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Recent acidification and changes in the subfossil chrysophyte flora of lakes in Sweden, Norway and Scotland

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The subfossil chrysophyte flora was investigated in sediment cores from eight lakes in Scotland and Scandinavia. In the Scottish lakes, scales were rare or absent. However, Scandinavian lakes contained numerous different chrysophyte scales. In Lilla Öresjön (Sweden) and Verevatn (Norway) the changes in the subfossil chrysophyte community reflect the recent acidification of these lakes.

Introduction

During the last decade, chrysophyte remains in sediments have been used for the interpretation of lake history (Battarbee *et al.* 1980; Munch 1980) and more recently the study of subfossil chrysophyte scales has been shown to be a useful tool in demonstrating lake acidification (Smol *et al.* 1984). As most chrysophytes have a planktonic life form, they are dependent on water quality and nutrient concentration for their survival. The various species have well-defined habitats and nutrient demands and have their optimum growth in different types of water. Therefore they can be used as good indicators of lake-water pH.

The scaled chrysophytes studied belong mainly to the genera *Mallomonas* and *Synura*. These organisms are free-swimming, unicellular or colonial, golden-brown flagellates with the cell surface covered by silica scales and bristles. Most chrysophytes also produce silicified resting stages called stomatocysts (previously called cysts or statospores) endogenously in the cell. When the organisms die, the silica scales and stomatocysts are deposited in the lake sediment and are often preserved. The morphology of scales and stomatocysts is taxon-specific. However, to make a correct identification of these organisms, their ultrastructure has to be studied by using electron microscopy.

Study sites and methods

The lakes studied in this investigation were Lochan Uaine, Lochan Dubh, Loch Doilet, Loch Tinker and Loch Chon in Scotland, Röyrtjörna and Verevatn in Norway and Lilla Öresjön in Sweden. For more information see Battarbee & Renberg (this symposium).

The Scottish sediment cores were taken with a Mackereth mini-corer and the Scandinavian ones with a freeze corer. The sediment cores were sectioned into 0.5 cm or 1 cm slices. For chrysophyte analyses, weighed subsamples were digested in 30 % H_2O_2 at room temperature for one to two weeks. The samples were then carefully rinsed with distilled water and diluted to a known volume. For the investigation of chrysophyte scales a defined volume of the sample was dropped onto a cover glass, air dried and mounted with naphrax. The scales were identified and counted with a Zeiss standard phase-contrast microscope at magnification 1250 times. Normally 200 scales were counted per subsample, or at least 100 when scales were very scarce.

The scaled chrysophytes were divided into pH categories according to Siver & Hamer (1989). These pH categories are constructed in the same manner as those of the system devised by Hustedt (1939) for diatoms: ACB, acidobiontic; ACF, acidophilous; IND, indifferent (= circumneutral); ALKF, alkaliphilous; ALKB, alkalibiontic (table 1).

Results and discussion

The Scottish sediments contained no, or very few, chrysophyte scales. However, the Scandinavian sediments, especially Lilla Öresjön and Verevatn, contained many different scales (table 1). The investigation of the subfossil scales shows an obvious change in the chrysophyte flora during recent years in these two sites.

Table 1. Weighted mean pH, pH categories and abundance of chrysophyte scales in sediments from Röyrtjörna, Verevatn and Lilla Öresjön

(*Mallomonas*, *M*; *Synura*, *S*; numerous scales, + + +; several scales, + +; single scales, +; no scales found, −; see text for details of pH categories; weighted mean pH values from Siver & Hamer (1989).

Taxon	weighted mean pH	pH categories	Röyrtjörna	Verevatn	Öresjön
M. canina	4.9	ACB	+	+ + +	+ + +
S. sphagnicola	5.3	ACB	+	+ + +	+ + +
M. allorgei	5.8[a]	ACB	−	+	+ + +
M. lychenensis	5.9[a]	ACB	−	+ + +	+
S. echinulata	5.9	ACB–ACF	−	+ + +	+ + +
M. punctifera	5.9	ACF	+	+ + +	+ + +
M. hamata	6.0	ACB–ACF	+	+ + +	+ + +
S. spinosa	6.1	ACF	−	+ + +	+
M. caudata	6.7	IND	+ +	+ + +	+ + +
M. crassisquama	6.9	IND	+ +	+ + +	+ + +
M. teilingii	7.2[a]	ALKF	+	−	−
M. tonsurata	7.6	ALKF–ALKB	−	−	+ + +
M. acaroides	8.1	ALKB	+	−	−

[a] Mean pH values from Swedish localities.

Sediments from all the lakes investigated here also contained many chrysophyte stomatocysts of various sizes and appearances. A study of these will be presented in future papers.

Röyrtjörna

In this lake few subfossil scales of chrysophytes were found (table 1). The most common species recorded were *Mallomonas crassisquama*, *M. caudata*, and *M. acaroides*. The relative abundance of these species changed little throughout the core with mean values of about 55%, 30% and 15%, respectively, indicating relatively high pH conditions and no evidence for recent acidification.

Lilla Öresjön

See figure 1. In the 25 cm long sediment core, the chrysophyte community changed considerably. Scales of 7 *Mallomonas* and 2 *Synura* species (table 1) were found in large quantities. Below a depth of 7.5 cm–10 cm, stable conditions prevailed and *Mallomonas crassisquama*, *M. caudata* and *M. tonsurata* were most abundant. Between 2.5 cm and 7.5 cm, there was a transitional zone in which *M. caudata* reached a maximum, *M. crassisquama* decreased and acidophilous–acidobiontic species including *M. canina*, and *M. allorgei*,

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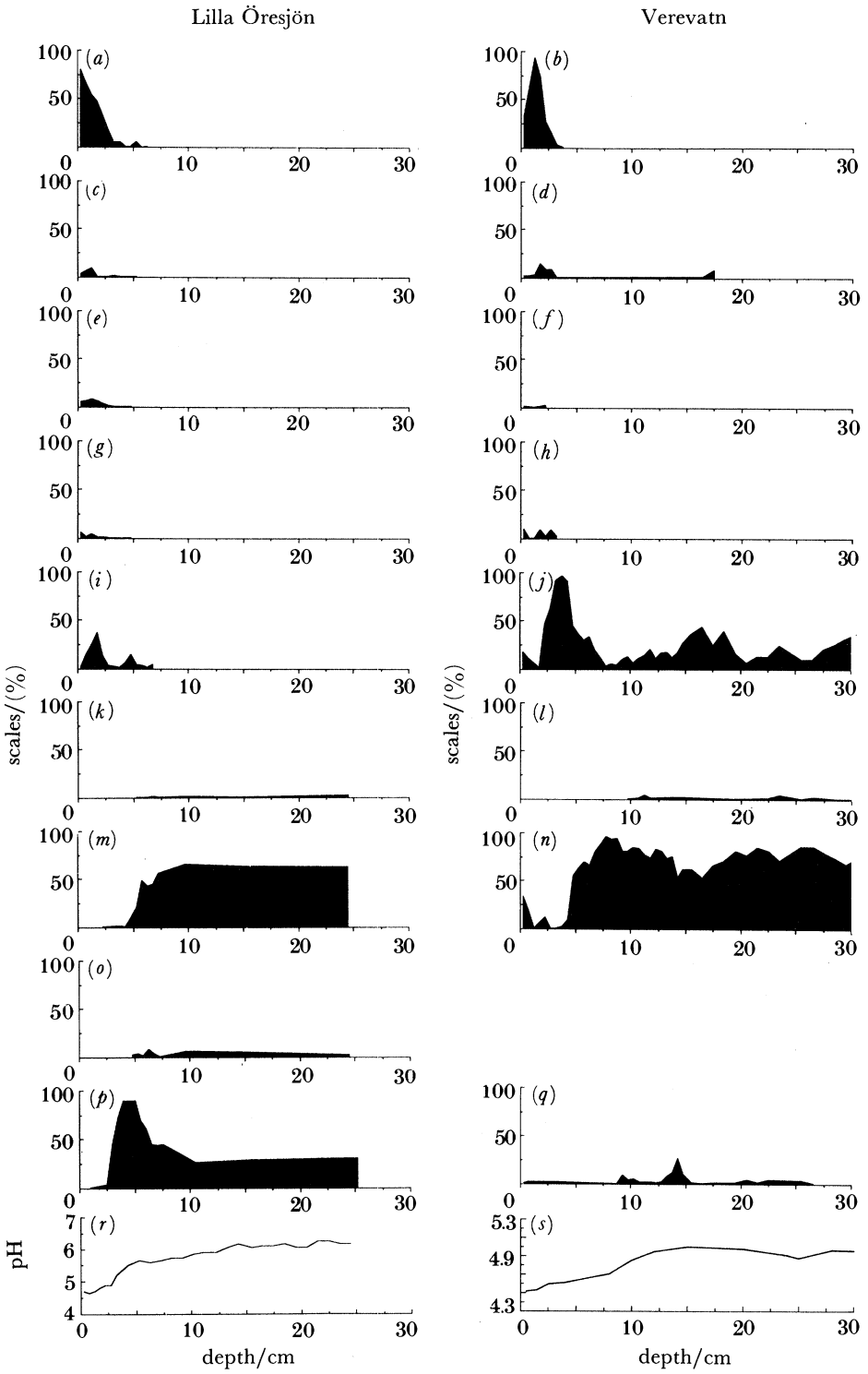

FIGURE 1. The distribution of *Mallomonas* and *Synura* scales, and the variation in diatom-inferred pH in sediment cores from Lilla Öresjön, Sweden and Verevatn, Norway (Berge *et al.* and Renberg *et al.*, this symposium). (Levels analysed for scales: Öresjön, 0 cm–5 cm every 0.5 cm, 5 cm–10 cm every 1.0 cm and 10 cm–25 cm every 5.0 cm; Verevatn, 0 cm–15 cm every 0.5 cm and 15 cm–30 cm every 1.0 cm.) (*a*, *b*) *M. canina* (ACB), (*c*, *d*) *M. hamata* (ACB/ACF), (*e*, *f*) *S. sphagnicola* (ACB), (*g*, *h*) *S. echinulata* (ACB/ACF), (*i*) *M. allorgei* (ACB), (*j*) *M. lychenensis* (ACB), (*k*, *l*) *M. punctifera* (ACF), (*m*, *n*) *M. crassiquama* (IND), (*o*) *M. tonsurata* (ALKF/ALKB), (*p*, *q*) *M. caudata* (IND), (*r*, *s*) pH (diatoms).

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M. hamata, *Synura sphagnicola* and *S. echinulata* appeared. In the uppermost 2.5 cm these latter species expanded and *M. canina* became dominant.

The first slight change started to appear at a depth of 10 cm, about 1925. However, the major shift at 5 cm depth from alkaliphilous–alkalibiontic to acidophilous–acidobiontic species represents a change that occurred about 25 years ago and corresponds with the main period of acidification as inferred from diatom analysis (Renberg *et al.*, this symposium).

Verevatn

See figure 1. Verevatn had a similar species composition of scaled chrysophytes to Lilla Öresjön (table 1). Below 5 cm–7.5 cm, the chrysophytes were dominated by *Mallomonas crassisquama* and *M. lychenensis*. In addition there were small amounts of *M. caudata* and *M. punctifera*. At about 17 cm *M. hamata* appeared. Between 2.5 cm–7.5 cm *M. lychenensis* peaked whereas *M. crassisquama* decreased to extremely low values. In the top 2.5 cm *M. lychenensis* was replaced by the acid tolerant species *M. canina*, *M. hamata*, *Synura echinulata* and *S. sphagnicola*. These changes in the chrysophyte assemblages are in good agreement with the recent acidification history of the lakes as inferred from diatom analysis (Berge *et al.*, this symposium).

The Scandinavian lake sediments contained many scales and stomatocysts. In Lilla Öresjön and Verevatn the change from alkaliphilous–alkalibiontic to acidophilous–acidobiontic chrysophyte taxa was clear and coincided with the diatom-inferred drop in pH at both sites. Röyrtjörna did not show a change in the chrysophyte community. This also agrees with the diatom data, which indicate that the decrease in pH over the last 100 years was insignificant. The similar development and changes in the chrysophyte communities of Lilla Öresjön and Verevatn might be because they have similar geology and have been exposed to more or less the same amount of acid deposition.

Scottish lakes

In the sediment from the Scottish lakes no, or very few, scales were preserved. The absence of scales in these sediments could be due to several factors, the scaled chrysophytes might not have been present in the algal communities of the lakes, or the scales might, for some unknown reason, have dissolved. However, in Loch Tinker and in Loch Chon a few scales were recorded, namely *Mallomonas crassisquama*, *M. acaroides*, *M. caudata* and *Synura echinulata*. These taxa indicate neutral to alkaliphilous pH conditions. Most probably the genera *Mallomonas* and *Synura* were rare in the Scottish sites. In Lochan Uaine very small stomatocysts dominated and these were too small to belong to the genera *Mallomonas* or *Synura*, but could perhaps be the stomatocysts of the genera *Spiniferomonas* or *Paraphysomonas*. These are also scale-bearing chrysophytes, but the scales are small, thin and easily dissolved. In the other Scottish sediments investigated, round, smooth stomatocysts were most frequent and many belonged to the genus *Dinobryon*. However, the pH range for the *Dinobryon* species is wide and most are unsuitable for use as pH-indicators.

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