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Coherent patterns of environmental change at multiple organic spring sites in northwest Australia: Evidence of Indonesian-Australian summer monsoon variability over the last 14,500 years

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ABSTRACT

At present, knowledge of late Quaternary variability of the Indonesian-Australian summer monsoon in the Australian tropics is limited. Organic spring deposits, which occur throughout the Kimberley region of northwest Australia, are valuable archives that contain records spanning the past ~14,500 years. In this study we compare multiple proxies from three organic springs. Principal Components Analyses demonstrates similar patterns of change in the elemental and non-pollen palynomorph (NPP) datasets between the springs, implying regional drivers are responsible for changes in these proxies. By comparison, the pollen records differ between each of the springs, with the assemblage at each thought to be influenced by spring recharge and evolution rather than climate variability. In order to empirically and objectively assess the synchronicity of changes, we applied Monte Carlo empirical orthogonal function (MCEOF) analysis to one variable in each µXRF and NPP dataset (Si/Ti ratios and *Pseudoschizaea* accumulation rates, as these proxies are expected to reflect hydrological conditions in springs) to assess regional patterns of change in site moisture. This analysis revealed periods of increased monsoonal precipitation from ~14,500–7500 cal. yr BP corresponding with deglacial sea level rise, high orbital tilt coupled with warmer sea surface temperatures, and with possible links to a southward migration of the Inter Tropical Convergence Zone (ITCZ) during the Younger Dryas. Monsoonal precipitation was reduced from 7500 cal. yr BP coinciding with the culmination of deglacial sea level rise and a possible northward shift in the mean position of the ITCZ, in addition to between 2600 and 1000 cal. yr BP corresponding with increased moderate-to-strong ENSO events.

1. Introduction

Understanding late Quaternary environmental change in the Kimberley region of Australia's tropical north is essential for providing context for the area's globally important archaeological and rock art records, as well as for understanding the development and variability in the region's climate. Precipitation across northern Australia is predominantly derived from the Indonesian-Australian summer monsoon (IASM), one of the largest monsoon systems on Earth. However knowledge of IASM variability in the Australian tropics over long timescales is scant, particularly in the northwest.

In northwest Australia sediment preservation, proxy information and geochronology can be affected by extreme seasonality. This seasonality can result in chronological hiatuses and unconformities due to cessations in sediment accumulation or aeolian deflation during dry phases, or by scouring during wet periods (Head and Fullager, 1992; Magee et al., 1995), whilst proxy information and chronological control may be affected by oxidation and chemical weathering (Field et al., 2018). As a result, there are a limited number of well preserved, high-resolution sedimentary records of palaeoenvironmental change. Organic spring deposits offer an alternative to the more typical sedimentary archives from

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which palaeoenvironmental records have commonly been constructed. They have been identified in several arid/semi-arid locations in Australia, South Africa, Kenya and Jordan, and have yielded valuable palaeoenvironmental and climatic information in these locations where the preservation of palaeoenvironmental information is otherwise lacking (see Field et al., 2018, and references within). In the Kimberley, springs containing peaty deposits have been found in a number of locations, therefore creating an opportunity to use sedimentary records to study past climatic and environmental change in this region.

Black Springs, an organic spring deposit located in the North Kimberley Bioregion (Government of Western Australia, 2011, Fig. 1), has been previously analysed for pollen, micro-charcoal, trace element geochemistry, organic content and humification, providing an impression of monsoon variability over the last ~15,000 years (McGowan et al., 2012; Field et al., 2017). However, springs can be small, isolated systems subject to complexities (e.g. spring mound evolution may reflect its sensitivity), which is problematic for reliably inferring climatic and environmental changes across a wider area. Therefore, whilst Black Springs has yielded valuable climate information, it remains unclear if it is recording a regional climate signal, or whether it is reflecting local spring dynamics or microclimate.

It is possible to partition changes in proxies recorded in palaeoenvironmental records to regional and local factors, and test the issue of replicability by using records from multiple sites within close proximity (e.g. Schmieder et al., 2011; Mills et al., 2014; Roberts et al., 2016). Agreement between sites may be hypothesised to reflect a regional-scale signal (i.e. reflecting broad changes on the scale of >1000 s km^2), whereas a lack of correspondence is assumed to reflect a component of local variability (i.e. 10s–100 s km^2) (Roberts et al., 2016; Tyler et al., 2015).

It is worth noting that apparent inter-site differences may also be a result of chronological imprecision, or relative preservation (Payne and Blackford, 2008; Roberts et al., 2016). In environments like those in the monsoon tropics such as the Kimberley, this can be particularly problematic since these climatic settings generally restrict the accumulation of sediment with clear time dependent indicators, such as annual laminae. Therefore this requires the application of geochronological techniques such as radiocarbon, optically stimulated luminescence (OSL) and lead-210 dating in order to construct age models for these environments. Each of these techniques is subject to analytical and calibration errors that can introduce large temporal uncertainties making it difficult to identify the precise timing of events and shared trends between sites (Anchukaitis and Tierney, 2012; Tierney et al., 2013). Moreover, the application of standard dating methodologies has been shown to be problematic in springs due to hydrological, geomorphic and biological conditions (Field et al., 2018). In these environments convoluted radiocarbon ages were concluded to be the result of complex carbon pathways due to groundwater fluctuations and biological processes. Similarly, a combination of

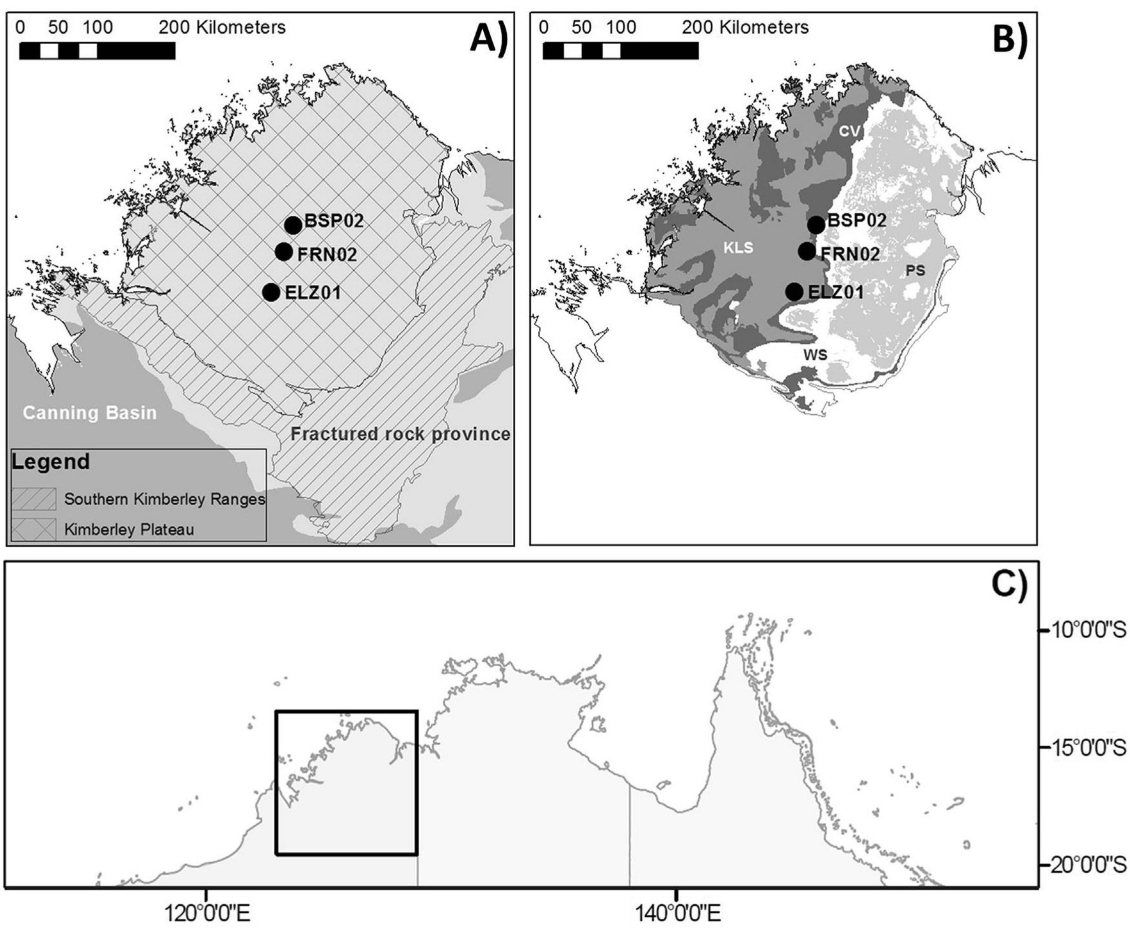

Fig. 1. Location of the three springs (BSP02, FRN02, ELZ01) in relation to: (A) physiographical divisions adapted from Wende (1997) and hydrogeological divisions adapted from Brodie et al. (1998). (B) Simplified geological divisions of the Kimberley Plateau, indicating the location of major lithological units including the Kimberley Sandstone (KLS; medium grey), Carson Volcanics (CV; dark grey), Warton Sandstone (WS; white) and Pentecost Sandstone (PS; light grey) adapted from Brocx and Semeniuk (2011). (C) Overview map of northern Australia, location of panels (A) and (B) are indicated by the black square.

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