Quaternary Science Reviews 179 (2018) 153–157

Contents lists available at ScienceDirect

Quaternary Science Reviews

journal homepage: www.elsevier.com/locate/quascirev

# Dating Antarctic ice sheet collapse: Proposing a molecular genetic approach

Jan M. Strugnell [a, b, *], Joel B. Pedro [c], Nerida G. Wilson [d, e]

[a] Centre for Sustainable Tropical Fisheries and Aquaculture, James Cook University, Townsville, Qld, 4810, Australia
[b] Department of Ecology, Environment & Evolution, La Trobe University, Melbourne, Vic, 3086, Australia
[c] Center for Ice and Climate, Niels Bohr Institute, University of Copenhagen, Copenhagen, 2100, Denmark
[d] Molecular Systematics Unit, Western Australian Museum, Welshpool, WA, 6106, Australia
[e] Animal Biology, University of Western Australia, Crawley, WA, 6009, Australia

ARTICLE INFO

*Article history:*
Received 24 August 2017
Received in revised form
9 November 2017
Accepted 10 November 2017
Available online 20 November 2017

*Keywords:*
Antarctic
West Antarctic Ice Sheet
Marine ice sheet instability
Interglacial
Eemian
Genetic

ABSTRACT

Sea levels at the end of this century are projected to be 0.26–0.98 m higher than today. The upper end of this range, and even higher estimates, cannot be ruled out because of major uncertainties in the dynamic response of polar ice sheets to a warming climate. Here, we propose an ecological genetics approach that can provide insight into the past stability and configuration of the West Antarctic Ice Sheet (WAIS). We propose independent testing of the hypothesis that a trans-Antarctic seaway occurred at the last interglacial. Examination of the genomic signatures of bottom-dwelling marine species using the latest methods can provide an independent window into the integrity of the WAIS more than 100,000 years ago. Periods of connectivity facilitated by trans-Antarctic seaways could be revealed by dating coalescent events recorded in DNA. These methods allow alternative scenarios to be tested against a fit to genomic data. Ideal candidate taxa for this work would need to possess a circumpolar distribution, a benthic habitat, and some level of genetic structure indicated by phylogeographical investigation. The purpose of this perspective piece is to set out an ecological genetics method to help resolve when the West Antarctic Ice Shelf last collapsed.



## 1. Introduction

The West Antarctic Ice Sheet (WAIS) lies on bedrock that is mostly below sea level and that slopes downward in the inland direction (Fig. 1) (Fretwell et al., 2013). Mercer (1978) warned that this 'marine ice sheet' configuration may be inherently unstable in a warming climate, with severe consequences: complete melt (collapse) of the marine component of the WAIS would raise global sea level by over 3 m (Bamber et al., 2009). There is not yet a consensus on how quickly such a collapse could occur in response to future global warming scenarios, or on the ocean and atmosphere temperature thresholds required to trigger it (Church et al., 2013; Ritz et al., 2015; De Conto and Pollard, 2016). Determining how the ice sheet responded to past warmer than present climate states can provide an important test for climate and ice sheet models and inform ongoing debate.

Marine diatoms found in sediment samples from beneath the WAIS indicate that major retreat has occurred during the Pleistocene but the dating is insufficient to resolve exactly when (Scherer et al., 1998). Offshore marine records are similarly inconclusive (Scherer et al., 2008; Naish et al., 2009). In particular, it is not known if the WAIS collapsed during the Last Interglacial (LIG; 130,000–116,000 years ago), when global temperatures were around 2 °C warmer and sea levels 5.5–9 m higher than today (Dutton and Lambeck, 2012; Otto-Bliesner et al., 2013). To reach the upper bound of the LIG sea level rise estimate a complete WAIS collapse would be required, however the lower end could be accounted for by loss of the Greenland ice sheet (2–4m NEEM Community Members, 2013), ocean thermal expansion and loss of small ice caps and glaciers (<1 m) (Dutton and Lambeck, 2012). Attempts to resolve the LIG configuration of the WAIS based on water isotope signals in Antarctic ice cores have so far also failed to resolve the question, with one recent study supporting collapse (Steig et al., 2015) and another arguing that the isotope signal is more readily explained by major sea ice retreat (Holloway et al.,

* Corresponding author. Centre for Sustainable Tropical Fisheries and Aquaculture, James Cook University, Townsville, Qld, 4810, Australia.
*E-mail address:* jan.strugnell@jcu.edu.au (J.M. Strugnell).

https://doi.org/10.1016/j.quascirev.2017.11.014
0277-3791/

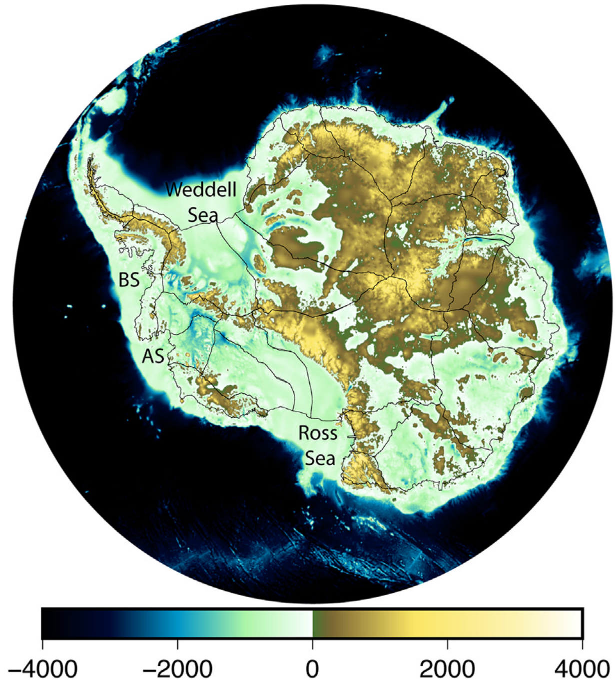


**Fig. 1.** Antarctic sub-glacial bed elevation (m), from Bedmap2 (Fretwell et al., 2013). Place names mentioned in the text are marked: Amundsen Sea (AS) and Bellingshausen Sea (BS). Figure adapted from Graham et al. (2017).

2016). Constraining the magnitude of Antarctic ice mass loss during the LIG has important implications for understanding its contribution to future sea level rise.

Retreat of the WAIS would open seaways (Fig. 2), initially between the Weddell and Amundsen Seas, and in the case of a full collapse, between the Weddell, Amundsen and Ross Seas (Vaughan et al., 2011). In this perspective we argue that genetic exchange through such ancient seaways will be recorded in the genomes of benthic marine species and that genomic techniques therefore offer an independent method to constrain past WAIS configuration.

### 1.1. Marine ice sheet instabilities

Dynamic flow of ice from the WAIS into the ocean is largely controlled by the buttressing effect of extensive floating ice shelves in the Ross and Weddell Seas and smaller ice shelves in the Amundsen and Bellingshausen seas. Ice shelf thinning, caused by warm ocean water melting the ice from below (Shepherd et al., 2004), or by surface melt and meltwater percolation from above (Scambos et al., 2000), reduces the back-stress that the ice shelves apply to land ice. A marine ice shelf instability is triggered where the reduced back-stress and resulting increase in the flux of ice from inland causes thinning of the ice at the point at which it begins to float (the grounding line), in turn setting up a runaway process in which the grounding line retreats back inland (Mercer, 1978). An additional destabilising mechanism involves the mechanical collapse of ice cliffs (Bassis and Walker, 2012; De Conto and Pollard, 2016). In regions where fringing ice shelves have been lost and where the grounding line thicknesses exceeds around 800 m, the resulting ice cliff faces cannot be supported by the yield strength of the ice and will collapse, driving ice retreat yet further inland. Meltwater produced by surface melt or rainfall further enhances (through hydrofracturing) both the marine ice sheet and marine ice cliff instabilities (De Conto and Pollard, 2016).

A recent simulation of the Antarctic response to LIG climate conditions finds that the WAIS is highly sensitive to marine ice cliff instability and ocean warming (De Conto and Pollard, 2016). When the model is run with 3°C subsurface ocean warming and the physics of marine ice sheet instability the WAIS remains largely intact and the seaways remain closed (Fig. 2a). When the model is run with the same ocean warming and including the physics of marine ice sheet instability, marine ice cliff instability and hydrofracturing, the WAIS collapses early in the LIG, opening seaways between the Weddell, Amundsen and Ross Seas (Fig. 2c). The dominant factor in WAIS collapse under the revised physics is marine ice cliff instability, which erodes the >1000 m thick marine ice sheets that currently block these seaways. Hydrofracturing is not important during the LIG since temperatures are too low (De Conto and Pollard, 2016). An intermediate state in which a seaway opens between the Weddell and Amundsen Sea but not through to the Ross Sea is also plausible (Fig. 2b, Vaughan et al., 2011; De Conto and Pollard, 2016). Constraining the configuration of previous WAIS seaways therefore provides a crucial test of ice sheet model physics and assumptions on sub-surface ocean warming relevant to both the past and future WAIS stability.

### 1.2. Current biological evidence for a trans-Antarctic seaway

Collapse of the WAIS has primarily been investigated using geological data and ice sheet modelling, however support also exists for a historic trans-Antarctic seaway from biological data. The community composition of extant bryozoan (Barnes and Hillenbrand, 2010; Vaughan et al., 2011) and gastropod and bivalve (Linse et al., 2006) assemblages have been shown to be more similar between the Weddell Sea and the Ross Sea than other regions around the Antarctic shelf including those in close proximity to these locations that also possess similar ecological conditions. However these studies were limited by small sample sizes and low spatial coverage. In addition, macroevolutionary signals can be misleading in an area such as Antarctica where true distributional data is often obscured by the presence of cryptic species, (i.e. distinct species that unable to be distinguished using morphological characters).

Two early genetic studies revealed hints that there were greater levels of similarity between Weddell Sea and Ross Sea populations, compared to other locations (isopod *Glyptonotus*, Held and Wägele, 2005; bivalve *Lissarca*, Linse et al., 2007). However, both studies lacked robust spatial and sample representation, which is necessary to determine whether similar genetic signatures in the Ross and Weddell Seas simply reflect a pattern present throughout East Antarctica (versus maritime Antarctic Peninsula), or rather, are indicative of an historic seaway. A later study that did include samples from East Antarctica identified similar genetic signatures between Weddell Sea, Ross Sea and Amundsen Sea populations of the octopod, *Pareledone turqueti* (Strugnell et al., 2012), with contrasting genetic patterns present at the Antarctic Peninsula region and the Scotia Arc. Although the population genetic signature present from Prydz Bay, East Antarctica, differed from that which was dominant in the Weddell Sea/Ross Sea/Amundsen Sea populations, the sample size ($n = 3$) from this region was too small to be conclusive. Due to limitations in samples size and marker choice, none of these studies have been able to use their data in a hypothesis testing framework to investigate or date historic trans-Antarctic connectivity. Recently, a hypothesis testing framework (Approximate Bayesian Computation) was employed to compare seven historical scenarios of the evolution of the brittle star, *Ophionotus victoriae*, however this study likely included several cryptic species in a single data set, thus lowering their power of detection, and also lacked samples from East Antarctica (Galaska et al., 2016). To date, robust attempts at testing for a trans-