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Interglacial/glacial changes in coccolith-rich deposition in the SW Pacific Ocean: An analogue for a warmer world?

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ABSTRACT

Satellite observations of middle to high latitudes show that modern ocean warming is accompanied by increased frequency and poleward expansion of coccolithophore blooms. However, the outcomes of such events and their causal processes are unclear. In this study, marine sediment cores are used to investigate past coccolithophore production north and south of the Subtropical Front. Calcareous pelagites from subtropical waters off northernmost New Zealand (site P71) and from subantarctic waters on Campbell Plateau (Ocean Drilling Program [ODP] site 1120C) record marked changes in pelagite deposition. At both locations, foraminiferal-rich sediments dominate glacial periods whereas coccolith-rich sediments characterise specific interglacial periods. Sediment grain size has been used to determine relative abundances of coccoliths and foraminifers. Results show coccoliths prevailed around certain Marine Isotope Stage (MIS) transitions, at MIS 7b/a and MIS 2/1 at P71, and at MIS 6/5e at ODP 1120C. Palaeo-environmental proxies suggest that coccolithophore production and deposition at P71 reflect enhanced nutrient availability associated with intense winter mixing in the subtropical Tasman Sea. An increased inflow of that warm, micronutrient-bearing subtropical water in concert with upper ocean thermal stratification in late spring/summer, led to peak phytoplankton production. At ODP 1120C during MIS 6/5e, an increased inflow of subtropical water, warm sea surface temperatures and a thermally stratified upper ocean also favoured coccolithophore production. These palaeo-environmental reconstructions together with model simulations suggest that (i) future subtropical coccolithophore production at P71 is unlikely to reach abundances recorded during MIS 7b/a but (ii) future subantarctic production is likely to dominate sedimentation over Campbell Plateau as modern conditions trend towards those prevalent during MIS 5e.

1. Introduction

A key question facing environmental science is 'How will the ocean respond to the present phase of changing climate?' (IPCC, 2013). This question is particularly relevant to phytoplankton, which forms the base of the marine food chain and is a key modulator of the uptake and release of CO_2 (e.g. Legendre, 1990; Iglesias-Rodríguez et al., 2002; Rost and Riebesell, 2004). In the modern ocean, coccolithophore blooms can be observed as milky white zones in satellite images (MODIS, http://modis.gsfc.nasa.gov/; SeaWiFS, http://oceancolor.gsfc.nasa.gov/SeaWiFS/). These observations, verified by ocean sampling, show that the global distribution of blooms has changed over the last 20–30 years with coccolithophores advancing into higher latitudes along with the poleward expansion of subtropical waters (Smyth et al., 2004; Cubillos et al., 2007; Winter et al., 2014). New Zealand is no exception, with preliminary assessment of remotely sensed images of coccolithophore blooms off and south of Chatham Rise pointing to an increase in bloom frequency (NIWA, 2009, C. Law; pers. comm. NIWA 2014), concomitant with a southward expansion of subtropical waters (e.g., Hill et al., 2008).

Coccolithophores are calcifying phytoplankton that inhabit the upper photic zone of the ocean. They are the most productive calcifying organism on Earth and play an important role in the carbon cycle, by both drawing down CO_2 during photosynthesis, and releasing CO_2 during calcification (Baumann et al., 2004; Rost and Riebesell, 2004; Zondervan, 2007). They are sensitive to changes in the photic zone, including light levels, nutrient availability, sea surface temperatures (SSTs) and water column stratification (Tyrrell and Merico, 2004; Zondervan, 2007). Despite their importance, the potential response of coccolithophore productivity to projected ocean change is uncertain (Rost and Riebesell, 2004; Zondervan, 2007; Winter et al., 2014).

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While systematic satellite observation of coccolithophore blooms spans less than four decades, longer albeit lower resolution records come from Quaternary interglacial sediments. Marine sediment cores from New Zealand highlight distinct changes in carbonate skeletal composition over time: glacial periods are typically represented by foraminiferal-rich sediment, whereas interglacial periods favour coccolith deposition (Carter et al., 1999). However, quantification and causes of these marked alternations are not clear. Research into coccolithophores off New Zealand is limited to their latitudinal distribution (Burns, 1972; Rhodes et al., 1995; Hiramatsu and De Deckker, 1997a; Saavedra-Pellitero et al., 2014), downcore distribution of Pleistocene assemblages (Hiramatsu and De Deckker, 1997b; Fenner and Di Stefano, 2004; Wells and Okada, 1997) and observation of modern blooms in coastal waters (Rhodes et al., 1995). Elsewhere, palaeoceanographic studies have focussed on coccolithophore species assemblages and the interplay between diatom and coccolithophore productivity over glacial/interglacial cycles (e.g. Okada and Wells, 1997; Flores et al., 2003; Incarbona et al., 2010; Saavedra-Pellitero et al., 2011). Apart from studies investigating relative coccolith and foraminiferal abundances in modern/Holocene core tops (Baumann et al., 2004; Frenz et al., 2005; Broecker and Clark, 2009), studies have not addressed changes in the relative abundances of these microfossil groups through time, or the factors affecting coccolithophore production over extended warm periods as represented by interglacial periods. Such information has the potential to identify the outcomes of prolonged warming under modern climate change.

In this paper we use grain size distributions to assess changing proportions of coccolithophores and foraminifers over interglacial/glacial cycles from the New Zealand sector of the Southwest Pacific Ocean and Southern Ocean. These changes and their potential causes, as derived from a combination of palaeoceanographic proxies and modern observations, are resolved for the subtropical and subantarctic settings that characterise the region (Fig. 1).

2. Regional setting

The study is based on subtropical core P71 from northeast of New Zealand (33°51.3′S, 174° 41.6′E, 1919 m water depth), and subantarctic Ocean Drilling Program (ODP) hole 1120C, core 1H (50°03.815′S, 173° 22.299′E, 543 m water depth) from Campbell Plateau. Core SO136-55 (50°09.61′S, 173°21.91′E, 563 m water depth), located just 13 km from ODP 1120C, is also included to support the age model of ODP 1120C (Fig. 1).

Piston core P71 was recovered near the southeastward-flowing East Auckland Current (EAUC), a branch of the subtropical Tasman Front, which in turn is part of the South Pacific Subtropical Gyre (Roemmich et al., 2007; Stanton, 1973) (Fig. 1). The site is also proximal to the North Cape Eddy; an anticyclonic warm-core feature that re-circulates approximately 50% of the EAUC. The Eddy also changes its location by up to 150 km annually (Stanton et al., 1997; Sutton and Roemmich, 2001).

The uppermost watermass at P71 is warm, saline (>34.7 psu) Subtropical Water (STW). Its modern mean annual SST is 19.3 °C, varying from ~22 °C in summer to ~17 °C in winter (Sutton and Roemmich, 2001; CARS, 2009). Productivity in the STW is co-limited by nitrate and light (Murphy et al., 2001). A spring increase in chlorophyll *a* (up to ~0.5 mg/m^3) is evident in remotely sensed images. It reflects increasing spring light levels and a shallowing seasonal thermocline due to lower wind stress (Murphy et al., 2001; Chiswell, 2011). Within the core of the North Cape Eddy, chlorophyll *a* is depleted, while it is enriched on the margin of the Eddy (Murphy et al., 2001).

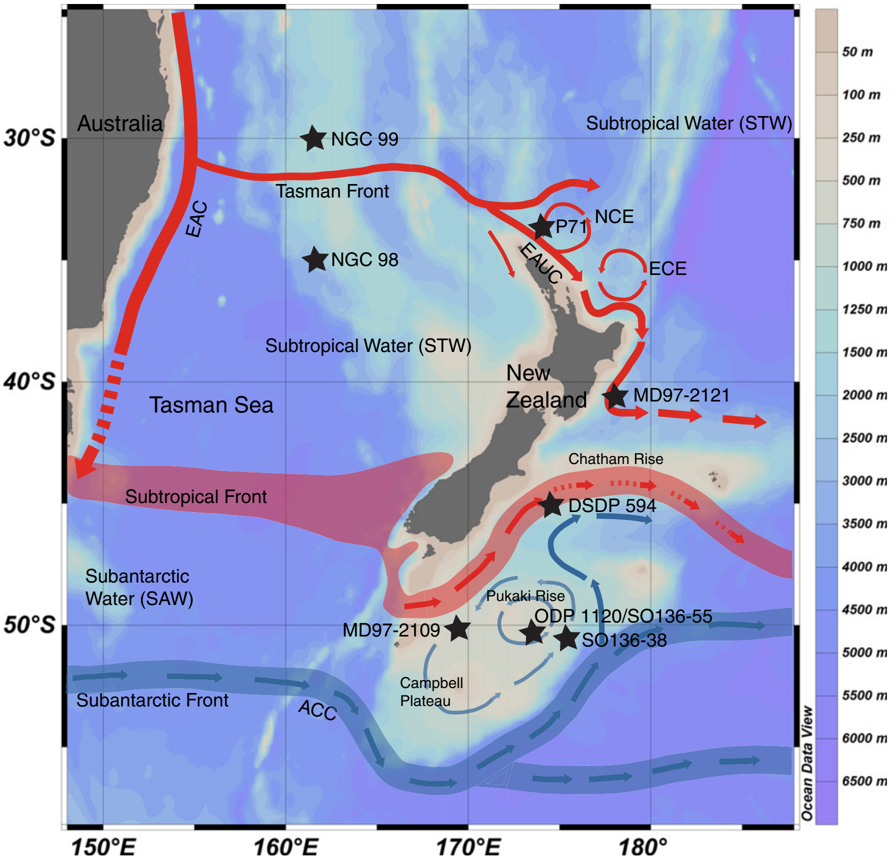

Fig. 1. Core locations used in this study and main surface currents and surface water masses, modified from Orpin et al. (2008) and Smith et al. (2013). EAC = East Australian Current. EAUC = East Auckland Current. NCE = North Cape Eddy. ECE = East Cape Eddy. ACC = Antarctic Circumpolar Current. Warm surface currents are in red, while cold surface currents are in blue. Dashed arrows on STF represent weaker flow compared to full arrows. Bathymetry is in metres below sea level.