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# Evidence for global teleconnections in a late Pleistocene speleothem record of water balance and vegetation change at Sudwala Cave, South Africa

Helen Green [a,*], Robyn Pickering [a], Russell Drysdale [b], Brett C. Johnson [c], John Hellstrom [a], Malcolm Wallace [a]

[a] School of Earth Sciences, University of Melbourne, Victoria, 3010, Australia
[b] School of Land and Environment, University of Melbourne, Victoria, 3010, Australia
[c] School of Physics, University of Melbourne, Victoria, 3010, Australia

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ABSTRACT

Understanding the global response to millennial-scale climatic events is essential to our comprehension of climatic teleconnections and projection of future change, however the extent and nature of their expression in areas of the Southern Hemisphere is often viewed as equivocal. Here we report uranium–thorium dating of speleothem formations sampled at Sudwala Cave in the north-eastern Lowveld region of South Africa's summer rainfall zone (SRZ). The growth intervals of multiple formations, alongside a detailed chronology and multi-proxy analysis of two periods of growth, 40–35 ka and 13.8–12.8 ka, in a stalagmite (SC1), provide information regarding key fluctuations in the palaeoclimatic and palaeoenvironmental conditions during the Late Pleistocene. High-resolution stable isotope, trace element, and micro-Raman analysis are used alongside petrographic investigation to provide a detailed assessment of the climatic conditions associated with the onset and termination of growth in SC1. The combined Raman and petrographic analysis represents a rare approach, enabling the identification of aragonite–calcite shifts both within and across growth intervals and diagenetic events, potentially significantly influencing the recorded signal and often resulting in the major loss of chemical information. Consequently, the identification of this post-depositional chemical alteration could become a crucial prerequisite in speleothem palaeoclimatology, particularly in areas prone to aragonite speleothem deposition susceptible to calcite conversion, such as cave sites hosted by dolomitic karst systems. The multiple proxies used in this study highlight the complex forcing relationships between climatically related environmental change and local cave conditions on speleothem precipitation, contesting a common paradigm by associating drier conditions at Sudwala with the initiation of speleothem growth. The growth interval identified in stalagmite SC1 during the late deglaciation (13.85–12.79 ka) coincides convincingly with both the Southern Hemispherically-Forced Antarctic Cold Reversal (14.1–12.8 ka), and the Younger Dryas (12.9–11.5 ka) of Northern Hemispheric origin, identifying Southern Africa as a vital location for the investigation of the hemispheric to global expression of the millennial-scale fluctuations of the last deglaciation.



## 1. Introduction

One of the longest standing debates in Late Quaternary climate variability surrounds the mechanism of climate-signal transfer from the region of forcing to the rest of the globe and the synchronicity of this response. High-latitude palaeoclimatic records produced for each hemisphere have documented high-amplitude, millennial-scale change as characterizing the last deglaciation (Dansgaard et al., 1989; Alley et al., 1999; Broecker, 2000; Barbante et al., 2006). Determining the geographic reach and precise timing of these rapid climate fluctuations is essential for establishing both the dominant forcing mechanisms and the underlying ocean–atmosphere processes by which these climatic changes are propagated globally. Changes in oceanic circulation and ice cover at

* Corresponding author. School of Earth Sciences, McCoy Building, Cnr Swanston and Elgin Streets, University of Melbourne, Parkville, Victoria, 3010, Australia. Tel.: +61 (0) 3 8344 6933; fax: +61 (0) 3 8344 7761.
*E-mail address:* Greenhe@unimelb.edu.au (H. Green).

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high northern latitudes are commonly considered as the drivers of Quaternary climate change (Alley et al., 1993; Grootes et al., 1993; Weaver and Hughes, 1994; Masson-Delmotte et al., 2005a, 2005b). However, whilst the abrupt climate events of the last deglaciation are well defined in ice-core records from the polar regions of both hemispheres, their manifestation beyond the poles is less well constrained (Shakun and Carlson, 2010; Newnham et al., 2012; Petherick et al., 2013), with a particularly significant lack of representation of Southern Hemisphere records. This situation has led to some controversy, for example, regarding whether or not the Younger Dryas event of the North Atlantic can be recognized in records from Southern Hemispheric landmasses (e.g. Tibby, 2012; Green et al., 2013).

Situated at the interface of tropical, sub-tropical, and temperate climate systems, as well as the Indian, Atlantic and Southern oceans, southern Africa is well positioned to record Southern Hemispheric circulation changes and is consequently important for the study of large-scale environmental changes over glacial–interglacial cycles (Fig. 1). However, the generally semi- to hyper-arid climates experienced in South Africa are not conducive to the preservation of a range of palaeoecological proxy data sources and consequently the region is characterized by only a limited number of well-dated, high-resolution records of climate change (Holmgren et al., 1995; Partridge et al., 1997, 2002; Repinski et al., 1999; Pickering et al., 2007; Holzkamper et al., 2009).

Despite the shortage and fragmentary nature of existing palaeoclimatic records from this region, speleothems from various caves located across the sub-continent preserve multi-proxy evidence of past climate change, including some of the most complete, robust and highest-resolution records for this region (Talma and Vogel, 1992; Brook et al., 1998; Repinski et al., 1999; Stevenson et al., 1999; Lee-Thorp, 2001; Holmgren et al., 2003; Pickering et al., 2007; Bar-Matthews, 2010; Brook et al., 2010) (Fig. 1). With their growth dependent on a number of climatically significant variables, episodes of speleothem deposition at all locations provide important information regarding fluctuations in climatic conditions, with the onset or termination of growth in one or more samples potentially indicative of a significant threshold in environmental conditions at the cave surface (e.g. Ayliffe et al., 1998). Further detailed information can be acquired by more detailed petrographic and geochemical investigations along the speleothem (e.g. stalagmite) growth axis, with the potential to provide information regarding environmental conditions at the cave site at the time of deposition (e.g. Belli et al., 2013). In this paper, we present a high-resolution, multi-proxy speleothem record from Sudwala Cave, situated approximately 37 km from the town of Nelspruit in the province of Mpumalanga, South Africa (Fig. 1). Despite representing the longest cave in the Transvaal Drakensberg Escarpment dolomites (Fig. 1), speleothem studies in Sudwala Cave have been relatively limited with only very few ($n = 4$) U-series dates published on the largest columnar formations, with ages ranging between 4.3 ± 4 and 282.50 ± 51.4 ka (Brook et al., 1997). The size of many of these speleothems suggests growth over extensive time intervals, indicating the formations to be of a substantial age. However, without further U–Th age determinations little can be

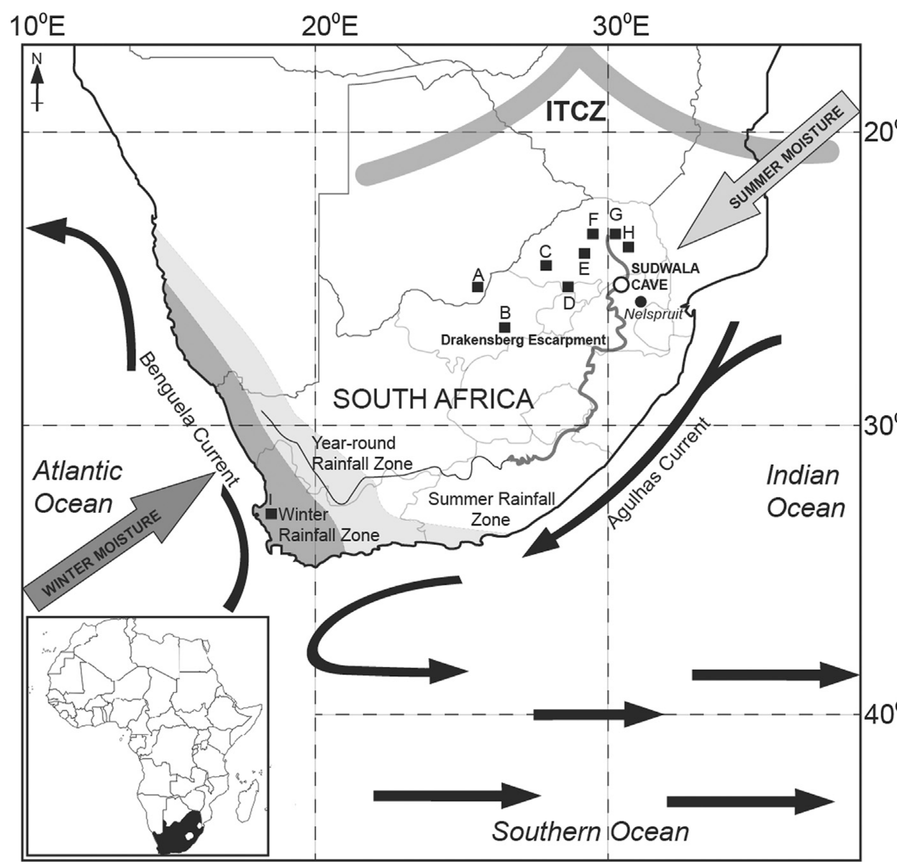


**Fig. 1.** Location of Sudwala Cave and other sites mentioned in the text (note that here the new provincial boundaries of South Africa are shown, while older publications refer to the former Transvaal province). The key precipitation zones (winter, year-round and summer) are highlighted alongside key oceanic currents, the Inter-tropical Convergence Zone (ITCZ) and The Drakensberg Escarpment (grey line). The key sites of palaeoclimatic studies mentioned in the text are identified (A; Lobatse Cave, B; Sterkfontein Cave, C; Tswaing Crater; D; Gladysvale Cave, E; Wonderkrater, F; Cold Air Cave, G; Wolkberg Cave; H; Echo Cave I; Hyrax Midden Site (Chase et al., 2011)).