Biogeochemical silica mass balances in Lake Michigan and Lake Superior

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Abstract. Silica budgets for Lake Michigan and Lake Superior differ in several respects. Mass balance calculations for both lakes agree with previous studies in that permanent burial of biogenic silica in sediments may be only about 5% of the biogenic silica produced by diatoms. Because dissolution rates are large, good estimates of permanent burial of diatoms can not be obtained indirectly from the internal cycle of silica (silica uptake by diatoms and subsequent dissolution) but must be obtained from the sediment stratigraphy. The annual net production of biogenic silica in Lake Michigan requires 71% of the winter maximum silica reservoir which must be maintained primarily by internal cycling in this large lake whereas the comparable silica demand in Lake Superior is only 8.3%. The greater silica demand in Lake Michigan is the result of phosphorus enrichment which has increased diatom production. It is hypothesized that steady-state silica dynamics in Lake Michigan were disrupted by increased diatom production between 1955 and 1970 and that a new steady state based on silica-limited diatom production developed after 1970. Mass balance calculations for Lake Michigan show in contrast with previous work that the hypothesized water column silica depletion of $3.0 \text{ g} \cdot \text{m}^{-3}$ could have occurred even though 90% or more of the biogenic silica production is recycled.

Introduction

Oceanographers have been concerned for a number of years with the silica cycle and the problems of obtaining a silica mass balance for the oceans (see Calvert 1983, DeMaster 1981). In contrast relatively little work has been done on silica mass balances in the Great Lakes. The only comprehensive study was the mass balance for Lake Superior by Johnson and Eisenreich (1979). Questions related to mass balances were addressed for Lake Michigan (Parker et al., 1977), for Lake Erie and Lake Ontario (Nriagu, 1978), and for Lake Huron (Robbins, 1980).

Certain characteristics of the Great Lakes are ideal for studies of silica mass balances. Lake Michigan and Lake Superior are large with hydraulic residence times of 100 and 138 years (Schelske and Roth 1973) and silica residence times of 36 and 69 years, respectively (Table 1). Therefore, these systems are similar to the oceans in that the quantity of silica in the water
mass is not affected greatly by annual inflows or outflows. Because of much shallower depths, they differ from the oceans in that a larger fraction of the silica reservoir in the water mass is utilized annually in biogenic silica production. This relationship is evident from the 100-fold shorter residence times of biogenic silica in Lake Michigan and Lake Ontario compared to the oceans. These deep lakes also are holomictic so homogeneous silica concentrations occur annually during the winter-spring thermal mixing period. Annual net diatom production therefore can be estimated indirectly from silica disappearance in the water column without correcting for inputs from upwelling, sediments, or tributaries except in the relatively small nearshore zone (Schelske et al., 1984). These conditions contrast markedly with those in shallow fresh-water systems (Bailey-Watts, 1976), estuarine systems (D’Elia et al., 1983), and nearshore Lake Michigan (Quigley and Robbins, 1984) where sediment release is important on time scales that are much shorter than one year and from large, shallow Canadian lakes which have maximum diatom production in late summer and autumn (Hecky et al. in prep.).

Silica mass balances differ from those in the oceans because it appears that steady-state conditions have not been maintained in any of the Great Lakes during the past 150 years. From studies of biogenic silica in sediments, (Schelske et al., 1983b) inferred that silica depletion occurred not only in Lake Michigan waters in the 1960s but also in Lake Erie and Lake Ontario in the 1800s. Robbins (1980) speculated that silica dynamics in Lake Huron were not steady state because outputs exceeded inputs and because rates of amorphous silica deposition increased 50% in recent sediments. Recently obtained data also indicate that rates of biogenic silica accumulation have increased in recent Lake Superior sediments (Stoermer et al. in prep.).