tom topography, and the like. Also, the change in concentration of pollutants is buffered by precipitation and redissolution of materials in bottom sediments, and modified by bacterial action, photosynthesis, and many other factors, in addition to displacement. The assumption of homogeneous dispersal of the pollution in the lake, though physically unrealistic, is a compromise between a fast, purging displacement and a slow diffusion which is the controlling mechanism when there is channeling or stratification. The applicability of the mathematical relationship given above will, therefore, vary with the lake system. With the lower lakes, the model should apply fairly closely. The upper lakes, however, are deeper, and they are divided by underwater barriers that result in more horizontal and vertical stratification of essentially static water. Also, there is a distribution of intake water around their perimeter rather than from a single upper-lake source. The time for their recovery would likely be even longer than the hundreds of years calculated. Contamination of these upper lakes would, therefore, be a major disaster for which there is no apparent solution.

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3. Research supported by the AEC under contract with Union Carbide Corporation.

12 December 1966

Opal Phytoliths in a North Atlantic Dust Fall

Abstract. *Minute bodies (less than 80 microns) of isotropic silica, originally precipitated by terrestrial plants, are found together with freshwater diatoms in falls of dust over the ocean. Eolian transport from Africa can explain the occurrence of similar plant remains in deep-sea sediments of the equatorial Atlantic as far west as the Mid-Atlantic Ridge.*

On 17 January 1965, H.M.S. *Vidal* encountered an intense dust storm southeast of the Cape Verde Islands, approximately 500 km from Africa (Fig. 1). Steaming westward, the ship remained within the storm for more than 30 hours; during daylight the sun was completely obscured. A sample of the dust, recovered from a compressor intake screen (*1*), consisted primarily of clay and silt-sized mineral grains; the two most abundant biogenic components, freshwater diatoms and opal phytoliths (Table 1; *2*), made up about 25 percent of the silt fraction. Freshwater diatoms and phytoliths blown from Africa by the northeast trade winds and recovered at sea were first described in detail by Ehrenberg (*3*). Kolbe (*4*) later reported their occurrence in Atlantic deep-sea sediments.

It has generally been assumed that diatoms occurring in the dust are swept up by the wind from desiccated beds of swamps, lakes, and streams, or from older diatomaceous deposits in arid regions, but that the phytoliths are released from grasses and carried into the atmosphere by prairie fires (*4–7*). However, the silt fraction of some topsoils is more than 50 percent phytoliths (*8*), which may therefore be a component of any wind-blown sediment

Table 1. Frequency distribution (by count) and size ranges of phytoliths, by shape, in *Vidal* dust (nomenclature after Baker, *8*).

Shape	Incidence (%)	Axes (μ) Long.	Axes (μ) Interm.	Figure	Classification (*3*)
Rod	30	7–80	2–25	2, f and g	*Lithostylidium serra* *L. amphiodon* *L. laeve* *L. curvatus*
Dumbbell (with double swelling, batonnet)	10	10–22	6–18	2, c–e	*L. clepsammidium* *L. formica*
Barrel	14	8–14	6–12	2h	*Lithosphaeridium irregulare*
Capstan and hourglass	6	6–18	5–10	2, a and b	*Lithostylidium bioconcavum*
Nondescript	40	4–30	3–20		

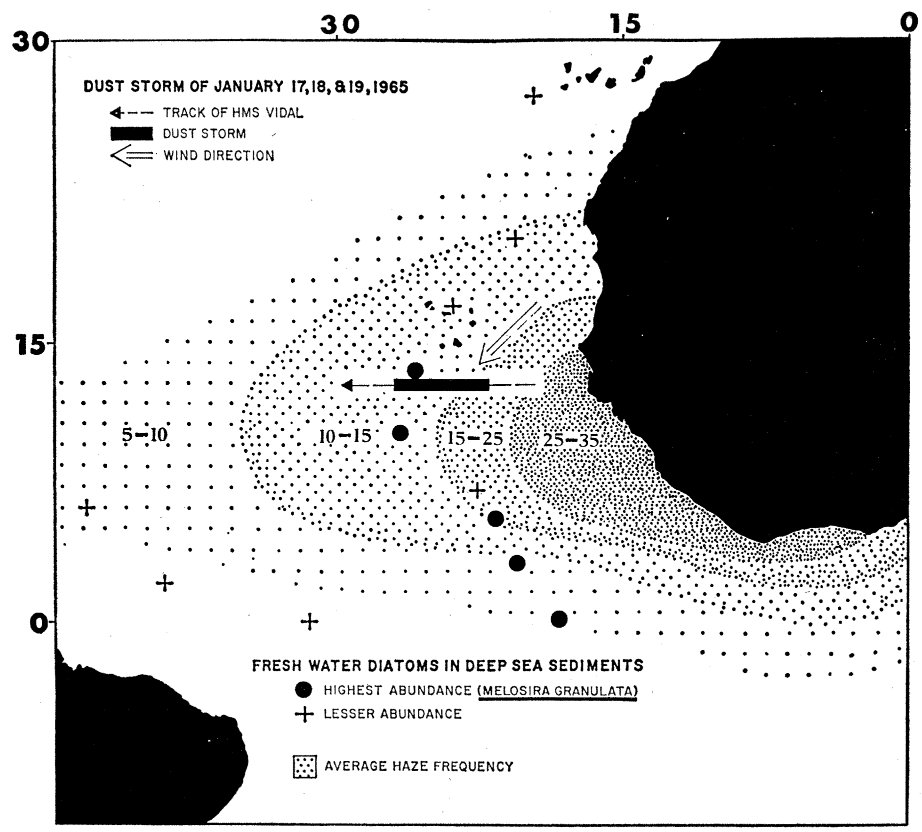

Fig. 1. Phytoliths and freshwater diatoms in a dust storm and in deep-sea sediments (*3*), in relation to haze frequency (*14*). The distribution of haze (Dec.–Feb.) reflects significant transport of dust to the Atlantic by the northeast trade winds (*7*). Phytoliths are associated with freshwater diatoms both in sediment cores and in the dust sample recovered during the storm by H.M.S. *Vidal*.

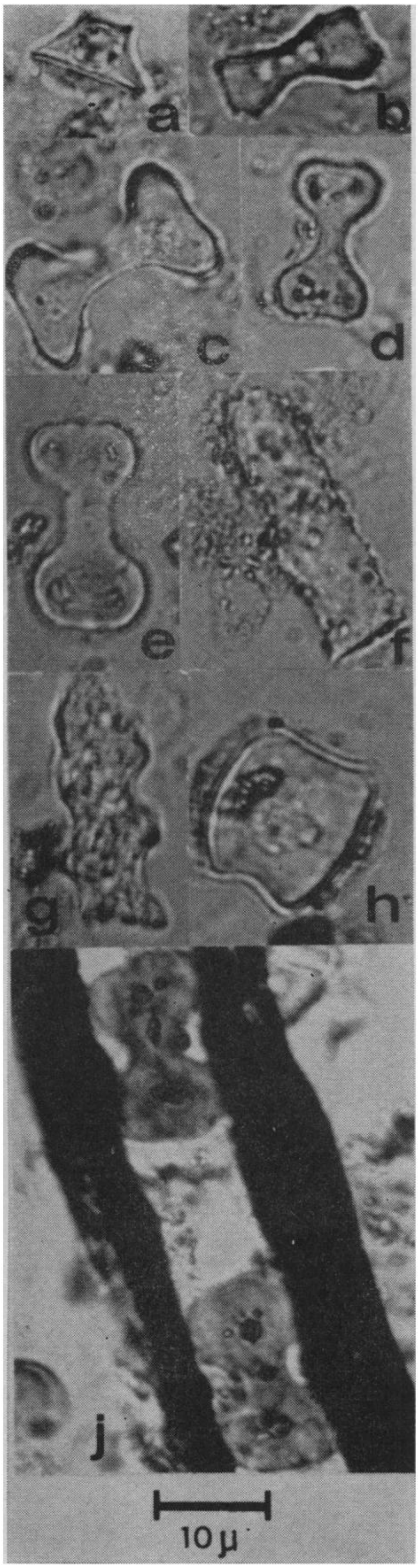

Fig. 2. Capstan (a), hourglass (b), dumbbell (c–e), rod (f, g), and barrel (h) shapes among phytoliths from a dust storm in the equatorial Atlantic. A few phytoliths were still bound together, in their original orientation, by plant tissue (j).

in areas in which opal-precipitating vegetation occurs. Vegetation in arid regions is commonly concentrated near evanescent bodies of water, where diatom-rich deposits may occur; thus the association in north African dust is a natural one.

Ehrenberg (*3*) in 1847 described 34 different forms of "Phytolitharia" that he found in dust given him by Darwin, but these opal bodies subsequently received little or no attention (*6, 7, 9, 10*). Phytoliths are discrete, solid bodies of opaline silica, with a specific gravity of approximately 2.15 and a size distribution ranging at least from fine silt to fine sand (*2, 8, 11*); many are distinctive in shape and easily identified. Since in physical properties they do not differ significantly from many common minerals, phytoliths could well serve as an index of the movement of sediment to and within the ocean basins.

Most of the forms illustrated by Ehrenberg are present in the dust sample recovered aboard *Vidal*. The many distinctive shapes include rods (with smooth, serrated, wavy, or saw-toothed edges), dumbbells, barrels, and capstans (Fig. 2); they are predominantly colorless to pinkish, but a few forms are light to dark brown.

A few freshwater diatoms common to the *Vidal* dust sample and deep-sea sediments (*4*) include *Melosira ambigua, M. granulata, Epithemia argus, Pinnularia borealis, Cyclotella ocellata,* and *Stephanodiscus astraea*. Dust falls containing freshwater diatoms have been reported over an area extending from the Canary Islands almost to the equator, encompassing essentially the same latitudinal zone in which the diatoms are found in pelagic sediments (Fig. 1; *3, 4, 10*).

The frequency ratio of phytoliths to freshwater diatoms in *Vidal* dust was approximately 60:40. The most abundant species of diatom, *M. granulata*, comprised 8 percent of the biogenic components, and the distinctive dumbbell- and batonnet-shaped phytoliths made up 6 percent. A few dumbbell-, barrel-, and rod-shaped phytoliths were still supported by plant tissue (Fig. 2j).

Kolbe (*4*) described and illustrated only dumbbell- and batonnet-shaped "silicified epidermal cells" (phytoliths) from the *Albatross* deep-sea sediment cores. These forms occurred exclusively in cores rich in freshwater diatoms; in frequency they ranked second to only the most abundant diatom, *M. granulata*; in a few instances they were retained "in their organic connection with traces of the cuticle still adhering" (*4*).

Wind (*5*), oceanic surface currents (*5*), turbidity currents (*12*), and catastrophically destroyed land masses (*13*) have each been proposed to explain the occurrence of these continental plant remains in midocean. But there is no need to invoke catastrophes or to stretch the capacity of turbidity currents to explain these occurrences; it is established that phytoliths and freshwater diatoms can be transported by wind farther than 1000 km in relative proportions similar to those observed in deep-sea sediments (*15*).

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References and Notes

1. The new compressor had been used for 2 days only. No material was visible megascopically on the screen before the storm; after it, the abundant accumulation of dust was easily brushed from the surface of the screen.
2. "Opal phytoliths are minute bodies of isotropic silica which have been precipitated as unwanted material or as reinforcement of cell structures in some plants, including grasses, sedges, reeds, and some woods, and hence are sometimes referred to as 'plant opal' or 'grass opal' bodies." G. Baker, *Australian J. Botany* **7**, 64 (1959).
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15. The deep-sea sediments contain an intimate association of freshwater diatoms and phytoliths, plant tissue supporting a few phytoliths, and one horizon that is essentially devoid of marine phytoplankton. The question of whether oceanic currents could also transport these two biogenic components in close association for more than 1000 km in order to produce similar deposits is debatable. Samples of particulate matter suspended in the water, from a few well-chosen localities, should provide an answer to this question.
16. Supported by NSF grant GA 580. We thank Admiral S. Ritchie and Roger Zaunere whose initiative and care in collecting the dust sample made this report possible. Lamont Geological Observatory contribution No. 1024.

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