Diatoms in the Ocean Deeps

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The conception of a rain of diatoms from the plankton to the ocean deeps is, at first thought, a reasonable one. Further thought, however, makes it appear extremely unlikely. Because diatoms occur in swarms, particularly in certain areas of the oceans, it seems to have been assumed that they descend more or less vertically to form diatomaceous ooze. In fact, in deeper waters, we could expect them to become widely dispersed, especially as their form is such as to retard vertical movement. Further, there is the question of the gradient of silica concentration with depth, and the effect of pressure thereon. Harvey (1945) states that the silica content of seawater, in general, has been found to increase with depth, and that it is probably in true rather than colloidal solution. This suggests that the diatom tests are dissolved as they fall through the water after the death of the cell.

Wiseman and Hendey (1953) found large numbers of the diatom *Ethmodiscus rex* (Rattray) Hendey in material collected from the Mariana Trench by H.M.S. "Challenger" in 1951. These authors speculate regarding the origin of the tests, pointing out that *E. rex* is rare in the plankton, and that, "there is no indication that the species is found living in the waters immediately over the deposit itself." They do not consider the possibility that the diatom is autochthonous.

During a microscopic examination of a mud sample from the Weber Deep (depth, 7,400 m.) in a search for living bacteria, I observed a number of benthic types of diatom frustules. The sample studied was collected by Claude E. ZoBell and Richard Y. Morita during the "Galathea" expedition in 1951, and has since been kept in a pressure bomb at 10,500 p.s.i. and 10°C.

MICROSCOPIC OBSERVATIONS

Some of the frustules seen appeared to contain protoplasmic material (Fig. 1), as did some *Globigerina* and *Nummulites* which were also observed. Some showed dense spherical bodies, usually four in number, which could have been microspores (Figs. 2, 3). The larger *Coscinodiscus* forms appear to have burst, as did the form shown in Figure 3, probably owing to the rapid release of pressure when the bomb was opened. The smaller *Coscinodiscus* remained intact for the most part.

The cells from some preserved material were stained with various aniline dyes and took up the stain. When stained with acridine orange and viewed under fluorescent light they fluoresced orange-red, whereas the empty frustules did not fluoresce. Hence it may be concluded that the stained cells did contain protoplasm. It is impossible that both cell and protoplasm could have been preserved intact during a slow descent of 7,400 metres from the photic zone, so the evidence that these forms are autochthonous is very strong. Further, many of the frustules of all the species

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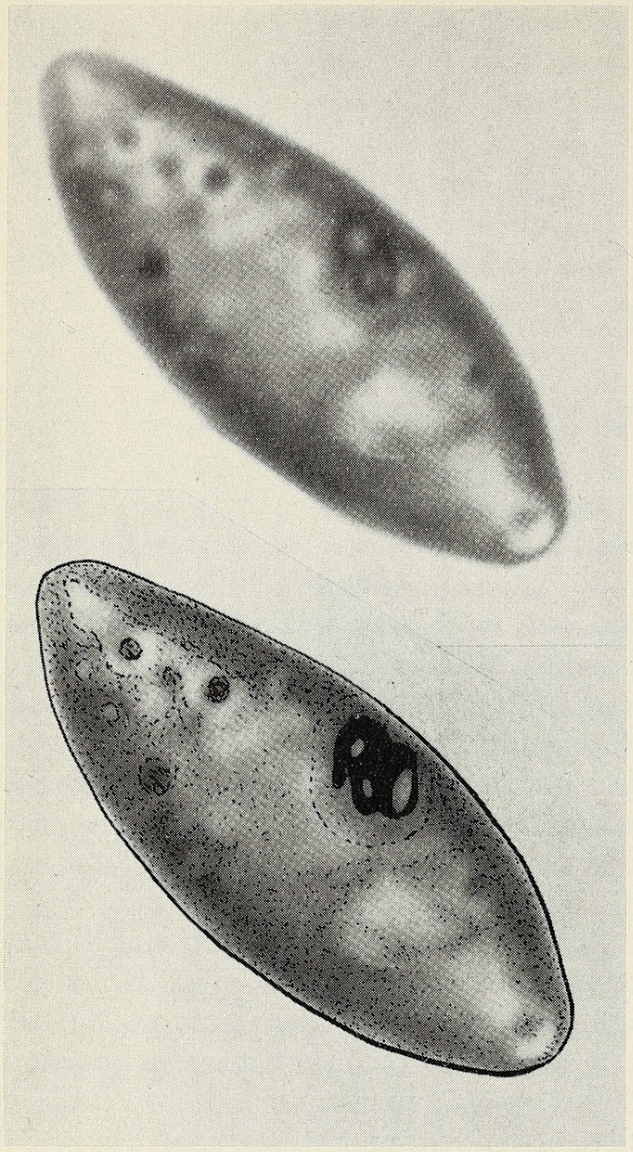

FIG. 1. A naviculoid diatom from the Weber Deep. It contained a brown pigment, vaculoes, fat(?) globules, and nucleus but no chloroplasts. Lower figure retouched. (Phase contrast.)

observed were intact, and appeared quite fresh and uneroded. No planktonic forms were observed, nor were there even fragments of such species as *Rhizosolenia*, *Chaetoceras*, etc., as one would expect from the "rain" theory.

Table 1 lists all of the "Galathea" stations from which bottom material was examined. The samples were first examined directly and again after digestion with hydrochloric acid. Cell contents were seen in material from stations 463 and 492.

In Table 2 the species of diatoms observed and the station from which they came are listed.

The samples all contained numerous sponge spicules, and the presence of these and of the sessile forms *Synedra* and *Melosira* suggest that these diatoms may be epiphytic on the sponges. It is interesting to note also that all, or nearly all, the forms mentioned in Table 2 are found as fossils, and that *Melosira granulata* and *Cocconeis pendiculus* are not recorded from seawater. Since the flora associated with the ocean deeps is unique, it would appear that we are dealing with a separate biocoenosis. Studies made by ZoBell (1952) on the bacterial flora contained in the same samples confirm this.

EXPERIMENTAL

If the diatoms are autochthonous, as I suggest, they must be living saprophytically. Recently, Lewin (1953) has described experiments in which diatoms were grown heterotrophically in the dark in a medium containing tryptone and glucose. She points out in her paper that if the diatom cultures are not pure, the bacteria outgrow the diatoms. Accordingly I obtained two cultures of her heterotrophic strains in order to test their growth under pressure, at the same time endeavouring to grow some diatoms in culture from the "Galathea" material.

All the cultures were made in the following medium—an adaptation of that suggested by Lewin:

Solution a	K_2HPO_4	0.02 g.
	$MgSO_4$, $7H_2O$	0.02 g.
	$CaNO_3$, $4H_2O$	0.01 g.
	Glucose	5 g.
	Tryptone	1 g.
	Distilled water	100 ml.
Solution b	Seawater	900 ml.
	Agar (if required)	15 g.

The solutions were sterilized separately and after cooling to about 50°C. were combined.

The cultures, placed in small tubes so as to leave an airspace above, were closed with neoprene stoppers, placed in pressure bombs (ZoBell and Oppenheimer, 1950) and pressurized at 1, 100, 200, and 500 atmospheres.

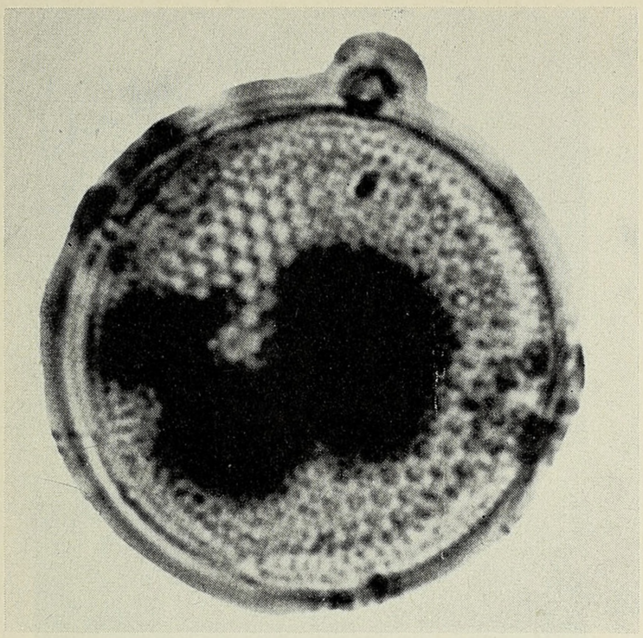

FIG. 2. *Coscinodiscus marginatus* Ehr. from Weber Deep showing dense spherical bodies (microspores?).

In addition, the "Galathea" material was pressurized at 1,000 atmospheres. In the case of the pure cultures, suspensions were made in a small amount of the medium, and 0.1 ml. was pipetted into the small tubes which were then partially filled with the medium. After 14 days, the bombs were opened, the tubes centrifuged for 15 minutes at 4,000 r.p.m., the density of the deposit estimated, and the material examined microscopically. The following observations were made.

1,000 Atmospheres Pressure

"Galathea" material only. Some *Coscinodiscus marginatus* with cell material.

500 Atmospheres Pressure

"Galathea" mud. *Coscinodiscus* containing refractile bodies and a long straight rod-like body.

Culture 6 M. Cells square with 2 to 4 green, somewhat refractile bodies, deposit density rated as 1. (Fig. 4*a*.)

Culture 13 M. Cells oval to rounded, with refractile bodies; greenish to brownish. Deposit density, 1.

200 Atmospheres Pressure

"Galathea" mud. *Coscinodiscus* with refractile bodies, and cell material between the valves.

Culture 6 M. Cells square to oblong, with greenish-brown chloroplasts. Notably heavy sediment of cells; density, 2.

Culture 13 M. Cells oval, more elongate than at 500 atmospheres. Chloroplasts brown, nucleus evident; vacuoles frequent, with particles either in Brownian movement or rotating. Cells frequently paired as though they had divided recently.

100 Atmospheres Pressure

"Galathea" mud. *Coscinodiscus* observed apparently containing cellular material; other empty tests seen.

Culture 6 M. Cells normal in appearance, i.e., like original culture. Growth heavier than at 1 atmosphere. Density, 2.

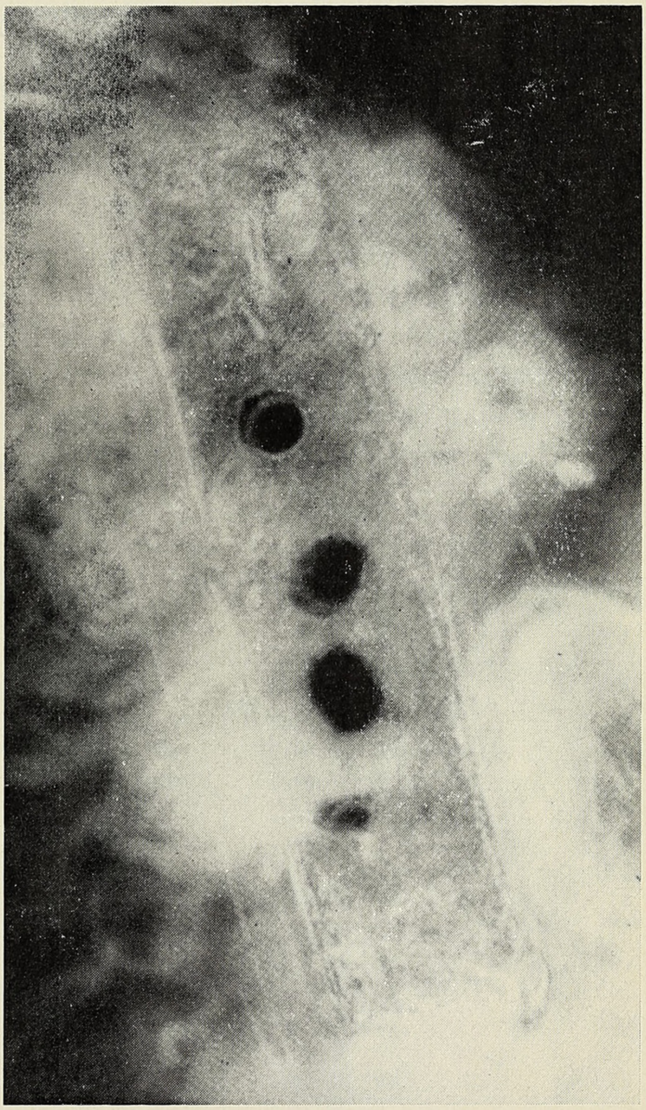

FIG. 3. Naviculoid diatom from Weber Deep which appears to have burst at side and end. (Phase contrast.)

Culture 13 M. Paired cells frequent. Cells oval, frequently with a vacuole at one end containing particles in motion. Fair growth, more than at 1 atmosphere. Density, 1–2.

1 Atmosphere Pressure

Culture 6 M. Cells similar in form to those of parent culture; poor growth. Density, 1. (Fig. 4*b*.)

Culture 13 M. Cells more oval than at high pressure. Density slightly less than at 100 atmospheres.

There appears to have been more growth at 100 and possibly at 200 atmospheres than at 1 atmosphere, but little or no growth at 500 atmospheres. Cells were more square in 6 M and circular (13 M) at high pressures.

Material from these cultures was transferred to agar slopes. Cultures 6 M grew on this medium from 1, 100, 200, and 500 atmospheres, and there was some evidence of growth of 13 M at 500 atmospheres, but the other cultures were overgrown by bacteria.

The experimental evidence suggests that diatoms taken from atmospheric pressure may grow heterotrophically or remain viable at pressures up to 500 atmospheres, and this supports the possibility of the growth of

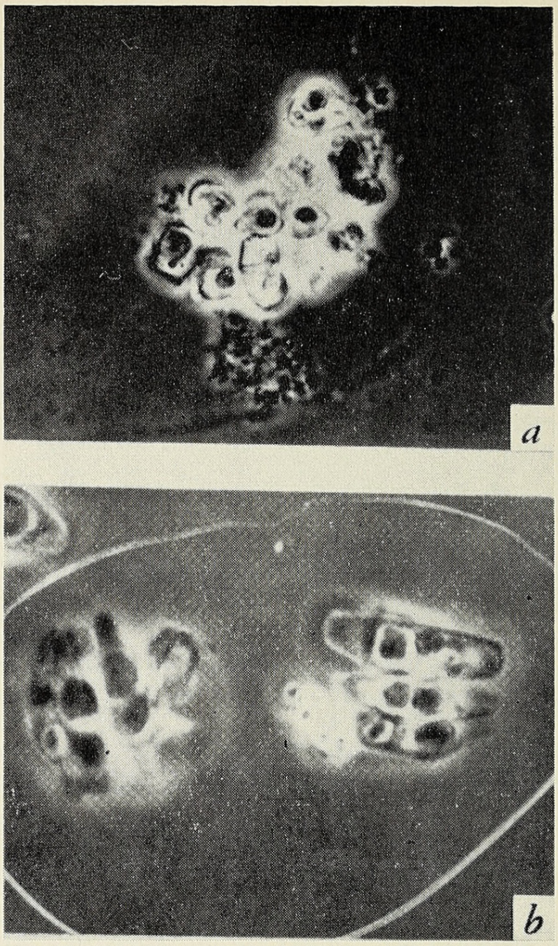

FIG. 4. Diatoms of culture 6M: *a*, Grown at 500 atmospheres pressure; *b*, grown at atmospheric pressure in bomb. (Phase contrast.)

TABLE 1

SPECIMENS OF BOTTOM MATERIAL EXAMINED COLLECTED BY THE "GALATHEA"

STATION	LOCATION Lat.	LOCATION Long.	WATER DEPTH (Metres)	DATE COLLECTED	DEEP	DIATOMS PRESENT
418	10°20′N	126°30′E	10,387	15/ 7/51	Mindanao	....
422	10°49′N	126°01′E	2,010	24/ 7/51	Mindanao	+
440	10°25′N	126°40′E	10,610	14/ 8/51	Mindanao	+
463	10°16′N	109°51′E	7,214	3/ 9/51	Sunda	+
492	5°31′S	131°01′E	7,445	20/ 9/51	Weber	+
496	5°36′S	131°06′E	7,465	23/ 9/51	Weber	+
497	....	....	9,000+	24/ 9/51	Weber	+
517	6°31′S	153°58′E	9,020	11/10/51	Solomons	+
517 ?	6°31′S	153°58′E	9,255	13/10/51	Solomons	....
608	44°31′S	167°50′E	390	18/ 1/52	Milford Sound	+
645	35°16′S	178°40′E	8,515–8,425	13/ 2/52	Kermadec	....
650	32°20′S	176°54′W	6,794	16/ 2/52	Kermadec	....
658	35°51′S	178°31′W	7,837–7,901	21/ 2/52	Kermadec	+
677	38°38′S	175°53′W	6,370	4/ 3/52	Kermadec–Tonga	....
678	28°30′S	175°53′W	9,437	4–5/ 3/52	Kermadec–Tonga	....
678 (water)	28°30′S	175°53′W	9,335	4–5/ 3/52	Kermadec–Tonga	....
686	20°53′S	175°31′W	10,080	11/ 3/52	Kermadec–Tonga	....