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Carbon isotope stratigraphy and depositional oxia through Cenomanian/Turonian boundary sequences (Upper Cretaceous) in New Zealand

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ABSTRACT

Stratigraphic sections across the Cenomanian/Turonian boundary (C/T boundary) are identified in New Zealand and were deposited in southern high latitudes of the palaeo-Pacific. Lithological evidence for Cretaceous Oceanic Anoxic Event 2 (OAE2), which preceded and spanned the C/T boundary, is lacking in these sections. The correlative interval is identified, however, from a positive 2‰ carbon isotope excursion (CIE) and from clustered highest occurrences of Cenomanian-restricted dinoflagellate taxa together with the lowest occurrence of Turonian *Heterosphaeridium difficile*. A zone lacking benthic macrofossils encompasses the CIE. In some sections, this interval is also characterized by distinctive red mudstone beds; the thickest such red bed (6–18 m thick) may overlap or just overlie the main part of the CIE interval. Shelly macrobenthos, notably inoceramid bivalves, disappeared >500 kyr prior to the CIE. This suggests that environmental deterioration associated with OAE2 may have preceded the inferred volcanic trigger that has been identified from other regions. Strong intermediate water depth oxia during OAE2, which contrasts with oceanic anoxic conditions that occurred elsewhere on the globe, apparently prevailed during the later phase of OAE2 in the southernmost Pacific. New data from New Zealand indicate that causal mechanism(s) of OAE2 may be complex.

1. Introduction

Cretaceous oceanic anoxic events (OAEs) are well-known geological events that resulted in widespread deposition of organic-rich marine sediments (Schlanger and Jenkyns, 1976), most typically in pelagic carbonate sequences (e.g., Arthur and Premoli Silva, 1982; Arthur et al., 1987; Schlanger et al., 1987). OAE2 at the end of the Cenomanian (93.6 Ma; Ogg et al., 2008; 93.9 Ma; Meyers et al., 2012) is one of the most intensively studied such intervals because of its association with a large perturbation of the carbon cycle (Arthur et al., 1988) and its proximity in time to the Cretaceous thermal maximum (e.g., Clarke and Jenkyns, 1999; Poulsen et al., 2003). It has, in addition, been considered to mark a second-tier global extinction event (e.g., Sepkoski and Raup, 1986; Barnes et al., 1995; Harries and Little, 1999; but cf. Smith et al., 2001). Spatial and temporal patterns of palaeoceanographic change across the OAE2 horizon, based on microfossil palaeontology (e.g., Parente et al., 2008; Pearce et al., 2009; Linnert et al., 2010), stable isotopes (e.g., Ohkouchi et al., 1999; Jenkyns et al., 2007; Forster et al., 2008) and other geochemical proxies (e.g., Kolonic et al., 2005; Forster et al., 2007; Mort et al., 2007; van Bentum et al., 2009; Jarvis et al., 2011) have revealed photic zone euxinia and transient mid-term cooling ("Plenus Cold Event") in the Tethyan and proto-North Atlantic regions during deposition of the sediments. Recently, metal concentration and osmium and lead isotope data have suggested that massive volcanic eruptions associated with large igneous province formation (Snow et al., 2005; Kuroda et al., 2007; Turgeon and Creaser, 2008) may have triggered the climatic and oceanographic changes that occurred during OAE2 (Barclay et al., 2010).

Most studies to date have been based on pelagic strata from Tethyan or Atlantic regions. Even though the Pacific was the largest ocean on Earth during the Cretaceous Period, no continuous OAE2-correlative horizons have been studied except for a small number of clastic successions in Japan (Hasegawa, 1997; Nemoto and Hasegawa, 2011). Despite the obvious interest, no

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complete sections through OAE2 have been identified or described from the South Pacific region. In particular, although mid-Cretaceous clastic successions are known from New Zealand (e.g., Crampton et al., 2001), the Cenomanian/Turonian (C/T) boundary has never been located confidently or precisely. This reflects both the endemic nature of many New Zealand fossil species and the consequent difficulty of correlating New Zealand stages to the international time-scale (Cooper, 2004), and the lack of obvious sedimentary expression of OAE2 in any studied sections (e.g., Hikuroa et al., 2009). Here, we present new data on lithology, biostratigraphy and carbon isotope stratigraphy through four New Zealand on-shore sections that potentially include the C/T boundary, and we locate OAE2-correlative intervals in three of these sections.

Our goals are three-fold. First and foremost, the results presented here are important for inter-regional correlation and timescale development. Secondly, we hope to provide data that will begin to elucidate palaeoceanographic and palaeoclimatic responses in the southernmost Pacific to OAE2. During the mid-Cretaceous, New Zealand lay at a palaeolatitude of about 70°S (Sutherland, 1999) and our observations are consistent with the presence of oxygenated intermediate-depth water in southern high latitudes of the Pacific Ocean during the period of OAE2 (cf. Hay et al., 1999; Otto-Bliesner et al., 2002; Hay, 2009). Lastly, although Cretaceous black shales have not been identified in the New Zealand region, hydrocarbon generation modelling of the East Coast Basin of the North Island indicates that there could have been hydrocarbon generation from mid-Cretaceous source rocks (Field and Uruski, 1997). This inference is consistent with the presence of thermogenic gas seeps in localities where latest Cretaceous and younger source rocks are modelled as immature for gas generation (Field and Uruski, 1997), and with the presence of an oil seep on Raukumara Peninsula that may be derived from mid-Cretaceous rocks (Killops, 1996). The East Coast Basin appears to have a viable petroleum system and, although it is still regarded as a frontier region, most of the area is under licence to active hydrocarbon exploration companies. Our third aim, therefore, is to help constrain the likely position and expression, if any, of OAE2 in the New Zealand stratigraphic record.

All samples discussed here are housed at GNS Science, Lower Hutt, New Zealand; geochemical samples are assigned "P" (petrological) numbers within the relevant topographical map sheet and are catalogued within the PETLAB Database (http://pet.gns.cri.nz/index.jsp); palaeontological samples are assigned "f" (fossil) numbers and are catalogued by relevant topographical map sheet within the Fossil Record File Database (http://www.fred.org.nz/index.jsp). Outcrop photographs with sample localities marked (indexed using field sample numbers, see Tables 1 and 2) can be downloaded from the Fossil Record File.

2. Geology and setting

The C/T boundary is inferred to lie within the upper part of the Arowhanan Stage of the New Zealand geological timescale (Cooper, 2004; Hollis et al., 2010). Marine siliciclastic strata of Arowhanan age are distributed widely throughout the East Coast Basin (sensu Field and Uruski, 1997), from Marlborough (northeastern South Island) to the Raukumara Peninsula (eastern North Island; Fig. 1). In addition, they occur within structurally complex sequences in Northland (Isaac et al., 1994). All four sections studied here lie within the East Coast Basin; from north to south, they are the Mangaotane A and B, Glenburn and Sawpit Gully sections (comprising adjacent, partially overlapping northern and southern sections).

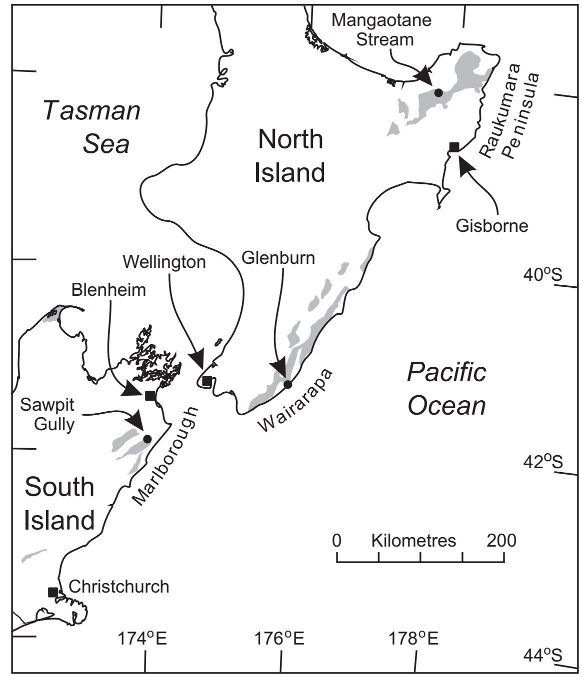

Fig. 1. Map of central New Zealand showing key localities discussed in the text. Grey shading indicates distribution of Albian–Maastrichtian rocks.

2.1. Mangaotane A section

Mangaotane Stream is a tributary of the Motu River, and it drains the southern part of the Raukumara Range, Raukumara Peninsula, approximately 60 km north-northwest of Gisborne (Fig. 1). The section exposed over several kilometres of this stream was identified by Wellman (1959) as the interval stratotype for the Arowhanan, Mangaotanean and Teratan New Zealand stages. Subsequently, revised lower boundary stratotypes of all three stages have been designated in the stream (Crampton et al., 2001; Cooper, 2004). Previous descriptions of the locality are listed in Crampton et al. (2001), and a general introduction to the geology of the Raukumara Peninsula is given in Mazengarb and Speden (2000).

The interval studied here extends over 255 m stratigraphically and is exposed continuously in both banks of Mangaotane Stream along an east-northeast-flowing leg at a prominent "Z-bend" (Fig. 2). The base of the section is at grid reference NZ Topo50 BE42 (Houpoto) 19306877 (±5 m); the top of the section is at BE42 19156864 [NZMS 260 map series, sheet X16 (Motu), 29273012 (±5 m) to X16 29122999]. An east-west-trending fault cuts across the stream and there is some uncertainty in correlation across this fault and the stream, although there does not appear to be very significant omission or repetition of section across this structure, based on both macro- and microfossil correlations. The section was sampled for the present study in April 2002, November 2005 and March 2009. The three sample suites were integrated in the field using comprehensive outcrop photographs taken during each of the earlier sampling campaigns. In a few cases, significant changes in the appearance of outcrops between 2002 and 2005 prevented precise correlation of sample sites (indicated on Fig. 3), although errors are likely to be small (<1 m).

The oldest strata in the section comprise overturned, indurated, centimetre- to decimetre-interbedded, mudstone and very fine sandstone of the Waitahaia Formation (Fig. 3); the proportion of sandstone decreases up-section from ~30% to <5%. Overlying this