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The effect of submerged plateaux on Pleistocene gyral circulation and sea-surface temperatures in the Southwest Pacific

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ABSTRACT

Uniquely in the Southern Hemisphere the New Zealand micro-continent spans the interface between a subtropical gyre and the Subantarctic Circumpolar Current. Its 20° latitudinal extent includes a complex of submerged plateaux, ridges, saddles and basins which, in the present interglacial, are partial barriers to circulation and steer the Subtropical (STF) and Subantarctic (SAF) fronts. This configuration offers a singular opportunity to assess the influence of bottom topography on oceanic circulation through Pleistocene glacial – interglacial (G/I) cycles, its effect on the location and strength of the fronts, and its ability to generate significant differences in mixed layer thermal history over short distances.

For this study we use new planktic foraminiferal based sea-surface temperature (SST) estimates spanning the past 1 million years from a latitudinal transect of four deep ocean drilling sites. We conclude that: 1. the effect of the New Zealand landmass was to deflect the water masses south around the bathymetric impediments; 2. the effect of a shallow submerged ridge on the down-current side (Chatham Rise), was to dynamically trap the STF along its crest, in stark contrast to the usual glacial–interglacial (G–I) meridional migration that occurs in the open ocean; 3. the effect of more deeply submerged, downstream plateaux (Campbell, Bounty) was to dynamically trap the SAF along its steep southeastern margin; 4. the effects of saddles across the submarine plateaux was to facilitate the development of jets of subtropical and subantarctic surface water through the fronts, forming localized downstream gyres or eddies during different phases in the G–I climate cycles; 5. the deep Pukaki Saddle across the Campbell-Bounty Plateaux guided a branch of the SAF to flow northwards during each glacial, to form a strong gyre of circumpolar surface water in the Bounty Trough, especially during the mid-Pleistocene Climate Transition (MIS 22-16) when exceptionally high SST gradients existed across the STF; 6. the shallower Mernoo Saddle, at the western end of the Chatham Rise, provided a conduit for subtropical water to jet southwards across the STF in the warmest interglacial peaks (MIS 11, 5.5) and for subantarctic water to flow northwards during glacials; 7. although subtropical or subantarctic drivers can prevail at a particular phase of a G–I cycles, it appears that the Antarctic Circumpolar Current is the main influence on the regional hydrography.

Thus complex submarine topography can affect distinct differences in the climate records over short distances with implications for using such records in interpreting global or regional trends. Conversely, the local topography can amplify the paleoclimate record in different ways in different places, thus enhancing its value for the study of more minor paleoceanographic influences that elsewhere are more difficult to detect. Such sites include DSDP 594, which like some other Southern Ocean sites, has the typical late Pleistocene asymmetrical saw-tooth G–I climate pattern transformed to a gap-tooth pattern of quasi-symmetrical interglacial spikes that interrupt extended periods of minimum glacial temperatures.

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1. Introduction

In the open ocean, surface water masses and fronts freely migrate toward the equator during coolings and the poles during warmings (e.g. Morley, 1989; Howard and Prell, 1992; Passlow et al., 1997; Nees et al., 1999; Kawagata, 2001). In contrast, New Zealand (Fig. 1) is a largely submerged micro-continent spanning ~20 ° of latitude and is a partial barrier to South Pacific circulation. In the south and east there are several submarine ridges and plateaux (200–1000 m depth) projecting into the flow paths of the globe-encircling Antarctic Circumpolar Current and South Pacific-wide Subtropical Gyre and their associated water masses and ocean fronts. Previous studies indicate that these submarine impediments interfere with the usual latitudinal migration of surface waters observed in the open ocean during glacial–interglacial (G–I) cycles (e.g., Weaver et al., 1998; Neil et al., 2004; Schaefer et al., 2005; Wilson et al., 2005). Thus the region provides a unique perspective on the paleoceanographic response to G–I cycles, when hydrography is strongly constrained by bottom topography. For example, ODP Site 1119 is 1 ° latitude north of DSDP Site 594 (Fig. 1) and both have similar present-day SSTs, but during the last 1 myr, DSDP 594 has been up to 5 °C warmer and 3–4 °C cooler than ODP 1119 (Wilson et al., 2005). Although we focus on local effects of bottom topography our data are a global example of the interplay between passive and dynamic controls on near-surface hydrography.

Study of the interplay between bottom topography and water masses east of New Zealand in the late Pleistocene has been aided by some of the thickest deep-water sedimentary sequences in the South Pacific (e.g., Carter et al., 1996; Carter and McCave, 2002). Previous studies have inferred Southwest Pacific SSTs and climate, usually based on a single site (e.g., Stewart and Neall, 1984; Dersch and Stein, 1991; King and Howard, 2000; Marret et al., 2001; Carter and Gammon, 2004; Carter, 2005; Crundwell et al., 2008). These results have mostly been interpreted in terms of the strength and inter-hemispheric timing of global and southern hemisphere climate cycles (e.g. Nelson et al., 1985; Pahnke et al., 2003; Pelejero et al., 2003; Pahnke and Zahn, 2005; Barrows et al., 2007; Carter et al., 2008). Some studies have also considered the influence of water mass and frontal movements (e.g., Fenner et al., 1992; Nelson et al., 1993; Wells and Okada, 1997; Carter et al., 2004; Scott and Hall, 2004; Carter and Manighetti, 2006; Crundwell et al., 2008), though these are sometimes difficult to assess on the basis of a single site. In departures from the norm, Weaver et al. (1998) andSikes et al. (2002) investigated G–I movements of the STF on the basis of eight and four sites respectively, back to Marine Isotope Stages (MIS) 6–4; and Neil et al. (2004) investigated G–I movement and strength of the SAF from 8 sites also extending back to MIS 6–5. Two studies, which contribute data to this synthesis, have previously compared SST estimates (using modern analogue technique, MAT) over the last 1 myr from two pairs of sites — one north and south of the Chatham Rise (DSDP 594, ODP 1125, Schaefer et al., 2005); and one pair in the Bounty Trough, south of Chatham Rise (DSDP 594, ODP 1119, Wilson et al., 2005).

This synthesis combines the planktic foraminiferal census counts from five previous studies (1101 samples, ~300,000 specimens) for the last 0.8–1 myr from four DSDP and ODP sites (Table 1) — two north (1123, 1125) and two south (594, 1119) of the Chatham Rise and present STF (Wells and Okada, 1997; Weaver et al., 1998; Schaefer et al., 2005; Wilson et al., 2005; Crundwell et al., 2008). The censi (supporting on-line material Appendix 1) are used to generate new SST estimates that form the basis for interpreting the history of the influence of the bathymetry of the submerged New Zealand micro-continent on surface ocean circulation and fronts over the last 1 myr.

1.1. Age models

To enable comparisons between our four study sites, we standardized the biostratigraphic-, tephra- and isotope-based chronologies of each over the last 0.8–1 myr by retuning existing age models to the global stack of benthic foraminiferal δ^{18}O records compiled by

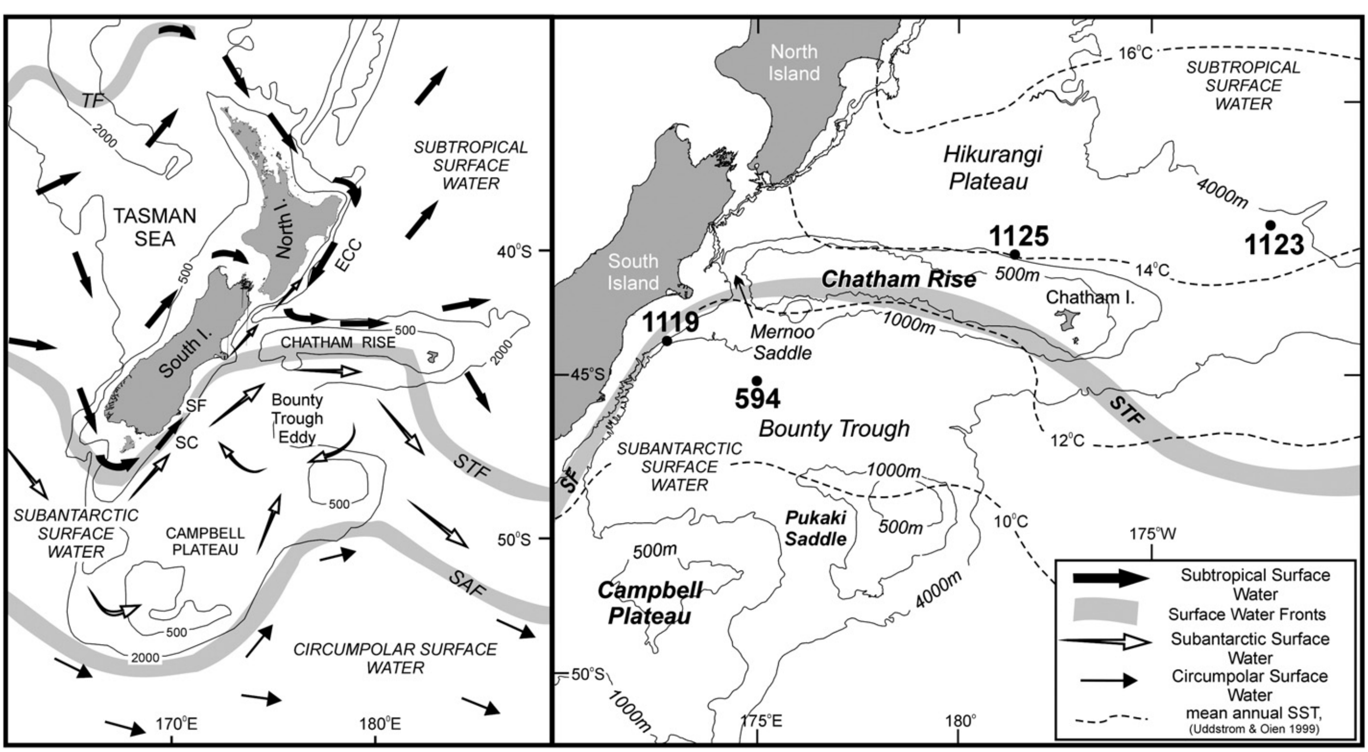

Fig. 1. Left: Location of the four study sites and present surface currents and fronts around New Zealand in the Southwest Pacific (from Carter et al., 1998). Also shown are 500 m and 2000 m bathymetric contours. ECC = East Cape Current, SAF = Subantarctic Front, STF = Subtropical Front, SC = Southland Current, SF = Southland Front, TF = Tasman Front. Right: Mean annual sea-surface isotherms (January 1993–December 1997) over the study sites east of central New Zealand (from Uddstrom and Oien, 1999). Also shown are 1000 m and 4000 m bathymetric contours.