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Late Quaternary palaeoenvironmental change in the Australian drylands

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ABSTRACT

In this paper we synthesise existing palaeoenvironmental data from the arid and semi-arid interior of the Australian continent for the period 40–0 ka. Moisture is the predominant variable controlling environmental change in the arid zone. Landscapes in this region respond more noticeably to changes in precipitation than to temperature. Depending on their location, arid zone records broadly respond to tropical monsoon-influenced climate regimes, the temperate latitude westerly systems, or a combination of both.

The timing and extent of relatively arid and humid phases vary across the continent, in particular between the westerly wind-controlled temperate latitudes, and the interior and north which are influenced by tropically sourced precipitation. Relatively humid phases in the Murray-Darling Basin on the semi-arid margins, which were characterised by large rivers most likely fed by snow melt, prevailed from 40 ka to the Last Glacial Maximum (LGM), and from the deglacial to the mid Holocene. By contrast, the Lake Eyre basin in central Australia remained relatively dry throughout the last 40 ka, with lake high stands at Lake Frome around 35–30 ka, and parts of the deglacial period and the mid-Holocene. The LGM was characterised by widespread relative aridity and colder conditions, as evidenced by extensive desert dune activity and dust transport, lake level fall, and reduced but episodic fluvial activity. The climate of the deglacial period was spatially divergent. The southern part of the continent experienced a brief humid phase around ~17–15 ka, followed by increased dune activity around ~14–10 ka. This contrasts with the post-LGM persistence of arid conditions in the north, associated with a lapsed monsoon and reflected in lake level lows and reduced fluvial activity, followed by intensification of the monsoon and increasingly effective precipitation from ~14 ka. Palaeoenvironmental change during the Holocene was also spatially variable. The early to mid-Holocene was, however, generally characterised by moderately humid conditions, demonstrated by lake level rise, source-bordering dune activity, and speleothem growth, persisting at different times across the continent. Increasingly arid conditions developed into the late Holocene, particularly in the central arid zone.

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1. Introduction

Australia is the world's driest inhabited continent. Approximately half of the land mass is either arid or semi-arid. The area experiencing such climates fluctuated considerably due to varying global climate cycles during the Quaternary, but the extent and intensity of these fluctuations, while receiving increasing attention, remain poorly defined.

In recent years substantial developments have been made in our understanding of environmental change in the arid interior, namely through: 1) a larger chronological dataset focussing on luminescence dating; 2) further consideration of the interpretation of proxy records; and 3) more systematic integration of techniques for palaeoenvironmental reconstruction. In this review we incorporate new data and methods not previously available in earlier reviews, enabling a more robust correlation with regional and global palaeoclimatic records. Due to the poor preservation potential of organic material such as pollen and charcoal, in most cases palaeoenvironmental reconstruction for the Australian continental interior must rely on geomorphic archives such as dunes, playas and fluvial systems which, while discontinuous, broadly preserve responses to climatic change.

This paper presents a review of arid and semi-arid zone palaeoenvironmental records for the Australian continental interior over the past 40 ka. This period is characterised globally, including within Australia, by substantial climatic changes, including the stadial and interstadial oscillations of marine isotope stage (MIS) 3, the Last Glacial Maximum (LGM), and the deglacial transition to Holocene interglacial climates (Walker et al., 1999; Turney et al., 2006). Earlier reviews demonstrated that the Australian continental interior was subject to variation in both the intensity and spatial extent of arid conditions during this period (Bowler, 1976; Bowler and Wasson, 1984; Wasson and Donnelly, 1991; Nanson et al., 1992b; Hesse et al., 2004). More recently published data provide additional information relating to landscape response to precipitation variability and, to some extent, changes in wind regime and intensity. These data come in the form of reconstructions of desert dunefield reactivation, expansion and contraction, varying lake levels, river hydrology, and speleothem growth. This review interprets arid zone environmental change through the convergence of this new information with earlier data.

2. The Australian continental interior

The majority of inland Australia experiences an arid to semi-arid climate (Fig. 1A). Since the continental interior lacks substantial topographic barriers to climatic systems, the region is primarily subject to the influence of seasonal zonal circulation, with a major effect exerted by continental heating and land-sea temperature contrast (Gimeno et al., 2010). Broadly, southern Australia experiences winter dominance in rainfall associated with westerly cold fronts. It is also evident from the orientation of longitudinal dunes in the south that westerly winds have been responsible for desert dunefield formation (e.g. Wasson et al., 1988; Fitzsimmons, 2007). Northern Australia is influenced by the summer monsoon and southeasterly trade winds in the winter, the latter being particularly influential in the northeast. In summer, precipitation in the central and northern drylands may also be derived from inland-migrating troughs and depressions formed by heating over the oceans. The arid core of the continent, centred on the large playa Lake Eyre, receives on average 125–150 mm annually, with high interannual variability. This precipitation is not dominated by any one climatic system over another (Fig. 1A). Compared with many deserts, precipitation in the Australian deserts is relatively high. Consequently inland Australia is relatively well vegetated compared with other deserts (Hesse and Simpson, 2006; Hesse, 2010). No parts of dryland Australia are classified as hyperarid.

The continental interior contains extensive longitudinal (linear) dunefields (Fig. 1B), which form broadly parallel to the resulting sand-shifting wind vectors (McKee, 1979; Rubin and Ikeda, 1990; Reffet et al., 2010). These occupy approximately one third of the continent, and extend beyond the presently arid regions (Wasson et al., 1988; Hesse, 2010), providing evidence of more extensive aridity in the past (Bowler, 1976; Hesse, 2010). Despite minor modern mobilisation of dune crests, particularly in the drier centre of the continent, the dunes are presently relatively stable and immobile (Hesse and Simpson, 2006). Exceptions to dune stability can be found in areas which have been disturbed by clearing for agriculture and grazing, for example in the vicinity of watering holes on pastoral leases, and farmed areas in southeastern South Australia in contrast to the conservation reserves in comparable landscapes in Victoria. A state of intermittent partial dune activity prevails under the present climatic conditions. The longitudinal dunes are distributed in a counter-clockwise whorl focused on the centre of the continent at 26 °S (Fig. 1B) (Jennings, 1968; Brookfield, 1970; Hesse, 2010), proposed to have been produced by the interaction of the westerlies in the south and easterlies in the north (Hesse, 2011). Dune distribution is complicated at the regional scale by the interplay between climate, topography, lithology and sediment supply (Jennings, 1968; Hesse, 2010), and the varying dominance of these factors through time. Consequently there is still controversy over the relative importance of supply, availability and transport limitation in dunefield formation. Supply limitation has long been recognised as allowing the growth of so-called "source-bordering" dunes in riparian and shoreline settings (Butler et al., 1973; Cohen et al., 2010).

The interior of the continent also contains large catchments and ephemeral playa lakes. The eastern portion of the arid zone is dominated by two large catchments: the Lake Eyre basin (LEB) that drains internally to Lake Eyre and the Frome-Callabonna lake system, and the Murray-Darling basin (MDB) that drains to the Southern Ocean. Together they comprise approximately one third of the continent (Fig. 1A). Both catchments have at least part of their headwaters located within the summer-dominated rainfall zones to the north (the MDB less so), and terminate in the westerly-influenced region. In the LEB, Cooper Creek and the Diamantina River system flow southwestward through the Strzelecki and Tirari dunefields. The Riverine Plain of the MDB, formed by the Murray, Murrumbidgee and Lachlan Rivers, comprises permanent watercourses characterized by low energy flow (Kemp, 2004). The now abandoned Willandra Creek diverges from the Lachlan River into the presently dry Willandra Lakes system (Bowler and Magee, 1978; Bowler et al., 2003). Transverse source-bordering dunes, including lunettes and palaeoshorelines, occur in association with playas and palaeochannels in both catchments.

3. Methods for palaeoenvironmental reconstruction in arid Australia

3.1. Geomorphology, sedimentology and stratigraphy

The landforms of the inland deserts are a product of increasing aridification which began prior to the onset of the Quaternary (Bowler, 1982). This trend initiated with the playa lakes (English et al., 2001) and stony desert pavements (Fujioka et al., 2005), and was followed by the development, and subsequent expansion and contraction, of desert dunefields (Fujioka et al., 2009). Successive arid and relatively humid phases are reflected in the response of these landforms (Bowler, 1976; Fujioka and Chappell, 2010). Enhanced aridity may correspond to landscape instability,