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Short communication

Holocene climate change in southernmost South Africa: rock hyrax middens record shifts in the southern westerlies

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ABSTRACT

South Africa's southern coastal margin is recognised as being a highly dynamic climatic region that plays a critical role in both regional and global atmospheric and oceanic circulation dynamics. Our understanding of the past dynamics of this system, however, has been limited by the number and nature of datasets available that can be used to infer changes in key climatic parameters in the region. In this paper we present new high resolution $\delta^{13}C$ and $\delta^{15}N$ data from two independently dated rock hyrax (*Procavia capensis*) middens from Seweweekspoort in South Africa's Groot Swartberg mountains. These data provide information regarding both past vegetation and hydroclimatic change, and allow a regional integration of available data that explore the long-term dynamics of mid-latitude circulation systems in the African sector of the Southern Hemisphere. Combined, a negative relationship is apparent between temperature and humidity in this area of the southern Cape, and these changes can for the first time be clearly linked to variations in Antarctic sea-ice extent and shifts in the southern westerly storm track. This dynamic is particularly evident between 5 and 7 cal kBP, when a reduction in sea-ice extent and a southward shift of the westerlies are manifested regionally by increased temperatures and a phase of marked aridity.

1. Introduction

South Africa's southern coastal margin is a key area of interest for understanding both regional and global climate dynamics (Walker, 1990; Cohen and Tyson, 1995; Reason, 2001; Biastoch et al., 2009; Beal et al., 2011). Strongly influenced by both temperate and tropical climate systems and the Agulhas Current heat conveyor, the region is recognised as a particularly dynamic region in terms of long-term climate change (see Chase and Meadows, 2007). Despite the region's climatic sensitivity and its potential as an indicator of past climate variability, our specific understanding of these dynamics is limited to modern meteorological studies (Walker, 1990; Walker and Shillington, 1990; Reason, 2001), long, coarse-scale records from marine cores (Peeters et al., 2004; Bard and Rickaby, 2009; Caley et al., 2011), and a limited number of fragmentary terrestrial archives, generally of low temporal resolution (e.g. Martin, 1968; Scholtz, 1986; Carr et al., 2006). Notable exceptions do exist, however, with the $\delta^{13}C$ and $\delta^{18}O$ data and palaeotemperature reconstructions from a speleothem from Cango Cave (Talma and Vogel, 1992), and sea-surface temperature (SST) reconstructions from $\delta^{18}O$ data derived from marine molluscs from the Nelson Bay Cave coastal rock shelter (Cohen and Tyson, 1995) (Fig. 1) providing relatively detailed data concerning environmental variability in terrestrial and marine environments respectively.

While the Cango Cave and Nelson Bay Cave records provide some scope to explore marine–terrestrial interactions in this region, comparisons have been hindered by what appear to be largely independent, unrelated signals. The Cango Cave record is widely cited as reflecting southern African palaeotemperatures, and as an indicator of the relative influence of tropical versus temperate moisture bearing systems (winter vs. summer rainfall) (e.g. Tyson

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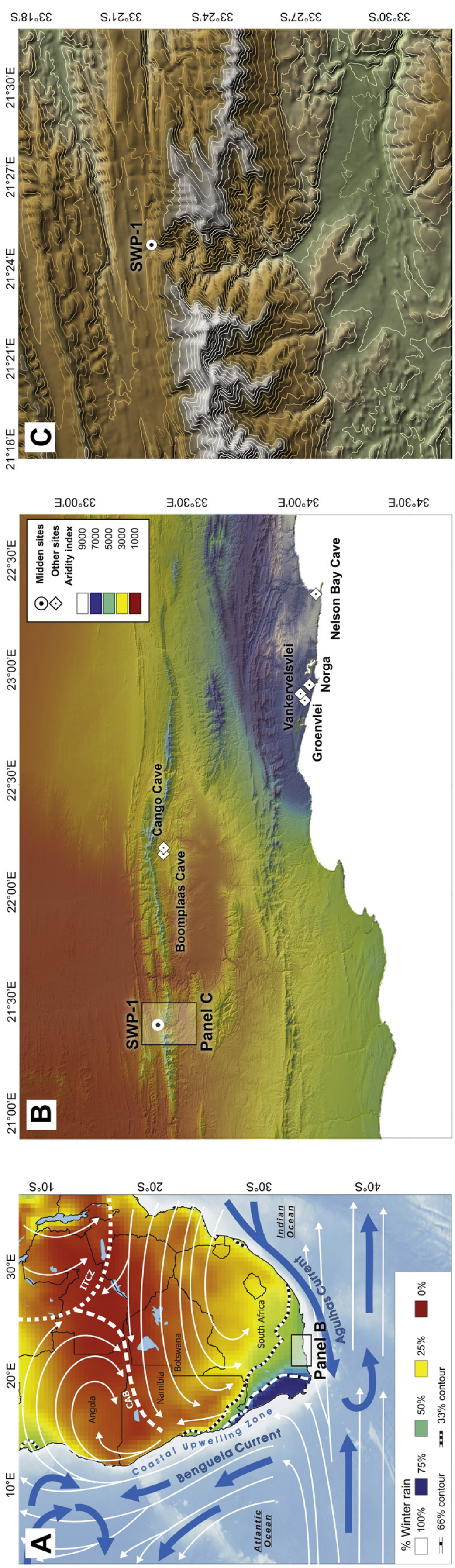

Fig. 1. (A) Map of southern Africa showing seasonality of rainfall and sharp climatic gradients dictated by the zones of summer/tropical (red) and winter/temperate (blue) rainfall dominance. Winter rainfall is primarily a result of storm systems embedded in the westerlies. Major atmospheric (white arrows) and oceanic (blue arrows) circulation systems and the austral summer positions of the Inter-Tropical Convergence Zone (ITCZ) and the Congo Air Boundary (CAB) are indicated. The location of the study site in the transitional southern Cape region is shown. (B) Map of southern coastal region with the Seweweekspoort sites and other key palaeoenvironmental sites indicated. (C) Topographical map of Seweweekspoort, with the SWP-1 site (which includes SWP-1-1 and SWP-1-5) indicated. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

and Lindesay, 1992). The Nelson Bay Cave SST data were used to test a mechanistic model linking regional atmospheric and oceanic upwelling dynamics in this region. The model posited that lower (higher) near-coastal SSTs would be associated with increased (decreased) upwelling along the south coast, which were driven by increased easterly (westerly) flow. These large scale phenomena were themselves associated with overall wetter (drier) conditions in the continental summer rainfall dominated interior.

In this paper we present high resolution $\delta^{13}C$ and $\delta^{15}N$ data from two independently dated rock hyrax (*Procavia capensis*) middens from Seweweekspoort in South Africa's Groot Swartberg mountains, 75 km west of Cango Cave and 200 km WNW of Nelson Bay Cave. These data provide information regarding both past vegetation and hydroclimatic change, and provide a perspective that allows for a regional integration of available data to explore the long-term dynamics of mid-latitude circulation systems in the African sector of the Southern Hemisphere.

1.1. Regional setting

The Groot Swartberg is, along with the Langeberg and Outeniqua mountains to the south, one of the major ranges in the east–west axis of the Cape Fold Mountains. Extending ~200 km parallel to the Indian Ocean, which lies 100 km to the south, the range represents an important divide between the humid–sub-humid climate of the southern Cape coastal plain and the arid Great Karoo in the continental interior (Fig. 1). The range also sits at the interface of southern Africa's two major climate regimes: the winter rainfall zone to the west and the summer rainfall zone to the northeast (cf. Chase and Meadows, 2007). The present nature and seasonal distribution of rainfall across South Africa is the result of the combined influence of 1) the seasonal intensification and northward expansion of the westerlies and associated frontal depressions that transport moisture to the site during the winter, 2) disturbances in tropical easterly flow, which transport moisture from the Indian Ocean during the summer, and 3) a range of disturbances related to the interaction of temperate and tropical systems, such as ridging anticyclones and southerly meridional flow, which promote the advection of moisture from the Indian Ocean to the southern margin of the subcontinent (Tyson, 1986; Tyson and Preston-Whyte, 2000).

Seweweekspoort is a deep transversal valley in the eastern Groot Swartberg Mountains and palaeoenvironmental archives in this locale are therefore ideally situated to consider the past dynamics of these major climate systems (Fig. 1). Traditional palaeoenvironmental archives such as lakes and wetlands are rare in southern Africa, but recent research has demonstrated the antiquity and utility of rock hyrax middens – accumulations of dried urine and faecal pellets – as palaeoenvironmental archives (see Chase et al., 2012 for full description). Two middens were analysed for this study: Seweweekspoort-1-1 and Seweweekspoort-1-5 (SWP-1 and SWP-1-5; 33.37°S, 21.41°E, 1100 m amsl.). These are located on a west-facing cliff on the northern slope of the pass (Fig. 1). The middens are taken from two locations within the same larger shelter (SWP-1), formed by a ~100 m overhanging cliff, approximately 20 m apart. SWP-1-1 is the more sheltered of the two, located under a large subsidiary overhang, while SWP-1-5 is located on a more open shelf, exposed to the sun.

In terms of vegetation, the site is located in the North Swartberg Sandstone Fynbos, but less than a kilometre to the north is the Matjiesfontein Shale Renosterveld (Mucina and Rutherford, 2006). The former is, depending on altitude and aspect, predominantly asteraceous, proteoid and restioid fynbos, while the latter is dominated by asteraceous elements, particularly *Elytropappus rhinocerotis*, *Eriocephalus sp.* and *Euryops sp.*, and by an increasing