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Research paper

A revised Paleocene (Teurian) dinoflagellate cyst zonation from eastern New Zealand

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ABSTRACT

Organic-walled dinoflagellate cyst (dinocyst) assemblages are documented from Paleocene (New Zealand Teurian Stage) sediments in five sections from eastern New Zealand: Tawanui, Angora Road and Toi Flat-1 core in the East Coast Basin, mid-Waipara River in the Canterbury Basin, and ODP Site 1121 on the eastern margin of Campbell Plateau. Based on dinocyst results from these sections, along with published earliest Paleocene records from the East Coast, Canterbury and Great South Basins, a revised Paleocene (Teurian) dinocyst zonation is proposed. The zones are labelled as NZDP — New Zealand Dinocyst Paleocene — and are all interval zones. The eight zones, NZDP1 to NZDP8, encompass the entire Paleocene, from the Cretaceous–Paleogene boundary at 66.04 Ma to the Paleocene–Eocene boundary at 55.96 Ma. Correlation of the NZDP zones with the International and New Zealand Time Scales is provided, and is primarily based on correlation with calcareous nannofossil biostratigraphy. Three new dinocyst species are described: *Leptodinium? pustulatum* sp. nov., *Cerodinium angulatum* sp. nov., and *Vozzhennikovia tawanuiensis* sp. nov.

1. Introduction

The Paleocene Epoch (66.04 to 55.96 Ma), or New Zealand Teurian Stage (Cooper, 2004), represents a globally significant transition in climate systems and carbon cycles from cooler climates of the Late Cretaceous into the greenhouse world of the Early Eocene (e.g., Zachos et al., 2001, 2008; Westerhold et al., 2011; Hollis et al., 2012). In the New Zealand region, the Paleocene was a time of tectonic quiescence with the New Zealand microcontinent isolated from Australia and Antarctica (Fig. 1), and extensive passive margin transgressive sediment deposition along the margins of the microcontinent (Ballance, 1993; King et al., 1999; Sutherland and King, 2008).

Although foraminifera and calcareous nannofossils are the primary microfossil groups that underpin the New Zealand Paleogene Time Scale (Jenkins, 1966; Edwards, 1971; Jenkins, 1971; Hornibrook et al., 1989; Morgans et al., 2004), calcareous microfossils have a patchy distribution in Paleocene sediments. This is due to sediments often having low levels of carbonate or being non-calcareous, poor preservation of calcareous microfossil assemblages, and a lack of low-latitude calcareous biostratigraphic marker taxa being recorded in New Zealand Paleocene sediments (Hornibrook and Harrington, 1957; Hornibrook and Edwards, 1971; Moore, 1989; Morgans et al., 2004). In contrast, diverse and well-preserved organic-walled dinoflagellate cyst (dinocyst) assemblages are found in almost all marine settings of Paleocene age, from nearshore to deep marine environments (Strong et al., 1995; Crouch and Brinkhuis, 2005; Willumsen and Vajda, 2010). Numerous dinocyst studies have been carried out in New Zealand, with long-established Jurassic to Eocene zonations (Wilson, 1984, 1987, 1988), and more recent refinements of Late Cretaceous and Eocene zones (Schiøler and Wilson, 1998; Roncaglia et al., 1999; Willumsen, 2003, 2011; Morgans et al., 2004; Clowes, 2009).

The New Zealand Teurian Stage is currently encompassed by three formal dinocyst interval zones (Fig. 2): the *Trithyrodinium evittii* Zone, *Palaeocystodinium golzowense* Zone, and the lowermost part of the *Apectodinium homomorphum* Zone (Wilson, 1984, 1987, 1988; Cooper, 2004). There is scope, however, to establish a more detailed Paleocene dinocyst zonation (Wilson, 1988; Beggs et al., 1992; Willumsen, 2011), as already exist in other regions such as Australia (Partridge, 2001, 2004) and Northwest Europe (Heilmann-Clausen, 1985; Powell, 1988; Mudge and Bujak, 1996). With an increasing focus on the paleoclimatic importance of the Paleocene Epoch (e.g., Petrizzo, 2005; Bernaola et al., 2007; Hollis et al., 2012) and petroleum potential of Paleocene sediments in New Zealand (e.g., Moore et al., 1987; Killops et al., 2000; Schiøler and Roncaglia, 2007; Schiøler et al., 2010), it is timely to review Teurian dinocyst assemblages with the aim of establishing a high-resolution zonation.

In this paper, we examine dinocyst assemblages from Paleocene sections in eastern New Zealand, establish a revised Paleocene dinocyst

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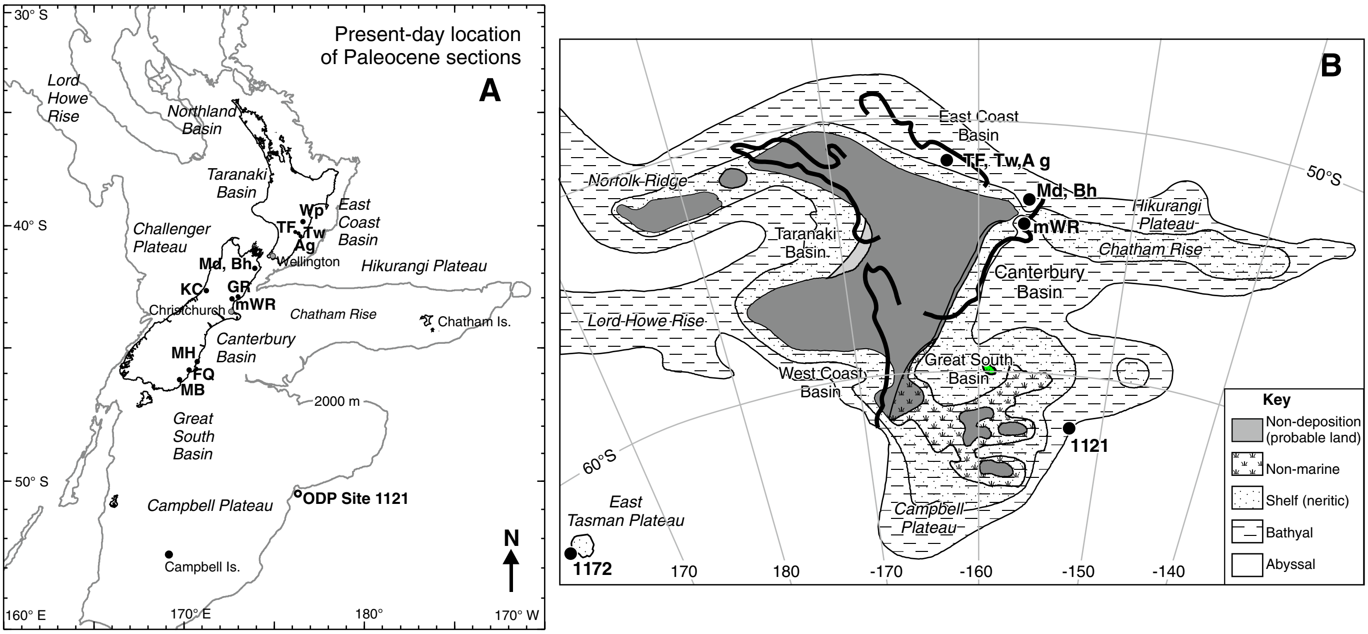

Fig. 1. Location of New Zealand sections, ODP Site 1121 and other localities mentioned in the text, along with sedimentary basins around New Zealand (A), and (B) paleogeographic reconstruction of the New Zealand region ~60 Ma. Tw = Tawanui, TF = Toi Flat-1 core, Ag = Angora Road, Wp = Waipawa, Md = Mead Stream, Bh = Branch Stream, mWR = mid-Waipara River, GR = Grey River, KC = Kumara-2 core, MH = Moeraki–Hampden, MB = Measly Beach core, FQ = Fairfield Quarry.
After King et al. (1999) and modified from Hollis et al. (2009).

zonation, and correlate this scheme to calcareous nannofossil zones and the International Geological Time Scale of Gradstein et al. (2012). We adopt the formal subdivisions of the Paleocene Epoch/Series established by Schmitz et al. (2011) and Gradstein et al. (2012): Early/Lower (Danian), Middle (Selandian), and Late/Upper (Thanetian).

2. Previous dinocyst work

Initial studies of dinocysts in New Zealand were completed by G.J. Wilson, who has published numerous studies incorporating biostratigraphy and taxonomy from Jurassic to Eocene sections (Wilson, 1967, 1978, 1982, 1984, 1987, 1988; Strong et al., 1995; Wilson and McMillan, 1996; Schiøler and Wilson, 1998). Wilson (1984) established a New Zealand Late Jurassic to Eocene dinocyst zonation, and provided an amended Paleocene to Middle Eocene zonation based on records from the Waipawa section, southern Hawkes Bay (Wilson, 1988) and mid-Waipara River section, North Canterbury (Wilson, 1987; Fig. 1).

High-resolution documentation of dinocyst assemblages across the Cretaceous–Paleogene (K–Pg) boundary (66.04 Ma) and Paleocene–Eocene (P–E) boundary (55.96 Ma) has recently been carried out on sections from eastern New Zealand. A detailed sequence of dinocyst bioevents and acme intervals across the K–Pg boundary (Willumsen, 2000, 2003, 2004, 2011) are recognised from Mead and Branch Streams, Clarence Valley, East Coast Basin (Fig. 1), and discussed in relation to the existing Paleocene dinocyst zonation (Wilson, 1988) and integrated with foraminiferal datums and the South Pacific radiolarian zonation (Hollis, 1993, 2002). In addition, dinocyst records from the K–Pg boundary are detailed from mid-Waipara and Grey Rivers, Canterbury Basin, and Fairfield Quarry, Great South Basin (Fig. 1; Willumsen, 2003, 2006; Willumsen and Vajda, 2010; Ferrow et al., 2011; Willumsen, 2012).

Dinocyst zones have been established for the earliest Eocene (Crouch, 2001; Morgans et al., 2004), based mainly on the Tawanui section, East Coast Basin (Fig. 1). The P–E boundary, or Paleocene–Eocene Thermal Maximum (PETM), is marked by the onset of a globally recognised negative carbon isotope excursion (CIE) and benthic foraminiferal extinction event (e.g., Zachos et al., 2001; McInerney and Wing, 2011). In New Zealand sections, the onset of the PETM is also coincident with the beginning of the lowest common occurrence (>~40%) of the *Apectodinium* genus (Crouch et al., 2001). This *Apectodinium* acme has been recorded within the PETM worldwide (Bujak and Brinkhuis, 1998; Sluijs et al., 2007, 2008, 2011; Bijl et al., 2013).

3. Stratigraphy

The Paleocene sections examined in this study are located in the East Coast and Canterbury sedimentary basins, and on the eastern flank of Campbell Plateau (Fig. 1). Paleocene sediments in eastern New Zealand are part of an overall fining-upward transgressive sequence that began in the latest Cretaceous and continued through to the Eocene (Ballance, 1993; King et al., 1999).

In the East Coast Basin, samples were collected from the Tawanui and Angora Road sections and Toi Flat-1 core, southern Hawkes Bay (Fig. 1). Early and Middle Paleocene sediments of the East Coast Basin are dominated by fine-grained, non-calcareous to calcareous siliceous mudstone of the Whangai Formation (Moore, 1988). This formation is typically overlain by the Waipawa Formation, a distinctive dark mudstone found throughout the East Coast Basin and other New Zealand sedimentary basins (Moore, 1989; Killops et al., 2000; Schiøler et al., 2010). The Waipawa Formation is a poorly-bedded, bioturbated, dark mudstone (Moore, 1989), with distinctive geochemical markers such as high total organic carbon (TOC), isotopically heavy $\delta^{13}C_{TOC}$ and abundant 24-*n*-propylcholestanes (Killops et al., 2000), that is dated late Middle to early Late Paleocene (calcareous nannofossil Zone NP6 to lower NP7) (Hollis et al., 2012). To the south, in Canterbury and Great South Basins, the coeval facies-equivalent to the Waipawa Formation is the Tartan Formation (Cook et al., 1999; Schiøler and Roncaglia, 2007; Schiøler et al., 2010). Above the Waipawa Formation in the East Coast Basin, sediments comprise poorly-bedded, calcareous, smectite-rich mudstone of the Wanstead Formation (Moore and Morgans, 1987). In some East Coast sections, the base of the Paleocene coincides with the base of a distinctive Whangai Formation member, the glauconitic Te Uri Member. At Tawanui, the upper part of the Te Uri Member is correlated with the Waipawa Formation, which is in turn overlain