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Plio-Pleistocene climate change and the onset of aridity in southeastern Australia

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ABSTRACT

Extreme global climate change in the Late Neogene is well known. In Australia, climate changed from wet conditions in the Late Neogene to the arid conditions that characterize much of the continent today. We constrain the nature and timing of the onset of aridity in southeastern Australia by detailed stratigraphic analysis of palaeo megalake Bungunnia. The demise of the megalake has previously been thought to herald the onset of arid climatic regimes and the sedimentary record of this event has become a proxy-type section for understanding Plio-Pleistocene climate in southern Australia. Our investigations of this sedimentary record reveal regionally extensive and correlatable aeolo-lacustrine quartz silts that represent a major and previously unrecognised step in the aridification of the continent, prior to the demise of the megalake. The age of the aeolo-lacustrine silts is constrained to be around 1.4 Ma to 1.5 Ma, just prior to the middle Pleistocene transition. The silts are preserved in a record of maximum lake fill and not long after their deposition the lake began to contract. Our data show that the youngest lake sediment, the Bungunnia Limestone, is diachronous and preserved on at least 5 distinct terraces, ranging over more than 20 m in elevation. The terraces are interpreted to represent downcutting events during arid conditions, while the sediments on each terrace represent deposition during wet periods. The mineralogy of the limestone preserved on these terraces changes from calcite, aragonite and dolomite dominated at higher elevations to gypsum and magnesite dominated on the lower terraces, providing a unique record of the increasing amplitude of arid climatic cycles. These observations suggest that the onset of aridity in southern Australia was progressive and step-wise, beginning significantly earlier than previously suggested.
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1. Introduction

In Australia, arid climatic regimes characterize much of the continent today and one-third of the landmass receives an annual rainfall of less than 250 mm. It is well known, however, that the currently arid areas of inland Australia were significantly wetter from the early Cainozoic until at least the early Miocene (e.g., Kershaw et al., 1994; Martin, 2006). Arid climatic and geomorphic features from the mid-late Quaternary to the present are also well documented (e.g., Nanson et al., 1992; Hesse et al., 2004). However, the interval of change from the Plio-Pleistocene to the Quaternary remains poorly understood and the timing and origins of the modern arid climatic regime remain unresolved. Globally, the Plio-Pleistocene is a time of great climatic change (e.g., Clark et al., 2006) and understanding this interval is the subject of intense research endeavour. A trend to increasingly arid climates in this period is reflected by the development of the Atacama Desert around 3 Ma (Hartley and Chong, 2002), major step-like increases in aridity in Africa around 2.8 Ma and 1.7 Ma (deMenocal, 2004) and the establishment of a permanent Northern Hemisphere ice sheet in the same period (e.g., Lear et al., 2000; Kulhmann et al., 2006). Globally, the impacts of these climatic shifts have been profound: there are numerous examples of changes in species development and/or distribution in this interval (e.g., Vizcaino et al., 2004; Edwards et al., 2007; Meloro et al., 2008; Palombo et al., 2009) and the step-wise aridification of Africa, for example, is thought to have played an important role in forcing the evolution of hominids (e.g., Stanley, 1992; Reed, 1997; Bobe and Behrensmeyer, 2004; Wynn, 2004). Notwithstanding the significance of climate change in this interval, the timing of onset of arid climatic regimes remains poorly constrained in many regions and the factors controlling the change in climatic dynamics are still debated (e.g., Cane and Molnar, 2001).

Much of our current knowledge of climatic change in the late Neogene is derived from variations in the isotopic signature of marine sediments (e.g., deMenocal, 1995; Lisiecki and Raymo, 2005; Raymo et al., 2006). However continental sediments, and particularly lake basins, can also provide sensitive archives of environmental and climatic change as well as evidence of the factors controlling these changes (e.g., Carroll and Bohacs, 1999). Here we review evidence for the onset of arid climatic conditions in southeastern Australia and use the stratigraphic record preserved in palaeo megalake Bungunnia to make inference on the nature and timing of Plio-Pleistocene climate cycles. Our new stratigraphic analysis of the basin reveals a sequence of lacustrine sediments that suggest the onset of aridity involved progressive step-wise climatic change beginning 1.5–1.4 Ma, just

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prior to the mid-Pleistocene transition. The time scale and magnetic field reversal data of Ogg and Smith (2004) are used throughout this paper.

2. Aridity in Australia

In Australia, a number of observations suggest that the continent was characterized by warm and wet climatic conditions throughout the Miocene, including: (1) the presence of extensive Miocene–Pliocene lateritic weathering surfaces (e.g., Firman, 1973; Alley, 1998; Webb and Golding, 1998); (2) the occurrence of tropical taxa in Miocene marine sediments (e.g., Li et al., 1996; Gallagher and Gourley, 2007) and (3) palynological evidence for extensive temperate rainforest in southeastern Australia (e.g., Macphail et al., 1994; Kershaw et al., 1994). The fully arid conditions of the Pleistocene are also well documented. For example, palynological data show evidence for extensive open woodland and grassland vegetation at this time (e.g., Kershaw et al., 1991; Wagstaff et al., 2001; Sniderman et al., 2007) while geomorphological and sedimentological observations suggest extensive desert dune systems throughout the Pleistocene (e.g., Herczeg and Chapman, 1991; Chen et al., 1991; Nanson et al., 1992; Hesse et al., 2004; Fitzsimmons et al., 2009). Based principally on the apparent timing of contraction of large lakes, as well as documented faunal changes, Bowler (1976), Martin (1978) and others have suggested that the first steps toward aridification began sometime in the late Miocene, and increased into the Plio-Pleistocene. Unfortunately, however, there are very few continuous sequences that provide a window into the key period between the late Miocene and the early Pleistocene and the timing and mechanism of climatic change in this interval remain poorly understood.

Our contemporary understanding of the trend to arid climatic regimes in Australia is based largely on the work of Bowler (1976) and Martin (1978) together with a large body of more recent work that builds upon and extends these earlier observations (e.g., Kershaw et al., 1991; Chen and Barton, 1991; Macphail, 1997; Dodson and Macphail; 2004; Fujioka et al., 2009). Particularly influential previous contributions on the topic are those of Bowler (1976) and Bowler (1982) that draw upon the stratigraphic record of Lake Bungunnia in southeastern Australia (Fig. 1) to understand this arid shift. Bowler's (1982) work suggests that the demise of Lake Bungunnia heralded the onset of fully arid climatic regimes in Australia. The paper by An et al. (1986) subsequently provided magnetostratigraphic data to suggest

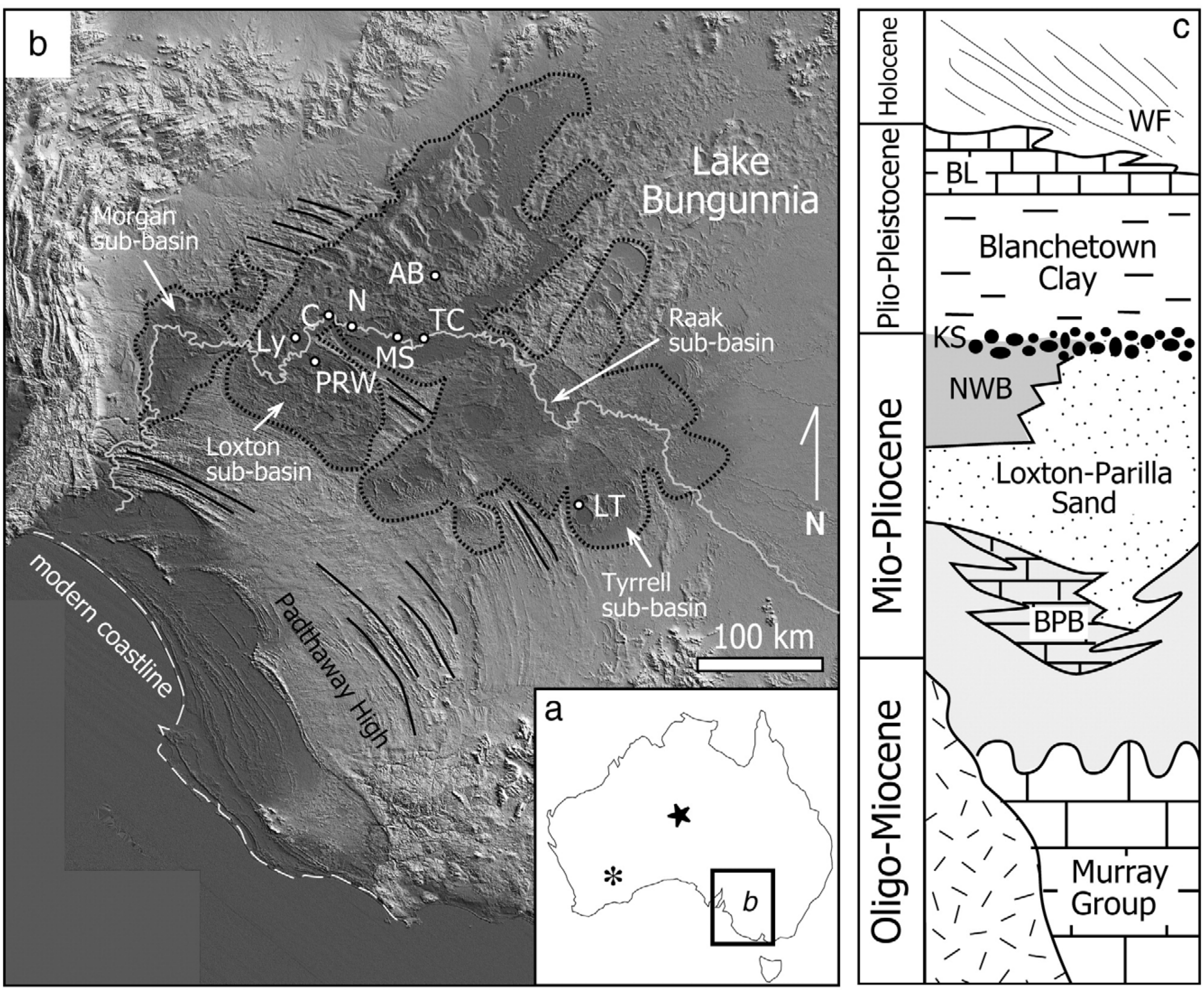

Fig. 1. (a) Location map showing the position of Lake Bungunnia in southeastern Australia; Asterisk shows the location of Lake Lefroy in Western Australia; Star shows the location of Lake Amadeus in central Australia (b) SRTM data showing the interpreted size of Lake Bungunnia, illustrated here at its maximum extent corresponding to *Lake level 1*; Outcrop localities are shown: Ly = Lyrup, PRW = Pike River West, AB = Anabranch, TC = Tincha Creek, C = Chowilla, LT = Lake Tyrrell, MS = Moorna Station, N = Nampoo Station. The Nampoo Station, Lake Victoria and Rufus River Sections are located within 20 km of one another. Principal lake sub-basins are also indicated. Heavy lines show the trend of strandlines of the Loxton–Parilla Sand; medium grey line indicates position of modern Murray River. (c) Schematic stratigraphic relationships of major units within the Murray Basin. WF = Woorinen Formation, BL = Bungunnia Limestone; KS = Karoonda Surface; NWB = Norwest Bend Formation; BPB = Bookpurnong Beds. Unlabelled grey shading is a period of non-deposition.

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