14. Note that the standard deviations in the values for any one sample are chiefly derived from the statistical nature of the counting process.
15. Maximum values for radium content of impurities were computed by assuming that all of the measured radium in the sample was contributed by the impurities.
16. Samples were obtained from six companies: The Eagle-Picher Co., St. Joseph Lead Co., The Bunker Hill Co., Siegle Co., National Lead Co., and Associated Lead Manufacturers Ltd.; and from E. C. Hulmer, G. L. Stukenbroeker, H. Kühn, W. Bousted, and A. W. deWild. We thank these companies and individuals, as well as R. F. Weise, T. H. Davies, T. G. Fox, T. P. Kohman, and J. Walker and E. R. Feidler for valuable assistance. The work was carried out at the Nuclear Science and Engineering Corporation, Pittsburgh, in association with the National Gallery of Art Research Project, at Mellon Institute. The National Gallery of Art, Washington, D.C., is currently supporting further study of the method at Mellon Institute.
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Natural Displacement of Pollution from the Great Lakes

Abstract. *A simplified mathematical model of a lake system indicates that, if the pollution of the Great Lakes were discontinued, the natural flow through the lower Great Lakes would be sufficient to remove about 90 percent of the waste in about 20 years. On the other hand, hundreds of years would be required to displace the pollution from Lake Michigan and Lake Superior.*

Approximately 30,000,000 people dump their waste into and drink water from the Great Lakes. During the last few years, the rapidly increasing pollution has become a matter for serious concern. The water in the lower lakes has become offensive, and the cost to the public is tremendous for the increased amount of water treatment required, the loss of recreational use, and the decreased number of fish that are caught (*1, 2*). Multibillion-dollar programs are being proposed to decrease the pollution and to clean up the lake water (*2*). Many recent publications review the problem of contamination and eutrophication and methods for their control, but none have been found which present quantitative data on the effect of natural displacement by the flow of water through the lakes.

To illustrate the time required for self-purging of the lakes, I have made a mathematical analysis of a simplified model of a lake system. The analysis is predicated upon three assumptions: (i) the precipitation on the lake just equals the evaporation; therefore, the flow rate (R) to and from the lake is the same; (ii) the concentration of pollutants in the streams entering the lake (C_1) is constant; and (iii) the pollutants are added to the lake itself at a constant rate (Q) and are distributed so that their concentration (C_2) is uniform throughout the volume (V) of the lake. A material balance around this lake system gives the relationship of the change in the concentration of pollutants in the lake with time (T):

$$\begin{aligned} C_2 = C_2^0 &\exp(-RT/V) \\ &[C_1 + (Q/R)]\,[1 - \exp(-RT/V)] \end{aligned} \quad (1)$$

where C_2^0 is the concentration of pollutants in the lake at the initial time ($T = 0$).

A graph of this function illustrates the rate of buildup of pollutants in an initially uncontaminated lake, $C_2/[C_1 + (Q/R)]$ (curve A, Fig. 1), or the rate of recovery of a contaminated lake when the addition of pollutants is discontinued, C_2/C_2^0 (curve B of Fig. 1). In either case, 90 percent of the final concentration is reached when the volume of water that has flowed through the lake is 2.3 times the volume of water in the lake.

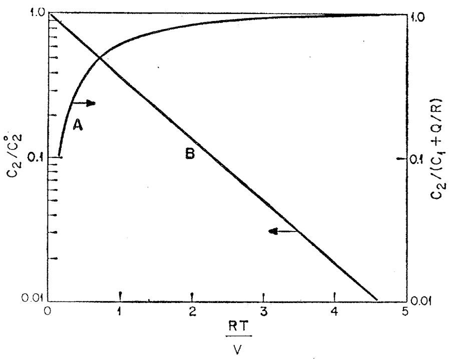

Fig. 1. Effect of water displacement rate (RT/V) of lake on the concentration of material in the lake. Curve A shows the rate of buildup of pollutants in an initially uncontaminated lake ($C_2^0 = 0$); Curve B shows the rate of recovery of a lake when addition of pollutants is discontinued ($C_1 = 0$ and $Q = 0$).

The lower Great Lakes have a relatively high flow-to-volume ratio. The flow through Lake Erie is 0.38 volume per year (Table 1). The concentration of pollutants would, therefore, reach a nearly steady state in about 6 years if the rate of addition of pollutants to the lake were constant. (The concentration continues to increase largely because of the continuing increase in the rate at which pollutants are added to the lake.) If the addition of pollutants were completely discontinued, 90 percent of the waste would be carried from Erie in about 6 years.

Since the wastes from Lake Erie flow into Lake Ontario, no program for cleaning up Lake Ontario alone can be effective. Lake Ontario contains about four times as much water as Erie but has only about 20 percent more flow rate. If the addition of pollutants to both lakes were discontinued, approximately 20 years of series flow would be required to remove 90 percent of the pollution from Ontario.

Because of the low flow ratio of the upper lakes, Lake Michigan would require about 100 years to deplete its contamination by 90 percent through natural flow; Lake Superior would require more than 500 years.

The mathematical relationship used in these estimates ignores many of the factors which influence the contamination of lakes. In actual lake systems, the flow of water through the lake is modified by wind and eddy currents, by the bypassing of bays, by channeling, by thermal stratification, by bot-

Table 1. Data on the Great Lakes system (*1*).

Characteristic	Lake Superior	Lake Michigan	Lake Erie	Lake Ontario
Length (km)	560	490	385	309
Breadth (km)	256	188	91	85
Area (km²)				
Water surface, United States	53,618	58,016	12,898	9,324
Water surface, Canada	28,749		12,768	10,360
Drainage basin land, United States	43,253	117,845	46,620	39,370
Drainage basin land, Canada	81,585		12,224	31,080
Drainage basin land, total	124,838	117,845	58,793	70,448
Drainage basin (land and water), total	207,200	175,860	87,434	90,132
Maximum depth (m)	406	281	60	244
Average depth (m)	148	84	17	86
Volume of water (km³)	12,221	4871	458	1636
Average annual precipitation (mm)	736	787	863	863
Mean outflow (liter/sec)	2,067,360	5,012,640	5,550,720	6,626,880
Average retention time of water (yr)	189	30.8	2.6	7.8

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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References and Notes

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

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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.

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		

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

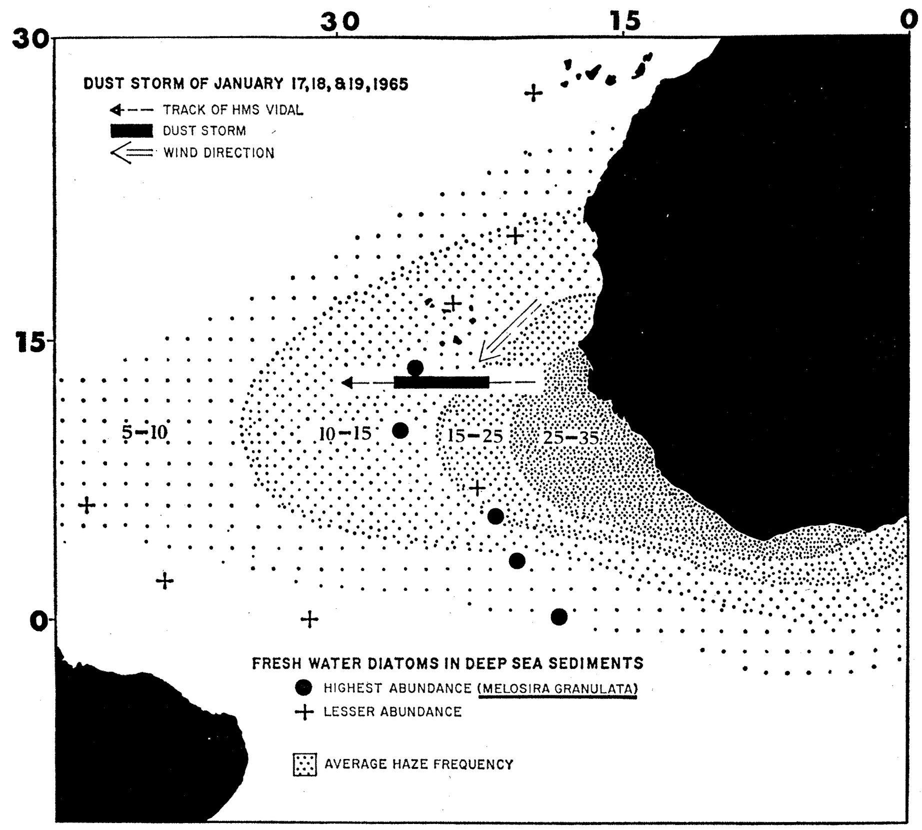

Fig. 1. Phytoliths and freshwater diatoms in a dust storm and in deep-sea sediments (*3*), in relation to haze frequency (*14*). The distribution of haze (Dec.–Feb.) reflects significant transport of dust to the Atlantic by the northeast trade winds (*7*). Phytoliths are associated with freshwater diatoms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