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Reduction of oceanic temperature gradients in the early Eocene Southwest Pacific Ocean

Benjamin R. Hines [a,*], Christopher J. Hollis [b], Cliff B. Atkins [a], Joel A. Baker [a,c], Hugh E.G. Morgans [b], Percy C. Strong [b]

[a] School of Geography, Environment and Earth Sciences, Victoria University of Wellington, New Zealand
[b] GNS Science, Lower Hutt, New Zealand
[c] School of Environment, The University of Auckland, New Zealand

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ABSTRACT

We present a Southwest Pacific Ocean paleothermometry transect using new and existing foraminiferal Mg/Ca data from six Eocene locations from eastern New Zealand to southwestern Campbell Plateau, spanning 10° of paleolatitude (43° to 53°S). Sea surface and seafloor temperatures (SST and SFT) have been calculated taking into account the partition coefficients of calcite and Paleogene Mg/Ca_{sw} ratios, and used to determine values for the power component (*H*) of this relationship in foraminiferal calcite from paired proxy ($\delta^{18}O$ and Mg/Ca) records from Canterbury Basin. This study presents the first Eocene paleotemperature record for the East Coast Basin and, in so doing, shows the absence of a meridional temperature gradient over 10° of latitude during the Early Eocene Climatic Optimum (EECO) and provides evidence for a very weak to absent gradient from the equatorial Pacific to 53°S at this time of extreme global warmth. The application of a new subsurface TEX_{86} calibration correlates remarkably well with Mg/Ca seafloor temperature trends from the continental slope setting (<1000 m paleodepth) of the sites sampled in this study, suggesting that TEX_{86} is recording an upper ocean subsurface temperature record, rather than simply SST values. SST-SFT gradients demonstrate a notable reduction, decreasing to 3–5 °C across the EECO. The comparable ocean temperatures of the East Coast Basin, Canterbury Basin and DSDP Site 277 during this time support the intensification of a proto-East Australian Current (EAC), explaining the distribution of tropical sea temperatures extending into the high-latitude Southwest Pacific Ocean during the EECO. Seafloor temperatures (~1000 m paleodepth) likely correspond to a northern, intermediate water source during the early Eocene, before switching to a cooler southern-derived source in the middle to late Eocene.
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1. Introduction

Early Paleogene climate was characterised by temperatures that were significantly warmer than the present day, reaching a peak during the Early Eocene Climatic Optimum (EECO; 50–53 Ma). Proxy evidence from several localities indicates that the Southwest Pacific Ocean experienced a pronounced warming in the EECO that was followed by a stepwise cooling during the middle and late Eocene (Bijl et al., 2013; Hollis et al., 2012; Creech et al., 2010), culminating in the development of the first extensive Antarctic ice sheets in the earliest Oligocene (Shackleton and Kennett, 1975; Cramer et al., 2011). Paleogene proxy-based paleoclimate reconstructions from the southwest and tropical Pacific imply little to no latitudinal temperature gradient during the early Eocene, which is difficult to reconcile with the known climate dynamics and model studies (Bijl et al., 2013; Hollis et al., 2012).

The thermodynamically controlled incorporation of magnesium into the calcite tests of foraminifera enables the derivation of past sea temperatures (e.g., Rosenthal et al., 1997; Lear et al., 2002; Eggins et al., 2003). However, post-depositional sedimentary contamination and diagenetic alteration of foraminiferal calcite can artificially bias Mg/Ca paleotemperature determinations (e.g., Barker et al., 2003; Kozdon et al., 2011). Application of the laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS) method of determining elemental abundances for paleotemperature estimates provides the means to robustly assess issues associated with variable preservation, diagenetic coatings and sediment infilling of foraminifera tests by allowing the identification and removal of post-depositional effects and contaminated trace element depth profiles (Eggins et al., 2003; Creech et al., 2010). Mg/Ca sea temperature reconstructions for the Canterbury Basin have demonstrated good agreement with other paleotemperature proxies (Burgess et al., 2008; Hollis et al., 2012; Creech et al., 2010). In this study we extend the early Eocene record beyond the Canterbury Basin in order to develop a regional synthesis of Southwest Pacific sea temperature distributions and relate these to global circulation models.

* Corresponding author.
E-mail address: Ben.Hines@vuw.ac.nz (B.R. Hines).

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An interval that spans the Paleocene–Eocene boundary at Deep Sea Drilling Project (DSDP) Site 277 on the Campbell Plateau (paleolatitude ~53°S) is combined with three East Coast Basin sections (paleolatitude ~43–44°S) exposed in the North Island of New Zealand, and previously published records from two localities in the Canterbury Basin (paleolatitude 55 and 56°S) in order to establish a new early Eocene sea temperature record spanning a ~10° latitudinal gradient. Palinspastic reconstructions place the New Zealand subcontinent between 42° and 54°S during the early Eocene, based on the paleomagnetic reference frame of Torsvik et al. (2012) as recommended by van Hinsbergen et al. (2015). This study adds new analyses to existing Mg/Ca records from Hampden (Burgess et al., 2008; Hollis et al., 2012), and DSDP Site 277 (Hollis et al., 2015), with the addition of three new sites from the East Coast Basin.

2. Depositional setting and stratigraphy

2.1. Depositional setting

The east coasts of the North and South Islands of New Zealand contains several hemipelagic Paleogene sedimentary successions from which moderately to well-preserved foraminiferal assemblages have been recovered. In this study, Mg/Ca proxy based paleo-sea temperatures have been obtained from three newly studied sections (Aropito, Tawanui and Tora) in the East Coast Basin, along with new data from Hampden Beach and DSDP Site 277, which are then integrated with two published records (mid-Waipara River, Hampden Beach and DSDP Site 277; Hollis et al., 2012, 2015) from the Canterbury Basin (Fig. 1). In particular, two sample suites were collected from the earliest to middle Eocene (Waipawan to Bortonian local stages) Wanstead Formation exposed in the Tawanui and Aropito sections in southern Hawke's Bay (Moore and Morgans, 1987), along with a lower to middle Eocene (Waipawan to Runangan) section at Pukemuri Stream, Tora, southeast Wairarapa (Hines et al., 2013). These sections were used to produce a new paleotemperature record for the central East Coast Basin (Fig. 2).

Benthic foraminiferal paleodepth indicators for the East Coast Basin during the early to middle Eocene imply an upper bathyal (500–1000 m) water depth for the Wanstead Formation at Aropito and Tawanui (Moore and Morgans, 1987; Kaiho et al., 1993), which is equivalent to the estimated paleodepth of 800 m for the Pukemuri Siltstone from the Tora section (Hines et al., 2013). These depths correspond to intermediate water. In the Canterbury Basin, the lower to Middle Eocene Ashley Mudstone exposed in the mid-Waipara River section has an estimated paleodepth of ~500 m (Hollis et al., 2012), which is also consistent with intermediate water. The Kurinui Formation exposed at Hampden Beach, Otago, was deposited at a shallower paleodepth of 200 m (Hollis et al., 2012). Benthic foraminiferal indicators from DSDP Site 277 imply an upper bathyal depositional depth of 800–1000 m.

2.2. Stratigraphy and age control

The upper Paleocene (Teurian) to upper middle Eocene (Bortonian) sedimentary succession in the Aropito and Tawanui sections in southern Hawke's Bay is characterised by poorly bedded, calcareous, smectitic, green–grey mudstone of the Wanstead Formation (Moore and Morgans, 1987; Kaiho et al., 1993). A lower to upper Eocene (Mangaorapan to Kaiatan) succession is exposed in the Pukemuri Stream section at Tora, southeast Wairarapa. The lower part of the section (Mangaorapan to Heretaungan) comprises grey, poorly bedded mudstone and sandy mudstone of the Pukemuri Siltstone, which is unconformably overlain by Bortonian to Kaiatan, poorly bedded, highly calcareous, green–grey mudstone of the Wanstead Formation.

Age control is based on the 2012 International Geological Timescale (GTS 2012; Gradstein et al., 2012). The ages assigned to New Zealand stage boundaries are based on Raine et al. (2015 – NZGTS2015). Foraminiferal, calcareous nannofossil and radiolarian datums were used to construct age–depth plots for all six sections in this study (Fig. 2; Supplementary Files 1 and 2). The linear sediment accumulation rates derived from these plots have been used to assign ages to our samples, which allows us to compare temporal trends between all six localities. The age–depth plots for DSDP Site 277 and the mid-Waipara and Hampden sections (Hollis et al., 2012, 2015) have been recalibrated to GTS 2012 and NZGTS2015 (Raine et al., 2015).

3. Analytical techniques

3.1. Sample preparation

This study is based on 3251 new analyses of foraminiferal tests in 78 sediment samples collected from five sections, from the southern Hawke's Bay to Campbell Plateau. Sea surface temperature (SST) records of this study from the East Coast and Canterbury Basins were based on the Mg/Ca ratios of *Morozovella crater*, *M. lensiformis*, *Acarinina primitiva* and *A. collactea*, which inhabited a surface mixed-layer habitat (upper 200 m; Pearson et al., 2006). Samples from DSDP Site 277 are predominantly late Paleocene to Earliest Eocene in age and, as such, the species *Morozovella aquea*, *M. subbotinae*, *Acarinina soldadoensis* and *A. coalingensis* were analysed. The planktic genus *Subbotina* was used as an indicator of thermocline temperatures (~400 m; Pearson et al., 2006), but was not subdivided beyond genus level. The benthic species *Cibicides eocaenus* and *C. truncatus* were used to provide seafloor floor temperatures (SFT), which is thought to represent intermediate water in the lower bathyal setting of the East Coast Basin. Foraminifera were picked from the 150–300 μm fraction and individually washed in

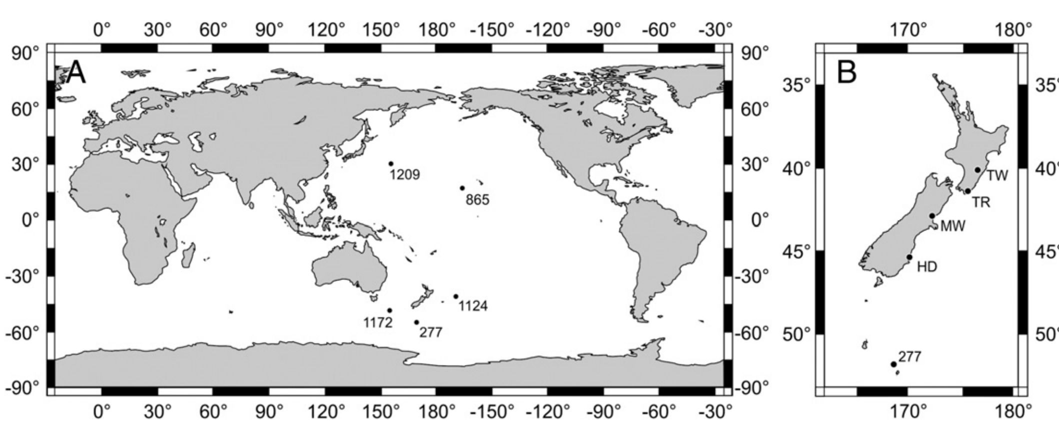

Fig. 1. Location of stratigraphic sections used in this study. A) Map showing the present-day position of ODP Sites 865, 1124, 1172, 1209 and DSDP Site 277. B) Map of New Zealand showing the localities sampled in this study. TW = Tawanui and Aropito; TR = Tora; HD = Hampden Beach; 277 = DSDP Site 277. The location of mid-Waipara River (MW) is also shown.

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