Coring of laminated lake sediments for pigment and mineral magnetic analyses, Søndre Strømfjord, southern West Greenland

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Lake sediments are natural archives that provide long-term records of past changes in climate-catchment processes as well as changes in biological communities in lakes. The thousands of lakes in West Greenland are poorly studied but ideally suited to palaeoclimate and lake-catchment interaction projects because of the minimal level of anthropogenic impact and their tight links to regional climate. In 1999, therefore, activity in the Kangerlussuaq / Søndre Strømfjord area (Fig. 1) continued with both a summer limnological sampling programme (Brodersen & Anderson 2000, this volume) and a late winter to early spring expedition to retrieve sediment cores from lakes at the head of the fjord. In our previous coring trips along Søndre Strømfjord we identified a number of lakes with laminated sediments (Anderson & Bennike 1997; Anderson *et al*. 1999). Initially, it was thought that these finely resolved laminated sediments were restricted to lakes with permanently stratified water columns (meromictic lakes). However, it appears that lakes with laminated sediments are more widespread in West Greenland that hitherto thought.

The main aim of the 1999 winter field work was to obtain fresh cores from those sites that were cored two years previously (Brayasø or Lake 4, Store Saltsø or Lake 17 and Lake 6; Fig. 1; Anderson *et al*. 1999). Fresh cores were required for pigment analysis because once a core has been taken from a lake, exposure to oxygen and light will cause sedimentary pigments to degrade rapidly. Another aim was to take freeze cores from sites that were previously identified as having laminated sediments but from which only short (25–30 cm) cores with a Kajak gravity corer had been taken. As a result of the high water content of the surficial sediments in lakes, it is necessary to use a freeze corer, especially if any fine resolution sampling is to be successful.

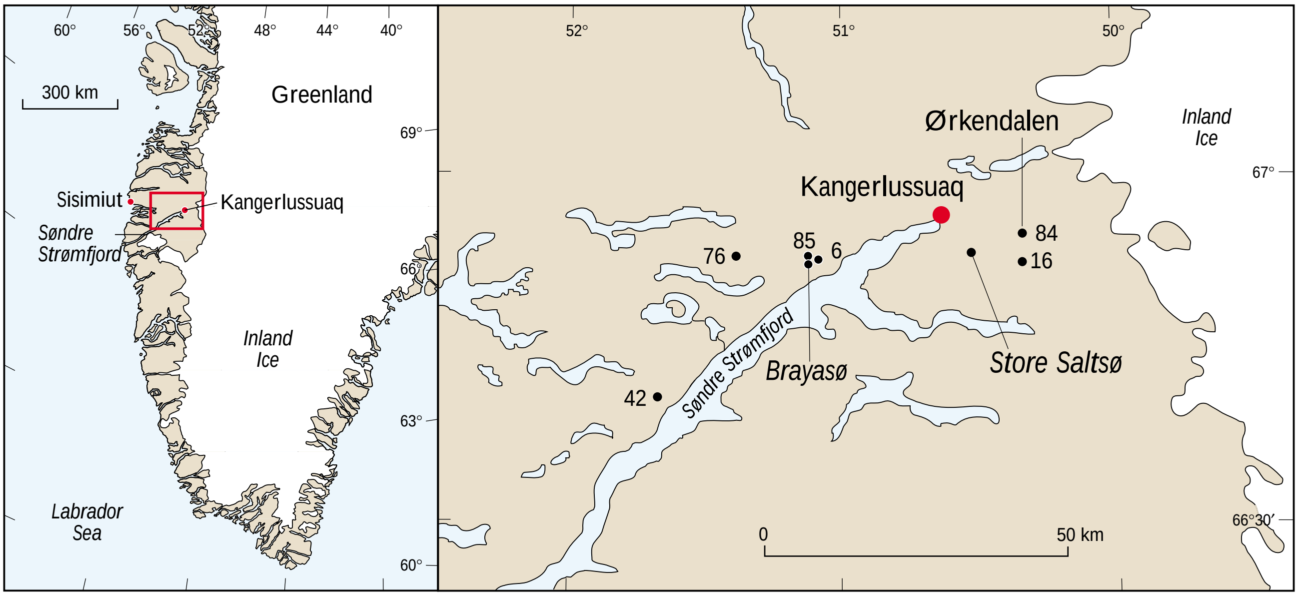

Fig. 1. Location maps showing the study region in southern West Greenland and the location of the lakes cored in 1999 around the head of Søndre Strømfjord.

Bulk magnetic susceptibility measurements of the cores taken in 1997 (Clarke 1998) had indicated the possibility of using magnetic parameters as palaeoclimatic proxies, as has been done elsewhere (Sandgren & Risberg 1990; Dearing 1991). The mineral magnetic signal in lake sediments can reflect catchment (e.g. soil erosion) as well as in-lake processes (autogenic formation of magnetite or post-depositional, diagenetic changes and dissolution). In some situations, atmospheric inputs may be important. Given the well-known aeolian activity in this area (Dijkmans & Törnqvist 1991), it was decided, therefore to obtain a core from a lake close to some of the large aeolian deposits that are abundant in the Kangerlussuaq area.

Finally, as part of a contribution to the SNF-funded project *The influence of climate change on past and present biological structure in Greenland lake*s, sediment cores were taken from a range of water depths from a single lake to enable the calculation of sediment and microfossil accumulation rates at a whole-basin scale. This approach counters problems with the heterogeneity of sediment deposition in basins and permits estimates of 'whole-lake' palaeoproductivity.

Field work

Russian and freeze coring of lake sediments is much easier from the solid base provided by ice (Fig. 2). The field work took place between 28 April and 10 May 1999, when ice thickness on most lakes was still about 1.6 m.

Fig. 2. The field team on Lake 84. One group is extruding a Kajak core whilst the other collects water samples for chemical analysis and field measurements of the water column for conductivity, pH, temperature and oxygen saturation.

At those lakes (Brayasø, Store Saltsø, Lakes 6 and 84) where single core sequences were taken from the deepest part of the lake, the coring procedure was the same. First, the deepest part of the basin was identified and then a freeze core taken; see Anderson *et al.* (1999) for a description of the method. Close-by, new holes were then cut through ice to enable overlapping drives to be taken with the Russian corer. At these sites the total length of sediment recovered varied between 1.5 and *c.* 2 m. Lake 84 was a new site chosen primarily for its location close to the large aeolian deposits in Ørkendalen and it will be analysed in detail using mineral magnetic techniques. A small lake, 12 m deep, Lake 84 contains sediments that proved to be clearly laminated throughout.

At Lake 16, a bathymetric survey was completed; although small, the lake has two basins of 12 and 7 m depths. A freeze core and Russian core sequence were taken at the deepest point, as at other lakes. The thickness of the sediment in the central part of the basin was just over 3 m. Russian core sequences were taken at nine sites within the basin at different water depths. At each of these sites a Kajak core of the surficial sediments was taken and sectioned in the field. The Russian cores were wrapped and boxed in the field and returned to the field station at KISS (Kangerlussuaq International Science Support). Probing with the Russian core rods was also undertaken to identify the limit of organic sedimentation within the shallow water, littoral zone.

Table 1. Comparative depths and lake-water conductivities for those lakes with laminated sediments

Lake	Location	Maximum depth (m)	Conductivity (µS cm^{-1})
4 (Brayasø)	66°59.3´N 51°02.8´W	22.4	2538
17 (Store Saltsø)	66°59.4´N 50°35.9´W	11.3	2707
6	66°59.8´N 51°06.6´W	12.8	3476
16	66°54.8´N 50°27.3´W	12.0	60
42	66°44.3´N 51°48.6´W	12.5	1744
76	66°56.3´N 51°33.3´W	24.0	350
84	66°59.2´N 50°19.7´W	12.0	101
85	66°58.9´N 51°03.4´W	12.4	604

Single freeze cores were also taken from Lakes 76 and 42, which lie about 35 km and 55 km south-west of Kangerlussuaq airport (Fig. 1). Although only 12 m deep Lake 42 is slightly saline (Table 1) and meromictic, i.e. the water column is permanently stratified. In contrast, Lake 76 is small and very deep (24 m) in relation to its surface area but is dimictic, i.e. the water column mixes at the start and end of the summer, and has a lower conductivity. Both these lakes have clearly laminated sediments but at Lake 76 only the uppermost 25 cm of the core were laminated. At Lake 42, the sediment structure was similar to the saline lakes at the head of the fjord (Brayasø and Lake 6) with distinct calcite layers and purple sulphur bacterial bands (see Anderson *et al.* 1999).

Magnetic minerals in lake sediments

A number of lakes from the Kangerlussuaq region, including Brayasø and Lake 6 have been analysed for various magnetic properties in order to identify magnetic mineral assemblages and their variations through time (Fig. 3). The similarity of the signal from the two lakes suggests some synchronous response of the two lakes to environmental change, which is supported by the comparable changes in the laminations. The similarity of the profiles indicates that the signal in the magnetic minerals is reflecting some regional forcing mechanism on the lakes as opposed to catchment or lake-specific signals. The sediment may have been derived from in-blown dust deposits thus reflecting changes in controls on aeolian deposition such as wind strength and levels of precipitation. Another possible explanation may be lake-level lowering, which is evident from former lake terraces (see Anderson *et al* 1999). This process would have led to more sediment becoming periodically available to be reworked into the lake system. Other lakes from the area are being analysed to assess the repeatability of the signal throughout the region and identify which catchment features (e.g. geology, catchment size, altitude) appear to influence the magnetic signal.

Sedimentary pigments

Algae and photosynthetic bacteria produce many different types of pigments (chlorophylls and carotenoids), some of which are specific to particular algal/bacterial groups and so can be used as taxonomic markers. When deposited in lake sediments they often preserve well and their record in sediment cores can be used to reconstruct past algal and bacterial communities. Pigments can be easily extracted with organic solvents (Sanger 1988) and separated by high-performance liquid chromatography (HPLC). Identification and quantification is aided by on-line diode-array spectrophotometry (Jeffrey *et al.* 1997).

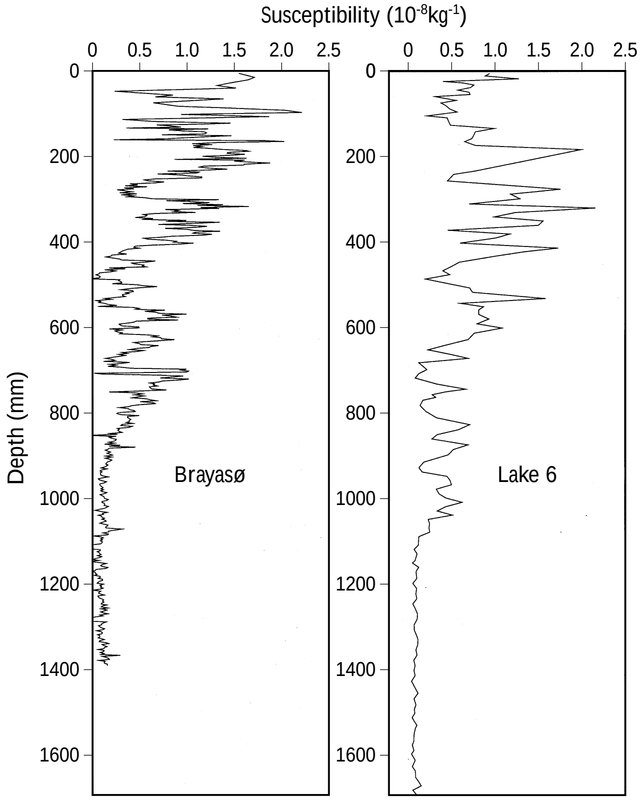

Fig. 3. Down-core low-field magnetic susceptibility profiles from Brayasø and Lake 6. Data are taken from Russian cores and freeze cores for the upper sediments after stratigraphic correlation between the two core types.

Our use of sedimentary pigments takes a two-fold approach. Firstly, a pigment training set is under construction to allow pigments to be used to reconstruct environmental parameters, as is being done for diatoms and salinity (Vinebrooke *et al.* 1998; Anderson *et al.* 1999; Fritz *et al.* 1999). Current work underway involves the statistical determination of those variables which are most significant in controlling/predicting sedimentary pigment assemblages in these low Arctic lakes.

Secondly, a comparison of pigment-inferred changes in algal and bacterial populations during the Holocene with other palaeoclimate reconstructions inferred from other independent proxies (diatoms, chironomids and isotopes) is being undertaken. This approach permits

Fig. 4. Pigment extracts from consecutive samples down a freeze core from Brayasø: left to right, from surface to about 7 cm depth. The darker red coloration visible in samples 2, 3, 5 and 12 is caused by a pigment (Okenone) produced by purple-sulphur bacteria that can be seen as purple bands in the original sediment.

a statistical assessment of the response of lake algal and bacterial communities to changing environmental conditions. For example, the pigment records can be compared with diatom-inferred conductivity (which primarily reflects effective precipitation in this area) and chironomid-inferred lake-water temperature (Brodersen & Anderson 2000, this volume).

This type of approach is being taken in Brayasø where the pigment record is characterised by periods of deposition of extremely high concentrations of purple-sulphur bacteria pigments, visible as distinctive purple bands in the sediment core. Figure 4 shows pigment extracts from a freeze core from Brayasø before separation by HPLC. The clear changes in the types of pigments present down the core are clearly visible in the extracts. Purple-sulphur bacteria require anoxic conditions to survive and tracking their abundance throughout the lake history can provide information about the intensity of lake stratification, which is itself related to climate. Early results suggest that stratification intensity is intimately linked to salinity fluctuations in the lake, probably due to the build-up of salinity density gradients in the water column. Other pigments in the core indicate marked algal community switches throughout the Holocene. Work is now focusing on determining the causal mechanisms behind the switches.

Laminations in Arctic lakes

Annually laminated sediments are very important environmental archives because of the possibility they offer for high resolution sub-sampling, calculation of microfossil accumulation rates and the inherent chronology (O'Sullivan 1983; Petterson 1999). Formation of annual laminations requires minimal sediment mixing and a distinct seasonal input. In many lakes, these different seasonal inputs are well understood and relate to factors such as the spring minerogenic input followed by organic production in the summer (Renberg 1981). In some high Arctic lakes the differentiation is associated with meltwater fluxes (Hughen *et al.* 2000). Although very finely laminated, we are uncertain as to whether the laminations in the West Greenland lakes are annual or not. Interestingly, we have yet to find laminated sediments in any of the coastal lakes although those lakes that were previously fjords do contain them (Anderson *et al.* 1999). The mechanism of lamination formation is unclear. While there is clearly calcite precipitation at some sites (Brayasø, Lakes 6 and 42) and the formation of layers by purple-sulphur bacteria is associated with anoxia and stratification, the causal process at Lake 16, for example, needs to be clarified. The roles of extended ice cover and strong thermal stratification are also important.

As well as the lakes referred to here, a Kajak core was also taken in May from another new site, Lake 85, which also proved to have extremely distinctive and coloured laminations. The water chemistry of this lake was sampled in the summer and has a relatively low conductivity and a maximum water depth of 12.4 m (Table 1). Previously we thought that the better laminations were confined to the meromictic lakes. Sites like Lake 85 indicate that this is not the case. Moreover, maximum depth and conductivity in those lakes with fine laminations varies considerably (Table 1). If we can identify the causal process we should be able to interpret the down-core changes in lamination thickness and colour with more confidence. As well as requiring a better understanding of their limnology and in-lake processes, it will also need a more holistic view of lake-catchment interactions. In any case, it is clear that the palaeoclimatic potential of the lakes in West Greenland is enormous.

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