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A late Quaternary record of monsoon variability in the northwest Kimberley, Australia

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ABSTRACT

Understanding of the late Quaternary environment of Australia's vast Kimberley region has to date been hindered by the region's lack of classic palaeoenvironmental archives such as deep lake sediments. However, mound spring peat deposits in the region have been found to be a potentially rich archive of palaeoenvironmental data. Here we present a high resolution record from Black Springs mound spring in the Kimberley's northwest, filling some of the current gaps in knowledge of the region's environmental history. This builds on a ~6000 year record developed from the same site and indicates that since the Last Glacial-Interglacial Transition the Australian summer monsoon has varied greatly in intensity, with an increase in monsoonal precipitation from ~14,000 yr BP and pronounced drying in the late Holocene. Despite some chronological uncertainties thought to be due to the inclusion of younger, microscopic root fragments, changes in the record compare well with other records of climatic change from the Kimberley, and across tropical northern Australia.

1. Introduction

The climate of Australia's vast Kimberley region is dominated by the Australian summer monsoon, which forms part of a wider climate system, including the Indo-Pacific Warm Pool (IPWP) which plays a major role as a global heat source driving planetary scale circulation (Keenan et al., 1989, 2000). Despite a mean annual rainfall of ~1000 mm/yr, high seasonality (>70% of rainfall occurs between January and March) combined with mean annual potential evapotranspiration of ~1900 mm/yr has created a water-limited environment (Bureau of Meterology (2016)). Consequently, there are few sites that preserve high resolution, unaltered records of palaeoenvironmental change. Many of the lakes and wetlands in the region are seasonally ephemeral, implying that their records may be compromised by desiccation (e.g. leading to aeolian deflation) during the dry season, and by scouring from heavy monsoonal rains and flooding in the wet season (Head and Fullager, 1992). The majority of the high resolution palaeoclimate records that do exist from the Kimberley are from caves (e.g. Denniston et al., 2013a, 2013b, 2015) with only a handful of records of corresponding vegetation change (e.g. McConnell and O'Connor, 1997; Wallis, 2001; McGowan et al., 2012; Proske et al., 2014; Proske, 2016). As a result the late Quaternary environment and climate of the region and Australia's tropical savannah as a whole remains poorly understood (Reeves et al., 2013).

The Kimberley has a long history of human habitation stretching back ~49,000–44,000 years (Balme, 2000; Fifield et al., 2001; Hiscock et al., 2016). Consequently its archaeological history is of great significance, particularly as it contains one of the greatest concentrations of rock art globally (Aubert, 2012). Understanding the late Quaternary climate of the Kimberley is therefore essential for providing context for this unique archaeological record. The late Quaternary is also a period of significant climatic and environmental change associated with the Last Glacial-Interglacial Transition (LGIT). In this study a ~15,000 year record combining pollen, charcoal, degree of humification and loss-on-ignition (LOI) data is developed from an organic mound spring, Black Springs in the Kimberley's northwest. This record extends and builds on an existing ~6000 year palaeoenvironmental record from the same site (McGowan et al., 2012). The record presented here documents the first humification and LOI data for Black Springs, and the first humification dataset for the Kimberley. Recently acquired surface pollen samples have also been utilised in this study to assist interpretation of the extended pollen record. This study confirms

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that, despite the lack of permanent water sources and sediments with good fossil preservation, mound spring peat deposits in the Kimberley are a potentially rich archive of palaeoenvironmental data.

1.1. Mound springs and climate proxies

Peat deposits have been shown to be excellent natural archives of environmental change (Chambers et al., 2012). Whilst the majority of these are located in the high latitudes or high altitude environments (Gaiser and Ruhalnd, 2010), peat deposits are found in many climatic zones including drier environments, where they are most typically associated with springs (Boyd and Luly, 2005). An organic mound will only form at a spring where outflow is higher than the rate of evaporation, thereby preventing desiccation and mineralisation and where discharge is sufficiently low to prevent mound erosion (Ponder, 1986). Most commonly mounds are derived from aeolian deposits, precipitated calcium carbonate, or silicates in volcanic provinces (McCarthy et al., 2010). However, mounds comprised of peat will also form where there is sufficient water in otherwise challenging environments (Boyd, 1990a). Examples include those in the Australian arid and tropical zones (e.g. Boyd, 1990b; Boyd and Luly, 2005; McGowan et al., 2012), in the East African arid zone (e.g. Owen et al., 2004) and in South Africa (e.g. Scott, 1982a, 1982b, 1988; Scott and Vogel, 1983; Scott and Nyakale, 2002).

Organic mound springs are classed as minerotrophic since water is derived largely from artesian aquifers as well as meteoric sources (Barber and Charman, 2005; Backwell et al., 2014). These springs develop with distinct stages of growth, outlined by Ponder (1986). A juvenile spring typically forms in a small depression which infills with runoff derived alluvium and aeolian sediments, precipitates from groundwater and decomposing vegetation. In these early stages spring discharge is typically vigorous with a pool forming at the vent and outflow channels conveying the water into a wetland or spring “tail”. The presence of a perennial water source enables the establishment of vegetation at the spring, with subsequent decomposition of this vegetation contributing to mound growth. As time progresses and the peat mound increases in size less alluvial runoff-derived sediment is incorporated into the spring. When a spring is active the buried peats remain relatively fresh due to anaerobic conditions and/or the waterlogged nature of the site (Backwell et al., 2014) with capillary creep and outward diffusion of water through the mound limiting oxidation (McCarthy et al., 2010). Groundwater outflow and peat wetness is related to meteoric recharge via pressure transmitted through the aquifer regardless of water retention time (McCarthy et al., 2010). Humification, a proxy for bog surface wetness, will reflect changes in outflow which in this environment is assumed to reflect long term patterns (hundreds to thousands of years) in precipitation which drives aquifer recharge. Spring development and morphology can be reflected in both the fossil pollen assemblages (Boyd, 1990b) and the changing organic content at the site from which secondary conclusions about climatic conditions can be made given knowledge of modern vegetation distributions in relation to climate (Moss, 2013). Charcoal accumulation can provide insight into local and regional fire activity (Mooney and Tinner, 2011).

This study uses multiple measures of mound spring conditions to produce a robust, high resolution reconstruction of changes in the strength of the Australian summer monsoon since the LGIT, whilst also providing a record of spring development and morphology. This record will provide context for ongoing archaeological research in the Kimberley and increase current understanding of the region's late Quaternary climate.

2. Regional setting

2.1. Location and hydrogeology

Black Springs (15.633°S; 126.389°E) is a peat mound spring located in the North Kimberley Bioregion (Government of Western Australia, 2011) (Fig. 1). The peat mound is fed by freshwater from local aquifers of low to moderate productivity within the Kimberley's fractured rock province, distinct from the highly productive extensive aquifers of the Canning and Bonaparte sedimentary basins to the east and west, respectively (Brodie et al., 1998). The mound stands ~2 m above the surrounding terrain with organic material comprised predominantly from decomposing vegetation that is growing on the mound.

2.2. Climate

Precipitation in the Kimberley is dominated by the Australian summer monsoon and tropical cyclones, both of which typically occur during the austral summer between December and March (DJFM) associated with the seasonal southward migration of the Inter-Tropical Convergence Zone (ITCZ) (Suppiah, 1992). The monsoon trough separates the trade winds to the south and westerlies to the north, with strong convection embedded in the latter (McBride, 1987). Active monsoon periods correspond with a more southerly position of the monsoon trough over the Pilbara Heat Low, whereas weaker monsoon activity corresponds with a more northerly ITCZ position (Suppiah, 1992). Mean annual precipitation (1988–2016) at Drysdale River Station, 7.8 km from Black Springs, is 1110 mm/yr with the vast majority (on average 908 mm) falling during the summer (DJFM). Temperature data from Doongan Station (1988–2016, 29.2 km from Black Springs) indicates that there is little variation in temperature throughout the year (33.2 °C in January and 29.7 °C in July) with an average annual temperature of 33 °C (Bureau of Meterology (2016)).

A number of modern drivers of climate variability affect the strength of the Australian summer monsoon. The 40–60 day Madden-Julian Oscillation (MJO) alters the strength of westerly airflow into the monsoon trough (Wheeler et al., 2009), and the IPWP to the north of the Kimberley acts as a key source of moisture and heat to the atmosphere (Huang and Mehta, 2004) fuelling monsoon activity across tropical Australasia. Variability in sea surface temperatures (SSTs) is also a key factor driving Australian rainfall patterns (Taschetto et al., 2010). The El Niño/Southern Oscillation (ENSO) operates over a 3–7 year cycle and is the most influential driver of Australian rainfall variability in the tropical north during the austral summer (Risbey et al., 2009). ENSO is embedded within the Walker Circulation, which under normal conditions is associated with convection over Indonesia and subsidence over the eastern Pacific (McPhaden, 2004). During El Niño events the location of subsidence is near Australia which can disrupt moisture advection and suppress rainfall over the region (Jourdain et al., 2013). In northwest Australia (including the Kimberley) the impacts of ENSO are currently subdued (McBride and Nicholls, 1983; Bureau of Meterology (2016)), but may have been more significant in the past. Despite the current muted influence of ENSO, La Niña events (which result in increased spring and summer precipitation in the Kimberley) and strong El Niño events, such as in 1982–1983 (which resulted in decreased precipitation), can cause significant rainfall variability over northwest Australia (Bureau of Meterology (2016)). Similarly, during El Niño Modoki events, which are characterised by warm SSTs in the central Pacific Ocean and anomalously cool SSTs in the west and east (i.e. a double Walker circulation) (Ashok et al., 2007), the monsoon in northwest Australia is shorter yet more intense due to the anomalous cyclonic