Past Environmental Proxies from the Middle Stone Age at Sibudu, Kwazulu-Natal, South Africa

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Abstract

Middle Stone Age technological and behavioural developments in southern Africa are central to understanding the emergence of modern humans, and elucidating the role of environmental change in this trajectory is dependent on emerging palaeoclimatic reconstructions. Climate proxies from Middle Stone Age sites are often poorly preserved, coarsely resolved or subject to anthropogenic selection and are not considered in favour of global environmental proxies despite the fact that the modern climate regimes at the relevant archaeological sites differ profoundly. Sibudu has a well-preserved Middle Stone Age sequence that has yielded abundant palaeoclimate proxy data. Isotopic analysis of charcoal, charcoal anatomy and species representation, macro- and micro-faunal remains, sediment texture, mineralogy and magnetic susceptibility, pollen and macrobotanical remains provide evidence for the environmental succession specific to this site. The isotopic data suggest that archaeological charcoal was not significantly post-depositionally altered. During the Howiesons Poort (65–62 ka) the local environment was thickly forested, moist and more humid than during the 58 ka occupations. The environment changes during the post-Howiesons Poort occupation (~58 ka) into the late MSA occupation (~48 ka); conditions became drier and colder than present with vegetation shifting to open savanna grassland or woodlands.

Résumé

Les évolutions technologiques et comportementales du Middle Stone Age dans le sud de l'Afrique sont essentielles pour comprendre l'émergence de l'Homme moderne, et la compréhension du rôle des changements environnementaux dans cette trajectoire dépend des reconstitutions paléo-climatiques émergentes. Les données indirectes liées au climat du MSA sont souvent mal conservées, de résolution grossière ou soumis à une sélection d'origine anthropique et sont abandonnées au profit des données indirectes liées aux conditions environnementales globales, en dépit du fait que les régimes climatiques modernes sur les sites archéologiques étudiés diffèrent profondément. Sibudu a une séquence bien conservée du Middle Stone Age qui a fournit d'abondantes données paléoclimatiques indirectes. L'analyse isotopique de charbons de bois, l'anatomie du charbon de bois et la représentation des espèces, des restes de faunes macroscopiques et microscopiques, la texture des sédiments, la minéralogie et la susceptibilité magnétique, le pollen et les restes macrobotaniques fournissent des indices de l'évolution de l'environnement spécifique à ce site. Au cours de la période Howiesons Poort (65–62 ka), l'environnement local est couvert de forêts épaisses et humide, plus humide encore lors des occupations de 58 ka. L'environnement change au cours de l'occupation post-Howiesons Poort (~ 58 ka) jusqu'a la fin de l'occupation MSA (~ 48 ka) : il devient plus sec et plus froid qu'à présent et la végétation se mue en grande savane herbeuse ou boisée.

Keywords: Sibudu, Middle Stone Age, Howiesons Poort, stable carbon isotopes, charcoal, environmental proxies

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Introduction

Archaeological evidence from Blombos Cave, Pinnacle Point and Sibudu archaeological sites reflects the emergence of complex human behaviour in southern Africa over the last 160,000 years (Henshilwood *et al.* 2001; Wadley *et al.* 2009; Marean 2010; Marean *et al.* 2010), but the environmental context for this trajectory has not been fully developed, notwithstanding preliminary research (Bar-Matthews *et al.* 2010; Bruch *et al.* 2012). Under the modern climate regime the sites that contain Middle Stone Age (MSA) occupations are distributed between summer rainfall (Rose Cottage Cave, Umhlatazana, Border Cave and Sibudu), winter rainfall (Blombos Cave, Pinnacle Point, Diepkloof Cave) and year-round rainfall (Klasies Main site, Boomplaas) regions. The mechanisms that drive climate in southern Africa often lead to inverse rainfall responses in summer and winter rainfall regions and this has implications for the economic adaptation of peoples in different areas during the MSA. The frequency and duration of droughts (Usman & Reason 2004) as well as the longer-term climate band shifts (Tyson 1999) and associated environmental changes would have had a profound influence on where people lived. Localised environmental reconstructions from faunal and botanical remains from the sites are potentially influenced by the selections made by the occupants, while reconstructions from speleothem isotopic analyses may be ambiguous and sedimentary records may be poorly resolved. As a result the environmental context for human behaviour is often interpreted from global-scale climate reconstructions that may not apply across all sites. Complications with such interpretations, particularly with archaeological sites located in the mid-latitudes such as Sibudu, may be due to differences between northern and southern hemisphere records, especially with the timing of major events (Jansen *et al.* 2007; Hall & Woodborne 2010). When major global climatic events are synchronous they should manifest in regional and local palaeoenvironmental records. In the case of Sibudu, local environmental changes recorded in proxy evidence (*e.g.*, charcoal isotopes, faunal assemblages and macro-botanical remains) from the site may be linked to global events represented in Antarctic ice cores, marine core isotope records and sea-surface temperature records. This highlights the necessity for accurate dating and age models for palaeoenvironmental records, particularly as one looks further back in time (Jansen *et al.* 2007).

Sibudu is an important MSA archaeological site in southern Africa (***Fig. 1***) because of the excellent preservation in the deep sediments in the rock shelter. The modern climate is characterised by high summer temperatures and precipitation (Min: 23°C, Max: 33°C, ± 1000 mm per annum) and mild winters (Min: 16°C, Max: 25°C) (Hall 2010; Bruch *et al.* 2012). Most sediment build-up within the site is derived from anthropological debris (Pickering 2006; Goldberg *et al.* 2009), and the site contains stratified time-related informally- and formally-named lithic assemblages (Wadley & Jacobs 2004, 2006). From oldest to most recent, these assemblages represent pre-Still Bay (layers BS to LBG), Still Bay (layers RGS, RGS2), Howiesons Poort (layers PGS to GR), post-Howiesons Poort (layers Br under YA2 to BSp), late MSA

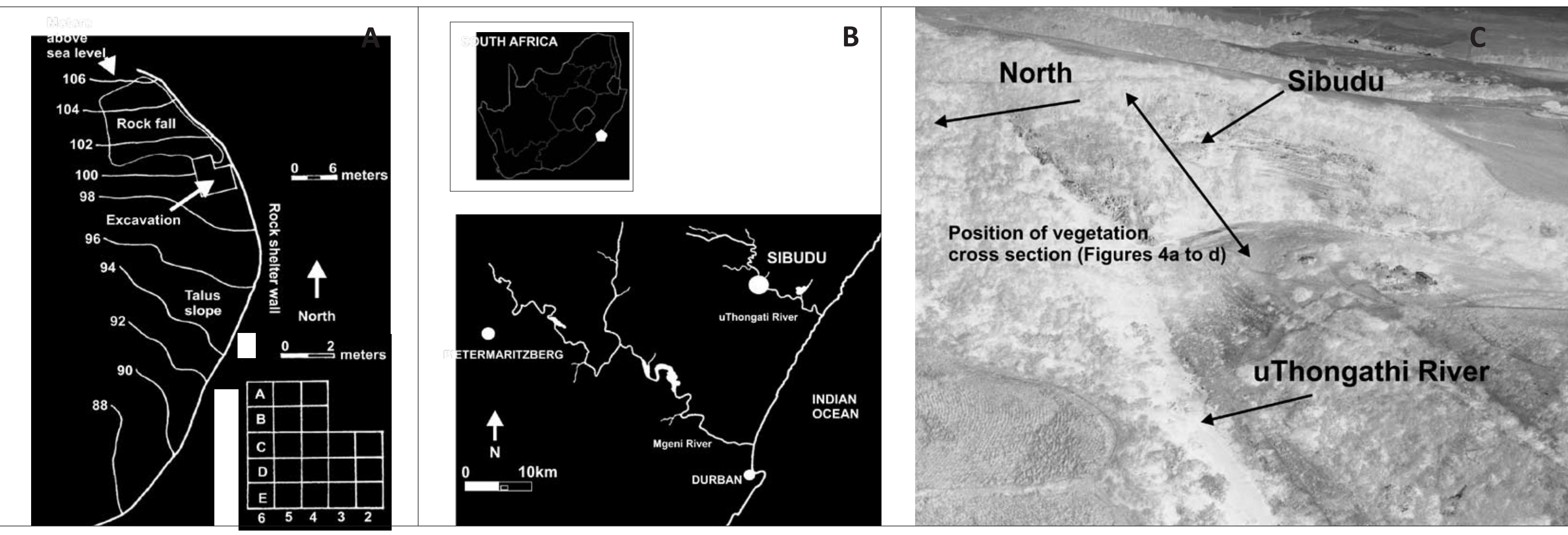

Fig. 1. A: Plan of Sibudu. B: Location of Sibudu. C: Aerial photograph of the Sibudu modern environment showing the location of the shelter, the uThongathi River and orientation of the past vegetation reconstruction transects presented in ***Fig. 4***. The aerial photograph is courtesy of Geoff Nichols.

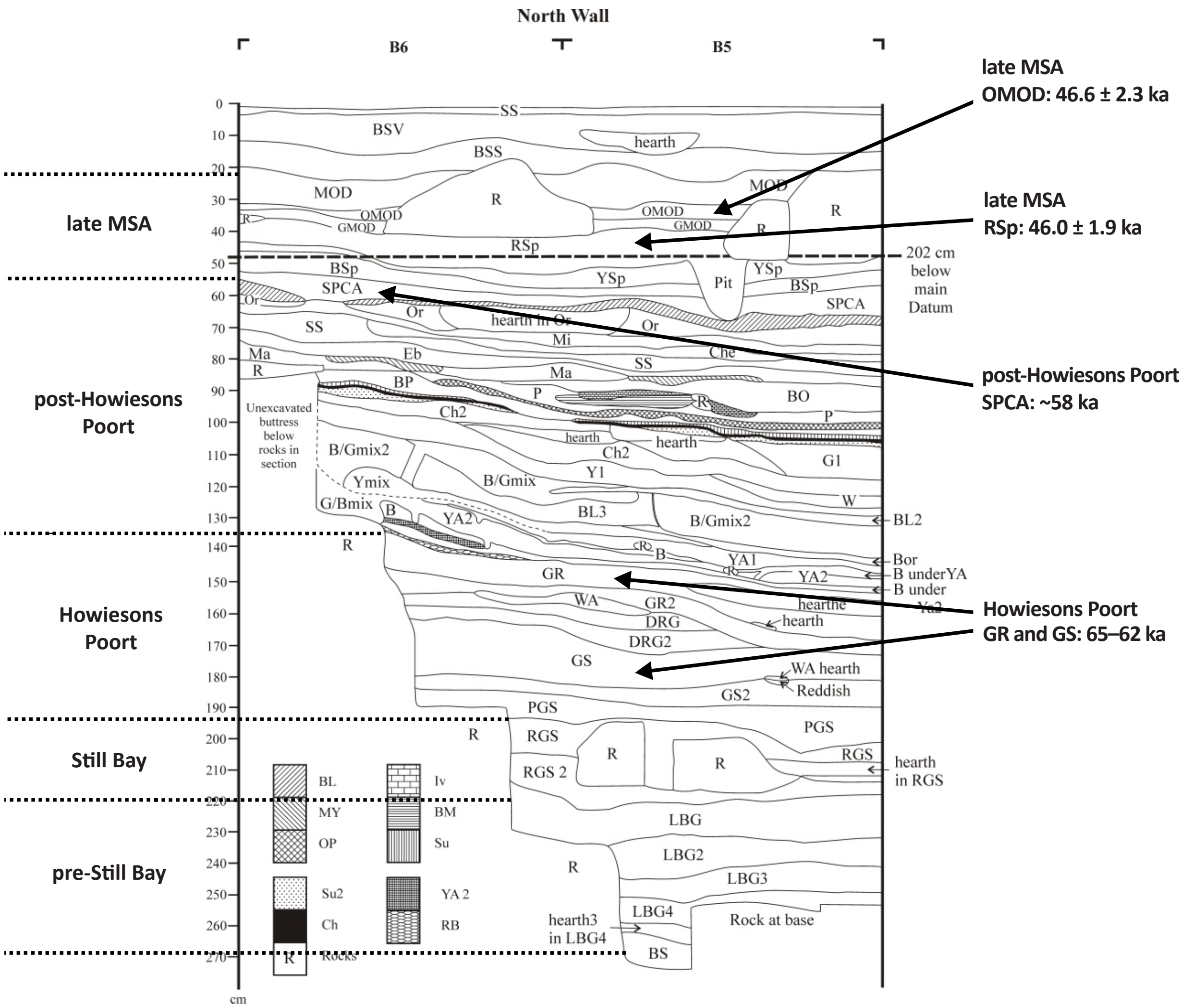

Fig. 2. Stratigraphy of the trial trench in the northern grid at Sibudu. The layers and available ages (Jacobs *et al.* 2008a, b) from where charcoal samples for this study were collected are indicated.

(layers YSp to PB) and final MSA (layers Mou to Co) (***Fig. 2***). The pre-Still Bay, post-Howiesons Poort, late MSA and final MSA are informal assemblages that have been preliminarily described (Villa *et al.* 2005; Cochrane 2006; Villa & Lenoir 2006; Wadley & Jacobs 2006) and are intended for use only with respect to Sibudu.

The chronology was created using Optically Stimulated Luminescence (OSL) techniques on single quartz grains, yielding 21 ages (Jacobs 2004; Wadley & Jacobs 2004, 2006; Jacobs *et al.* 2008b, b; Jacobs & Roberts 2008). The Howiesons Poort occupation falls between 65–62 ka, the Still Bay dates to 70 ka and the pre-Still Bay to between 77 and 72 ka (Jacobs *et al.* 2008a; Jacobs & Roberts 2008). There are obvious geological hiatuses of 9.8 ± 1.3 ka and 12.6 ± 2.1 ka between the three more recent age clusters, so the site was not continually occupied (Wadley & Jacobs 2006; Jacobs *et al.* 2008b). Due to the hiatuses it is not possible to provide a continuous sequence of environmental change, but detailed environmental data are available for the occupation pulses.

Multi-disciplinary research has enabled reconstruction of palaeoenvironments for the Howiesons Poort and post-Howiesons Poort, that is, from about 65 to 58 ka (***Tab. 1***). Studies include: geomagnetic susceptibility (Herries 2006), mineralogy (Schiegl *et al.* 2004; Schiegl & Conard 2006), geology (Pickering 2006), woody taxa identification from charcoal (Allott 2004, 2005, 2006), carbonised seeds (Wadley 2004, 2006; Sievers 2006; Sievers & Wadley 2008), pollen (Renaut & Bamford 2006) and macro- and micro-faunal remains (Cain 2004, 2005, 2006; Plug 2004, 2006; Glenny 2006; Wells 2006; Clark & Plug 2008; Wadley *et al.* 2008). Environmental interpretations based on proxy evidence from archaeo-

Layer	Age (ka)	General environmental trends	Carbon isotopes	Seeds	Charcoal	Phytoliths & Pollen	Macrofauna	Microfauna	Mineralogy	Mag Sus.
Occupational hiatus between late and final MSA **~48 ka occupation: late MSA**										
PB Ore, Ore2 LBMOD Cad, Pu	49.9 ± 2.5			Also overall increase in deciduous species					High amounts of both calcite and gypsum	
MOD OMOD OMODBL OMOD2 OMODBL GMOD, BMOD	49.1 ± 2.5 46.6 ± 2.3 47.6 ± 1.9	Cooler with more deciduous taxa	*Celtis* $\delta^{13}C$ values more negative	*Pavetta* and sedge species present in most of the layers	*Acacia, Erica* charcoal is present in the upper layers		Large and medium sized bovids present		High amounts of both calcite and gypsum	Warmer conditions indicated. **NOTE**: there is a contradiction between the Mag sus and other proxies
RSp YSp	46.0 ± 1.9	Warming period with highly mosaic environment	*Podocarpus* $\delta^{13}C$ values more negative	*Phoenix reclinata, Pavetta* sp., sedges	*Acacia, Erica, Podocarpus*	Grass	Large and medium sized bovids present	*Mastomys natalensis* indicates succession	Calcite, high gypsum	Warmer
Occupational hiatus between Post-Howiesons Poort and late MSA **~58 ka occupation: Post-Howiesons Poort**										
BSp BSp2	57.6 ± 2.1	Cooler and drier phase with increased grasslands		*Asparagus* sp. and sedges occur	*Erica, Acacia, Ficus*		Large and medium sized bovids present		High calcite, gypsum	
SPCA BL, Or		Warmer conditions with increased woodlands	*Celtis* & *Podocarpus* $\delta^{13}C$ values less negative	*Asparagus* sp., Sedges	*Erica, Podocarpus, Leucosidea*	Sedge, *Acacia*	Large and very large bovids present		High calcite, high gypsum	
Mi SS	 59.6 ± 2.3	Cooler phase, more grassland		Seed assemblage dominated by evergreen species		Grass	Large bovids		High gypsum	
Che, Eb Ma, MY		Warm, dry period			Dry-adapted species present in assemblage		Large bovids	*Mastomys natalensis* indicates succession	Gypsum	Cool
BO P OP	59.0 ± 2.2	Cold phase and very dry with very reduced forested areas		*Asparagus* sp.	*Acacia, Erica, Ziziphus*		Large bovids		Gypsum	Warm
BP Iv BM Ch Su, Su2		Warming period, cooler and drier than present		*Asparagus* sp., *Podocarpus* occur in the majority of these layers		*Acacia*, Grass, Fern and Sedge species	Large bovids including species such as buffalo and equids		Gypsum in all the layers, increasing amounts in lower layers	A warming trend is indicated in these layers
G1 Ch2 Y1 B/Mix BL2, BL3 Bor, Ymix YA1 YA2 Br under YA2	 58.3 ± 2.0 58.6 ± 2.1 58.2 ± 2.4	Coldest period in the MSA with more open savanna and grassland environments		Sedge species present in all of these layers		Grass, Sedge and *Acacia*	Large bovids in all of these layers		High gypsum in all the layers, increasing amounts in lower layers and also the presence of calcite	Indications of cold conditions in all layers
Potential hiatus between Howiesons Poort and Post-Howiesons Poort **65 to 62 ka occupation: Howiesons Poort**										
GR GR2 GS GS2 PGS	61.7 ± 1.5 63.8 ± 2.5 64.7 ± 1.9	Cold, humid and moist conditions with predominance of evergreen forests dominated by *Podocarpus*	*Celtis* & *Podocarpus* $\delta^{13}C$ values more negative. *Podocarpus* values have high variability	Sedge species present in all of these layers	*Podocarpus* dominates the assemblage and other forest species are present		Small forest species and lots of aquatic species. Blue duiker dominant small bovid	Presence of Gambian Giant Rat & Geoffroy's Horseshoe Bat indicate presence of forests and humid conditions	Layers dominated by calcite and the presence of some gypsum	

Table 1. Sibudu: summary of proxy environmental evidence. Stratigraphy (Wadley & Jacobs 2006), ages (Jacobs *et al.* 2008a, b), formal and informal lithic designation (Wadley & Jacobs 2006), isotopic data (Hall *et al.* 2008), botanical (Wadley 2004; Allott 2006; Renaut & Bamford 2006; Sievers 2006) and faunal data (Plug 2004, 2006; Cain 2006; Glenny 2006; Wells 2006; Clark & Plug 2008), geology and mineralogy (Schiegl *et al.* 2004; Pickering 2006; Schiegl & Conard 2006) and magnetic susceptibility (Herries 2006).

logical material may be problematic for a number of reasons (Wadley 2006). These include the introduction of selection bias by natural agents, the original human inhabitants of the site as well as by the site excavators. However, the identification of many sources for the floral, faunal and geological material found at Sibudu provides environmental evidence from a range of localised habitats that would have existed around the site in the past. The degree of material preservation and diagenetic alteration may also influence interpretation. In the case of Sibudu, the interpretation of changing local environmental conditions is strengthened due to a multi-disciplinary combination of high-resolution dating of the site and diverse lines of evidence.

Recently the fossil floral material from Sibudu was subjected to a GIS-based Coexistence Approach (CA_{GIS}) analysis (Bruch *et al.* 2012). The CA_{GIS} analysis shows that during the Howiesons Poort (HP) Industry winters were slightly colder and drier than present, whereas during summer, temperatures and precipitation were similar to today. The method is based on the assumption that the climate requirements of plant taxa has changed very little since the Neogene and are thus similar to those of their nearest living relatives. Developed by Mosbrugger & Utescher (1997), CA_{GIS} provides a means of accounting for the fact that natural changes in vegetation may be masked by behavioural changes of the inhabitants of a site. As the method is based on the taxonomic composition of a fossil plant assemblage, all categories of the Sibudu fossil plant assemblage (*e.g.*, seeds, pollen, charcoal and leaves) were combined with twelve climatic and three vegetation parameters to interpret palaeoenvironmental changes in the local vegetation.

Charcoal isotope data is the most recently proposed environmental proxy from the MSA layers of Sibudu and is linked to climate changes in response to sea surface temperatures in the Indian Ocean, shifts in temperate and tropical weather systems and variations in the position, strength and temperature of the Agulhas Current along the south coast (Hall *et al*. 2008; Hall & Woodborne 2010; Chase 2010). Although stable carbon isotopic analysis of charred organic matter has been used to track changes in palaeovegetation (*e.g.*, Behling & da Costa 2001; Bechtel *et al.* 2002, 2003; Biedenbender *et al*. 2004) and $\delta^{13}C$ values of archaeological charcoal have been used to track changes in precipitation (February 1992, 1994a, b; February & van der Merwe 1992; Ferrio *et al.* 2006; Aguilera *et al.* 2008; Fiorentino *et al.* 2008; Masi *et al.* 2013), the success of the approach is dependent on the extent to which the environmental signal in wood is transformed in the charcoal formation process and subsequently during burial. The carbon isotope composition of plant material can change during combustion and the extent of the change depends on the plant organ combusted, its chemical composition, tissue ratios, surface area, the availability of oxygen and the combustion temperature (Leavitt *et al.* 1982; Cahier *et al.* 1985; Bird & Gröcke 1997; Ballentine *et al.* 1998; Turekian *et al.* 1998; Schleser *et al.* 1999; Baldock & Smernik 2002; Poole *et al.* 2002; Krull *et al.* 2003; Steinbeiss *et al.* 2006; Turney *et al.* 2006; Hall *et al.* 2008; Bird & Ascough 2012).

Hall *et al.* (2008) showed that an environmental signal *is* preserved in charcoal under constant combustion conditions and that, in the case of *Podocarpus*, the signal associated with humidity is particularly reliable, but they failed to account for potential post-depositional changes that might have occurred at Sibudu. Although charcoal is considered to be biologically and chemically inert, it undergoes an extremely slow process of degradation and contaminant absorption (*e.g.*, humic and fluvic contaminants) during burial (Skjemstad *et al.* 1996; Bird & Gröcke 1997; Cohen-Ofri *et al.* 2006; Forbes *et al.* 2006). Diagenetic change to charcoal occurs between sedimentation/burial of the charcoal and subsequent excavation and may include chemical decomposition, microbial degradation and groundwater leaching (Styring *et al.* 2013). This diagenetic alteration can result in the biased removal of certain portions of organic matter, the addition of exogenous organic matter (particularly humic acids) and the replacement of endogenous organic matter with exogenous material. These diagenetic alterations may change the isotopic value of the residual organic matter of charcoal samples. In order to account for such potential influences on the carbon isotopic composition of charcoal samples, the agreed method for the pre-treatment of charcoal is the AAA method (Acid-Alkali-Acid) to remove potential contaminants (Ascough *et al.* 2011a, 2011b; Fraser *et al.* 2013; Styring *et al.* 2013). The $\delta^{13}C$ values from charcoal may still be considered as a valid method for palaeoclimatic reconstruction provided that appropriate care is taken to account for any post-depositional variation (Bird & Ascough 2012).

Here we explore the extent to which post-depositional effects may have affected the isotopic composition of the charcoal. We focus on the charcoal from two tree genera: *Podocarpus* and *Celtis*. *Podocarpus* is considered to be a dominant climax genus in many of the tropical and subtropical forest types in South Africa (Palmer & Pitman 1972; Acocks 1988; Killick 1990; Schmidt *et al.* 2002; Pooley 2003), and its adaptability to different environmental conditions (which may affect the $\delta^{13}C$ value) allows the genus to establish and maintain its presence. The genus requires high moisture availability and it grows from sea-level to 2150 m. The presence of a *Podocarpus* community implies a forested environment with effective precipitation, while an absence or limited occurrence of the genus implies reduced forest and drier conditions. *Celtis* species are more widespread and are adaptable to a larger range of environments than *Podocarpus*, particularly drier extremes (Van Wyk & Van Wyk 1997; Acocks 1988; Coates-Palgrave 2003; Pooley 2003). We then examine the consistencies between this and other ancient environmental proxies from Sibudu.

Material and methods

A detailed analysis of the Sibudu charcoal assemblage was carried out by Allott (2004, 2005, 2006). All of Allott's charcoal samples were taken from the initial trial trench which, at the time of sampling, was the deepest part of the excavation. Charcoal was sampled from the sediment matrix and not from distinct hearth features (Allott 2006).The archaeological charcoal was identified using a range of documented anatomical features visible under an incident light microscope. These key features were compared with identified charcoal samples from modern reference collections to allow identification to family, genus, species or type (Allott 2006). Allott's (2006) charcoal analysis revealed that a broad range of fuel wood was utilised at Sibudu, but it was not possible to distinguish between wood selection based on choice or environmental availability. The human selection of wood fuel is an important factor (Archer 1990), but the local availability of wood is of more important consideration than fuel properties (Van Wyk & Gericke 2000). This suggests that the Sibudu charcoal assemblage is a good indicator of the temporal components of local woody vegetation surrounding the shelter.

For the purpose of carbon isotope analysis 122 charcoal samples identified as *Podocarpus* by Allott were obtained from the Grey Rocky (GR) and Grey Sand (GS) layers, both of which occur within the Howiesons Poort (62–65 ka) suite of layers. Seven samples of *Celtis* charcoal were taken from GS. Twenty samples of *Podocarpus* comprising *P. latifolius* and *P. falcatus* (Allott 2004, 2005, 2006) and 12 samples of *Celtis* were taken from Spotty Camel (SPCA, ~58 ka), which is within the post-Howiesons Poort suite of layers. Fifteen samples of *Podocarpus* were from Red Speckled (RSp) (46.0 ± 1.9 ka). Thirty-six samples of *Celtis* were obtained from the Orange Mottled Deposit (OMOD) (46.6 ± 2.3 ka). These samples are representative of the late MSA suite of layers.

Archaeological charcoal samples were pre-treated with 1 % HCl overnight and washed with distilled water until pH neutral. Aliquots of approximately 0.2 mg were combusted on-line in a Flash Elemental Analyser (1112 series) integrated via a Con-flo IV system with a Delta V Plus Isotope Ratio Mass Spectrometer, housed at the Palaeoscience & Isotope Laboratory, CSIR, Pretoria (all instrumentation supplied by Thermo, Bremen, Germany). Each sample was run in duplicate and if the replicate precision was unacceptable (>0.10 ‰ variation), an additional sub-sample was run. The average precision for the replicates of the archaeological samples was <0.08 ‰ (Hall *et al.* 2008).

In order to account for the potential effects of post-depositional contaminants, such as humic substances and/or ground water carbonates, subsets of *Podocarpus* and *Celtis* charcoal from each period were further pre-treated using the Acid-Alkali-Acid (AAA) method (De Vries & Barendsen 1952). The charcoal was treated with a 1 % HCl solution, washed with distilled water and then treated with a 0.5 % sodium hydroxide (NaOH) solution overnight in a refrigerator, washed with distilled water until pH neutral and then treated again with a 1 % HCl solution, washed and dried. These samples were combusted in precisely the same manner as the original samples. The average precision for replicates of the subsets was <0.09 ‰.

Results

The $\delta^{13}C$ values of a particular tree or woody shrub vary according to local site specific factors such as aspect, soil type and proximity to water sources. The isotopic values of *Podocarpus* reflect a physiological response to the environmental conditions: when water stress increases, isotopic values increase. Where the isotopic values oscillate between high and low values it implies that the tree endured dry and moist environmental conditions. Accordingly, both the absolute value of the isotopes and their variance have environmental implications. A low variance suggests that the trees are using a limited range of their physiological adaptive responses to cope with prevailing environmental conditions, and either the environment shows little temporal variability or the trees existed at the outer limit of their adaptive range.

The mean $\delta^{13}C$ values for the archaeological charcoal analyses are presented in ***Figure 3*** and summarised in ***Table 2***. The data are composed of the original $\delta^{13}C$ values presented in Hall *et al.* (2008) and new $\delta^{13}C$ values for the archaeological charcoal samples pre-treated by the AAA method.

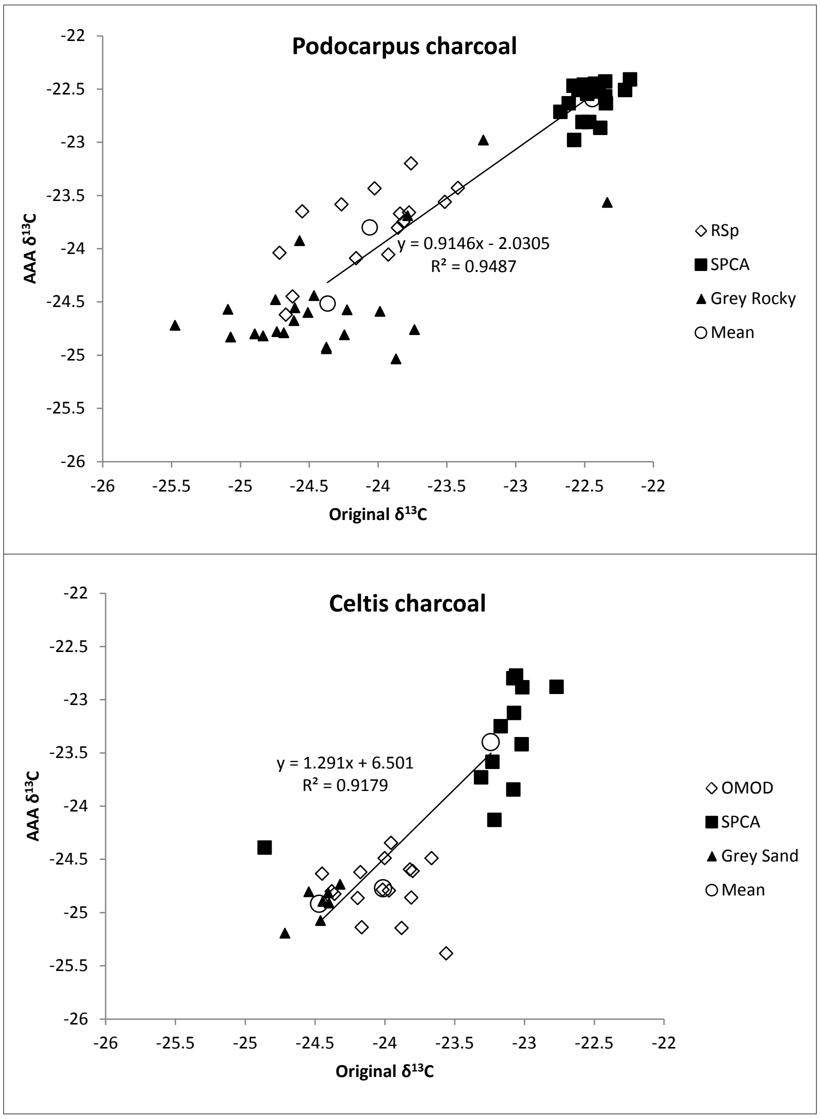

Fig. 3. Original versus AAA treated $\delta^{13}C$ values for *Podocarpus* and *Celtis* archaeological charcoal from Sibudu. A linear trend line and associated equations are provided. The mean $\delta^{13}C$ values for each layer are displayed as open circles. The sample size from each sample set is large enough to allow meaningful inferences regarding the climatic conditions during each archaeological period.

When the $\delta^{13}C$ values of the original charcoal samples are compared with their equivalent AAA $\delta^{13}C$ values, they suggest that there was relatively little post-depositional contamination of the Sibudu charcoal. The carbon isotope values for the original samples and the AAA samples of both the *Podocarpus* and *Celtis* charcoal from all layers were plotted against each other (***Fig. 3***). A linear trend line shows that there is a 1:1 relationship between the data (*Podocarpus* r^2= 0.95 and *Celtis* r^2= 0.92 respectively), indicating that the isotopic differences between layers are conserved. A Spearmann's Rank Correlation test indicates that the AAA pre-treatment did not significantly alter the carbon isotopic values obtained for each layer (*Podocarpus* ρ= 0.838, *Celtis* ρ= 0.718, $p< 0.5$ for both) and that the environmental interpretation based on the non-AAA treated data is sound.

On average there is 0.2‰ difference between the *Podocarpus* $\delta^{13}C$ AAA and original values and a 0.5 ‰ difference between the *Celtis* $\delta^{13}C$ AAA and original values. The AAA isotopic values for both *Podocarpus* and *Celtis* are in general slightly more negative than the original values. The standard deviation, range and variance values from the AAA samples are very similar to those of the original samples (***Tab. 2***). On the basis of these results, the observed isotopic values of the archaeological charcoal from Sibudu can be considered to reflect an environmental signal, rather than post-depositional contamination. It is important to note that the degree of post-depositional contamination of charcoal must be assessed on a site-by-site basis.

In layer GR (Howiesons Poort) *Podocarpus* $\delta^{13}C$ values have a range of 3.14 ‰ and a variance of 0.45 ‰. The wide range of carbon isotope values obtained from *Podocarpus* charcoal suggests that climate was variable with wet and dry conditions and the trees were not restricted in their adaptive response by prevailing environmental conditions during the

	Podocarpus					
	RSp		**SPCA**		**Grey Rocky**	
Period	Late MSA		Post-Howiesons Poort		Howiesons Poort	
OSL Date	46.0 ±1.9 ka		~58 ka		62–65 ka	
	Original	**AAA**	**Original**	**AAA**	**Original**	**AAA**
Mean	-24.06	-23.80	-22.44	-22.60	-24.37	-24.52
Std dev.	0.42	0.39	0.13	0.17	0.67	0.50
Variance	0.18	0.15	0.02	0.03	0.45	0.25
Range	1.30	1.42	0.50	0.57	3.14	2.06
Minimum	-24.72	-24.62	-22.68	-22.98	-25.48	-25.04
Maximum	-23.42	-23.20	-22.17	-22.41	-22.34	-22.98
n	15	15	20	19	23	23
Correl		0.68		0.38		0.61
Covar		0.10		0.01		0.20
	Celtis					
	OMOD		**SPCA**		**Grey Sand**	
Period	Late MSA		Post-Howiesons Poort		Howiesons Poort	
OSL Date	46.6 ± 2.3 ka		~58 ka		62–65 ka	
	Original	**AAA**	**Original**	**AAA**	**Original**	**AAA**
Mean	-24.01	-24.77	-23.24	-23.40	-24.47	-24.92
Std dev.	0.26	0.27	0.53	0.54	0.13	0.16
Variance	0.07	0.07	0.28	0.29	0.02	0.03
Range	0.89	1.04	2.09	1.62	0.40	0.46
Minimum	-24.45	-25.39	-24.86	-24.39	-24.72	-25.20
Maximum	-23.56	-24.35	-22.77	-22.78	-24.32	-24.74
n	16	16	12	12	7	7
Correl		0.68		0.75		-0.13
Covar		0.18		0.01		-0.01

Table 2. Summary statistics for archaeological *Podocarpus* and *Celtis* charcoal carbon isotope data from Sibudu. This table incorporates isotope data from Hall *et al.* (2008) and new values obtained from subsets of charcoal samples that were further treated using the acid-alkali-acid (AAA) method.

Howiesons Poort. In the post-Howiesons Poort SPCA layer *Podocarpus* $\delta^{13}C$ values are positive relative to the Howiesons Poort values indicating drier conditions, and they have a narrow range of 0.5 ‰ and the variance is very low (0.02 ‰). This suggests that the local distribution of *Podocarpus* was highly restricted during the post-Howiesons Poort and that it existed at the limit of its adaptive responses to the local environment. In the late MSA (layer RSp) *Podocarpus* $\delta^{13}C$ values are again more negative than the post-Howiesons Poort values, with a range of 1.3 ‰ and variance of 0.18 ‰. This suggests wetter conditions than in the SPCA layers and implies that a *Podocarpus* population utilising a wider range of adaptive responses to local environmental conditions was again established, although the range of responses was not as varied as that seen during the Howiesons Poort.

The mean absolute $\delta^{13}C$ values for *Celtis* charcoal from contemporary MSA layers show a similar isotopic distribution pattern to that of *Podocarpus*. *Celtis* $\delta^{13}C$ values are relatively negative during the Howiesons Poort and late MSA and relatively positive during the post-Howiesons Poort (***Tab. 2***). However, when the range and variance of the *Celtis* data are considered, these provide low values during the Howiesons Poort compared with those of the *Podocarpus* samples, suggesting a limited adaptive response to the local environmental conditions. During the post-Howiesons Poort and late MSA the *Celtis* data have a higher range and variance than *Podocarpus*. This suggests that both genera could have been affected in different ways by a change in the environment. In dry areas/conditions carbon isotope compositions are affected by relative humidity and soil water status. Under conditions of high moisture availability, sunlight and temperature are responsible for changes in isotopic composition (McCarroll & Loader 2004). The more positive $\delta^{13}C$ values for charcoal samples therefore suggest dry, warm conditions during the post-Howiesons Poort to which *Celtis* is better adapted than *Podocarpus*. The more negative values seen in the Howiesons Poort are indicative of higher moisture availability and cooler conditions favourable for *Podocarpus*.

Discussion

Sibudu is located in a vegetation mosaic that probably persisted throughout the MSA occupations because the aspect of the site and the proximity of the uThongathi River (***Fig. 1***) affect the range of faunal and botanical diversity (Wadley 2006). The river would have allowed the localised occurrence of certain taxa that would not otherwise have survived in drier areas surrounding the site. The north-eastern slopes and the plateau are more exposed to sunlight than the southern slopes and currently support deciduous woodland, savanna and grassland communities (***Fig. 1***). The cooler, sheltered south-western cliffs, in which Sibudu is situated, support evergreen forest taxa and would have provided refugia for forest species during drier-than-present periods (***Fig. 1***). Care is needed when drawing conclusions about changes to climatic and environmental conditions. The anthropogenic origin of the sediments makes the interpretation of proxy environmental evidence, such as geomagnetic susceptibility, more complex. Small-scale oscillations in the magnetic susceptibility curve from Sibudu have been attributed to due amounts of anthropogenically derived material (*e.g*., from hearths) intermixing (Herries 2006). Large-scale events such as the transition from a cold, dry, glacial phase during MIS 4 to a warmer, moister, interstadial MIS 3 are also reflected in the magnetic susceptibility data (Herries 2006, 2009). However, Goldberg *et al.* (2009) point out that the Sibudu sediments are almost entirely anthropogenic and that magnetic susceptibility readings are unlikely to represent climatic change.

Non-isotopic proxy environmental evidence from the site are summarised in ***Table 1***, but some of the interpretations require definitions. *Forests* comprise predominantly evergreen trees, typically 8 to 30 m in height, a variety of climbing taxa and epiphytes and low-growing shrubs and ferns on the forest floor, and canopy cover is continuous (Rutherford & Westfall 1986). *Savanna* is a mixed tropical and subtropical vegetation type comprising predominantly deciduous woody species with a grass component (Scholes 1997); it can be divided into sub-types that are dependent on the distribution of woody species. When woody species provide up to 75 % canopy cover, the savanna may be referred to as *woodland* (Rutherford & Westfall 1986). Reconstructions of local environment for the Howiesons Poort, post-Howiesons Poort and late MSA periods are summarised below and illustrated in ***Figure 4***.

Howiesons Poort occupations (65–62 ka)

The occurrence of sedge seeds in all the MSA layers suggests the presence of perennial water in the uThongathi River (Sievers 2006). Aquatic reptiles and mammals, fresh water molluscs and a variety of waterfowl also attest to a permanent water source close to the shelter (Plug 2006). A number of evergreen forest taxa have been identified in the charcoal assemblage, including *Podocarpus,* which is the dominant genus (Allott 2005, 2006). Other taxa such as *Kirkia* spp. (not present in the area today), which is a dry-adapted genus, were also identified, implying the presence in the vicinity of Sibudu of plant communities requiring drier-than-present conditions. The CA_{GIS} analysis of the Howiesons Poort flora suggests that at times during this period of occupation environmental conditions would have been slightly drier and colder than present during winter, but that summer conditions may have been similar to those of today, facilitating the presence of dry-adapted plant communities (Bruch *et al.* 2012). The macrobotanical evidence implies a predominantly forested environment, but with neighbouring patches of woodland/savanna (***Fig. 4A***) of a kind for which there is no modern analogue.

The botanical evidence is supported by the faunal assemblage. Forest-dwelling mammals such as *Cephalophus natalensis* (red duiker), *Philantomba monticola* (blue duiker), *Potamochoerus porcus* (bushpig), *Tragelaphus scriptus* (bushbuck) and *Chlorocebus aethiops* (vervet monkey) are present in the faunal assemblage (Clark & Plug 2008). These species are characteristic of modern *Podocarpus* spp. forest (Cooper 1985), although they may occur in other types of wooded environments. The faunal assemblage at this time mostly comprises (91.4 %) species inhabiting closed or semi-closed habitats (Clark & Plug 2008). Only 8.6 % of species that favour open environments, such as *Syncerus caffer* (African buffalo), *Connochaetes taurinus* (blue wildebeest) and *Hippotragus equinus* (roan antelope) are present in the assemblage. Nonetheless, they imply that there must have been patches of open woodland/savanna and this supports the earlier suggestion that a mosaic of vegetation types probably existed throughout the site occupations. Further evidence for humid, moist, forested environments in the vicinity of the site is provided by the presence of micromammalian species, such as the Gambian giant rat (*Cricetomys gambianus*) and Geoffroy's horseshoe bat (*Rhinolephus clivosus*) (Skinner & Chimimba 2005; Glenny 2006). The Gambian giant rat implies cooler-than-present conditions because it cannot tolerate mean summer temperatures above 34°C. Numerous calcite crystals within the deposits indicate more humid conditions during this time than later in the sequence where gypsum predominates (Pickering 2006; Schiegl & Conard 2006; Wadley 2006). Both calcite and gypsum require moisture to form, but gypsum is more soluble in water than calcite and is therefore a better indicator than calcite of locally arid conditions.

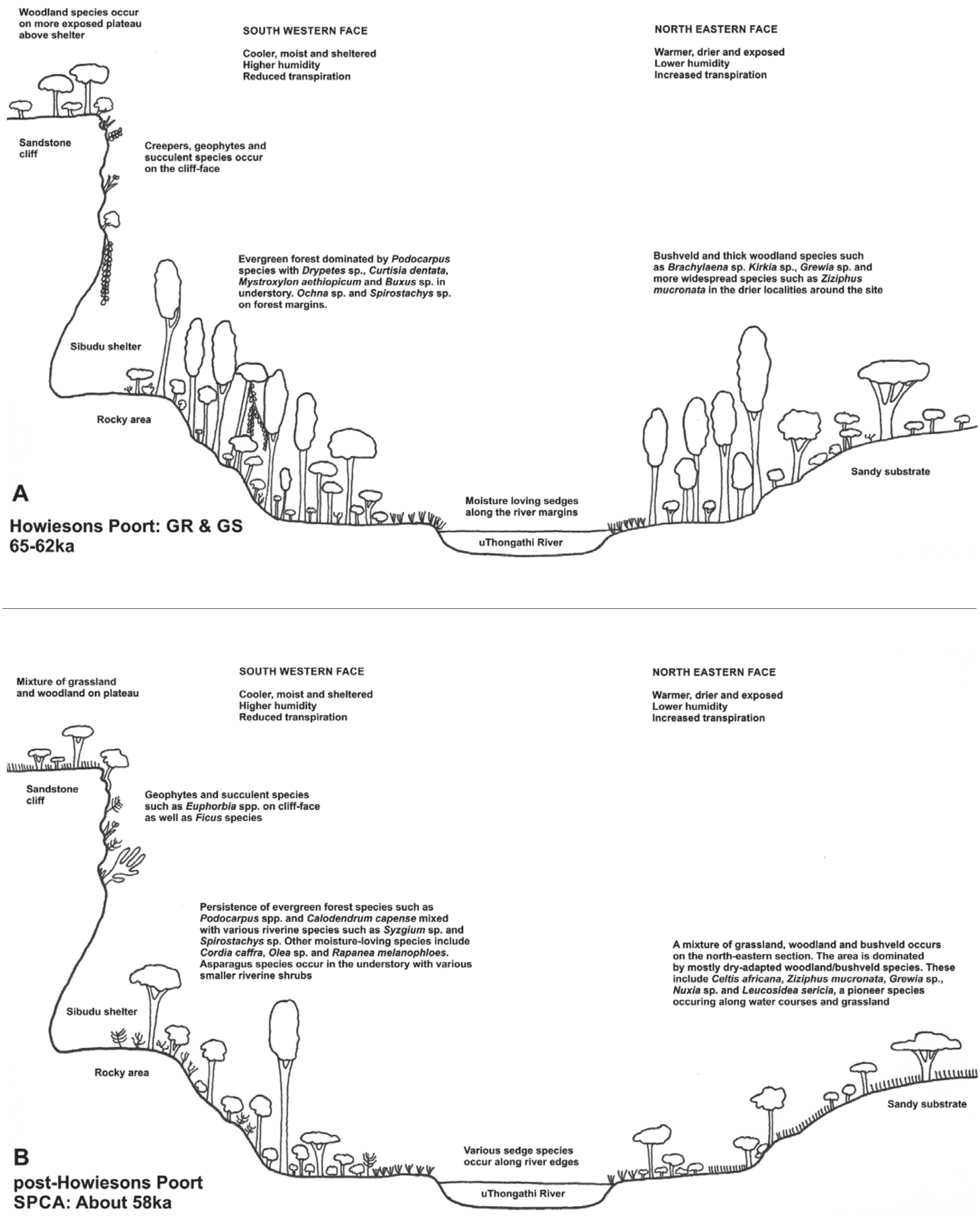

Fig. 4. Schematic reconstruction of (A) the Howiesons Poort (layers GR and GS) vegetation communities and (B) the post-Howiesons Poort (layer SPCA) vegetation communities, based on botanical evidence (Wadley 2004; Allott 2006; Renaut & Bamford 2006; Sievers 2006).

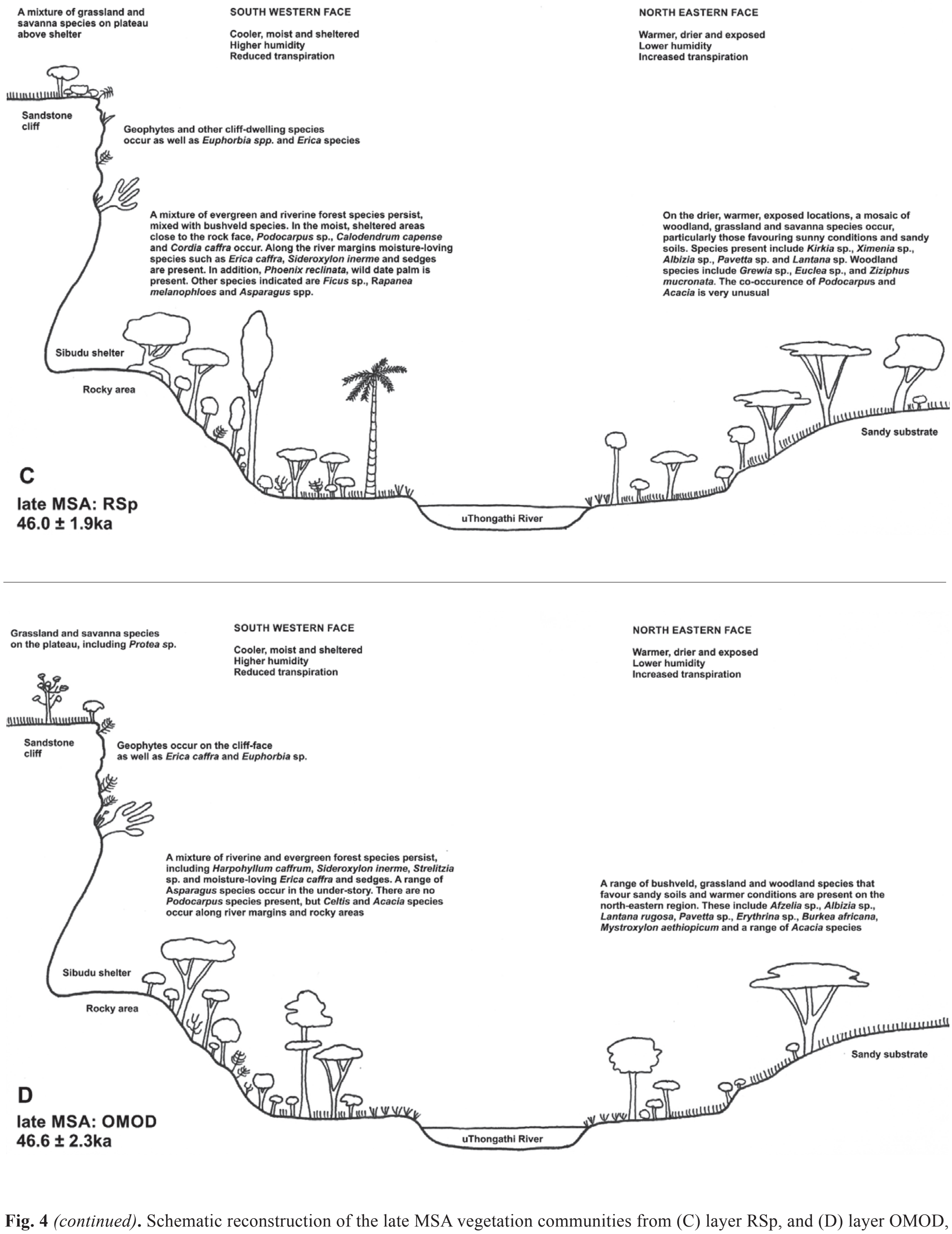

Fig. 4 *(continued)***.** Schematic reconstruction of the late MSA vegetation communities from (C) layer RSp, and (D) layer OMOD, based on botanical evidence (Wadley 2004; Allott 2006; Renaut & Bamford 2006; Sievers 2006).

The proxy evidence from the Howiesons Port layers suggests that the environment around Sibudu Cave was cooler than present. This possibly allowed for more effective moisture retention that supported a substantial evergreen forest, probably on the south-western slopes, with patches of open woodland/savanna within exploitation range of the inhabitants of Sibudu (***Fig. 4A***). The charcoal $\delta^{13}C$ values from the Howiesons Poort and late MSA layers fall within the range of modern *Podocarpus* charcoal values (-28.07 ‰ to -23.42 ‰) for trees from Seaton Park, KwaZulu-Natal, and this is the nearest available modern analogue.

Post-Howiesons Poort occupations (~58 ka)

The changing composition of plant and animal communities in the deep sequence of the post-Howiesons Poort layers provides evidence for oscillating climatic conditions from the coldest period at the end of MIS 4 into MIS 3. Correspondence analysis of the seed and faunal data (Reynolds 2006) from this period implies time-related fluctuations in response to a changing environment. Magnetic susceptibility readings imply that the coldest conditions in the Sibudu sequence occurred in the earliest of the post-Howiesons Poort layers (called post-Howiesons Poort MSA 2 by Clark & Plug 2008) at the transition between MIS 4 and MIS 3. CA_{GIS} analysis suggests that during this period it was colder and drier than present and summer precipitation was less than today (Bruch *et al.* 2012). In more recent layers, magnetic susceptibility results show alternating cooler and warmer conditions with an overall warming trend, although temperatures remained lower than present (Herries 2006). The sediments were largely deposited due to anthropogenic activities within the site (Pickering 2006; Goldberg *et al.* 2009); therefore the magnetic susceptibility data should be interpreted with care. The lower magnetic susceptibility readings may correlate with periods of reduced human activity rather than a change in the environment, although major climatic events are recorded (Herries 2009).

The post-Howiesons Poort seed assemblage comprises a mixture of sedges and woody tree and shrub species (***Fig. 4B***). Cyperaceae nutlets occurring in the lower layers indicate the presence of open or semi-permanent water (Sievers 2006). The majority of other identified seeds originate from woody evergreen taxa, but deciduous taxa increase in the upper, more recent layers that coincide with the warming trend. Pollen and phytoliths include representatives of grasses, sedges and fern spores (Schiegl *et al.* 2004; Renaut & Bamford 2006; Schiegl & Conard 2006). The frequency of grass phytoliths increases in the upper layers and this may reflect an increase in grasslands around Sibudu, but this interpretation must be made cautiously because grass could have been used for tinder in some of the fireplaces (Schiegl *et al.* 2004) and also in the plant bedding that was frequently laid on the shelter floor (Wadley *et al.* 2011). Woody species from the charcoal assemblage indicate a continuous presence of an evergreen riverine forest component (Allott 2004, 2005, 2006). *Podocarpus* reappears in the post-Howiesons Poort layer called SPCA where *Acacia* species are absent, following the general trend for the two genera to be mutually exclusive (Wadley 2006). *Leucosidea sericea*, which can be a pioneer, was identified in the charcoal assemblage of two post-Howiesons Poort (~58 ka) layers (Allott 2006). This species does not occur near to the coast under modern environmental conditions; it occupies high altitudes and is often in areas with cold winters with frost (Killick 1990; Pooley 2003).

The faunal assemblage of the youngest post-Howiesons Poort layers is markedly different in species composition from the earlier Howiesons Poort layers. Small bovid species decrease through the oldest post-Howiesons Poort layers, until they are almost absent in the youngest post-Howiesons Poort layers where large species dominate the assemblage, including equids and large to very large bovids (Plug 2004; Cain 2006). Grazers appear throughout, but they are present in higher frequencies in the upper layers (Plug 2004; Cain 2006; Clark & Plug 2008) suggesting a shift from exploiting fauna in closed forest/woodland communities to those in drier, more open savanna/grassland communities. The Natal multimammate mouse (*Mastomys natalensis*), a pioneer species, is found in layer My (Glenny 2006). Although the species has a wide habitat tolerance, it is not a forest dwelling species and has a degree of water independence, allowing it to occur in dry areas (Meester *et al.* 1979; De Graaff 1981; Skinner & Smithers 1990).

After an initial cold phase during the post-Howiesons Poort, a warming trend is observed in the combined proxy evidence. In contrast to the afforestation that existed in the Howiesons Poort, open woodland and grassland communities seem more common by ~58 ka. There is an intriguing possibility that the initial post-Howiesons Poort occupations may have taken place during an early phase of succession; this is implied by the presence of the pioneer species *Leucosidea sericea* (shrub) and *Mastomys natalensis* (rodent). The charcoal $\delta^{13}C$ values from the post-Howiesons Poort layer SPCA fall within the range of modern values (-25.32 ‰ to -20.07 ‰) of a *Podocarpus* specimen from a refuge forest community from the Baviaans Kloof, Eastern Cape, where *Podocarpus* is restricted to river margins where there is sufficient moisture availability.

Late MSA layers (~48 ka)

Proxy environmental evidence from the late MSA layers suggests an initial period of warming followed by a cooler period. The occurrence of Cyperaceae nutlets (Sievers 2006) and the presence of hippopotamus (*Hippopotamus amphibious*) (Plug 2006) attest to the presence of a permanent water source. Seeds from evergreen taxa persist, but the frequencies of deciduous species increase throughout the late MSA sequence (Sievers 2006). The CA_{GIS} analysis of the flora suggests that the late MSA occupations experienced warmer conditions than the Howiesons Poort and post-Howiesons Poort and that summer precipitation had slightly increased (Bruch *et al.* 2012). The charcoal assemblage also reveals an increase in deciduous woody species (Allott 2006) and the vegetation profile can be interpreted as deciduous savanna woodland with common taxa including *Acacia* spp., *Albizia* spp. and *Celtis* spp. (***Fig. 4C*** and ***D***). In layer RSp (***Fig. 4C***) there is an unusual combination of *Acacia* and *Podocarpus*. This combination of genera is not seen in any other MSA layer at Sibudu (Allott 2006; Wadley 2006). RSp is the youngest Sibudu layer to contain *Podocarpus*; there is no evidence for its presence in more recent layers (Allott 2006). The phytolith composition at this time shows an overall decrease in grass and an increase in trees (Schiegl *et al.* 2004) suggesting that grassland patches were reduced at the expense of woodland.

The faunal species composition of the late MSA layers suggests a mixed environment. The RSp layer has produced a diverse faunal species profile with savanna, grassland and forest/woodland dwelling species present (Plug 2004; Cain 2006; Wells 2006). The Gambian giant rat (*C. gambianus*) is represented again in layer RSp, indicating the presence of forested areas and rainfall over 800 mm per annum (Skinner & Chimimba 2005; Glenny 2006). A substantial environmental change prior to or during the formation of RSp at 46.0 ka is suggested by the re-occurrence of the Natal multimammate mouse (*M. natalensis*) (Glenny 2006). Indirect evidence for a climate change between the post-Howiesons Poort and late MSA is also suggested by a hiatus of 9.8 ± 1.3 ka between these two occupational phases (Jacobs *et al.* 2008b). Environmental conditions were likely unsuitable for the use of the shelter as a permanent dwelling during the hiatus, perhaps because of a particularly arid phase (Jacobs *et al.* 2008b). Magnetic susceptibility readings suggest an initial cooling period in OMOD (Herries 2006), followed in MOD by a further warming trend.

Interpreting the charcoal isotope data

Proxy environmental data from Sibudu indicate that environmental conditions during the Howiesons Poort (65–62 ka) were cool and humid favouring the presence of evergreen forests (including *Podocarpus*) on the southern slopes near the site (***Fig. 4A***). The mean $\delta^{13}C$ values for *Podocarpus* are the most negative (GR = -24.62 ‰ and GS = -24.47 ‰) suggesting that there was relatively high moisture availability at this time. The $\delta^{13}C$ values have a high sample variance and wide range indicating that the genus was growing in a variety of habitats, for example, close to the river and on the drier hillside. Although *Celtis* is present contemporaneously, its $\delta^{13}C$ values have a low sample variance and range, suggesting a limited adaptive response to the shelter talus slope and open, dry north-eastern hillside opposite the shelter.

The $\delta^{13}C$ values for *Podocarpus* charcoal from the post-Howiesons Poort (~58 ka) have very low sample variance and range, and they are less negative values than those of the Howiesons Poort sample. The low variance suggests that *Podocarpus* was exceedingly constrained by the prevailing environmental conditions and was limited in its adaptive responses. The less negative absolute values than before suggest that the genus was responding to more arid conditions. Other factors that may affect carbon isotopic values in trees include relative humidity and soil water states in drier areas and in wetter areas the amount of summer irradiance and temperature (McCarroll & Loader 2004). *Celtis* $\delta^{13}C$ values from the same period have a higher variance and range than *Podocarpus*, suggesting that *Celtis* has a wider distribution and adaptive response to the more arid conditions at about 58 ka. Other proxy data from the post-Howiesons Poort imply that forested areas were greatly reduced by the final phase of this long sequence and that conditions were drier and with less moisture availability than during the 65–62 ka Howiesons Poort occupations.

During the late MSA (~48 ka) occupation represented here by layer RSp, changes in proxy environmental data suggest that a mosaic vegetation occurred around Sibudu, comprising a mixture of grassland, savanna, woodland, evergreen and riverine forest communities (***Fig. 4C*** and ***D***). The sheltered south-western areas would have favoured evergreen forest species, such as *Podocarpus*. Stable carbon isotope values of *Podocarpus* charcoal from the late MSA (RSp layer) show a higher variance and range than those from the post-Howiesons Poort, but much lower than those of the Howiesons Poort charcoal. This suggests that at about ~48 ka, only certain microhabitats were suitable for *Podocarpus*. Mean $\delta^{13}C$ values for *Podocarpus* and *Celtis* are more negative again in the late MSA, sug-gesting that available moisture levels were higher than those during the post-Howiesons Poort. No *Celtis* char-coal was found in layer RSp, but $\delta^{13}C$ values for *Celtis* charcoal from layer OMOD (also with an age of ~48 ka) suggest that the genus was able to establish itself in a similar fashion as seen at ~58 ka (***Fig. 4D***). The sample variance and range for the OMOD data are similar to those of the SPCA data suggesting that environmental conditions during both periods were suitable for *Celtis*.

Conclusion

Stable carbon isotope values from archaeological charcoal samples of two genera, *Podocarpus* and *Celtis*, from MSA layers at Sibudu Cave, have provid-ed proxy environmental data that support those from other archaeological sources. The consistencies in the environmental interpretation of the $\delta^{13}C$ charcoal data and the other palaeoenvironmental proxies from Sibudu Cave through time imply that the patterns in the isotopic data are not an artefact of charcoal forma-tion at different burning temperatures, nor are they an artefact of post-depositional contamination.

The integration of the different environmental proxies from Sibudu suggests that during the Howi-esons Poort (65–62 ka) the local environment was thickly forested, moist and more humid than at ~58 ka. The environment changed during the post-Howiesons Poort occupation (~58 ka) into the late MSA occupa-tion (~48 ka); it became drier and colder than present with vegetation shifting to open savanna grassland or woodlands.

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