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Climatic variability in Mfabeni peatlands (South Africa) since the late Pleistocene

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ABSTRACT

It has been postulated that a bipolar seesaw interhemispheric mechanism dominated the relationship between the Northern and Southern hemisphere climates since the late Pleistocene. A key test for this proposition would be to undertake palaeoenvironmental studies on terrestrial archives in climatically sensitive regions. Southern Africa's contemporary C_3 and C_4 terrestrial plant distributions display a definitive geographical pattern dictated by different growing season rainfall and temperature zones; however, the region is generally archive poor due to its overall semi-arid climate and high relief topography. The Mfabeni peatland, with a basal age of c. 47 k yrs calibrated before present (kcal yr BP), is one of the oldest continuous coastal peat deposits in Southern Africa. Molecular leaf wax isotopes ($\delta^{13}C_{wax}$) were generated for a 810 cm long core, and combined with previously published bulk geochemical ($\delta^{13}C_{bulk}$, %TOC), palynological, and stratigraphic data, to reconstruct the late Pleistocene and Holocene palaeoenvironments. We interpreted environmental shifts associated with the Heinrich 4, Last Glacial Maximum, deglacial and Holocene periods, which are consistent with adjacent Indian Ocean sea surface temperature records. However, the other shorter climate perturbations during the Heinrich 5, 3, 2, 1, Antarctic cold reversal and Younger Dryas, were muted, most likely due to local hydrological overprinting on the Mfabeni record. A general anti-phase sequence was observed between the Mfabeni record and better established Northern Hemisphere events, underpinning the bipolar seesaw interhemispheric mechanism proposed for global climate forcing since the Late Pleistocene.

1. Introduction

There has long been a quest amongst the paleoclimatology community to establish if a North-South interhemispheric climate relationship existed during the late Pleistocene and Holocene. Varying degrees of anti-phase interhemispheric coupling have been shown by several studies (Baker et al., 2014, 2016; Bard et al., 1997; Blunier et al., 1998; Chase et al., 2011; Kaplan et al., 2010; Putnam et al., 2010; Scheufuß et al., 2011; Schmittner et al., 2003) with numerous mechanisms for climate forcing postulated, prompting a requirement for additional high resolution regional palaeoenvironment studies to corroborate or challenge these hypotheses. One of the more popular theories is the bipolar seesaw (Broecker, 1998; Stocker, 1998; Stocker and Johnsen, 2003) caused by the slow-down or switching off of the oceanic Atlantic Overturning Meridional Circulation (AMOC) that transfers heat from the equatorial and Southern Oceans towards the higher latitudes in the Northern Hemisphere (Chase et al., 2015). Understanding how regional and global climate forcing mechanisms interacted in the recent geological past is critical for modelling global weather patterns in response to anthropogenic influences, not only for food security but its impact on biodiversity. Majority of climate studies have focused on marine sediment cores that are influenced by different sources upwind and/or upstream during the time of their deposition (Railsback et al., 2016) which can complicate the continental signal. Therefore, much emphasis is now being placed on discovering new terrestrial climate archives to unravel the impact of past climate on hydrologic conditions within the core continental precipitation zones. Southern Africa is situated at the junction between tropical, sub-tropical and temperate climate systems, with varying topography/altitudes, and three distinctive rainfall

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zones, namely winter rainfall (WRZ), all-year rainfall (ARZ) and summer rainfall (SRZ) zones (Fig. 1). However, this unique region suffers from a lack of continuous terrestrial climate archives, mainly due to a semi-arid climate and high relief topography that is not conducive for archive preservation. The Mfabeni peatland, which is located on the eastern shores of South Africa (Fig. 1), returned a basal ^{14}C age of c. 47 kyrs calibrated before present (kcal yr BP), establishing the record as one of the oldest known continuous terrestrial archive of its kind in Southern Africa (Baker et al., 2014; Grundling et al., 2013), that provides a unique opportunity to conduct high-resolution glacial and interglacial palaeoecological investigations of past climate in Southeast Africa.

Approximately 85% of all terrestrial plant species use the C_3 photosynthetic pathway to fix carbon (Ehleringer et al., 1997). In contrast, the C_4 pathway is restricted to the Dicotyledonae and Monocotyledonae clades, with the greatest diversity found within the widespread monocots group dominated by the Poaceae (grasses) and Cyperaceae (sedges) families (Ehleringer et al., 1997). Vogel et al. (1978) found that the regional C_4 grasses predominate in the SRZ, whereas C_3 grasses are more prevalent in the WRZ and high altitude regions of the eastern escarpment of South Africa. On the other hand, Stock et al. (2004) showed that temperature variations did not fully account for the C_3 and C_4 Cyperaceae (sedges) family distributions in South Africa, but seem to be more closely related to annual rainfall. They suggest that the C_4 sedges evolved under wetland conditions, but are more abundantly represented in warm and moist (sub) tropical areas (Rommerskirchen et al., 2006), although not at such high proportions as the C_4 Poaceae family (up to 95% in SRZ; Vogel et al., 1978).

The different biochemical pathways employed by C_3 and C_4 plants during photosynthesis causes a variation in degrees of $^{13}C/^{12}C$ fractionation, resulting in characteristic bulk $\delta^{13}C$ values ranging from −22‰ to −30‰ for C_3 and -10‰ to −14‰ for C_4 plants (Vogel et al., 1978). This difference in the biochemical pathways, gives rise to distinct leaf wax $\delta^{13}C$ ($\delta^{13}C_{wax}$) signatures that are preserved in peat deposits. The causes of shifts in the proportions of C_3 and C_4 plants over time are still subject to intense scientific debate. Originally it was thought that the Hatch-Slack pathway employed by C_4 plants during photosynthesis was more efficient and therefore favoured under low atmospheric CO_2 (Cerling et al., 1997; Ehleringer et al., 1997). More recent studies have indicated that changes in the balance of C_3/C_4 plants can be affected by local environmental factors such as temperature and aridity (Castañeda et al., 2009; Huang et al., 2001; Khon et al., 2014; Schefuß et al., 2003; Scott, 2002; Xue et al., 2014; Yamamoto et al., 2010). Energy models have previously been employed to predict the range of temperatures and atmospheric ρCO_2 under which C_3 and C_4 pathways may have selective advantages in grasslands (Ehleringer, 1978). Under current CO_2 concentrations, the C_4 pathway was predicted to have a higher photosynthetic efficiency at growing season temperatures in excess of 27 °C, while the C_3 pathway was more efficient at temperatures below 22 °C (Ehleringer et al., 1997). It has also been observed that C_4 tropical grasses display a higher water use efficiency (WUE) rate than their

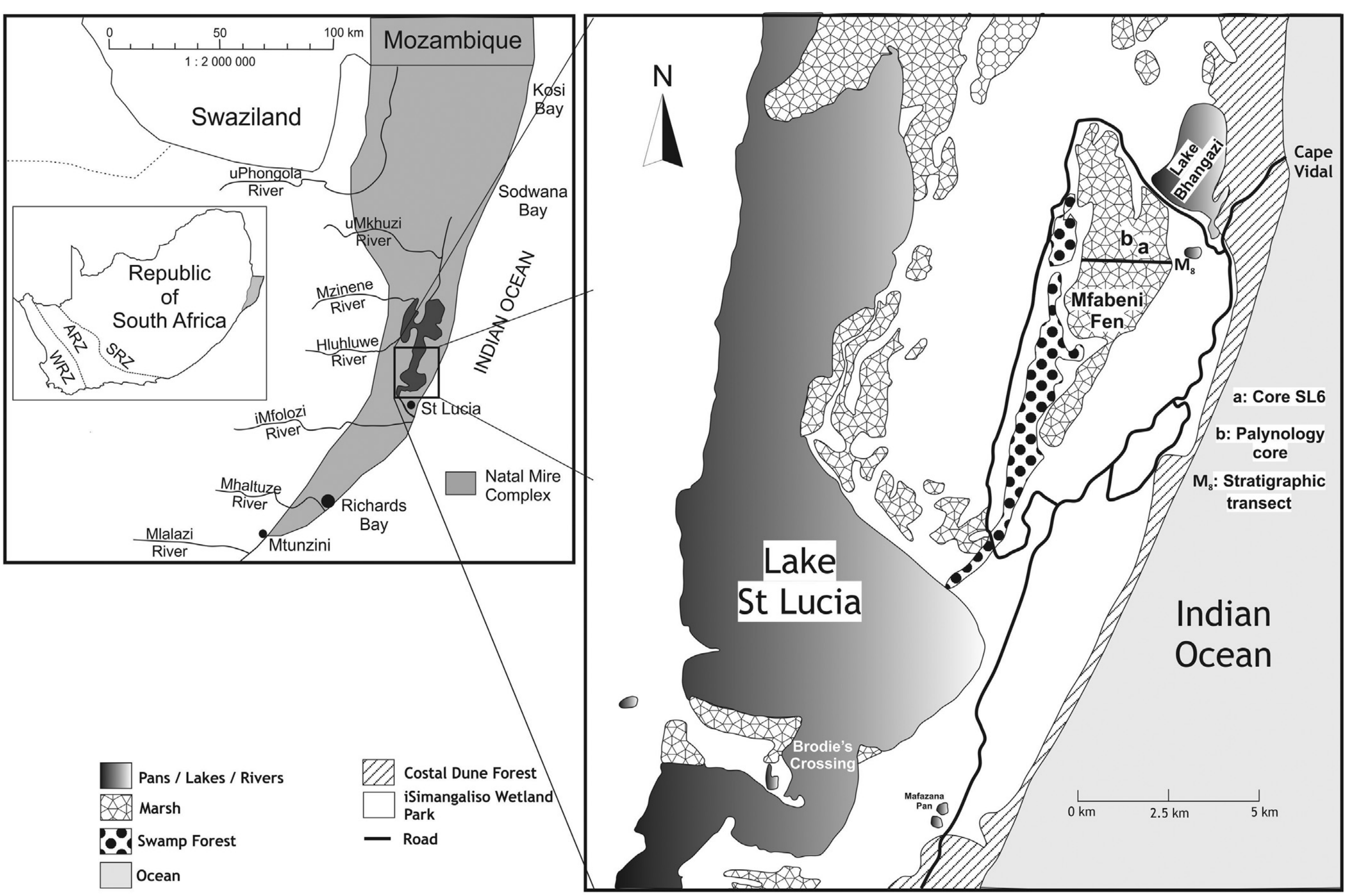

Fig. 1. Location of core SL6 (a) in the Mfabeni peatland, iSimangoliso Wetland Park, northern Kwazulu-Natal, South Africa. Location of palynology core (b; Finch and Hill, 2008) and most proximal and deepest stratigraphic transect (M_8; Grundling et al., 2013) included for orientation. WRZ = winter rainfall zone; ARZ = all-year rainfall zone; SRZ = summer rainfall zone. Modified from Baker et al. (2016).