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# Dry lake beds as sources of dust in Australia during the Late Quaternary: A volumetric approach based on lake bed and deflated dune volumes

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ABSTRACT

Dust affects Earth's climate, ecology and economies across a broad range of scales, both temporally and spatially, and is an integral part of the earth's climate system. Previous studies have highlighted the importance of inland lake beds to dust emissions both locally and globally. This study aims to explore the relative volumetric importance of ephemeral lakes that emit dust to the Australian southeastern dust path over the last glacial cycle. SRTM DEMs and GIS analyses of long-term (up to 80 ka) lake-bed deflation volumes and deposition of sand-sized sediment onto downwind source bordering dunes were used to derive estimates of transported dust mass. A strong power relationship was found between lake area and the mass of deflated lake bed sediments. Total dust masses for the largest 53 lakes in southeastern Australia were derived using the relationship between lake area and dust mass and used to determine an upper value for total dust mass deflated from lake beds in southeastern Australia. Ephemeral lake-derived dust was found to represent at most 13% of the dust derived from southeastern Australia deposited in the southern Pacific over the last 80 ka or 22% over the last 40 ka. Lake Eyre (the largest lake) has contributed at most 3% of the Australian southeast dust plume. These results imply that there are significant additional sources of dust in Australia over these timescales, such as floodplains or dunefields, and that modelling must allow for diverse climatic and geomorphic controls on dust production.



## 1. Introduction

Dust affects Earth's climate, ecology and economies across a broad range of scales, both temporally and spatially. Mineral dust leads to complex feedbacks within the atmosphere resulting in a net cooling effect over the oceans, a net warming effect over ice and a much more complicated feedback over terrestrial environments where the albedo of the surface varies significantly (Durant et al., 2009; Schmittner et al., 2012; Claquin et al., 2003). Dust also alters nutrient cycles through the removal of nutrients from source regions and deposition in dust sinks (McTainsh and Strong, 2007; Hesse et al., 2003; Zobeck and Fryrear, 1986; Griffin et al., 2001). Dust also affects the hydrological cycle, dependent upon several factors, including the relative humidity, size of dust particles, density and extent of the dust plume and type of weather system (Rosenfeld et al., 2001).

At a global scale there is still uncertainty about the absolute and relative contribution of dust from different source areas and landforms (Bullard et al., 2011; Prospero et al., 2002; Ginoux et al., 2012; Crouvi et al., 2010). Ephemeral lake beds have been observed to contribute to large dust clouds in most continents and have been proposed as one of the major source landforms of dust over late Quaternary time-scales (Zender et al., 2003; Bullard et al., 2011; Prospero et al., 2002; Ginoux et al., 2012).

Beyond the short (approximately 35 years) satellite observation record of dust in the atmosphere (Prospero et al., 2002; Ginoux et al., 2012), the role of lake beds as dust source areas is not clear as these systems are also subject to processes which operate on a much longer temporal scale. Conflicting processes, such as the

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effects of variable hydrological conditions, the formation of biological and physical crusts, and the cracking of this crust during extended dry periods, makes the activity of these systems highly variable (Reynolds et al., 2007; Leys and Eldridge, 1998; Valentin and Bresson, 1992; Strong, 2002). Crust formation can result in an armouring of lakebeds and a decrease in dust emissions while crust decay can produce an increase in dust emissions (Buck et al., 2011; Reynolds et al., 2007). Variability in seasonal vegetation growth and dieback on ephemeral lakebeds and their margins alters the protection of surface sediment from the wind (Lu and Shao, 2001; Okin et al., 2006; Ravi et al., 2007). As a result, prediction and the quantification of dust transport is difficult and therefore the long-term contribution of dry and ephemeral lake beds to the global dust budget is uncertain.

Australia is the largest source of dust to the atmosphere, oceans and ice sheets of the Southern Hemisphere during interglacials (Revel-Rolland et al., 2006) and a major contributor during glacial intervals of the late Quaternary (Hesse, 1994; Lamy et al., 2014). Ephemeral lakes are widespread in inland and southern Australia (Bowler, 1983; Revel-Rolland et al., 2006). Lake beds are also known to have been the source of recent large dust events and to be one of the most important recent dust source types, along with alluvial plains and rangelands (Bullard et al., 2008, 2011; Ginoux et al., 2012).

Over time-scales of millennia to millions of years deflation is thought to have led to the excavation of many ephemeral lake beds in arid and semi-arid areas (e.g. Bowler, 1983; Gilbert, 1895; Lancaster, 1978). Features associated with excavation by deflation are shoreline lunette dunes, source-bordering sand dunes and loess or dust mantles (Bowler, 1986; Miller et al., 2010), and these have been observed in drylands of Australia (Zheng et al., 1998), Southern Africa (Holmes et al., 2008), the Southern High Plains of the United States (Rich, 2013) and elsewhere. These geomorphic features form the basis of our examination of the dust emission from ephemeral lakes over the late Pleistocene.

The focus of this study was on inland ephemeral dry lake systems in the southeastern quadrant of Australia. This study aimed to explore Australian ephemeral lake systems which have provided dust to the south-eastern Australian dust path first hypothesised by Bowler (1976). Lack of suitable data prevented the examination of the secondary northwestern dust path, with the exception of Lake Eyre which contributes to both dust paths (McGowan and Clarke, 2008; Strong et al., 2011).

Four lake systems from arid central Australia to the southeastern margin of the semi-arid zone were chosen for investigation: Lake Eyre, the Willandra Lakes, Lake Tyrrell and Lake Urana (Fig. 1). Each of these lakes has features consistent with deflation by wind, have some existing chronological and stratigraphical information and are likely to have been contributing to the dust blown into the south-eastern dust path and deposited over the continent (Hesse and McTainsh, 2003; Hesse et al., 2004), the southwest Pacific Ocean (Kawahata, 2002; Hesse, 1994; Lamy et al., 2014) and Antarctica (Li et al., 2008; Revel-Rolland et al., 2006). Lakebeds within the Lake Eyre Basin are amongst the largest lakes within southeastern Australia and are currently the most active areas of dust entrainment (Ginoux et al., 2012).

Our initial working hypothesis was that each lake bed was formed primarily by deflation, with minimal external sediment inputs or external drainage, and that the deflated lake bed volume is accounted for by the volume of proximal dunes plus the volume of sediment lost in long-distance suspended dust. We initially derived lake volumes and dune volumes to inversely derive the amount of deflated dust from each lake. These volumes were then used to derive a general relationship between lake size and amount of dust and applied to the largest lakes within the southeastern portion of Australia. The results were compared against the marine sediment record to determine the relative contribution of lake to the total dust budget from the Australian continent during the late Quaternary.

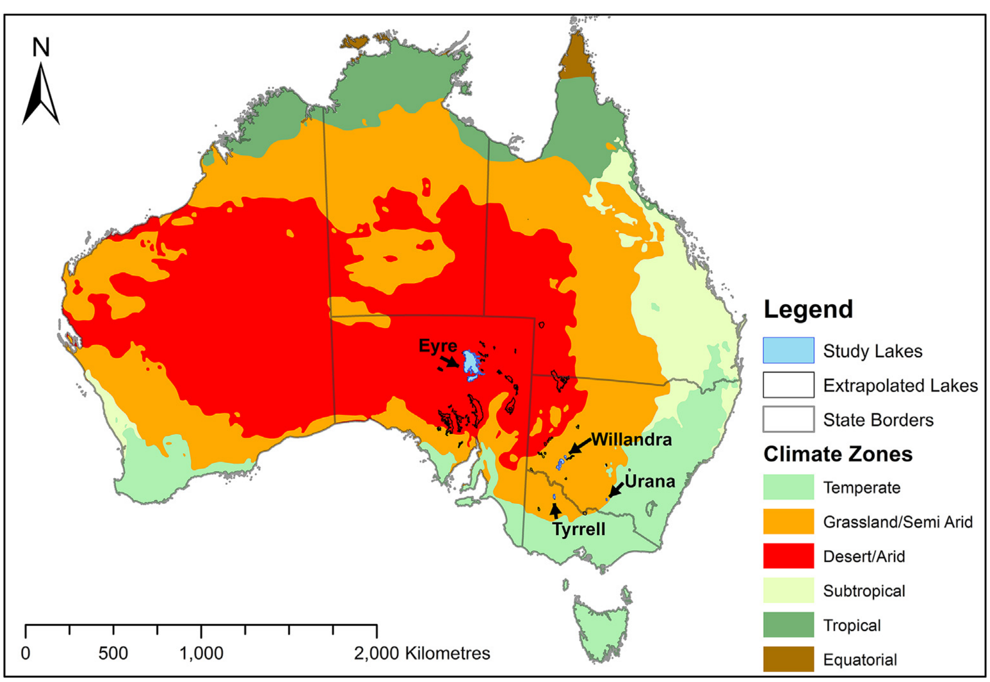


**Fig. 1.** Map showing Australian climate zones and the location of the studied lake basins and the additional largest 49 lakes for which deflated dust volumes were extrapolated from the derived relationship between lake area and lake volume.