Seasonal and sub-seasonal diatom palaeoceanographic records from the last deglaciation, Palmer Deep, western Antarctic Peninsula

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1. INTRODUCTION

The Antarctic ice sheet is recognised as a central player in the global ocean and atmosphere system. One of the most dynamic regions of the continent is the Antarctic Peninsula. Here ecological and cryospheric systems respond rapidly to climate fluctuations.

Palmer Deep (~64°55'S, 64°25'W) is a series of three fault bounded basins situated on the inner continental shelf on the western side of the Antarctic Peninsula (Figure 1). This natural sediment trap currently sits beneath a region of high seasonal diatom primary productivity. A 4.4 metre thick laminated diatom ooze was preserved in Basin I of Palmer Deep (ODP Site 1098) at a core depth of ~45.0-40.6 mcd (metres composite depth). Laminae or thin beds of orange-brown diatom ooze (Figure 3 b and c) alternating with blue-grey diatom-bearing terrigenous sediments (Figure 3 d and e) overlie a glaciomarine diamict. Dated at ~12,000-13,000 yrs BP (Domack et al., 2001), the diatom rich laminated interval was deposited during the last deglaciation.

Highly polished thin sections have been analysed using scanning electron microscope (SEM) backscattered electron imagery (BSEI) and SEM secondary electron imagery (SEI) to investigate the sediment fabrics and diatom assemblages of this deglacial laminated ooze.

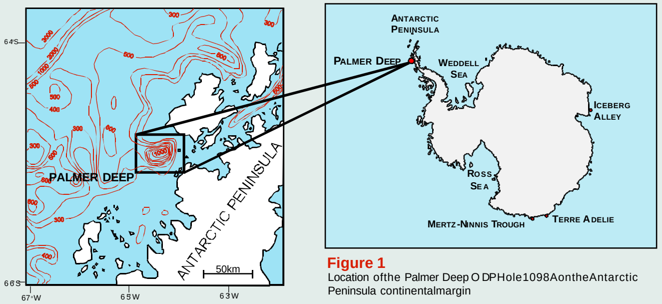

Figure 1
Location of the Palmer Deep ODP Hole 1098A on the Antarctic Peninsula continental margin

2. OBSERVATIONS

- A decrease in thickness of both the diatom ooze and diatom-bearing terrigenous laminae was observed upcore (Figure 2).
- 191 pairs of orange-brown diatom ooze lamina alternating with blue-grey terrigenous laminae.
- High concentrations of *Hyalochaete Chaetoceros* spp. resting spores are observed in the orange-brown diatom ooze laminae (Figure 3a, b and c). *Chaetoceros* species are also found in diatom-bearing terrigenous laminae but in a lower concentration (Figure 3 a, d and e).
- A more diverse diatom assemblage is observed in the blue-grey diatom bearing terrigenous laminae (Figure 3 a, d and e) e.g. *Corethron criophilum, Coscinodiscus bouvet, Odontella weissflogii* and *Thalassiosira antarctica*.
- Sub-seasonal diatom blooms are seen in the diatom bearing terrigenous sediment (Figure 4a). Near-monospecific assemblages of *Coscinodiscus bouvet* (Figure 4 h and i), *Corethron criophilum* (Figure 4 f and g), *Thalassiosira antarctica* (Figure 4 d and e) and *Odontella weissflogii* (Figure 4 b and c) occur intermittently throughout the deglacial interval.

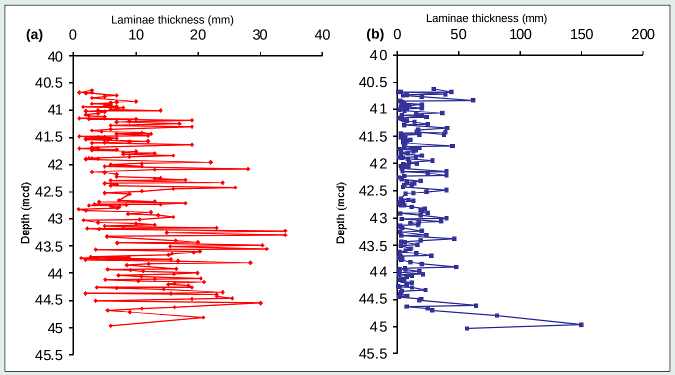

Figure 2
(a) Graph showing biogenic lamina thicknesses through the deglacial interval, 40.63-44.97 mcd.
(b) Graph to show terrigenous laminae thickness through the deglacial interval, 40.62-45.03 mcd.

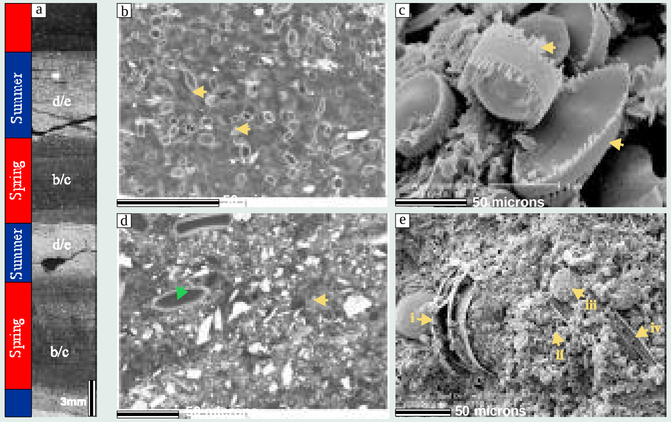

Figure 3
(a) Backscattered secondary electron imagery (BSEI) photomosaic of alternating diatom ooze biogenic laminae (dark - spring) and diatom bearing terrigenous laminae (light- summer) from 42.66 to 42.63 mcd.
(b) BSEI photo of diatom ooze biogenic laminae composed of *Chaetoceros* spp. resting spores (gold arrows).
(c) Secondary electron imagery (SEI) photo of *Chaetoceros* spp. resting spores (gold arrows) from the biogenic laminae.
(d) BSEI photo of terrigenous laminae. *Chaetoceros* spp. (gold arrow) and *Thalassiosira antarctica* resting spores (green arrows) present. The white fragments are terrigenous grains.
(e) SEI photo of terrigenous laminae with mixed diatom assemblage. Gold arrows: i) *Coscinodiscus bouvet* girdle bands; ii) *Chaetoceros* spp. resting spores; iii) *Thalassiosira antarctica* resting spore; iv) *Fragilariopsis* spp.

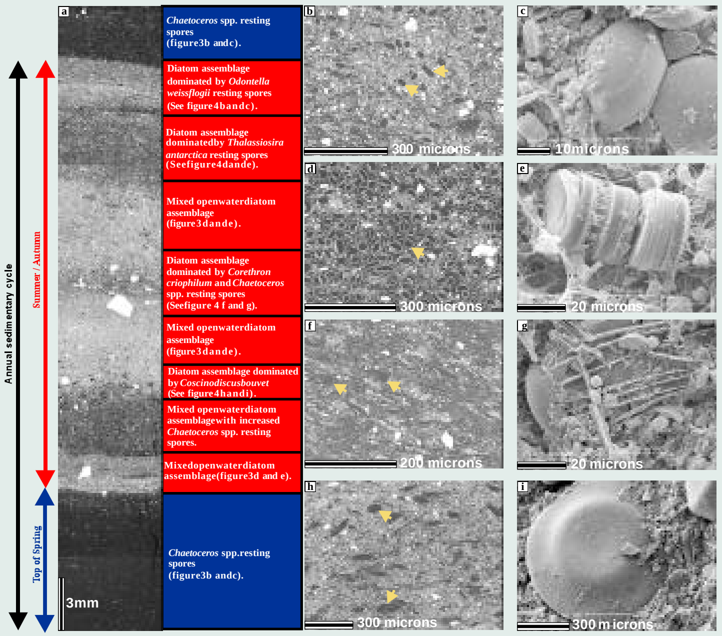

Figure 4
(a) Backscattered secondary electron imagery (BSEI) photomosaic of sub-laminae within the terrigenous laminae (43.11-43.09 mcd) **(b)** BSEI photo of *Odontella weissflogii* (gold arrows) dominated sub-lamina. **(c)** Secondary electron imagery (SEI) photo of *O. weissflogii* sub-lamina. **(d)** BSEI photo of *Thalassiosira antarctica* resting spore (gold arrow) dominated sub-lamina. **(e)** SEI photo of *T. antarctica* resting spore dominated sub-lamina. **(f)** BSEI photo of *Corethron criophilum* (gold arrows) dominated sub-lamina. **(g)** SEI photo of *C. criophilum* dominated sub-lamina. **(h)** BSEI photo of *Coscinodiscus bouvet* dominated sub-lamina. **(i)** SEI photo of *C. bouvet* (gold arrows) dominated sub-lamina.

3. DISCUSSION

The orange-brown diatom ooze and the blue-grey diatom-bearing terrigenous sediments result from seasonal diatom depositional events.

Spring: The thickness of the orange-brown diatom ooze (Figure 3 b and c) in this environment was probably controlled by deglacial retreat of the proximal ice front. As the retreating ice sheet became more distal from Palmer Deep a decrease in the spring ice melt led to a less stratified water column and a reduced productivity. Therefore, a decrease in biogenic silica flux to the sediment during the later stages of deglaciation resulted in decreasing thickness of laminae upcore (Figure 2). The productivity of *Chaetoceros* spp. resting spores in the deglacial sedimentary sequence is much higher than today, implying a difference in environments such as the proximity of a nutrient source. In the initial stages of deglaciation the ice rafted terrigenous material nutrient source associated with the ice sheet would be closer, creating more suitable growth conditions for *Chaetoceros* species.

Summer: The more open-water Antarctic diatom assemblage in the blue-grey diatom-bearing terrigenous laminae (Figure 3 d and e) results from summer/autumn sedimentation associated with increased terrigenous input, and is related to ice-free, more oceanic, lower nutrient conditions following total melt of seasonal sea ice. Therefore, the decrease in laminae thickness upcore (Figure 2) was probably controlled by deglacial retreat of the proximal ice front. Terrigenous laminae become rarer above this deglacial sedimentary sequence.

Winter: Winter is not represented in this deglacial sedimentary sequence because annual sea ice cover reduces sediment flux to minimal levels.

The sub-seasonal diatom blooms repeatedly seen in summer laminae (Figure 4 and 5) suggest a change in shelf waters throughout the summer. Three possible mechanisms for this feature are:

1. High Tides
A brief period of higher tides in the summer or an increase in autumnal tide amplitude could bring coastal diatom blooms up against a frontal zone produced by estuarine (meltwater) flow (Leventer *et al.*, 2002). The environmental stress caused by this salinity barrier would cause the diatoms to rapidly form resting spores. Tidal pulses would supply repeated diatom blooms to the sediment.

2. High cyclone intensity
High cyclone frequencies are associated with the Circumpolar Trough (CPT), a low pressure system which encircles Antarctica. In the austral summer the CPT is found to be extreme off the west AP coast. Subsequently a variety of air trajectories could push diatom blooms against the estuarine salinity barrier causing them to sink and begin resting spore formation.

3. Intrusion of Circumpolar Deep Water (CDW)
The intrusion of CDW onto the continental shelf would change the salinity, nutrients and temperature of shelf waters and could influence the occurrence of different diatom species blooms and/or the formation of deposition. The melting of ice creates more buoyant, less saline waters with the outward flow drawing the CDW up onto the shelf; a self perpetuating cycle (Potter and Paren, 1985). A seasonal and inter annual variability in the frontal boundary between the Antarctic Circumpolar Current (ACC) and Weddell Sea Transition Water (WSTW) could control the upwelling of CDW onto the continental shelf. The resultant changes to shelf waters could enhance multiple species specific productivity.

4. CONCLUSIONS

- Annual depositional events have been identified in the deglacial interval.
- *Chaetoceros* spp. resting spores (figure 3 b and c) overwhelmingly dominate the spring orange-brown laminae.
- A more open-water Antarctic diatom assemblage characterises the summer, more terrigenous-rich laminae.
- Annual sea ice cover prevents any sedimentation in the winter.
- Sub-seasonal near-monospecific diatom blooms have been identified in summer laminae (Figure 4 and 5). High tides and high cyclone intensity have been proposed as possible causes that could have introduced conditions which enhance specific species productivity. However we believe the most likely cause for the multiple monospecific sub-laminae is the upwelling of the CDW induced by the sub-seasonal and inter-annual variation in the impingement of ACC onto the continental shelf.
- The Palmer Deep deglacial laminated interval has given an insight into seasonal and sub-seasonal variability in Antarctica during a period of rapid climate change.

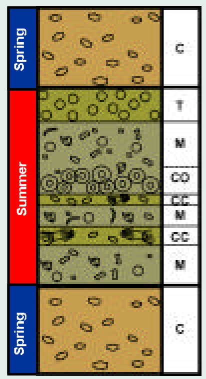

Figure 5
Schematic representation of the sub-seasonal sub-laminae within the terrigenous laminae. Compiled from BSEI data.
C= *Chaetoceros* resting spores
M= Mixed diatom assemblage
CC= *Chaetoceros* resting spores and/or *Corethron criophilum*
CO= *Coscinodiscus bouvet* or *Odontella weissflogii* resting spores
T= *Thalassiosira antarctica* resting spores

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