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A magneto- and chemostratigraphically calibrated dinoflagellate cyst zonation of the early Palaeogene South Pacific Ocean

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ABSTRACT

Investigation of the early Palaeogene palaeoecological and palaeoclimatological evolution of the Polar Regions is hindered by the absence of calcite microfossils in sedimentary archives, which are conventionally the main dating tool. To overcome this problem, we have generated large datasets of organic dinoflagellate cyst (dinocyst) assemblages from Southern Ocean shelf sediments over the past decade, and we here calibrate these to the Geomagnetic Polarity Time Scale (GPTS) using magnetostratigraphy and stable isotope stratigraphy. This now for the first time allows a high-resolution Southern Pacific Ocean dinocyst zonation for the late Palaeocene to late Eocene (58–36 million years ago; Ma). We compile published dinocyst chronologies from Ocean Drilling Program (ODP) Hole 1171D on the South Tasman Rise, Hole 1172A/D on the East Tasman Plateau and Integrated Ocean Drilling Program (IODP) Hole U1356A on the Wilkes Land margin. Correlation to dinocyst zonations from New Zealand lead to revisions of the magnetostratigraphic age model at Holes 1171D and 1172A/D. Stable carbon and oxygen isotope records reveal the stratigraphic location of the Palaeocene–Eocene Thermal Maximum (~56 Ma) and the Middle Eocene Climatic Optimum (~40 Ma), respectively. The resulting zonation consists of thirteen dinocyst zones, calibrated to the Geomagnetic Polarity Time Scale (GPTS) of Vandenberghe et al. (2012), which can likely be applied to the entire Southern Ocean. Finally, we apply the revised stratigraphy to all published TEX$_{86}$ data, a biomarker-based proxy for sea surface temperature (SST), from ODP Site 1172 to assess long-term climate evolution. This shows that Southwest Pacific SST trends mimic the global compilation of benthic foraminiferal oxygen isotopes even better than previously appreciated.

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1. Introduction

Throughout the past decades, interest has risen for high-latitude sediments from the early Palaeogene 'greenhouse' period (~65 to 35 Ma), particularly for palaeoclimate reconstructions (Wrenn and Beckman, 1982; Wrenn and Hart, 1988; Hannah, 1997; O'Brien et al., 1998, 2004; Brinkhuis et al., 2006; Moran et al., 2006; Sluijs et al., 2006, 2009a; Ivany et al., 2008; Bijl et al., 2009; Hollis et al., 2009, 2012; Pross et al., 2012; Houben et al., 2013). This is because atmospheric CO_2 levels during the early Palaeogene were likely analogous to those projected for the coming centuries should fossil fuel emissions continue unabated (Zachos et al., 2008), allowing documentation of the polar climatic end member in a greenhouse world.

A traditional problem in high latitude palaeoceanography is the precise dating of the sedimentary archives. Calcite fossil groups, such as foraminifera and calcareous nannoplankton, which are well calibrated to geomagnetic polarity time scales, are typically poorly or not preserved in high-latitude settings (Wilson et al., 1998; Florindo et al., 2003; Barker et al., 2007). In addition, siliceous microfossils such as diatoms and radiolaria dissolve when buried below a sub-surface diagenetic front (e.g., Rice et al., 1995). The only consistently available microfossils in high-latitude early Palaeogene sediments are organic dinoflagellate cysts (dinocysts), which are often abundant and well preserved in marginal marine sediments (Wrenn and Hart, 1988; Brinkhuis et al., 2003a,b). However, this group still lacks a well-calibrated biostratigraphic framework in both the Arctic and Antarctic regions. As a consequence, while several authors reported fossil and geochemical results that implied remarkable insight into the general warmth of the Polar Regions (e.g., Barron, 1987; Francis, 1988; Ehrmann, 1998; Ivany et al., 2008), detailed correlations to mid- and low latitude sites remained difficult.

The Southern Ocean is of particular interest to the palaeoclimate community, notably because the South Pacific Ocean was the region of intermediate-water formation during the early Palaeogene (Thomas et al., 2003; Huber and Caballero, 2011; Sijp et al., 2011). Through intermediate-water formation, the Southern Ocean has an important role in ocean circulation and global climate: palaeoclimatic changes in the Southern Ocean surface waters are effectively transported to other regions through deep convection. The oceanic surface circulation changed during the Eocene due to the tectonic evolution in the Southern Ocean, such as the opening of tectonic 'gateways' (Tasmanian Gateway, Drake Passage). This may have had a pivotal role in explaining the climatic evolution as interpreted from benthic foraminiferal oxygen isotopes, which reflect intermediate water temperatures and global ice volume. While the tectonic deepening of the Tasmanian Gateway in the late Eocene is well-documented through the study of sediment records from around Tasmania (Stickley et al., 2004a), the earlier history of opening has until recently been less well-constrained with sedimentary archives. Over the past 15 years, ocean drilling activities in the Southern Ocean have not only brought a wealth of palaeoclimate information, but also the potential of much improved age assessments through the integrated bio-magneto-chemostratigraphical approach. The Ocean Drilling Program (ODP) recovered early Palaeogene sedimentary successions around Tasmania during Leg 189 in 2000, e.g., at Sites 1171 and 1172 (Fig. 1; Exon et al., 2001). An initial bio-magnetostratigraphic age model (including dinocysts) was published based on shipboard and initial shore-based analyses (Stickley et al., 2004b; Williams et al., 2004). Extensive research at Site 1172 over the past years lead to the identification of transient climate–carbon cycle perturbations such as the Palaeocene–Eocene Thermal Maximum (PETM; Sluijs et al., 2011) and the Middle Eocene Climatic Optimum (MECO; Bijl et al., 2010). These represent chrono-stratigraphic tie points, and allow for a significant improvement of the age model. In addition, the sedimentary succession at Site U1356 recovered in 2010 by the Integrated Ocean Drilling Program (IODP) offshore the Wilkes Land Margin, Antarctica (Fig. 1) provides additional age constraints for early–middle Eocene dinocyst stratigraphy through integration with magnetostratigraphy (Tauxe et al., 2012).

We here compile all existing dinocyst and magnetostratigraphic data at Holes 1171D, 1172A/D and U1356A, and subsequently compare these to dinocyst zonations from New Zealand (Wilson, 1988; Crouch, 2001; Crouch and Brinkhuis, 2005). Based on these correlations, we present a revised bio-magneto-chemostratigraphic age model for Holes 1171D and 1172A/D that allows for a South Pacific dinocyst zonation scheme. The dinocyst zonation proposed here allows high-resolution calibration of Southern Ocean sedimentary archives that are sampled previously and will be drilled in the future. To present the state-of-the-art palaeoclimatological evolution of the Southwest Pacific Ocean, we apply our proposed dinocyst zonation to a compilation of published records of a biomarker-based proxy for sea surface temperature (SST), TEX_{86}, which portrays the palaeoclimatic evolution of the Southwest Pacific Ocean.

2. Plate tectonics, oceanography and biogeography of the Southwest Pacific Ocean

2.1. Tectonic evolution of the South Pacific and South Indian Ocean

The breakup of supercontinent Gondwana around the Jurassic–Cretaceous boundary times (~145 Ma; Willcox and Stagg, 1990) resulted in rifting between Australia and Antarctica. Continental crustal stretching and thinning occurred pulse-wise, and formed the Australo-Antarctic Gulf. Continued rifting eventually resulted in the formation of oceanic crust in the Australo-Antarctic Gulf by the late Cretaceous (~83 Ma; Close et al., 2009). Sea floor spreading rates were slow initially (1.5–7.5 mm/year; Close et al., 2009), and Antarctica and Australia remained attached at the Tasmanian side. During the late Cretaceous, Australian and South American terrestrial mammal assemblages exchanged, via a land connection over the Tasmanian land bridge (Woodburne and Case, 1996). Diversifying mammal assemblages on Australia from 64 Ma onwards signify the formation of a marine barrier, the Tasmanian Gateway. Crustal anomaly studies have shown a distinct increase in sea floor spreading rates in the Australo-Antarctic Gulf from 48 Ma onwards (Fig. 2b, c; Close et al., 2009). Some continental blocks surrounding the Tasmanian Gateway slowly deepened, such as the East Tasman Plateau (Röhl et al., 2004a) while others, such as the South Tasman Rise (Cande and Stock, 2004; Exon et al., 2004a) show more rapid subsidence. The subsidence of particularly the South Tasman Rise allowed for the westward flow of southwest Pacific surface waters through a shallow southern opening of the Tasmanian gateway into the Australo-Antarctic Gulf from 49–50 Ma onwards (Bijl et al., in press). Continued drowning (Röhl et al., 2004a) ultimately evolved in rapid deepening of continental blocks surrounding Tasmania starting at ~35.5 Ma (Stickley et al.,