MASTER

DISSOLUTION OF DIATOM FRUSTULES AND SILICON CYCLING IN
LAKE MICHIGAN, U.S.A.

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Introduction

Diatoms require dissolved silicon for the formation of the silicate frustule that surrounds the cell. Potential sources of this silicon include dissolution of frustules produced by previous diatom communities, inputs of dissolved silicon from land drainage, and dissolution of silicate minerals. Frey (1974) suggested that very little silicon is recycled from dissolution of frustules in Belham Tarn, U.K., and that diatom production probably depends on land drainage inputs. However, greater than 50% of the sedimentary diatoms were dissolved and recycled in Lough Neagh, U.K. (Battarbee, 1972). In the Laurentian Great Lakes, Duthie and Sreenivasa (1971) described a paucity of diatom frustules in the sediment, suggesting that much of the silicon is recycled before the silicate frustules are permanently buried in the sediment. Although these observations indicate the importance of specific silicon sources in lakes, our general knowledge of the sources, sinks, and biogeochemical behavior of silicon in aquatic ecosystems is poor.

We investigated the relationship between diatom-frustule production, sedimentation and dissolution to determine the importance and the mechanisms of silicon recycling in a large temperate lake, Lake Michigan.

Methods

We measured the vertical distribution of total suspended sediment ($\text{TSS} = \text{g/m}^3$), diatom abundance (frustules/m^3) and diatom biomass (g C/m^3) at 5-m intervals to a depth of 40 m on monthly cruises from April

to December 1975 at station 74-5 (Fig. 1), as described by Parker et al. (1977a,b). Surface area integrals were calculated (0-40 m) and the data are presented on a m^2 basis. The concentration of soluble reactive silicon ($\text{g } \underline{\text{rSi}}/\text{m}^2$) and particulate amorphous silicon or diatom frustules ($\text{g } \underline{\text{aSi}}/\text{m}^2$) were measured throughout the water column at station 74-5 by automated colorimetric analysis, as described by Conway et al. (1977). We determined particulate amorphous silicon as the percentage of the dry sediment collected in the epilimnion and in sediment traps that were suspended at 37 m and 60 m below the surface for ~30 day intervals from April to November at station 74-5, as described by Parker et al. (1977a). We measured the concentration of diatom frustules (frustules/g dry sediment) in 14 dated sediment cores (^{210}Pb technique, Robbins and Edgington, 1975), as described by Parker and Edgington (1976). We measured the concentrations of $\underline{\text{aSi}}$ and $\underline{\text{rSi}}$ (in interstitial water) in a core collected at station 74-5, as described by Parker and Edgington (1976).

Results and Discussion

Maximal epilimnetic $\underline{\text{rSi}}$ concentration occurred in winter and early spring, but the level declined rapidly during the development of the spring diatom bloom in May and June (Fig. 2a). We observed a concomitant increase in $\underline{\text{aSi}}$ concentration during the bloom. Peaks in diatom abundance and biomass also occurred in May and June (Fig. 2b). However, diatom abundance declined when $\underline{\text{rSi}}$ levels declined below a limiting silicon concentration $\approx 6.8 \text{ } \mu\text{moles } \underline{\text{rSi}}$ (Parker et al., 1977b). As the bloom waned, total silicon ($\underline{\text{rSi}} + \underline{\text{aSi}}$) in the epilimnion declined in

response to zooplankton grazing and frustule settling. This resulted in minimal silicon levels in the epilimnion in early August.

Hypolimnetic rSi concentration increased throughout the summer and by early fall advection transported sufficient rSi into the epilimnion to initiate the development of a fall diatom bloom. Maximal diatom abundance and biomass occurred in October and November. The aSi concentration increased slightly during the fall bloom, but it did not attain the concentration observed in spring since the diatom community consisted of smaller species that had less heavily silicified frustules. The fall diatom bloom waned in early winter, perhaps in response to reduced light intensities, but not because of reduced rSi level. During winter, diatom abundance was low and rSi levels were restored to pre-spring bloom levels. These observations demonstrate the seasonal cycle of diatom production and the strong relationship between diatom bloom sequencing and the availability of epilimnetic rSi resources.

The mechanisms responsible for the restoration of the rSi resources necessary for bloom development were evaluated by tracking the loss of diatom frustules and aSi during settling of particulate material from the epilimnion to the bottom sediment. For comparative purposes, the concentration of frustules and aSi were normalized per unit of dry sediment.

A comparison of the percent aSi per unit of suspended sediment in the epilimnion, and per unit of sediment collected in the traps, showed that a progressive reduction in percent of aSi occurred during settling

(Fig. 2c,d). The seasonal distribution of frustules per gram of dry sediment showed a similar reduction. The average loss of $\underline{a}\text{Si}$ and frustules during settling from the epilimnion into the traps and to the surface of the bottom sediment are shown in Table 1. These data suggest that approximately 76—98% of the frustules are dissolved before they can be incorporated in the bottom sediment. Zooplankton grazing fractures the frustules and appears to strongly enhance the dissolution process (Ferrante and Parker, 1976). Frustule dissolution appears to account for the major fraction of the increase in $\underline{r}\text{Si}$ in the hypolimnetic water.

The concentration of diatom frustules per gram of dry sediment in the 14 sediment cores decreased by at least two orders of magnitude with depth in each core equivalent to ≈ 80 —100 years B.P. (Fig. 3). In three cores the concentration of frustules diminished to undetectable levels at 150 years B.P. The vertical distribution of frustules and the concentration of $\underline{a}\text{Si}$ and interstitial $\underline{r}\text{Si}$ in the sediment core from station 74-5 were compared (Fig. 4). A rapid reduction in number of frustules and $\underline{a}\text{Si}$ during the first 10 years of burial in the sediment corresponds to an increasing concentration of $\underline{r}\text{Si}$ in the interstitial water. The maximum $\underline{r}\text{Si}$ concentration occurs at ≈ 25 —35 years B.P. Below the maximum all three variables appear to decline at about the same rate. These data strongly suggest that frustules are dissolving within the sediment and that the sediment may also provide $\underline{r}\text{Si}$ to the hypolimnetic water by diffusion.

The importance of silicon recycling was estimated by comparing the annual silicon requirement for diatom production with the data on land drainage inputs of $\underline{r}\text{Si}$ and with the data on frustule decomposition.

Based on the number of frustules produced per year and the average silicon content of frustules, as described by Parker and Edgington (1976), the annual silicon requirement is $\approx 64 \text{ g Si/m}^2 \cdot \text{yr}$. Based on a conversion of net annual diatom production, in units of carbon, to units of silicon (Parker et al., 1977a) a second estimate suggests that $\sim 53 \text{ g Si/m}^2 \cdot \text{yr}$ is required. The annual input of rSi from land drainage was estimated by Ayers (1970) and Upchurch (1972) as 9.35×10^7 and $9.82 \times 10^7 \text{ kg Si/yr}$, respectively. This represents $\sim 1.66 \text{ g Si/m}^2 \cdot \text{yr}$ or ~ 2.5 to 3.0% of the annual silicon requirement for diatom production. The annual loss of silicon to the surficial sediment was estimated by converting the annual frustule deposition rate in the 14 sediment cores to units of silicon (Parker and Edgington, 1976). This calculation suggested an annual deposition of $\sim 1.33 \text{ g Si/m}^2 \cdot \text{yr}$.

These observations suggest that the majority of the annual silicon requirement for diatom production is provided by dissolution of frustules and inputs of rSi from the watershed. Watershed inputs appear to compensate for the loss of frustules to the sediment.

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Table Captions

Table 1. Loss of diatom frustules during settling as indicated by the average concentration of diatom frustules and amorphous silicon per gram of dry sediment in the epilimnion, sediment traps and surficial bottom sediment at station 74-5.

780

Depth	Average frustules/g dry sed	% Reduction	Average g <u>a</u> Si/g dry sed	% Reduction
0-40 m	3.92×10^8	0	0.086	0
37-m trap	1.16×10^8	70	0.077	10
60-m trap	5.03×10^7	87	0.060	30
Surficial bottom sediment (67 m)	6.31×10^6	98	0.021	76

Figure Captions

Figure 1. Location of Lake Michigan sampling stations.

Figure 2. Seasonal distribution of (a) the concentration of reactive and amorphous silicon, (b) diatom abundance and biomass, (c) total suspended sediment and the proportion contributed by amorphous silicon, and (d) the proportion of amorphous silicon in the material collected in sediment traps. (The m^2 values are based on depth integrals from the surface to 40 m.)

Figure 3. Vertical distribution of diatom frustules in 14 dated sediment cores (core depth as years Before Present).

Figure 4. Concentration gradients of soluble reactive silicon in the interstitial water, diatom frustules, and amorphous silicon from a sediment core collected at station 74-5.