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Terrestrial climate evolution in the Southwest Pacific over the past 30 million years

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ABSTRACT

A reconstruction of terrestrial temperature and precipitation for the New Zealand landmass over the past ∼30 million years is produced using pollen data from >2000 samples lodged in the New Zealand Fossil Record Electronic Database and modern climate data of nearest living relatives. The reconstruction reveals a warming trend through the late Oligocene to early Miocene, peak warmth in the middle Miocene, and stepwise cooling through the late Neogene. Whereas the regional signal in our reconstruction includes a ∼5–10° northward tectonic drift, as well as an increase in high altitude biomes due to late Neogene and Pliocene uplift of the Southern Alps, the pattern mimics inferred changes in global ice extent, which suggests that global drivers played a major role in shaping local vegetation. Importantly, seasonal temperature estimates indicate low seasonality during the middle Miocene, and that subsequent Neogene cooling was largely due to cooler winters. We suggest that this may reflect increased Subantarctic influence on New Zealand vegetation as the climate cooled.

1. Introduction

Near-drowning of New Zealand during the Oligocene (Landis et al., 2008; Strogen et al., 2014) was followed by a period of tectonic uplift that began approximately at 25 Ma with reactivation of movement along the Pacific–Australian plate boundary (Batt et al., 2004; King, 2000). The New Zealand landmass has since consisted of a series of evolving archipelagos located in the mid-latitudes of the south west Pacific (Lee et al., 2001; Mildenhall and Pocknall, 1984). Due to its relatively small land mass, New Zealand's terrestrial climate has been closely coupled to conditions in the surrounding oceans (Pole, 2003). During the Oligocene – early Miocene, 'New Zealand' was located north of the proto-Subtropical Front and was surrounded by subtropical water transported from low latitudes south down the east coast of Australia (Beu, 1990; Buening et al., 1998; Hornibrook, 1992; Nelson and Cooke, 2001). Pulses of warmer, subtropical water may have reached New Zealand at times during the middle Miocene (Hornibrook, 1992). Today the Subtropical Front surrounds New Zealand's South Island and currents from the Subantarctic transport cool water northward (Chiswell et al., 2015). Growth of more persistent terrestrial ice sheets in Antarctica during the latter part of the middle Miocene was accompanied by northward expansion of Subantarctic Surface water across the Campbell Plateau, which brought the Subtropical Front in close proximity to the New Zealand landmass (Field et al., 2009; Hayward et al., 2004; Nelson and Cooke, 2001); similar to the present day (Chiswell et al., 2015).

Our understanding of Oligocene – Quaternary New Zealand terrestrial climate is derived mainly from Miocene macroscopic plant fossils preserved in lacustrine and lignite deposits from the South Island provinces of Southland and Otago (e.g. Pole (2014), Pole et al. (2003), Pole and Moore (2011), Reichgelt et al. (2013, 2015)), and from Miocene – Pliocene pollen assemblages recovered from a range of depositional settings, e.g. Mildenhall (1980), Mildenhall and Pocknall (1984, 1989), Pocknall and Mildenhall (1984). Other, non-biological proxies for terrestrial climate, include mineral indicators and provenance data that record the effects of climatically-driven erosion from the Southern Alps during the late Miocene–present (Carter and Gammon, 2004; Heenan and McGlone, 2013).

In this study, we compiled fossil pollen and spore data from the New Zealand Fossil Record Electronic Database (FRED) to create an estimate of New Zealand terrestrial climate evolution over the last 30 million years, using recently compiled modern range

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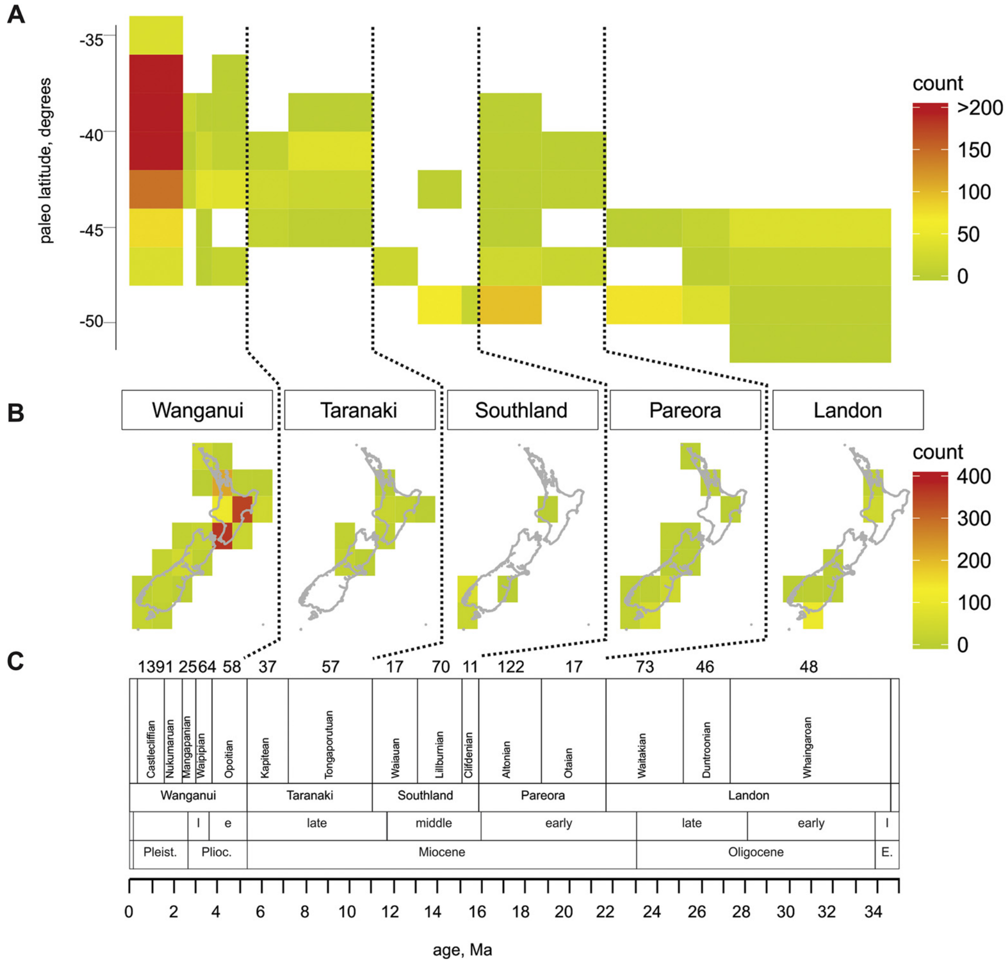

Fig. 1. Distribution of samples used in this study. **A.** Density plot showing paleo-latitude of samples, grouped by New Zealand stage. **B.** Density plot showing modern location of samples, grouped by New Zealand Series. **C.** Number of samples assigned to each single New Zealand stage. (For interpretation of the colours in this figure, the reader is referred to the web version of this article.)

data for 70 modern analogues to the fossil taxa. FRED (online at http://www.fred.org.nz/) is a public database that contains a range of information for fossil localities in New Zealand. FRED contains about 98000 locality records registered at regional recording centres since 1946, and includes palynomorph species lists from more than 5500 samples of Paleocene to Recent age.

Long-term paleoclimatic reconstructions are often dominated by ocean-based proxies, which is particularly true in the Southern Hemisphere given the paucity of terrestrial records. The approach presented in this paper provides unique insight into terrestrial climatic evolution in the southwest Pacific. It illustrates southern mid-latitude climate response to stepwise global cooling since the Miocene Climate transition, the expansion of the Antarctic cryosphere, and Southern Ocean change since the late Oligocene.

2. Methods

2.1. Data extraction from FRED

Samples with an age assignment to a single New Zealand Stage of Whaingaroan (early Oligocene) or younger, which also contained at least six of the 70 fossil pollen or spore taxa for which a modern affinity of genus level or finer has been suggested, were extracted from the FRED database. Samples from drill hole cuttings were excluded to avoid problems occasionally encountered with caving and reworking of microfossils in this type of sample. A synonymy list for each of the seventy taxa was compiled by reviewing and updating the synonymies from Raine et al. (2011), augmented by a review of the list of spore and pollen names that appear in FRED. The synonymy list used here is included in Supplementary Table ST1. Modern affinities are after Raine et al. (2011).

The search returned 2036 samples, with a mean of 10.7 modern analogue taxa per sample. The majority (1391) of these samples were of Nukumaruan or younger (Quaternary) age, with the remaining 645 samples distributed across the 13 New Zealand Stages of Oligocene–Pliocene age (Fig. 1). The smallest number of samples uniquely assigned to a single New Zealand stage was 11; which were from the Clifdenian Stage (middle Miocene, 15.9–15.1 Ma). Although any registered user is welcome to submit samples to the FRED database, 98% of the 2036 samples used in this study were analysed by researchers at GNS Science or its institutional predecessors and >75% (1564 samples) were examined by a single palynologist (D.C. Mildenhall).

In the FRED database, age is assigned to each sample by the scientist who submitted the record, and is usually by reference to a Stage, or range of Stages, of the New Zealand Geological Time Scale (Cooper, 2004; Raine et al., 2015). Multiple ages have been assigned to about 10% of the samples used in this study. Multiple ages can arise when overlapping or conflicting ages are assigned by workers on different fossil groups extracted from the same sample, when a reassessment of the age determination is made on a fossil assemblage in a previously submitted sample, or where new observations are made of a fossil group that had already been recorded from that sample. In this study, we took the most recent age determination that had been made for each fossil group. Where samples

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