# A record of Holocene paleoclimatic variability from Neny Fjord, Antarctic Peninsula

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**Summary** Comprehensive analyses of marine sediments recovered from Neny Fjord, Marguerite Bay, yield a high-resolution record of Holocene climate variability. The ~12 m jumbo piston core was collected aboard the Nathanial B Palmer in 2002. The core contains mostly silty, clay-rich, diatomaceous sediments and bioturbated, very fine, sandy, diatomaceous muds with occasional horizons of sand-rich sediments. The chronostratigraphy for the core is derived from radiocarbon-dated foraminifera and shell fragments, collected from several horizons throughout the core. The base of the core, dated to 8,060 $^{14}C$, reveals an ice-distal facies with high concentration of diatoms, low magnetic susceptibility and sub-rounded grain morphology. This is consistent with an early Holocene warm period, with deglaciation of the fjord having occurred prior to 8,060 $^{14}C$ yrs. Between ~6000 and ~4500 $^{14}C$ yrs climate cooling is indicated by reduced sedimentation rates and increasingly coarse terrigenous flux. The diatom flora suggests a reduced growing season with more variable concentrations in response to episodic deposition associated with the lower sedimentation rates and pulses of coarse-grained material. From ~4500 $^{14}C$ yrs the dates suggest a ~1500 $^{14}C$ yrs sedimentary hiatus occurred during which there is only deposition of fine sand-rich laminae. This is inferred to be a period of ice-shelf or glacial advance over the site. Above the hiatus, the sediments reveal a short lived return to an ice distal setting followed by neoglacial cooling from ~2000 $^{14}C$ yrs. The neoglacial is characterised by a lithological gradation from moderately bioturbated, clay-rich, diatomaceous mud to a well bioturbated, fine-sandy, diatom mud. Diatom concentrations decrease up core and the assemblage data reflect increasing sea-ice influence over the site and a decline in the contribution of autumn bloom species. In summary, the diatom assemblage data coupled with the sedimentary facies descriptions provide compelling evidence of Holocene climatic variability in Neny Fjord.

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## Introduction

It is now accepted that the Earth experienced an average warming of ~0.6ºC during the last century (Parker et al., 2000), and that warming is likely to continue during the 21st century. The recent temperature changes show a strong spatial heterogeneity at the global scale, with more intense warming evident at high latitudes than at low latitudes (Mann et al., 1998), and the most pronounced variability at a sub-continental scale. In the Antarctic Peninsula the rate of warming already far exceeds the global average with a 2.6ºC temperature rise over the last fifty years (Vaughan et al. 2003).

Quantifying the human impact over recent decades is difficult due to the paucity of knowledge on natural climate variability, external forcing (solar activity) and climate feedback mechanisms over this timescale. There is a fundamental need to document natural climate variability on appropriate timescales (Holocene) and in key regions known to be sensitive to climate change (the Antarctic Peninsula), to determine the frequency and response of regional climate to natural forcing. This will provide the evidence needed to test competing models about the causes of the most important climate changes of the past. Although models are used to predict future climate change, to trust them, we need to be assured that they can reproduce the spatial and temporal pattern of past natural climate variability and its relationship to atmospheric and oceanographic forcing.

The sensitivity of the Antarctic Peninsula region is often attributed to complex feedbacks and energy exchanges between the ocean, atmosphere and cryosphere. Sea ice plays a central role in controlling heat and gas exchange between the ocean and atmosphere, yet is poorly constrained in models and climate reconstructions. Diatom assemblage data provide an established proxy for sea ice extent in the Southern Ocean, and the potential to reveal seasonal patterns of productivity and ocean conditions. Peninsula glaciers are particularly susceptible to changes in temperature and precipitation because of the maritime climatic regime and northerly location. Nearly all Peninsula glaciers have retreated in recent decades (Cook et al., 2005) yet the limited data provides no historical perspective. Marine geological records provide the best means to reconstruct glacial dynamics, in order to assess the relative importance of local and regional controls.

Detailed studies of both marine and lake records from the Antarctic region have provided excellent paleoclimatic reconstructions and document several Holocene climate optima and minima. However, there is significant debate about whether these climatic variations are in phase, and also about their causes and effects. Using sediment facies descriptions, diatom assemblage data and radiocarbon dating to compile detailed paleoclimatic records in the AP will

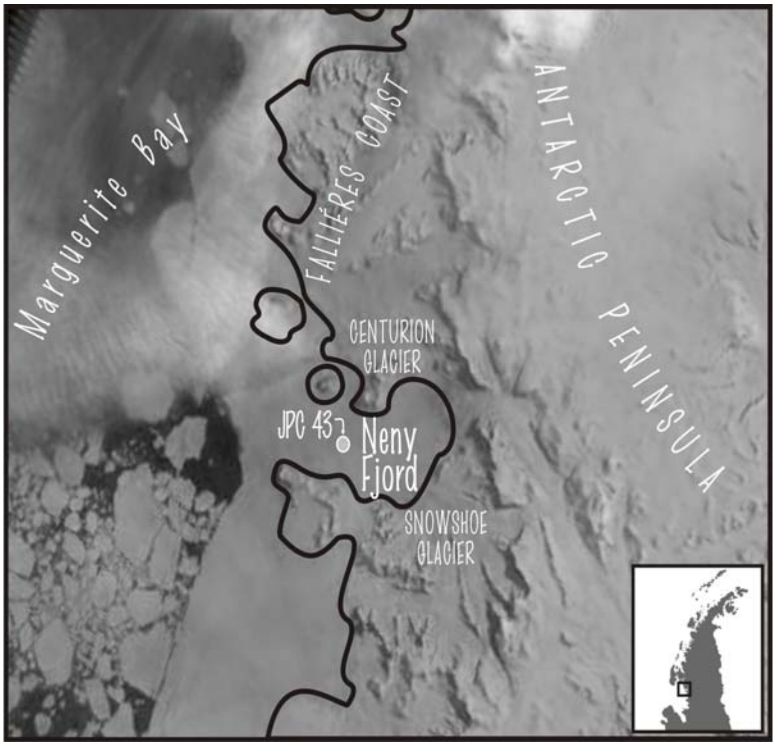


**Figure 1.** Map showing location of Neny Fjord and the core site (JPC 43).

help to constrain timings and forcing mechanisms behind Holocene climate events. This type of study will perform a vital role in assessing how the AP interacts with the global climate system.

## Site Location

Neny Fjord (Figure 1) is a polar fjord situated within the Antarctic sea-ice zone, at a latitude approaching the northern limit of the polar-climatic regime. The inlet physiography is typical, exhibiting steep mountainous fjord walls, a single basin reaching depths of over 600 m and a shallow sill towards the mouth. Fjord sedimentation is primarily controlled by localized factors, including proximity to glacier front, climate, sea-ice cover, bathymetry and drainage basin size (Griffith and Anderson, 1989; Domack and McClennon, 1996). Sediment units are often thick, due to relatively rapid rates of deposition, and may therefore contain expanded Holocene sedimentary records (Anderson, 1999). Here, we interpret a 12 m jumbo piston sediment core collected during the *Nathaniel B. Palmer 2002* (*NBP0201*) scientific cruise, to examine how the paleo-ice systems reacted to climate variations.

## Methods

The~12m was split and -43 was split, described and analysed using a *Geotek* multi-sensor core logger at the Antarctic Marine Geology Research Facility, Florida State University, primarily to measure magnetic susceptibility. Shear strength was measured using a handheld *TorVane* sediment penetrometer, at 50 cm intervals. Relative grain size distributions (volume %) for each sample were calculated using a *Malvern Hydro* grain size analyser. Dateable material was recovered and sent for accelerator mass spectrometer (AMS) radiocarbon dating (Figure 2).

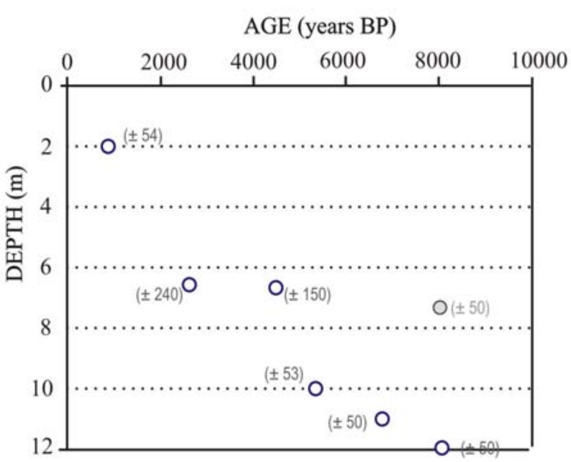


**Figure 2.** Graph showing radiocarbon dates for Neny Fjord JPC 43.

Samples for quantitative diatom analyses were taken at 20 cm intervals throughout the core. Slides were prepared according to Scherer (1994) and assemblage data compiled from counts of at least 400 diatom valves. Counting protocols of Schrader as modified by Laws (1983) were followed and diatoms were identified to species level where possible. Identifications were based on the taxonomic references of Hasle and Syvertsen (1997) and Priddle and Fryxell (1985) and supplemented with Johansen and Fryxell (1985) for the genus *Thalassiosira* and Armand and Zielinski (2001) and Jordan et al. (1991) for the *Rhizosolenia* and *Proboscia* genera. Due to the dominance of *Chaetoceros* resting spores (CRS), additional counts of 400 valves excluding CRS were completed in order to assess the paleoenvironmental significance of minor species.

## Results and Discussion

***~8,060 – ~6000 $^{14}$C yr:***

The basal section of the core comprises a heavily bioturbated, silty, clay-rich diatomaceous mud unit, and contains relatively high amounts of subangular to subrounded medium-sized basalt pebbles and rare fine sand laminae, all exhibiting abrupt contacts. Grain size distribution data show a typical sand content of less than 8 % and silt content of 87 % - 89 %. The unit coarsens up-core into a relatively sand-rich section at the top.

Diatom concentrations are consistently >200 million valves per gram in the early Holocene sediments (Figure 2). The diatom assemblage is characterised by the highest relative abundances of open ocean and shelf diatoms (*Fragilariopsis kerguelensis* and *Odontella weisflogii*). Their presence in the basal sediments reflects the influx and mixing of warm waters over the continental shelf of Marguerite Bay. Sea ice diatoms are also relatively abundant and contribute over 5% of the total diatom assemblage showing that sea ice cover was persistent throughout the winter (Gersonde & Zielinski, 2000). *Thalassiosira antarctica* and *Eucampia antarctica* are also an important component of this early Holocene assemblage and are indicative of autumn productivity prior to sea ice formation and iceberg/glacial ice runoff, respectively. The presence of both autumn bloom species and sea ice species suggests that although sea ice cover was a significant condition during this period, the formation of sea ice was late enough not to preclude autumn bloom production.

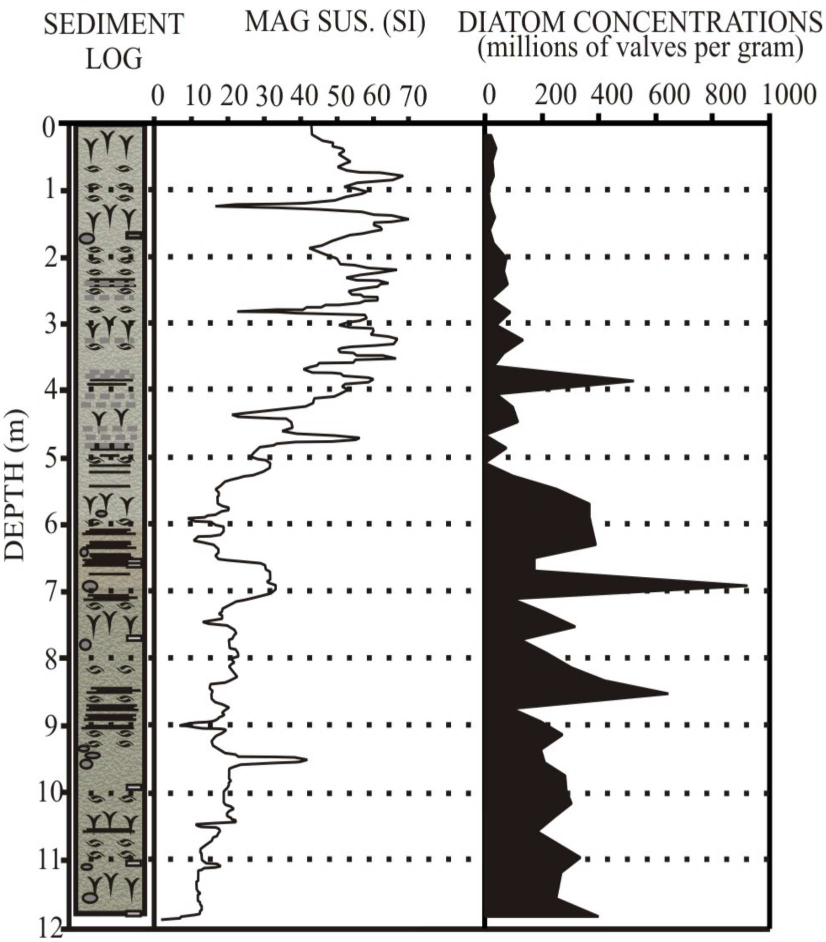


**Figure 3.** Sediment Log, Magnetic Susceptibility record (black line) and the diatom concentrations (black shaded area).

***~6000 - ~4500 $^{14}$C yr:***

Sediments in this section of the core consist of predominantly fine sand-rich laminations, with moderate bioturbation and abrupt contacts. Grain size distribution data show a high sand content (11 %), high silt content (86 %) and relatively low clay content (3 %).

The reduction in the presence of open ocean and shelf diatoms during this cooling episode marks the withdrawal of open ocean influenced water masses from the inner shelf. Sea ice diatoms also decline during this period, whilst the contribution of the autumn bloom species, *Thalassiosira antarctica* remains high. The decline in sedimentation rates (Fig. 2) during this section of the core suggests that the peak in diatom concentrations (Fig. 3) reflects the reduced input of terrigenous sediments rather than an increase in productivity. Since the diluting effect of terrigenous sediments is removed so that the biogenic flux provides the dominant contribution to the sediment. The relative abundance of *Dactyliosolen antarctica* girdlebands and *Eucampia antarctica* during this period are likely to be a function of preservation within the sediments as they are both renowned for their robust silicification. This preservation signal is consistent with the reduced sedimentation rate.

***~4500 – ~2000 $^{14}$C yr:***

The hiatus is evidenced by abruptly-terminating fine sand laminae corresponding to an increase in the magnetic susceptibility signal. Laminations range in thickness from mm to cm, and show an increase in frequency and magnitude with depth. The sand layers are overlain by a horizon of moderately-bioturbated olive-grey, clay-rich muds. The hiatus is not represented as a particular diatom assemblage but the sample interval is such that the event may not be resolved until a higher resolution record is completed for this section.

***~2000 $^{14}$C yr to present:***

The contact at the base of this unit is relatively diffuse and is delineated by a gradational lithologic transition from well-bioturbated fine sandy muds to moderately-bioturbated olive grey clay-rich muds. The magnetic susceptibility

(Fig. 3) is relatively uniform throughout the upper 4 metres of the core and the sediments are correspondingly finer with sand concentrations dropping from 5 % to just 1 % and silt concentrations increasing to 93%.

The diatom assemblage documents a rise in the sea ice diatoms with sea ice cover inferred to be as pervasive as during the early Holocene. The main change in the diatom community is realised in the clear decline in autumn diatoms (*Thalassiosira antarctica)* in this top section of the core. This implies that sea ice was forming earlier in the year, precluding the opportunity to develop significant autumn blooms before sea ice formation recommenced.

## Conclusions

The paleoclimate record from Neny Fjord demonstrates this southerly fjord is still sensitive to broad climatic variability through the Holocene. We are able to resolve seasonal dynamics using the diatom assemblage data and to assess the relative contributions of terrigenous and biogenic facies. We show that Neny Fjord experienced the main climate fluctuations of the Holocene and propose that the Neny Fjord sediment record may afford the potential to resolve higher frequency climate features, including seasonal dynamics and sub-millennial climatic trends.

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