Earth and Planetary Science Letters 284 (2009) 113–123

Contents lists available at ScienceDirect

Earth and Planetary Science Letters

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

Circum-Antarctic age modelling of Quaternary marine cores under the Antarctic Circumpolar Current: Ice-core dust–magnetic correlation

R.S. Pugh [a,b,*], I.N. McCave [b], C.-D. Hillenbrand [a], G. Kuhn [c]

[a] British Antarctic Survey, High Cross, Madingley Road, Cambridge, CB3 0ET, UK
[b] Godwin Laboratory for Palaeoclimate Research, Department of Earth Sciences, University of Cambridge, Downing Street, Cambridge, CB2 3EQ, UK
[c] Stiftung Alfred-Wegener-Institut für Polar- und Meeresforschung in der Helmholtz-Gemeinschaft, Am Alten Hafen 26, D-27568 Bremerhaven, Germany

A R T I C L E I N F O

Article history:
Received 1 June 2008
Received in revised form 7 March 2009
Accepted 15 April 2009
Available online 4 June 2009
Editor: P. DeMenocal

Keywords:
Antarctic circumpolar current
magnetic susceptibility
dust
correlation
Cycladophora davisiana
Scotia Sea

A B S T R A C T

Sediments in the belt under the Antarctic Circumpolar Current (ACC) contain high quantities of siliceous microfossils (mainly diatoms) and very little to zero carbonate. This prevents establishment of the age by the usual methods of oxygen isotope stratigraphy at most coring sites. Downcore variation in magnetic susceptibility (MS) from cores from the Scotia Sea closely resembles the temporal pattern of dust concentration and flux in East Antarctic ice cores. The validity of the temporal correlation between marine MS and EPICA Dome C (EDC) dust on the EDC3 time scale is established through ^{14}C dating of the acid insoluble organic matter back to 30 ka, and radiolarian abundance stratigraphy of *Cycladophora davisiana* back to 180 ka. The correlations are good ($r > 0.80$) and give credence to the use of MS-dust as a means of establishing chronostratigraphy in carbonate-free pelagic sediments from the Southern Ocean. This correlation has been established in >10 cores in the Scotia Sea. The circum-Antarctic validity of the pattern is shown in correlations to MS in sediment cores from the Indian and SW Pacific sectors of the Southern Ocean. During MIS 3 (57–29 ka), when sedimentation rates at correlated core sites exceeded 10 cm ka^{-1}, three MS maxima in the marine sediments and dust peaks at EDC, respectively, correspond to the cool periods between Antarctic warm events A1–A4. We have not established the precise cause of the correlation, but its validity around the circum-Antarctic west wind belt suggests that the material was either all transported by wind or was supplemented by wind-driven current transport. The fact that it occurs also in sections with a low terrigenous content suggests a fine grained, high-susceptibility material such as magnetite as the likely source.

1. Introduction

Calcareous microfossils are generally lacking in Southern Ocean sediments south of the Polar Front (PF). Therefore, the two most important methods for dating late Quaternary marine sediments, oxygen isotope stratigraphy and radiocarbon (^{14}C) dating on foraminifera tests, are only rarely possible. Here we explore three alternative independent methods for determining age in such settings. The first two methods are the well-established AMS ^{14}C dating of the acid-insoluble organic fraction (AIO) of the bulk sediment, and the relative abundance of the radiolarian species *Cycladophora davisiana* in the 63–250 µm size fraction. These are used to assess the robustness of a third method: correlation of the downcore magnetic susceptibility (MS) of the sediments with variations in dust concentration and flux in the East Antarctic EPICA Dome C (EDC) ice core (hereafter 'MS/dust correlation'). This allows transfer of an ice-core age model to marine sediments.

MS of marine sediments from the Scotia Sea has already been shown to represent glacial-interglacial cyclicity and MS peaks have been utilised for lithostratigraphic correlation (Pudsey and Howe, 1998; Howe and Pudsey, 1999). Hofmann (1999) showed that the MS profiles of sediment cores from the southern Scotia Sea resemble the pattern of dust concentration in the Vostok ice core (East Antarctica). We note that it is not possible to assess leads and lags in this way, but it does afford a rapid way of establishing an age model for some high-latitude Southern Hemisphere marine cores. We explore the correlation first in three sediment cores from the Scotia Sea, and then from the Indian and SW Pacific sectors of the Southern Ocean, demonstrating circum-Antarctic applicability. We also examine fluxes of sediment and susceptibility around the Southern Ocean implied by this dating technique.

1.1. Regional setting

Ocean circulation in the Scotia Sea is dominated by the Antarctic Circumpolar Current (ACC), the largest ocean current in the world with an average net baroclinic transport of 136.7 ± 10.4 Sv through Drake Passage (Cunningham et al., 2003). The ACC is the only ocean

* Corresponding author. Godwin Laboratory for Palaeoclimate Research, Department of Earth Sciences, University of Cambridge, Downing Street, Cambridge, CB2 3EQ, UK.
E-mail address: robert.s.pugh@gmail.com (R.S. Pugh).

0012-821X/$ – see front matter © 2009 Elsevier B.V. All rights reserved.
doi:10.1016/j.epsl.2009.04.016

current connecting all the major ocean basins, facilitating the global transport of heat, salt and nutrients between the Atlantic, Pacific and Indian Oceans (Nowlin and Klinck, 1986). It is driven by surface stress exerted by vigorous westerly winds contained in a belt between 45°S and 55°S (Nowlin and Klinck, 1986; Rintoul et al., 2001), thereby providing an important global link between the ocean and atmosphere. Flow speed decreases with depth but extends to the seabed in most places and is strongly influenced by regional bottom topography (Gordon et al., 1978).

In the Scotia Sea, the ACC flows between the Subtropical Front (STF) to the north and the Southern Boundary of the ACC (SBACC), which coincides with the northern limb of the Weddell Gyre. ACC flow is concentrated in three circumpolar, vertically-coherent, bottom-reaching fronts, from north to south: the Subantarctic Front (SAF), the PF and the Southern ACC Front (SACCF) (Orsi et al., 1995). Four distinct surface water mass regimes are separated by these three fronts, in whose vicinity the ACC flows at least two to three times faster than in the zones between them (Lenn et al., 2007). ACC fronts are regions of steep horizontal temperature and salinity gradients, are strongly influenced by the seabed topography and tend to display a meandering pattern where topography is relatively featureless (Moore et al., 1999).

2. Materials and methods

2.1. Sediment cores

Piston cores (PC, with 1.5 m trigger cores, TC) 288 and 290 were collected in March 2000 on cruise JR48 aboard RRS James Clark Ross. Core TPC290 ('TPC' refers to the TC + PC composite, spliced using their MS records) is a repeat of TPC078 collected in 1993. TPC288 (see Table 1 for positions) is located just south of the present SACCF, while TPC290 is located south of the PF (Fig. 1). Gravity core PS2319-1 was collected in 1992 on cruise ANT-X/5 aboard RV Polarstern and is located south of the SACCF.

Sedimentation at all sites is current-controlled. This is shown by 3.5 kHz sub-bottom characteristics: the seabed is relatively smooth with a distinct reflection, sub bottom penetration is deep (50–70 m) and the sub-bottom reflectors are parallel and continuous.

Based upon visual description, smear slides and x-radiographs, all the cores contain alternating biogenic- and terrigenous-dominated lithological units. Biogenic units comprise mostly homogenous, olive to olive-grey diatomaceous mud and diatom ooze. Terrigenous units are typically about twice as thick as the biogenic units and consist of mostly homogenous, grey to blue-grey diatom-bearing mud. The sediments are principally structureless, but some intervals contain a few faint greenish or greyish laminae, or are slightly mottled and burrowed. Large dropstones are scarce, but intervals containing scattered smaller clasts occur in both cores.

2.2. Methods

Methods for analysis of PS2319-1 are given in Diekmann et al. (2000) and the following apply only to TPC288 and TPC290. Opal content of samples was determined indirectly during their preparation for particle size analysis. Each sample (typically ~3 g of dry sediment) was wet sieved at 63 µm and biogenic silica was removed by heating with sodium hydroxide (NaOH). Smear slides were viewed under a microscope to check for successful opal removal. Opal content in weight % (wt.%) was calculated for the <63 µm fraction. The coarse fraction (>63 µm) in the samples is small (typically between 2 and 5 wt.%) and contains ice-rafted debris (IRD), so opal content in the fraction <63 µm is a close estimate of total opal content.

Accelerator mass spectrometer AMS ^{14}C dating was carried out on the AIO fraction of the bulk sediment samples. Samples for radiocarbon analyses were taken from core-tops and close to sharp lithological boundaries or prominent shifts in MS. 10 g of wet sediment were sampled for each radiocarbon analysis. The ^{14}C dates obtained from several labs are reported in Supplementary Data

Table 1
List of marine sediment cores from the Scotia Sea and surrounding region, their respective age models and the result of the correlation (r) between their MS profiles and Antarctic dust concentration (correlations are mapped in Fig. 1).

Number (Fig. 1)	Core	Latitude (°)	Longitude (°)	Area	Age model	Reference	Correlation (r)	MIS stages
1	PC031	−58.05	−44.33	Scotia Sea	Radiolarian biostratigraphy	Pudsey and Howe (1998)	0.563	1–3
2	PC034	−59.79	−39.60	Scotia Sea	Radiolarian biostratigraphy		0.648	1–4
3	KC064	−53.87	−48.34	Scotia Sea	Radiolarian biostratigraphy	Pudsey and Howe (1998); Pudsey and Howe (2002)	0.693	1–2
4	PC066	−53.99	−47.85	Scotia Sea	Radiolarian biostratigraphy	Howe and Pudsey (1999); Howe et al. (2002); Pudsey and Howe (2002)	0.116	1–6
5	PC079	−56.75	−43.28	Scotia Sea	Radiolarian biostratigraphy	Pudsey and Howe (1998)	0.653	1–4
6	KC081	−56.74	−42.97	Scotia Sea	Radiolarian biostratigraphy	Pudsey and Howe (1998); Pudsey and Howe (2002)	0.690	1–3
7	KC083	−59.37	−41.97	Scotia Sea	Radiolarian biostratigraphy	Pudsey and Howe (1998); Pudsey and Howe (2002)	0.616	1–2
8	TPC288	−59.14	−37.96	Scotia Sea	Radiolarian biostratigraphy	This study	0.672	1–6
9	TPC290/ TPC078	−55.55	−45.02	Scotia Sea	Radiolarian biostratigraphy	This study	0.669	1–6
10	PS2515-3	−53.56	45.31	Scotia Sea	Radiolarian biostratigraphy, ^{14}C	Diekmann et al. (2000)	0.731	1–5
11	PS2319-1	−59.79	42.68	Scotia Sea	Radiolarian biostratigraphy	This study; Hofmann (1999); Diekmann et al. (2000)	0.430	1–6
12	GC037	−61.11	−39.18	Jane Basin	Radiolarian biostratigraphy	Pudsey and Howe (1998)	0.736	1–3
13	PC067	−52.37	−46.00	Falkland Trough	Radiolarian biostratigraphy	Unpublished BAS core data	0.634	1–4
14	KC069	−52.05	−41.29	Falkland Trough	Radiolarian biostratigraphy	Unpublished BAS core data	0.444	1–3
15	PS1575-1	−62.85	−43.33	Weddell Sea	Litho-/Chemostratigraphy	Bonn et al. (1998)	0.016	1–9
16	PS2813-1	−66.73	−50.00	Weddell Sea	Lithostratigraphy	Diekmann et al. (2003)	−0.129	1–12
17	PS1778-5	−49.01	−12.70	South Atlantic	Radiolarian biostratigraphy	Brathauer and Abelmann (1999)	0.189	1–7
18	PS1565-2	−63.92	−69.54	Bellingshausen Sea	Litho-/Chemostratigraphy	Hillenbrand et al. (2008)	0.408	1–6
19	VC236	−64.27	−58.41	Larsen shelf	^{14}C	Pudsey and Evans (2001)	−0.260	1–3
20	VC244	−64.29	−58.58	Larsen shelf	^{14}C	Pudsey and Evans (2001)	0.279	1–3
21	VC275	−64.60	−58.10	Larsen shelf	^{14}C	Pudsey and Evans (2001)	−0.117	1–3
MD94-103		−45.60	86.50	SE Indian ridge	^{230}Th	Dezileau et al. (2000); Mazaud et al. (2007)	0.812*	1–6
MD94-104		−46.50	88.10	SE Indian ridge	^{230}Th	Dezileau et al. (2000); Mazaud et al. (2007)	0.853*	1–7
NBP9802-4-PC1		−64.20	170.80	SW Pacific		Anderson (unpublished)	0.700*	1–14
NBP9802-6-PC1		−61.88	169.98	SW Pacific	^{230}Th	Chase et al. (2003)	0.853*	1–3

Starred values denote correlations performed using Analyseries to tie the MS profiles to Antarctic dust concentration (see Section 2.2), rather than using an alternative age model.