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Note

Paleolimnological significance of observed distribution patterns of chrysophyte cysts in arctic pond environments

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Abstract

In a survey of 35 high arctic ponds, chrysophycean cysts were relatively more common in moss periphyton and epilithon habitats, than in surface sediment samples. The highest percentages of cysts relative to diatoms were found in the semi-aquatic mosses. Although chrysophytes are generally considered to be planktonic, periphytic taxa may be common in high latitudes. The ratio of diatom frustules to chrysophyte cysts in arctic sediment cores may be tracking different environmental variables than paleolimnologists may intuitively expect based on observations from more temperate regions.

Introduction

A characteristic feature of all chrysophytes (Chrysophyceae, Synurophyceae) is the ability to form siliceous resting cysts, called stomatocysts (= statospores), which are believed to be species-specific (Duff *et al.*, 1994). Because cysts are often well preserved in lake sediments, there has been considerable interest in using these indicators to augment paleolimnological interpretations (e.g. see reviews by Cronberg, 1986; Smol, 1988, 1990, 1994). The fact that chrysophytes often dominate the plankton of arctic lakes and ponds (Moore, 1979; Wallen & Allen, 1982; Sheath, 1986) makes the study of stomatocysts in these environments particularly important. Arctic paleolimnology has also enjoyed heightened interest because high latitude regions may be especially sensitive to climatic and other environmental changes, and direct measurements of environmental change are lacking.

Much work remains on describing cyst morphotypes and linking the cysts to the taxa that produce them, as well as documenting the ecological optima and tolerances of these bioindicators. Progress is being made on these problems in several lake regions (e.g. Duff *et al.*, 1994), including the Arctic, where cyst assemblages have been studied in the sediments of lakes (Duff & Smol, 1988, 1989), ponds (Duff *et al.*, 1992), and even fossil peat profiles (Brown *et al.*, 1994).

Because most cyst morphotypes have yet to be linked to the taxa that produce them and because little autecological data are yet available, Smol (1985) suggested that, as an interim step, researchers could simply report the ratio of diatom frustules to chrysophyte cysts. Although much ecological information is lost by lumping all chrysophytes into one category, this index still provides an approximate measure of the relative abundance of the two algal groups. In temperate regions, such as Southern Ontario, this index may provide an approximate inference of lake trophic changes (Smol, 1985), as chrysophytes tend to be less common in eutrophic environments. Other paleolimnologists have used the ratio of diatoms and cysts for a variety of studies (e.g., Smol, 1983; Risberg, 1990; Engstrom *et al.*, 1991; Stoermer *et al.*, 1991; Hickman & Schweger, 1991; Yang *et al.*, 1993; Zeeb & Smol, 1993; Cumming *et al.*, 1993).

We have been studying a suite of 36 high arctic ponds on Cape Herschel (78 °37′N, 74 °42′W), Ellesmere Island, NWT, for several limnological and paleolimnological variables (e.g., Douglas, 1989, 1993; Douglas & Smol, 1993, 1994a, b; Duff *et al.* 1992; Nogrady & Smol, 1989). The ponds are typically shallow (<2 m), clear, oligotrophic, and freshwater, and are described in detail elsewhere (Douglas, 1989, 1993; Douglas & Smol, 1994a). The ponds thaw in late June or early July, but may again begin to freeze by early August. Because of their small volumes, these ponds may be especially sensitive bellwethers of environmental change.

Chrysophyte cysts preserved in the surface sediments of the Cape Herschel study ponds were described by Duff *et al.* (1992), who tentatively speculated that some of the cysts may be produced by periphytic taxa. As the authors cautioned, their data were circumstantial. For example, ponds with large moss substrates (e.g. Horseshoe Pond) contained unusual cyst floras.

We had the opportunity to explore further the relative abundance of cysts in the various periphytic communities on Cape Herschel as part of a subsequent diatom survey of the moss epiphyton, epilithon and surface sediment assemblages from the 35 ponds (Douglas, 1993; Douglas & Smol, 1994b). Whilst identifying and counting the diatoms, we also enumerated chrysophyte cysts and expressed the counts relative to the number of diatom frustules (Smol, 1985). We were surprised to find the highest relative abundances of cysts in the moss periphyton and epilithon samples, and not in the pond sediments. This paper describes these results.

Materials and methods

Periphyton samples (Douglas, 1993; Douglas & Smol, 1994b) were collected from the same 35 study ponds used for the surface sediment diatom (Douglas & Smol, 1993) and chrysophyte cyst (Duff *et al.*, 1992) surveys; Brackish Pond was omitted because it is tidally influenced. The study ponds were selected to represent as broad an environmental spectrum as possible on the Cape (e.g., differences in conductivity, altitude, bedrock composition, size, and drainage characteristics).

During the 1983, 1984, 1986, and 1987 field seasons, we monitored the study ponds for a variety of limnological variables (Douglas & Smol, 1994a). Detailed outlines of sampling and lab procedures are in Douglas (1989, 1993) and Douglas & Smol (1993, 1994a, b), and are briefly summarized below.

Epilithic communities were sampled by collecting five submerged rocks from each pond and brushing the periphytic community into a small vial with a soft toothbrush. The rocks were chosen to reflect the various epilithic habitats present in each pond (e.g., depth, rock type, etc.); however, given the small size and shallowness of the ponds, the substrates were fairly homogenous.

Epiphytic communities, if present, were also sampled. Bryophytes[1] were by far the most common plant substrates, and so we restricted our epiphyton samples to moss substrates. Submerged (non-*Sphagnum*) mosses were present and sampled from 22 of the 35 ponds. An additional six 'wet' moss samples (defined as mosses that were not submerged, but were sufficiently wet that water could be squeezed from them) were collected from the pond edges that supported no submerged moss. All samples were stored in 15 ml plastic scintillation vials and preserved in Lugol's iodine solution. We examined submerged moss and rock samples collected during mid-season (and preferably on the same day) from the 1986 season.

Chrysophyte cysts are siliceous, and so microscope slides were prepared following standard diatom techniques (Battarbee, 1986; specific details in Douglas, 1993 and Douglas & Smol, 1994b). Strewn mounts were used exclusively.

Diatoms were identified and counted along transects (Douglas, 1993; Douglas & Smol, 1994b). Usually, a minimum of 250 diatom valves was counted from each sample. In the case of 'wet mosses', diatoms were scarce and so fewer diatoms were enumerated. The results of the diatom surveys are described in Douglas (1989, 1993) and Douglas & Smol (1994b). We also counted the chrysophycean cysts we encountered during our diatom counts. These cyst sums are expressed relative to the number of diatom frustules (two valves = one frustule) plus chrysophyte cysts, following Smol (1985), [i.e. D:C = (number of diatom frustules/number of chrysophyte cysts + number of diatom frustules) × 100].

[1] A total of 121 species of moss have been identified from Cape Herschel (Bridgland, 1986). We did not identify the moss taxa in this study.

Results and discussion

The proportions of diatom frustules to chrysophycean cysts (D:C) from the 35 surface sediment (from Duff *et al.*, 1992), 35 epilithon, 22 submerged moss, and 6 'wet' moss samples are presented in Table 1. Chrysophytes are widely considered to be planktonic, and certainly often dominate the plankton in arctic systems (e.g., Moore, 1979), and so we anticipated finding many more cysts in the pond surface sediments than in the moss and rock substrates, as sediments should more closely reflect planktonic assemblages. Instead, we found relatively more, and often many more, chrysophyte cysts in the epilithon and moss epiphyton. Even more surprising was that the relative proportion of cysts was especially high in the wet mosses, where one might expect to find only aerophilic algae. For example, the average D:C is 97.9 for surface sediments, 86.1 for epilithon, 86.0 for submerged mosses, and 38.0 for wet mosses. If the Col Pond sample, a high elevation site where we found no cysts in the wet moss (i.e. a D:C = 100), is removed from the wet moss calculations, then the average D:C drops further to 21.7 [Col Pond water levels fluctuate widely during the course of a season, and so a 'wet' moss sample in this pond may actually be dry for much of the season].

We found the above results surprising. Chrysophytes are usually considered to be planktonic organisms with very few benthic members, and in fact many textbooks and phycologists consider them to be euplanktonic. This has been confirmed by many surveys from temperate and tropical regions. However, contrary to our expectations, cysts were generally relatively less common in the surface sediment assemblages, and more common in the periphytic habitats. Several hypotheses might account for these observations.

The first explanation might be that periphytic chrysophytes do indeed exist in relatively high numbers in high arctic regions such as Cape Herschel. Although very little data are available from the Arctic, and to our knowledge no data exist from the High Arctic, there are indications that benthic chrysophyte taxa may be more common in high latitude regions (Hilliard & Asmund, 1963). At this time, we do not have any data on periphytic chrysophyte assemblages from our or any other arctic ponds; however, A. Wolfe (personal communication) has also found relatively high numbers of chrysophyte cysts in mosses from Baffin Island lakes. The presence of a distinct periphytic chryso-

Table 1. The diatom frustule to chrysophyte cyst ratio (D:C), expressed as percentages (see Smol, 1985), for the four assemblages examined in this study. Thirteen sites did not support any submerged mosses; in six of the sites, 'wet' mosses (i.e. mosses near the shoreline that were sufficiently wet so that water could be squeezed from them) were present, and these D:C values were also calculated. The surface sediment D:C values are from Duff *et al.* (1992)

Pond	Surface sediment	Rock	Submerged moss	'wet' moss
Col P.	99.1	97.9	–	100
P.15	97.2	95.0	74.9	–
P.18	93.8	94.8	97.8	–
P.N.W. Horseshoe	100	77.3	–	–
Elison P.	93.8	89.6	93.5	–
Paradise P.	94.6	83.8	–	–
Cape Herschel Lagoon	92.7	91.6	46.6	–
Beach Ridge P.	98.2	92.1	87.8	–
Plateau P. 1	100	90.0	–	–
Plateau P. 2	97.2	92.1	–	–
Horseshoe P.	97.6	97.8	95.4	–
Willow P.	97.5	96.7	100	–
P. N. Willow	97.2	41.7	–	–
Moraine P.	97.8	92.6	97.4	–
P.13	100	95.8	–	81.8
P.12	99.1	93.0	97.5	–
P.10	95.0	75.5	–	–
P.8	97.5	100	92.6	–
P.2	98.1	86.6	97.0	–
P.3	95.3	89.8	60.6	–
P.28	98.1	97.7	95.9	–
P.6	99.0	68.2	–	24.2
P.24	100	72.0	–	1.4
P.32	98.3	98.6	97.9	–
P.S.P. 7	99.1	94.6	94.7	–
P.7	99.1	90.7	90.3	–
P.14	99.1	89.7	91.0	–
P.1	100	96.7	91.8	–
P.27	100	49.3	28.1	–
Ephemeral P.	100	80.3	89.8	–
Camp P.	94.8	94.8	77.9	–
Elison P.	98.3	93.4	93.8	–
Poppy P.	99.1	92.2	–	1.2
Cold P.	100	64.4	–	–
P.26	100	59.5	–	19.95
Means	97.90	86.16	86.01	38.00
n	35	35	22	6

phyte flora would confirm the speculations made in the Duff *et al.* (1992) study.

If periphytic chrysophyte taxa exist in the Arctic, then this raises some exciting possibilities for paleolimnological work. For example, the presence of mosses in a high arctic system may be tracking a climate signal, at least in an indirect way (Douglas & Smol, 1993; Douglas, 1993). Diatoms characteristic of the moss epiphyton can be used in paleolimnological studies to infer past changes in mosses. However, if a second group of indicators (i.e. cysts), which are present on the same microscope slides, could be used in these analyses, then interpretations could be considerably strengthened. Moreover, if distinct cyst assemblages characterized the wet moss habitats, one might eventually develop an index of moisture quantity, which could be used, for example, to assess the past moisture content of fossil moss assemblages. This might have considerable potential in paleoenvironmental reconstructions of fossil peat profiles, where distinct chrysophyte cyst floras have been recorded (Brown *et al.*, 1994).

A second possibility is that these ratios are simply reflecting lower diatom numbers in the epiphyton and epilithon, and especially in the wet moss samples. While this may be affecting the ratios, there is little doubt that cysts occur, often in large numbers, in these habitats. Alternatively, encystment might simply be more common in the more extreme environments, such as the wet mosses. Nonetheless, a periphytic assemblage still appears to exist, and could be used in environmental reconstructions.

Our observation that cysts are relatively more common on wet rather than submerged mosses is substantiated by a more detailed analysis of moss periphyton from Horseshoe Pond. This site is the only pond on Cape Herschel that has along one side of its perimeter a vertical moss bank (<50 cm high). We analysed three periphyton subsamples from this moss bank: 1) submerged moss periphyton from the bottom of the moss bank; 2) moss periphyton from near the waterline; and 3) 'wet' moss periphyton from the top of the moss bank. In accordance with the data in Table 1, the D:C was 98.9 for the bottom sample, 94.7 for the submerged sample near the waterline, and 36.4 for the wet moss sample from top of the bank. Chrysophyte cysts were again relatively more common in the drier habitat.

Another surprising observation was that some of the ponds that recorded no cysts in the surface sediments had relatively high numbers of cysts attached to the epiphyton and epilithon (e.g. Pond 26, Pond 27; Table 1). This might suggest that, in at least these pond environments, periphytic cysts may not be adequately dispersed and deposited in the surface sediments. Diatoms, however, do appear to be well integrated from the different microhabitats to the surface sediments (Douglas, 1993; Douglas & Smol, 1994a).

From a phycological perspective, it would now be important and interesting to investigate the living periphyton more closely – not with acid-digested samples as we did here, but to begin investigations on the present-day periphyton. If many periphytic chrysophytes do exist in these arctic ponds, then this has considerable phycological and paleolimnological implications. Moreover, it also suggests that simple ratios in arctic pond sediments may not reflect the plankton as one might intuitively suspect. If chrysophytes are indeed common on rock and moss substrates in arctic regions, and even relatively more common on semi-aquatic mosses, then simple ratios of chrysophyte cysts to diatom frustules will be indicating different environmental variables in arctic pond sediments than in more temperate regions. Whilst one might intuitively think that a higher percentage of cysts might reflect a more developed planktonic community, perhaps related to higher water levels in these ponds, the reverse may actually be the case.

We conclude with a recommendation that has been echoed before in papers dealing with chrysophyte cysts in lake and pond sediments: Work should be accelerated on describing cyst morphotypes, on documenting the ecological variables that these morphotypes can infer, and on linking morphotypes to the living taxa that produced them. Cysts are well preserved in high arctic pond sediments, and indeed the D:C changed over time in a series of dated cores from Cape Herschel (Douglas, 1993). Our data indicate that D:C ratios should be interpreted cautiously in arctic ponds, as general phycological patterns observed in lower latitudes may not be applicable to these environments. Late-glacial and early postglacial environments of temperate lakes, where cysts may be very abundant, may also contain cysts from periphytic taxa. The challenge is now to interpret these and other changes correctly.

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