Protistenkunde. Moore (1954) has recently reviewed the whole subject exhaustively, and has followed Hogg and Haeckel in recognizing a third kingdom of organisms, the Protista, for those microscopic unicellular creatures which for various reasons do not seem to fall happily into either the plant or animal kingdoms.

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Diatoms are composed of two siliceous valves, most of which fit together in a manner similar to the two halves of a flat pill box, with a siliceous band or girdle covering the junction. The exact composition of this siliceous valve is not reliably known, but appears to be a hydrous silica having the general formula of SiO$_2$.nH$_2$O, similar to the mineral opal. Although the refractive indices of the two forms of silica are very nearly the same, significant differences exist between the hydrous silica of opal and that of the diatom valve, probably related to the value of the integer $n$, which appears to be smaller for the diatoms than for opal. This is suggested by the greater resistance to corrosion by both strong acids and fairly strong bases characteristic of the diatom silica. Diatoms have long been considered to have "indestructible siliceous shells", but this apparent indestructibility is not sufficient to preserve them in porous sediments through which alkaline waters have moved.

The taxonomic classification of the diatoms has occupied the attention and exercised the imagination of many students of these organisms for more than a hundred years. At one time the classification was based upon the soft parts, in particular upon the arrangement of the chromatophores containing the photosynthetic dyes. This soon proved to be unworkable as these features were observable only in living diatoms, and the criteria subsequently accepted were based upon the shape, intricate structure, and often elaborate ornamentation of the siliceous valve and not at all upon the ephemeral soft parts. This is particularly advantageous for paleontological and paleoecological interpretations, as it virtually eliminates uncertainty in the generic and specific identifications made by biologists working with living diatoms and by paleontologists using fossil ones. Thus each discipline can make effective use of the vast literature on diatoms, both living and fossil. The structure and ornamentation of the valve is remarkably constant for any given species, and is capable of precise biometric measurement, so that species can be identified with a high degree of certainty.

The classification of the diatoms was stabilized in 1896 by Schütt who proposed a satisfactory and workable one, which was published in Engler and Prantl's Natürliche Pflanzenfamilien. He considered the diatoms to be an order of Algae, Bacillariales (Diatomeae), divided into two suborders, Centrales, in which the structure and markings are more or less radial and related to a central point, and the Pinnatales, in which the structure and markings are related to a longitudinal line. A number of ambiguities in this classification developed during the nearly 40 years that it was almost universally adopted until Hendey (1937) proposed a modification of it, considering the diatoms as a Class of Algae, Bacillariophyceae, comprising one order, Bacillariales, which is divided into 10 suborders. This has proved to be a workable classification, eliminating many of the ambiguities inherent in the older system. The final step of resolving the doubt regarding their plant or animal status and assigning them to the Protista does no significant violence to Hendey's classification. The group comprises over 300 genera and between 12,000 and 16,000 species, depending upon whether one is a lumping or a splitting. Among this large number of species practically every known geometric shape has been used by these creatures, as well as many that bear no close resemblance to anything else.
Diatoms live today in marine, brackish, and fresh water, as well as in many more specialized habitats, such as hot springs, fresh water pools on oceanic ice floes, moist soil, peat bogs—in fact, wherever water non-toxic to them is present with at least partial exposure to sunlight. Some are pelagic, free-swimming organisms which spend their entire lifetime in the surface waters down to the depth to which actinic light can penetrate, usually not more than 60 to 100 meters. Others live attached to stones, aquatic plants and other submerged objects, or form the greenish brown slime coating the bottoms of shallow ponds and streams. Deep oceanic waters contain only the pelagic types, whereas the littoral zones contain both pelagic and benthonic forms. Estuaries and lagoons contain not only distinctly brackish types, but some truly marine forms and some truly freshwater forms which are introduced from the sea on one hand and from rivers or streams on the other. Similarly, deep nonmarine lakes contain only pelagic forms at some distance from shore, changing to mixtures of pelagic and attached forms in the shallower margins near shore. Near the mouths of streams, fluvial forms, brought in by the streams mix with the lacustrine and marine types. Different species and in some cases genera of diatoms are confined to one or more of these habitats, reflecting their individual tolerances for water of various combinations of salinity, temperature, pH, nutriments, etc. Thus the study of fossil diatoms preserved in sedimentary rocks can yield paleoecological information of considerable value to the geologist, as defensible inferences can be made regarding the environment in which their enclosing sediments were deposited.

GEOLoGIC RANGE

Reported occurrences of diatoms in Paleozoic rocks have been found to be erroneous, as in each case more careful work has indicated that the presence of diatoms was due to contamination with younger material, either in the laboratory or in the field. The whole subject of the existence of pre-Mesozoic diatoms was extensively explored by Pia (1931), who found no authentic occurrences. Although a few diatoms have been found in what appear to be Jurassic rocks, the earliest large assemblage of well preserved ones have come from the marine Moreno shale of Late Cretaceous age in the Panoche Hills, Fresno County, California. Hanna (1927, 1934) described many new species and some new genera from this locality, to be followed by Lefebure and Chenevière (1939), and by Long, Fuge, and Smith (1946), who added considerably to the original list so that today the Moreno assemblage consists of 36 genera and 120 species. This assemblage contains an overwhelming proportion of extinct species, and is so diversified that it is highly probable that the origin of the diatoms as a biologic unit may have taken place much earlier, either in the earlier Mesozoic or possibly even sometime during the Paleozoic. Marine diatoms are known from rocks representing all succeeding units of geologic time up to and including the Recent, with increasing diversification until today there are hundreds of described genera and many thousands of species.

Apparently the nonmarine diatoms have had a somewhat shorter geologic history, the earliest one known having been found in the Florissant lake beds
of middle Oligocene age near the town of Florissant, Teller County, Colorado. Here again, the degree of diversification of the Florissant assemblage, although somewhat less than in the case of the marine Moreno shale assemblage, is great enough to suggest strongly a pre-Oligocene origin for the non-marine diatoms. The known geologic record of the nonmarine diatoms is both shorter and less continuous than that of the marine ones, as the next earliest occurrence is in the lower Virgin Valley beds of Merriam (1907). These beds in Humboldt County, Nevada, have been called late middle Miocene in age on the basis of extensive vertebrate faunas. Diatoms are represented in all succeeding units of geologic time.

The sudden appearance of large numbers of individuals and species of marine diatoms in Late Cretaceous time and the equally sudden appearance of the nonmarine forms in middle Oligocene time poses a question which has not been answered satisfactorily. Their absence in earlier rocks is due, most probably, to lack of preservation. In this connection, Roy A. Bailey, of the U. S. Geological Survey (oral communication, December, 1959) has stated that no preserved opals are known from pre-Cretaceous rocks. Although the diatom silica appears to be more stable than opal in the laboratory, it is possible that its stability in the rocks is not enough greater than that of opal to be preserved.

**GEOGRAPHIC DISTRIBUTION**

Diatoms today inhabit the photic zone, usually the upper 60 to 100 meters, of all marine waters of the globe in such quantities that they constitute a major item of food for larger animals, and have been called the "grass of the sea". Their concentration in sea water ranges from a few thousands of diatoms per liter to over 10 million per liter. The oceanic, pelagic types are carried for long distances by ocean currents, on the feet and feathers of birds, by fish, and by the wind. Although many species prosper better in somewhat restricted habitats governed by optimum salinity, temperature, pH, and the like, the random scattering of these organisms by the agencies briefly outlined results in many of them landing in a satisfactory habitat and hence quickly establishing themselves far from their point of origin. As will be shown later this rapid transportation over wide areas has also been a factor in the distribution of these organisms in the geologic past.

The nonmarine diatoms have a similar wide distribution and today different assemblages inhabit virtually all types of aqueous environments, lakes, rivers, brackish estuaries, ponds, bogs, marshes, ice floes, hot and cold springs, and even moist soil. In fact, it may be said safely that diatoms are the most ubiquitous creatures that leave hard parts for the Cenozoic fossil record. This wide distribution is made possible by the fact that diatoms are able to remain viable during long periods of almost complete desiccation, and some are able to produce heavy-walled virtually hermetically sealed resting spores which remain viable even after long periods of complete desiccation.

**TYPES OF ENCLOSING SEDIMENTS**

Fossil diatoms have been found in all types of water laid sediments with the exception of very clean sandstones and conglomerates. They may occur in
such great numbers that they form a diatomite, a micro-coquina made up almost entirely of diatoms, in which very small amounts of clay or volcanic ash may be present as impurities. They may occur as a major or minor constituent in shales, claystones, mudstones, siltstones, clayey or silty sandstones, and in both bedded and concretionary limestones. They also commonly occur in water-laid tuffs. Inasmuch as they are nearly always present in all bodies of non-toxic water, the proportion of diatoms to clastic materials in a sediment often provides a useful clue to rapidity of deposition. Pure diatomites, which are deposited very slowly, for example, clearly indicate a period during which little or no clastic material was being carried into the basin of deposition. The worldwide correlation between thick deposits of diatomite and contemporary volcanism has been observed by many workers, beginning with Ehrenberg (1846), and has been ably summarized by Taliaferro (1933). Volcanic ash constitutes one of the most readily available sources of soluble silica needed by the diatoms, and shards of volcanic glass are often found in beds of diatomite, particularly when they attain thicknesses of more than a few feet. Reinhold (1937) has considered that the common association of diatoms and volcanic ash may be due in part, at least, to the fact that the diatom test would be less likely to be dissolved in water saturated with silica derived from the volcanic ash.

PRESERVATION

The known distribution of diatoms in sedimentary rocks is probably more closely dependent upon their preservation than upon their original occurrence in the different basins of deposition. The absence of these ubiquitous creatures in a sedimentary rock commonly requires a more searching explanation than does their presence. The most obvious explanation and one for which there is abundant field evidence, is that the diatoms were present in the sediments at one time, but have been leached by alkaline or silica starved water either immediately after deposition or by percolating alkaline ground water at some time after deposition or even following tectonic movements which raised the beds above sea level. Diatom silica is normally fairly stable and can resist leaching for long periods of geologic time as long as the pH of the sediment does not exceed 4 to 5. The solubility of silica (SiO₂) increases five fold between pH 5 and 8. No data are available for the solubility of diatom silica (SiO₂•nH₂O), but it must be much greater than the non-hydrated form. Therefore the finding of an abundant assemblage of well preserved diatoms in the Moreno shale of Late Cretaceous and Paleocene (?) age suggests that the pH of any water in contact with the formation was always quite low, probably never much above pH 4 or 5. Even when the pH has been higher and hence leaching has occurred, it is often possible to find well preserved diatoms in calcareous concretions, if the calcium carbonate forming the concretions came into the sediment before any alkaline waters. At first sight this appears to be a large if, but the following examples will illustrate the fact that this has happened in at least some instances.

One of the best examples of the progressive effects of leaching is the classic and extraordinarily well exposed section of the Miocene Monterey formation in Chico-Martinez Creek on the east slope of the Temblor Range, northwest of the
town of McKittrick in Kern County, California. Here the upper 800 feet (stratigraphically) of the section consists of punky diatomite composed almost entirely of well preserved diatoms. Stratigraphically below this unit is one comprised of over 1000 feet of porcellanite, massive in the upper part and laminated in the lower part. This unit contains no preserved diatoms in the porcellanite although numerous impressions of them can be seen on fresh bedding surfaces with a hand lens, indicating that they were once present in abundance. Stratigraphically below this is a unit of over 4000 feet of laminated porcellanite (or porcellaneous shale) in which not even impressions of diatoms can be found, although the rock is otherwise similar to the unit above it. No diatoms can be recovered from any of the porcellaneous rocks below the 800 foot diatomite at the top of the section, because the diatoms have been completely dissolved and their silica redeposited almost in situ, in fact this is almost certainly the process whereby the rocks in the lower part of the section became porcellaneous. Stratigraphically below the laminated porcellanite the proportion of cherty shale and chert increases through another interval of over 1000 feet, and here, of course, no diatoms can be recovered.

At various stratigraphic levels throughout the porcellanites and cherts below the 800 foot diatomite at the top of the section, zones of calcareous concretions occur. Some of these are discontinuous beds of nodules or ovoid concretions, ranging from about an inch to over a foot in major diameter, and some are fairly continuous calcareous beds of uneven thicknesses up to a maximum of a foot or more, traceable for thousands of feet along the strike. These calcareous concretions yield abundant and well preserved diatoms from their unweathered interiors. Bramlette (1946), who studied the Monterey formation in great detail, has traced fine laminations in the beds of barren porcellanite into and through some of the diatomaceous calcareous concretions, indicating that the calcium carbonate was secondary, but earlier than the alkaline solutions which leached the diatoms. Thus it appears certain that the Monterey formation, having in many areas in the Coast Ranges a stratigraphic thickness of approximately 1 mile, was once largely composed of diatoms, most of which have been leached and the silica from their tests redeposited in situ to form porcellaneous shale and chert. The diatoms are clearly rock builders of gigantic proportions. The number of diatoms involved in building such a body of rock becomes a staggering figure in view of the fact that actual counts of diatoms from the Monterey formation have resulted in a realistic figure of about 21,000,000 diatoms per cubic inch.

Another example, this time from nonmarine rocks, will serve to illustrate another aspect of the preservation problem. The Furnace Creek formation of Miocene or Pliocene age in Furnace Creek Wash on the east drainage into Death Valley, Inyo County, California consists dominantly of lacustrine claystones and mudstones containing in places great quantities of sodium and calcium borates. In fact, before 1926 the largest commercial production of borates came from the Furnace Creek formation. As a result, the pH of these sediments is high, up to pH 9 or over in many places. Intensive search has revealed no diatoms in the claystones and mudstones of this formation, but a few have been
found in interbeds of freshwater limestone. These limestones are rarely concretionary, but are more commonly bedded, with thicknesses up to several feet. In one instance, a clean white limestone at the top of the Furnace Creek formation yielded an abundant assemblage of well preserved diatoms of late Pliocene or early Pleistocene age. In the lower part of the same formation, the diatoms recovered from limestones are often so badly leached that specific identification is difficult. However, in the same beds that contain the leached ones are several species of diatoms whose Recent counterparts live in hot springs, some of which are still active nearby. The hot springs diatoms, of which the most common in the Furnace Creek formation is *Denticula thermalis* Kützing, are always well preserved, indicating that the silica forming their shells is less soluble in alkalies than that found in other diatoms. It appears probable that this may be due to somewhat less hydration of the silica.

**USE IN STRATIGRAPHY**

The diatoms, both marine and nonmarine, like most other groups of fossils, have both short ranging and long ranging species. Each assemblage of diatoms, with the possible exception of those from very late Pleistocene rocks, will have some extinct species as well as some that are still represented in living assemblages elsewhere.

The following table lists the percentage of living species present in a number of marine diatomaceous rocks from various places in the world, and from Late Cretaceous to late Pleistocene in age. To give some comparison with the marine mollusks, Lyell’s early, 1832, figures are given, followed by Schuchert’s, 1915, revision:

<table>
<thead>
<tr>
<th>Mollusks</th>
<th>Age</th>
<th>Diatoms</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lyell</td>
<td>1832</td>
<td></td>
</tr>
<tr>
<td>90-95</td>
<td>95-100</td>
<td>Atlantic Coast ...............</td>
</tr>
<tr>
<td>35-50</td>
<td>50-90</td>
<td>San Joaquin fm., Calif. ......</td>
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<tr>
<td></td>
<td>{ Late Pliocene</td>
<td>Sisquoc fm., Calif. ..........</td>
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<td></td>
<td>{ Late Miocene to Middle Pliocene*</td>
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<tr>
<td></td>
<td>{ Late Miocene</td>
<td>Upper part of Monterey fm., Calif.</td>
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<tr>
<td></td>
<td>{ Middle Miocene</td>
<td>Calvert fm., Md. &amp; Va.</td>
</tr>
<tr>
<td>17</td>
<td>20-40</td>
<td>Upper part of Temblor fm.</td>
</tr>
<tr>
<td></td>
<td>Early Miocene</td>
<td>Calif.</td>
</tr>
<tr>
<td></td>
<td>Oligocene</td>
<td>Santos shale, Calif. .........</td>
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<tr>
<td></td>
<td>Eocene and Oligocene*</td>
<td>Oamaru, New Zealand ..........</td>
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<tr>
<td>3.5</td>
<td>1.5</td>
<td>Kreyenhagen fm., Calif. ......</td>
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<tr>
<td></td>
<td>Late Cretaceous and Paleocene (?)</td>
<td>Jutland .....................</td>
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<td></td>
<td></td>
<td>Barbadoes ....................</td>
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<tr>
<td></td>
<td></td>
<td>Ananino, Simbirsk, Russia ...</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Moreno shale, Calif. ........</td>
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* Age of rocks from which diatoms were obtained.
The wide distribution of diatom species and assemblages makes them particularly useful for stratigraphic correlation. For example, the Temblor formation of Miocene age in Oil Canyon, north of Coalinga, California, contains a diatom assemblage composed of over 50 percent of extinct species as well as number of extinct genera. Many of these species and some of the genera are known in California only from the Temblor formation, although the diatoms from both older and younger formations nearby have been studied and compared. In Maryland, the Calvert formation of middle Miocene age contains the same extinct species and genera of diatoms, which occur both in outcrops forming cliffs along the west side of Chesapeake Bay from Fairhaven to south of Plum Point, along the Patuxent River near Nottingham (Ehrenberg, 1854; Boyer, 1904) and at depths of 1000 to 1140 feet in cores from a dry hole drilled by the Ohio Oil Company near Salisbury, Maryland (Lohman, 1948). No older diatomaceous strata belonging to the Choptank and St. Marys formations contain different diatom assemblages. Both the Temblor and Calvert formations have molluscan faunal elements which were independently determined as middle Miocene in age. The two diatom assemblages from the east and west coasts are so strikingly similar that they could easily be confused. Other examples could be cited, but there is no need to labor the point.

Another advantage enjoyed by the student of diatoms is the fact that a large and diversified assemblage of fossils can be obtained from a very small sample of rock. This permits accurate frequency counts to be made of the different species in an assemblage, which often permits sharper correlations over relatively short distances.

The nonmarine diatoms present more problems to the stratigrapher than do the marine ones on account of the much wider range of habitats they occupy. It is quite possible, for example, for two lake basins of identical age to contain quite different diatom assemblages. The many factors which control the growth of different species of diatoms, such as temperature, salinity, silica, and pH of the water, to mention only the most obvious ones, vary over much wider limits in nonmarine water bodies than in the sea. On the other hand, the dependence of most species upon optimum or at least tolerable values of these factors, make it possible to infer such optima from a fossil diatom assemblage and gain much paleoecological information of value to the geologist in reconstructing the environment in which the particular sedimentary rock was deposited. The precision with which this can be done would be greatly increased if all students of living diatoms would make more systematic and quantitative measurements of these essential factors, at the same time that the collections of living diatoms were made. It might result in fewer collections, but these would have vastly greater significance. The paleoecologist is at best an extrapolator and he is greatly hampered if he has only meager generalities from which to extrapolate.

Within the limitations set by these paleoecological considerations, the nonmarine diatoms are equally useful in age determination and for the correlation of strata. Fortunately, as new areas are studied, many of the lake sediments, fall into well defined patterns of paleoecology with the result that an increasing
amount of confidence can be placed upon age determinations based on non-marine diatoms. The percentage of living species in any nonmarine assemblage decreases with age at about the same rate as the marine counterparts.

REWORKING AND CONTAMINATION

The ease with which diatoms can be transported, although insuring wide and rapid dispersal, is also something of a disadvantage, as it makes reworking from other beds and contamination from other collections very easy. In general, this problem can be divided into two parts having distinctly different origins, but which affect the end product—a slide of diatoms under the microscope—in much the same way.

Reworking is obviously related to the normal geologic processes of erosion, transportation, and deposition. Fossiliferous rocks are constantly being eroded and the fossils in them transported to new sites of deposition, where they mix with Recent organisms. In the case of the larger fossils the transported distances are usually not great and the fossils commonly suffer obvious abrasion in the process. Diatoms, on the other hand, again by virtue of their minute size, can be transported great distances not only by water, but by wind, with little evidence of abrasion. For example, the Calvert Cliffs along the south-western shore of Chesapeake Bay contain beds of both mollusks and diatoms of middle Miocene age. These are constantly being eroded and the product acted upon by each tide and by waves. The mollusks eventually move to the sandy beach, where they are abraded and often completely ground up by waves and tides so that it is rare for them to be redeposited in the bay sediments in anything like their original condition. The diatoms, on the other hand, remain in suspension in the turbulent waters of the shore and are carried out to the deeper parts of the bay and deposited. It is quite probable that many of them are carried out to the open sea and deposited on the continental shelf. The abrashon on the diatoms in this process is very slight as they are protected by being surrounded by water. Thus middle Miocene diatoms are being deposited in Recent sediments somewhere in the bay or along the continental shelf. Fortunately, the actual number of older diatoms being incorporated into sediments in this manner is usually small compared with the vastly greater number of Recent forms with which they become mixed. The dilution factor is so large, that in any assemblage of Recent sediments from the bottom of the bay, the Calvert forms would be reported as very rare if found at all. Nevertheless occasions can arise where the dilution with Recent forms is not so great, and constant vigilance is needed in interpreting such assemblages.

In some instances, however, diatoms which have been transported for long distances constitute a large proportion of the diatom assemblages found. For example, in a study made of a series of deep sea cores collected across the North Atlantic between Newfoundland and Ireland (Loehman, 1941) it was found that the diatoms from the cores taken at depths of water ranging from 3,230 to 4,820 meters were not the cold water forms now inhabiting the surface waters of the North Atlantic at that latitude, but contained a high proportion of warm water forms which live today in the warmer equatorial waters.
The most probable explanation is that the diatoms, after death, started to sink somewhere near the equator and were carried northward to their final resting place at 50° N. latitude by the northeastward flowing Gulf Stream. It was estimated that as much as several hundred years may have been required for this trip. Fortunately, most diatomaceous sediments encountered by the micro-paleontologist are not deposited under such a combination of extremely deep water and a persistent ocean current. This study, however, emphasizes the need for caution in any paleoecological interpretations made on the basis of diatoms collected from the bottoms of deep ocean basins.

An obvious case of the reworking of older fossils into younger sediments occurred in the examination of a series of drill cores from twelve localities widely scattered along the west side of the San Joaquin Valley, California (Lohman, 1954), all of which penetrated, at depths of from 250 to 600 feet, a lacustrine deposit called the Corcoran clay by Frink and Kues (1954). All of these cores yielded a large assemblage of dominantly freshwater diatoms of late Pliocene to early Pleistocene age. One of the cores also yielded a few individuals of several extinct species of marine diatoms, two of which are known only from rocks of Oligocene age, one with a known range of Late Cretaceous to middle Miocene, and several with longer geologic ranges. At the present time many square miles of diatomaceous strata of the marine Kreyenhagen formation, known to contain these species, are exposed to erosion in the hills bordering parts of the west side of the valley. It appears quite probable that similar exposures of the Kreyenhagen formation were available to erosion during the deposition of the Corcoran clay, and that a few of these were carried into the basin. In working with such minute organisms as diatoms, one must be constantly alert to the possibilities of reworking, which are usually less obvious than the case just described.

The problem of contamination of one collection with another is an equally vexing one, but one which can be practically eliminated by scrupulous care and cleanliness both in making collections in the field and in preparing them for study in the laboratory. It is virtually certain that most of the reported occurrences of diatoms in rocks of Paleozoic age were the result of such contamination.

A convenient and safe container for individual collections of diatomaceous rocks in the field is the Kraft paper sample bag, about 4 x 7 inches in size, or even smaller. These are fitted with a metal strip which can be used to effectively seal the bag after the top has been turned down for a few tight folds. In the laboratory only simple glassware, such as beakers, capable of being effectively cleaned should be used, and collections undergoing the various chemical and physical operations should never be allowed to become dry. They should be kept covered with glass or plastic bell jars between operations. The laboratory preparation of the collections is essentially a problem of disintegrating the rock into its constituent particles without losing or breaking the diatoms, and then concentrating the diatoms by the removal of all other rock constituents. Such rigid requirements cannot always be met, nor is it always economically de-
sizable, as the removal of the last fraction of fine clastic material can be very difficult. A brief resume of the preparation process, which has since been improved in many respects, is given in my paper on the North Atlantic cores (Lohman, 1941, p. 56).

THE PUBLISHED RECORD

To list even a fraction of the thousands of papers and monographs on diatoms that have been published during the past 140 years would require much more space than is available. The quality of these papers is variable, reflecting both the competence of the men who wrote them and the quality of the often primitive optical equipment at their disposal. With a few notable exceptions, few of these men were either geologists, paleontologists, or stratigraphers, with the result that the present day micropaleontologist finds many of these monographs excellent for the identification of species but woefully lacking in vital stratigraphic data. Many authors, particularly the earlier ones, divided all diatoms into Recent and fossil, without regard to the relative ages or geologic ranges of the fossil forms. Some of the papers on living diatoms contain ecological data of value to the paleoecologist, others none. Many of these papers, particularly the older ones, are available only in the libraries of the larger universities and scientific institutions, and in the personal libraries of specialists. In spite of all these obstacles, the ubiquitous diatom is here to stay and promises to become an increasingly useful tool in stratigraphy and paleoecology.

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