KECK Geology Consortium
Learning Science Through Research
Published by Keck Geology Consortium
Short Contributions
29th Annual Symposium Volume
23rd April, 2016
ISBN: 1528-7491

PLIOCENE PALEOPRODUCTIVITY AND SEDIMENTATION AT ODP SITE 697 IN THE WEDDELL SEA, ANTARCTICA

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INTRODUCTION

Ice sheets are dynamic features on Earth's surface. This is especially true on Antarctica, where ice covers most of the continent and massive floating ice shelves extend beyond the land. Antarctica is subdivided into East and West, depending upon which latitude is being investigated, but more generally the divide is the Transantarctic Mountains. This 3,500 km long mountain range extends from Coats Land on the east side of the the Rhone-Filchner ice shelf, across to continent to the eastern side of the Ross Sea.

The Antarctic plays a crucial role in climate regulation and the waxing and waning of its ice sheets create global changes sea level height. Today, this ice-covered continent is thermally isolated from the rest of the ocean by the Antarctic Circumpolar Current, also known as the West Wind Drift (Figure 1A). This is the deepest (Euro-Argo, 2016) and largest current in the ocean, transporting between 100-150 million cubic meters of water per second (Smith et al., 2013). In the Northwestern part of the Weddell Sea, the densest water in the ocean, Antarctic Bottom Water (AABW) forms. AABW flows downward and outward from the Weddell Sea though several basins around the South Sandwich Islands as it moves into the rest of the world ocean basins (Figure 1B). Our knowledge of when this crucial arm of the ocean conveyor belt originated and Antarctic ice sheet dynamics in general is poor. This hampers our ability to predict and model future bottom water formation and ice sheet dynamics in response to a warming planet.

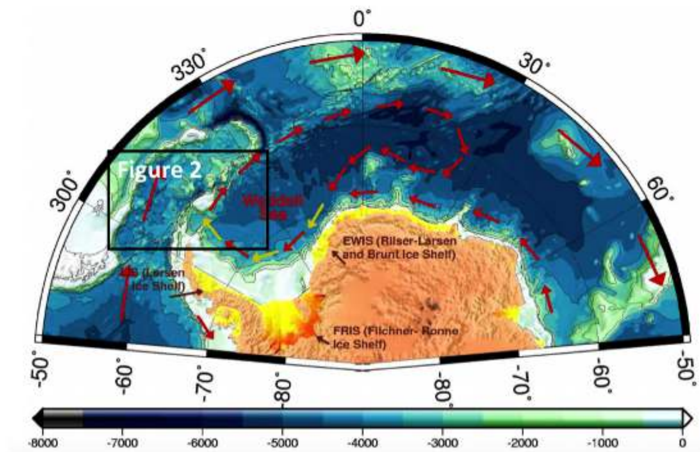

Figure 1A. Major ocean currents in the Weddell Sea and adjacent basins. Long red arrows indicate the clock-wise flowing Antarctic Circumpolar Current. The short red arrows show the movement of the Antarctic Coastal Current (East Wind Drift) which flows counter-clockwise and could bring icebergs from the east to the study site. The location of this current varies seasonally as ice extends from from the coast in the austral winter. When the East Wind Drift enters the Weddell Sea, it follows the coast and forms the Weddell Sea Gyre. The yellow arrows indicate the admixture of Ice Shelf Water into the marine mix. Ice shelves are marked in yellow to reddish color, indicating increasing ice thicknesses towards the inland ice shown in copper. Depth is given in meters below sea level. Darker colors are deeper. (from Thoma et al., 2005).

To begin to build a base of knowledge to we examined fifty meters of Pliocene-age sediment from five cores from ODP Site 697 (Figure 2). They span approximately 3.0-3.8 Myr (128.6-176.9 mbsf). We chose this interval because it is part of the mid-Pliocene Climatic Optimum (MPCO, Table 1), a time when atmospheric CO_2 levels were around 400 ppm. Sediment cores from this time interval in both the Ross Sea (Naish et al., 2009) and Wilkes Land

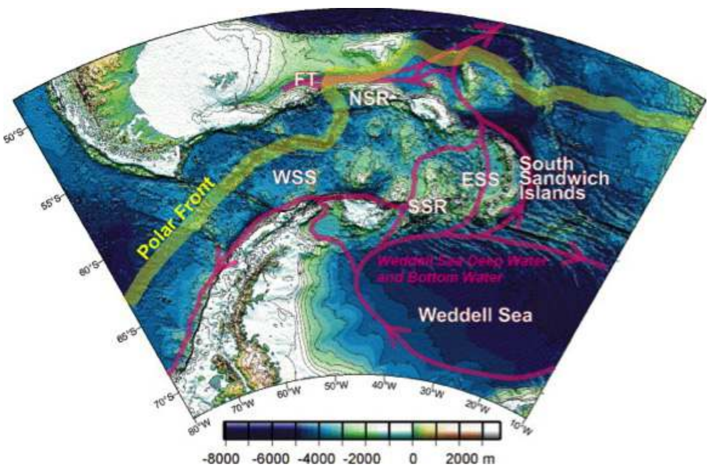

Figure 1B. Drake Passage bathymetry and bottom currents. Weddell Sea deep water flows into the South Atlantic Ocean through bathymetric lows into the East Scotia Sea (ESS), Falkland Trough (FT), North Scotia Ridge (NSR), South Scotia Ridge (SSR) and West Scotia Sea (WSS). The Polar Front is an averaged path from sea surface temperature data (Eagles et al., 2006).

Age (Ma)	Source	Reasoning/Data
3.3-2.9	Raymo et al., 2009	PLIOMAX Not listed (http://pliomax.org/)
3.3-3.0	Dutton et al., 2015	Benthic $\delta^{18}O$, LRO4
3.264-3.025	USGS PRISM4	Faunal and geochemical analyses coupled with new simulations
4.3-3.5	Patterson et al., 2014	Spectral Analysis Dominant periodicity of 40,000 from spectral analysis
4.4-4	Fedorov et al., 2013	SST proxy records Figure 2b equatorial and coastal upwelling zones in deep tropics and 2c subtropical coastal upwelling
4-5	Pagani et al., 2010	Not listed "Peak warming of early Pliocene"

Table 1. Approximate times of the Mid-Pliocene Climatic Optimum from different papers. It is clear that there is no consensus. In this study we are examining sediment from approximately 3.0 -3.8 my

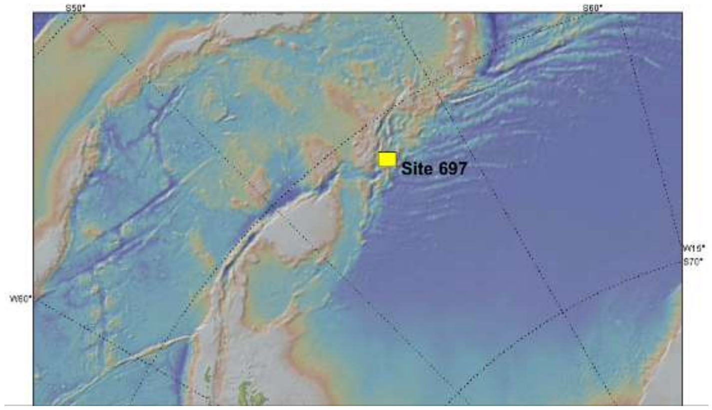

Figure 2. Location of Site 697 in 3800 m of water at one of the locations where AABW flows out of the Weddell Sea. (from GeoMapApp)

(Cook et al., 2007) show clear evidence of major melting. This is not a surprise for the sediments under the Ross Ice Shelf, because the Ross Ice Shelf is fed from ice that originates in West Antarctica. West Antarctica, largely covered by a floating ice shelf, has been considered unstable. Most models predict that it melted in the Pliocene and is expected to disintegrate in todays warming world contributing to approximately 5 m of sea level rise (Pollard and DeC onto, 2009). In contrast, the East Antarctic Ice sheet, primarily above sea level on a stable craton has been considered stable (DeConto and Pollard, 2003). The Wilkes Land coring (ODP Expedition 318, Cook et al., 2007) shows that this is not the case. As today's atmospheric CO_2 levels exceed 400 ppm, the potential for extensive Antarctic ice sheet melting and sea level rise need to be better understood. Estimates of the amount of Pliocene sea level rise vary considerably, from about 9 to 35 m.

THIS STUDY

ODP Site 697 lies in the Jane Basin (Figure 2), beyond the northern end of the Antarctic Peninsula, south of the South Orkney Islands. At 3480 meters water depth, it is a deepest of a three-site transect to examine the history of circum-Antarctic water masses. There, 320 m of Pleistocene and Pliocene sediment was recovered, dominated by terrigeneous mud with 0-40% diatoms and isolated ash layers. Today some AABW flows through the Jane Basin and into the Scotia Sea (Figure 1B). On the surface the Weddell Sea Gyre moves in a clockwise position around the basin. For much of the year this region is covered with ice, but climate-model predictions for the next two centuries show substantial decreases in sea ice, which will impact both the surface and deep water flow.

ODP Site 697 was cored in 1987 and only a single hole penetrated the sediment column. This means that even with good recovery, recovery is not complete. This is because of disturbance while coring, such as during storms, difficult to core material (sand

and dropstones), and because the drilling technique itself causes core disturbance. Coring of this slightly stiff sediment was done by advancing the extended-core barrel (XCB) ahead of the drill pipe. Sediment is easily disturbed by the water-pressure to operate the drilling equipment and the equipment itself. Nevertheless, recovery for the interval in this investigation was almost 90%.

A second and more important impediment to this research is the lack of age control. The Southern Ocean is caustic to calcium carbonate and at the 3480 m, Site 697 is well below the Calcium Cargouate Compensation Depth CCD. This means that any carbonate dating technique (calcareous nannofossils or foraminifera) and oxygen isotopes are not possible. Instead dating is dependent upon siliceous microfossils (diatoms, radiolarian, and silicioflagellates) and paleomagnetics. The correlation of biosilica datums to the geomagnetic polarity time scale is still poor (Tauxe et al., 2012). Polarity was measured in the cores, but good paleomagnetic measurements need 100% recovery and undisturbed cores. Nevertheless, we have used the paleomagnetic measurements that are available (O'Brien and Hamilton in Pudsey, 1990) and applied the Gee and Kent, (2007) timescale to the datums they identified. When our data is plotted against the Lisecki and Raymo benthic oxygen isotope stack, the match is not good. However, in future research with improved diatom stratigraphy and higher resolution analysis of chemistry, biosilica, diatoms and ice-rafted detritus, we hold the hope that the Site 697 data set will help to explain the global benthic isotope signal (Lisecki and Raymo, 2005) and the contribution of the Weddell Sea to deep water circulation.

Kate Cullen (Wesleyan University) examined the sediment composition using split core XRF counts and reflectance spectrography of selected fine fraction samples. This study allows us to identify changes in minerals and elements and thereby changes in provenance. This research will be combined with another study of the coarse fraction mineralogy and ages of hornblende to identify times when sediments were sourced from the East or West Antarctic ice sheets. These approaches will help us to identify

	Depth (mbsf)	Age (my) in Pudsey, 1990	Age (my) Gee & Kent, 2007
Blake SC, base	2.97	0.105	
Blake SC, top	4.59	0.155	
Brunhes/Matuyma	30	0.73	0.78
Jaramillo SC, base	42.95	0.98	1.07
Olduvai SC, top	67.8	1.66	1.781
Olduvai SC, base	86.3	1.88	1.968
C2An.1n/top	105.7	2.47	2.581
C2An.2n, top	132.8	2.99	3.11
C2An.2n, base	138.7	3.08	3.22
C2An.3n, top	147.6	3.18	3.33
C2An.3n (Gauss/Gilbert) base	164.25	3.4	3.58
C3n.1n, top	201	3.88	4.18
C3n.1n, base	207.5	3.97	4.29
C3n.3n, top	247.2	4.4	4.8
C3n.3n, base	261	4.47	4.89
C3n.4n, top	295.7	4.57	4.98

Table 2. Depth and age polarity reversals identified by O'Brien and Hamilton (unpublished) in Pudsey, 1990. Ages for polarity reversals have been updated to the Gee and Kent (2007) time scale.

both the origin and transport history of sediment and thereby to monitor ice sheet fluctuations.

Cindy Flores (Wesleyan University) measured the biosilica values for all samples. This is an excruciating process involving dissolution, multiple timed dilutions and comparing individual measurements to a standard curve to determine percent biosilica. The ocean is undersaturated in silica. Therefore, even those siliceous organisms such as diatoms that are present in the surface ocean are quickly dissolved before being incorporated into marine sediment. Abundant biosilica components of marine sediments only occur where the productivity is high enough to overcome dissolution. This usually means high productivity up-welling and/or extensive zones. In contrast when productivity is low, due to no upwelling or ice cover prevents diatom production, biosilica preservation is low.

Elena Robakiewicz (Oberlin College) prepared sediment samples from Core 13X (3.0-3.14 my) for diatom analyses and identified species that are adapted to colder and warmer climates. Identifying the species is critical to interpreting biosilica and IRD abundance because it sheds light on why biosilica values vary. Are they high because the area is ice free (warmer species) or extensive melting and nutrient supply (high IRD) or low because of colder conditions (cold species) with ice cover that doesn't melt (low IRD).

FUTURE WORK

This research lays the foundation for additional research at this site. Our data clearly show major differences in amount of biosilica (productivity), diatoms species, and composition (IRD and mineralogy). Better age dating, or more flexible interpretation of our ages may allow us to correlate our results with the light Lisecki and Raymo's (2015) global benthic isotope curve. However, our data is primarily reflecting surface processes (ice origin and flow, productivity) and may not allow us to identify the Weddell Sea component to deep ocean circulation. This information may be apparent by investigating the other two sites in this depth transect and contrasting them with Site 697.

ACKNOWLEDGEMENTS

This work would not have been possible without the assistance of the curator (Phil Rumford) and staff of the IODP Repository in College Station, TX. Claire McKinley provided assistance at all hours of the the day and night to help with the XRF scanner. We are also in debt to David Harwood who spent two weeks helping us to learn to identify diatoms, Tim Ku for providing his lab and expertise for the biosilica analyses and Zach Kaufman for the IRD abundance data and calculating ages and accumulation rates. Joel LaBella's contribution to every Wesleyan analysis must be acknowledged. None of this work would have been possible without the support of the Keck Geology Program.

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