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# PRELIMINARY INVESTIGATION OF A METHOD FOR DETERMINING PAST WINTER TEMPERATURES AT ELLIS FJORD, EASTERN ANTARCTICA, FROM FAST-ICE DIATOM ASSEMBLAGES

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***Abstract:*** The abundance of diatoms from the fast-ice mat community in sediment assemblages from the fjords of the Vestfold Hills has the potential to provide a proxy record of average winter temperature. Fast-ice cover on the fjords determines the proportion of diatoms from the fast-ice mat community in the sedimentary diatom assemblages. ANARE expeditioner records demonstrate a tentative relationship between fjord ice cover and average winter temperature. Short cores from Ellis Fjord, Taynaya Bay and Nella Fjord show fluctuations in the proportion of fast-ice diatoms but so far it has not been possible to correlate these with historical records.

**Key words:** fast-ice, diatoms, climate, Ellis Fjord

## 1. Introduction

Each autumn vast numbers of diatom cells are incorporated into the expanding sea-ice of the Southern Ocean. The growing ice is able to concentrate these cells by more than 1000 times that found in the surrounding sea-water (personal observation). In the pack-ice these cells are present as either nuclei of frazil ice crystals or concentrated in brine channels between the crystals (Horner, 1985). In coastal regions in spring a dense algal mat, comprised largely of diatoms, grows on the bottom of the fast-ice (McConville and Wetherbee, 1983; Watanabe, 1988). Some diatoms, such as *Fragilariopsis curta* V.H., are clearly closely associated with pack-ice and have been used in palaeoclimatic studies to indicate the extent of sea-ice during past glacial maxima (Burckle, 1984). Other taxa such as *Entomoneis kjellmannii* (Cleve) Thomas, *Berkeleya rutilans* (Trentphol) Cleve and *Nitzschia stellata* Mang. are characteristic of the fast-ice algal mat (McConville and Wetherbee, 1983; Watanabe, 1988) and have potential to indicate the past distribution of fast-ice. An ice coring program in November 1992 identified each of these species as prominant contributors to the bottom algal mat and strand community of Ellis Fjord (McMinn, unpublished data). Each of these species has also been found in the sedimentary diatom assemblages of the Vestfold Hills where their abundance was found to fluctuate both between cores and down core.

The overlying congelation ice community in Ellis Fjord was comprised of an almost monospecific assemblage of *Fragilariopsis cylindrus* V.H. (McMinn, unpublished data). This latter species is present in moderate numbers in the phytoplankton of Ellis Fjord throughout the summer (McMinn and Hodgson, 1993). It is unlikely to have been seeded from the melting sea-ice, as the ice in the fjord and also at nearby Davis breaks up and drifts seaward after only minor local sea-ice melting.

Ellis Fjord is a small, 15 km long, fjord-like embayment located 5 km south of Davis in the Vestfold Hills, eastern Antarctica (Fig. 1). It contains several anoxic sub-basins which contain high resolution stratigraphic sequences. Fast-ice reforms over the fjord by April and grows to a maximum thickness of approximately 1.8 m by early the following October. The extent of subsequent sea-ice melt and break-out, however, is variable between years. Some years for a brief period in summer the fjord is completely ice free. In other years it retains an almost complete ice cover while most years partial melt and break out is experienced.

The aim of this investigation is to determine whether the diatoms characteristic of the sea-ice algal mat and strand communities can be used to investigate past fast-ice cover in the fjords of the Vestfold Hills. Possible climatic controls on fast-ice breakout will then be examined to establish a link between the proportion of fast-ice diatoms in a sedimentary assemblage and changes in past climate. This research is still at a preliminary stage and it is recognised that further work is required to confirm the links between sea-ice/open water diatom production, the sedimentary diatom assemblages

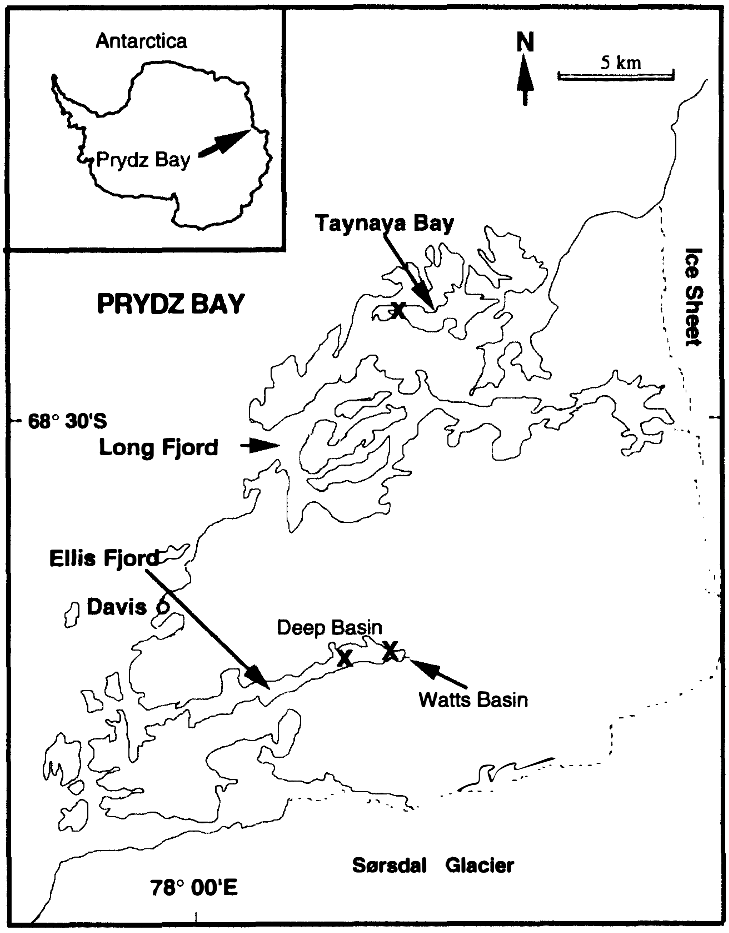


*Fig. 1. Location of coring sites in the Vestfold Hills, eastern Antarctica.*

and local climate change.

## 2. Methods

Several short, 20–40 cm long, sediment cores were taken from fjords of the Vestfold Hills with a Glew corer in November 1992 (Fig. 1). A core from Nella Fjord, located approximately 80 km south of Davis in the Larsmann Hills, was taken in December 1991. The cores were extruded in the field and subsectioned into either 0.5 cm or 1.0 cm intervals depending on sediment consistency. A small cut of each sample was prepared for diatom analysis and the remainder used for $^{210}Pb$ analysis. Preparation for diatom analysis involved washing in distilled water and mounting in Naphrax. 1200 cells in each sample were counted with a 100x, DIC oil immersion lens on a Zeiss Axioskop microscope. $^{210}Pb$ analyses were performed at Australian Nuclear Science and Technology Organisation (ANSTO), Sydney. Sedimentation rate was determined by the Constant Initial Concentration (CIC) method (Appleby and Oldfield, 1992).

The extent of past fast-ice cover on Ellis Fjord was estimated from verbal accounts of past expeditioners and is thus subject to possible memory error.

## 3. Results

### 3.1. *Sedimentation rate*

A core from Deep Basin, an anoxic basin in Ellis Fjord, recorded an extremely low sedimentation rate of 0.029 cm/yr. As the upper sediments were quite flocculent, the minimum sampling interval possible was 1 cm, or approximately 35 years. Fine scale resolution was thus not possible, although a record extending beyond 500 years was recovered (Fig. 2a). The $^{210}Pb$ sedimentation rate of a core from Watts Basin, Ellis Fjord, could not be determined as the sediments were subject to periodic bioturbation. However, this basin is currently anoxic and the core interval above 5 cm has remained unmixed and the state of diatom preservation is good (Fig. 2b). The sedimentation rate of a core from Taynaya Bay, an anoxic basin in the northern Vestfold Hills, was 0.1535 cm/yr and thus dates the sample at 5 cm at approximately 32 years before present (Fig. 2d). $^{210}Pb$ analysis of a core from Nella Fjord in the Larsmann Hills indicates considerable sediment mixing and so it is not possible to determine a reliable chronology (Fig. 2c). Only a rough indication of age is possible from the sedimentation rate, which falls between limits of 0.012 cm/yr and 0.070 cm/yr. This would date the bottom of the core, at 15.5 cm, between 221 and 1292 years before present.

### 3.2. *E. kjellmannii*

*Entomoneis kjellmannii* dominates the sea-ice algal mat community throughout Ellis Fjord. Abundance of *E. kjellmannii* in the core from Deep Basin, Ellis Fjord, was uniform, fluctuating between only 0.5% and 2.8%, suggesting that over the last 500 years there has been very little sustained, long-term change in ice cover in Ellis Fjord. The resolution of the core, however, was not sufficient to record fine scale, interannual fluctuations (Fig. 2a). The core from Watts Basin, Ellis Fjord, shows short term fluctuations in the abundance of *E. kjellmannii*, which are inversely correlated with the

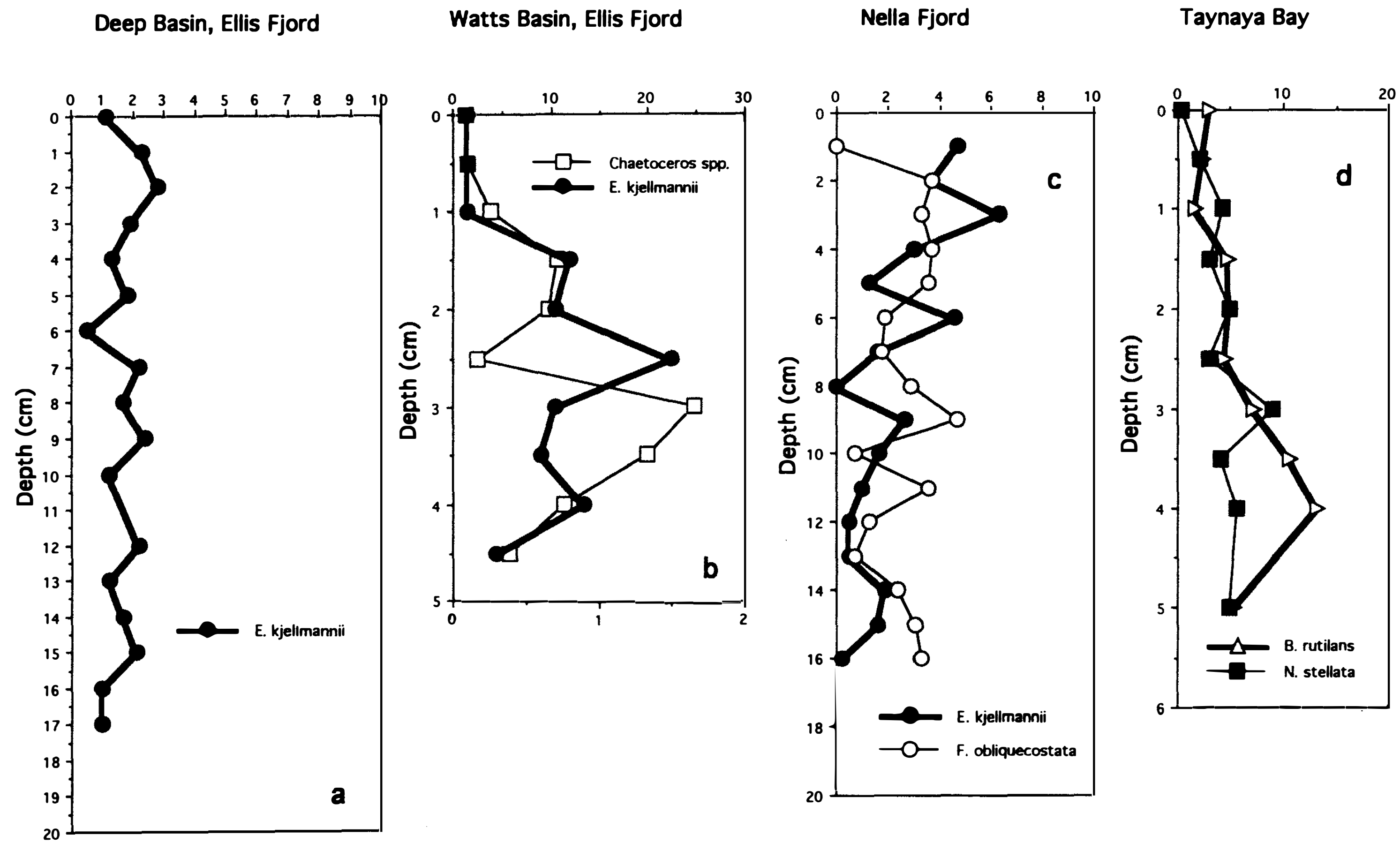


*Fig. 2.* *Distribution of fast-ice diatoms in sediment cores from the Vestfold and Larsmann Hills. (a) shows the distribution of* E. kjellmannii *in Deep Basin, Ellis Fjord; (b) shows the distribution of* E. kjellmannii *and* Chaetoceros *spp. in Watts Basin, Ellis Fjord; (c) shows the distribution of* E. kjellmannii *and* F. obliquecostata *in Nella Fjord; (d) shows the distribution of* B. rutilans *and* N. stellata *in Taynaya Bay.*

abundance of some planktonic species, *e.g. F. cylindrus*. As the dating of this core is uncertain, it is not possible to compare the fluctuations in abundance with recent records of ice extent (Fig. 2b). The abundance of *E. kjellmannii* in most other cores from the Vestfold Hills is too low to be used as a reliable proxy record of ice cover.

The core from Nella Fjord in the Larsmann Hills contained abundant *E. kjellmannii*. The abundance of *E. kjellmannii* in this core shows an inverse relationship with several planktonic species such as *Fragilariopsis obliquecostata*. This inverse relationship of the abundance of fast-ice diatoms with the abundance of planktonic species is expected if the duration of fast-ice cover controls planktonic diatom productivity (Fig. 2c). The general decline in abundance of *E. kjellmannii* over the length of this core is at least partly a product of diatom fragmentation by bioturbation. This process destroys the more fragile species and causes a relative enrichment of the more highly silicified species (McMinn, 1994). There is no evidence, however, of fragmentation of this species in the cores from the anoxic basins.

### 3.3. *B. rutilans and N. stellata*

The abundance of *B. rutilans* and *N. stellata* in cores from Ellis Fjord falls within a range between 0% and 1%. While these levels are consistent, they are too low for monitoring long term changes. Abundances in cores from Long Fjord and Nella Fjord are also very low. Cores from Taynaya Bay, Vestfold Hills, however contains *B. rutilans* in abundances between 1.6% and 13.3% and *N. stellata* between 0.3% and 9.0% (Fig. 2d). At this stage it is not possible to distinguish between down core fluctuations in abundance caused by either spatial variability or long term climate change.

## 4. Discussion

The extent to which the fast-ice remained in Ellis Fjord throughout the summer was estimated from verbal reports of past expeditioners, which were the only known source of data for this estimate. Fast-ice cover each summer was categorised as being either totally absent, partially present or complete. These estimates were compared with climatic variables such as average annual temperature, summer temperature, previous winter temperature, maximum ice thickness and average spring wind speed (Russell-Head and Simmonds, 1993; Allison, unpublished data). Only the average temperature of the previous winter showed any correlation with the extent of ice cover (Fig. 3). Although this correlation cannot be quantified because of the imprecise estimate of ice cover, a relationship can still be seen. No long term ice breakout data is unavailable for, Nella Fjord, Long Fjord or Taynaya Bay and ice breakout records from Davis Base, 5 km from the mouth of Ellis Fjord, show little correlation with those of the nearby fjord. Ice breakout at Davis seems to be more closely related to spring and summer temperatures, wind strength and duration and the occurrence of spring tides. The response of Ellis Fjord to average winter temperatures appears at this stage to be unique.

The sedimentary diatom assemblage in Ellis Fjord is comprised of contributions from both the fast-ice and the phytoplankton. The fast-ice component is probably relatively uniform in size from year to year (personal observation). Observational

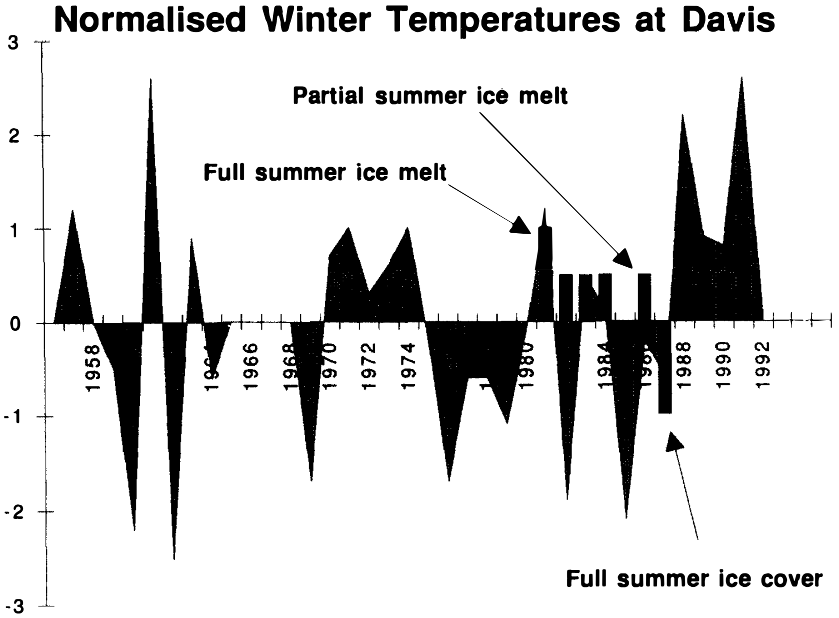


*Fig. 3. Correlation between fast-ice cover on Ellis Fjord and average winter temperature. Y axis of line graph is deviation from 35 year average winter temperature (climate data from* JACKA *et al., 1984). Y axis of bar graph represents fjord ice cover; long bar above 0 line represents full summer ice melt, half bar above 0 line represents partial summer melt; long bar below 0 line represents full summer ice cover.*

evidence over several years suggests that the brown algal mats typical of the base of the fast-ice develop early in October and have largely dissipated, regardless of the condition of the ice, by the end of December. The phytoplankton community of Ellis Fjord was described by McMINN and HODGSON (1993). The size of the phytoplankton contribution to the sediments is dependant on the extent of open water. A continuous summer ice cover considerably reduces the size of the summer phytoplankton bloom and results in a smaller contribution to the sedimentary diatom assemblage. Almost all primary productivity in Antarctic coastal regions occurs between late spring and early autumn and therefore the sedimentary diatom assemblage represents summer production. If the fjord is ice free for much of this period then the sedimentary diatom assemblage will be comprised of a large phytoplankton component and a relatively small fast-ice component. Conversely, if the fjord remains ice covered then the phytoplankton component will be smaller and the contribution from the fast ice relatively large. In this report these fluctuations are used to infer the extent of past ice cover.

## 5. Conclusions

To demonstrate that the abundance of sea-ice diatoms in fjord sequences of the Vestfold Hills can be used as a proxy record of average winter temperatures, links between fast-ice diatom abundance and ice cover and also between sea-ice cover and average winter temperature need to be established. So far it has not been possible to test these relationships in a dated core sequence in order to show that peaks in sea-ice diatom abundance definitely correspond with years of low average winter temperatures. This is because of either the low sedimentation rates at the sites investigated so far or because of the presence of bioturbation, which prevents precise age determination. There are many other potential coring sites in the fjords of the Vestfold Hills, which have anoxic bottom waters and higher rates of sedimentation. It remains to be established that the fast-ice cover at these locations is also related to average winter temperatures and thus whether these sites are also able to be used to provide records of past average winter temperatures.

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## References

Appleby, P. G. and Oldfield, F. (1992): Applications of Lead-210 to sedimentation studies. Uranium Series Disequilibrium, Applications to Earth and Environmental Sciences, ed. by M. Ivanovich and R. S. Harmon. Oxford, Clarendon, 910 p.

Burckle, L. H. (1984): Diatom distribution and paleoceanographic reconstitution in the Southern Ocean—Present and last glacial maximum. Mar. Micropaleontol., **9**, 241–261.

Horner, R. A. ed. (1985): Sea-ice Biota. Boca Raton, CRC Press, 215 p.

Jacka, T. H., Christou, L. and Cook, B. J. (1984): A data bank of mean monthly and annual surface temperature for Antarctica, the Southern Ocean and South Pacific Ocean. ANARE Res. Notes, **22**, 98 p.

McConville, M. J. and Wetherbee, R. (1983): The bottom-ice microalgal community from annual ice in the inshore waters of East Antarctica. J. Phycol., **19**, 431–439.

McMinn, A. (1994): Comparison of diatom preservation between oxic and anoxic basins in Ellis Fjord, Antarctica. to be published in Diatom Res.

McMinn, A. and Hodgson, D. (1993): Seasonal phytoplankton succession in Ellis Fjord, eastern Antarctica. J. Plankton Res., **15**, 925–938.

Russell-Head, D. and Simmonds, I. (1993): Temporal structure of surface weather parameters at Casey, Davis, Mawson and Macquarie Island. University of Melbourne, School of Earth Sciences Publication, **35**, 1–181.

Watanabe, K. (1988): Sub-ice microalgal strands in the Antarctic coastal fast ice area near Syowa Station. Sorui (Jpn. J. Phycol.), **36**, 221–229.

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