The Initiation of the Antarctic Ice Sheet and the Role of Atlantic Overturning Circulation

Amy Sparkes, Cardiff University

Supported by Antarctic Science

Project Summary

Ocean overturning circulation is responsible for a substantial proportion of global heat transport. During the early Cenozoic, the Southern Ocean and mid-latitudes were accountable for a greater proportion of deep-water formation than today. The transition from a southern source to a bipolar source of deep-water formation represented the greatest change in ocean circulation within the last 50 Myr (Miller *et al*. 2009). Here, the proposed project was focused on the initiation of the Antarctic ice sheet at the Eocene-Oligocene Transition (EOT), about 34 million years ago. There is evidence for a marked change in the overturning of the Atlantic Ocean from the middle Eocene onwards and associated with the EOT (Davies *et al*. 2001; Howe *et al*. 2001; Hohbein *et al.* 2012). Indeed, modelling studies suggest the strengthening formation of Northern Component Water (NCW), the paleo precursor to North Atlantic Deep Water (NADW), may have been associated with weakened Antarctic Bottom Water formation and hence reduced poleward heat transport into the Southern Ocean (Sijp and England, 2003), perhaps triggering or facilitating Antarctic glaciation. Interesting evidence from neodymium isotope records shows a divergence between εNd at Maud Rise (Southern Ocean) and Walvis Ridge (South Atlantic) around the time of EOT, with the Walvis Ridge Sites acquiring a more 'Atlantic' signature (Via and Thomas, 2006). Although this record suggests waters formed in the North Atlantic reached the southern hemisphere

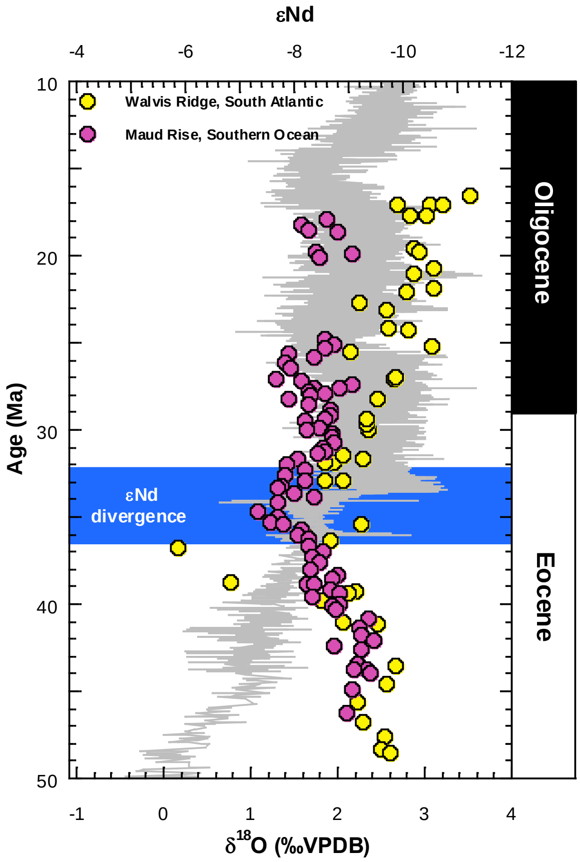

Figure 1 εNd from Walvis Ridge (South Atlantic) (Via and Thomas, 2006) and Maud Rise (Southern Ocean) (Scher and Martin, 2004) diverge around the EOT.

for the first time around the EOT and, hence, a tantalising link between Antarctic glaciation and the formation of NCW, it is not high enough resolution to constrain the timing of this relationship (Via and Thomas, 2006) (Figure 1).

While working on samples from ODP Site 925 (Ceara Rise, Western Equatorial Atlantic) for foraminiferal analysis, I discovered an unusual abundance (up to 19 per sample) of exceptionally well-preserved fish teeth (Figure 2). When fish teeth are well-preserved it is possible to chemically analyse them for their neodymium isotopic composition (εNd). εNd is commonly used as a water mass provenance tracer. In combination with the relatively short residence time of neodymium in the ocean (Tachikawa *et al*. 1999) compared to timescales of oceanic mixing, global heterogeneity in surface ocean εNd is largely due to regional differences in the isotopic signature of eroded bedrock material delivered to surface waters. Deep water masses acquire these signatures in areas of downwelling, which are modified by subsequent water mass mixing. The εNd signature of these bottom waters is incorporated and reliably preserved in fish teeth upon their burial at the seafloor (Staudigel *et al.* 1985; Martin and Scher, 2004).

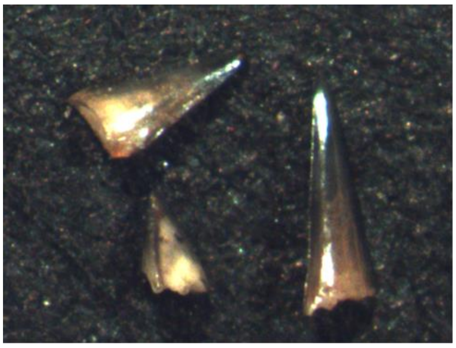

Figure 2 Fish teeth picked from ODP Site 925 sediment samples. Note the dark colour as opposed to the usual milky/honey colour indicating a high standard of preservation.

Given that its paleowater depth (~ 2500 metres at the EOT) placed ODP Site 925 in the core of modern NADW and such well-preserved fish teeth were present in the same samples used to reconstruct changes in Antarctic ice volume, this project aimed to test the following hypothesis:

Northern Component Water reached Ceara Rise immediately prior to the establishment of the Antarctic ice sheet.

To test this hypothesis, I proposed the development of a high-resolution record of fish tooth εNd from ODP Site 925 across the EOT. The timing of any change in εNd relative to the main phase of ice growth (identified by benthic foraminiferal δ^{18}O) would allow us to constrain whether the change in Atlantic Ocean circulation preceded or post-dated ice sheet growth, and hence whether it may have triggered or facilitated the inception of the Antarctic ice sheet.

Support from Antarctic Science

This project aimed to capitalise on recent infrastructure investment by Cardiff University. A new Nu Plasma II multi-collector ICP-MS was installed in the newly refurbished CELTIC laboratory during summer 2015. Financial support provided by Antarctic Science allowed me to visit the MAss Spectrometry and Isotope Geochemistry (MAGIC) laboratories at Imperial College London during September 2015. It was here that I was trained in neodymium isotope analysis by Professor Tina van de Flierdt and Dr Katharina Kreissig. Following my training and analysis of the samples from ODP Site 925 at Imperial College London, I used remaining funds to purchase laboratory consumables that will allow subsequent neodymium analyses to be carried out at Cardiff University.

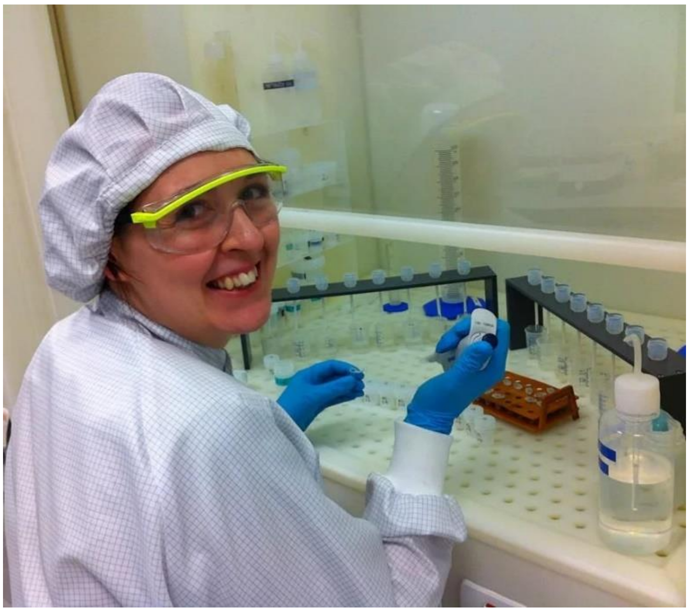

Figure 3 A. Sparkes learning analytical procedures at Imperial College London during September 2015.

This project would have been beyond the reach of the existing financial package in place for my postgraduate research. Hence, the financial support of Antarctic Science was integral in widening the scope of my PhD research. Not only did this support allow me to develop new analytical skills, but my visit to Imperial College London has resulted in ongoing collaboration. I am very grateful to Antarctic Science for providing such a wonderful opportunity and I heartily encourage other early career researchers to apply for the bursary.

Project Outcomes

The data generated during my time at Imperial College London is yet to be published. However, I presented my findings at the 12th International Conference on Paleoceanography (Utrecht, Netherlands) in September 2016. I was awarded one of the student poster prizes for my presentation of this work. The abstract is available below.

References

Davies, R., Cartwright, J., Pike, J. and Line, C. 2001. 'Early Oligocene initiation of North Atlantic Deep Water formation', *Nature*, 410: 917 – 920.

Hohbein, M.W., Sexton, P.F. and Cartwright, J.A. 2012. 'Onset of North Atlantic Deep Water production coincident with inception of the Cenozoic global cooling trend', *Geology*, 40 (3): 255 – 258.

Howe, J.A., Stoker, M.S. and Woolfe, K.J. 2001. 'Deep-marine seabed erosion and gravel lags in the northwestern Rockfall Trouh, North Atlantic Ocean', *Geological Society of London Journal*, 158: 427 – 438.

Martin, E.E. and Scher, H.D. 2004. 'Preservation of seawater Sr and Nd isotopes in fossil fish teeth: Bad news and good news', *Earth and Planetary Science Letters*, 220: 25 – 39.

Miller, K., Wright, J.D., Katz, M.E., Wade, B.S., Browning, J.V., Cramer, B.S. and Rosenthal, Y. 2009. 'Climate threshold at the Eocene-Oligocene transition: Antarctic ice sheet influence on ocean circulation' in: Koeberl, C. and Montanari, A. (eds) The Late Eocene Earth – Hothouse, Icehouse and Impacts, Special Paper 452, The Geological Society of America, Ch11: 169 – 178.

Scher, H. D. & Martin, E. E. 2004. 'Circulation in the Southern Ocean during the Paleogene inferred from neodymium isotopes', *Earth and Planetary Science Letters*, 228: 391 – 405.

Sijp, W.P. and England, M.H. 2003. 'Effect of the Drake Passage throughflow on global climate', *Journal of Physical Oceanography*, 34: 1254 – 1266.

Staudigel, H., Doyle, P. & Zindler, A. 1985. 'Sr and Nd isotope systematics in fish teeth', *Earth and Planetary Science Letters*, 76: 45 – 56.

Tachikawa, K., Jeandel, C., & Roy-Barman, M. 1999. 'A new approach to the Nd residence time in the ocean: the role of atmospheric inputs', *Earth and Planetary Science Letters*, 170: 433 – 446.

Via, R.K. and Thomas, D.J. 2006. 'Evolution of Atlantic thermohaline circulation: Early Oligocene onset of deep-water production in the North Atlantic', *Geology*, 34: 441 – 444.

Ocean Circulation Change at the Eocene-Oligocene Transition

Amy Sparkes[1], Caroline Lear[1], Paul Wilson[2], Steve Bohaty[2], Dan Lunt[3], Tina van de Flierdt[4], Claire Huck[4], Helen Coxall[5]

[1]School of Earth and Ocean Sciences, Cardiff University, sparkesav@cardiff.ac.uk
[2]National Oceanography Centre, Southampton
[3]Bristol University
[4]Imperial College London
[5]Stockholm University

The Eocene-Oligocene Transition (EOT) marks the initiation of widespread ice growth on Antarctica. It has been suggested that formation of proto-North Atlantic Deep Water (NADW) coincided with the EOT, perhaps triggering Antarctic glaciation. However, the role of changing ocean circulation and poleward heat transport as a trigger or feedback mechanism for this greenhouse-icehouse transition is uncertain. Here, material from ODP Site 925 (Ceara Rise, western equatorial Atlantic, currently bathed by NADW) spanning the EOT is used to develop proxy records of ice volume, temperature and water mass circulation by combination of $\delta^{18}O$ and trace metal ratios from benthic foraminiferal calcite, and εNd from fossil fish teeth. The aim is to constrain whether a reorganisation in ocean circulation pre-dated or post-dated AIS establishment and served as forcing mechanism or feedback for the EOT.

We document the two-step, ~1.5‰ shift in $\delta^{18}O$ across the EOT at this Site. Our trace metal records suggest a bottom water temperature cooling of approximately 2°C preceding the main phase of associated ice growth. Coincident with the carbon isotope shift, we find a peak in U/Ca and a decrease in B/Ca of benthic foraminiferal calcite. This could suggest a localised increase in productivity due to reorganisation of the ocean circulation regime of the North Atlantic. Neodymium isotope data at this low latitude depict exceedingly negative, non-radiogenic values (~-14.5) prior to the ice growth. Site 925 fish teeth εNd become more radiogenic (~-12.9) across the EOT. These are the most non-radiogenic values thus far attributed to the EOT. This may suggest either a reorganisation of regional ocean circulation or a change in weathering regime in the Amazon basin associated with the greenhouse-icehouse transition. Further εNd analysis of bulk sediment samples may constrain this interpretation.