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Variations in *Melosira islandica* valve morphology in Lake Ontario sediments related to eutrophication and silica depletion¹

Abstract—Different types of valves are found in *Melosira islandica* populations preserved in Lake Ontario sediments. Three morphotypes were distinguished, the more coarsely structured of which are most abundant in assemblages deposited before 1840. Finely structured forms become more abundant upcore, reaching maximum abundance ca. 1962. These changes appear to be

related to increased phosphorus loading and consequent silica depletion in Lake Ontario waters.

Melosira islandica O. Müll. is a widely distributed freshwater plankton diatom and is commonly dominant or subdominant in cold-season plankton assemblages, particularly in large, deep lakes. As in many species of *Melosira*, valve structure is highly polymorphic (Hustedt 1930). The variation in valve morphology of *M. islandica* has caused considerable comment and some apparent

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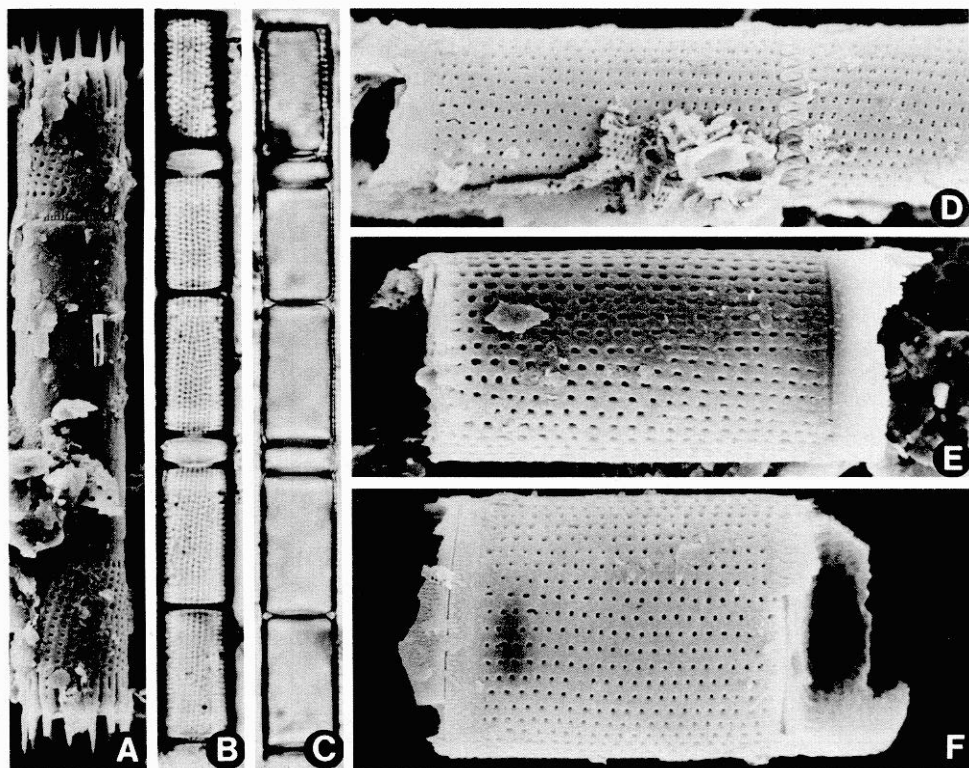


Fig. 1. Micrographs of specimens from sample 15 (14–15-cm depth interval, ca. 1896) Lake Ontario sediments. A. SEM of recently divided frustule of *Melosira italica* ($\times 2,000$). Note preservation of delicate intercalary bands covering newly formed valves. B. Top focus LM of *M. islandica* ($\times 1,000$) showing structure of type 3 (top), type 2 (next two), and type 1 (lower two) valves. C. Median focus LM of same specimen showing differing thickness of above three valve types. D. SEM of two type 3 valves showing surface features of puncta and spines ($\times 3,000$). E. SEM of type 2 valve showing surface structure of puncta and broken spines ($\times 2,700$). F. SEM of type 1 valve and attached broken fragment, showing same structures ($\times 2,700$).

taxonomic confusion in the limnological literature. Cleve-Euler (1912*a,b,c*) presented a detailed account of morphological variation in populations in lakes near Stockholm and developed an extended hypothesis relating morphological changes to life history strategies of the populations she observed. Cleve-Euler chose to call the organisms she worked with *M. helvetica*, but review of the material she worked with convinces us that it is the same species discussed here.

Stoermer et al. (1981) reviewed the morphology of *M. islandica* populations in the Laurentian Great Lakes; they found the full range of variations reported by earlier workers and noted that the morphological variations encountered appeared to be related to silicon availability. Schelske et al. (1983)

found that the highest rates of biogenic silica accumulation in cores from Lakes Michigan, Erie, and Ontario were associated with early eutrophication and that accumulation declined to an apparent steady state as eutrophication advanced. They attributed this to silica depletion in the water which limited diatom production and enhanced recycling of biogenic silica. If the above two conclusions are correct, the relative abundance of the different morphotypes of *M. islandica* should change during the postsettlement history of Lake Ontario, since it is at present the most silica-depleted of the Great Lakes (Schelske et al. 1983).

To test this hypothesis, we classified and enumerated morphotypes of *M. islandica* in several levels of a dated core from Lake

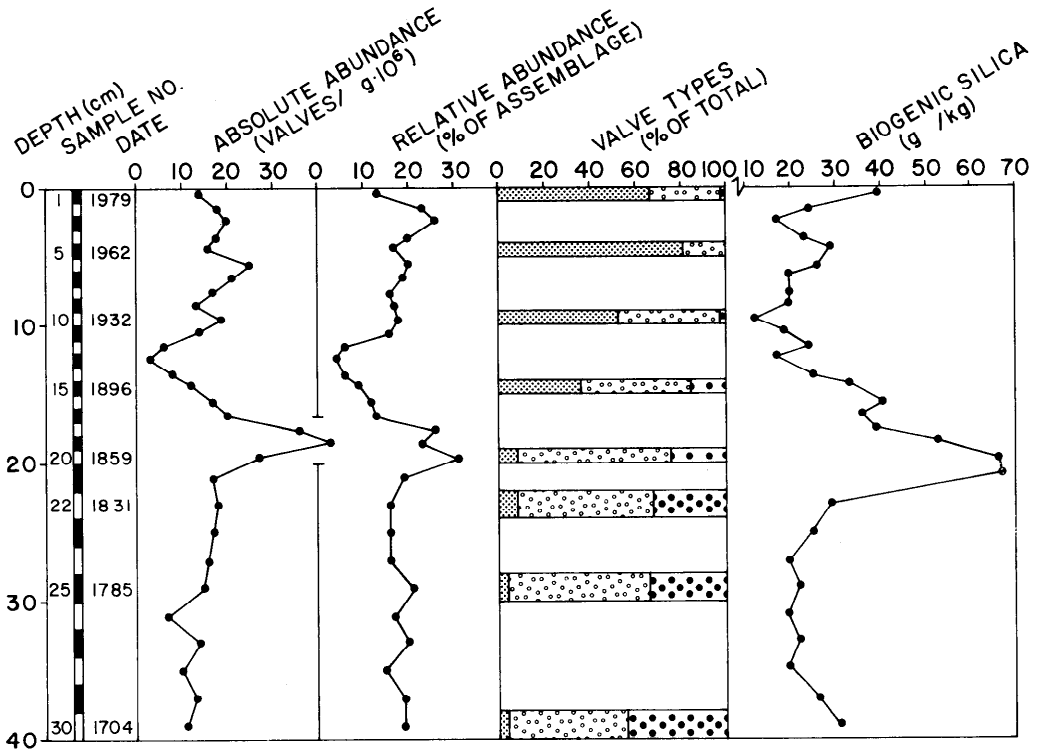


Fig. 2. Types of *Melosira islandica* valves present in core from Lake Ontario and related information. From the left: Depth below the sediment surface (cm). Sample number. Note that core was sectioned in 1-cm intervals to 20 cm and in 2-cm intervals thereafter. Median date for sample interval indicated based on ²¹⁰Pb dating. Absolute abundance of *M. islandica* (valves per g × 10⁶). Relative abundance of *M. islandica* (% of total diatom assemblage). Types of valve present at intervals indicated: type 1—light stipple left; type 2—medium stipple center; type 3—heavy stipple right. Biogenic silica (g kg⁻¹ dry wt of sediment).

Ontario. Estimates of absolute and relative abundance of *M. islandica* and biogenic silica concentration were available for this core (Stoermer et al. in prep.); we show them here for comparative purposes. Material analyzed was derived from a core taken and dated (²¹⁰Pb) by J. A. Robbins; we thank him for his help and cooperation. Cleve-Euler material was examined by E. F. Stoermer during work at the University of Lund. We thank H. Håkansson of that institution for obtaining it.

Three morphotypes of *M. islandica* were distinguished. The first is a finely structured form (Fig. 1B,C,F) sometimes referred to in the literature as *M. islandica* subsp. *helvetica*. The second has intermediate wall thickness (Fig. 1B,C,E) and is the most common morphotype found in modern phytoplankton communities in the upper Great

Lakes. The third has very thick walls (Fig. 1B,C,D) and is relatively uncommon in modern collections from the Great Lakes. In the following discussion we will refer to these as forms 1, 2, and 3, respectively.

In the core we examined (Fig. 2), type 2 and 3 valves are most abundant in strata deposited before heavy agricultural and industrial development of the Lake Ontario watershed. The relative frequency of type 1 valves increases slightly, with a concomitant decrease in the relative frequency of type 3, during the period of maximum biogenic silica accumulation (ca. 1840, Fig. 2). This coincides with the period of early intensive settlement and development of the Lake Ontario region (Schelske et al. 1983). As biogenic silica accumulation decreases, the relative frequency of type 1 valves continues to increase until they constitute 81%

of all *M. islandica* valves observed in sediments deposited during the early 1960s. At the same time the relative frequencies of type 2 and type 3 valves decrease: no type 3 valves at all were seen in sediments deposited during the early 1960s. Type 3 valves reappear and type 2 valves become more abundant in the surficial sediments. It should be noted that these estimates are probably conservative. The surficial sediments are the zone of active biogenic silica dissolution and, assuming that the thinner type 1 valves dissolve most rapidly, the proportion of type 2 and 3 valves may increase in this stratum before it is permanently buried.

Several hypotheses could be invoked to explain these observations. It might be imagined that the distribution of valve types is a preservation artifact, i.e. that assemblages in the deep sediments are a relict from which finely structured valves have been removed by selective dissolution. Our observations of specimen condition (Fig. 1A) argue strongly against this. In this core, all types of diatom valves are much better preserved in the deep sediments than above 15 cm.

It might also be argued that the morphological modifications observed are a population response to temperature change or some other physical factor. Two facts argue against this assumption. There is no known trend in physical variables of the Lake Ontario system coincident with the observed changes in morphology. Further, *M. islandica* populations in Lake Ontario (Stoermer and Ladewski 1978) and other areas of the Great Lakes (Stoermer and Ladewski 1976) are oligostenothermal and are found during winter circulation or below the summer thermocline so that they would be buffered from any likely physical effects.

The changes seen in morphology could also plausibly represent selection of particular strains due to changing chemical and biotic conditions in the lake. The available evidence argues against this. It is commonly noted (Cleve-Euler 1912c; Stoermer et al. 1981) that all types of valve can occur within a single filament and that a single cell may have valves of two different types.

Both the morphological modifications and the decline in biogenic silica accumulation

could be attributed to toxic materials entering the Lake Ontario system. This hypothesis cannot be discarded, since the lake has received a variety of such materials during the past century. On the other hand, we know of no specific observational or experimental evidence that would support it.

It is our conclusion that the change seen in *M. islandica* morphology is a response to silica limitation brought about by gross changes in the external phosphorus loading to Lake Ontario (Chapra 1977; Schelske et al. 1983). If this conclusion is accepted, it has some interesting implications.

In paleolimnological studies, it is sometimes assumed that the absolute abundance (e.g. Frederick 1981) or accumulation rate (e.g. Carney 1982) of diatom frustules in sediments are approximate indices of system production. This is true only if diatom production is not limited by the availability of silicon. Once silica limitation occurs, the accumulation of diatom frustules is diminished both by the decrease of diatom production and by enhanced dissolution and internal recycling of the available silicon pool. The accumulation of diatom frustules in sediments thus becomes an approximate function of external silicon loading and not of production or of the external supply of phosphorus (or other controlling nutrient). This quite clearly occurred in the Lake Erie core studied by Frederick (1981). It is interesting that populations of *Stephanodiscus niagarae* Ehrenb. in this core underwent subtle changes in morphology (Theriot and Stoermer 1984) which are associated with differences in ratios of available phosphorus to silicon in several North American lakes (Theriot 1983). The much more obvious morphological changes in *M. islandica* may provide a clear index of silicon availability and thus provide a valuable paleolimnological tool for evaluating the nutrient status of lakes in the past.

If we apply this index to the Lake Ontario core studied, it implies that maximum phosphorus loading and silica limitation occurred during the 1960s and early 1970s and that efforts to reduce phosphorus loadings, initiated in the early 1970s, were becoming effective by 1979. This appears to be in agreement with the very detailed history of

chemical changes available for Lake Ontario (Dobson 1981) and indicates that it may be useful in retrospective studies of lakes when detailed histories of water chemistry are not available.

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Control by organic coatings of the surface charge of estuarine suspended particles¹

Abstract—Particles in suspension in fresh, sea, and estuarine waters appear unambiguously to exhibit a small range of negative surface charge, as measured by electrophoresis. This uniformity is often attributed to the presence of organic or oxide surface coatings on the particles. Here we present experimental results which lend direct support to the idea of control of the particle surface charge by organic coatings. Iron oxide particles formed in situ in organic-free water exhibit the expected positive charge but, on immersion in water containing its natural organic material, rapidly acquire the negative charge normally found for field samples.

There is a growing body of evidence that the electrophoretic mobility (U_E), and hence the surface charge, of suspended particles from a wide variety of estuaries is always negative and falls in the range -0.7 to $-2.0 \times 10^{-8} \text{ m}^2 \text{ s}^{-1} \text{ V}^{-1}$ (Hunter and Liss 1979, 1982; Pauc 1980; Loder and Liss 1982; Hunter 1983). Similarly U_E measurements on suspended particles from fresh (Tipping et al. 1981) and seawater (Neihof and Loeb 1972, 1974; Hunter and Liss 1979; Loder and Liss 1982) also indicate negatively charged particles with U_E values in a somewhat narrower range than that given above for estuarine particles. Plankton in natural waters also appears to have a neg-

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