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# Chemostratigraphic documentation of a complete Miocene intermediate-depth section in the Southern Ocean: Ocean Drilling Program Site 1120, Campbell Plateau off New Zealand

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A B S T R A C T

An integrated chemostratigraphic ($^{87}Sr/^{86}Sr$, $\delta^{13}C$ and $\delta^{18}O$) study of benthic foraminifera is presented for a 210 m-thick, intermediate depth (upper/middle bathyal transition), Miocene nannofossil ooze section of Ocean Drilling Program Site 1120, Campbell Plateau off New Zealand. Our results indicate that new $^{87}Sr/^{86}Sr$, $\delta^{13}C$ and $\delta^{18}O$ profiles are wholly consistent with their respective Miocene reference curves. These observations facilitate identification of a total of five reliable chemostratigraphic datums, which are based on the fundamental structural changes in the $^{87}Sr/^{86}Sr$ curve and paired simultaneous $\delta^{13}C$ and $\delta^{18}O$ events. The resultant age–depth relationship clearly shows that the Miocene (20–5 Ma) biopelagic sedimentation on the Campbell Plateau was essentially continuous at a moderate to high, linear sedimentation rate (17.5 m/m.y. with an exception of the uppermost 13 m). Our findings do not support the shipboard biostratigraphic age model, which assumes that the critical early–middle Miocene transition was interrupted by a major hiatus (<~3 m.y.). Because of its unique bathymetric setting at a paleowater-depth of ~600 m, which is among the shallowest of the coeval isotopically studied deep-sea sections in the South Pacific/Southern Ocean, Site 1120 will serve as a reference section for surveying the evolution of intermediate-water paleoceanography in the Southern Hemisphere across the middle Miocene climatic transition.



## 1. Introduction

The middle Miocene represents a key inflection point in the long-term global cooling that occurred from the Late Cretaceous to the Cenozoic, marking the final transition into a full icehouse mode via expansion of the Antarctic cryosphere with an extraordinary rapidity (e.g., Holbourn et al., 2005; Shevenell et al., 2004). As a crucial step toward understanding the factor(s) controlling the Miocene paleoclimatic evolution, considerable attention has been given to the spatio-temporal reconstruction of ocean circulation, specifically the interaction of Northern Component Water (NCW; sourced from the North Atlantic), Antarctic Circumpolar Current (ACC) and Tethys Indian Saline Water (TISW) (Woodruff and Savin, 1989; Wright et al., 1992). Of these, warm TISW has been proposed as a major driver of the meridional heat transport toward the southern high-latitudes. The closure of the eastern Tethys gateway and resultant cessation of TISW production has been a leading hypothesis for the major development of East Antarctic Ice Sheet (EAIS) during the middle Miocene (Woodruff and Savin, 1989). These TISW dynamics have primarily been illustrated by a synoptic mapping of benthic foraminiferal $\delta^{13}C$ values from multiple Deep Sea Drilling Project (DSDP)/Ocean Drilling Program (ODP) sites in the South Pacific/Southern Ocean (Flower and Kennett, 1995; Shevenell and Kennett, 2004; Woodruff and Savin, 1989; Wright et al., 1992), assuming a deep-water connection via the Indonesian passage (see also Kuhnt et al. (2004) for an earlier estimate on the timing of tectonic restriction of this passage). These previous results recognized the dominance of TISW in the late early–early middle Miocene based on the absence of vertical and meridional $\delta^{13}C$ gradients. This paleoceanographic state was replaced by a state similar to the present-day conditions in the middle Miocene, which comprised high-$\delta^{13}C$ Southern Component Intermediate Water (SCIW), intermediate-$\delta^{13}C$ Southern Component Water (SCW), and low-$\delta^{13}C$ Pacific Deep Water (PDW) protruding into SCW.

While Miocene deep-water paleoceanography in the Southern Hemisphere has been surveyed in detail, the mode of intermediate-water circulation has not yet been elucidated. This is due to the paucity of available stable isotope records from shallower depths. Currently, the SCIW dynamics is constrained in only a few deep-sea sections for which the paleowater-depths are slightly deeper than 1000 m (Cooke et al., 2008; Shevenell and Kennett, 2004). The absence of Miocene stable

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isotope data from the upper to middle bathyal depth (200–600 m and 600–1000 m, respectively, according to the bathymetric terminology of Hayward et al. (2004)) does not allow in-depth investigation of the intermediate-water property and its impact on the paleoclimatic evolution, as has been done for the modern equivalent, Antarctic Intermediate Water (AAIW) (Bostock et al., 2004).

As a first step toward enhancing our knowledge of Miocene intermediate-water dynamics, this study aims to provide a sound chemostratigraphic framework for a Miocene hemipelagic section of ODP Site 1120 off New Zealand. Our goal is to show that this ODP site, with continuous sedimentation at a moderate to high sedimentation rate at the upper/middle bathyal transition, potentially serves as a Miocene reference section for the evolution of Southern Ocean intermediate-water paleoceanography.

## 2. Ocean Drilling Program Site 1120

### 2.1. General

During ODP Leg 181 in 1998, Site 1120 (Fig. 1) was located on the central Campbell Plateau, approximately 650 km southeast off South Island, New Zealand (50°3.8′S, 173°22.3′E; Shipboard Scientific Party, 1999a). Drilling was conducted on 4 holes (1120A to 1120D) at water-depths of 542.90–545.90 m, and the maximum penetration reached was 220.70 m below the seafloor (mbsf) at Hole 1120D. We assume that the middle Miocene paleowater-depth of Site 1120 was nearly the same as the present-day depth and that the paleolatitude was ~2° south of the present position to maintain consistency with the previous paleobathymetric and paleolatitudinal estimates for DSDP Site 594 on the Chatham Rise (Flower and Kennett, 1995) in the same tectonic domain. The bathymetric setting of Site 1120 is unique because it is among the shallowest of Miocene DSDP/ODP sites that have been isotopically studied for Miocene South Pacific/Southern Ocean paleoceanography (cf. Shevenell and Kennett, 2004).

The lithology of Site 1120 consists exclusively of white, bioturbated, more or less foraminifera-bearing, nannofossil ooze (Shipboard Scientific Party, 1999c). Site 1120 is dominated by biopelagic sediments with uniformly high $CaCO_3$ contents (>90%) (Shipboard Scientific Party, 1999c) because the central Campbell Plateau forms a topographic high isolated from the terrigenous sediment supply that passes down the submarine canyon systems that flank the plateau. The lithologic units identified were as follows: Unit I (0–4.3 mbsf, upper Pleistocene); Unit II (4.3–10.2 mbsf, lower Pleistocene); Unit III (10.2–54.9 mbsf, upper Miocene); and Unit IV (54.9–220.7 mbsf, lower to upper Miocene) (sub-bottom depths are from Holes 1120B and 1120D). This subdivision was based on smear slide observation for subtle compositional changes in the sediments, with an exception of the Unit I/II boundary where the Unit II chalk below this contact is yellowish and more compact. Biostratigraphic results indicate that the Unit I/II and II/III boundaries are paraconformities. Further, nannofossil biostratigraphy has been interpreted as pointing to an additional yet problematic paraconformity around 170 mbsf (see next Section 2.2).

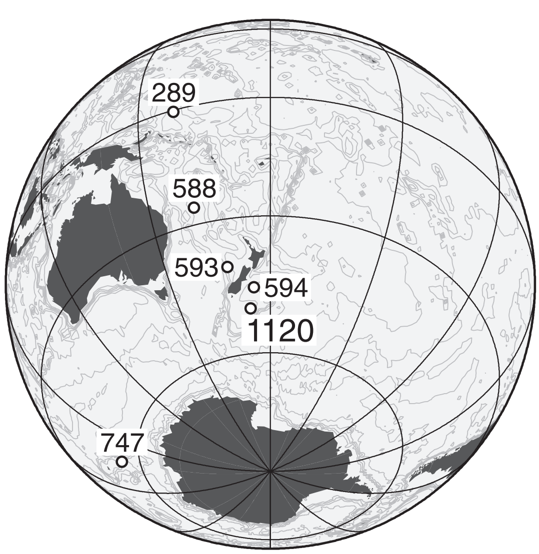


**Fig. 1.** Map showing present-day locations of ODP Site 1120, Campbell Plateau off New Zealand, and other Southern Ocean/South Pacific DSDP/ODP sites discussed in this study. Orthographic projection with 1000 m-spacing isobaths generated through Online Map Creation (http://www.aquarius.geomar.de/omc/).

### 2.2. Shipboard biochronology

For Site 1120, magnetostratigraphic chronology could not be established because of very weak intensities of natural remnant magnetization and magnetic overprints due to rust contamination from the drill pipe (Shipboard Scientific Party, 1999c). Therefore, the chronology of this site relies on shipboard biostratigraphic study of calcareous nannofossils, planktonic foraminifera, bolboforma, diatoms and radiolaria. The biochronology of Site 1120 depends on the southern high-latitude zonations complemented by regional New Zealand zonations (Shipboard Scientific Party, 1999b), owing to its latitudinal position to the south of the Subtropical Convergence. However, the zonation schemes previously utilized had not been fully scrutinized, and Leg 181 biostratigraphic results must therefore be viewed as preliminary, and subject to further refinement of southern high-latitude biozonations.

A total of 53 bioevents were selected for the age model of Site 1120 (Fig. 2A). The age–depth relationship of multiple microfossil taxa is rather inconsistent in the Miocene interval, with an exception of the interval at 50–80 mbsf. Nevertheless, 11 age-control points of calcareous nannofossils, planktonic foraminifera and radiolaria were chosen based on "subjective weighting" to illustrate a preferred age model and sedimentation rate (Fig. 2, broken line). Further complication was introduced by the fact that the narrow stratigraphic range (166.9–177.1 mbsf) of nannofossil *Sphenolithus heteromorphus* (total range = 18.5–13.5 Ma) was taken as an indication of paraconformity at ~170 mbsf. This means that late early–early middle Miocene sedimentation was interrupted by a hiatus of 1.5–3 m.y. (Shipboard Scientific Party, 1999c). However, this inference was not supported by planktonic foraminiferal biostratigraphy, and it might simply reflect an inadequately known range for *S. heteromorphus* in the Subantarctic ocean (Shipboard Scientific Party, 1999c). Despite such caveats, the inferred paraconformity was adopted without explicit reason in the summary chronostratigraphy of Shipboard Scientific Party (1999a), as shown in Fig. 2B. It was cited later by Carter et al. (2004) as a sedimentary expression of the intensified flow strengths of proto-AAIW during the Miocene (16.7–15.8 Ma).

## 3. Material and methods

A total of 96 ooze samples from Holes 1120B and 1120D (23.3–221.6 mbsf) were obtained for analyses. Our results (later) indicate that the examined interval spans about 20–8 Ma, implying that this sampling protocol has captured a stratigraphic resolution of ~0.12 m.y.

As a basic geochemical property, the $CaCO_3$ content (= TIC [wt.%] × 8.333) was measured for ~5 mg of powdered bulk sediment using a UIC $CO_2$ coulometer (Model CM5014) at Pusan National University. The analytical precision was 2% (± 1 SD).

Seventy-nine raw samples were treated with 5% $H_2O_2$ solution, wet-sieved at 63 µm, and oven-dried at <40 °C. For stable isotope analysis, about 10 well-preserved specimens of *Cibicidoides* benthic foraminifera were picked from the 125 to 250 µm sieve fraction. For Sr isotope analyses at 38 selected levels, several epifaunal benthic foraminiferal genera were used, so that a sufficient quantity of foraminiferal material (~0.5 mg) was employed for the measurements (each foraminiferal