SEDGES AS BEDDING IN MIDDLE STONE AGE SIBUDU

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DECLARATION

I declare that this thesis is my own unaided work for submission for the degree of Doctor of Philosophy at the University of the Witwatersrand. The degree is by publication and my publications, submitted paper and contribution in co-authored papers is detailed in the text. The thesis has not been submitted before for any degree or examination at any other University.

C. Sievers

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3 May 2013

ABSTRACT

Cyperaceae (sedge) nutlets dominate the archaeobotanical assemblage of fruits and seeds recovered from the Middle Stone Age deposits at the rock shelter Sibudu, KwaZulu-Natal, South Africa (Sievers 2006). My aim is to investigate the implications of the nutlet presence in terms of human behaviour and to demonstrate that the nutlets were likely brought into the shelter on sedge culms (stems) deliberately harvested by people and informally placed on the shelter floor to provide “bedding”, a surface for working, resting or sleeping. I use various empirical and experimental approaches to confirm the use of sedges for bedding at Sibudu as early as ~77 000 years ago, almost 50 000 years earlier than any previously identified archaeological bedding. The bedding consists of the sedges *Cladium mariscus* subsp. *jamaicense*, *Scleria natalensis, S. melanomphala, Cyperus* sp. and a panicoid grass, identified through Scanning Electron Microscopy

To investigate repeated and deliberate burning of bedding at Sibudu, I use experimental micromorphology and I compare the signatures of the Sibudu sediments with burned fresh sedge and grass bedding. I undertake further fire experiments, also in open air situations, to answer questions about burning sedge beds and the taphonomic implications. Experimental sedge bedding fires are hot and brief. The matrix beneath the fires affects the temperatures achieved both on the surface directly under the fire, and at depths of 2 cm and 5 cm below the surface; an ash matrix conducts heat more effectively than a matrix of 1–2 mm sized particles and allows for carbonisation of buried nutlets. The burning of dry and green bedding indicates that once the bedding is burning, the temperatures are sufficient to carbonise sedge nutlets below both dry and moist bedding.

The methodological innovations I introduce are the use of experimental micromorphology to address an archaeobotanical question and the use of GIS-based coexistence analysis of southern African archaeobotanical data to make interpretations about past climate. The analysis develops previous palaeovegetation research in the area (Sievers 2006; Wadley et al. 2008) and provides an environmental context for people/plant activities at Sibudu.

DEDICATION

This research is dedicated to those who collected sedges in the past and to those who continue to do so...

The series of photographs is set approximately 1 km downstream from the archaeological site, Sibudu Cave, and shows local women harvesting and preparing the sedge, *Cyperus involucratus*, to make mats for their own use and for sale. The mats are used for various purposes, but mostly to sit or sleep on (March 2011).

ACKNOWLEDGEMENTS

This Ph.D. has been an enjoyable and rewarding experience and this I owe to my supervisor, Professor Lyn Wadley, who gave me the encouragement and support to embark on and complete the research. I owe a huge debt to her for her inspiration and gentle, but firm guidance and I am grateful for all she has taught me about research and more. Smiling even now, I remember emails that made me laugh out loud. I thank her and Richard Wadley for their generosity. Thanks to my thesis committee for comments on my proposal and to Helen Kempson for being such an efficient scribe. I look back with pleasure on the work Helen, Silje Bentsen, Tammy Hodgskiss and I did together and extend huge thanks. Thank you Silje, for carrying the heaviest equipment and baking the delicious cinnamon buns (did you know that, according to Gavin Whitelaw, kneading dough is the best way to clean fingernails in the field?).

I thank my fellow authors for the privilege of working with them on the co-authored papers in this thesis. The reviewers' comments and the editors' publication of the papers are gratefully acknowledged too. At the end of each paper I acknowledge those who helped with research, background knowledge and practical matters. Simple acknowledgement does not, however, do justice to the generous advice, support and wide-ranging help provided by so many. For funding I am grateful to the National Research Foundation, the Palaeontological Scientific Trust, the University of the Witwatersrand (Wits) and to Lyn Wadley who provided funds for equipment, specialist analysis, transport costs, accommodation and expenses in the field and at conferences.

Many professional and amateur botanists shared their expertise and I thank them whole-heartedly: Tony Abbott, Clare Archer, Marion Bamford, Jane Browning, Neil Crouch, Hugh and René Glen, Esmé Franklin-Hennesy, the late Kath Gordon-Gray, Marinda Koekemoer, Sifiso Mnxati, Mkhipeni Ngwenya, Geoff Nichols, Ashley

Nicolas, Chris Reim, Yashica Singh, C.J. ’Roddy’ Ward and many friends at the regular Botanical Society excursions. For electron microscopy assistance I thank James Wesley-Smith and Priscilla Maartens at the University of KwaZulu-Natal, Miranda Waldron at the University of Cape Town and Mike Whitcomb, Alexander Ziegler and Jacques Gerber at Wits. I thank Miriam, John and the extended Dasa family in the Sibudu area for their warm welcomes and caring.

My sons, Dan and Will, and my close friends and my fellow archaeologists in KwaZulu-Natal and further afield have supported me with love, interesting discussions and patience, over the past three years. I love them all and thank them.

Sibudu team 2004

CONTENTS

LIST OF PAPERS

This thesis is based on five published papers and one submitted paper, which are reproduced in the formatting style of the respective journals in which they appear. The papers are listed below according to publication date.

Paper 1 Sievers, C., Muasya, A.M. 2011. Identification of the sedge *Cladium mariscus* subsp. *jamaicense* and its possible use in the Middle Stone Age at Sibudu, KwaZulu-Natal. *Southern African Humanities* 23, 77–86.

Paper 2 Sievers, C. 2011. Sedges from Sibudu, South Africa: evidence for their use. In: Fahmy, A.G., Kahlheber, S., D'Andrea, A.C. (eds) Windows on the African Past: Current Approaches to African Archaeobotany. Proceedings of the 6th International Workshop on African Archaeobotany, June 13–15, 2009, Helwan University, Cairo, Egypt. *Reports in African Archaeology* 3, 225–241.

Paper 3 Wadley, L., Sievers, C., Bamford, M., Goldberg, P., Berna, F., Miller, C. 2011. Middle Stone Age bedding construction and settlement patterns at Sibudu, South Africa. *Science* 334, 1388–1391.

Wadley, L., Sievers, C., Bamford, M., Goldberg, P., Berna, F., Miller, C. 2011. Middle Stone Age bedding construction and settlement patterns at Sibudu, South Africa. *Science* 334, 1388–1391. Supporting Online Material. DOI: 10.1126/science.1213317

Paper 4 Miller, C.E., Sievers, C. 2012. An experimental micromorphological investigation of bedding construction in the Middle Stone Age of Sibudu, South Africa. *Journal of Archaeological Science* 39, 3039–3051.

Paper 5 Bruch, A.A., Sievers, C., Wadley, L. 2012. Quantification of climate and vegetation from southern African Middle Stone Age sites: an application using Late Pleistocene plant material from Sibudu, South Africa. *Quaternary Science Reviews* 45, 7–17.

Paper 6 Sievers, C. *Submitted.* Experimental sedge bedding fires and the taphonomic implications. *South African Archaeological Bulletin*

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CHAPTER ONE – INTRODUCTION

1.1 Overview of the thesis

In this thesis I explore the use of sedges (Cyperaceae) at Sibudu Cave, a rock shelter situated in a cliff above the uThongathi River, approximately 12 km from the Indian Ocean, on the east coast of South Africa. I use empirical and experimental approaches to identify sedges at the shelter, investigate their routes of entry into the deposits, examine their taphonomy and consider their utilization by people occupying the shelter during the Middle Stone Age (MSA) between approximately 77 ka (thousand years) and 39 ka ago.

My methodological contribution is the use of experimental micromorphology to address archaeobotanical issues, specifically, to replicate the repeated laying down and burning of organic material, termed “bedding”, at Sibudu. Bedding provides an area on the shelter floor for sitting, sleeping, working or any other purpose requiring a place free of dust or other debris. Regular burning of the bedding and refurbishment with fresh material maintains the area.

Experimental carbonisation of fruits and seeds to trace their morphological changes as a result of exposure to heat, has generally been used for the identification of domesticated plants; here it is applied to non-domesticates, the small fruits (1–3 mm nutlets) of the Cyperaceae or Sedge Family. The Scanning Electron Microscopy (SEM) images of modern sedges are useful to archaeobotanists as well as botanists. I use SEM images to identify the ancient nutlets and hence the bedding materials laid down and used by people at Sibudu.

Through further experiments, I address taphonomy and examine the variables surrounding the carbonisation of plant material in archaeological deposits, specifically sedge nutlets under sedge bedding. I investigate the effect of the matrix under the bedding, variation of temperatures at various places under the bedding, the effect of the moisture content of the bedding and the taphonomic implications.

The presence of sedges in the Sibudu deposits provides information on the presence of water within foraging distance of Sibudu; sedges are generally plants of moist and wet environments. Although not the focus of this thesis, I include a climate and vegetation component to provide an environmental background. It involves the quantification of climate and vegetation using the combined seed and charcoal assemblages at Sibudu in a GIS-based coexistence analysis approach. This is the first time the method has been applied to archaeological data in southern Africa and it provides detail not possible through current methods for investigating past climatic conditions.

1.2 Hypotheses and aims

The hypotheses are that:

- sedge culms were deliberately harvested by people visiting Sibudu Cave during the MSA
- sedge culms were placed on the shelter floor as bedding
- sedge nutlets were sometimes carbonised as the result of deliberate burning of bedding for site maintenance

To test these hypotheses it is necessary to identify:

- the sedge nutlets
- route of entry of sedge nutlets into the Sibudu deposits
- use of sedges by people in the shelter
- taphonomic processes that caused the carbonisation of the sedge nutlets

1.3 Research approach and structure of thesis

This thesis incorporates single and co-authored published and submitted papers on research in overlapping disciplines. The papers are reproduced in the chapters summarised below and each paper is preceded by a detailed contents list. My research and the co-authored papers involved multidisciplinary collaboration:

botanists helped to identify nutlets and other botanical remains, a geomorphologist assisted with the analysis of microstratigraphy, a climate modelling specialist dealt with statistics, and my supervisor, a dedicated archaeologist with experience of many types of archaeological techniques and approaches, oversaw the project. The thesis is set out as follows:

Chapter 1 – Introduction

This chapter contains an overview of the thesis and statement of my hypotheses and aims. This is followed by chapter summaries, which include synopses of my papers and my contribution to each of them.

Chapter Two – Background

This chapter provides a background to the site, Sibudu and its environs, excavation and recovery methods at the site, stratigraphy and dating and an overview of the MSA research at the shelter. Certain aspects of the background information are repeated in each paper, while others are included only in certain papers; for ease of reference, this chapter provides a summary of the background information from all the papers.

Chapter Three – Botanical Research at Sibudu

This chapter provides a summary of the types of botanical remains at Sibudu, the approaches to the analysis and interpretation of fruits and seeds at Sibudu, and interpretations about people/plant relationships and past vegetation. The chapter ends with a copy of a co-authored paper:

Bruch, A.A., Sievers, C., Wadley, L. 2012. **Quantification of climate and vegetation from southern African Middle Stone Age sites: an application using Late Pleistocene plant material from Sibudu, South Africa.** *Quaternary Science Reviews* 45, 7–17.

The paper provides a vegetation and climate setting for the MSA occupations at Sibudu. It describes the first use in southern Africa of the GIS-based coexistence analysis approach using archaeological plant data and it indicates the value of this quantitative statistical tool. The method relies on the nearest living relative principle and is GIS-based in that the modern distribution of plants is used to calculate as far as possible the climatic tolerances for each of the identified seed and charcoal taxa present in the Sibudu assemblage. For each climate parameter, such as temperature and rainfall, and each assemblage (here the broad lithochronological periods at Sibudu), intervals are produced according to the maximum possible number of fossil flora that are able to coexist. The variation through time of these intervals provides an indication of the changing conditions. The approach reveals a refinement of detail not previously possible, namely, the mean minimum temperature of the coldest winter month appears to be the driving factor for climate change at Sibudu. This is the only parameter where the coexistence interval values do not overlap with modern ones: precipitation and temperature both annually and in the hottest and coldest quarters all overlap with modern parameter figures. More precision will be possible with larger samples and tighter tolerance ranges for taxa.

My contribution: I provided the fruits and seeds identification data used in this paper. Although most of the species identifications had been published previously (Sievers 2006) the information was used again and augmented with species that I have identified since then, including the period after 2010 when I registered for my Ph.D.

Chapter Four – Identification of Sedges at Sibudu

This chapter begins with a summary of the characteristics of sedges and of monocotyledonous plants that look similar to sedges and grow in similar habitats. The characteristics of the sedge *Cladium mariscus* are described in detail and are followed by the paper:

Sievers, C., Muasya, A.M. 2011. **Identification of the sedge *Cladium mariscus* subsp. *jamaicense* and its possible use in the Middle Stone Age at Sibudu, KwaZulu-Natal.** *Southern African Humanities* 23: 77–86.

The paper addresses the identification and use of sedges at Sibudu. SEM images of modern and ancient material confirm the identification of the nutlets of *Cladium mariscus* (L.) Pohl subsp. *jamaicense* (Crantz) Kük, and we argue for the use of this sedge as bedding material. A literature study of the ethnographic uses of the sedge and of the archaeological records of plant bedding is included in the paper.

My contribution: I initiated the research and applied for permission to sample sedge nutlets from the collections at the KwaZulu-Natal (KZN) Herbarium in Durban.

Sedge expert, Dr Muthama Muasya of the Botany Department at the University of Cape Town (UCT) agreed to collaborate and paid for the use of the SEM. I mounted the specimens and Miranda Waldon of the Electron Microscope Unit at UCT coated them and operated the SEM. Dr Muasya, Dr C. Stirton and I discussed the results. I wrote the paper and Dr Muasya commented on it and suggested minor changes.

Chapter Five – Routes of Entry

This chapter is concerned primarily with the possible routes of entry of sedge nutlets into the Sibudu deposits, an issue which is discussed in the paper:

Sievers, C. 2011. **Sedges from Sibudu, South Africa: evidence for their use.** In: Fahmy, A.G., Kahlheber, S., D'Andrea, A.C. (eds) Windows on the African Past: Current Approaches to African Archaeobotany. Proceedings of the 6th International Workshop on African Archaeobotany, June 13–15, 2009, Helwan University, Cairo, Egypt. *Reports in African Archaeobotany* 3, 225–241.

This single-authored paper provides a background to the study of sedges at Sibudu, as well as a literature study of archaeological and ethnographic uses of sedges. By eliminating natural and animal agents, a case is made for people as agents of deposition. This is a fundamental prerequisite for the determination of the use of sedges by people at the shelter, and I conclude that people harvesting sedges alongside and in the uThongathi River below the shelter, brought sedges, with nutlets attached, into the shelter. The paper was written before, but published after, the identification of the sedge, *Cladium mariscus* at Sibudu (Sievers & Muasya 2011).

Chapter Six - Bedding at Sibudu

This chapter presents the different lines of evidence that produced the earliest archaeological evidence of bedding construction, at ~77 ka, and the associated earliest evidence of the recognition by people of the medicinal properties of plants. Subsequent bedding maintenance strategies, presumably also to control pests, were the repeated refurbishment and burning of bedding. The *Science* paper and supplementary online material (SOM) was conceived of, co-ordinated and submitted by Prof. Lyn Wadley:

Wadley, L., Sievers, C., Bamford, M., Goldberg, P., Berna, F., Miller, C. 2011. **Middle Stone Age bedding construction and settlement patterns at Sibudu, South Africa.** *Science* 334, 1388–1391.

My contribution: I identified the basic bedding materials, namely sedges, and thus my contribution formed an integral component of the paper. My contribution began with sorting all the 1 mm sievings in the older layers (pre-Still Bay, Still Bay), most of the Howiesons Poort material and much of 1 mm sievings for the younger layers. Recovering the mineralised Still Bay remains was painstaking because the material is extremely delicate. Figure 2 in the paper is my work and the identifications of monocotyledons in table 1 were supplied by me. I participated in the writing of the paper and the SOM. In the SOM, the section on identification of monocotyledonous seeds, stems and leaves was written by me and I composed figure S13 and table S3. The experimental burning of sedge bedding reported in the SOM is a summary of the work by Miller and Sievers (2012) (see Chapter Seven of this thesis) and figures S14A and S14C refer to this research.

Chapter Seven – Experimental Micromorphology

This chapter demonstrates the value of experimental micromorphology for calibration of micromorphological interpretations of archaeological deposits. Although micromorphological investigations of archaeological deposits, and fire in archaeological deposits, are not new, this chapter reports on the first experimental micromorphological investigation to address an archaeobotanical issue. The methods and results of experimental fires designed to compare the micromorphologies of modern fires with those of ancient Sibudu combustion events, are set out in:

Miller, C.E., Sievers, C. 2012. **An experimental micromorphological investigation of bedding construction in the Middle Stone Age of Sibudu, South Africa.** *Journal of Archaeological Science* 39, 3039–3051.

My contribution: I approached Dr Miller for collaboration on this research and located the grasses and sedges for the experiments. Dr Miller and I did the experiments together, removed the experiment samples and impregnated them with resin. The acquisition and preparation of the archaeological samples was done by Dr Miller, who also provided the expertise for the making of the resin blocks. Prof.

Wadley funded the project and arranged for the thin sections and slides to be made at a specialist laboratory in the USA. I wrote the first draft of the paper, which was revised and substantially added to by Dr Miller, who reported on the micromorphology methods and interpretations. The identifications of the plants in the micromorphology slides were made by me.

Chapter Eight – More Burning of Sedge Bedding

This chapter describes more burning experiments with fresh sedge bedding, the temperatures conducted by different matrices below burning sedge beds and the taphonomic implications. The details are set out in the single-authored paper:
Sievers, C. *Submitted.* **Experimental sedge bedding fires and the taphonomic implications**. *South African Archaeological Bulletin*
In the paper, I provide evidence that an ash matrix below sedge bedding conducts heat more efficiently than coarse sand and as a result, the survival of nutlets in ash is lower than in a sand matrix, both on the surface below the bedding and at a depth of 2 cm below the surface. Temperatures vary across the surface under a bedding fire. However, no conclusive results were apparent about the effect of wind direction on these temperatures. Experiments to test the effect of the moisture level of the bedding on temperatures underscored the range of interconnected variables affecting the burning of sedge bedding.

Chapter Nine – Discussion and Conclusions

This chapter summarises and critically discusses the research presented in the previous chapters. I conclude that the aims of the thesis have been achieved; I have demonstrated that sedges were used as bedding in Middle Stone Age Sibudu.

Chapter Ten – Future Research

I discuss questions that were generated during the research and propose issues for future research. The heuristic value of my research is evident because projects can sprout as prolifically as sedge nutlets from the work completed here.

CHAPTER TWO - BACKGROUND

2.1 Description of Sibudu and environs

Sibudu Cave, also referred to as Sibudu, is located in the KwaZulu-Natal Province on the east coast of South Africa and is approximately 40 km north of Durban and 12 km from the Indian Ocean (Fig. 2.1). It is a south-west facing shelter situated at about 100 m above mean sea level (Wadley 2004), in Natal Group Sandstone that was back-cut by the uThongathi River approximately 150 000 years ago (Rodney Maud, pers. com. 2012). At present Sibudu is 20 m above the perennial uThongathi river (Fig. 2.2) and access is via natural steps in a short vertical rock face. During times of flood the river reaches chest level at the base of this access and crossing the river can be extremely dangerous (Fig. 2.3).

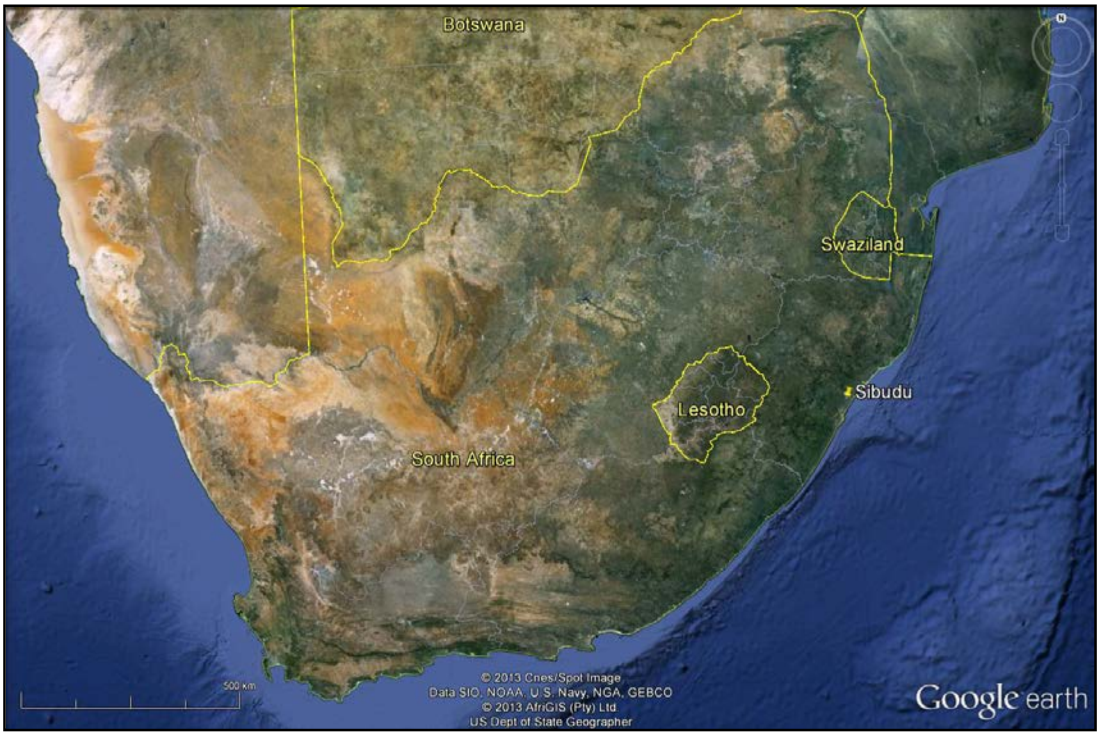

Figure 2.1 Geographical location of Sibudu in southern Africa. Scale: 500 km. (Google Earth 2013)

Figure 2.2 View downstream, from Sibudu, during exceptionally heavy rain (19/11/2009).

Figure 2.3 uThongathi River in flood (19/11/2009).

Figure 2.4 View upstream showing sedges growing along the uThongathi River banks. Sibudu is out of the picture, to the right. Flooding reaches chest-height at the foot of the cliff. The depth of the water in this photograph is approximately knee-height (27/02/2010).

The sandy river bed supports grasses, sedges, small shrubs and trees (Fig. 2.4), amongst others, *Syzygium cordatum*, *Millettia grandis*, *Ficus* spp. and invasive alien plants. On the northern slopes of the river, the cliff and steep valley has prevented the extension of sugarcane and subsistence farming, which takes place wherever there is arable land in the Sibudu environs. The valleys and cliffs are south-facing; this cooler aspect and the lack of agricultural development has preserved indigenous forest with many plant species (Appendix A), including the extremely rare *Celtis mildbraedii*, the Red-fruit White-stinkwood, on the drip line of the shelter. *Celtis mildbraedii* is a remnant of the wet, tropical coastal forests of East Africa and is found in only six other scattered locations in South Africa, all in KZN (Boon & Symmonds 2001). The species is considered endangered in KZN because of its low frequency, severely fragmented populations and apparent lack of recruitment (Boon & Symmonds 2001).

The forest around Sibudu is defined as ‘coastal scarp forest’ (C.J. Ward, pers. com. 2012) and from a biodiversity perspective, is probably the most important forest type in South Africa (Boon 2010). The Sibudu area falls within the KwaZulu-Natal Coastal Belt of the Indian Ocean Coastal Belt, also referred to as Subtropical Coastal Forest, a biome 10–35 km wide that extends from southern Mozambique in the north to Pondoland in the south and covers altitudes of 0–450 m (Mucina & Rutherford 2006). The biome is characterised by rolling hills and steep cliffs, which in the Sibudu area are evident in the north-facing slopes on the southern side of the uThongathi River and the cliff-face and valleys of the northern banks. This varied topography, the river itself, and the alluvium provide habitats for many different plant species. The hot, wet summers and mild winters complement the topography in contributing to high species richness. The climate is influenced by the southbound movement of the Intertropical Convergence Zone in summer (Tyson 1986) and the ameliorating influence of the warm Agulhas Current which flows southward along the coast of KZN. Rain falls mostly in summer, but is present throughout the year. This distinguishes the Subtropical Coastal Forest Biome from savanna, which experiences a period entirely free of rainfall (Mucina & Rutherford 2006). Average summer rainfall is 501–750 mm; average winter rainfall is 251–379 mm; average present-day temperatures for January are 22–25°C and average temperatures for July are 17–20°C (Grant & Thomas 1998). Humidity is high, especially in January and February and the area does not experience frost.

The indigenous vegetation around Sibudu is exploited by the local people for firewood, grazing, crafts, food, medicines and ritual purposes. Bark has been removed from at least three tree species growing on the Sibudu drip-line: *Celtis africana* known as the White-stinkwood (the wood mixed with crocodile fat is used against lightning), *C. mildbraedii* (Fig. 2.5) and *Schotia brachypetala,* the Weeping Boerbean, which has various medicinal uses. Local woman gather the leaves of *Obetia tenax,* the Mountain-nettle, laughing and yelping all the while at the sting of the leaves, which are cooked and eaten (the bark also provides strong twine). Two local women were once observed gathering *Aptenia cordifolia* growing just beyond the drip-line, to place in an infant’s burial (the plant is used as protection against sorcery) (pers. obs. Lyn Wadley, CS; uses recorded in Boon 2010). Culms of the sedge *Cyperus involucratus*, which grows along the river and in the shallows, are harvested to make mats (pg. v). These various plant uses noted, provide a glimpse into the wealth of local indigenous plant-use knowledge (Bryant 1909; Smith 1960; Watt & Breyer-Brandwijk 1962; Pooley 1980, 1993, 1998; Fox & Norwood Young 1982; Cunningham 1988; Hutchings et al. 1996; Van Wyk & Gericke 2000; Van Wyk et al. 2000; Arnold et al. 2002; Von Ahlefeldt et al. 2003; Cunning &Terry 2006; Paulsen et al. 2012; Zukulu et al. 2012). This rich heritage is sustained through the availability of the plants. A detailed botanical investigation of the Sibudu area needs to be completed and a final list of species is likely to number hundreds, almost all of them with recorded uses. Contemporary uses of the plants already recorded (Appendix A) range from fuel, food, drink, health and beauty to skills and crafts. Many of these plants may prove to have been used in the ancient past as well: two archaeological examples at Sibudu are the use of sedges for bedding and the medicinal use of *Cryptocarya woodii*, the River Wild-quince.

Figure 2.5 View of Sibudu from the north side of the shelter. The trunk of a large *Celtis mildbraedii* can be seen in the right of the photograph. The pale trunk near the sieves is *Celtis africana.* (Photo: L. Wadley 2011).

Encroachment of alien plants is a serious problem along the river course and in the forest. Since 1998, the invasive *Pereskia aculeata* (Barbados gooseberry) has moved down the cliff and valley and its vigorous thorny growth has to be pruned back to allow access to the shelter. *Pereskia* is smothering the indigenous flora. Ironically, the rampant *Pereskia* may prove to be the saving grace for the unique heritage at Sibudu by preventing access and possible damage to the rich archaeological deposits.

On the north-facing slopes, south of the uThongathi River, the alien invaders, *Chromolaena odorata* (triffid weed) and *Lantana camara* are rampant wherever farmland lies fallow. Along the track leading down to the river and the river bed itself, other invasives include *Ageratum* sp. (blue weed), *Colocasia esculenta* (*amadumbe*/cocoyam), *Cestrum laevigatum* (inkberry), *Mimosa pudica* (sensitive weed), *Nefrolepsis exaltata* (sword fern), *Psidium guajava* (guava), *Ricinus communis* (castor-oil plant), *Schinus terebinthifolius* (Brazilian pepper tree), and *Senna didymobotrya* (cassia). Nevertheless, many sedges and grasses are able to survive in the alluvial sand along the river course and large stands of *Cyperus involucratus* grow about 1 km downstream from Sibudu. These are the *Cyperus* culms that are harvested annually by local Zulu women to make sleeping mats that are sold locally and further afield (pg. v). The comfort, durability and low price of these mats ensure that this local craft is sustained.

The forest around Sibudu supports remnant wildlife such as Vervet Monkeys *Chlorocebus pygerythrus*, the Rock Hyrax or Dassie *Procavia capensis*, and small ungulates. Presumably small buck and wild pig are the prey of the hunting parties and their hunting dogs that I have observed emerging from the forest behind Sibudu. A list of the avian fauna present in the area has not been compiled, but the following birds have been noted: Red-winged Starling, Lanner Falcon, Lesser Striped Swallow, Swifts, White-necked Raven (all nesting in the cliff and shelter ledges), Cape Glossy Starling, Egyptian Goose, Purple Turaco, African Fish Eagle, Grey Heron, Cape Wagtail, Pied Kingfisher, Giant Kingfisher, Reed Cormorant, Yellow-billed Duck, Hadeda Ibis (nesting in the *Celtis mildbraedii*) and various doves.

2.2 Excavation and recovery methods

Standard excavation procedures are followed at Sibudu. The excavation grid is set up in 1 m squares identified by alphabetic letters from north to south and algebraic numbers from the rear to the front of the shelter. Each square is divided into four 50 cm quadrants, which are identified by lower case letters: quadrant *a* is in the northeast, *b* is in the southeast, *c* is in the northwest and *d* is in the southwest. Excavation follows the stratigraphy and material is bagged according to quadrant and layer. The colour and texture of each layer is generally reflected in the name of the layer, for example, the appended Sp in RSp, BSp and YSp refers to the speckled nature conferred by gypsum flecks in layers that are predominantly red, brown and yellow; GS refers to Grey Sand and GR to Grey Rocky (Wadley & Jacobs 2006). Munsell colour readings are taken for each unit. Features are removed separately and in the case of hearths, the top, middle and base are removed individually in order to record the preservation of carbonised organic material in different parts of the hearths.

Soil samples are taken for each layer and feature. Volumes of excavated deposit are recorded according to measurement markings on the sides of buckets; all material is sieved through stacked 2 mm and 1 mm sieves; and the volumes in each sieve are recorded. Prior to 2003, 1 mm sieves were not used. Before sorting, the bagged 1 mm sieved material is sieved a second time in stacked 1 mm and 0.425 mm geological sieves, to enable more efficient recovery of seed and fruit fragments. Dry sieving is used in preference to flotation because moisture, even on the tip of a fine paintbrush used to lift small seeds, has caused disintegration of the some of the fragile material.

Due to the low frequencies of fruits and seeds in most units, all sieved 1 mm material is generally sorted. A few units, for example, layer BSp, are thicker and extend further across the shelter floor. In such cases a minimum of 10 litres is retained from each excavated quadrant. The excavated deposit from across a particular unit is generally more than 10 litres, although there are exceptions, such as the different layers of a small hearth (ash, middle, charcoal base). All plant material from the 2 mm sieves is collected for analysis. All fruits, seeds and fragments of fruiting bodies in the 1 mm and 0.425 mm sieves are collected. I use 10x magnification for sorting the 1 mm sieved deposit. Identification is done under magnification up to 40x and in some cases, using SEM (Sievers & Muasya 2011)

2.3 Stratigraphy and dating

The Wadley excavations at Sibudu (1998–2011) have uncovered a three-metre deep sequence of clear and finely stratified layers (Figs. 2.6 and 2.7) that have been dated by single-grain optically stimulated luminescence (OSL) analysis of sedimentary quartz grains (Table 2.1; Jacobs et al. 2008a,b). The deposits are dry and the sediments are poorly sorted, which implies little or no waterborne transportation in the past (Pickering 2006). The sequence comprises the pre-Still Bay at the base of the excavations (layers BS to LBG), overlain by Still Bay (layers RGS2 and RGS), Howiesons Poort (layers PGS to GR), post-Howiesons Poort (layers YA2 to BSp), late MSA (layers YSp to PB) and final MSA (layers Mou to Co). The latter three informal lithic designations are used here pending further study of the ‘Sibudu Technocomplex’, or ‘Sibudan’ which are possible alternative labels (Conard et al. 2012; Lombard et al. 2012). OSL ages (Jacobs et al. 2008a,b) for the occupations are (Table 2.1): Pre-Still Bay, a single age of 77.2 ± 2.1 ka in the BS member and two ages, 73.2 ± 2.3 and 72.5 ± 2.0 ka in the LBG layer; Still Bay, a single age of 70.5 ± 2.0 ka in RGS; Howiesons Poort, three ages between 64.7 ± 1.9 and 61.7 ± 1.5 ka; post-Howiesons Poort, six ages with a weighted mean of 58.5 ± 1.4 ka; late MSA, six ages with a weighted mean of 47.7 ± 1.4 ka; final Middle Stone Age, two ages with a weighted mean of 38.6 ± 1.9 ka. Occupation is not continuous and there are hiatuses of 10.8 ± 1.3 ka and 9.1 ± 3.6 ka between the last three periods of occupation. These hiatuses lack any sediment; currently, there is no explanation for this. There is no Later Stone Age at Sibudu and Iron Age deposits lie directly upon the final MSA deposits. Large pits were dug through the final and late MSA deposits during the Iron Age occupation of the shelter, but they are clearly defined and do not extend deeper than the youngest layers of the post-Howiesons Poort (SPCA and BSp2). There is minor disturbance of the deposits by roots and bioturbation. Although rock fall from the roof of the shelter has disturbed the deposits in some places, there is no other geogenic disturbance, such as water flow through the deposits. It is clear that the rock fall has influenced the placement of features and organisation in subsequent occupations (Wadley 2012a).

The Sibudu deposits are overwhelmingly anthropogenic (Schiegl et al. 2004; Pickering 2006) and particularly after the Howiesons Poort, they are dominated by combustion events such as individual hearths, the remains of burnt bedding and 'reworked' ash (Wadley & Jacobs 2006; Goldberg et al. 2009; Bentsen 2012; Wadley 2012b). Although the stratigraphy is complex, the layers are clear and of centimetre scale. The post-Howiesons Poort comprises 80–100 cm of deposits made up of thirty-seven clearly distinguishable layers and they date to a relatively short occupation at ~58 ka (Fig. 2.6; Table 2.1). White, black and pink lenses can be seen in section and indicate the sequence generally observed in fires: white ashes from complete combustion lying on black incompletely combusted fuel (commonly referred to as 'charcoal') lying on sediment stained red from heat above.

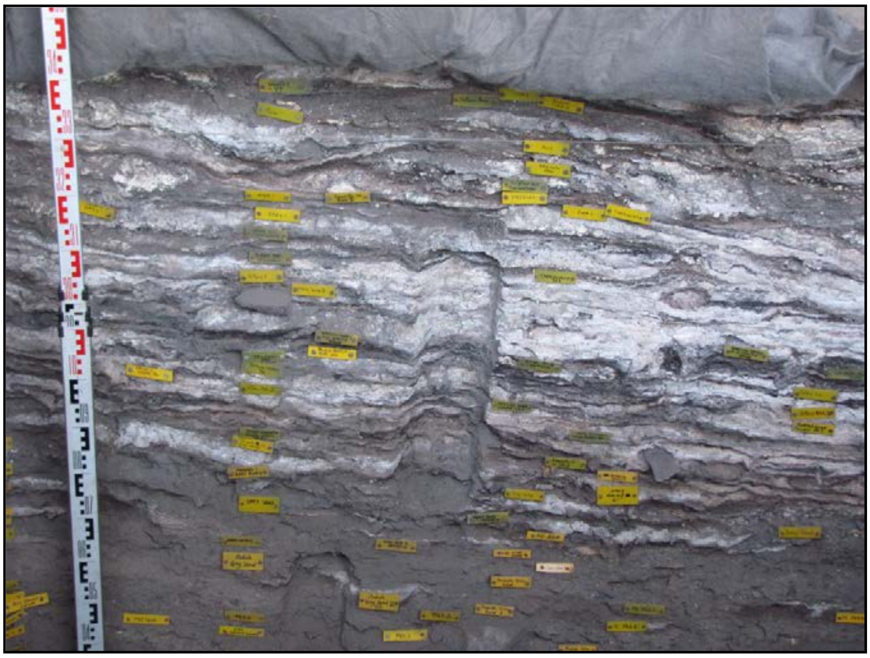

Figure 2.6. Well-defined, ashy, post-Howiesons Poort layers (~58 ka) (Wadley & Jacobs 2006; Jacobs et al. 2008a, b) at Sibudu. The section extends from layer PGS, a Howiesons Poort layer with an age of 64.7 ± 1.9 ka (Jacobs et al. 2008a), to Yellow Pox, a post-Howiesons Poort layer. The indented columns at the centre and lower left, mark where samples were removed for micromorphological analysis.

Table 2.1 Sibudu stratigraphic units, OSL ages (Wadley & Jacobs 2006; Jacobs et al. 2008a,b) and cultural associations based on lithic analysis.

Stratigraphic unit	OSL ages (ka)	Cultural association
Co	38.0 ± 2.6	final MSA
Bu	39.1 ± 2.5	
LBMOD	49.9 ± 2.5	late MSA
MOD	49.1 ±2.5	
OMOD	46.6 ± 2.3	
OMODBL	47.6 ± 1.9	
RSp	46.0 ± 1.9	
RD	49.4 ± 2.3	
BSp	57.6 ± 2.1	post-Howiesons Poort
SS	59.6 ± 2.3	
OP	59.0 ± 2.2	
Ch2	58.3 ± 2.0	
Y1	58.6 ± 2.1	
B/Gmix	58.2 ± 2.4	
GR2	61.7 ± 1.5	Howiesons Poort
GS2	63.8 ± 2.5	
PGS	64.7 ± 1.9	
RGS	70.5 ± 2.0	Still Bay
LBG	72.5 ± 2.0	pre-Still Bay
LBG2, LBG3	73.2 ± 2.3	
BS	77.2 ± 2.1	

The brightly coloured deposits at Sibudu that occur in the post-Howiesons Poort and younger layers represent massive combustion events and include much gypsum (Schiegl & Conard 2006; Wadley & Jacobs 2006). The scarcity of gypsum and of evidence of large combustion events below GR in the Howiesons Poort (GR2 has an age of 61.7 ± 1.5 ka [Jacobs et al. 2008a]) may indicate that there is a relationship between gypsum and the combustion events. Scheigl and Conard (2006: 149) consider the stability of gypsum ($CaSO_4{\cdot}2H_2O$) and calcite (the most stable polymorph of calcium carbonate, $CaCO_3$), amongst other evidence at Sibudu, to indicate dry conditions and minor degrees of diagenesis of the deposits. Dry conditions are confirmed by the general absence of water-borne particles in the sediment microscopy (Pickering 2006). The integrity of the deposits and the numerous fires have made for an excellent sequence of preserved botanical remains, which combined with the faunal remains and cultural material at Sibudu, have produced a detailed sequence that is unique in the MSA in South Africa.

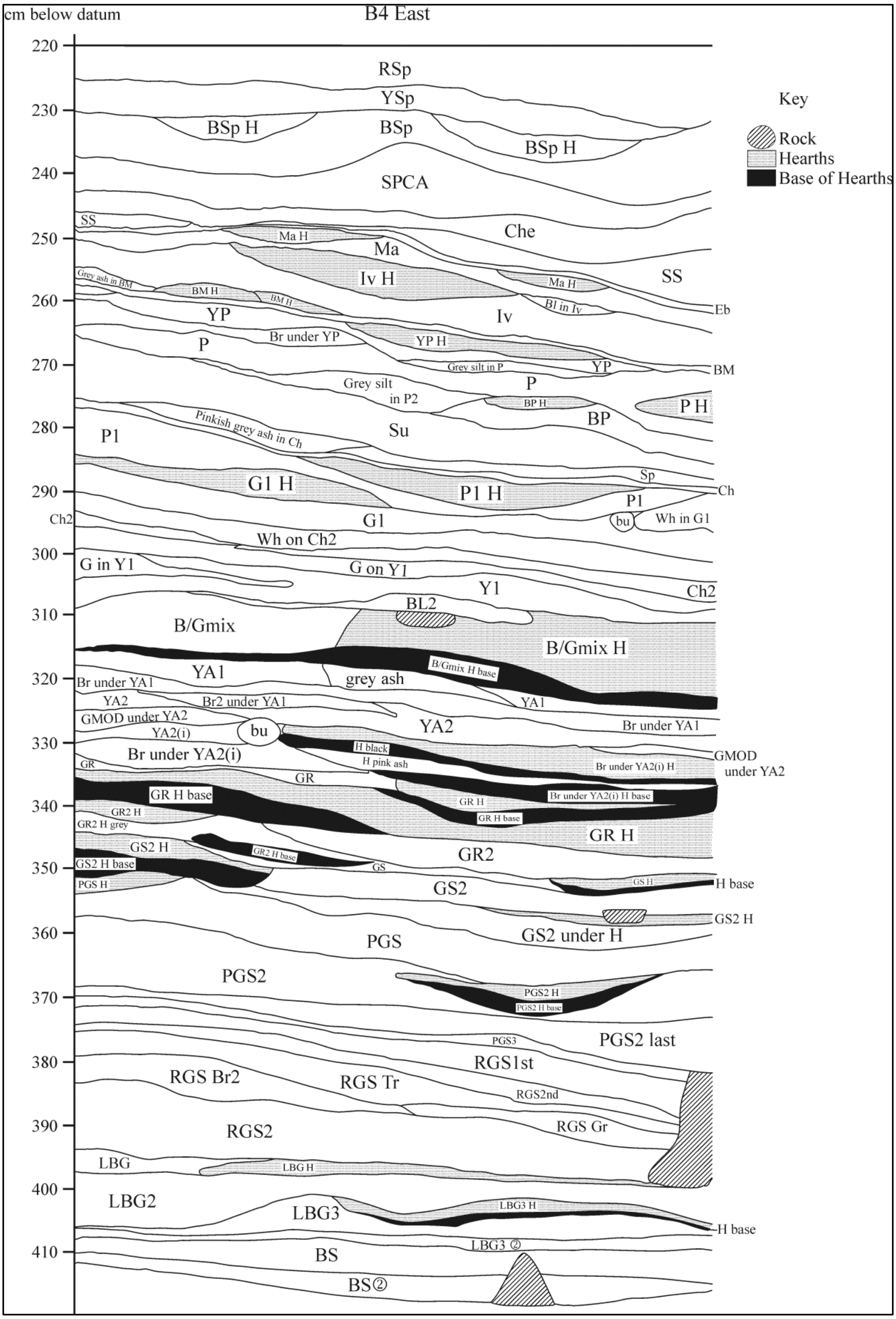

Figure 2.7 Sibudu east wall stratigraphy in square B4. Only layers BS2 to RSp are represented in this figure because of space limitations, but there are 16 BS layers and MSA layers OMOD and MOD occur above RSp. (FromWadley et al. 2011).

2.4 MSA research at Sibudu

Professor Lyn Wadley of the University of the Witwatersrand began the excavations at Sibudu in 1998 and the large multi-disciplinary team that has participated in the project includes local and international specialists in a diverse range of disciplines. The resultant multi-stranded evidence has added colour and detail to the rich tapestry of the past from Sibudu (Wadley 2008). An impressive list of publications and theses deals with the environment, technology, chronology and cultural sequence at the shelter (Wadley 2001a, 2004, 2005a,b,c, 2006, 2007, 2008, 2010a,b,c,d,e, 2011, 2012a,b,c; Allott 2004, 2005, 2006; Cain 2004, 2005, 2006; Lombard 2004, 2005, 2006a,b, 2007a,b, 2008, 2011; Lombard et al. 2004; Plug 2004, 2006; Schiegl et al. 2004; Wadley & Jacobs 2004, 2006; Williamson 2004, 2005; Wadley et al. 2004, 2008, 2009; Villa et al. 2005; Cochrane 2006, 2008; Delagnes et al. 2006; Glenny 2006; Herries 2006; Pickering 2006; Renaut & Bamford 2006; Reynolds 2006; Schiegl & Conard 2006; Sievers 2006; Villa & Lenoir 2006; Wadley & Whitelaw 2006; Wells 2006; Backwell et al. 2008; Clark & Plug 2008; d'Errico et al. 2008, 2012; Hall et al. 2008; Jacobs & Roberts 2008; Jacobs et al. 2008a,b; Plug & Clark 2008; Wadley & Mohapi 2008; Goldberg et al. 2009; Clark & Ligouis 2010; Lombard & Phillipson 2010; Clark 2011; Wadley & Kempson 2011; Conard et al. 2012; Hodgskiss 2012; Mohapi 2012).

The MSA of South Africa has produced evidence of a variety of behavioural practices that signal the cognitive complexity of anatomically modern humans. Terms such as cultural modernity, modern behaviour, symbolic thinking, symbolically mediated behaviour, symbolic material culture and complex cognition (Wadley 2001b, 2010a; Henshilwood et al. 2002, 2004; Texier et al. 2010) have been used to describe these innovations. At Sibudu these innovations are represented by shell beads (d'Errico et al. 2008); the manufacture and use of compound adhesives (Lombard 2007a and references therein; Wadley et al. 2009; Wadley 2010a); and circumstantial evidence for the use of snares (Wadley 2010b) and bows and arrows (Lombard 2007a and references therein, 2011; Wadley & Mohapi 2008; Lombard & Phillipson 2010). Sophisticated stone tools such as segments and points and fine bone points found at the site would have required hafting (Backwell et al.

2008). A number of specialised bone tool types are present at Sibudu, 30 000 years earlier than anywhere else in the world (d'Errico et al. 2012). These bone tools and other artefacts such as notched and serrated stone points (Wadley 2005a; Lombard 2012; Lombard et al. 2012) form part of the growing corpus of evidence pointing towards regional variation within the MSA (Texier et al. 2010; d'Errico et al. 2012; Mitchell 2012). Issues of chronology and preservation have bearing on this matter.

Organic remains are well-preserved at Sibudu and the information from charcoal, fruits and seeds and to a lesser extent, pollen and phytoliths (Allott 2004, 2005, 2006; Wadley 2004, 2006; Herries 2006; Renault & Bamford 2006; Reynolds 2006; Sievers 2006), has been combined with faunal interpretations (Plug 2004, 2006; Glenny 2006; Reynolds 2006; Clark & Plug 2008; Wadley et al. 2008) to provide a fuller window into the past. This is discussed in further detail in the next chapter.

CHAPTER THREE – BOTANICAL RESEARCH AT SIBUDU

Both macrobotanical and microbotanical analyses at Sibudu have contributed to an understanding of the vegetation around Sibudu and the interrelationship between people and plants during the time that deposits built up (Allott 2004, 2006; Herries 2006; Renault & Bamford 2006; Reynolds 2006; Sievers 2006; Wadley 2004, 2006). The analyses include charcoal, fruits and seeds, pollen, phytoliths and plant residues on stone tools.

For accurate interpretation of the remains it is imperative to consider agency or routes of entry into the deposit; what happened to the remains between deposition and excavation; excavation bias which includes recovery methods and sampling; and statistical analysis which includes methods of presentation of the data.

3.1 Approach to analysis and interpretation

I follow the principle that the morphology and physiology of modern plants vary little from those found in the Sibudu deposits and in the absence of alternatives, I turn to modern analogues for identification and interpretation of the ancient Sibudu plant taxa. I extend the standard botanical methods for plant identification to the carbonised and mineralised Sibudu archaeobotanical material. The approaches to archaeobotanical recovery, identification and interpretation are those summarised by Pearsall (2000) in her handbook of procedures for palaeoethnobotany.

Uniformities and actuality-based knowledge of materials provides firmer grounding on which to base inferences (Gifford-Gonzalez 2011). I follow ‘Middle Range Theory’ developed by Binford (1977) and apply hypotheses, formulated partly through ethnographic observations, as models for interpretations of the Sibudu archaeobotanical remains. My experimental approach is based on scientific principles, but variable conditions inherent in outdoor experiments, and emerging results influenced the direction and execution of the experiments. In this sense the ‘hermeneutic spiral’ applies (Hodder 1999). The experiments were devised to investigate the taphonomy of the carbonised bedding and to recognise and understand the effect of formation processes on the archaeological record.

For accurate interpretation of any archaeological data it is essential to understand the taphonomy and formation processes. Factors affecting archaeobotanical assemblages are the routes of entry of the material; preservation issues; recovery and identification of the remains; and the statistics used for presentation of the evidence.

In a shelter such as Sibudu where birds, animals, people and natural processes such as wind and gravity could all have contributed to the archaeobotanical assemblage, it is essential to establish the agents of plant material deposition (Sievers 2011). Once people have been established as the route of entry, one must consider the direct and indirect selective processes they exerted by gathering particular plants or plant parts and the effects on preservation of their processing and/or use of the plants. The effects of burning sedge bedding are explored in Sievers (submitted). Most plants in archaeological contexts are preserved by accident. Carbonised plant remains represent only a small part of the original plant assemblage and different types of plant remains are more or less likely to become charred and be preserved (Van der Veen 2007). Carbonised plant remains are found throughout the Sibudu sequence, particularly from ~73 ka onwards and with increasing frequency in the more recent layers (Allott 2006; Sievers 2006; Table 3.1). Mineralised plant remains are found in the ~77 ka layers and the identifications, formation processes and interpretations are reported in Wadley et al. (2011).

Table 3.1 Plant taxa identified from charcoal, seeds, pollen and phytoliths recovered from Sibudu MSA layers (Allott 2006; Renaut & Bamford 2006; Schiegl & Conard 2006; Sievers 2006; Wadley et al. 2011) grouped according to lithostratigraphic units and OSL dates (Wadley & Jacobs 2006; Jacobs et al. 2008a,b). Genus and species, if known, are noted. Family name only, is listed when identification is possible only to family level and no genus for the particular family has been recorded in a particular layer. Abbreviations: f.=final; l.=late; HP=Howiesons Poort; p=post; pre-SB=pre-Still Bay (~77–73 ka); x denotes presence.

Table 3.1 continued:

			~71ka	65-62ka	~58 ka	~48ka	~ 38 ka
	Family	pre-SB	SB	HP	p-HP	l. MSA	f. MSA
Acacia sp.	Fabaceae	-	-	-	x	x	x
cf. *Afzelia* sp.	Fabaceae	-	-	-	-	x	-
Albizia spp.	Fabaceae	-	-	-	-	x	-
Indet. charcoal	Anonaceae	-	-	-	x	x	-
Indet. charcoal	Apocynaceae	-	-	x	-	x	-
Asparagus sp.	Asparagaceae	x	-	x	x	x	x
Brachylaena spp.	Asteraceae	-	-	x	x	-	x
Bridelia sp.	Euphorbiaceae	-	-	-	x	x	-
cf. *Burkea africana*	Fabaceae	-	-	-	-	x	-
Indet. charcoal	Burseraceae	-	-	-	x	x	-
Buxus sp.	Buxaceae	-	-	x	x	x	-
Calodendrum capense	Rutaceae	-	-	-	x	x	x
Celtis africana	Celtidaceae				x		
Celtis sp.	Celtidaceae	-	-	-	x	x	-
Chrysophyllum viridifolium	Sapotaceae	-	-	-	-	x	-
Cladium mariscus	Cyperaceae	x	x	x	x	x	-
Clerodendrum glabrum	Lamiaceae	-	-	-	x	x	x
Indet. charcoal	Combretaceae	-	-	-	x	x	-
Cordia cf. *caffra*	Boraginaceae	-	-	-	x	x	x
Cryptocarya woodii	Lauraceae	x	-	-	-	-	-
Cryptocarya sp.	Lauraceae	-	-	-	x	-	-
Cunonia capensis	Cunoniaceae	-	-	-	x	x	-
Curtisia dentata	Cornaceae	-	-	x	-	x	-
Cussonia sp.	Araliaceae	-	-	-	-	x	-
Indet. seed	Cyperaceae	x	x	x	x	x	-
Indet. phytolith	Cyperaceae	-	-	-	-	-	x
Cyperus sp.	Cyperaceae	-	-	-	x	-	-
Cyphostemma sp.	Vitaceae	-	-	-	-	x	-
Deinbollia sp.	Sapindaceae	-	-	-	x	-	-
Diospyros sp.	Ebenaceae	-	-	-	x	x	-
Erica caffra	Ericaceae	-	-	-	x	x	-
Erica sp.	Ericaceae	-	-	-	x	x	x
cf. *Erythrina* sp.	Fabaceae	-	-	-	-	x	-
Euclea spp.	Ebenaceae	-	-	-	x	x	-
Ficus sp.	Moraceae	-	-	-	x	x	-
Grewia sp.	Tiliaceae	-	-	x	x	x	-
Harpephyllum caffrum	Anacardiaceae	-	-	-	-	x	-
Heteromorpha arborescens	Apiaceae	-	-	-	-	x	-
Kirkia sp.	Kirkiaceae	-	-	x	-	x	x
Indet. charcoal	Lamiaceae	-	-	x	x	x	-
Lantana cf. *rugosa*	Verbenaceae	-	-	x	-	x	-
Leucosidea sericea	Rosaceae	-	-	-	x	-	-

Table 3.1 continued:

			~71ka	65-62ka	~58 ka	~48ka	~ 38 ka
	Family	pre-SB	SB	HP	p-HP	l. MSA	f. MSA
Indet. Pollen	Liliaceae	-	-	-	x	-	-
Macaranga cf. *capensis*	Euphorbiaceae	-	-	-	-	x	-
Indet. charcoal	Malvaceae	-	-	-	x	-	-
Manilkara sp.	Sapotaceae	-	-	-	x	-	-
Morella cf. *pilulifera*	Myricaceae	-	-	-	-	x	
Mystroxylon cf. *aethiopicum*	Celestraceae	-	-	x	x	x	x
Nuxia sp.	Buddlejaceae	-	-	-	x	x	-
Ochna sp.	Ochnaceae	-	-	x	x	-	-
Indet. charcoal	Oleaceae	-	-	x	x	x	-
Pappea capensis	Sapindaceae	-	-	-	-	x	-
Pavetta spp.	Rubiaceae	-	-	-	x	x	-
cf. *Phoenix reclinata*	Arecaceae	-	-	-	-	x	x
Indet. seed	Poaceae	-	-	-	-	x	-
Indet. phytolith	Poaceae	x	-	-	x	x	x
Podocarpus falcatus	Podocarpaceae	-	-	-	x	-	-
Podocarpus spp.	Podocarpaceae	-	-	x	x	x	-
Indet. charcoal	Proteaceae	-	-	x	x	x	-
Protorhus longifolia	Anacardiaceae	-	-	-	x	x	-
Psychotria cf. *capensis*	Rubiaceae	-	-	-	-	x	-
Ptaeroxylon obliquum	Ptaeroxylaceae	-	-	x	x	-	-
Rapanea melanophloeos	Mysinaceae	-	-	-	x	x	-
Rhoicissus cf. *digitata*	Vitaceae	-	-	-	x	-	-
Indet. charcoal	Rhizophoracea	-	-	-	-	x	-
Rhus sp.	Anacardiaceae	-	-	-	x	x	-
Indet. charcoal	Rubiaceae	-	-	x	x	x	x
Sapium/Spyrostachys	Euphorbiaceae	-	-	x	x	x	-
Scleria melanomphala	Cyperaceae	x	-	-	-	-	-
Scleria natalensis	Cyperaceae	x	-	-	-	-	-
Sideroxylon inerme	Sapotaceae	-	-	x	x	x	x
Strelitzia sp.	Strelitziaceae	-	-	-	-	x	-
Syzygium sp.	Myrtaceae	-	-	-	x	-	-
Vitex sp.	Lamiaceae	-	-	-	x	-	
Xylotheca kraussiana	Flacourtiaceae	-	-	-	-	-	x
Ximenia sp.	Olacaceae	-	-	-	x	x	-
Ziziphus mucronata	Rhamnacaceae	-	x	x	x	x	x

Appropriate techniques for recovering botanical remains such as sampling and screening are important, but they are influenced by efficiency issues based on time, finances and returns. For the ancient material at Sibudu, dry sieving causes the least destruction and because of time constraints, 1 mm mesh was used for sieving. All material from the 2 mm sieves and except in some cases of very large samples (>100 litres) all material from the 1 mm sieves was sorted, i.e., no sampling was done. This was necessary in the older layers where material is not well-preserved and in the smaller units where there is a low frequency presence of archaeobotanical material. Generally, larger bulk samples produce greater species richness, but I considered recovery of as many species as possible for identification of the past vegetation preferable to statistically equivalent samples for comparison with each other. As it was, samples from stratigraphically adjacent layers were combined and even then did not produce high frequencies of botanical remains (Sievers 2006).

Issues of identification were hampered by the lack of comparative material and collection of modern comparative material is continuing. Nonetheless, the available comparative collection is large. Its inadequacy is due to the extraordinarily rich plant life in KwaZulu-Natal (more than 800 tree species alone), to the fact that climate change introduced taxa not presently in the area, and to the fact that fruiting plants do not fruit regularly and predictably in the wild, making seed collection difficult. Ancient sedge nutlets often lack surface diagnostic features because of bad preservation. The internal morphology of the nutlets is better preserved and SEM reveals diagnostic features (Sievers & Muasya 2011).

Identification of the remains presents qualitative information that can be used for seasonality of site occupation, past vegetation and changes in past vegetation. The GIS-based coexistence analysis approach employs quantitative data and is explained below. The results of the GIS-based coexistence analysis are given in section 3.5 Vegetation interpretations, and Bruch et al. (2012) reproduced at the end of this chapter.

A major problem in archaeobotanical research is bias, which is introduced repeatedly throughout the formation of the record and processes leading to interpretation of the material. Basically, biases are dependent on the nature of the material itself (abundance, size, robustness); its routes of entry into the deposit (including processing through digestive systems or preparation by people); the taphonomy and ultimate preservation of the material; the methods of recovery (sampling methods, sample size, sieving or flotation methods, sieve mesh size); skill at identifying context during excavation and recognising plant material during sorting; identification of the material (including appropriate archaeobotanical comparative collections and difficulties caused by similarities between taxa); interpretation of results (determination of absolute counts and selection of frequency measurements and statistics) and interpretation bias as a result of the archaeobotanist's theoretical background.

Statistics are an essential method of presenting otherwise unwieldy volumes of data, a way of facilitating comparisons, and a method of supporting interpretations. Various statistical measurements are available and have been applied to archaeobotanical assemblages depending on the type of evidence available and the questions that are asked: no single method is suitable for every research question or every analysis (Kintigh 1987; Popper 1988). Basic ratios like percentages or density measurements and more sophisticated multivariate analyses are appropriate according to the aims of the analysis and rigour the data are capable of sustaining (Pearsall 2000). The statistic used in the paper by Bruch et al. (2012), reproduced at the end of this chapter, is quantitative and involves coexistence analysis, which is used to document climate change evidenced in the Sibudu combined archaeobotanical assemblage of charcoal and seeds. The method is based on GIS data of the present climatic tolerances of the ancient Sibudu plant taxa. Section 3.5 concludes with comment on the applicability and success of the approach.

3.2 Identification of fruits and seeds

The establishment of a modern comparative sample for identification of the archaeological nutlets is essential, but protracted. Since 2000, I have been compiling a collection of seeds and fruits of modern indigenous plants in KwaZulu-Natal, and Lyn Wadley has been collecting material in the Waterberg region of Limpopo Province. The collection is housed in the Archaeology Department at the University of the Witwatersrand, Johannesburg and I have collected sufficiently large samples to have my own collection too. There is a large fruit, seed and nut collection, informally called "The Du Plessis Collection", which is available at the National

Herbarium, SANBI (South African National Biodiversity Institute) in Pretoria. Clare Archer of SANBI is compiling an atlas and an interactive key (light microscope level) for sedge nutlets. The website www.paleobot.org provides a forum for posting images for identification by the wider archaeobotanical community and the archaeobotany mailing list archaeobotany@jiscmail.ac.uk is another means to seek identification help.

Identification of fruits and seeds recovered from Sibudu is possible (Wadley 2004; Sievers 2006). Size, shape and basic attributes of the sedge nutlets can be observed using relatively low magnification (20x to 40x). The surface morphology of sedge nutlets is specific to different sedge species and if the preservation of the archaeological nutlets is sufficient, SEM can be used to identify ancient sedge nutlets to species (Sievers &Muasya 2011; Wadley et al. 2011). For carbonised nutlets, the internal morphologies of the nutlets can provide characteristics for identifications because they are better preserved than the outer surfaces. The shape categories from these identifications can be used as guides for identifications of nutlets where the outer surface morphology is not evident.

3.3 Plant remains from MSA Sibudu

3.3.1 Pollen

Pollen is present in eight of the 15 post-HP and late MSA Sibudu layers that have been analysed (Renaut & Bamford 2006). Pteriophyta (ferns), arboreal and non-arboreal pollens have been identified and occur in low frequencies: 34 % of the 71 pollen grains identified are grass and 49% are arboreal taxa such as Euphorbiaceae, Rutaceae, Ulmaceae and *Acacia* spp.. Sedge pollen, which is anemophilous (wind-distributed), is present in the post-Howiesons Poort (~58 ka) and late MSA layers (~48 ka). The pollen of *Cladium mariscus*, a sedge species that receives considerable attention in this thesis, cannot be distinguished from the pollen of other Cyperaceae (Pokorny et al. 2010). Grass pollen, also anemophilous, occurs in both the ~58 ka and ~48 layers. The faunal evidence indicates a predominance of large grazing fauna in these layers and supports the indications suggested by the grass pollen. In the ~48 ka layers a palm phytolith was identified (Wadley et al, 2011 SOM), supporting charcoal and seed identifications of this tree (Schiegl et al. 2004; Wadley 2004; Allott 2006). The common date palm, *Phoenix reclinata* grows in low-lying open grassland (Coates Palgrave 2002).

Pollen is not well-preserved at Sibudu (Renaut & Bamford 2006), but there is scope for more pollen research at Sibudu. Ideal conditions for pollen preservation are acidic, stable and dry (Dimbleby 1985). The Sibudu sediments are dry and predominantly ashy (Pickering 2006). The high incidence of fire at Sibudu likely had a negative effect on the preservation of pollen, both in terms of heat and pH as a result of the ash (alkaline). Soil pH measurements of 12 Sibudu layers (Williamson 2005; Table 3.2) were slightly alkaline in the final MSA (layer Ore pH 7.37) and in one layer in the late MSA (OMOD pH 7.64); slightly acidic for the other late MSA layer (RSp 6.4); and neutral for the uppermost layer of the post-Howiesons Poort (BSp 7.1). All eight other layers analysed for the post- Howiesons Poort were acidic with an average pH of 5.67. Twenty-six subsequent pH tests mostly from the post-Howiesons Poort, but including two from the late MSA and ten from the Howiesons Poort, were all mildly acidic, except for the reading from PGS (pH 7.54), the oldest layer in the Howiesons Poort (Wadley 2010f). The average pHs from for each of the periods (Table 3.3) are lowest for the post-Howiesons Poort. Varying samples sizes for the different periods may affect these averages. There are no pH readings yet available for Still Bay and older layers.

Table 3.2 Average pH readings for Sibudu soil samples. Readings from experimental fires courtesy of Silje Bentsen (pers. com. 2013).

Layers	No. of samples	Average pH
final MSA	1	7.37
late MSA	4	6.47
post- Howiesons Poort	23	5.98
Howiesons Poort	10	6.60
Experimental fires	4	9.54

Table 3.3 Sibudu soil pH values from Williamson* (2005), Wadley (2010f, 2012b table 1) and Bentsen (samples 27–30, pers. com. 2013), with excavation date where available. The dilution was 5:1 in distilled water. Exp=experiment.

	Sib. number	**Context**	**Quadrant**	**Date**	**pH**
final MSA	2*	Ore	D3b		7.37
late MSA	1*	OMOD	C3a		7.64
	15	RSp	B4a		6.14
	3*	RSp	B4b		6.41
	6	YA under RSp	B4a		5.67
post-Howiesons Poort	4*	BSp	D4c		7.10
	19	BSp	E4b		6.68
	5*	Ch-SPCA	C5c		6.40
	6*	GR-SPCA	C5c		5.90
	7*	SPS (SS)	B5d		5.53
	20	Mexican Yellow	B5c	20.10.1998	6.62
	8*	MEY (Mexican Yellow)	B5c		5.56
	9*	MUS	B6b		5.79
	9	Black Magic	C5c	06.03.2006	5.47
	10*	Choc 2	C5c		5.49
	18	Choc 2 Hearth 4 (crust)	C5b	14.03.2006	6.38
	7	Y1	C4c	30.10.2008	5.76
	8	Br/Grey mix white base	C4a	03.11.2008	5.81
	26	Black below Br/Grey mix	C4a	04.11.2008	5.90
	11*	Br/Grey mix 2	B5c		5.45
	12*	YA1	B5a		5.5
	5	YA	B4a	04.11.2008	5.86
	2	YA2	B4d	07.11.2008	6.01
	3	YA2(i)	C4	10.11.2008	5.85
	23	Br under YA2(i) Hearth 1 (top)	C4d	10.11.2008	6.08
	24	Br under YA2(i) Hearth 1 (middle)	C4a	12.11.2008	6.09
	25	Br under YA2(i) Hearth 1 (base) - black lens	C4d	16.11.2008	5.83
	16	Reddish brown Hearth 3	C4	07.02.2009	6.38
Howiesons Poort	4	GR Hearth e (top)	B4c	15.11.2008	5.90
	21	GR bone rich patch	C4b	06.02.2009	6.24
	22	GR2 Hearth 3	B4c	09.02.2009	6.51
	1	GS Hearth 2 (top)	C4a	18.02.2009	6.41
	13	GS	C4d	20.02.2009	6.68
	11	GS2	B4d	14.02.2009	6.85
	16	GS2 Hearth 1 (base)	C4	21.02.2009	6.63
	10	GS2 under hearth, Hearth 1 (base)	B4d	17.02.2009	6.82
	12	GS2 under hearth, Ash dump Hearth 1	C4	22.02.2009	6.62
	17	PGS	B4c	20.02.2009	7.54
Experiments	27	Exp 1 Ash dump		15.02.2009	9.70
	28	Exp 3 White ash a-quad		18.04.2009	10.86
	29	Exp 3 Black layer b-quad		18.04.2009	8.05
	30	Exp 3 Red/pink d-quad		18.04.2009	9.55

Modern experimental fires have much higher pH values than hearths at Sibudu (Tables 3.2 and 3.3). Is this because of diagenesis at Sibudu? Is the fuel type implicated? Is the sample provenance within a single fire important? In an experimental fire, an ash dump (pH 9.70) has intermediate values between the top white ash (pH 10.86) and the bottom black layer (pH 8.05) of an experimental fire (measurements courtesy of Silje Bentsen).

Whereas ethnoarchaeological studies in Guatemala and Mexico state that the alkaline pH in cooking areas is because of ash and the lime used in maize preparation techniques (Barba & Ortiz 1994; Fernandez et al. 2002), other studies indicate that the degree of carbonisation and temperature influences the pH, at least of wood ash, and that local soil characteristics need to be taken into account (Pullido-Novicio et al. 2001). Wood powders of sugi *(Cryptomeria japonica* D. Don) heated to 400 °C and incompletely carbonised were acidic in aqueous solutions, whereas the pH increased and the sugi wood ash became alkaline when heated to between 600 and 1000°C (Pulido-Novicio et al. 2001). Wood charcoals can be acidic or basic in aqueous solutions (Boehm 1994). These factors need to be considered in future in the Sibudu context. The issue is not addressed further here.

Apart from the influence of pH, the influence of moisture is also a factor to consider in the preservation of pollen. Gypsum is present particularly in the post-Howiesons Poort and younger layers. Some moisture is necessary for the growth of gypsum (Schiegl & Conard 2006), but too much moisture dissolves gypsum (Wadley et al. 2011 SOM).

3.3.2 Phytoliths

Phytolith presence at Sibudu is dominated by grasses, but non-arboreal and sedge phytoliths are present too (Schiegl et al. 2004; Scheigl & Conard 2006; Wadley et al. 2011). Monocotyledonous plants, such as grasses and sedges, are particularly prolific phytolith producers and can form large conjoined or ‘multi-celled’ phytoliths of sections of plant tissue (Shillito 2013). Articulated phytoliths such as these are preserved in the micromorphology of burnt bedding at Sibudu (Goldberg et al. 2009; Wadley et al. 2011). Other routes of entry of phytoliths into archaeological deposits are through the collection and burning of firewood, and via non-human agents such as wind, decomposing organic matter adjacent to and in the shelter and the fur and skin of animals (Schiegl et al. 2004). Modern soil samples from nearby, but outside the shelter, do not have many phytoliths, which suggests that wind may not have been an agent of phytolith deposition at Sibudu (Wadley et al. 2011 SOM).

The early studies of phytoliths at Sibudu indicated that a significant proportion of the phytoliths from the ash and hearths at the site show morphological damage (Schiegl et al. 2004). Phytolith morphology is preserved to at least 800°C (Shillito 2013) and Schiegl et al. (2004) suggested that the altered phytoliths at Sibudu were probably indicative of long-burning wood fires or the re-use of hearths. They observed signs of decay on the surfaces of phytoliths. High alkalinity (pH 9), such as those recorded for modern experimental fires (Table 3.3) causes the type of damage they observed on the Sibudu phytoliths.

In Chapter Six – Bedding at Sibudu (incorporating Wadley et al. 2011 and SOM), the preservation of phytoliths is discussed in greater detail and further identifications are presented. The clarity and detail of the phytoliths show that there is much scope for further phytolith studies at Sibudu, particularly in the preserved carbonised and mineralised bedding layers. There is no phytolith key for identification of southern African phytoliths and an in-depth study of the Sibudu phytoliths could contribute towards the establishment of a key.

3.3.3 Plant residues

Residue studies on Sibudu lithic points and segments have revealed plant gum and other plant residues on the artefacts (Wadley, Williamson, and Lombard 2004; Williamson 2004, 2005; see Lombard 2007a for Lombard references) and suggest that the artefacts were attached to wooden hafts/shafts with mastic including plant exude. Twine was sometimes used for attaching the points.

3.3.4 Carbonised macrobotanical remains

Carbonised macrobotanical remains were recovered from all MSA layers at Sibudu. They are preserved in higher frequencies in the more recent layers, particularly in the late MSA, ~48 ka (Allott 2004, 2005, 2006; Wadley 2004; Sievers 2006). The lower frequency recovered in the final MSA, ~38 ka, is likely because less deposit was recovered from these layers and because the layers were excavated during the initial seasons of the Sibudu project when 2mm was the smallest sieve mesh size that was used. The combined macrobotanical and microbotanical identifications (Table 3.1) have provided data for interpretations of past vegetation in the Sibudu area and for people/plant relationships, which are described in more detail below.

3.4 People/plant relationships

People/plant relationships at Sibudu have been explored in studies on the use of wood for domestic fires (Allott 2005, 2006); the use of sedges for bedding (Sievers 2006), developed in this thesis; the use of plant materials in mastic and the hafting of tools (Wadley, Williamson, and Lombard 2004; Williamson 2004, 2005; see Lombard 2007a for Lombard references); and the disposal of food waste through discard of bones into fires (Cain 2005; Clark & Ligouis 2010; Wadley 2012b). Other activities at Sibudu in which fire is implicated, concern the work surfaces provided by the cementation of ash (Wadley 2010d, 2012b) and the possible over-representation of red-coloured ochre (Wadley 2009, 2010e). Although deliberate heating of earth-coloured iron products has been reported (references in Wadley 2009) there is presently no evidence to suggest that ochre at Sibudu was deliberately heated to change its colour.

3.5 Vegetation interpretations

The information from charcoal, fruits and seeds and to a lesser extent, pollen and phytoliths (Allott 2004, 2005, 2006; Wadley 2004, 2006; Herries 2006; Renault & Bamford 2006; Reynolds 2006; Sievers 2006), has been combined with faunal interpretations (Glenny 2006; Plug 2004, 2006; Wadley & Whitelaw 2006; Clark &

Plug 2008; Reynolds 2006; Wadley et al. 2008) to provide a clearer window into the past.

It is likely that throughout the periods that Sibudu was occupied, a mosaic of habitats existed as a result of the local topography and the uThongathi River (Wadley et al. 2008). The amount of insolation affects the amount of moisture available to plants, that is, effective evapotranspiration. The cool moist cliffs around Sibudu, on the north side of the river, promote the growth of evergreen forest, which presently grows in the area. The hot, dry, north-facing slopes on the south side of the river are likely to have supported deciduous woodland and grassland under suitable rainfall and temperature regimes (Wadley et al. 2008). The presence of water-loving sedges, particularly *Cladium mariscus*, throughout the MSA sequence attest to the presence of standing water in the river and the charcoal and seed assemblages have many additional moisture-loving or riverine species (Allott 2006; Sievers 2006).

Freshwater fauna, including aquatic mammals (e.g., Hippopotamus, *Hippopotamus amphibius*), water birds, reptiles (e.g., Crocodile, *Crocodylus niloticus*), amphibians (e.g., Platanna, *Xenopus laevis*), fish, crustaceans and fresh water molluscs (Plug 2006) also indicate the presence of water nearby the shelter. The Marsh or Water Mongoose, *Atilax paludinosus*, has been identified throughout the deposits from the late Still Bay to the final MSA. Details of the faunal analysis results of the earlier Still Bay and older layers are not yet available.

The Water Mongoose, fresh water molluscs (Plug 2006) and Vlei Rats (*Otomys irroratus*) (Glenny 2006) throughout the MSA sequence support the suggestion that the uThongathi was a perennial river during the time the Sibudu sediments built up. Indications of moist conditions during the Howiesons Poort and Still Bay occupations come from the presence of the Gambian Giant Rat (*Cricetomys gambianus*) (Glenny 2006; Clark & Plug 2008). The environmental tolerances of the rat (Skinner & Chimimba 2005) suggest evergreen forest and woodland, maximum temperatures not above 34°C and annual rainfall greater than 800 mm (Glenny 2006). Mineralogical analysis supports the presence of high humidity during the Howiesons Poort, which is implied by the absence of gypsum.

The coexistence of grazing fauna, browsers and forest species (Wadley et al. 2008, table 2) supports the interpretation of different habitats around Sibudu throughout the sequence. The evidence from the macrobotanical analyses would appear contradictory if this were not the case. There is a lack of precision in age determinations in the distant past. Sibudu has a good suite of OSL ages (Jacobs et al. 2008a, b), but, even so, the standard deviations associated with the ages preclude the recognition of short time spans. This problem may mask short term changes within periods defined according to lithic analyses. The post-Howiesons Poort, for example, has been divided into earlier and later periods and analysis of the corresponding botanical remains would be useful. Although the charcoal at Sibudu is a result of selective collection by the inhabitants of the shelter, this selection was nevertheless determined by availability, which reflects the local vegetation. Similarly, although it may not be possible to determine accurately the routes of entry of the seeds and fruits in the Sibudu deposits, their presence is nonetheless a reflection of the local flora, even though it biased.

A method which shows great potential for interpretation of past climatic parameters in the Sibudu area is based on charcoal and seeds identifications. This quantitative method, the GIS-based coexistence analysis approach, is explained in the paper reproduced here. It shows a level of detail not possible through other methods and indicates the importance of the minimum mean winter temperature as a driving force during the periods that the Sibudu sediments formed.

The potential of the GIS-based coexistence approach is enhanced by larger samples, identification of taxa that have restricted tolerances and precision in the calculation of the tolerance ranges of identified. There are at least 30 taxa in the Sibudu archaeobotanical assemblage that await identification (Sievers 2006) and particularly if these taxa have limited moisture and temperature tolerances, their identification could lead to more detailed interpretations of past climatic parameters in the Sibudu area.

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Quantification of climate and vegetation from southern African Middle Stone Age sites – an application using Late Pleistocene plant material from Sibudu, South Africa

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ABSTRACT

In southern Africa numerous Middle Stone Age (MSA) sites document important steps in technological and behavioural development leading to significant changes in the lifeways of modern humans. To assess whether these cultural changes and developments may be related to environmental changes we need to ascertain past environments. To do this we apply a new quantitative method, the GIS-based Coexistence Approach (CA_{GIS}), on fossil plant material from the MSA site Sibudu, KwaZulu-Natal, South Africa. Previous qualitative environmental interpretations of the fossil fauna and flora of the site remain ambiguous. Because much of the material is anthropogenically introduced, it is difficult to distinguish between the effects of natural changes in the local vegetation and behavioural changes of the people that inhabited the shelter. CA_{GIS} can be applied to such biased assemblages and seems to be an adequate method to directly quantify palaeoclimate and vegetation parameters at an archaeological site.

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. Post-HP winters were drier and colder than present, presumably colder than during the HP. Summer temperatures remained the same, but summer precipitation decreased from the HP to post-HP. Vegetation cover was less than today, may be even less than during the HP. The late MSA was observably warmer than the older periods, especially during winter. At the same time summer precipitation slightly increased and vegetation became more dense, but still remained generally open similar to today's anthropogenic landscape.

Generally, climatic changes are most pronouncedly reflected in winter temperature parameters, especially in minimum winter temperatures, and to a lesser extent by changes in summer precipitation. The observed ecological trends seem to be affected mainly by variations through time in winter temperatures. This refinement of interpretation was not discernible using previous methods for analysing the Sibudu data.

1. Introduction

The challenge in reconstructing the Late Pleistocene climate of South Africa is that its isolated geographical situation makes it difficult to unravel the various parameters that influence regional climate. Chase and Meadows (2007), Holzkämper et al. (2009) and Chase (2010) discuss the issue in detail and conclude that southern African palaeoclimate does not respond to global climate change in a uniform way. Instead it is influenced by a variety of forcing mechanisms with different regional effects that do not allow the interpretation of local environments through correlation with global glacial/interglacial stages. Among the forcing mechanisms are changes in atmospheric circulation when the Westerlies transport moisture from the Atlantic Ocean onto the continent during winter, and when the easterly trade winds influence moisture transport from the Indian Ocean to eastern parts of southern Africa during summer. Changes in oceanic circulation are also important, in particular shifts of the Benguela and Agulhas Currents

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corresponding to changes in eustatic sea level and to shifts of the subtropical convergence (Chase, 2010). The absence of a clear response to these forcing mechanisms and a lack of linear correlation with Antarctic temperature records or other global archives (Chase, 2010; Caley et al., 2011), increases the importance and contribution of independent local data that provide direct information on the environment at specific times.

Another way to determine southern African past environments is to reconstruct vegetation cover and canopy density as measures of the general openness of the landscape and its changes in time. Methods available so far range from mainly qualitative, but widely used, interpretations based on mammal and plant communities, the proportion of arboreal vs. non arboreal pollen abundances (AP/NAP-ratio) when applicable (e.g. Scott, 1999), to a recently introduced quantitative method based on soil carbon isotopes applied presently only to eastern Africa (Cerling et al., 2011). Still, an objective method applicable to different kinds of environment to quantify and compare vegetation density from different sites is missing. One of the aims of this study is to test the applicability of a new approach to reconstruct vegetation density using plant fossils.

Fossil plant remains provide valuable information on past environmental conditions. Although few palaeobotanical data are available from southern Africa, some sites reveal rich and diverse fossil floras, most notably, Sibudu Cave, KwaZulu-Natal, South Africa, with its numerous fruits, seeds, pollen and charcoal flora. Such plant remains not only provide general information on past vegetation, but also serve as a sound base for the quantification of palaeoclimate and vegetation parameters.

Basically, there are two ways to quantify past environments from plant fossils: physiognomic, and nearest living relative approaches. Physiognomic approaches take advantage of empirical correlations between specific plant traits like leaf physiognomy (e.g., Wolfe, 1993; Wilf, 1997; Wiemann et al., 1998) or wood anatomy (e.g., Wheeler and Baas, 1993; Terral and Mengüal, 1999) and to a large extent they are independent of taxonomic determinations. A critical review of these methods is given by Wiemann et al. (2001).

Nearest living relative approaches rely on the close relationship between modern and fossil plants. For the Quaternary especially, it can be assumed that environmental requirements of plants have not changed significantly. Taxa with known climatic requirements that occur together in one fossil flora therefore are likely to have lived under the climatic conditions indicated by their overlapping climatic ranges. First approaches using this method were applied only on selected key taxa (Iversen, 1944; Hintikka, 1963; Grichuk, 1969; Zagwijn, 1996). Later, increasing sophistication of computer facilities allowed all available information to be included and common climatic ranges for all taxa were determined (Kershaw and Nix, 1988; Mosbrugger and Utescher, 1997; Fauquette et al., 1998; Klotz, 1999; Kühl et al., 2002; Kou et al., 2006).

Such methods are based on the taxonomic composition of the assemblages and so can generally be applied to all categories of plant material, such as pollen, wood, fruits, seeds and leaves. Because the methods depend on taxonomic determination, the more precise the identification, the more accurate and precise are the results. Thus, macrobotanical material, which often can be determined to species level, provides better results than pollen data that usually are determined to genus or family level.

As a result, some methods take advantage of empirical correlations between the composition of surface pollen spectra and climatic conditions and combine those data to increase the climatic resolution by restricting the applicability of the method to pollen floras (Guiot et al., 1989; Fauquette et al., 1998). However, in their

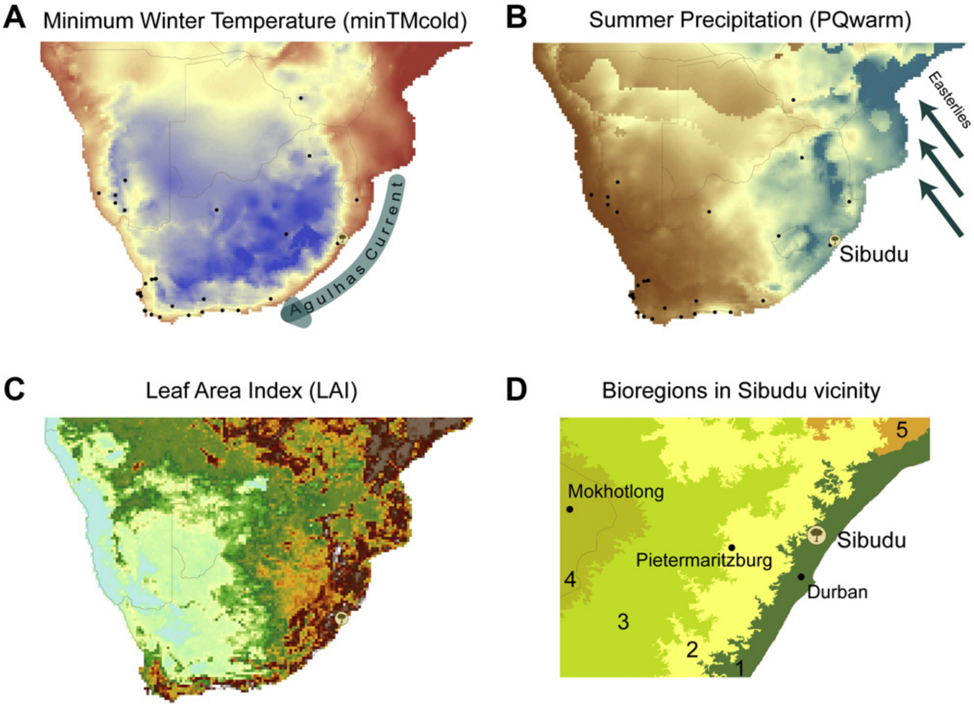

Fig. 1. Geographic position of Sibudu Cave and other MSA sites (black dots) in Southern Africa. The colour scale for map A with minMTcold range from (blue) −5.4 °C to (red) 17.5 °C, and for map B with QPwarm from (brown) 3 mm to (blue) 1142 mm. Map C shows the distribution of LAI values (based on Masson et al., 2003) ranging from zero (light blue) in the west to 5.43 (dark brown and grey) in the east. Map D gives a detail of the vegetation map of Mucina and Rutherford (2006) with bioregions, 1: Indian Ocean Coastal Belt, 2: Sub-Escarpment Savanna, 3: Sub-Escarpment Grassland, 4: Drakensberg Grassland, 5: Lowveld (from Mucina and Rutherford, 2006).

study of African plant taxa Watrin et al. (2007) document that there is no clear correlation between pollen and plant distribution and their respective climatic range. The distribution area of pollen from plants that produce high numbers of pollen can be very large and thus indicate a broad climatic range. In contrast, low pollen producers, like zoophilous plants, have a small pollen distribution area and may show a climatic range even narrower than the range of the actual plant (Watrin et al., 2007).

Both the physiognomic and nearest living relative methods, as described above are widely used in environmental reconstructions based on natural fossil plant assemblages and have produced reliable results in various applications from Neogene to Pleistocene (for Neogene see compilations in Bruch et al., 2007; Utescher et al., 2011; Pleistocene examples are Kühl and Gobet, 2010; Tarasov et al., 2011).

Applying quantitative methods of climate and environmental reconstructions to archaeobotanical material requires in depth consideration of taphonomic and anthropogenic factors. In archaeological contexts human selective processes play a large role in the composition of the assemblages; either directly, by gathering of fruits, seeds or fire-wood, or indirectly by influencing taphonomic processes at the site, for example with the destruction of material by burning and paradoxically, the preservation, through incomplete combustion, of material that might otherwise have decomposed and been lost to the record.

In southern Africa numerous Middle Stone Age (MSA) sites document important steps in technological and behavioural development leading to significant changes in the lifeways of modern humans. Sibudu has excellent organic preservation and allows exceptional insight into this period; it is furthermore important for cultural evidence that shows that people of the time had complex cognition and advanced technological skills. To what extent these cultural changes and developments are related or even triggered by environmental changes still remains a matter of debate (e.g., Wadley, 2006; Jacobs et al., 2008a, b; Jacobs and Roberts, 2009; Chase, 2010; Wadley et al., 2011).

2. Sibudu Cave and its palaeoenvironmental record

Sibudu Cave is located approximately 40 km north of Durban, about 15 km inland of the Indian Ocean, on a steep cliff overlooking the uThongathi River. Today this area is characterised by high summer precipitation due to the southward expansion during summer of the easterly wind regime, which transports moisture from the Indian Ocean onto the continent. Warm winters are caused by ocean heat transport from the warm Agulhas Current (Fig. 1). The current vegetation is strongly affected by anthropogenic disturbances. Only small patches of natural or close to natural, subtropical coastal forests survive on steep slopes and in river valleys, such as near Sibudu Cave. Mucina and Rutherford (2006), define this vegetation as the 'KwaZulu-Natal Coastal Belt', which is part of the 'Indian Ocean Coastal Belt' bioregion. The patches of forest in this region represent the southern-most extent of the humid, tropical to subtropical coastal forests of East Africa. These forests (woody vegetation with continuous canopy cover) are characterised by evergreen trees, usually between 8 and 30 m high (Rutherford and Westfall, 1986). After Olson et al. (2001) these forests are part of the ecoregion 'KwaZulu-Cape coastal forest mosaic' and belong to the biome 'Tropical and Subtropical Moist Broadleaf Forests'. Further inland the biome borders the 'Montane Grassland and Shrubland' biome (Olson et al., 2001), i.e. Savanna (after Mucina and Rutherford, 2006). The savanna is a tropical vegetation type co-dominated by woody plants and grasses (Scholes, 1997) and it is part of a continuum that includes open grassland, arid shrubland (with woody plants below 2 m), lightly wooded grassland, and deciduous woodland and dry forest. The woody plant layer of savanna can vary from widely spaced to 75% canopy layer, at which stage it is referred to as woodland (Rutherford and Westfall, 1986). The majority of savanna woody species are deciduous and shed all their leaves in a single season.

Table 1
List of those stratigraphic units of Sibudu Cave which provided plant material included in this study, their assignation to the cultural associations and OSL dates from Jacobs et al. (2008a, b). For a full explanation of the names of the stratigraphic units, please see Wadley and Jacobs (2006).

Cultural association	Stratigraphic units with plant material	OSL ages [ka]
Final MSA	East wall	
	Co	38.0 ± 2.6
	Bu	39.1 ± 2.5
	LBMOD	49.9 ± 2.5
	MC (hearth)	
	Es	
	Mou, DMou	
Late MSA	East wall	
	PB	
	Ore, Ore2	
	RSp	
	North wall	
	MOD	49.1 ± 2.5
	OMOD	46.1 ± 2.3
	OMOD2	
	OMOD2BL	
	GMOD, BMOD	
	RSp	46.0 ± 1.9
	YSp	49.4 ± 2.3
Post-Howiesons Poort	North wall	
	BSp	57.6 ± 2.1
	BSp2	
	SPCA	
	BL, Or	
	Mi	
	SS	59.6 ± 2.3
	Che, Eb	
	Ma, MY	
	BO	
	P	
	OP	59.0 ± 2.2
	BP	
	Iv	
	BM	
	Ch	
	Su	
	G1	58.3 ± 2.0
	Ch2	58.6 ± 2.1
	Y1	58.2 ± 2.4
	B/Gmix, B/Gmix2	
	BL2, BL3	
	BOr, Ymix	
	YA1	
	YA2	
Howiesons Poort	North wall	
	GR	
	GR2	61.7 ± 1.5
	GS	
	GS2	63.8 ± 2.5
	PGS	64.7 ± 1.9
Still Bay	North wall	
	RGS	
	RGS2	70.5 ± 2.0
Pre-Still Bay	North wall	
	LBG	72.5 ± 2.0
	LBG2, LGB3	73.2 ± 2.3
	LGB4	
	BS	77.2 ± 2.1

The archaeological succession at the site contains a long sequence of MSA occupations; the lithic assemblages include the pre-Still Bay (pre-SB), >77 ka (thousand years) old, the Still Bay (SB) Industry (~70 ka), Howiesons Poort (HP) Industry (65–62.5 ka), post-Howiesons Poort (post-HP) (~58 ka), late MSA (~48 ka) and final MSA (~38 ka) phases (Jacobs et al., 2008a, b; Wadley et al., 2011; see Table 1). Pulses of MSA occupation are separated by hiatuses that are as long as 10 ka.

The rich assemblages of fossil remains from Sibudu Cave provide valuable, however qualitative, information concerning the past environmental conditions. The analysis of charcoal from MSA layers in Sibudu by Allott (2006) shows evidence for environmental changes and wood selection from HP to final MSA, that is from about 65 to 38 ka. HP occupations are dominated by evergreen forest taxa and are interpreted as a warm, woodland savanna habitat growing in the vicinity of a riparian forest. Post-HP phase taxa are mainly from evergreen, riverine forest communities, some of them suggesting a shift in vegetation due to slightly cooler climates. During late MSA occupations fewer evergreen forest components and more bushveld taxa, which are common in northern, drier regions of South Africa, are present. At the stage of the final MSA, there are evergreen and deciduous taxa, many of which grow in KwaZulu-Natal today, while the occurrence of *Kirkia* sp., for example, again provides evidence for a dry habitat (Allott, 2006).

Sievers (2006) combines those results with her data from fossil fruits and seeds, and notes differences between HP and post-HP vegetation characteristics. Whereas both HP assemblages and final MSA assemblages are dominated by evergreen woody taxa, post-HP and especially the subsequent late MSA show a marked increase in deciduous taxa. This trend can be explained either by a shift towards a greater proportion of deciduous elements in the forest, an increase in deciduous elements in grassland, or a change in the percentage of woody cover in savanna, all as a result of changes in evapotranspiration, or the amount of moisture available to plants. Evapotranspiration depends on the relationship between temperature, precipitation and the amount of insolation. Increasing deciduous elements could indicate various combinations of these determinants, for example, lower precipitation and lower temperatures, similar precipitation, but increasing temperatures. However, interpretations based on the frequency of deciduous taxa should be viewed with caution: many taxa are facultative and may be evergreen or deciduous depending on what strategy best suits the prevailing conditions. Nevertheless, supporting evidence for warmer conditions has been suggested by magnetic susceptibility studies: sediments from post-HP times onwards show a gradual increase in magnetic susceptibility (Herries, 2006), which is interpreted by the author as steadily warming conditions.

Reynolds (2006) combined mammal and seed data from post-HP and younger layers in a statistical analysis. For all levels studied, correspondence analysis indicated a complex combination of forest, riverine and open savanna habitats with varying proportions of grassland. This interpretation was confirmed for the late and final MSA, by a study of micromammals by Glenny (2006) who described the environment as a complex mosaic of open savanna grassland and woodland under cooler, possibly drier, conditions than those of today. Additionally, Reynolds (2006) showed that a subtle habitat shift, from cool, dry, open woodland environments to more humid, forested environments, seems to occur after ~58 ka. This interpretation is not fully consistent with the analyses by Allott (2006) and Sievers (2006) who see the environmental change mainly between the HP and post-HP. A possible reason for the discrepancy may be the problem of bias in the archaeological record and different taphonomic processes influencing plant and mammal fossil assemblages.

Available phytolith data seem to reflect a change from grass-dominated habitats at about 58 ka to tree-dominated ones after 48 ka (Schiegl et al., 2004; Schiegl and Conard, 2006). Phytoliths and pollen show, however, that grass still was an important part of the vegetation after ~58 ka (Schiegl et al., 2004; Renaut and Bamford, 2006).

Generally, the available data combined suggest humid or moist conditions during HP, 65–62 ka, whereas post-HP at ~58 ka was the coldest phase in the Sibudu sequence with a colder and drier climate than today. A substantial warming accompanied by increasing humidity seems to have occurred during late MSA

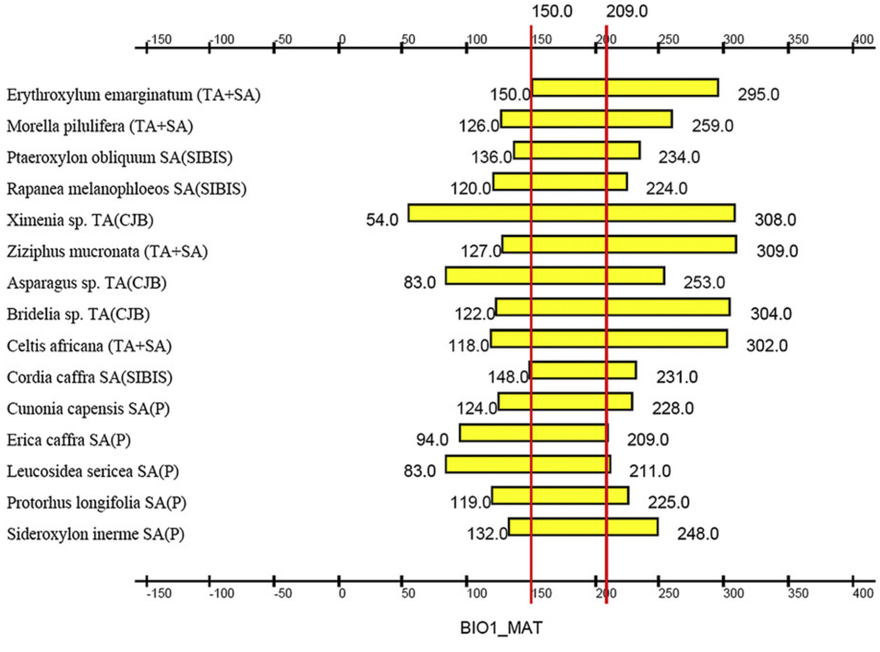

Fig. 2. Exemplary details of CA$_{GIS}$ analysis output for one assemblage (post-HP) and one parameter (MAT). Values are given here in [°C × 10] as in the original WORLDCLIM dataset.

supporting an environment very similar to today. This warming trend continues into final MSA although possibly under drier conditions.

However, the environmental interpretation of the fossil material remains ambiguous. Because much of the material is anthropogenically introduced to the site, it is difficult to distinguish between the effects of natural changes in the local vegetation and behavioural changes of the people that inhabited the cave. Cultural changes in behaviour such as different approaches to wood collection (Allott, 2006) or hunting strategies (Wadley, 2006) could camouflage or simulate a change in environmental conditions, so we do not yet have all the answers to environmental questions about Sibudu.

3. Methods

One reliable method to quantify terrestrial climate is the Coexistence Approach of Mosbrugger and Utescher (1997). The method is one of the Nearest Living Relative Techniques that is based on the assumption that since the Neogene the climatic requirements of plant taxa have remained similar to those of their nearest living relatives (NLRs). With the Coexistence Approach, for each climate parameter analysed, the climatic ranges in which a maximum number of NLRs of a given fossil flora can coexist is determined independently and considered the best description of the palaeoclimatic situation under which the given fossil flora lived.

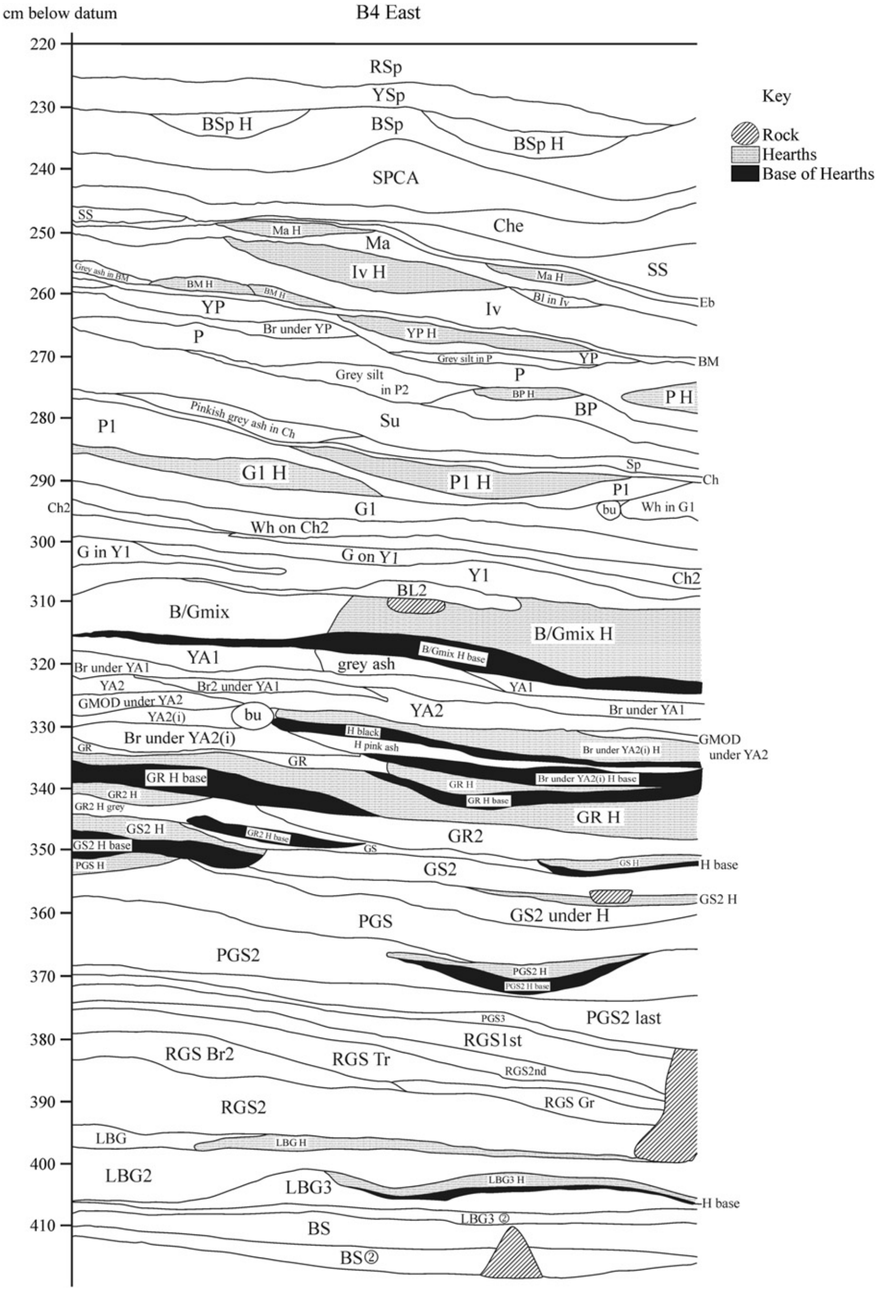

Fig. 3. East wall stratigraphy in the upper layers of Square C2, Sibudu. Layers Bu to RD are only represented at the back of the shelter.

The Coexistence Approach considers only the presence of taxa in a fossil flora, not their abundances. Therefore, it is applicable to situations of different taphonomic histories and also to biased assemblages, as is the case for the Sibudu Cave assemblages, which are mainly anthropogenic, but which are also likely to have been affected by post-depositional factors. Furthermore, it is generally applicable to all kinds of plant remains (pollen, leaves, fruits and seeds, wood), although best results are obtained for fossil floras with precise taxonomic determinations, preferably at species level.

The application of the classical Coexistence Approach is facilitated by the computer program ClimStat and the database Palaeoflora (www.palaeoflora.de) which contains climatic information on more than 1000 (mostly European and Asian) plant taxa. These climatic requirements are derived from meteorological stations within the respective distribution areas. Typically the resolution and the reliability of the resulting coexistence intervals increase with the number of taxa included in the analysis, and they are relatively high in floras with ten or more taxa for which climate parameters are known. The accuracy of the calculated climate data varies with respect to the parameter examined; it is highest for temperature-related parameters for which it is usually in the range of 1–2 °C. Results for Mean Annual Precipitation (MAP) reach an accuracy of 100–200 mm. Other precipitation parameters are less precise, but nevertheless may reflect the overall trends (Mosbrugger and Utescher, 1997).

However, African and especially southern African plant taxa are not listed in the Palaeoflora database. Therefore, new climatic information had to be obtained for this study. Distribution maps for African taxa which occur in the fossil plant record of Sibudu Cave were compiled from botanical literature and internet databases (see Appendix). Those maps were digitized, georeferenced in GIS by using the program ESRI ArcView, and transformed into shapefiles. Depending on the different sources, the maps include distribution information with very variable spatial resolution. Palgrave (2002) gives distribution areas (polygons), SIBIS.SANBI (2011) provides grid data with a resolution of 0.25° × 0.25°, and the CJB African Plant Database (2011) point data with an accuracy of ±2° latitude and longitude. These differences were taken into account by buffering the point shapefiles by 0.25° and 2°, respectively. The buffered shapefiles were intersected with the global climatology dataset WORLDCLIM, which is a raster dataset with a resolution of 10′ (www.worldclim.org). From the resulting raster data, all grid cells that exceed the altitude range of the analysed plant taxon were excluded from further consideration, as far as such information was available (taken mainly from SIBIS.SANBI, 2011). The maximum and minimum values of the extracted climate data were calculated for each climate parameter and taken as the climatic boundaries of the taxon.

The same procedure was repeated with a remotely sensed global raster dataset based on the ECOCLIMAP data of Masson et al. (2003) that was transposed to a resolution of 10′ to be comparable with the climate dataset. Here maximum and minimum values for three vegetation parameters (leaf area index (LAI), vegetation cover and greenness) were determined as indicators of the size of biomass on the land surface (e.g., Wittich, 1997). The vegetation cover and greenness parameters are given in values between zero (no vegetation) and one (complete vegetation cover and maximum photosynthesis activity, respectively). The LAI as a measure for canopy density gives the ratio of leaf area to per unit ground surface area (e.g., Kraus, 2008; Zheng and Moskal, 2009). In our dataset, the dimensionless variable ranges from zero (no leaves, i.e. no vegetation) up to 5.4 in tropical rainforests with a more than five times larger leaf area than ground area, e.g. with a dense multi-storey canopy. By measuring vegetation density, canopy density, and photosynthesis activity, the three parameters considered also give an estimate of the openness of the habitats preferred by the respective taxon.

After the determination of the requirements concerning climate and openness of habitat for as many taxa of the fossil flora as possible, the application of the GIS-based Coexistence Approach (CA_{GIS}) follows the same procedure as the classical Coexistence Approach. It takes advantage of the program ClimStat to calculate the climatic range in which the maximum number of taxa can coexist, independently for each parameter considered (see Fig. 2). Those coexistence intervals provide a quantitative description of the environmental situation under which the given fossil flora lived.

The method relies strongly on the modern distribution of plants and their relationship with climate. In addition to uncertainties related to the relatively coarse resolution of the available distribution maps, the fact that the occurrence of plant species is not exclusively related to climate provides further uncertainties. Precipitation especially can be less important for plants than general water availability that could be provided also by groundwater. This leads to a lower resolution of parameters related to precipitation than for temperature-related parameters (Mosbrugger and Utescher, 1997). Furthermore, anthropogenic disturbances add considerable problems and present distributions are not necessarily a reflection of potential vegetation; many living species are restricted to areas that may not reflect the actual climatic tolerances of the plant. Therefore, taxa that show a very restricted climatic range and are considered relicts can be excluded from the analysis. Still, the general effect of these problems on the method is a reduction of reliability. But, several methodological studies showed that with an increasing number of taxa the reliability of the method increases and uncertainties can be levelled out. Usually, floras are considered reliable when there are ten or more taxa for which climate parameters are known (Mosbrugger and Utescher, 1997; Bruch et al., 2002; Uhl et al., 2003).

For the analysis of the vegetation parameters that reflect the openness of vegetation the situation is more complicated because anthropogenic disturbances can affect both the distribution of the plant as discussed above and the remotely sensed data. Irrigation

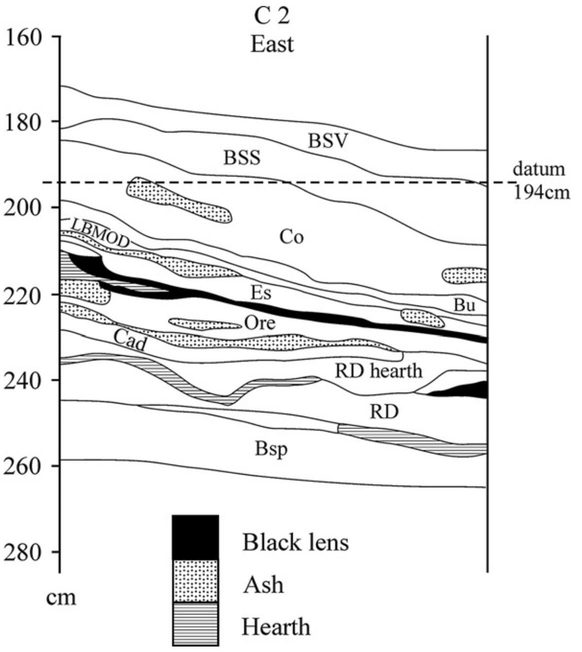

Fig. 4. East wall stratigraphy in the lower layers of Square B4, Sibudu. Bu = burrow.

Table 2
Parameters analysed in this study and their abbreviations used in the text.

Parameter	Abbreviation
Mean annual temperature	MAT
Minimum temperature of the coldest month	minTMcold
Maximum temperature of the warmest month	maxTMwarm
Mean temperature of the coldest quarter	TQcold
Mean temperature of the warmest quarter	TQwarm
Mean annual precipitation	MAP
Precipitation of the wettest month	PMwet
Precipitation of the driest month	PMdry
Precipitation of the driest quarter	PQdry
Precipitation of the wettest quarter	PQwet
Precipitation of the coldest quarter	PQcold
Precipitation of the warmest quarter	PQwarm
Leaf area index	LAI
Greenness	
Vegetation cover	

will increase values because it promotes more lush vegetation cover than would occur naturally; forest clearance will reduce values. In any case, the resulting range of the vegetation parameter for a taxon will become wider than under natural conditions, and so will the resulting coexistence intervals. Therefore, the results for vegetation parameters will not be wrong, but simply less distinct.

Even with such shortcomings, CA_{GIS} seems to be an adequate method and, at present, one of the few available to quantify directly palaeoclimate and vegetation parameters at an archaeological site.

4. Material

To test the potential of the Coexistence Approach for archaeological contexts, in this study the method is applied to the rich palaeobotanical material from Sibudu Cave. Carbonized seeds, nuts and the stones of fruits are present in 13 layers from pre-SB to final MSA (Sievers, 2006) allowing for the identification of 35 taxa, 17 of them to species level. In the charcoal assemblages, 75 taxa in total were identified coming from eight stratigraphic layers which range from HP to final MSA (Allott, 2006). The taxonomic determination to species level in 19 cases contributes significantly to the application of the Coexistence Approach and underlines the importance of charcoal analysis for palaeoenvironmental studies. Unfortunately no charcoal material older than the HP (65-62 ka) has been identified yet. With respect to the pollen record (Renaut and Bamford, 2006), poor preservation and very low diversity meant that the taxa were determined only to family level and do not contribute to our results.

The Sibudu Cave plant record has been compiled mainly from literature data as mentioned above, but some new determinations from current studies of C. Sievers were included. Those new finds are indicated in the Appendix.

All fossil material was assigned to the established units pre-Still Bay, Still Bay, Howiesons Poort, post-Howiesons Poort, late MSA, and final MSA (see Table 1, Figs. 3 and 4). The fossil assemblages from different layers within each of these defined cultural units were combined to represent each unit as a whole. The resulting six composite assemblages are listed in the Appendix. Due to the low number of taxa in pre-SB and SB, only the assemblages of HP, post-HP, late MSA, and final MSA were suitable for applying the Coexistence Approach (CA_{GIS}). For this study 12 climate and three vegetation parameters have been quantified as listed in Table 2.

All results are given in Table 3 and Fig. 5, and together with the compiled basic data will be stored in the ROAD database system at www.roceeh.net.

5. Results and discussion

5.1. Temperatures

The results obtained from CA_{GIS} analysis show a general increase of temperatures from the HP at ~65 ka to the final MSA at ~38 ka (Fig. 5, Table 3). This trend is most pronounced in values of winter temperature parameters, especially in minimum winter temperatures (minMTcold). Summer temperatures seem to be not affected, or at least less affected, by these climatic changes. A trend of increasing winter temperatures and presumably stable summer temperatures results in a decrease of seasonality and more equable conditions regarding temperature. The most pronounced shift in climatic conditions appears from the post-HP to the late MSA. HP and post-HP temperatures seem to be quite similar, with a slight, but not significant, tendency towards cooler conditions during post-HP. The late and final MSA do not reflect any remarkable differences. Due to the low number of taxa that could be included in the analysis of the final MSA assemblage, the resulting coexistence intervals are generally broader than for the late MSA. The same might be true for HP results, whereas broader intervals of post-HP

Table 3
Results of CA_{GIS} analysis for all parameters and modern values for the vicinity of Sibudu Cave as derived from WORLDCLIM dataset (10′ raster data).

Assemblage name	HP		Post-HP		Late MSA		Final MSA		Modern
No. of taxa analysed	10		16		27		7		
Borders of coexistence intervals	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	
Mean annual temperature [°C]	13.6	22.2	15	20.9	17.6	20.9	16.9	23.1	20.7
Minimum temperature of the coldest month [°C]	3.4	10.3	3.4	9.6	7.8	10.3	6.5	11.4	11
Maximum temperature of the warmest month [°C]	23.6	31.9	24.6	31.3	24.6	31.3	24.6	34.9	28.1
Mean temperature of the coldest quarter [°C]	10.9	17.8	11.2	16.3	14.6	17.4	13.7	18.6	17.3
Mean temperature of the warmest quarter [°C]	18	25.7	18.6	25.2	20.4	25.2	19.8	26.3	23.7
Mean annual precipitation [mm]	365	1192	420	1141	491	1141	420	1141	949
Precipitation of the wettest month [mm]	69	210	69	164	94	164	72	165	117
Precipitation of the driest month [mm]	2	21	3	21	3	21	0	21	31
Precipitation of the driest quarter [mm]	13	74	16	74	16	74	9	74	103
Precipitation of the wettest quarter [mm]	132	589	182	439	251	439	209	439	347
Precipitation of the coldest quarter [mm]	13	202	32	110	32	166	9	166	103
Precipitation of the warmest quarter [mm]	65	589	121	439	251	439	209	439	347
Leaf area index	0.67	4.01	0.7	3.7	1.42	3.7	1.27	3.7	2.83
Greenness [%]	0.28	0.93	0.25	0.87	0.49	0.87	0.44	0.87	0.84
Vegetation cover [%]	0.61	0.98	0.54	0.97	0.64	0.97	0.64	0.97	0.92

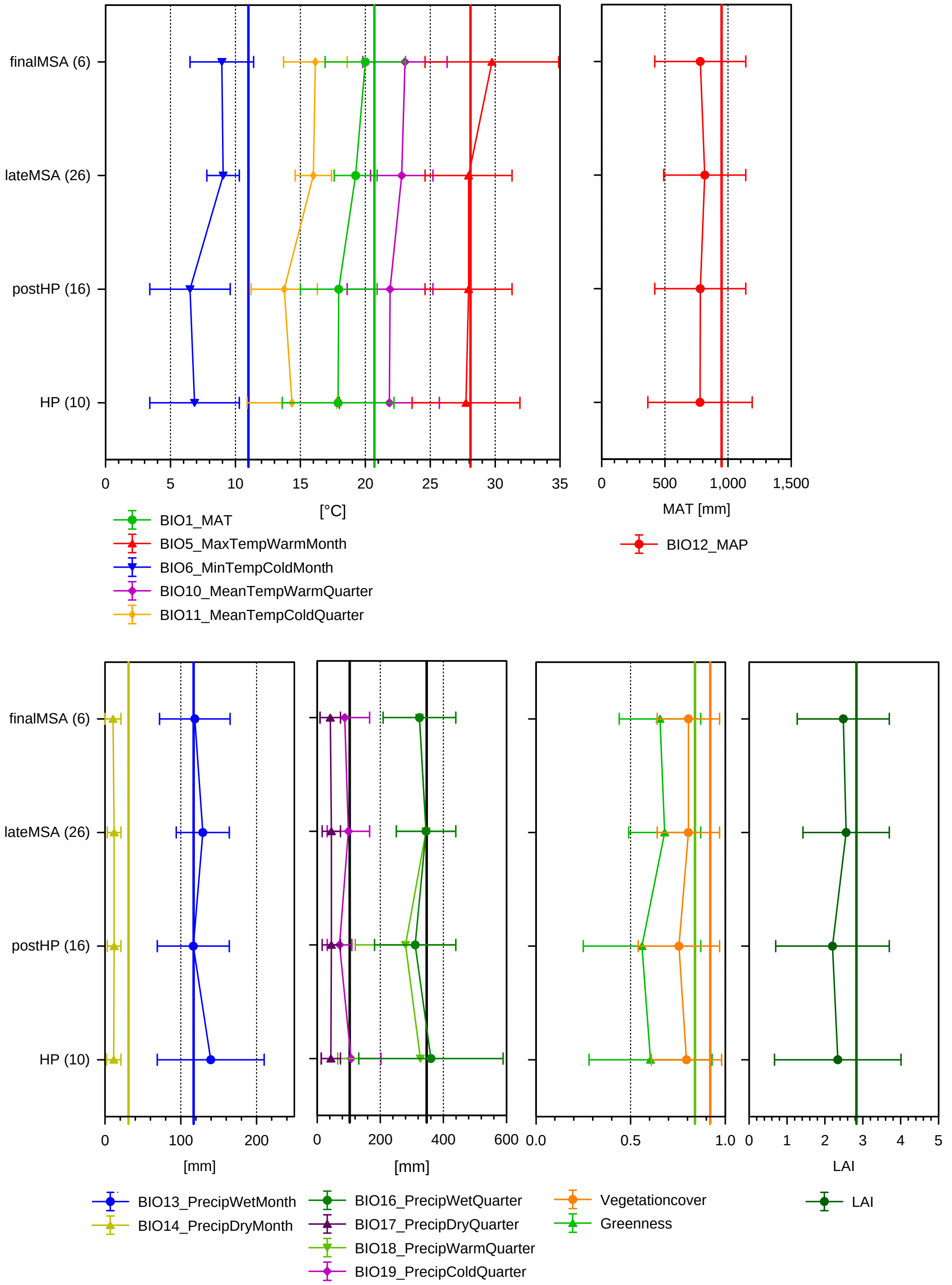

Fig. 5. Results of CA_{GIS} analysis for all parameters. Modern values for the vicinity of Sibudu Cave are indicated by bold vertical lines.

values cannot be explained by a low number of taxa, but seem rather to reflect colder conditions. Generally, lower temperatures lead to the prevalence of taxa with wider climatic tolerances, which in turn result in broader climatic coexistence intervals; a correlation empirically supported and discussed by Pross et al. (2000).

Only the absolute values for minMTcold significantly document conditions cooler than present (Fig. 5). Here, the calculated coexistence intervals do not overlap with modern values; the warmest boundaries of the coexistence intervals give values of at least 1 °C colder than present day data (except for the final MSA), with the post-HP being the coldest of the four phases with a minimum winter temperature at least 1.5 °C lower than present. For all other temperature-related parameters the coexistence intervals always include the modern values within their range, and none of these display significant climatic changes. Summer temperatures for all four phases analysed give values almost the same as modern ones.

However, the general trend as it is documented in the shifts of mean values of the coexistence intervals is obvious and in good agreement with former qualitative interpretations (Fig. 5). Taking into account the mean values of our results, minimum winter temperatures in the HP could have been about 4 °C (in the range 1–8 °C) colder than today. The post-HP phase might even have been slightly cooler, at least during winter. The late and final MSA clearly was pronouncedly warmer than the previous periods, especially during winter, with minimum winter temperatures only 1–3 °C cooler than today. There was therefore a gradual trend towards temperatures similar to those of present.

Our data largely confirm the environmental interpretations made from plant and animal data. Glenny (2006) statement that all phases may have been cooler than today can be confirmed for winter temperatures. The same is true for the suggested substantial warming after the post-HP (Wadley, 2006) that as well seems to affect mainly winter temperatures based on our data presented here. However, a cooling trend from HP to post-HP phase cannot be confirmed by our data, but may be hidden within the broad ranges of the obtained coexistence intervals. Generally, the observed ecological trends seem to be affected mainly by variations through time in winter temperatures. This refinement of interpretation was not discernible using previous methods for analysing the Sibudu data.

5.2. *Precipitation*

The most intriguing feature of the analysed precipitation parameters is the clear correlation between precipitation values of the warmest and the wettest quarters, and the driest and coldest quarters, respectively (Fig. 5). Those seasonal precipitation parameters prove the existence of a rainy season predominantly in summer as it is established today. This indicates the influence of the same atmospheric circulations patterns as today and the persisting influence of humidity transport from the Indian Ocean, and generally supports a correlation of Sibudu Cave precipitation signals with Indian Ocean sea surface temperatures (SSTs) as suggested by Chase (2010).

All analysed precipitation parameters show values not significantly different from modern ones (Fig. 5). General shifts are very slight and might be more affected by methodological problems (number of taxa included in the analysis) than by true climatic changes. Subtle shifts in precipitation patterns may have occurred that are not detectable by the resolution available to us, e.g. within the range of the coexistence intervals obtained.

Still, the mean values of precipitation parameters imply a decrease of summer precipitation from the HP to the post-HP and a subsequent increase towards the late MSA. This trend correlates with the quantitative interpretations summarized in Section 2 above. In the same way, changes in Indian Ocean SSTs derived from isotope data (van Campo et al., 1990: Fig. 2b) show SSTs about 3 °C cooler during the HP and post-HP (65–62 ka and ∼58 ka), but only about 2 °C cooler during the late and final MSA phases (48 ka and 38 ka) indicating a decreasing transport capacity of moisture from the ocean.

These quite vague hints of changes in precipitation apply only to summer precipitation. Driest month and driest quarter precipitation values do not depict any changes and are slightly lower than present, which results in slightly lower mean annual precipitation than today (Fig. 5). Based on our data, the detected changes in faunal and floral composition as discussed in Section 2 therefore seem to reflect very minor shifts in summer precipitation.

However, if occupations at Sibudu were restricted to phases that were relatively humid and with dense vegetation (phases of paedogenesis) as stated by Wadley (2006) and Wadley and Jacobs (2006), then it is not surprising that our data do not depict severe changes in climate; the really different climatic phases may be not represented by the sequence. Since the Sibudu sediments are anthropogenically derived, it is not possible to study environmental changes at the site during periods of non-occupation.

5.3. *Vegetation density*

Generally, the reconstruction of vegetation parameters (Fig. 5) gives very broad and unspecific results, which presumably is due to the anthropogenic disturbances in the underlying modern dataset, the coarse resolution of both distribution maps and vegetation data, and may be also due to the wide tolerances of the plants that were analysed. Despite these shortcomings, the results obtained do show a clear trend towards denser vegetation during late and final MSA phases compared to the HP and post-HP (Fig. 5). This corroborates the qualitative interpretation towards more forested environments after post-HP (Schiegl et al., 2004; Reynolds, 2006). However, a quantitative reading of our data remains difficult. In mean, all values remain below modern ones; a trend which is especially pronounced for the post-HP at ∼58 ka. The palaeovegetation in the vicinity of Sibudu Cave during the occupation phases might have been a similar mosaic to today or it may have been even less forested than today, although today deforestation is purely anthropogenic. Therefore, our results fit well the general interpretation of a mosaic of open savanna grassland, woodland, and mainly riparian patches of forest by Reynolds (2006) and Glenny (2006).

6. Conclusions

Our analysis of fossil plant material from Sibudu Cave confirms the potential of the $\mathrm{CA}_{\mathrm{GIS}}$ application for analysis of Late Pleistocene African floras. The method is appropriate for archaeological contexts if sufficient plant material with reliable taxonomic determination is available.

The quantification of palaeoclimate provides valuable information on the climatic parameters responsible for climatic changes. This approach can help to explain the changes detected in the fossil record with other methods. Moreover, this method was applied for the first time also to estimate the openness of vegetation. Although the issue of vegetation openness remains vague, there seems to be potential for further studies in this direction and higher resolution analyses may increase the informative value of this approach. Such a standardised method can provide comparable data for very different phytogeographical regions and may help to detect large-scale trends in the development of vegetation structures and biomes. Those data may also be useful in the future for the validation of vegetation modelling results.

Even if some smaller climatic changes may be hidden within the sometimes broad coexistence intervals, our data support and quantify former interpretations of environmental changes from the HP until final MSA.

During the HP winters were slightly colder and drier than present, whereas summer temperatures and precipitation were similar to today. Vegetation density might have been a little lower than today.

At the time of the post-HP, winters were drier and colder than present, presumably colder than during the HP. Summer temperatures remained the same but summer precipitation decreased from the HP to post-HP. Vegetation cover was lower than today, may be even lower than during the HP.

The late MSA was pronouncedly warmer than the older periods, especially during winter. At the same time summer precipitation slightly increased and vegetation became more dense but still remained generally open similar to today's anthropogenically altered landscape.

Due to the low number of taxa that could be included in the analysis of the final MSA assemblage, the resulting coexistence intervals are generally broader than for late MSA and do not reflect any remarkable differences with the latter.

In the future, similar studies on other, contemporaneous sites, such as Diepkloof Rock Shelter (Tribolo et al., 2009) or Apollo 11 (Vogelsang et al., 2010), will help quantifying spatial differences in climate, and may contribute to a better understanding of the development and patterns of southern African climate during Late Pleistocene. This may also assist with answering the question of whether environmental changes effected any part of the cultural development from Still Bay to late MSA industries.

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Appendix A. Supplementary material

Supplementary data related to this article can be found online at doi:10.1016/j.quascirev.2012.04.005.

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CHAPTER FOUR – IDENTIFICATION OF SEDGES AT SIBUDU

4.1 Characteristics of sedges, grasses, rushes and reeds

Cyperaceae (sedges) are monocotyledonous plants that, on a superficial level, closely resemble Poaceae (grasses, some also referred to as reeds), Juncaceae (rushes) and Restionaceae (restios) (Haines & Lye 1983; Obermeyer 1985; Gordon-Gray 1995; Hilliard 1996; Dorrat-Haaksma & Linder 2012; Van Oudtshoorn 2012). These similarities are recognised in the uses of the plants, which overlap considerably (Van Wyk & Gericke 2000). Three other families are sometimes mistaken for sedges: Eriocaulaceae, Typhaceae and Xyridaceae (Hilliard 1996). The familiar 'Bullrush', *Typha capensis*, belongs to the family Typhaceae.

Grasses, reeds, rushes, restios and sedges all have small and inconspicuous flowers or florets making up spikelets which comprise the inflorescences. The general characteristics of these families are set out in Table 4.1, but there are exceptions: not all sedges have triangular culms (stems) and *Cyperus involucratus*, widely used for making mats, has culms that are circular in cross-section. Sedges and rushes generally have long smooth culms with leaves clustered at the base, whereas grasses and restios have regular nodes along the culms. Amongst others, the sedge exceptions are *Scleria natalensis* and *S. melanomphala* (Wadley et al. 2011), which have nodes. On a superficial level they could easily be confused with grasses if it were not for their triangular culms. Sedge, restio and rush culms are solid, whereas grass culms are hollow. *Cladium mariscus* is the exception and the culms are hollow at the centre. *Cladium* also has leaves at nodes along the culm. Restios have bladeless leaves and leafsheaths are found at the nodes. The leafsheaths of restios split down to the base and sometimes drop off, leaving characteristic abscission rings. Some sedge species, for example, the Berg Palmiet *Tetraria thermalis*, look similar to restios, but the leafsheaths wrap cylindrically around the culm and are not split (Dorrat-Haaksma & Linder 2012).

Table 4.1 General comparison of the characteristics of grasses, sedges, restios and rushes (exceptions occur). Bract=modified leaf; Caryopsis=single seeded fruit, e.g. wheat, rice; Capsule=dry fruit which splits open to release seeds; Glabrous=smooth, without hairs, scales or bristles; Inflorescence= flower-bearing part of the plant; Ligule=flap of tissue or fringe of hairs at join of leaf blade and leafsheath; Node=part on culm where leaves develop; Nutlet=small hard fruit, indehiscent (not splitting open when ripe); Sheath=reduced leaf (Gordon-Gray 1995; Hilliard 1996; Dorrat-Haaksma & Linder 2012).

	Grasses	Sedges	Restios	Rushes
Flowers	Small, inconspicuous	Small, inconspicuous	Small, inconspicuous	Small, inconspicuous
Inflorescence position	Tip of culm, upper portion	Tip of culm, upper portion	Tip of culm	Just below tip
Culm	Usually hollow	Solid, often triangular	Cylindrical, flattened or square, mostly solid	Solid, some chambered
Nodes	Present all along the culm	Long smooth culms	Present all along culm	Long smooth culms
Leaf position	At nodes	Usually clustered at base	Bladeless, sheaths at nodes	Usually clustered at base
Leaf sheath	Split to base	Tubular	Split to base	Usually open at base
Leaf blade	Often hairy	Glabrous	Leaves reduced to sheaths	Glabrous
Fruits	Caryopsis	Nutlets	Nutlets and capsules	Capsule
Other features	Ligule	Inflorescences mostly rigid	Flowers hidden by bracts	

It is likely that sedges, grasses, rushes and aromatic leaves were used for bedding as early as ~77 ka (Wadley et al. 2011). Later Stone Age bedding at De Hangen (Parkington &Poggenpoel 1986) shows the combined use of sedges, rushes, grasses and an aromatic herb, but it is not advisable to project observations of Later Stone Age bedding into the Middle Stone Age. Factors that may make sedges more attractive bedding than many grasses (Ashley Nicolas, pers. com. 2011) are:

- sedges have a cuticle that makes them more water repellent than grasses. This could possibly prevent damp from rising, as well as mitigate against sodden bedding from sweat, urine or butchering residues. Rising damp does not appear to be a problem at Sibudu, where only very slight moisture has been observed on the shelter floor even after particularly violent rain storms (Fig. 2.1)
- sedges generally do not have as many hairs as grasses and so may be less irritating to the skin
- sedges are flexible, whereas grasses become more brittle with age, and hence sedges are likely to be more comfortable
- sedges are stronger and last longer than grasses

4.2 Identification of sedges at Sibudu

The identification of carbonised nutlets of the sedge *Cladium mariscus* is described in the paper reproduced here and the identifications of a *Cladium mariscus* culm and nutlets of *Scleria natalensis* and *S. melanomphala* are described in Wadley et al. (2011).

The description, distribution, tolerances and uses of *Cladium mariscus* are set out in the paper below. *Cladium* inflorescences produce prolific nutlets (Fig. 4.1). The nutlets are ovoid and up to 3 mm long. Each nutlet consists of a thin endocarp covered by a hard lignified mesocarp, which in turn is covered by an exocarp with large air-filled cells (Fig. 4.2).

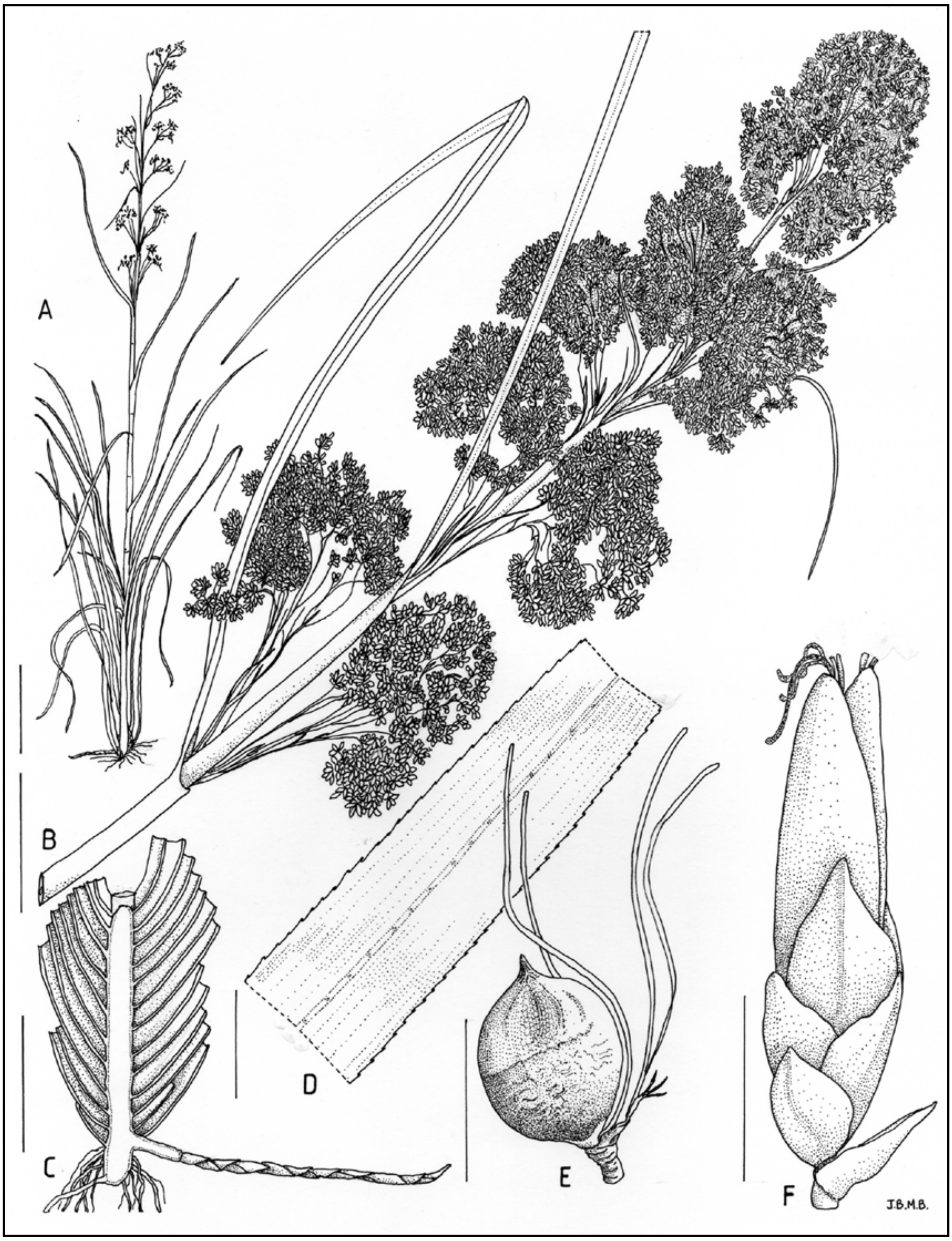

Figure 4.1 *Cladium mariscus* subsp. *jamaicense*. A, plant; B, inflorescence; C, section though base of plant; D, part of leaf showing scabrid margin; E, achene with 2 filaments and upper unisexual floret with 2 filaments and rudimentary gynoecium; F, spikelet prior to enlargement of achene. All from *Ward* 9082 (NU). Reproduced from *Strelitzia* 2 (1995), with the kind permission of the South African National Biodiversity Institute, Pretoria. Drawn by Jane Browning.

Bars: A = 250 mm; B, C = 50 mm; D = 10 mm; E, F = 2 mm.

Waterborne fruits like those belonging to *Cladium*, and other sedge taxa like *Oxycaryum cubense* and *Bolboschoenus,* have appropriate adaptations for distribution by water. In this respect *Cladium* is superficially similar to a coconut, fibrous on the outside to catch air to keep the fruit afloat and with an impervious layer, on the inside, to protect the seed from salt and water (Jane Browning, pers. com. 2011). Unlike *Cladium*, the coconut is a drupe, not a true nut and the coconut seed (white flesh and the coconut milk) adheres to the endocarp, whereas in *Cladium* the seed floats free from the rest of the fruit except at the hilum, a single point of attachment to the fruit.

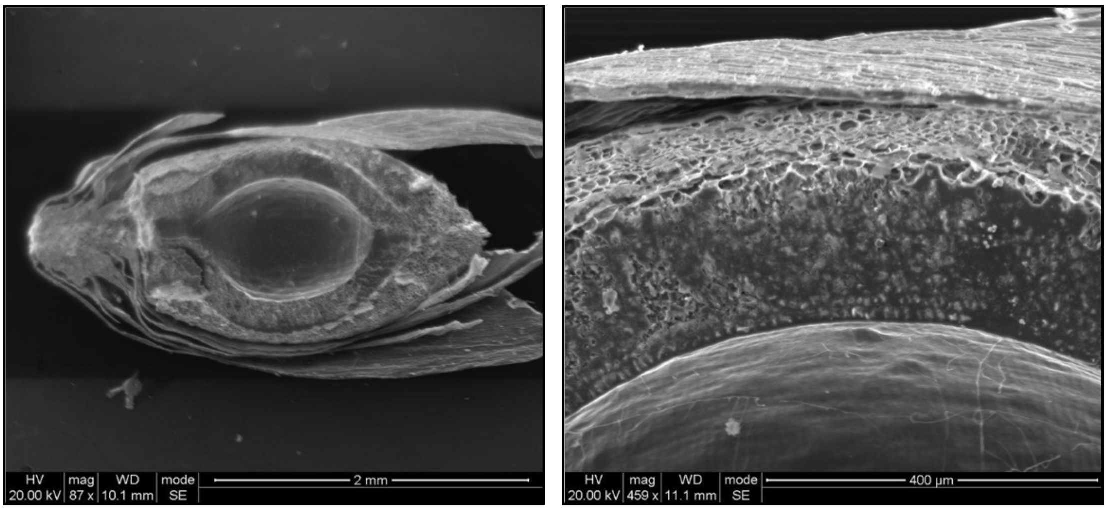

Figure 4.2 The internal morphology of a fresh *Cladium mariscus* nutlet. The spongy exocarp, filled with hollow cells to provide buoyancy in water, is concentrated towards the base and especially the apex of the fruit, and is narrower along the sides of the nutlet.

When exposed to heat as from a fire, the *Cladium* exocarp becomes very fragile and in the Sibudu assemblage, remains only as small adhering fragments. The Sibudu mesocarps, loosely referred to as carbonised, have become blackened and sufficiently transformed to prevent further chemical or biological decay, thus enhancing the likelihood of preservation in the deposits. A carbonised *Cladium* culm (Wadley et al. 2011) indicates the nutlets were likely introduced on culms. The harvesting of *Cladium* leaves by cutting near the base of the plant would automatically include any inflorescences further up the plant, if harvesting were during summer; by late autumn all nutlets appear to have dropped from the mother-plants. The published paper (Sievers & Muasya 2011) reproduced at the end of this chapter describes the methods and identification of *Cladium mariscus* nutlets.

A second, tentative, identification of a carbonised sedge nutlet is that of *Albildgaardia ovata* (Burm. f.) Král. (Fig. 4.3), but the identification cannot be confirmed because the fragile nutlet broke during analysis.

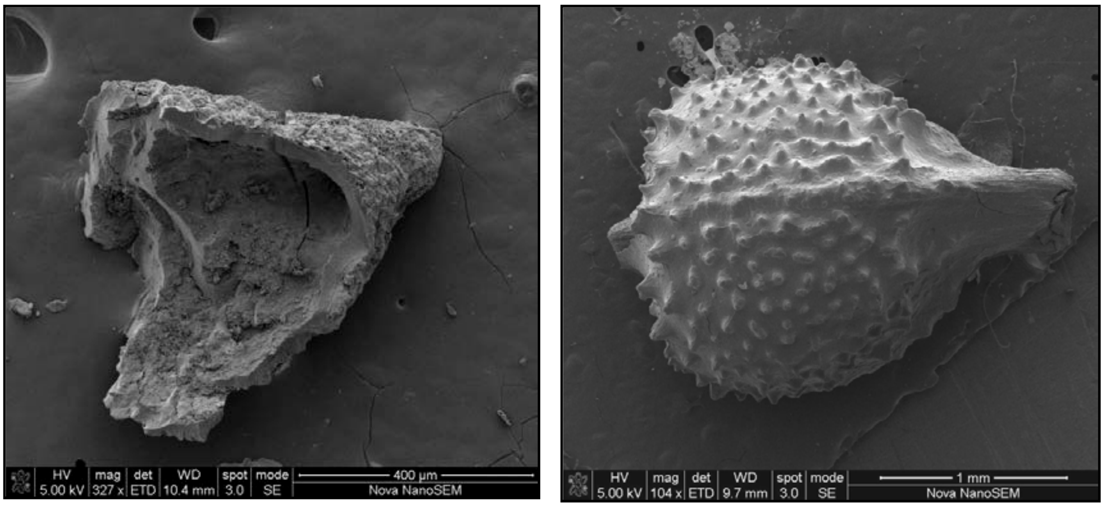

Figure 4.3 The ancient nutlet (left) from layer MOD, quadrant A5c (~48 ka) shattered during the SEM process. Before it broke, the nutlet resembled a modern *Albildgaardia ovata* nutlet (right). The similar, but less prominent surface features and more ovate-lanceolate shape of the ancient nutlet indicated that it might be an immature specimen.

Sievers, C., Muasya, A.M. 2011. **Identification of the sedge *Cladium mariscus* subsp. *jamaicense* and its possible use in the Middle Stone Age at Sibudu, KwaZulu-Natal.** *Southern African Humanities* 23: 77–86.

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Background

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Southern African Humanities **23**: 77–86 September 2011 KwaZulu-Natal Museum

Identification of the sedge *Cladium mariscus* subsp. *jamaicense* and its possible use in the Middle Stone Age at Sibudu, KwaZulu-Natal

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ABSTRACT

The Middle Stone Age deposits at Sibudu contain sedge (Cyperaceae) nutlets, which previously have been interpreted as indirect evidence of bedding. Scanning electron microscopy was used to identify the sedge nutlets through comparison of archaeological specimens with modern analogues. The presence of nutlets of *Cladium mariscus* (L.) Pohl subsp. *jamaicense* (Crantz) Kük, a 1–3 m tall sedge with long scabrid leaves, was unexpected and challenges the bedding hypothesis because of the minute sharp hairs along the midrib and margins of the leaf blades. Nevertheless, we argue for the use of *Cladium* as bedding material, possibly as the foundation on which softer matter was laid. It is possible that the *Cladium* nutlets and rhizomes may have been eaten and that the plant was also used as kindling or fuel.

KEY WORDS: Middle Stone Age, Sibudu, Cyperaceae, *Cladium mariscus* subsp. *jamaicense*, bedding, kindling, fuel.

Downcutting into the Natal Group sandstones produced a shelter that overlooks the perennial uThongathi River that flows into the Indian Ocean approximately 12 km due east, on the KwaZulu-Natal coast of South Africa. The shelter, Sibudu Cave, is approximately 55 m wide and 18 m deep and has provided a living floor that contains evidence of visits by hunting and gathering peoples from at least 77 ka (thousand years) ago until about 38 ka ago (Wadley & Jacobs 2006; Jacobs & Roberts 2008; Jacobs et al. 2008).

Excellent preservation in clear and finely stratified layers has allowed multidisciplinary research led by Professor Lyn Wadley (University of the Witwatersrand) to produce a record of well-dated Middle Stone Age (MSA) occupations spanning the pre-Still Bay (~72 and ~77 ka), Still Bay (~70 ka), Howiesons Poort (~62 to ~65 ka), post-Howiesons Poort (~58 ka), late MSA (~48 ka) and final MSA (~38 ka) (Wadley 2006; Wadley & Jacobs 2006; Jacobs & Roberts 2008; Jacobs et al. 2008).

Numerous large and small hearths, burning events and 'ash dumps' are preserved in the Sibudu deposits and these provide evidence of the woods used by the shelter inhabitants and a window onto prevailing palaeoenvironments (Allott 2004, 2006; Wadley 2006). Carbonised fruits and seeds have also been preserved and have been used for reconstructions of past vegetation (Wadley 2004; Sievers 2006) and people-plant relationships (Sievers 2006, in press; Sievers & Wadley 2008). Sedge nutlets (single-seeded indehiscent fruits with a hard covering, also called achenes) dominate the Sibudu archaeobotanical assemblage (Sievers 2006). Although it is possible that they were eaten by the Sibudu inhabitants, we argue that their introduction to the shelter was by virtue of their attachment to sedge culms (stems), which were harvested and brought into the shelter to provide a surface for resting, sleeping or working, or on which to place items such as food out of the dust. This bedding hypothesis is supported by micromorphological evidence that shows layered organic material through much of the Sibudu sequence (Goldberg et al. 2009; Goldberg & Berna 2010). The organic material is mostly carbonised and often associated with laminar layers of phytoliths, so Goldberg et al. (2009) hypothesised that it was deliberately burnt for site-maintenance purposes. Identifications of Cyperaceae phytoliths supplement those of Cyperaceae pollen, at least in the post-Howiesons Poort (Renaut & Bamford 2006), and this further supports the hypothesis that the sedge was used as bedding. The suitability of sedges for bedding is evident from ethnographic records, which report the extensive use of sedges in southern Africa for weaving mats (Van Wyk & Gericke 2000).

Previous tentative identifications of the sedge nutlets from the Sibudu deposits were made to genus and, in some cases, provisionally to species level: *Abildgaardia ovata*, *Schoenoplectus* cf. *brachyceras* and *Scleria* cf. *angusta*, as well as *Ficinia* sp. and *Fuirena* sp. (Sievers 2006, in press; Wintjes & Sievers 2006). In this study, scanning electron microscopy (SEM) was used for the identification of ancient nutlets though a comparison of micrographs of the ancient nutlets and modern analogues.

METHODS

The sedge flora in KwaZulu-Natal is fairly well studied (Gordon-Gray 1995). Modern nutlets were taken from specimen vouchers of 11 sedge species at the KwaZulu-Natal Herbarium in Durban (Table 1). A further modern sample was collected at Umbilo Ponds, Durban. The criteria for choosing the modern nutlets were similarities in outline (oval and obpyriform) and size (1–2 mm) to the ancient sedge nutlets, which were selected from late MSA and post-Howiesons Poort layers to provide a range of morphotypes from about 48 ka and 58 ka old (Table 2).

The equipment used was a Nova NanoSEM 230 manufactured by FEI, situated at the Scanning Electron Microscopy Unit at the University of Cape Town. Samples of modern nutlets were placed uncovered in clay crucibles and carbonised in a household oven. The term carbonised is used in the general sense understood by archaeologists, with no reference to the chemical properties of the material. Carbonised and uncarbonised samples of the modern nutlets were sectioned to provide an internal

TABLE 1

Modern Cyperaceae nutlets selected for SEM from specimens housed at the KwaZulu-Natal Herbarium. Place and date of collection provided where collector name and number are not available.

Species	**Collector name and number**
Abildgaardia ovata (Burm. f.) Král	D. Johstone 571
Cladium mariscus (L.) Pohl subsp. *jamaicense* (Crantz) Kük	C.J. Ward 9082
Ficinia laciniata (Thunb.) Nees	R.G. Strey 5569b
Ficinia stolonifera Boeck.	M. Jordaan 708
Fimbristylis ferruginea (L.) Vahl	C.J. Ward 13509
Fuirena ecklonii Nees	V.R. Clark 14
Rhynchospora brownii Roem. & Schult.	A. Abbott 2234
Rhynchospora holoschoenoides (Rich.) Herter	R.A. Lubbe 123
Schoenoplectus litoralis (Shrad.) Palla	Umbilo Ponds, January 2009
Scleria achtenii De Wild.	D.R. MacDevette A15
Scleria angusta Nees ex Kunth	G.R. Nichols 432
Scleria woodii C.B. Clarke	C.J. Ward 10684

surface for scanning. Modern and archaeological nutlets were positioned on metal stubs by means of double-sided tape and were coated with a thin layer of gold-palladium alloy to produce a conductive surface, which is required to produce good-quality micrographs. The coating took place in a vacuum of approximately 10^{-1} millibars (mb) and the SEM chamber was operated at 10^{-6} mb. The samples were viewed at 5 kV with the secondary detector.

TABLE 2

Provenance of Sibudu nutlets selected for SEM. MOD = Mottled Deposit; SS = Speckled Sunrise; YA = Yellow Ash; Br = Brown; u = under; H = Hearth. Cultural designation based on lithic technology (Wadley & Jacobs 2006) and OSL ages (Wadley & Jacobs 2006; Jacobs et al. 2008).

Quadrant, layer	**Cultural designation**	**Age in ka**
A5c, MOD	late MSA	49.7 ± 1.8
C5a, SS2	post-Howiesons Poort	56.2 ± 1.9
B4d, YA2	post-Howiesons Poort	
B4c, YA2(i)	post-Howiesons Poort	
C4c, Br u YA2(i) H1 base	post-Howiesons Poort	
C4d, Br u YA2(i) H2 base	post-Howiesons Poort	~58

RESULTS AND DISCUSSION

The archaeological samples were extremely fragile and breakage occurred during the preparation process. Attempts to produce cross-sections of archaeological nutlets were unsuccessful and invariably led to crumbling of the nutlets. Micrographs of the inner detail of ancient nutlets are from serendipitous breakage, not deliberate sectioning. Sectioning of modern charred samples was also difficult and bisections parallel to the central axis of the nutlet were not always produced.

A sedge nutlet has one seed whose wall is fused to the ovary wall, is indehiscent and generally lenticular or three-sided in cross-section. Occasionally it is round or almost round in cross-section, as in some species of the genera *Scleria*, *Ficinia* and *Cladium*. The rounded cross-section of the nutlet is not always obvious in line drawings or micrographs of the nutlets.

The modern sedges in this study, species of the genera *Cladium*, *Scleria*, *Ficinia*, *Schoenoplectus*, *Rhynchospora*, *Fimbristylis* and *Fuirena*, were specifically selected because the shapes and sizes of the respective nutlets indicated that they were the most likely candidates resembling the ancient nutlets. This assessment was based on a literature study (e.g. Haines & Lye 1983; Gordon-Gray 1995) as well as on examinations conducted by CS of all the Cyperaceae vouchers at the KwaZulu-Natal Herbarium, Durban, and of the dedicated and comprehensive sedge nutlet collection compiled by Clare Archer of the South African National Biodiversity Institute (SANBI), Pretoria.

Comparison of micrographs of modern *Cladium mariscus* subsp. *jamaicense* and ancient nutlets from Sibudu indicate that the ancient nutlets are *Cladium mariscus* subsp. *jamaicense*. The shape or external morphology of the nutlets (Figs 1a, c) and the basal ends (Figs 1b, d) closely correlate. The ancient nutlet in Figure 1 is from the late MSA at Sibudu, approximately 48 ka ago. There is also a good match (Fig. 2) between the internal morphologies and basal ends of modern, carbonised *Cladium mariscus* subsp. *jamaicense* nutlets and ancient (carbonised) nutlets. The ancient nutlet in Figure 2 is from

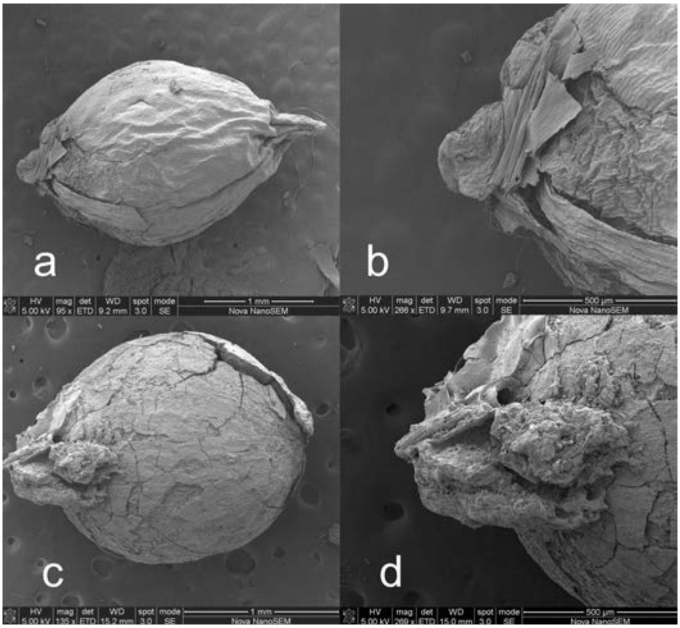

Fig. 1. External morphology of (a) modern, uncarbonised *Cladium mariscus* subsp. *jamaicense* nutlet; (b) modern, uncarbonised basal end; (c) ~48 ka old carbonised nutlet from MOD, quadrant A5c; (d) ancient, carbonised basal end. Scale bars: 1 mm (a), (c); 500 μm (b), (d).

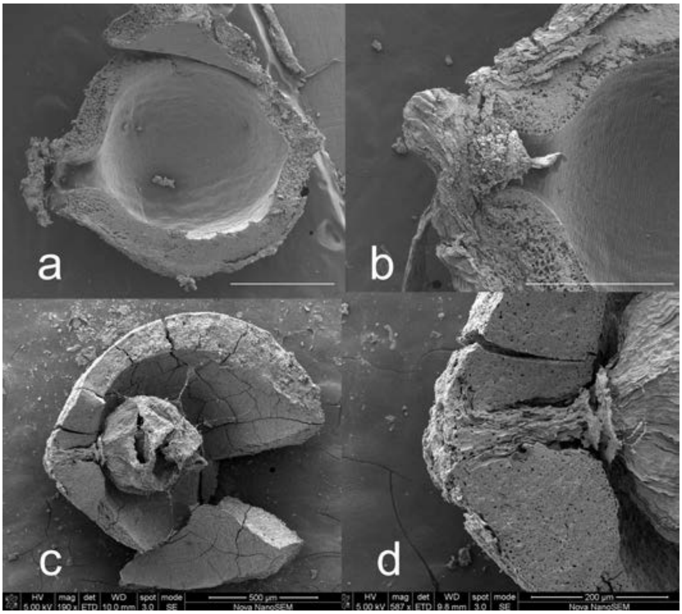

Fig. 2. Internal morphology of (a) modern *Cladium mariscus* subsp. *jamaicense* nutlet; (b) detail of modern basal end; (c) ~58 ka nutlet from base of Hearth 2 in Brown under Yellow Ash 2(i), quadrant C4d; (d) ancient basal end. All nutlets are carbonised. Scale bars: 500 μm (a), (c); 400 μm (b); 200 μm (d).

the post-Howiesons Poort, approximately 58 ka ago. Furthermore, the thickness of the modern ovary walls corresponds with the thickness of the walls of the Sibudu nutlets.

Whereas the modern *Cladium* nutlets are a good match for the ancient nutlets, the modern *Scleria* nutlets exhibit two features that do not match the archaeological nutlets, namely the shape of the basal end where it is attached to the flowering shoot (Figs 3a, b), and the thin nutlet wall (Fig. 3c). When the hypogynium (extreme left in Fig. 3a) is removed, the irregular shape of the ovary is visible in the external (Fig. 3b) and internal outline (Fig. 3c). This does not correspond with the shapes of the ancient nutlets. The thin walls of *Ficinia laciniata* (Thunb.) Nees (Fig. 3d) and *F. stolonifera* Boeck. (Fig. 3e) also exclude them as likely identifications for the Sibudu material. The almost round cross-section of the ancient nutlets was not matched by the other modern nutlets when they were carbonised: *Schoenoplectus litoralis* (Schrad.) Palla remained plano convex (flat on one side and rounded on the other) (Fig. 3 f), while *Rhynchospora brownii* Roem. & Schult., *R. holoschoenoides* (Rich.) Herter (Figs 4a, b) and *Fimbristylis ferruginea* (L.) Vahl (Fig. 4c) remained lenticular. *Fuirena ecklonii* Nees nutlets (Fig. 4d) also remained three-sided when carbonised.

Cladium is a small genus of about four species worldwide, amongst which the leafy perennial, *C. mariscus* (Fig. 5), is the most widespread (Goetghebeur 1998). This species has a wide distribution across southern Africa, occurring as an emergent hydrophyte (an aquatic plant/living in water) or helophyte (marsh plant) from sea level to altitudes of 1400 m (Archer 2003). Its distribution in KwaZulu-Natal was far wider previously; it is now found mostly in the north, in the marshes that surround the estuary at Kosi

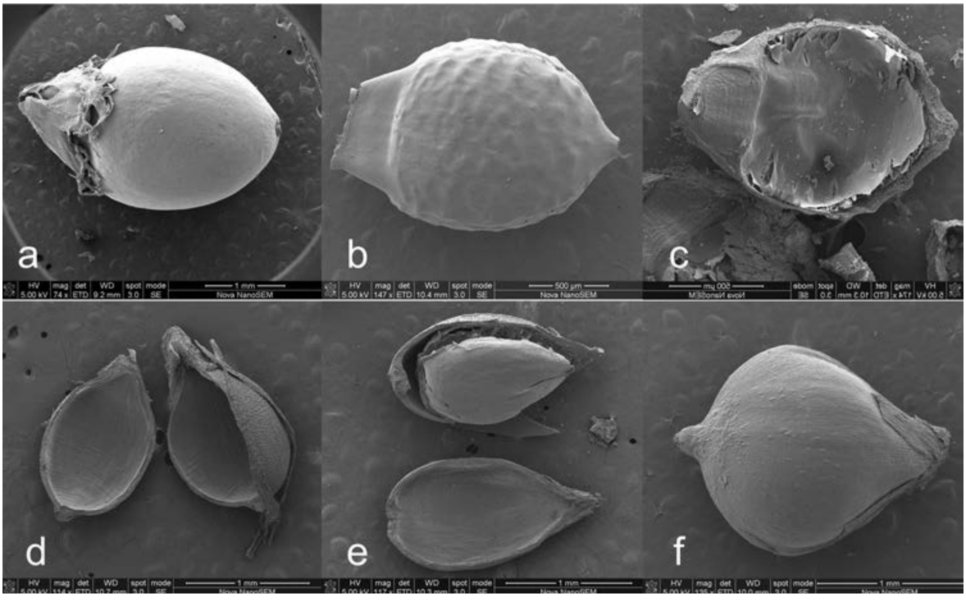

Fig. 3. Uncarbonised, modern nutlets showing (a) external morphology of *Scleria angusta* with intact hypogynium; (b) external morphology of *Scleria woodii* with hypogynium removed; (c) internal morphology of *Scleria achtenii*; (d) internal morphology of *Ficinia laciniata*; (e) internal morphology of *F. stolonifera* showing solitary seed; (f) *Schoenoplectus litoralis* (base right, style left). Scale bars: 1 mm (a), (d), (e), (f); 500 µm (b), (c) .

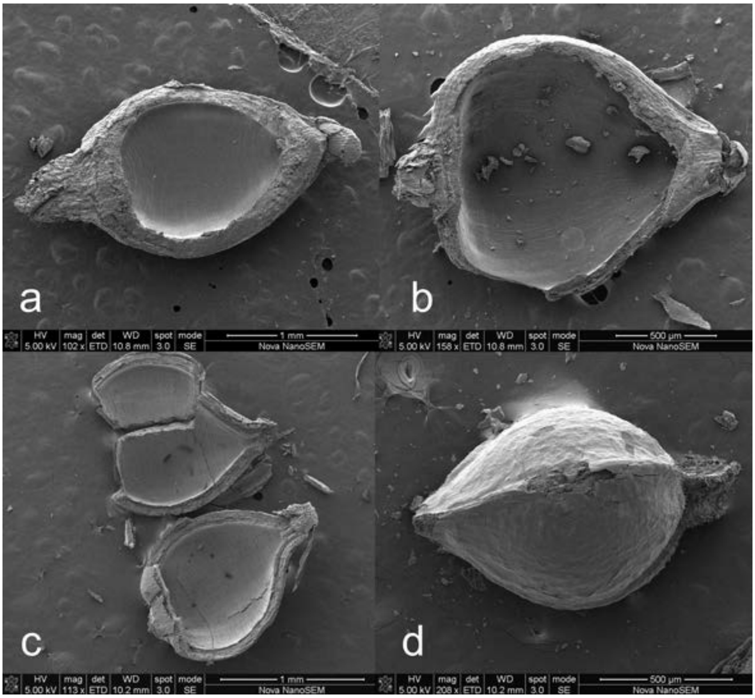

Fig. 4. Uncarbonised, modern (a) *Rhynchospora brownii*, (b) *R. holoschoenoides*, (c) *Fimbristylis ferruginea*; carbonised, modern (d) *Fuirena ecklonii*. The basal ends of *Rhynchospora* and *Fimbristylis* are to the right; on the left are style bases, or remnants of the styles, which supported the stigmas to expose them for pollination. Note that (d) is an intact fruit and trigonous (three-sided) (base left, style right), and that (a, b, c) all lack evidence of the single seed within the fruit. Scale bars: 1 mm (a), (c); 500 µm (b), (d).

Bay (Begg 1980), from Lake Sibaya and the margins of Musi Swamps, and inland, further south, along streamlets in the Ifafa and Umtentweni area (Gordon-Gray 1995). The reduction in distribution is probably the result of encroaching human population and the cultivation of sugar cane (K. Gordon-Gray pers. comm. 2011). For *Cladium* to survive, the water table should not be more than 15 cm below the surface, and water depth not more than 40 cm (Conway 1942). The plant will not tolerate shade and provided its roots are in the water it thrives in sunlight and hot temperatures. The roots are susceptible to frost (ibid.). *Cladium* is able to tolerate a range of salinities (Howard-Williams 1980), but cannot withstand too frequent harvesting, burning or trampling (Conway 1942). *Cladium* nutlets are water-distributed (Conway 1942; Gordon-Gray 1995) and the large cells in the ovary wall (pericarp) (Fig. 2a, b) trap air that keeps the nutlet buoyant during water transportation. Although *Cladium* clearly exhibits this water-borne reproductive strategy, the presence of rhizomes indicates that it also employs vegetative reproduction. A further reproductive strategy employed is pseudo-vivipary, or multiplication by vegetative fragments (Gordon-Gray et al. 2009). This involves a reversal to vegetative growth before fruits mature, enabling the dissemination of plantlets by water, and thus avoiding the time and uncertainties of seed distribution and germination.

Fig. 5. *Cladium mariscus* subsp. *jamaicense*. Main photo: habitat on the northern banks of Lake Mgobeseleni, northern KwaZulu-Natal (April 2011). Inset: detail of the inflorescence from a specimen growing at Rondevlei Nature Reserve near Cape Town (December 2010).

Cladium mariscus has an erect, often curved, woody rhizome, usually about 10 mm thick, which gives rise to several stems (Haines & Lye 1983). The stems are about 10 mm thick at the base, but become thinner along their 1–3 m length. They are glabrous (smooth, without hairs), erect, round or bluntly trigonous (triangular) and are hollow except at the nodes. This distinguishes *Cladium* from other sedges, which have pith-filled culms and mostly, no nodes. The basal leaves can be up to 2 m long and 6 cm wide, and leaves higher up the stem have long tubular leaf sheaths (ibid.). The common name generally applied to all *Cladium* species, 'saw-sedge' (Sanderson & Prendergast 2002) or 'saw-grass' (Gordon-Gray 1995), appropriately applies to the very tough, sharp teeth-like projections on the leaf margins and midrib. The saw-like edge is reflected in the seTswana name, *thipana tsi batsome*, or 'knife of hunters' (Ellery & Ellery 1997), and is the reason that harvesters of saw-sedge in seventeenth-century England bound their hands and arms with protective stockings (Rowel 1986).

Fuel, kindling and thatching are the uses listed for *Cladium mariscus* in the various publications on the exploitation of British plants (Rowel 1986). In the mid-eighteenth century, bakers in Cambridge considered the sedge a necessity of life to heat their ovens (ibid.). It was so highly regarded as a fuel that it was the only fuel purchased for the bakehouses at St John's and Corpus Christi Colleges during the seventeenth century. Special leather gloves were used to harvest the sedge and every college at Cambridge had a sedge loft. The leaves and dried culms are quick burning, whereas the roots and rhizomes are slow-burning and could have provided good fuel (Manniche 1989 in Crawford 2007). Whereas saw-sedge was heavily utilised for thatching in the past in Britain, it is harvested now only on a limited scale for this purpose (Sanderson & Prendergast 2002). The culms and leaves of the sedge are used for thatching in Europe and Africa, and for paper-making in Malaysia, the Americas (Simpson & Inglis 2001), Romania and the Danube Delta (Gordon-Gray 1995). The leaves are used for tying materials in Hawaii (Simpson & Inglis 2001).

POTENTIAL ROUTES OF ENTRY INTO SIBUDU

The tough scabrid leaves of *Cladium* discourage grazing (Ellery & Ellery 1997). Conway (1942: 213–14) says *Cladium* is "never grazed", but adds that Highland cattle readily eat the growing shoots. Such shoots would not have mature inflorescences with fruits, thus the dung of herbivores eating them is highly unlikely to contain nutlets. Cut sedge has been used as fodder in Sweden during periods of hay shortage (ibid.), but even if *Cladium* were a starvation food for large herbivores during times of drought in KwaZulu-Natal, it is unlikely that grazers could have left dung in the shelter because access to Sibudu involves a steep climb which they would have found impossible to negotiate. At Sibudu the collection of animal dung for fuel is unlikely because of the availability of other more easily collected fuel in the surrounding forest and along the river margins. People could be implicated in the distribution of the sedge nutlets if they harvested the whole plants to prepare and eat the rhizomes, the soft basal part of the basal leaves and/or nutlets. Although *Cladium* nutlets are adapted for water dispersal rather than by other means, it is possible that rodents, other small mammals and birds eat the nutlets. It is unlikely that any of these animals that are adapted to the wet conditions where *Cladium* grows, would enter Sibudu to store the nutlets or deposit droppings or dung. Moreover, the ancient nutlets are mostly intact, an unlikely condition for nutlets as a food source: nutlets by definition contain nourishment within, rather than on the outer surface.

Cladium mariscus has not previously been reported from any archaeological deposits. Although *Cladium* occurs in Egypt, a comprehensive study of the widespread use of Cyperaceae in that region does not include *Cladium* (Crawford 2007). *Cladium* is not mentioned in any publications relating to historical or ethnographic uses of plants in southern Africa. The tough, sharp projections on the leaves suggest *Cladium* would not make a comfortable bed on its own. However, it might make a good covered cushion or mattress. Sanderson and Prendergast (2002: 40) report that "the skilled craft of straw wrapped saw-sedge seating is common in France". It is possible that *Cladium* was used at Sibudu in a similar manner to the use of *Blepharis* (Acanthaceae) at Big Elephant Shelter in Namibia, where the bedding hollows were filled with prickly *Blepharis*, which was covered over with grass and leaves (Wadley 1979). The *Blepharis* ripped apart the hands of the excavator. Conway (1942: 214) writes about the "dead-leaf mattress" of *Cladium*. Mattresses have been stuffed with many materials in the past, and the nutlets at Sibudu might be evidence of the harvesting of *Cladium* for informal 'mattresses' that were not wrapped or stitched like modern ones.

Conway (1942: 214) states that "the 'dead-leaf mattress' is very readily flammable and the dried leaves of *Cladium* were formerly used as kindling". Layers of dried *Cladium* plants are likely to have burned well to produce the carbonised layers of phytoliths and organic material at Sibudu that have been cited as bedding. This may have been burnt for site maintenance purposes (Goldberg et al. 2009; Goldberg & Berna 2010), though it may sometimes have ignited accidentally when situated close to camp fires. Experimental work (Sievers & Wadley 2008) suggests that this carbonisation could also have occurred post-depositionally and accidentally as a result of fires lit above the sedge bedding.

More than half of the archaeobotanical assemblage at Sibudu consists of carbonised sedge nutlets (Sievers 2006). *Cladium* nutlets occur throughout the sequence, but their total frequency has not yet been determined. Temperature, rate of heating and length of exposure to heat can all affect the shape and size of fruits and seeds when they are subjected to heat treatment and carbonised (see, for example, Braadbaart 2004; Braadbaart et al. 2007). Experiments are planned to test the range of variation amongst modern carbonised *Cladium* nutlets for comparison with the ancient nutlets.

CONCLUSIONS

Seed remains from Pleistocene contexts are generally interpreted in terms of palaeovegetation (Messager et al. 2008), whereas at Sibudu it is also possible to interpret seeds or nutlets in terms of people-plant interactions. The evidence indicates the use of saw-sedge, *Cladium mariscus*, by people who were visiting Sibudu during the MSA. It is likely that the sedges were laid down on the shelter floor to provide a 'mattress' on which soft plants such as forbs or grass would be placed for protection against the scabrid leaf margins and midribs. It is also possible that saw-sedge was sometimes used for kindling or fuel, and experiments to test this suggestion are planned. The Sibudu hearths contain such a variety of the woody taxa that would have been available from the forest enclosing the shelter, that the deliberate collection of sedges from the river for exclusive use as fuel would be surprising.

ACKNOWLEDGEMENTS

CS especially thanks Lyn Wadley for her continued guidance and support. Funding for CS from the National Research Foundation and the Palaeontological Scientific Trust (PAST), and for AMM from the National Research Foundation, is gratefully acknowledged. The clear micrographs are the work of Miranda Waldron, SEM operator at UCT. Acknowledgement and thanks go to Yashica Singh and the KwaZulu-Natal Herbarium for nutlets from the Herbarium vouchers, and to Clare Archer of SANBI. Thanks too to Kath Gordon-Gray and Dorian Fuller for their helpful comments on the manuscript. Nombuso Ncobo from the Parks, Leisure and Cemeteries Division of the eThekwini Municipality is thanked for permission to collect sedges at Umbilo Ponds.

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CHAPTER FIVE – ROUTES OF ENTRY

A crucial factor to consider in the interpretation of archaeobotanical remains is the routes of entry or agents of deposition of the botanical material. All possible agents of deposition need to be considered and other routes eliminated if people are to be established as the route of entry. The paper reproduced in this chapter (Sievers 2011*)* sets out the possible routes of entry of sedge nutlets into the Sibudu MSA deposits and argues that people are the most likely agents of deposition, that the introduction of the sedge nutlets was not deliberate and that the nutlets were carried into Sibudu because they happened to be on sedge culms, which were harvested in the uThongathi River below the shelter and placed upon the shelter floor as informally constructed bedding. Ethnographic and archaeological reports of the use of sedges in Africa and southern Africa indicate many uses of sedges, including use as bedding material.

Delays in the publication of this paper meant that the identification of *Cladium mariscus* (Sievers & Muasya 2011), which was done after submission of the final draft of this paper, was not included in it. The identifications in the paper reproduced below were not confirmed. The putative immature *Albildgaardia ovata* nutlet reported in this paper shattered during the subsequent SEM process, thus preventing a positive identification.

Sievers, C., 2011. **Sedges from Sibudu, South Africa: evidence for their use.** In: Fahmy, A.G., Kahlheber, S., D'Andrea, A.C. (eds) Windows on the African Past: Current Approaches to African Archaeobotany. Proceedings of the 6th International Workshop on African Archaeobotany, June 13–15, 2009, Helwan University, Cairo, Egypt. *Reports in African Archaeology* 3, 225–241.

Thesis pages 67–76. Page numbers below refer to those in the published paper.

CONTENTS

Sedges from Sibudu, South Africa: Evidence for their Use

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Abstract: *Sedge nutlets are present in Middle Stone Age layers at Sibudu from about 70 ka to about 38 ka ago. The likely source of sedges is the nearby perennial uThongathi River. It is unlikely that birds, small mammals and reptiles, wind or water deposited the sedge nutlets in the shelter. The most likely scenario is that the nutlets were introduced serendipitously on sedge culms deliberately harvested by people using the shelter. Burning experiments demonstrate that post-depositional fires could have played a role in the carbonisation of the nutlets. The presence of sedge culms in the deposits is supported by micromorphological studies. The evidence from Sibudu indicates that people in the Middle Stone Age were harvesting and using sedge culms as a surface on which to sit, sleep or work.*

Keywords: *Cyperaceae, bedding, Middle Stone Age*

Introduction

Sibudu is a shelter situated in the Natal Group Sandstone cliffs overlooking the perennial uThongathi River, approximately 12 km from where it flows into the Indian Ocean on the east coast of South Africa (*Fig. 1*). Dedicated study of the Middle Stone Age (MSA) deposits at the shelter started in 1998 under the directorship of Professor Lyn Wadley from the University of the Witwatersrand, Johannesburg, South Africa. Excavations are ongoing, with material from approximately 21 m^2 being analysed by a multidisciplinary team of local and international scientists (WADLEY & WHITELAW 2006). Clear, finely stratified layers with good preservation of bone and carbonised plant material have been dated by single grain Optically Stimulated Luminescence (OSL). On the basis of the radiometric dating and lithic material the deposits have been divided into a final MSA (38.6 ± 1.9 ka), late MSA (47.7 ± 1.4 ka), post-Howiesons Poort (58.5 ± 1.4 ka), Howiesons Poort (61.7 ± 1.5 – 64.7 ± 1.9 ka), Still Bay (70.5 ± 2.0 ka) and pre-Still Bay (VILLA *et al.* 2005; WADLEY 2005, 2006, 2007; COCHRANE 2006; DELAGNES *et al.* 2006; VILLA & LENOIR 2006; WADLEY & JACOBS 2006; JACOBS & ROBERTS 2008; JACOBS *et al.* 2008a, 2008b; WADLEY & MOHAPI 2008). Faunal remains are well-preserved and show a range of large and small mammals, birds and reptiles (PLUG 2004, 2006; GLENNY 2006; CLARK & PLUG 2008; PLUG & CLARK 2008).

Botanical remains from Sibudu consist of charcoal, phytoliths, fruit, including seeds and nuts, but little pollen (ALLOTT 2004, 2006; SCHIEGL *et al.* 2004; WADLEY 2004; RENAUT & BAMFORD 2006; SCHIEGL & CONARD 2006; SIEVERS 2006; WINTJES & SIEVERS 2006).

The presence of sedge nutlets in the Middle Stone Age layers at Sibudu was first reported in 2006 (SIEVERS 2006). This paper develops the implications of their presence in more detail with respect to agency and human behaviour. By examining and rejecting routes of entry via animals and natural agencies such as wind and water, an argument is made that the sedges were harvested by people, probably for use as bedding, and that the introduction of the nutlets was incidental by virtue of their attachment to the sedge culms. Micromorphological studies of the Sibudu deposits (GOLDBERG *et al.* 2009; GOLDBERG & BERNA 2010) provide strong support for the bedding interpretation.

The term bedding refers to the use of organic matter to cover restricted areas for sitting, sleeping or keeping items such as food out of the dust. Bedding may consist of any suitable organic matter such as sedges, grasses or even soft herbs and shrublets. Grass bedding has been inferred from the high density of grass phytoliths between hearths and along the back wall of the shelter Tor Faraj in Israel (ROSEN 2003; HENRY *et al.* 2004). This late Levantine Mousterian occupation predates more recent evidence, also from Israel, from the hunter-gatherer site

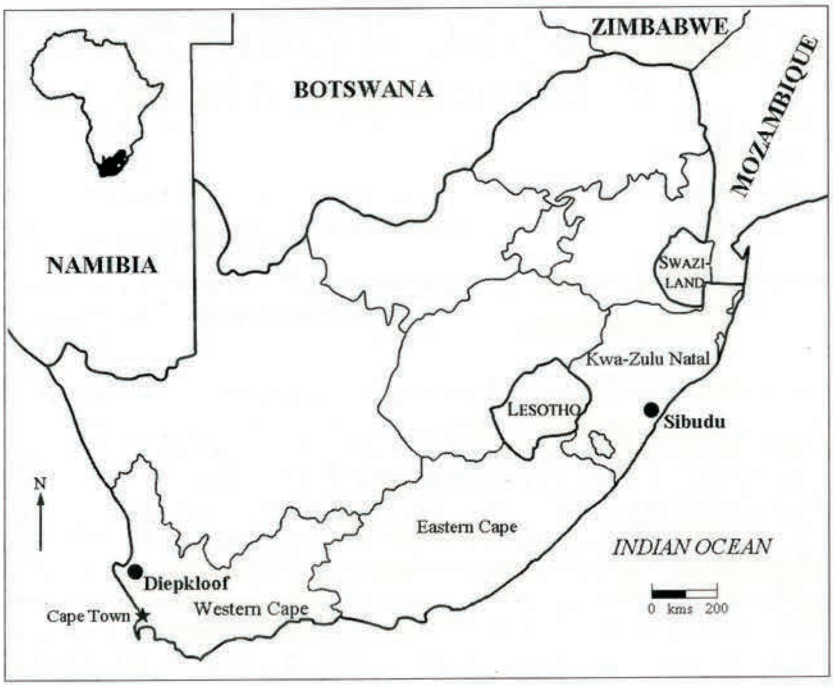

Fig. 1. Map of southern Africa, showing selected provinces in South Africa and the location of the MSA sites Sibudu and Diepkloof.

Fig. 2. The uThongathi River and Sibudu, situated in the cliff behind the vegetation in the centre of the photograph. A large *Celtis mildbraedii* hides the extent of the shelter towards the upper left. The view is downstream.

of Ohalo II where defined resting areas and bedding remains were found on an intentionally constructed floor of an Upper Palaeolithic structure about 23 ka old (Nadel *et al.* 2004). The bedding is of grass arranged in a repeated pattern around a central hearth and along the walls of the dwelling. Grass bedding has also been identified at the Late Mousterian site of Esquilleu Cave in Cantabria, Spain, where phytoliths indicate repetitive preparation of grass bedding by Neanderthals near a central hearth (Cabanes *et al.* 2010). In South Africa, the oldest bedding reported is from Strathalan Cave B where "grass patches" approximately 29 ka old have been recorded (Opperman 1996: 45). At Sibudu the evidence is earlier and points to the use of sedges for bedding. The position of the shelter above the uThongathi River (*Fig. 2*) on a steep south-facing cliff that supports evergreen forest suggests that sedges are likely to have been more readily available to Sibudu inhabitants than grass. A bed of freshly cut sedges makes a fragrant, cool and comfortable resting place on a hot day, and dry sedges serve as insulators against the cold of the earth during less clement times. Sedge culms may have been used for more than one purpose, but it is likely that they were used for sitting or lying on; even dogs prefer a resting place of sedges, rather than dust. Apart from comfort, parasites may also have been a factor: a clean bed of sedges is an attractive choice. Sedges are rich in silica, a factor that may retard mildew build-up, rodent predation (ROSEN 2005) or even other pests. It is likely that sedges may become infested with parasites over time. GOLDBERG *et al.* (2009) suggested that the bedding at Sibudu was deliberately burned to get rid of such pests.

Identification of the Sibudu sedges

Identification and quantification of the sedge nutlets from Sibudu is on-going. Whereas pollen and phytoliths have been identified only as belonging to the Cyperaceae family, sedge nutlets have been identified to family (*Fig. 3*) and provisionally to genus and possible species level: *Abildgaardia ovata*, *Schoenoplectus* cf. *brachyceras* and *Scleria* cf. *angusta* (C. Archer, South African National Biodiversity Insititute, pers. comm. 2006), as well as *Ficinia sp.* and *Fuirena* sp. (M. Muasya, Botany Department, University of Cape Town, pers. comm. 2009). Scanning Electron Microscopy is planned to confirm these identifications. Although analysis is still in progress, it is clear that sedge nutlets are present throughout the Middle Stone Age at Sibudu, except in the most recent, ~38 ka old final Middle Stone Age deposits. This absence may be the result of the larger mesh size (2 mm) used in earlier excavations of the upper layers at Sibudu. After 2002, sampling incorporated a 1 mm mesh. Dry sieving was used in preference to flotation because exposure to moisture causes disintegration of the extremely fragile Sibudu material. Excavation of layers and less frequently, of 5 cm spits when stratigraphy was not clear, was in 50 cm x 50 cm squares. The location of the botanical remains was recorded according to quadrant and stratigraphic layer or feature. Except where such a unit yielded less than one bucket (10 litres), a minimum volume of 10 litres was collected across each unit. Because of the low frequency of botanical remains (*Tab. 1*) and the many units of limited horizontal and vertical extent, usually all excavated material from a unit was sorted. As excavation proceeded in subsequent seasons, additional samples from the same layers were collected and analysed.

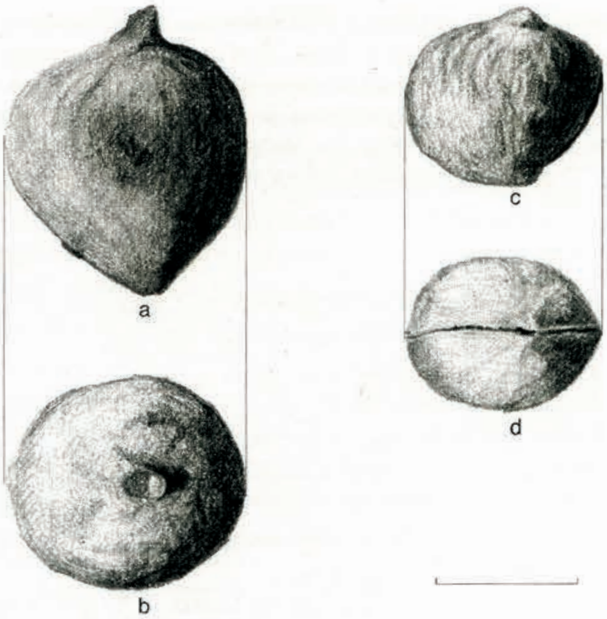

Fig. 3. Carbonised sedge nutlets from Sibudu. Adapted from WINTJES & SIEVERS (2006). The scale bar represents one millimetre.

The available identifications have implications for vegetation reconstruction for the periods during the Middle Stone Age when Sibudu was inhabited. The sedges specifically indicate the presence of water in the nearby uThongathi River and this interpretation is supported by faunal and other botanical material recovered from Sibudu deposits (ALLOTT 2004, 2006; PLUG 2004, 2006; GLENNY 2006; SIEVERS 2006; CLARK & PLUG 2008; PLUG & CLARK 2008). However, interpretations about vegetation and climate have been reported elsewhere (ALLOTT 2004, 2006; WADLEY 2004; SIEVERS 2006; WADLEY & WHITELAW 2006) and do not fall within the ambit of this paper. This paper is concerned with the use of sedges by occupants of the shelter, and after brief overviews of the ethnographically and archaeologically recorded uses of sedges, I will discuss the possible routes of entry of the sedge nutlets and argue that sedges were deliberately harvested for use as bedding.

Ethnographically recorded uses of sedges in southern Africa

In the drier parts of southern Africa, *uintjies* (an Afrikaans word meaning 'little onions' and referring to various indigenous bulbs and corms) traditionally have been a staple food. Cyperaceae is an important *uintjie* family (VAN WYK & GERICKE 2000). The easily harvested bulbs of *Cyperus fulgens* are particularly favoured. Less favoured are *C. usitatus* bulbs and *C. esculentus* tubers, which are borne mostly terminate on horizontally spreading rhizomes. The young shoots of *C. textilis* are eaten while still enclosed in their basal sheath and SMITH (1966) reports that young children extract the soft pith of the culms using their teeth. Tubers of *Eleocharis dulcis*, both raw and cooked, are considered a delicacy in the Okavango Delta of Botswana (ELLERY & ELLERY 1997). VAN DER MERWE *et al.* (2008) also list

	BS to LBG	RGS2 to RGS	PGS to GR	YA2 to G1	Su to Mi	Or to SPCA	BSp2 to BSp	YSp to RSp	BMOD to OMOD2	OMOD	MOD	Ore2 to Co	Total
		> 60 ka			~ 60 ka				~ 50 ka			~ 37ka	
Acacia sp.					1					1+pod			2+pod
Asparagus sp.	1		1	4	24	23	16	6	3	9	4	4	95
Calodendrum capense						x		x		x	x	x	x
Canthium sp.										x	1		1
Celastraceae							1						1
Chrysophyllum viridifolium											2		2
Clerodendrum glabrum					1					1			2
Cordia cf. *caffra*					x	1		2				1	4
Cussonia sp.											1		1
Cyperaceae	2	11	24	16		28		44		128	332		585
Cyphostemma sp.											4		4
Diospyros sp.											1		1
Ehretia rigida								1		1	2	1	5
Erythroxylum emarginatum				1*							4*		5*
Euclea sp.				1	1		1	1			3		7
Grewia sp.			x	7	4	1	1	1					14
Harpephyllum caffrum									1	6	4		11
Lantana cf. *rugosa*			1					3		4	17		25
Type 5 (cf. *Olea* sp.)	x	x	x	31	10	1	2	x		1	x		45
Pappea capensis										1			1
Pavetta spp.				2		1		11	2	23	72		111
Poaceae											1		1
Podocarpus falcatus					x								x
Protorhus longifolia				1	x	2	x*			x	6		9
Psychotria capensis									2				2
Rapanea melanophloeos										1			1
Rhoicissus digitata					2								2
Rhus sp.				1	1					2	6		10
Rubiaceae											1		1
Sideroxylon inerme			1	1			x	3	6	6	1	1	19
Strelitzia sp.										2			2
Vepris lanceolata										4	2		6
Ziziphus mucronata		x	x				1	2	7	4	7	3	24
total	**3**	**11**	**27**	**65**	**44**	**57**	**22**	**74**	**21**	**194**	**471**	**10**	**999**

Tab. 1. Sibudu Cave inventory of MSA identified fruits and seeds (Sievers 2006). Cultural sequence according to Wadley & Jacobs (2006); OSL age clusters according to Jacobs *et al.* (2008a, 2008b). 'x' indicates the presence of a taxon represented by a fragment, or fragments less than half the size of the seed. A somewhat insecure identification is indicated by *.
Legend: Abbreviations for the cultural units are as follows: BS, Brown Sand; LBG, Light Brownish-grey; RGS, Reddish-grey Sand; PGS, Pinkish-grey Sand; GR, Grey Rocky; YA, Yellow Ash; G, Grey; Su, Sulphur; Mi, Midnight; Or, Orange; SPCA, Spotty Camel; BSp, Brown Speckled; YSp, Yellow Speckled; RSp, Red Speckled; BMOD, Brown Mottled Deposit; OMOD, Orange Mottled Deposit; MOD, Mottled Deposit; Ore, Oreo; Co, Coffee.

the succulent lower stem of *Schoenoplectus corymbosus*, and the rhizomes and culms of *Cyperus denudatus*, *C. dives* and *C. papyrus* as edible.

Some of the sedges are favoured for uses other than for food. The soft and spongy culms of sedges such as *Cyperus textilis*, *C. sexangularis* and *Schoenoplectus brachyceras* are especially popular for making sleeping and sitting mats (Van Wyk & Gericke 2000). The traditional beehive hut or *matjieshuis* (an Afrikaans word for a hut constructed of mats) of Namaqualand is made from mats of *Cyperus* and *Scirpus* in particular. The differentiation between 'hard' and 'soft' sedges, "*hardematjiesgoed*" ('hard matting material', *Scirpus spathaceus* — now *Pseudoschoenus inanis*) and "*sagtematjiesgoed*" ('soft matting material', *Cyperus textilis*) was noted in 1811 by the traveller Burchell (Smith 1966: 33). The thick, long, soft and spongy culms of *Schoenoplectus* species do not last as long as the thin, harder and more durable culms of *Juncus* species (Van Wyk & Gericke 2000) and lack of availability of the latter, possibly from over-harvesting, may be a reason for the current widespread use of *Schoenoplectus* for making Zulu sleeping mats.

Cyperaceae are also used for basketry (Van Wyk & Gericke 2000; Cunningham & Terry 2006), although in the past it is likely that light, strong bags of leather were favoured by mobile foragers over less flexible and heavier woven baskets. Similarly, mats would have been bulky and inconvenient baggage for foragers and the labour involved in weaving sedge mats may have been avoided by placing sedges directly on the shelter floor.

Other uses of Cyperaceae have been recorded ethnographically. A solution of the ash of dried, burnt *Cyperus alternifolius* plants is used in the cooking of leafy and other vegetables in Malawi (WILLIAMSON 1972). A sedge plant, botanical name unspecified, is also used for potash, as well as to sew together stems of *Phragmites mauritianus* to make mats (*ibid.*). A salt substitute in the Okavango Delta in Botswana is the ash of *Pycreus nitidus* (ELLERY & ELLERY 1997).

The highly aromatic roots of *Kyllinga alba* contain an unknown essential oil similar to that found in the perfumed and medicinal *Cyperus rotundus* (VAN WYK & GERICKE 2000). The *Kyllinga* roots are traditionally used as stoppers in ostrich eggshell bottles, possibly because of antibacterial properties that keep the water fresh, and the pleasant fresh taste that the root imparts. Roots and tubers of *Cyperus esculentus*, *C. longus* and *C. sexangularis* are reputed to have medicinal properties (HUTCHINGS *et al.* 1996), and WATT & BREYER-BRANDWIJK (1962) report that although the sap of *C. longus* is poisonous and burns the skin, tuber infusions are used as enemas. Various medicinal uses are listed for *C. articulatus*, *Pycreus nitidus* and *Scleria melanomphala* (ELLERY & ELLERY 1997). Although the projection of such uses into the distant past is ill-advised, it is likely that the widely reported edible and 'mat' properties of sedges are likely to have been recognised and exploited in the past.

Archaeological records for the use of sedges in Africa

Isotopic analysis of the tooth enamel of two *Australopithecus boisei* specimens from Tanzania led VAN DER MERWE *et al.* (2008) to propose that *Cyperus papyrus* and other sedges are strong candidates for a staple diet of early hominins. It has even been suggested that the harvesting and eating of underground storage organs, such as those from sedges, promoted both habitual bipedality and adaptations of the jaws and teeth of early hominins (WRANGHAM *et al.* 2009).

HILLMAN (1989) suggests that the underground storage organs of several *Cyperus* species (including *C. papyrus* – papyrus reed), *Schoenoplectus* spp. (bulrushes; but note that in southern Africa the term bulrush is widely used to refer to *Typha capensis*), *Typha* spp. (cattail) and *Phragmites* (common reed) were exploited by hunter-gatherers in the Late Palaeolithic in Upper Egypt. Evidence recovered from Wadi Kubbaniya in Upper Egypt indicates that sedge tubers, mostly from the wild nut-grass *Cyperus rotundus*, were a major source of carbohydrates in the floodplain of the Nile Valley approximately 19,000–17,000 years ago. Moreover, seeds of *Scirpus* sp., a club-rush, in faeces provide evidence that sedge nutlets too were eaten. The tubers of *C. rotundus* and *C. esculentus* have been found from the Neolithic through pharaonic times, and their presence in the stomachs of pre-dynastic burials attests to their use as food (CRAWFORD 2007 and references therein). CRAWFORD (2007) cites primary and secondary evidence of the importance of the Cyperaceae family to ancient Egyptians as food, animal fodder and bedding, fuel including fuel from animal dung, both internal and external medicine, the manufacture of reed bundle rafts, cordage, matting, sandals, basketry, sieves, paper and perfume and for ritual and religious uses such as for incense, garlands or stuffing of mummies.

In Later Stone Age (LSA) deposits at Melkhoutboom in the Eastern Cape, South Africa, edible *C. usitatus* was identified from corms and corm parts (bulbs) in a surface bulk sample (DEACON 1976). *C. textilis* stems were found in the main bedding unit where this sedge was used for mats and for fine and coarser cordage, which was woven into fine 10 mm mesh nets probably used to carry plant foods such as bulbs. Evidence of similar knots from *C. textilis* at Scott's Cave indicates a time depth of about 5000 years for the making of nets (WELLS 1965; DEACON 1976). The matting, cordage, and netting from a cave near Bredasdorp, in the southern Cape, was estimated to be of much more recent origin. Two-stranded twine and matting strands of *C. textilis* were found at De Hangen, a shelter in the south-western Cape (PARKINGTON & POGGENPOEL 1986). Use of *C. textilis* for both mats and cordage is recorded from LSA sites in the Eastern Cape, namely The Havens Cave, Rautenbach's Cave, Kleinpoort Shelter, Groot Kommandokloof Shelter and Nuwekloof Shelter (BINNEMAN 1997, 1998, 1999, 2000). At all the sites except Nuwekloof Shelter, *C. usitatus* remains are dominant among the underground plant food resources. At Scott's Cave, *C. usitatus*, also dominant, have their central cores removed and appear crushed.

Also in the Eastern Cape, at Strathalan B Cave, MSA "bedding patches" were recorded (OPPERMAN & HEYDENRYCH 1990: 93). These bedding areas, radiocarbon dated to 22,000 years ago, were composed predominantly of grass, sometimes with roots and stems still attached. No parts of Cyperaceae plants were identified, except for pollen, which was probably introduced by wind. The approximately 29,000 year old layers at Strathalan B Cave that had grass patches also lacked evidence for sedges (OPPERMAN 1996). Beds of dry grass were recorded in a cave at Bredasdorp, as was *Zostera* in Oakhurst Shelter (GROBBELAAR & GOODWIN 1952: 96), but these occurrences are not as ancient as the Strathalan B remains. In the Western Cape, bedding is reported from De Hangen (PARKINGTON & POGGENPOEL 1986), Klein Kliphuis

Fig. 4. Southern bank of the uThongathi River below Sibudu, with *Typha capensis* (left foreground), *Cyperus involucratus* (centre) and *C. dives* (right).

(Van Rijssen & Avery 1992) and Diepkloof (Texier *et al.* 2010). The bedding patches from De Hangen are probably about 450 years old and primarily consist of stems with attached inflorescences of the sedges *Cyperus* or *Mariscus*, the rush *Juncus capensis*, the grass *Ehrharta calycina*, and *Helichrysum expansum*, a shrublet recorded ethnographically for use as bedding material (Parkington & Poggenpoel 1986). Klein Kliphuis Shelter has two late Holocene bedding units (Van Rijssen & Avery 1992). Neither includes sedges, and grass in the upper unit was identified as *Sporobolus virginicus*. "Burnt bedding" in 60,000 year old sediments at Diepkloof was identified during micromorpological analysis, but further details are not provided (Texier *et al.* 2010: 6181).

Routes of entry for the Sibudu sedge nutlets

A vital issue for the interpretation of the Sibudu sedges is to determine whether anthropogenic, geogenic or biogenic agents were responsible for their presence in the deposit. A detailed study of the routes of entry for the sedges is in progress. Here I present a summary of the various possible depositional agents.

Natural processes as entry routes

Examination of the situation and habitat in which sedges are found *(Figs. 2 and 4)* eliminates water, wind and gravity as agents for the introduction of the sedge nutlets into the shelter. Sedges are indicators of wetland areas and are generally associated with estuarine, lacustrine, riverine and bog environments (Gordon-Gray 1995), which in the Sibudu context indicates the uThongathi River situated at the bottom of the cliff about 30 m lower than the shelter floor. The poor sorting of the shelter's deposits and the angularity of the sand grains within those deposits argue against water as a depositional agent (Pickering 2006). Micromorphological analysis (Goldberg *et al.* 2009) demonstrated that the deposits are almost entirely anthropogenic.

Although sedge pollen is anemophilous (Renaut & Bamford 2006), sedge nutlets are not wind-distributed since they lack the classic reproductive structures of windborne seeds. The riverside habitat of the sedges in the valley below the shelter also argues against wind and gravity as distributional agents of the nutlets (*Fig. 5*).

Birds and small mammals as agents of distribution

Classic attachment structures are missing on sedge nutlets, which rules out the possibility of zoochorous entry via attachment to animals (or people). Waterfowl (D. Allen, Durban Natural Science Museum, pers. comm. 2006) and the small rodents that eat sedges are not obligate or even occasional cave-dwelling animals (P. Taylor, University of Venda, pers. comm. 2006), which rules out the possibility of stored caches of sedge nutlets and droppings containing sedge nutlets in the shelter. Sedge nutlets have little or no flesh and are eaten for the nutrients stored within the nutlet. Most of the sedge nutlets in the Sibudu assemblage are whole, implying that they are unlikely to have been eaten and passed through the stomachs of birds or other vertebrates,

Fig. 5. View of the uThongathi River from Sibudu. The view is downstream.

including humans. Birds of prey are known to discard the crops of seed eaters (D. Allen, pers. comm. 2006) and it is possible that birds preying on seed eaters, *e.g.*, lanner falcons, may have nested on the cliff above the shelter and dropped the crops of their prey containing undigested seeds into the deposits. Such potential events do not adequately explain the high frequency of sedge nutlets in the archaeobotanical assemblage.

People as routes of entry

Elimination of other routes of entry leaves people as the most likely agents for the introduction of the sedge nutlets. Various uses of sedges have been recorded ethnographically and archaeologically in southern Africa, such as use for food, basketry, matting, medicine, twine and the manufacture of netting (see above). Further afield, Cyperaceae phytoliths in archaeological contexts also suggest the use of sedges (*Scirpus* sp.) for fuel, basketry and matting at Çatalhöyük (Rosen 2005) and at Mallaha (Rosen 2007), and for food at Wadi Kubbaniya (Hillman 1989). Crawford (2007) cites an even wider range of everyday and religious and ritual uses of Cyperaceae. At Sibudu it is possible that the whole sedge plant was harvested and the discrete elements used for different purposes, including bedding and food. According to ethnobotanical records, nutlets, bulbs, rhizomes and the lower portions of the culms of many types of sedge are widely eaten by people (Peters *et al.* 1992; Simpson & Inglis 2001). Grindstones were used in the preparation of sedge tubers at Wadi Kubbaniya (Hillman 1989) and at Çatalhöyük (Baysal & Wright 2005 cited in Atalay & Hastorf 2006), but at Sibudu no tools used specifically for the preparation of sedges for consumption have been identified. Seven upper grindstones or grindstone fragments were found in the ~58 ka layers and animal fat, tissue and bone residues on five of these suggest they were used to process animal products (Cochrane 2006; Wadley 2006). The few traces of plant fibre present are thought to be incidental, perhaps from the surrounding sediment (L. Wadley, University of the Witwatersrand, pers. comm. 2010). The absence of lower grindstones does not necessarily imply they were not present: ethnographic examples indicate that lower grindstones may be of wood, which is unlikely to survive (Hillman 1989).

Sedges are ideal for bedding or matting because of the smooth and straight, but flexible culms that can be up to two metres long or more. Ethnographic examples (Van Wyk & Gericke 2000) confirm the desirability of sedges for matting. At Sibudu, sedge nutlets would have been introduced incidentally on culms harvested by people for bedding (Sievers 2006; Sievers & Wadley 2008). There is no direct evidence at Sibudu for the weaving of the sedge culms into mats, but micromorphological studies (Goldberg *et al.* 2009) support the interpretation that the sedges were laid down as bedding on the shelter floor. The micromorphological studies identified numerous layers which consisted almost exclusively of finely laminated charred fibrous material and phytoliths. The use of sedges for twine and for food during the MSA at Sibudu cannot be discounted, particularly because sedges, being strong and flexible, are ideal for twine and because sedges are a valuable and easily harvested source of nutrients. But irrespective of whether or not sedges were eaten or otherwise used, the layers of laminated phytoliths and charred fibrous material (Goldberg *et al.* 2009; Goldberg & Berna 2010) reinforce the interpretation that the culms were laid on the shelter floor and so would have provided a surface which could be used for resting, sleeping or working.

How and why were the Sibudu sedge nutlets carbonised?

Goldberg *et al.* (2009) suggested that the sedge culms at Sibudu were deliberately burned to maintain the living area and possibly get rid of pests. On-going research involving experiments and micromorphological examination has been designed to test this hypothesis. Previous experiments with fire indicate that serendipitous carbonisation of buried material by post-depositional fires may occur in dry shelter environments such as Sibudu (Sievers & Wadley 2008). These experiments, called "burning" experiments because of the burning of firewood in open fires, differ from "heat treatment" experiments undertaken in laboratories where a range of important variables can be precisely controlled. Although critical variables such as temperature and length of exposure to heat cannot be as well controlled in the outdoor experiments, these actualistic situations provide insights that might not be apparent from laboratory experiments and demonstrate plausible scenarios of events that might have taken place in the distant past.

The burning experiments (Sievers & Wadley 2008) have demonstrated that surface fires situated directly above buried seeds can carbonise the seeds. Seeds in the oxidising conditions of the surface fire become ashes (*ibid.*) but the reducing atmosphere and an appropriate temperature under the fire, even a relatively low temperature (*e.g.*, 150°C) can result in seed carbonisation if maintained for a sufficiently long period. Remains up to 10 cm below the fires may be carbonised depending on the various properties of the remains, surrounding matrix, temperature and duration of the fire. Finely stratified layers five centimetres in thickness or less are common at Sibudu, which means that buried sedge nutlets at the site may have been carbonised by unrelated fires placed above them a considerable time after they were deposited.

Conclusions

The carbonised sedge nutlets provide evidence that people in the Middle Stone Age deliberately harvested sedges, carried them up from the uThongathi River into Sibudu and laid them on the shelter floor to provide a surface probably for resting, sleeping or working. This interpretation is supported by the presence of numerous layers of finely laminated fibrous charcoal and phytoliths identified in the Sibudu deposits (Goldberg *et al.* 2009; Goldberg & Berna 2010). Ongoing research of the sedges and sediments at Sibudu has the potential to elaborate further on the use of bedding by modern humans during the Middle Stone Age.

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CHAPTER SIX – BEDDING AT SIBUDU

The papers (Wadley et al. 2011; Wadley et al. SOM) reproduced in this chapter, present the multiple lines of evidence for bedding at Sibudu:

1. micromorphological
2. experimental
3. macrobotanical and microbotanical
4. clay fragments, some containing diatoms and some with plant impressions

I discuss the lines of evidence in more detail in Chapter Nine – Discussion and Conclusions.

The earliest archaeological evidence of bedding currently reported from anywhere in the world is represented at Sibudu by mineralised remains at about ~77 ka. Subsequent bedding at the site is preserved through carbonisation. The presence of aromatic *Cryptocarya woodii* leaves on the ~77 ka (unburned) bedding suggests that the plant's insect-repellent properties were recognised and used (Wadley 2012a). The carbonised bedding in more recent layers suggests that fire was used as a maintenance activity, presumably to get rid of fusty bedding and insects.

The identification of the burned bedding in the micromorphological profiles of Sibudu sediments stimulated outdoor fire experiments, which formed one of the lines of evidence supporting the bedding hypothesis. It also led to two papers (Miller & Sievers 2012; Sievers submitted), which involved the burning of sedge and grass bedding.

Wadley, L., Sievers, C., Bamford, M., Goldberg, P., Berna, F., Miller, C. 2011. **Middle Stone Age bedding construction and settlement patterns at Sibudu, South Africa.** *Science* 334, 1388–1391.

Thesis pages 81–85. Page numbers below refer to those in the published paper.

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Wadley, L., Sievers, C., Bamford, M., Goldberg, P., Berna, F., Miller, C. 2011. **Middle Stone Age bedding construction and settlement patterns at Sibudu, South Africa.**

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CONTENTS – MATERIALS AND METHODS

Middle Stone Age Bedding Construction and Settlement Patterns at Sibudu, South Africa

Lyn Wadley, *et al.*

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A third reason may be the neglect of dust radiative forcing in some previous LGM studies (*21*) despite ample evidence from the paleoenvironmental record that dust levels were much higher (*25*, *26*). Sensitivity tests (Fig. 3) (SOM section 7) show that dust forcing decreases the median ECS_{2xC} by about 0.3 K.

Our estimated ECS_{2xC} uncertainty interval is rather narrow, <1.5 K for the 90% probability range, with most (~75%) of the probability mass between 2 and 3 K, which arises mostly from the SST constraint. This sharpness may imply that LGM SSTs are a strong physical constraint on ECS_{2xC}. However, it could also be attributable to overconfidence arising from physical uncertainties not considered here, or from misspecification of the statistical model.

To explore this, we conduct sensitivity experiments that perturb various physical and statistical assumptions (Fig. 3 and figs. S14 and S15). The experiments collectively favor sensitivities between 1 and 3 K. However, we cannot exclude the possibility that the analysis is sensitive to uncertainties or statistical assumptions not considered here, and the underestimated land/sea contrast in the model, which leads to the difference between land- and ocean-based estimates of ECS_{2xC}, remains an important caveat.

Our uncertainty analysis is not complete and does not explicitly consider uncertainties in radiative forcing due to ice-sheet extent or different vegetation distributions. Our limited model ensemble does not scan the full parameter range, neglecting, for example, possible variations in shortwave radiation due to clouds. Nonlinear cloud feedback in different complex models make the relation between LGM and CO_2 doubling–derived climate sensitivity more ambiguous than apparent in our simplified model ensemble (*27*). More work, in which these and other uncertainties are considered, will be required for a more complete assessment.

In summary, using a spatially extensive network of paleoclimate observations in combination with a climate model, we find that climate sensitivities larger than 6 K are implausible, and that both the most likely value and the uncertainty range are smaller than previously thought. This demonstrates that paleoclimate data provide efficient constraints to reduce the uncertainty of future climate projections.

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Middle Stone Age Bedding Construction and Settlement Patterns at Sibudu, South Africa

Lyn Wadley,[1,2]* Christine Sievers,[1] Marion Bamford,[3] Paul Goldberg,[4,5] Francesco Berna,[5] Christopher Miller[4]

The Middle Stone Age (MSA) is associated with early behavioral innovations, expansions of modern humans within and out of Africa, and occasional population bottlenecks. Several innovations in the MSA are seen in an archaeological sequence in the rock shelter Sibudu (South Africa). At ~77,000 years ago, people constructed plant bedding from sedges and other monocotyledons topped with aromatic leaves containing insecticidal and larvicidal chemicals. Beginning at ~73,000 years ago, bedding was burned, presumably for site maintenance. By ~58,000 years ago, bedding construction, burning, and other forms of site use and maintenance intensified, suggesting that settlement strategies changed. Behavioral differences between ~77,000 and 58,000 years ago may coincide with population fluctuations in Africa.

Genetic and phenotypic (skull) data indicate that after 80 thousand years ago (ka), human populations went through bottlenecks, isolations, and subsequent expansions (*1*–*3*). Concurrently, the Middle Stone Age (MSA) of South Africa witnessed a variety of emerging behavioral practices by anatomically modern humans, including use of shell beads and engraving (*4*–*6*), innovative stone technology (*7*), the creation and use of compound adhesives (*8*), heat-treatment of rock (*9*), and circumstantial evidence for snares (*10*) and bows and arrows (*11*). Less emphasis has been placed on innovations in domestic organization and settlement strategies, which might also have been influenced by major demographic changes that were occurring in Africa. Here, we present geoarchaeological and archaeobotanical evidence (*12*) from the South African rock shelter Sibudu (fig. S1) for changing domestic practices in the form of construction of plant bedding starting at ~77 ka, approximately 50,000 years earlier than records elsewhere. Most evidence for bedding in the Pleistocene has been inferential, except for that from Esquilleu Cave, Spain (*13*); Strathalan B Cave, South Africa, dated 29 to 26 ka (*14*); and Ohalo II, Israel, dated to 23 ka (*15*).

Sibudu is situated on a cliff 20 m above the uThongathi River (figs. S2 and S3), 40 km north of Durban and 15 km inland from the Indian Ocean. Excavations have been conducted here

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since 1998 and have revealed a sequence of several discontinuous MSA occupation layers preserved within 3-m-deep sediments (figs. S4 to S6) (*12*). Single-grain, optically stimulated luminescence (OSL) ages indicate that the occupations range from ~77 to 38 ka (*16*) (table S1). The periods of occupation and abandonment during this time are similar to patterns at other southern African sites (*16*), although Sibudu has one of the most complete later MSA sequences. Between 71 and 62 ka, artifacts at the site include perforated seashells and a suite of bone tools (*17*, *18*). Such artifacts are better known from sites on the coast located >1000 km south of Sibudu.

At least 15 occupation horizons (table S1) (*12*) incorporate centimeter-thick, compacted layers of finely laminated, herbaceous material, including stems and leaves, that are capped by laminated, articulated phytoliths (Figs. 1 and 2, A to C, and figs. S7 to S9). Here, we describe in detail five plant-rich horizons [Table 1 and supporting online material (SOM) text]. Most of the layers extend for at least 1 m and up to 3 m across the excavated area (fig. S10). Taxon identification of the tangled, broken stems and leaves is not often possible, although a *Cladium* sp. culm has been recognized (Fig. 2A). Other culm fragments with smooth or longitudinally striated surfaces and narrow leaves with longitudinal parallel venation (Fig. 2C) identify the plants as monocotyledons, such as sedges, rushes, or grasses. The arrangement of vascular bundles in plant stems seen in thin section (fig. S11) is an additional attribute of monocotyledons. Grass (Poaceae) phytoliths have been detected in some but not all layers (Fig. 2B and table S2) (*12*). Sedge and rush identifications are well-supported by the presence of >600 fruits of Cyperaceae (sedges) (*19*) and Juncaceae (rushes), which are normally plants of wet habitats and could not occur naturally within the dry rock shelter (table S3). Scanning electron microscope (SEM) images demonstrate that most fruits are *Cladium mariscus* subsp. *jamaicense* (L.) Pohl (Crantz) Kük (Fig. 2D), but *Scleria natalensis* C.B. Clarke (Fig. 2E), *Scleria melanomphala* Kunth, and *Juncus* sp. (Fig. 2F) are also represented (Table 1). Occupation debris is intimately associated with all the monocotyledon-rich layers. In thin section, we identified narrow layers of chipped stone and crushed, burnt bone within plant layers (fig. S12); these delimit multiple subsurfaces, implying that the plant layers were regularly refurbished with fresh culms and leaves. Riverine clay occurs as sand-sized aggregates (Fig. 3, A and B) within the layers, suggesting that the plants, with clay still adhering to them, were collected by people from the uThongathi River valley. Several clay fragments exhibit monocotyledonous leaf or stem impressions (Fig. 3, A and C).

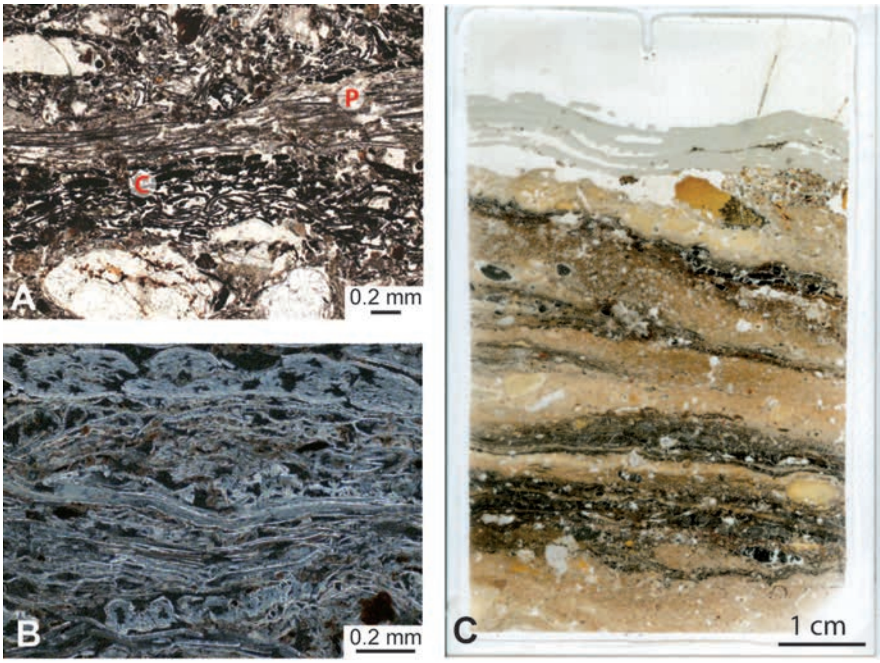

Fig. 1. Micromorphology (photomicrographs and flatbed scan) of selected bedding layers from Sibudu. (**A**) Laminated, articulated phytoliths ("P") overlying laminated, carbonized monocotyledonous stems ("C"), layer Ore (~48 ka). The image was produced with plane-polarized light (PPL). (**B**) Siliceous plant bedding, layer BS6 (~77 ka), PPL, with dark field illumination. (**C**) Flatbed scan of a thin section showing repeated construction and burning of bedding, layer H1 in Br. under YA2(i) (~58 ka). Multiple couplets of laminated phytoliths (light-colored material) and laminated, carbonized monocotyledonous stems (dark-colored material) rest directly on each other.

Table 1. Selected bedding samples from Sibudu: provenances, ages, and identified monocotyledons. "X" denotes presence.

Square	Layer	OSL age (ka) (*16*)	Monocotyledons	
			Fruits	Stems
B4/C4	BS6	77.2 ± 2.1	*Cladium mariscus*, *Scleria natalensis*, *Scleria melanomphala*	x
B4	LBG	72.5 ± 2.0	*Cladium mariscus*, *Juncus* sp.	x
C4	PGS	64.7 ± 1.9	*Cladium mariscus*	x
B4 and C4	Br. under YA2(i)	between 61.7 ± 1.5 and 58.2 ± 2.4	*Cladium mariscus*, *Cyperus* sp.	*Cladium* sp.
E2	Ore	~48	Not sampled	x

In thin section, the finely laminated plant-rich strata appear compressed, probably the result of repeated trampling. The atypical occurrence of wet habitat plants within the shelter, and their laminated, compacted microstructure with artifactual inclusions, implies that the features are of anthropogenic origin. The evidence strongly suggests that the plant layers were used as a type of floor preparation, usually called "bedding" by archaeologists, but probably used—such as in KwaZulu-Natal today (fig. S13) (*12*)—as a surface for working and sleeping. Similar micromorphological characteristics were produced in experiments designed to burn compacted sedges (fig. S14) (*12*) and in bedding described from younger archaeological sites (*15*). Most, but not all, of Sibudu's bedding appears burned, resulting in carbonization of fibrous plant material at its base where oxygen was scarce, and ashing of plant material at the top where oxygen was available. The laminated, articulated phytolith layers formed on the ashed surface of the bedding, where temperatures were higher than in the base (Fig. 1, A and C).

The oldest bedding, dating to 77 ka, is approximately 1 by 2 m in area but may extend beyond the excavation grid. It includes an unburned layer of white, fossil dicotyledonous (broadleaved) leaves (Fig. 4), 0.2 mm thick, overlying an 8-mm layer of monocotyledonous leaves and stems. Well-preserved, articulated monocotyledonous phytoliths are seen in thin section (Fig. 1B and table S2). Fourier transform infrared spectroscopy (*12*) shows that the leaf tissues are impregnated with opal (fig. S15 and table S4). The leaves preserve distinct venation and stomata (Fig. 4, A to D, and fig. S16), and are all from *Cryptocarya woodii*

Engl. (*12*). Today, this tree occurs in forest, woodland, ravines, and along streams (*12*). Many woody plants grew near Sibudu during the MSA (*19*, *20*); thus, single-taxon windborne leaf litter seems improbable. *Cryptocarya* species are used extensively as traditional medicines. Although *C. woodii* is not as toxic as other South African *Cryptocarya* species, its crushed leaves are aromatic and contain traces of α-pyrones, cryptofolione, and goniothalamin (*21*), chemicals that have insecticidal and larvicidal properties against, for example, mosquitoes (*22*–*25*). Mosquito-borne diseases are endemic to many parts of Africa, and rural communities still use indigenous plants to dispel mosquitoes (*26*). Early use of herbal medicines may have awarded selective advantages to humans, and the use of such plants implies a new dimension to the behavior of early humans at this time.

After ~73 ka, all bedding at Sibudu is burned. If use of *C. woodii* continued, the evidence was destroyed because the leaves produce few phytoliths (fig. S17), and these cannot presently be identified (*12*). Accidental ignition of bedding may sometimes have occurred, yet repeated carbonization throughout the sequence suggests intentional burning perhaps to eliminate pests and garbage, enabling further site occupation. Such site maintenance is reported in the ethnographic literature (*27*).

Human use of Sibudu appears to have intensified during post-Howiesons Poort occupations. Dating and sediment micromorphology (SOM text and table S1) demonstrate that the rate of anthropogenic sedimentation increased. In a 90-cm stratigraphic column of post–Howiesons Poort occupations dated to a relatively short period with a weighted mean of 58.5 ± 1.4 ka (*12*), 37 clearly distinguishable layers are present. Individual bedding layers are more numerous there than lower in the sequence. Additionally, complex associations—commonly several centimeters thick—seem to represent swept ashes from hearths (*28*), a practice absent before 58 ka. Sweeping and banking of ashes has been recorded historically in the Kalahari (*29*). The density of stone tools also suggests intensified activity ~58 ka. We sampled a sediment column intensively over an area of 2 m^2. We obtained a total of 8033 unbroken stone flakes (*30*) in sediments aged ~58,000 years—that is, 4462 flakes m^3 versus only 2244 flakes m^3 in the 70,000-year-old layers. Intensification at ~58 ka may have resulted from longer visits, more visits, or larger groups than previously and is consistent with the evidence for more regular site maintenance. Other data also support an interpretation of greater populations at ~58 ka. First, ages of MSA occupations from several well-dated southern African sites (*16*) confirm that more sites have occupations at ~58 than ~70 ka. Second, genetic and

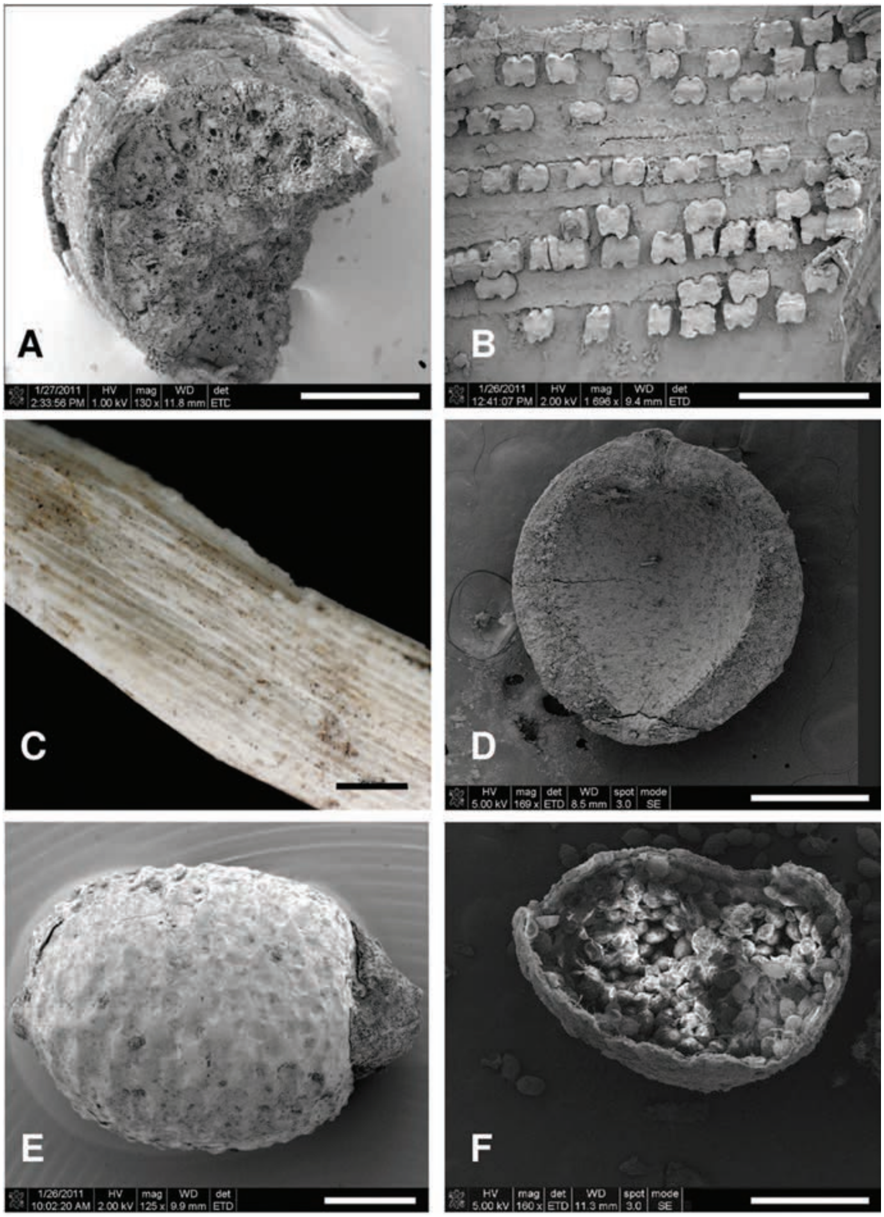

Fig. 2. SEM images of Sibudu sedge (Cyperaceae) and rush (Juncaceae) fruits, sedge culm and grass (Poaceae) phytoliths, and a photograph of a monocotyledonous leaf. (**A**) Carbonized stem of *Cladium* sp., square C4b, layer H1 Br. under YA2(i) (~58 ka). (**B**) Grass phytoliths, square B4b, layer BS6 (~77 ka). (**C**) Siliceous monocotyledonous leaf, square C4b, layer BS6 (~77 ka). (**D**) Internal morphology of carbonized half nutlet, *Cladium mariscus* subsp. *jamaicense*, square B4c, layer YA2(i) (~58 ka). (**E**) Siliceous sedge nutlet, *Scleria natalensis*, square C4b, layer BS6 (~77 ka). (**F**) Carbonized rush fruit, *Juncus* sp., square C4d, layer LBG2 (~73 ka). Scale bars, (A) and (C) to (F) 0.5 mm; (B) 50 μm.

phenotypic variation suggest that bottlenecks at ~80 to 60 ka were followed by rapid population growth, as well as by expansions within and out of Africa at ~56 ka (*2*).

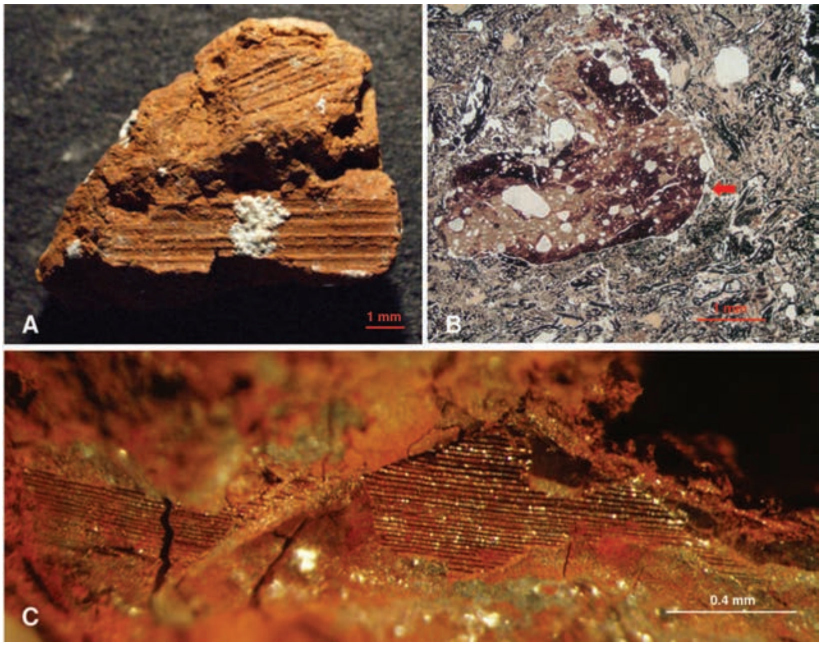

Fig. 3. Selection of riverine clay fragments from Sibudu sediments. (**A**) Clay fragment with monocotyledonous plant impressions, square B5d, layer YA2 (~58 ka). (**B**) Photomicrograph of clay fragment, square B4, layer OMOD (~48 ka). (**C**) Clay fragment with monocotyledonous leaf impressions, square C6c, layer YA (~58 ka).

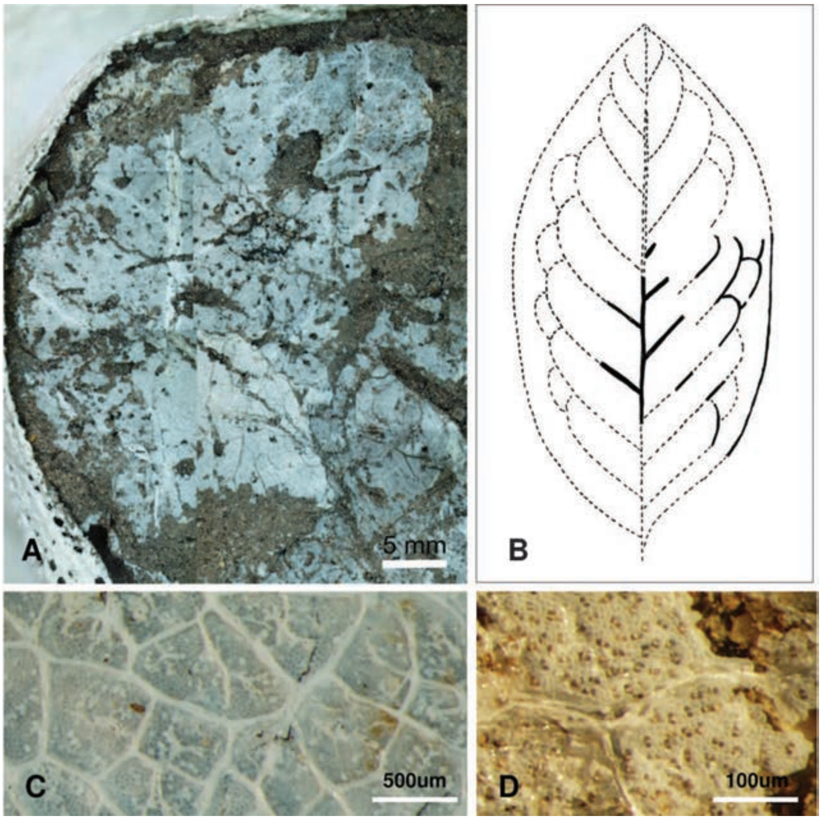

Fig. 4. *Cryptocarya woodii* leaf from Sibudu's ~77 ka bedding. (**A**) Almost complete leaf with wide and irregularly spaced secondary veins arising from the thick primary vein. Loops of the brochidodromous secondary veins can be seen on the top left. (**B**) Sketch of leaf with solid lines representing preserved venation. Dashed lines represent missing part of leaf, based on this and other specimens. The thick margin is visible. (**C**) Detail of fine venation with square to polygonal areoles containing bifid quaternary veinlets. This is the inner view of the upper epidermis, and there are no stomata. (**D**) Inner view of lower epidermis, showing butterfly-like stomata (thin paired cells).

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Middle Stone Age Bedding Construction and Settlement Patterns at Sibudu, South Africa

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Materials and Methods

Excavation

All archaeologically-recovered materials described here have been excavated or sampled from Sibudu, KwaZulu-Natal, South Africa, under the direction of LW. For general excavation procedures at Sibudu see (*S1*). LW used a surgical scalpel to expose fossil leaves on platforms of sediment that were reinforced with jackets of gypsum-impregnated bandages. No chemical preservatives were used.

OSL dating

Sediment samples were collected and quartz grains taken from these in the laboratory for single grain optically stimulated luminescence dating. Extraction, processing and statistical calculation are described elsewhere (*S2-S5)* and the ages are listed in table S1. Some additional explanation is needed for the statistical method used to calculate the ~58 ka suite of ages from the post-Howiesons Poort sequence. The youngest point estimate of age (57.6 ka) is in the topmost post-Howiesons Poort layer, BSp, and the oldest point estimate (59.6 ka) is in the older sample from layer SS, and not from the deepest sample in the post-Howiesons Poort set, that is 58.2 ka from layer B/Gmix. The important issue is that the youngest and oldest ages are statistically consistent with each other at the 68% confidence interval (1-sigma) and, therefore, at the 95% confidence interval (2-sigma) also. Thus the ages of these two samples are not significantly different and this comparison can be extended to all six post-Howiesons Poort ages. This procedure by Jacobs and Roberts used the 'homogeneity test' of Galbraith (*S4*), which is a standard statistical test, not unlike a chi-squared test. The P-value obtained from the homogeneity test is >0.98, which means that the null hypothesis (that all of the ages are consistent with a common value) cannot be rejected. However, the size of the uncertainties on each of the OSL ages is too large to allow the separation of variations in age of a few centuries or less. Such short spans of time cannot be recognised when each of the age uncertainties is +/- one or two millennia at 1-sigma. So, while it is true that the bottom sediments must have accumulated some time before the overlying sediments, the difference in their timing happened too quickly to discern using OSL dating. All of the post-Howiesons Poort sediments could have accumulated in a century or in 1000 years, for example, but the precision on the OSL ages does not allow this interpretation. It would be wrong to pick the oldest and youngest ages and say that these represent an age bracket, because the youngest sample could easily be 2000 years older, and the oldest sample could easily be 2000 years younger. The parsimonious approach is to take the weighted mean of the ages because the homogeneity test shows that they are statistically indistinguishable and, therefore, consistent with a depositional event of a few millennia duration or shorter. The weighted mean of the post-Howiesons Poort ages is 58.5 ± 1.4 ka. Weighted mean ages have been calculated this way elsewhere (*S5*).

Mineralogy and sediment micromorphology

Schiegl collected more than 500 loose sediment samples from Sibudu so that each Sibudu layer was represented in the mineralogical sampling strategy (*S6, S7*). These samples were prepared, processed and analyzed in the Geoarchaeology Laboratory at Tübingen as described in *S6* and *S7*. Micromorphological samples were collected from Sibudu, and prepared and analyzed as described in (*S8-S10*) using a Zeiss AxioImager petrographic microscope in the Geoarchaeology Laboratory at Tübingen. Results are provided in the SOM Text.

Experimental burning of sedge bedding and a study of its sediment micromorphology

In order to test the hypothesis that the plant-rich layers represent bedding, we conducted an experiment reproducing a possible scenario for their formation. We collected *Cyperus involuncratus* Rottb. (sedge) culms and inflorescences, allowed them to dry, and then cut them into 30cm-long sections. We excavated a hole (30x30cm wide and 6cm deep) in the clayey Berea Red Sand (BRS) that occurs at Durban, South Africa and placed the cut sections of culms into the hole, layering them at 90 degrees to one another. Once the hole was filled, the sedges were compacted under the repeated rolling of a tennis-court roller. The roller was then left stationary on the sedges for 45 minutes in order to replicate ancient trampling of the bedding. Following compaction, the sedges were ignited and allowed to burn until the flames died. This process was repeated four times. After the final fire, the burnt sedges were covered with a layer of BRS and the tennis-court roller was placed above them to replicate natural compaction of sediments, which would have occurred at Sibudu over time. After a week of compaction, the roller was removed and the experimental area was excavated. A block of sediment including the experimental bedding layer was removed and processed for sediment micromorphological analysis. Similar experiments were performed with another sedge, *Schoenoplectus litoralis* Palla., and two grass species, *Panicum deustum* Thunb. and *Setaria plicatilis* (Hochst.) Engl.

In thin section (fig. S14), the experimental results appear very similar to the archaeological examples of bedding. Compaction and burning reduced the volume of fresh organic material by up to 98%, producing a thin layer composed of micro-laminated fibrous charcoal and laminated phytoliths. The experimental results suggest that the model of formation proposed for the bedding layers is consistent with the archaeological material. One interesting result of the experiment was that no calcareous ash rhombs were produced during combustion. Calcareous ash rhombs are also absent from archaeological examples of burnt sedges, suggesting that the phytoliths form the main component of sedge "ash."

Identification of phytoliths

There is no phytolith classification key for South Africa's diverse plants. The phytolith identifications (*S6*, *S7)* (table S2; Figs. S11 and S17) were therefore made by referring to data from other continents and to the phytolith inventory of central African soils (*S11*). The methodology used for extracting phytoliths from sediments is described in *S6* and *S7*. It was possible to distinguish grass and tree phytoliths, though a palm was also identified in the ~48 ka layer RSp (*S6, S7*). Some phytoliths display morphological changes that make them difficult to recognize or count. These changes might have come about because of the high pH values associated with ash (*S7*). Phytoliths are unlikely to have been blown into Sibudu because there are not many phytoliths in the modern soil samples near, but outside the site. The phytolith abundances at Sibudu are thought to be the result of the combustion of plant matter, though some may be the result of microbial degradation of fresh plant matter (*S7*). There are varying proportions of monocotyledonous phytoliths and dicotyledonous phytoliths from Schiegl's (*S6, S7*) samples.

Monocotyledonous phytoliths, including sedges, were recognised by MB in thin sections obtained from sediment micromorphological samples (table S2; fig. S11). These include multicellular structures with smooth margins typical of sedges, elongate echinate long cells in the monocot leaf epidermis, smooth cylindroids from monocots, and tracheary elements from monocots or dicots. There are also some well-preserved cellular details preserved such as the Kranz structures from C4 leaves and transverse sections of very small, inrolled monocot leaves such as may occur in dried up grass or sedge leaves.

Modern *Cryptocarya woodii* leaves were examined by MB for their phytolith content. First, fresh leaves were cleared by soaking them for a week in commercial bleach (sodium hypochlorite, diluted with distilled water to 1.75%). Leaf fragments were mounted on a microscope slide, upper and lower epidermis separated and studied for the cuticle and stomata. Other leaf fragments with both upper and lower epidermis in place were stained with gentian violet to improve the contrast and studied under half polarized light to locate the silica bodies. They were observed in only some of the larger veins in the leaf. No epidermal silica was seen. Secondly, leaf ashing was carried out to investigate *C. woodii* phytolith content in burnt leaf samples. Twenty washed and dried leaves and petioles of *C. woodii* were crushed and put into a porcelain crucible, covered with aluminium foil, and ashed in a muffle furnace at 450 degrees Celsius for three hours. A small amount of the ash was mixed with hydrogen peroxide to disaggregate the pieces which were then mounted on two microscope slides with a coverslip. The slides were scanned at 400x magnification on a Zeiss Axiophot petrographic microscope and photographed with an Olympus DP72 digital camera. Phytoliths are not abundant in the leaves of modern *C. woodii* whether they are cleared or ashed (fig. S17). The samples were scrutinised under polarised light. Cleared leaves showed only vascular tracheids, while ashed leaves showed vascular tracheids and very few leaf skeletons together with other typical dicot morphotypes.

Identification of monocotyledonous seeds, stems and leaves

Samples from Fig. 2, A, D and F were sputter coated with a gold palladium alloy and viewed in secondary electron (SE) emission mode at 5 kV in a Nova NanoSEM 230. A FEI Quanta 400F Environmental Scanning Electron Microscope (ESEM) operating at 1 - 2 keV, SE mode, was used for samples Fig. 2, B and E, which had also been coated with gold palladium. A Nikon AZ 100 was used to photograph the leaf blade in Fig. 2C. A large collection of modern seeds, leaves and culms was used for the identifications. Most material was collected by CS in the field, but vouchers were also studied at the KwaZulu-Natal Herbarium, Durban, and the South African National Biodiversity Institute, Pretoria.

Carbonized Cyperaceae (sedge) nutlets, one-seeded indehiscent fruits 1-2.5 mm in length, occur throughout the MSA sequence at Sibudu, except in the ~38 ka layers (*S12*, *S13*). It is generally not possible to identify the nutlets securely beyond family level because of the absence of characteristic surface features that are seen in Scanning Electron Microscopy (SEM) images of modern nutlets. However, SEM images of the external and internal shape (Fig. 2D) of some nutlets indicate that they are *Cladium mariscus* subsp. *jamaicense* (L.) Pohl (Crantz) Kük. A carbonized *Cladium* stem (Fig. 2A) was also found, in the ~58 ka layer Br. under YA 2(i). The transverse section of the stem presents scattered vascular bundles throughout, but concentrated towards the perimeter. Identifiable characteristics are better preserved in the siliceous sedge nutlets than in the carbonized nutlets. Two species of siliceous *Scleria* nutlets have been recovered from the BS layers ~77 ka old; *Scleria natalensis* C.B Clarke in BS6 (Fig. 2E); a fragment of cf. *S. melanomphala* Kunth in B5/B6 and two cf. *S. melanomphala* nutlets in BS7. Tightly and thickly packed siliceous botanical material in layer BS6 contains monocotyledons (Figs 1B and 2, E and F). Grass (Poaceae) is present amongst the monocotyledons. Bilobate short cell (dumbbell) phytoliths horizontally aligned in parallel rows (Fig. 2B), observed in the epidermis of panicoid leaves, indicate the occurrence of panicoid grass. Only two Juncaeae (rush) fruits have been recovered, both were carbonized, very fragile and ~73 ka old. One fruit disintegrated and the other belongs to the genus *Juncus* (Fig. 2F). Rushes and sedges are generally associated with water or moist situations (table S3) and the presence of these at Sibudu reflects the proximity of the uThongathi River, which runs below Sibudu at the base of the cliff (fig. S3). Even today, sedges and rushes are collected from the uThongathi River (fig. S13) for weaving sleeping mats. Weaving has not been observed at Sibudu; it appears that people laid bundles of sedges and rushes directly on the shelter floor to create bedding.

Identification of *Cryptocarya woodii* Engl. leaves

The fossil leaves were kept in their plaster jackets. An Olympus SZX16 reflected light binocular microscope with a magnification up to 100x, LED ring light source and Olympus DP72 digital camera and Stream Essentials® software were used. The key of Hickey and Wolfe (*S17*) and (*S18, S19*) helped to identify (from leaf shape and fine venation) the family Lauraceae, with five genera of which *Cryptocarya* is appropriate. *C. woodii* has the broad elliptic leaf, thickened marginal vein (Fig. 4A), stomata and oil cells observed in the fossils (Fig. 4, C and D). Modern leaves were cleared for comparison by soaking them for 3-4 days in $NaHClO_2$ and rinsing in tap water. Upper and lower epidermis were separated and photographed under a Zeiss Axiophot transmitted light microscope at 400x magnification.

The leaves have retained their life-form anatomical features (fig. S16). Since they have been fragmented vertically and horizontally it is possible to reconstruct both internal and external features using more than 30 fragments. Only one type of leaf occurs and it is broadly elliptic in shape (maximum 70 x 30 mm) with an attenuate apex, but unknown base. The primary venation is pinnate with a broad primary vein and thickened entire margin (fig. S16). Secondary venation is brochidodromous with alternate to sub-opposite secondary veins arising at an acute angle. There are no intramarginal veins. Tertiary venation is random reticulate and forms square to polygonal areoles which contain bifid quaternary veinlets. The mesophyll layer contains some oil cells. Epidermal cells are isodiametric with straight anticlinal walls. Stomata occur only on the lower epidermis and have one pair of subsidiary cells aligned with the guard cells (brachyparacytic). Leaf shape and fine venation are characteristic to the level of family. The key of Hickey and Wolfe (*S17*) indicates that entire margined, simple leaves with simple brochidodromous venation, intramarginal veins absent and intercostal venation random, occur in the Magnoliidae and Laurales in particular. A tendency towards acrodromous venation occurs in the Amborellaceae, Hernandiaceae and Lauraceae. The fossil leaves could be shown to belong to the family Lauraceae (*S17-S19*). Lauraceae has five genera. *Litsea* is not indigenous so will not be considered; *Cassytha* is a parasite with very small leaves; *Dahlgrenodendron* has one species with leaves larger than the fossil; there are two species of *Ocotea* but with clear domatia at the base of the leaves so can be excluded. There are six species of *Cryptocarya*, four of which can be excluded on the basis of leaf shape. Therefore extant samples of *Cryptocarya woodii* and *Cryptocarya myrtifolia* were studied. To further identify the fossil leaves extant leaves from local members of the taxa were collected, cleared using $NaHClO_2$, and studied under a microscope. *C. woodii* has a broad elliptic shape and the distinctive thickened marginal vein seen in the fossil material. The stomata and the oil cells of this species and the fossil are also the same.

Fourier Transform Infrared Spectroscopy (FTIR) of *Cryptocarya woodii* leaf

Fragments of *C. woodii* leaves were analyzed by FTIR spectroscopy using a Thermo-Nicolet Nexus 470 IR spectrometer. Representative FTIR spectra were obtained by grinding a few tens of micrograms of sample with an agate mortar and pestle. About 0.1 mg or less of the sample was mixed with about 80 mg of KBr (IR-grade). A 7 mm pellet was made using a hand press (Qwik Handi-Press, Spectra-Tech Industries Corporation) without evacuation. The spectra were collected between 4000 and 400 cm^{-1} at 4 cm^{-1} resolution (fig. S15).

SOM Text

Stratigraphy (figs. S4 to S6)

Layers Co and Bu, with ages of ~38 ka, occur only in squares C2, C3, D2, D3, E2, and E3 (figs. S3 and S4). Ore and LBMOD, with ages of ~48 ka, are also represented only in the eastern part of the grid (fig. S4). Occupations with ages ~48, ~58 and pre-62 ka have wider distribution across the excavation grid. The centimetre-scale stratigraphy at Sibudu is described in detail elsewhere (*S1*). The sediments are largely derived from human activities, especially combustion events that include hearths, ash raked from hearths, and burnt bedding material (fig. S6).

Micromorphological analysis of sediment thin sections

Micromorphological analysis of thin sections of layers at Sibudu suggests that herbaceous plants were brought to the shelter by humans, to use as a type of floor preparation or bedding, which was subsequently burned, most likely by humans. This interpretation was based on several key characteristics of the proposed bedding layers. In thin section, these layers are composed almost exclusively of micro-laminated fibrous charcoal, displaying anatomical features typical of monocotyledonous plants. The laminated fibrous charcoal layers grade into an overlying layer of micro-laminated phytoliths. Within many of the supposed bedding layers, we identified sand-sized aggregates of clay and quartz silt, including some that appeared gleyed and others that contained numerous diatoms. The most obvious source for these aggregates is the uThongathi River, located 20m below the shelter site. Based on the association of the clay aggregates and the remains of wetland plants, it seems likely that the plants were transported to the shelter from the uThongathi River valley. The compacted and micro-laminated microstructure of the layers suggests that they underwent extensive trampling, a hypothesis supported by the frequent occurrence of *in situ*, crushed burnt bone. Many of the bedding layers appear relatively thick (up to 8 cm), and contain numerous stringers and traceable surfaces within the bedding layer as a whole. These observations suggest that the plant material was repeatedly brought to the site on top of older bedding surfaces, perhaps as a means of replenishing and repairing old beds. One of the most striking characteristics of the bedding layers is that most are burned. This is indicated by the carbonization of the plant material at the base of the layer (laminated fibrous charcoal) and the laminated phytoliths at the top. Calcareous ashes are strikingly absent from the burnt bedding layers. This may be a result of taphonomic processes; however, ashes are well preserved in other layers at Sibudu, and experiments (Fig S14) suggest that calcareous ash rhombs may not typically form from the burning of bedding. Combustion of the bedding would have ashed the plant material on top, leaving the phytoliths behind, but would have carbonized the plant material at the base, where oxygen was less available. The main components of the bedding layers are isotropic (opal phytoliths and carbonized plant material), making analysis with cross polarized light (XPL) difficult. Therefore, all photomicrographs below use PPL, so that all components are clearly visible.

Below we present selected examples through the sequence to illustrate change and continuity in bedding construction and its maintenance.

Squares B4 and C4, Layer Brown Sand 6 (BS6)

The layer BS (Munsell color 7.5 YR 4/3 brown) (note: all Munsell colors were determined in the field using natural light) *(S20)* has an age of 77.2 ± 2.1 ka (table S1). Its top horizon is partly cemented. Layer BS has been vertically subdivided during excavation into layers BS and BS2-BS14. Layers are separated by the appearance of a distinct 'floor' either marked by features such as fireplaces or bedding, or simply by clear stone tool horizons. In BS6, fossil remains of siliceous monocotyledonous stems, sedge culms and sedge seeds extend intermittently as a bedding layer across two square meters of the excavation grid and may continue into unexcavated squares. In thin section, BS6 is composed largely of laminated phytoliths and siliceous plant material that retains its original anatomical characteristics (Fig. 1B). Unlike other examples of bedding at Sibudu, no carbonized plant material has been identified in BS6. In addition, sand-sized fragments of differentially burnt bone are found within the bedding layer. These fragments of burnt bone were likely heated elsewhere and redeposited within the bedding layer. The difference in color between the bone fragments suggests that they were not subsequently re-heated, implying that the bedding of BS6 was not burnt.

Square B4, Layer Light Brownish Grey (LBG)

Layer LBG, dated to ~73 ka ago, contains the oldest evidence of burnt bedding at Sibudu. The three-to-four mm thick bedding layer (Munsell color 10 YR 6/2 light brownish-grey), comprises articulated phytoliths interfingered with stringers of longitudinally-sectioned stems of monocotyledons (fig. S7). The phytoliths preserve clear anatomical characteristics of the original plant anatomy. Below the phytolith and carbonized stem layer, is a thin layer of carbonized organic material and a centimeter-sized burnt bone fragment that exhibits a color-gradation from dark brown at the contact with the phytoliths to yellow at the base. Both the carbonized organic material and burned bone demonstrate that the bedding layer was burned in place.

Square C4, Layer Pinkish Grey Sand (PGS)

In PGS the loose (Munsell color 5 YR 6/2 pinkish-grey) sediment, with an age of 64.7 ± 1.9 ka, is trampled and compressed, yet micromorphological features remain intact. A single-component, burnt, ashy layer (10R 7/1 light grey on its surface, and 7.5 YR 3/1 very dark grey, at its base) is 30 cm wide, and was named 'Hearth 1' (H1) during excavation. However, micromorphological observations suggest that the feature is not a hearth, but burned plant bedding. The bedding in PGS is a four-to-five mm thick lens comprising carbonized monocotyledon stems that appear laminated (fig. S8). In between stringers of longitudinally-sectioned stems is siliceous material that retains some cellular structure. It is likely that the amorphous silica was derived from phytoliths. The sediment above and below H1 in PGS consists of quartz sand, sand-sized fragments of burnt bone and charcoal, and other combustion-derived components. Below the base of the feature, in the underlying sediment, is a one-to-two mm thick zone of rubefication, demonstrating that the feature was burnt in place.

Squares B4 and C4, Layer Brown under Yellow Ash 2(i)(Br.under YA2(i))

Br. under YA2(i) is undated, but lies between layers with ages of 61.7 ± 1.5 ka and 58.2 ± 2.4 ka. The sediment matrix in the field is light brown (Munsell color 5 YR 3/2 greyish-brown). A large, 12 cm deep, multi-component combustion feature is truncated by the section wall, but, based on the excavated area, its horizontal extent must be at least 350 x 300 cm (fig. S10). It was labelled 'Hearth 1' (H1) during excavation and it has white (2.5YR 8/1 white), rufous (5YR 2.5/2 dark reddish-brown), and black (10 YR 2/1 black) layers. A large flat rock delineates its north-western boundary. A patch of carbonized monocotyledon stems was recovered close to the rock. Several small hearths and two putative ash dumps are near the burned bedding. Micromorphological analysis demonstrates that the feature H1 in Br. under YA2(i) is burned bedding and not a large hearth. At least five couplets of laminated articulated phytoliths and carbonized monocotyledon stems and leaves appear directly on top of one another (fig. S9). The phytolith layers are on average between five and two mm thick and they grade into the underlying carbonized layers that are between ten and five mm thick (fig. S9). The phytoliths in the various layers exhibit different stages of preservation, with some appearing fresh with sharp and clear edges, and others appearing partially distorted, although still clearly articulated and preserving their original anatomical structures.

Square E2, Layer Oreo (Ore)

Layer Ore, ~48 ka old, has sediment matrix with a Munsell color 5YR 2/2 dusky brown. There are at least three layers of laminated articulated phytoliths and compacted and carbonized stems and leaves of monocotyledons that are stratified on top of one another (Fig. 1A). The phytolith layers are on average two-to-three-mm thick and grade into underlying layers, up to one centimeter thick. The overlying phytolith layers are also compacted and laminated. Sub-centimeter-sized fragments of charcoal and burnt bone and ochre are found within the laminated layers.

Mineralogy, diagenesis, and preservation of the archaeological record

Micromorphological analysis shows that the major components of the non-anthropogenic materials at Sibudu are quartz, clay, and quartzitic sandstone fragments. The ash and hearth layers are composed of calcitic wood ash, phytoliths, siliceous aggregates, charcoal, and bone. The bedding layers are mainly composed of phytoliths, fresh, humified, and/or carbonized plant materials. The main authigenic mineral phases are gypsum, amorphous silica, and phosphate (mostly apatite). Extensive mineralogical investigation using Fourier Transform Infrared Spectroscopy (FTIR) and Scanning Electron Microscopy coupled with Energy Dispersive X-ray Spectroscopy (EDAX) was conducted at Sibudu by Schiegl *et al.* (*S6, S7*). A list of the principal mineral and organic phases identified in the different layers of the stratigraphic sequence is given in table S4. The major ubiquitous mineral phases detected are quartz (from sand and rock fragments), opal (from phytoliths, siliceous aggregates, and amorphous silica), and apatite (from bone, authigenic calcium phosphate, and phosphatized calcitic wood ash). Trace levels of other phosphatic minerals, including leucophosphite, taranakite, and crandallite were also detected. Charcoal is the most ubiquitous organic phase.

The mineralogical investigation shows some significant differences along the stratigraphic column. Calcite, in fact, occurs only in a few of the pre-62 ka layers, while it is widely distributed in the ~58 ka and younger layers. Similarly, gypsum is absent in the lowest strata but is ubiquitous in the upper strata, starting in the 58ka layers (*S6, S7*). Micromorphology and mineralogy thus show that the sediments at Sibudu contain a characteristic mineralogical association composed of apatite, opal, and calcite. In particular, the co-occurrence of apatite and calcite indicates that the sediments are dominated by alkaline to sub-alkaline conditions. Such chemical conditions are favourable for a moderate preservation of most minerals, bone, ashed plant material, and wood ashes (*21*) but may produce a less favourable environment for charred and uncharred organic materials (*22*). At Sibudu, though, the microclimatic conditions produce extraordinary dry conditions that favour the preservation of organic and inorganic materials, by significantly slowing any chemical reaction. Nevertheless Schiegl and Conard (*S7*) found that the crystallization of gypsum, characteristic of arid environments, provoked the mechanical fragmentation of bone and charcoal.

The preservation of phytholiths at Sibudu deserves a special discussion. Micromorphological observations show that phytoliths appear generally well preserved with the exception of some deformation, most probably due to precipitation of new authigenic amorphous silica (opal). Micromorphology and mineralogy, both demonstrate that authigenic opal occurs widely at Sibudu. In layer BS6, for instance, the tissues of leaves of *C. woodii* are completely impregnated with authigenic opal (fig. S15). The occurrence of significant amounts of authigenic silica associated with well preserved phytoliths suggests that the soil solution in the sediments is saturated (or closely saturated) with dissolved silica (silicic acid) and that the dissolution of phytolith opal is therefore suppressed. Authigenic opal generally forms as a consequence of precipitation in soil of apatite and other phosphates released in solution by decomposing organic material (*S23, S24*). In fact, phosphates precipitate on the surface of clay minerals disrupting their charge balance and causing the disaggregation of their lattice with consequent release of silica into the soil solution (*S25*). Another possible source of authigenic opal is the dissolution of a consistent portion of heated phytoliths. It has been recently shown that the solubility of the opal in phytoliths vary significantly due to different biomineralization processes, phytolith morphology, and diagenesis (*S26*). In particular, Cabanes *et al.* (*S26*) have shown that the solubility of opaline phytoliths increases significantly once the phytoliths have been heated. Nevertheless, micromorphological analysis failed to identify clear signs of phytolith dissolution (e.g. etching) at Sibudu.

In summary, mineralogical investigations, and the suite of minerals and their distribution, suggest that chemical diagenesis at Sibudu is moderate and that it did not play a major role in the formation of the bedding. Specifically, the integration of micromorphological and mineralogical investigations excludes the occurrence of major dissolution of layers composed of wood ash, supporting the hypothesis that the context of the bedding layer is pristine.

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Acknowledgements

We thank R.G. Roberts and Z. Jacobs for advice on interpreting the OSL ages, E. Franklin Hennessy for advice on identifying *Scleria melanomphala,* S. Bentsen for redrawing fig. S10, and C. Dean for advice on the field curation of the *C. woodii* leaves.

Fig. S1.

Position of Sibudu.

Fig. S2

Sibudu excavations, March 2011.

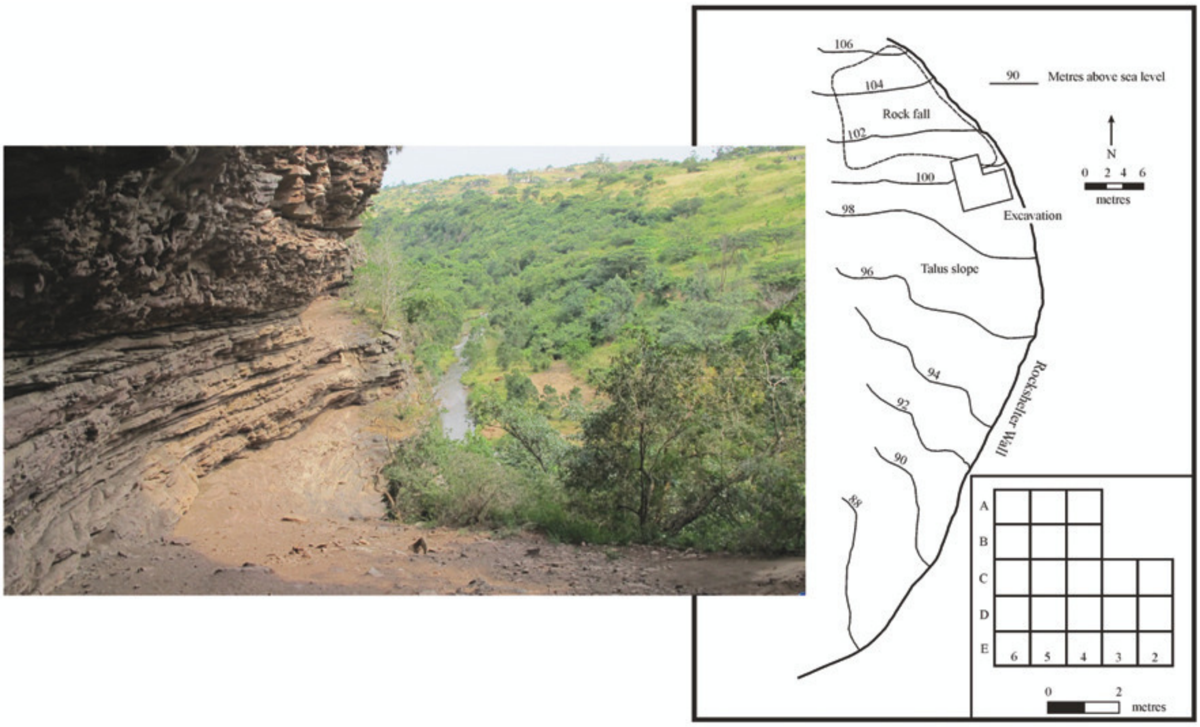

Fig. S3
Sibudu looking out over the uThongathi River, and a site plan showing the excavation grid.

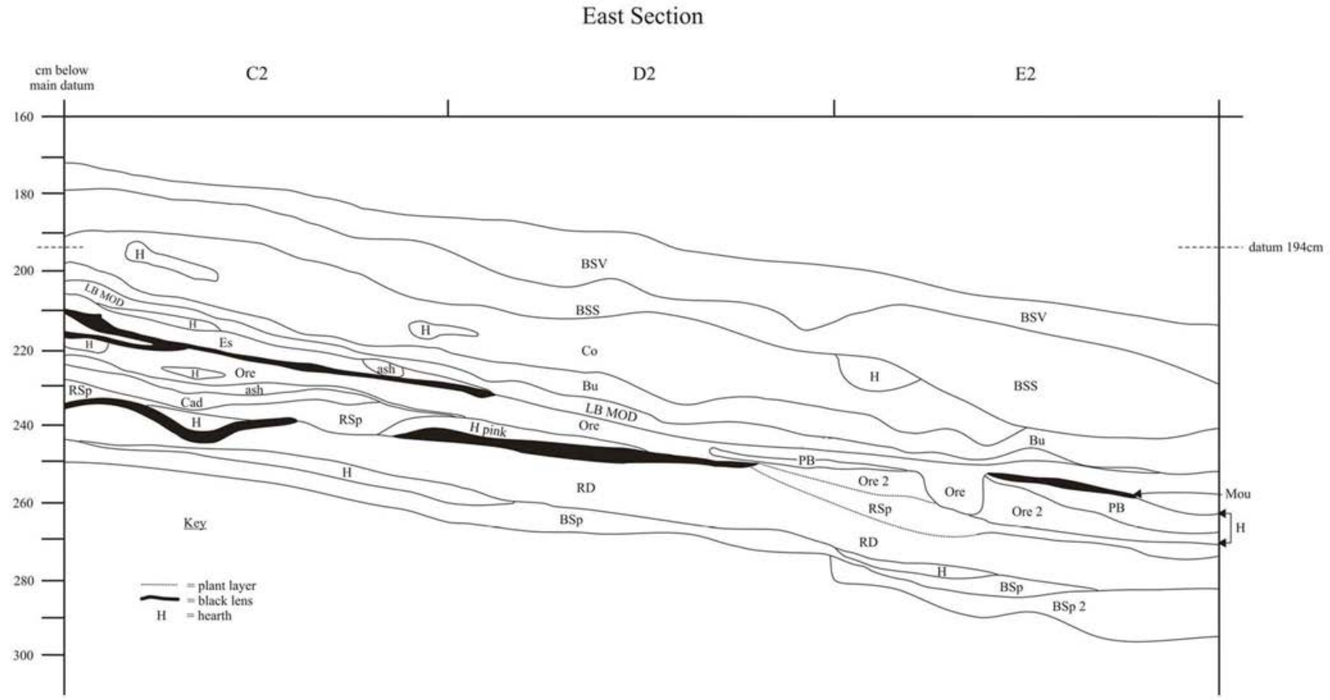

Fig. S4.

Sibudu east section of squares C2, D2 and E2 showing the sequence of final and late MSA occupations. BSV and BSS are Iron Age occupations. Co and Bu are occupations with ages of 38.0 ± 2.6 and 39.1 ± 2.5 ka, respectively. LBMOD has an age of 49.9 ± 2.5 ka.

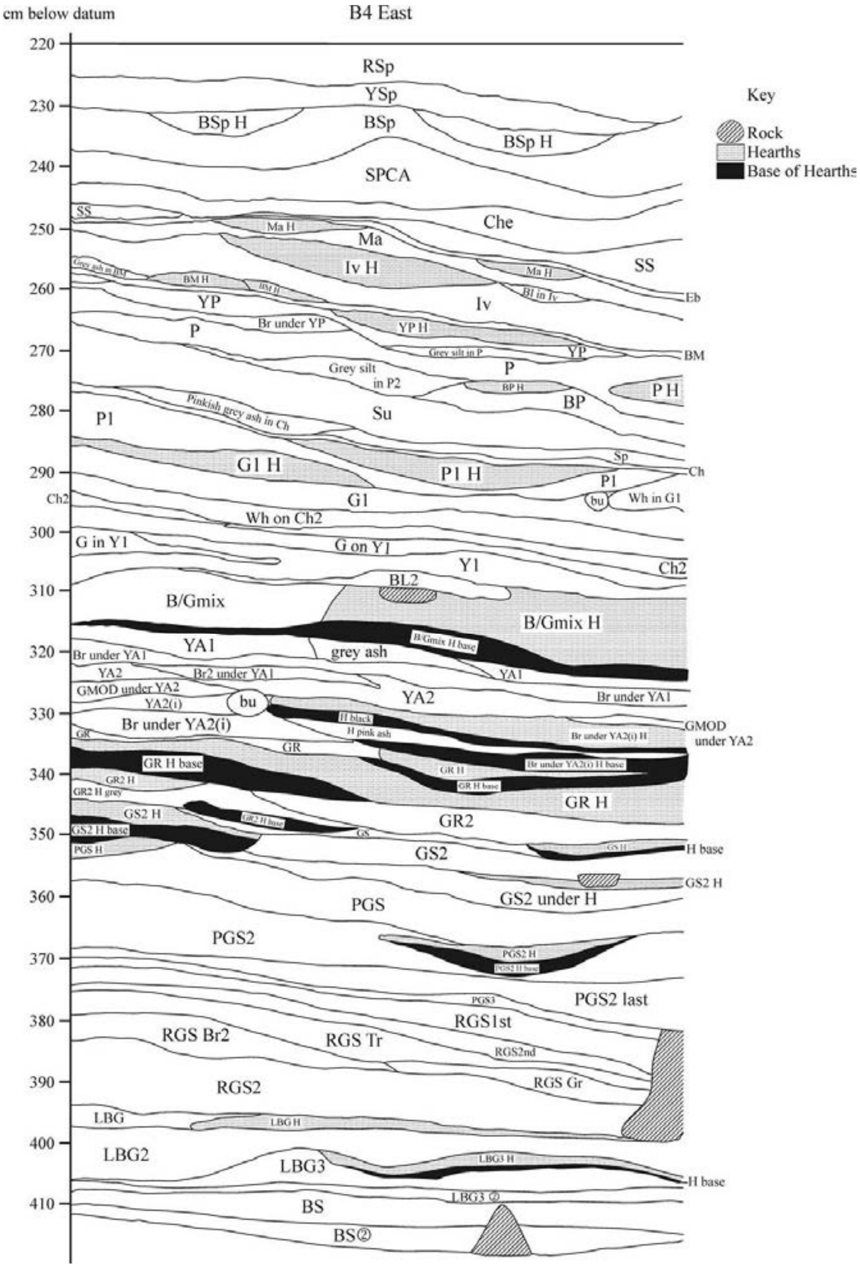

Fig. S5.
Sibudu east wall stratigraphy in square B4. Only layers BS2 to RSp are represented in this figure because of space limitations, but there are 16 BS layers and MSA layers OMOD and MOD occur above RSp.

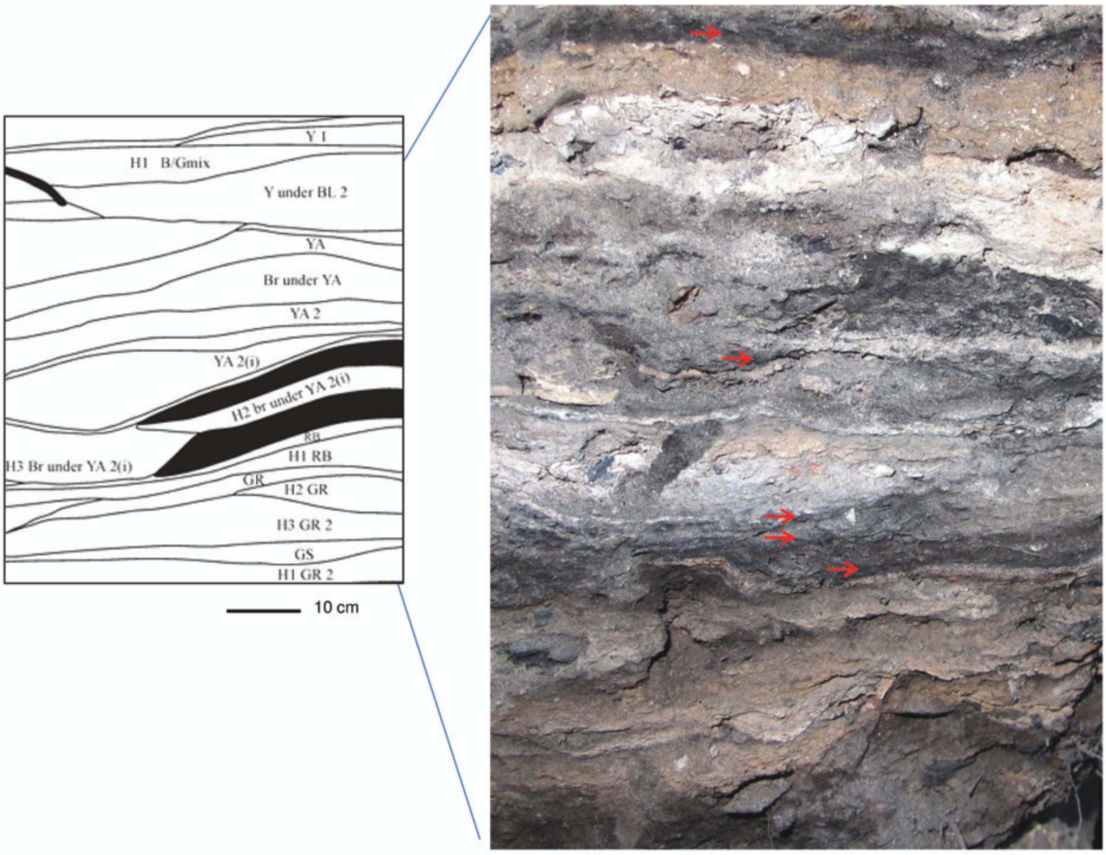

Fig. S6.
Part of the stratigraphy in the south wall of square C4, with a photographic insert of finely laminated, burned plant layers (red arrows) in some of the ~58 ka occupations.

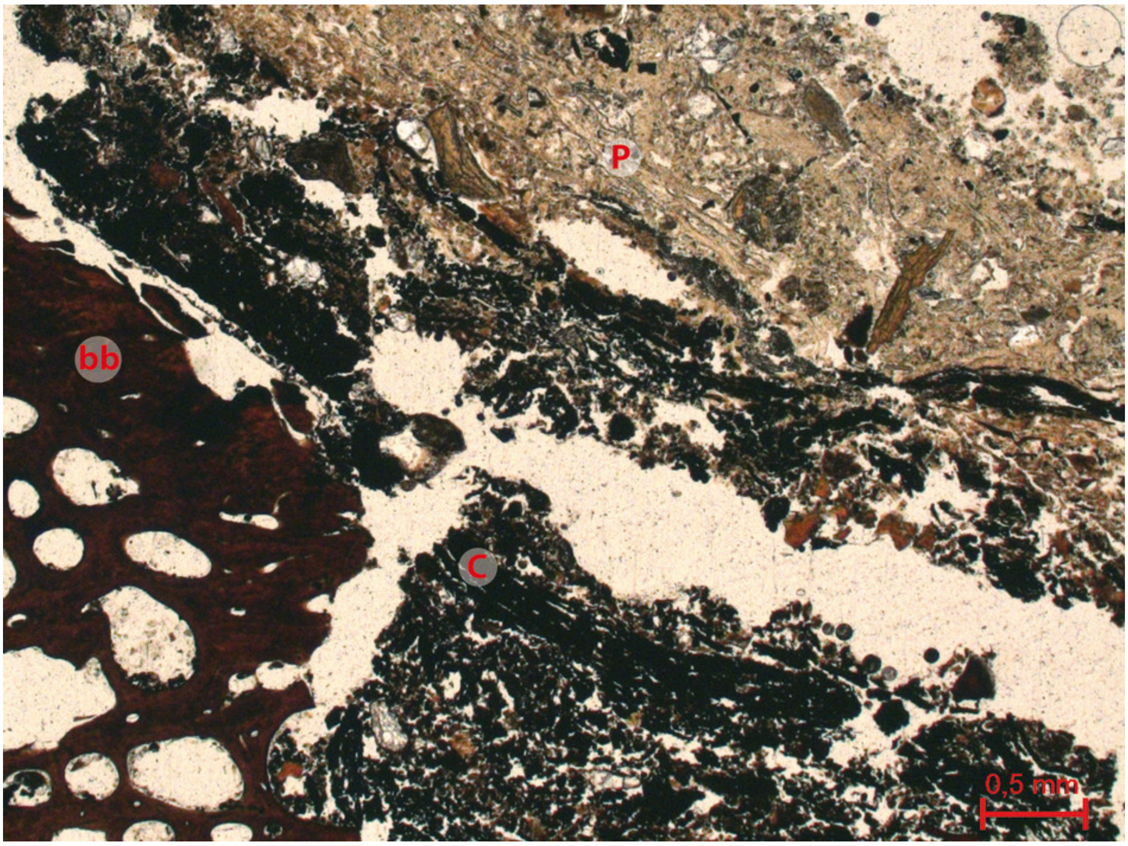

Fig. S7.
The oldest example of burnt bedding at Sibudu from layer H3 in LBG (~73 ka). Photomicrograph of laminated phytoliths (**p**) and carbonized monocotyledonous stems (**c**). Large burnt bone fragment (**bb**) is in the left of the image. Calcareous ashes are absent from this and other bedding layers. However, the carbonized base of the layer suggests that it was burnt, and that the phytoliths form the largest proportion of the produced "ash." PPL.

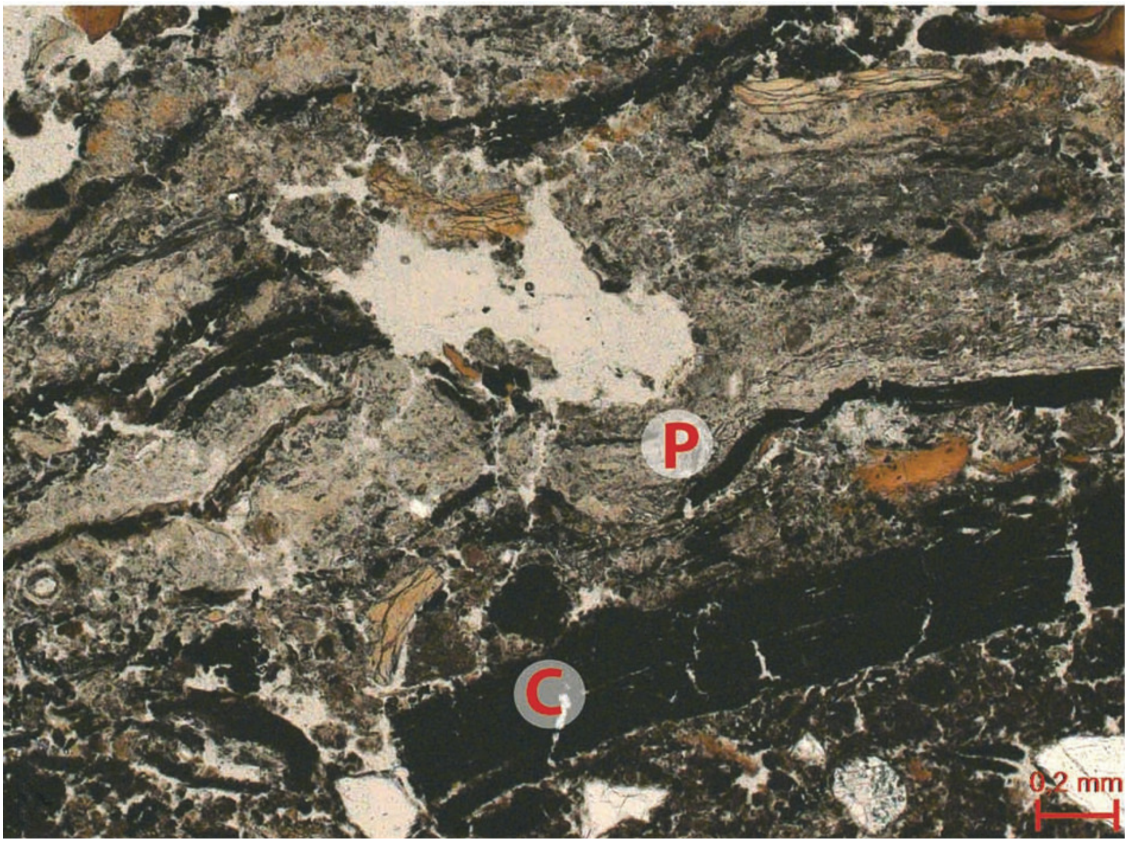

Fig. S8.
Laminated, carbonized monocotyledonous stems (**c**) interfingered with siliceous material derived from phytoliths (**p**), layer H1 in PGS (~65 ka). Brown inclusions are mostly burnt bone fragments. The inclusion of occupational debris, such as bone fragments and chipped stones, suggests that the bedding was not simply used for sleeping, but also served as a type of floor for other activities. PPL.

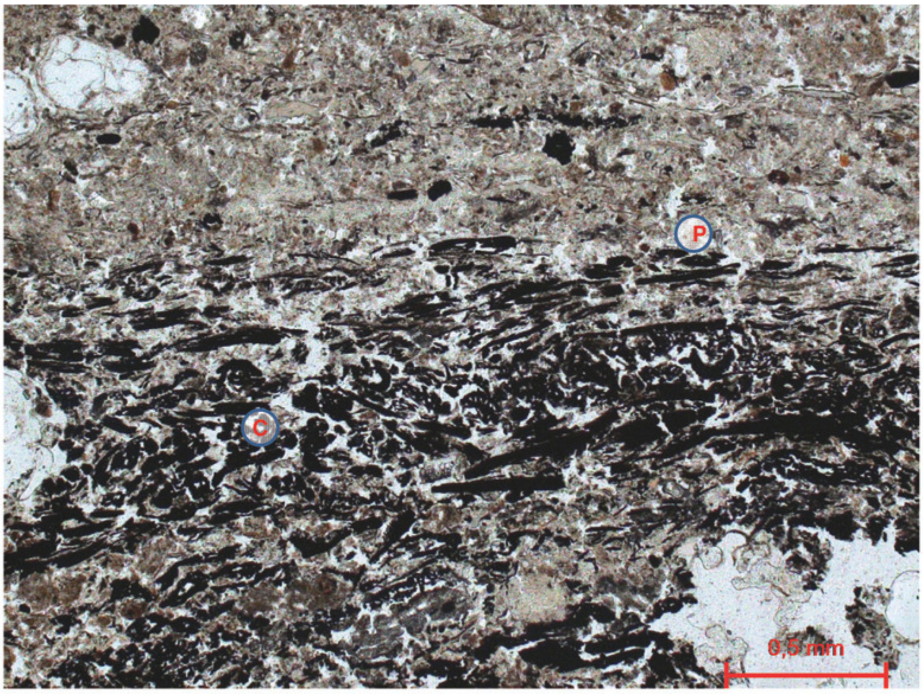

Fig. S9.
Photomicrograph of burned bedding in Sibudu layer H1 in Br. under YA2(i) (~58 ka). Laminated articulated phytoliths (**p**) overlie laminated carbonized monocotyledonous stems (**c**). The phytoliths are partially deformed, but they do preserve some clear aspects of their original structure. Calcareous ashes are not found in the bedding layers, but are preserved elsewhere in the site. The alteration of the phytoliths maybe the result of precipitation of amorphous silica. PPL.

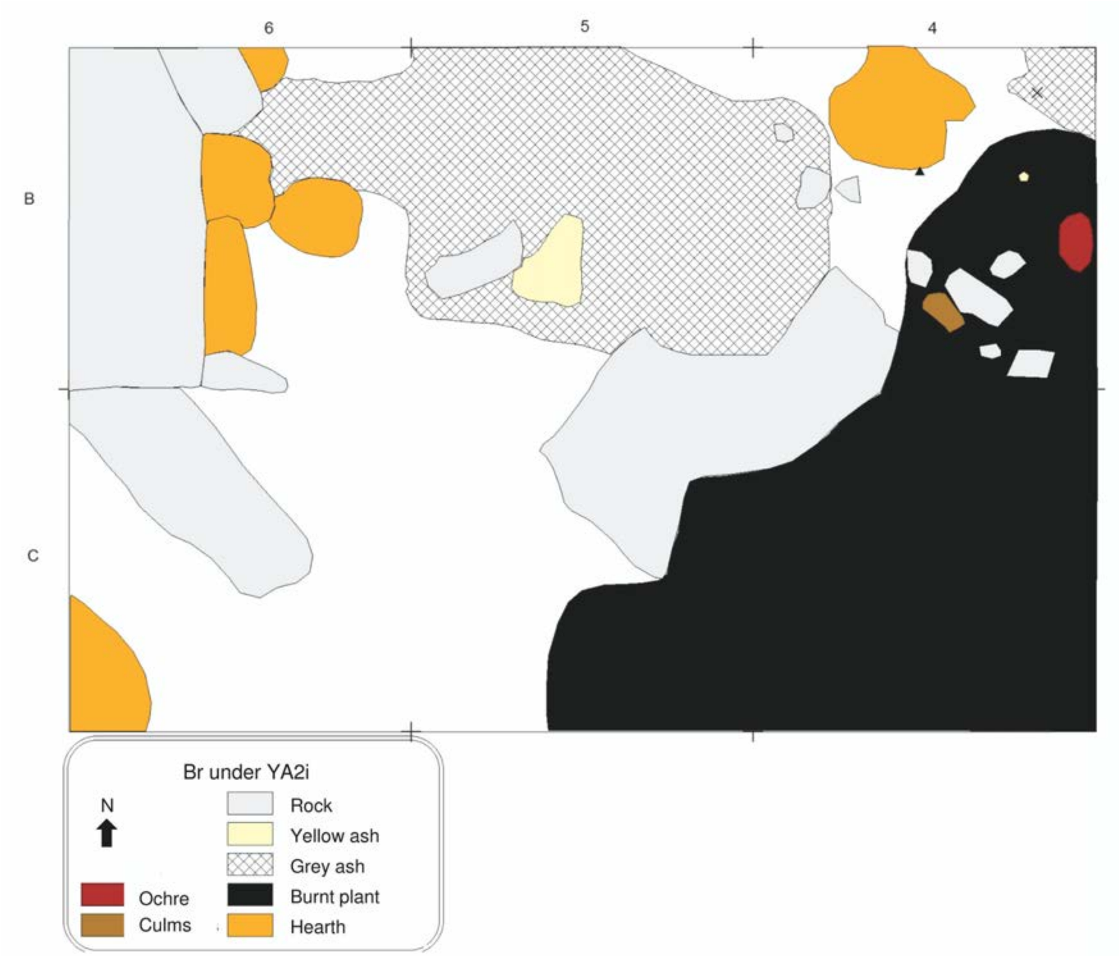

Fig. S10.
Plan of features in layer Br. under YA2i (~58 ka). The area of carbonized plant (black) is the base of the bedding. Note the patch of carbonized culms preserved in square B4.

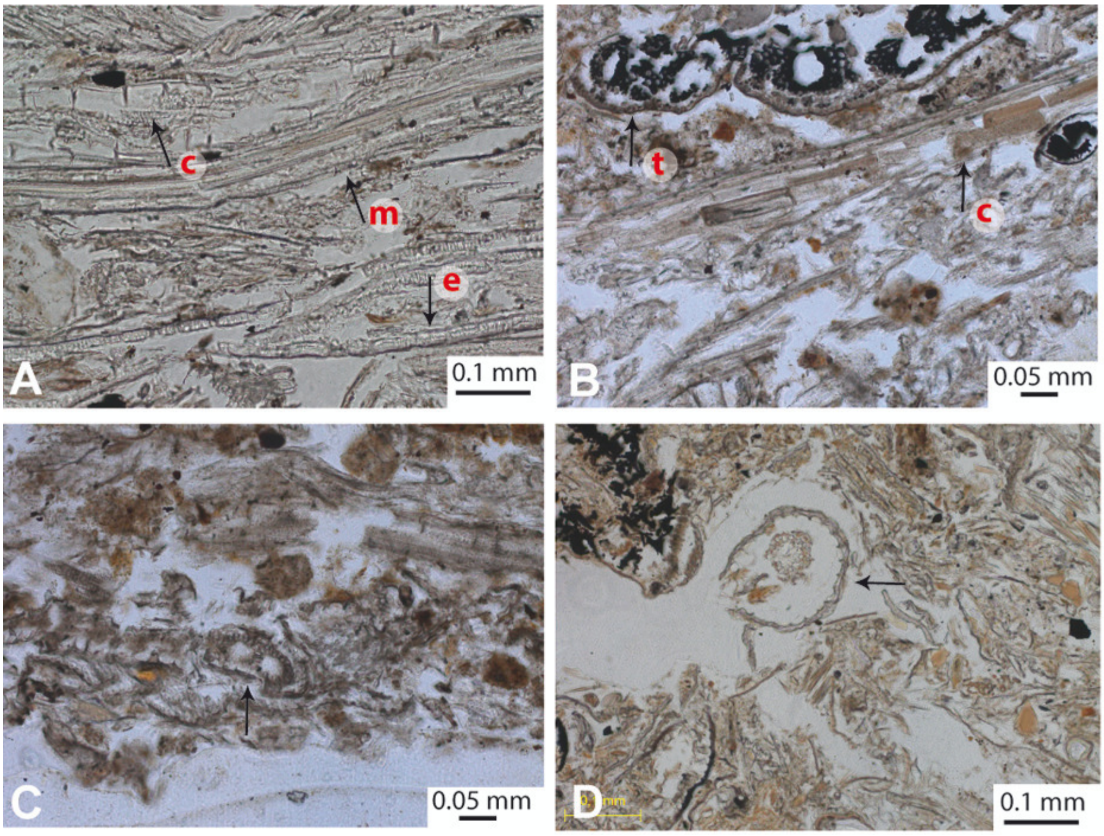

Fig. S11.
Photomicrograph of siliceous plant material from phytolith layers in thin section. **(A)** Layer BS6 with smooth cylindroids of monocots (upper arrow **c**), multicellular structure with smooth margins of monocots but most probably sedges (central arrow **m**) and a transverse section through leaf epidermis (lower arrow **e**). **(B)** Layer Ore presenting a transverse section through a leaf (left arrow **t**) and cylindroids from monocots (right arrow **c**). **(C)** Layer Ore showing a transverse section through a leaf displaying clear Kranz structure (tightly packed cells radiating from an empty centre where the vascular structure would have been) of a C4 monocot. **(D)** Layer OMOD exposing curled structures with inner spikes (probably long cell echinate phytoliths) that are the epidermal cells of a curled monocot leaf, for example from dried grass or sedge leaves that curl inwards. Some vascular bundles are also preserved in this section.

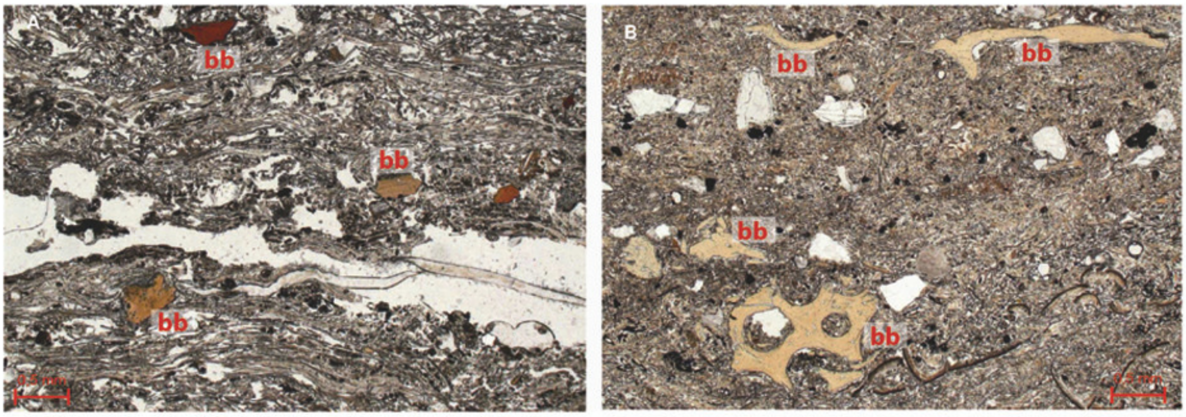

Fig. S12.
Photomicrographs of burned bone fragments (**bb**). **(A)** Bone fragments in unburned plant bedding, layer BS6 (~77 ka). Note that the sand-sized fragments of burnt bone exhibit different colors, suggesting differential heating. The lack of carbonized plant material within this layer, and the inclusion of differentially burnt bone fragments, suggests that this bedding layer was not burned. PPL. **(B)** Bone fragments in burned plant bedding from layer OMOD-MOD (~48 ka). Here, the bone fragments appear burned to the same degree, suggesting that they were heated *in situ*. The presence of carbonized plant material at the base of this phytolith layer suggests that it was burned.

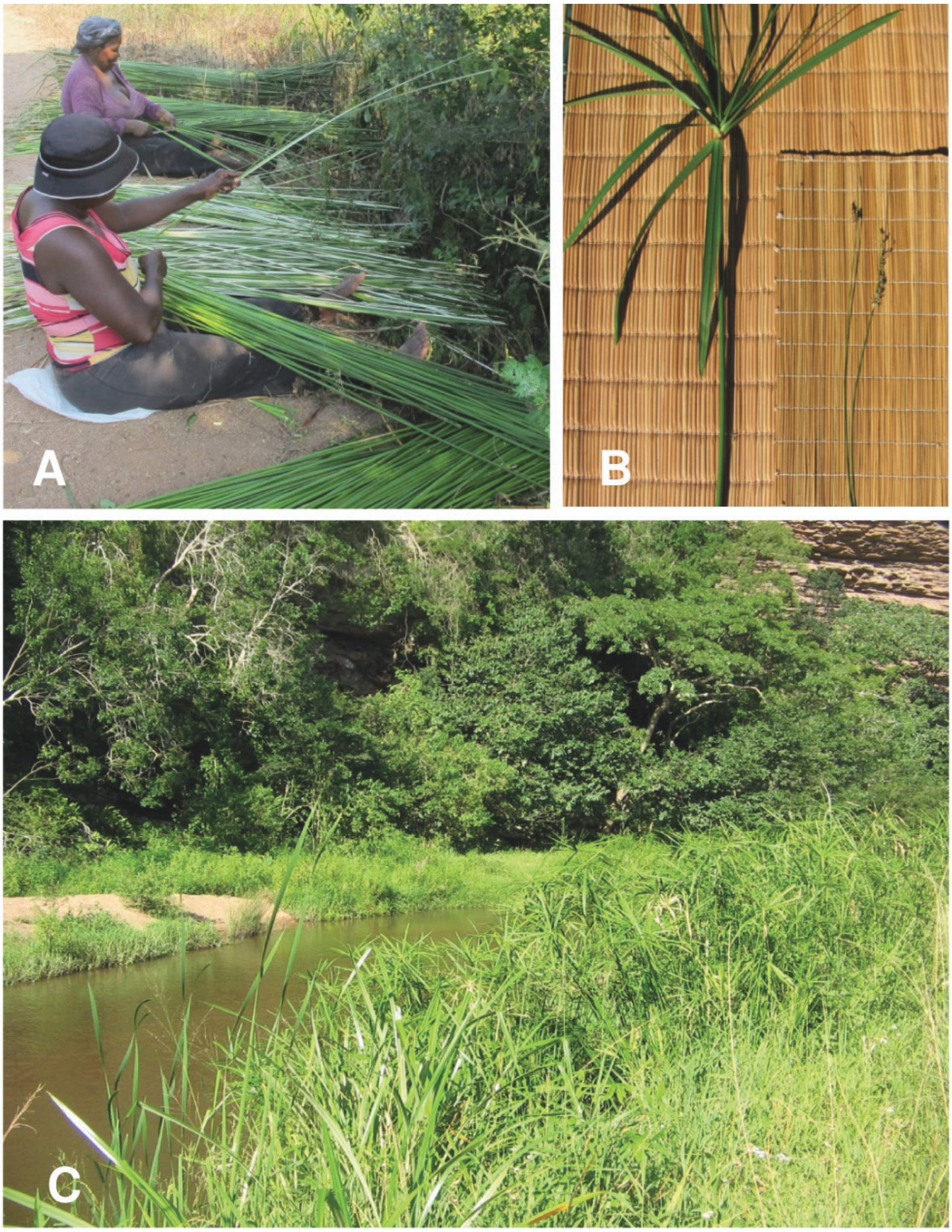

Fig. S13.
Modern use of sedges and rushes. (**A**) Zulu women preparing sedge culms (*Cyperus involucratus* Rottb.) for weaving of mats, approximately one kilometer downstream from Sibudu (March 2011). (**B**) Woven mats of sedge (*Cyperus*) on left and rush (*Juncus*) on right. (**C**) Sedges growing on the banks of the uThongathi River. Sibudu is situated in the cliff above the trees.

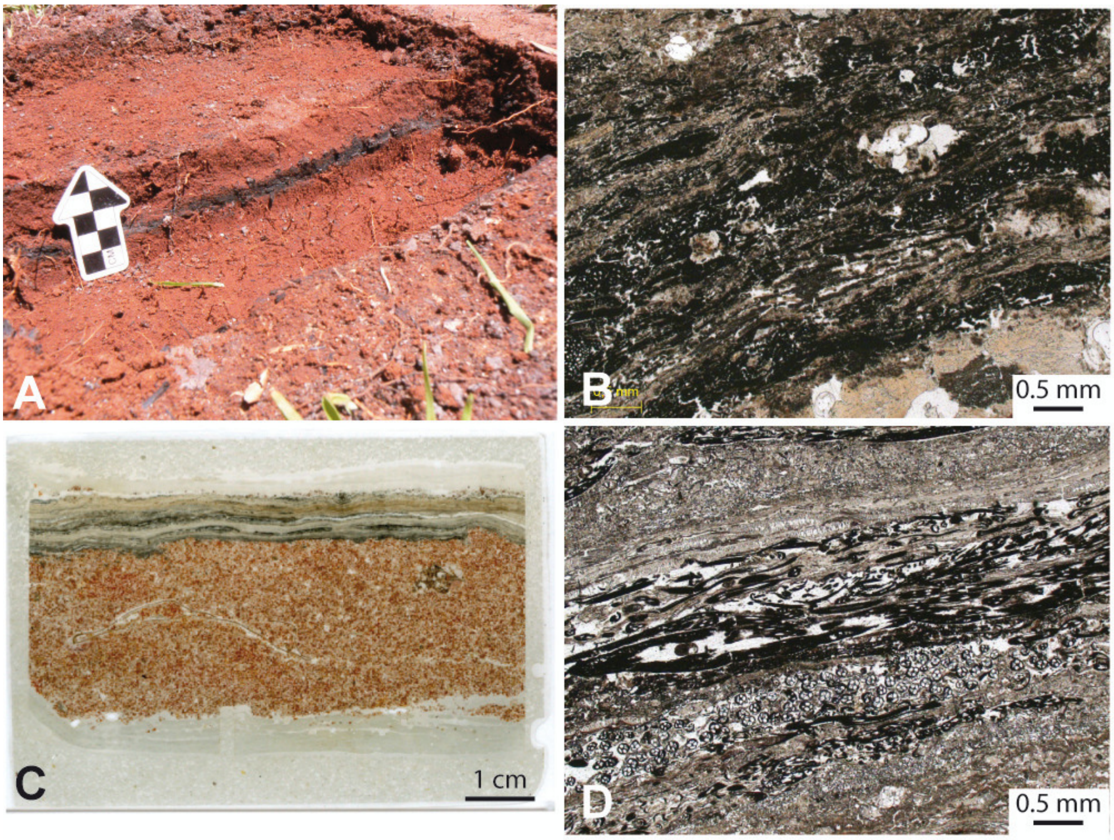

Fig. S14.
Example of experimentally produced bedding, compared to archaeological examples of bedding. **(A)** The experimental bedding layer in the field, with Berea Red Sand of the Durban area as a substrate. During excavation of the layer, matted stems and leaves were clearly visible. **(B)** Example of archaeological bedding from Sibudu in thin section, layer H1 in Br. under YA2(i) (~ 58 ka). Note the interfingering of fibrous charcoal, derived from monocotyledonous stems, and phytoliths. PPL. **(C)** Flatbed scan of thin section of experimental bedding layer. Note the clear laminations of dark-colored, carbonized stems and white laminations of phytoliths. The red-colored material is the experimental substrate. **(D)** Experimental bedding in thin section. Note the laminated appearance of the phytoliths, and inclusion of carbonized plant material (dark-colored material). Calcareous ashes were not found in thin section within the experimental bedding. This may suggest that burning of sedges does not produce significant amounts of calcareous ashes, which may explain their absence in bedding layers at Sibudu. PPL.

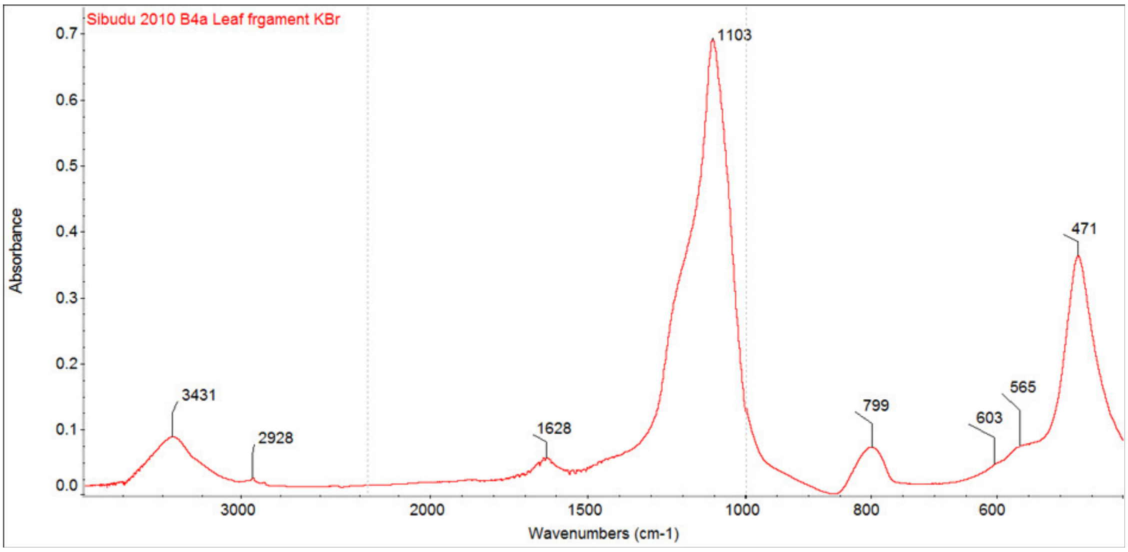

Fig. S15.
Representative FTIR spectrum of the inset *Cryptocarya woodii* leaf fragment, found in square B4a, layer BS6 and dated to ~77 ka ago. The spectrum shows characteristic IR absorptions of pure opal at 470, 800, 1100 cm^{-1} and traces of phosphate at 603 and 565 cm^{-1}.

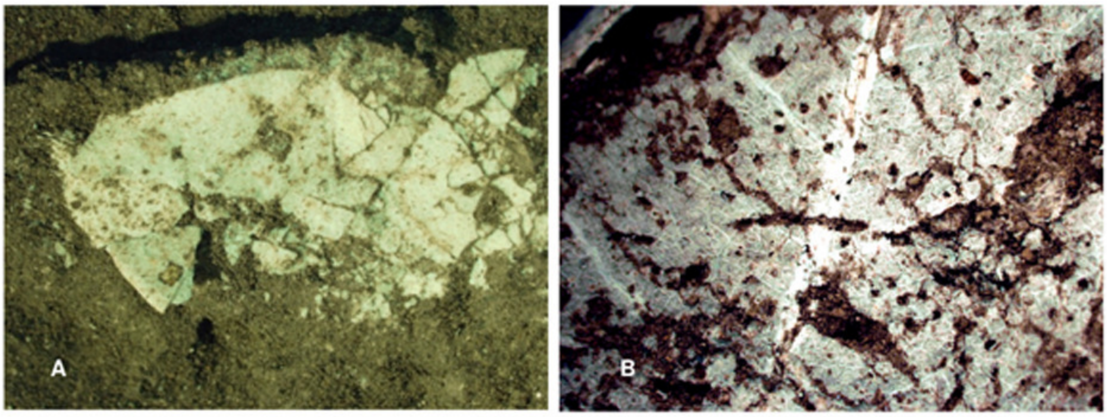

Fig. S16.
Fragments of *Cryptocarya woodii* leaves showing the broadly elliptic shape and the pinnate primary venation with a broad primary vein.

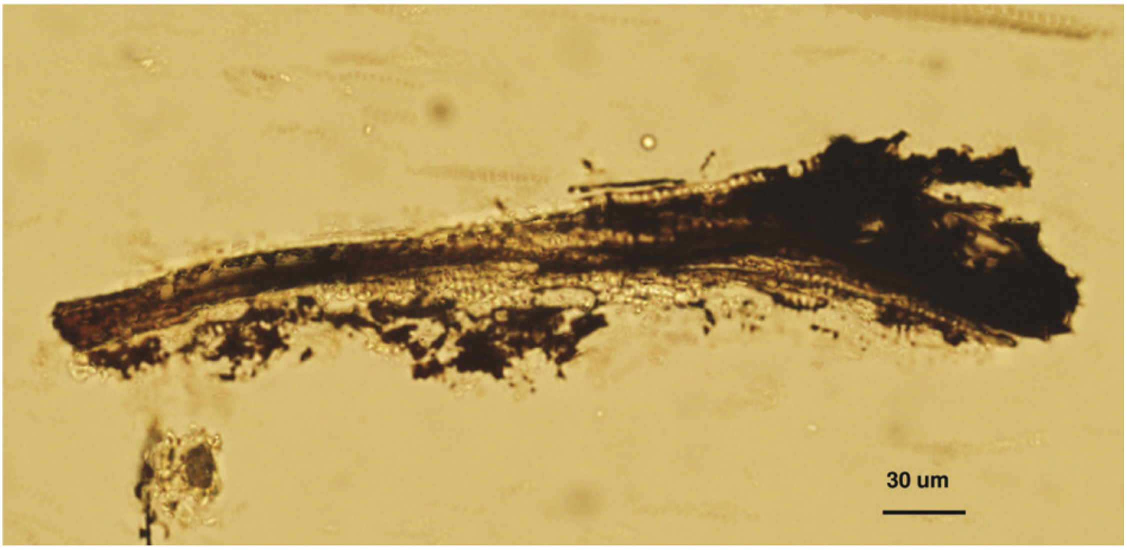

Fig. S17.
Photomicrograph of tracheary phytoliths from the ashed leaves of modern *Cryptocarya woodii* in a wet slide mount and photographed at 400x magnification, plain light (Zeiss Axiophot petrographic microscope and Olympus DP72 digital camera).

Table S1. Sibudu stratigraphic units, OSL ages (*S6, S7*) location of sediment micromorphological samples (X), associated evidence for bedding (X), bedding evidence described in this paper (X) and cultural associations.

Stratigraphic unit	**OSL ages (ka)**	**Sediment micromorphology sample collected**	**Sediment micromorphological evidence for bedding**	**Cultural association**
Co	38.0 ± 2.6			late MSA
Bu	39.1 ± 2.5			
LBMOD	49.9 ± 2.5			final MSA
MC				
Es				
Mou, DMou, PB				
Ore, Ore2		X	X	
Cad, Pu				
MOD	49.1 ±2.5			
OMOD	46.6 ± 2.3	X	X	
OMODBL	47.6 ± 1.9			
OMOD2				
OMOD2BL				
GMOD,BMOD				
RSp	46.0 ± 1.9	X	X	
RD	49.4 ± 2.3	X		
YSp				post-Howiesons Poort MSA1
BSp	57.6 ± 2.1	X	X	
BSp2				
SPCA, BL, Or				
Mi		X	X	
SS	59.6 ± 2.3	X	X	
Che, Eb		X	X	
Ma, MY		X		
BO		X		
P		X		
OP	59.0 ± 2.2	X		
BP		X		
Iv				
BM		X		
Ch				
Su,Su2				
P1				
G1				post-Howiesons Poort MSA2
Ch2	58.3 ± 2.0	X	X	
G on Y1		X		
Y1	58.6 ± 2.1	X		
B/Gmix	58.2 ± 2.4	X	X	
BL2, BL3		X		
Bl. u. Br.Grey		X	X	
BOr, Ymix				
YA1				
YA2		X	X	
Mottled Grey		X		
Br. under YA2		X	X	
DRG				

Table S1. Continued. Sibudu stratigraphic units, OSL ages (*S6, S7*) location of sediment micromorphological samples (X), associated evidence for bedding (X), bedding evidence described in this paper (X) and cultural associations.

Stratigraphic unit	**OSL ages (ka)**	**Sediment micromorphology sample collected**	**Sediment micromorphological evidence for bedding**	**Cultural association**
GR		X		Howiesons Poort
GR2	61.7 ± 1.5	X		
GS				
GS2	63.8 ± 2.5	X		
GS3				
PGS	64.7 ± 1.9	X	X	
PGS2		X		
PGS3				
RGS	70.5 ± 2.0	X		Still Bay
RGS2				
LBG	72.5 ± 2.0	X	X	pre-Still Bay
LBG2, LBG3	73.2 ± 2.3			
LBG4				
BS	77.2 ± 2.1			
BS1				
BS2				
BS3				
BS4				
BS5				
BS6		X	X	
BS7				
BS8				
BS9				
BS10				
BS11				
BS12				
BS13				
BS14				
BS15				
BS16				

Table S2. Phytoliths identified in Sibudu photomicrographs, layers BS6, Br. Under YA2i (*), B/Gmix (#), OMOD, Ore2 and Ore. **p** = phytoliths present.

	BS6 samples									*****		**#**	**OMOD samples**											
Phytolith Morphotype	**1**	**2**	**3**	**4**	**5**	**7**	**9**	**10**	**11**	**1**	**2**	**1**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Multicellular structure, smooth margin, sedge	**p**		**p**			**p**	**p**		**p**	**p**			**p**		**p**			**p**						
tracheids	**p**																							
Epidermal skeletons, monocot								**p**	**p**															
Epidermis side view		**p**		**p**	**p**	**p**	**p**						**p**	**p**	**p**	**p**	**p**			**p**	**p**	**p**		**p**
TS leaf mesophyll			**p**	**p**	**p**									**p**										**p**
Cylindroids, sedge						**p**	**p**					**p**									**p**	**p**		
TS Kranz structure, C4 monocot																								
Branching (root/stem)																								
Parallelepiped facetated, sedge																								
Parenchyma stem cortex?	**p**																							
elongate echinate long cell, monocot																			**p**					
Culm long section																							**p**	
Bilobates, C4 grass																								

	OMOD samples								**Ore2 samples**						**Ore samples**														
Phytolith Morphotype	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**1**	**2**	**3**	**4**	**5**	**6**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
Multicellular structure, smooth margin, sedge				**p**													**p**								**p**	**p**	**p**	**p**	
tracheids														**p**															
Epidermal skeletons, monocot																													
Epidermis side view			**p**				**p**				**p**			**p**										**p**					
TS leaf mesophyll							**p**			**p**	**p**				**p**	**p**			**p**		**p**								
Cylindroids, sedge	**p**											**p**			**p**				**p**		**p**			**p**					
TS Kranz structure, C4 monocot																								**p**					**p**
Branching (root/stem)																					**p**								
Parallelepiped facetated, sedge									**p**				**p**																
Parenchyma stem cortex?																		**p**	**p**		**p**		**p**						
Elongate echinate long cell, monocot																													
Culm long section	**p**							**p**																					
Bilobates, C4 grass						**p**																							

Table S3. The distribution and habitat of sedges and rushes found in Sibudu. Sedges (Cyperaceae) and rushes (Juncaceae) are generally associated with estuarine, riverine, lacustrine, vlei (bog) and temporary moist areas such as seepages, although some sedges have adapted to drier conditions (*S14-S16*).

Plant name	**Distribution in KwaZulu-Natal (KZN)**	**Habitat**
Cladium mariscus (L.) Pohl subsp. *jamaicense* (Crantz) Kük	Coast, Maputaland (in South Africa generally, widely distributed along coast and far inland)	Wet habitats, often in swamps, along lake edges and streams. Tolerances: high anaerobic, high $CaCo_3$, medium salinity, low drought and pH between 4.5 and 8.4. Intolerant of shade.
Scleria natalensis C.B. Clarke	Coast, Zululand, Maputaland (endemic KZN, Transkei)	Perennial with evergreen leafy parts occurring in local almost pure stands in semi-shade in wet or seasonally moist (often seepage) areas, at low altitudes along the coast belt
Scleria melanomphala Kunth	Coast, Zululand, Maputaland	Robust perennial with evergreen aerial parts, in permanently wet, fairly open habitats
Cyperus L. sp.		Generally associated with moist habitats, although some *Cyperus* species have adapted to drier conditions
Juncus L. sp.		In wet surroundings, such as riverbanks, marshes, sandy beaches, salt pans, or in temporary moist depressions along roads, fields and open spaces, often covering large areas

Table S4. Minerals and organic compounds identified by FTIR and/or SEM-EDAX analyses in the sediments at Sibudu (modified from (*S7*)).

Mineral name	**Chemical formula**
Calcite	$CaCO_3$
Apatite	$Ca_5(PO_4,CO_3)_3(OH,Cl,F)$
Gypsum	$Ca_2SO_4 \cdot 2\ H_2O$
Quartz	SiO_2
Kaolinite	$Al_4(Si_4O_{10})(OH)_8$
Opal	$SiO_2 \cdot nH_2O$
Siliceous aggregates (SAs)	$SiO_2 \cdot nH_2O$
Charcoal	C
Leucophosphite	$K_2(Fe,Al)_4[(OH)_2/(PO_4)_4] \cdot 4H_2O$
Taranakite	$K_3Al_5H_6(PO_4)_8 \cdot 18H_2O$
Crandallite	$CaAl_3H[(OH)_6/(PO4)_2] \cdot H_2O$

CHAPTER SEVEN – EXPERIMENTAL MICROMORPHOLOGY

This chapter, which includes the paper by Miller and Sievers (2012), describes the first use of experimental micromorphology to address an archaeobotanical issue; specifically, formation processes associated with the laminated burned bedding present in the MSA layers at Sibudu (Goldberg et al. 2009; Goldberg & Berna 2010; Wadley et al. 2011). In both in this and the next chapter, scientific method is followed to set up inferences for past practices and the reasoning is based on the uniformities of materials and the exigencies of the burning of herbaceous material (Gifford-Gonzalez 2010).

The experiments involved the preparation of micromorphological profiles of the Sibudu deposits (Fig. 7.1) and the construction and burning of fresh sedge and grass bedding to produce micromorphological profiles (Fig. 7.2) to compare with the ancient profiles. The conclusions reached in this paper provided one of the strands of evidence to support the identification of bedding in the MSA layers at Sibudu, described in Wadley et al. (2011). The published paper reproduced at the end of this chapter provides detail on the aims, processes, results and conclusions of the experimental micromorphology.

Figure 7.1 Christopher Miller removing a sediment block from the Sibudu deposits (18/02/2012).

Figure 7.2 Preparation of a micromorphological profile of an experimental fire.

Miller, C.E., Sievers, C. 2012. **An experimental micromorphological investigation of bedding construction in the Middle Stone Age of Sibudu, South Africa**. *Journal of Archaeological Science* 39, 3039-3051.

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An experimental micromorphological investigation of bedding construction in the Middle Stone Age of Sibudu, South Africa

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ABSTRACT

We conducted experiments to compare the micromorphological signatures of modern burnt sedge and grass bedding to laminated layers of carbonized material and phytoliths in Middle Stone Age deposits at the shelter, Sibudu. The experiments were designed to clarify the formation processes associated with the laminated layers and to investigate whether these previously identified layers of bedding were deliberately burned or not. The results indicate that the laminated layers were most likely produced by human activity related to the construction, maintenance and burning of bedding. Furthermore, our experiments demonstrate that large volumes of vegetal material could have produced the relatively thin, archaeological deposits of burnt bedding.

1. Introduction

Multiple lines of evidence have suggested that the construction, maintenance, and deliberate burning of bedding was a major activity carried out during the Middle Stone Age (MSA) occupation of Sibudu and that bedding constitutes a significant component of the sedimentary units identified at the shelter (Goldberg et al., 2009; Sievers, 2006; Sievers and Wadley, 2008; Wadley et al., 2011). This paper addresses three questions relating to the burnt bedding hypothesis: could the repeated placement of sedges or grasses, their use as bedding, and their subsequent burning create the laminated fibrous charcoal and phytolith layers seen in thin sections of the archaeological deposits? Could the micromorphological signature of the archaeological bedding indicate whether it was ignited directly, or was it burnt as a result of later construction of overlying hearths? Do different types of plant bedding produce different micromorphological signatures? In order to address these questions, and to calibrate our micromorphological interpretations, we conducted a series of experiments involving the construction and burning of bedding. The results and observations of these experiments are reported here.

1.1. The site of Sibudu

Since 1998, Lyn Wadley of the University of the Witwatersrand, Johannesburg, has headed a multidisciplinary research program at Sibudu, a rock shelter 15 km inland from the Indian Ocean, in KwaZulu-Natal province on the east coast of South Africa (Fig. 1). Intense pulses of occupation during the MSA between approximately 77 ka and 38 ka are represented by excellent preservation of organic remains, a wealth of lithic artifacts, the earliest record of bone arrow heads and one of the earliest records of shell beads in Africa (Backwell et al., 2008; d'Errico et al., 2008; Jacobs et al., 2008a,b; Wadley and Whitelaw, 2006; Wadley et al., 2009). Enhanced working memory and complex cognition are indicated by the evidence of the hafting of stone tools using ochre and other materials, and the use of bow and arrow technology, snares and traps (Wadley and Mohapi, 2008; Wadley et al., 2009; Lombard and Phillipson, 2010; Wadley, 2010).

The nearly 3 m deep sequence at Sibudu has been stratigraphically divided into around 60 distinct units consisting of anthropogenic components derived from various combustion activities (Goldberg et al., 2009; Schiegl and Conard, 2006; Schiegl et al., 2004). The approximately 58 ka deposits are largely composed of distinct lenses, beds and laminations, whereas the underlying deposits (62–65 ka; 72 ka) appear more homogenous yet contain numerous, discrete lenses of charcoal and ash.

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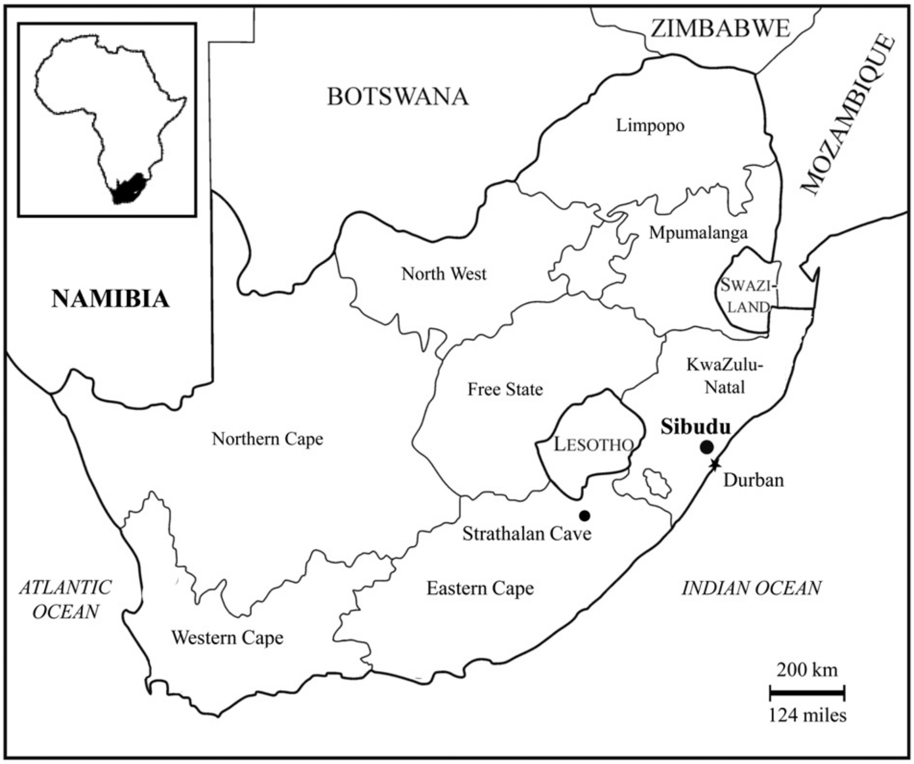

Fig. 1. Map showing geographical situation of Sibudu.

Micromorphological analysis has indicated that people were the main depositional agent at the site and that the lenses and laminations represent distinct anthropogenic deposits formed by the construction of hearths, the sweeping and dumping of ashes from hearths, the trampling of combusted material, and the construction and burning of bedding (Goldberg et al., 2009; Goldberg and Berna, 2010; Wadley et al., 2011).

1.2. Bedding construction in an archaeological context

The preservation of archaeological bedding is not unknown, particularly in South Africa. Excavators have recovered thick mats of vegetal material that they have interpreted as the remains of human bedding in Holocene (Binneman, 1997, 1998, 1999, 2000; Grobbelaar and Goodwin, 1952; Parkington and Poggenpoel, 1971; Van Rijssen and Avery, 1992) and Pleistocene (Opperman and Heydenrych, 1990; Opperman, 1996; Texier et al., 2010) sites. Beyond South Africa, indirect evidence for construction of bedding has been implied by the high proportion of phytoliths preserved in sites, such as Grotte XVI (Karkanas et al., 2002), Amud (Madella et al., 2002) and Tor Faraj (Henry, 2003; Rosen, 2003), and the identification of possible sleeping areas between hearths at Abric Romani (Vallverdú et al., 2010). More direct evidence for bedding in a Mousterian context has been identified at Esquilleu Cave, where layers of articulated phytoliths were identified by micromorphological analysis (Cabanes et al., 2010). Discrete areas with bedding remains were found on the constructed floor of a grass hut at the water-logged site of Ohalo II, dated to 23 ka (Nadel et al., 2004). The oldest archaeological evidence for bedding besides Sibudu (Wadley et al., 2011) is also from South Africa, from Strathalan Cave B, a shelter in the Eastern Cape Province (Opperman, 1996), where patches of packed grass are associated with a hearth that has been dated to 29 ka ago.

1.3. Evidence for bedding at Sibudu

The presence of bedding at Sibudu was first suggested by Sievers (2006) and Sievers and Wadley (2008), based on the high frequency of sedge nutlets (one-seeded fruits, about 1–3 mm in length) found at the site. The authors suggested that the entry of the nutlets to the site was through the collection of sedge culms (Sievers, 2006, 2011), which were most likely brought to the site to construct a floor preparation for sleeping, resting or working.

Micromorphological studies (Goldberg et al., 2009; Goldberg and Berna, 2010) supported the archaeobotanical interpretation, suggested by nutlet presence, of informally constructed bedding at the site. The micromorphological analysis applied the concept of microfacies (Flügel, 2004) to identify units whose formation was linked to different human activities. Goldberg et al. (2009) identified the burnt bedding microfacies association by the repeated vertical occurrence of three distinct microfacies: a lower microfacies unit consisting of laminated fibrous charcoal, derived from herbaceous material; a middle microfacies unit consisting of laminated fibrous charcoal and laminated phytoliths; and a final capping microfacies unit consisting solely of laminated phytoliths (Fig. 2). These layers are usually a centimeter thick or less; however, complexes of these microfacies associations can form layers that are up to several centimeters thick. Although most appear to form discontinuous lenses, some of the more extensive layers are laterally traceable across at least a meter or more of the site. The gradational contacts between the three distinct microfacies units suggested that the laminated charcoal and the laminated phytoliths had a similar origin and were deposited simultaneously. However, the upper portion of the unit had undergone post-depositional alteration. Goldberg et al. (2009) suggested that the gradation from laminated fibrous charcoal at the base to laminated phytoliths at the top of the layers was the result of *in situ* burning.

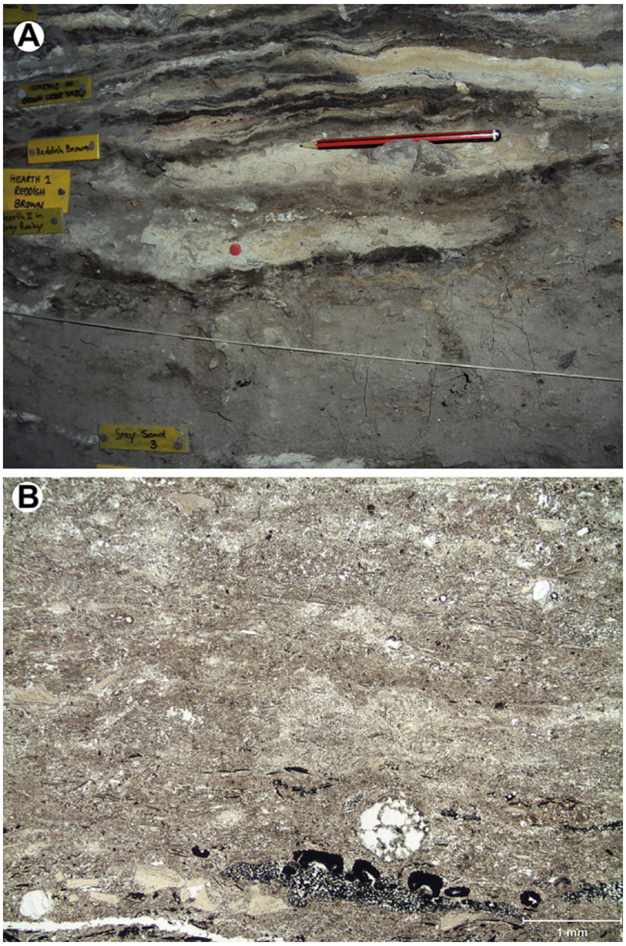

Fig. 2. Examples of deposits interpreted as bedding at Sibudu, in the field, and in thin section. A) In the field, the deposits of Sibudu appear as laminations of black alternating with white. B) In thin section, many of the white-colored layers are composed of laminated phytoliths, as seen here. The darker-colored layers are composed of laminated, fibrous charcoal, likely derived from monocotyledonous plants, such as sedges or grasses.

The general model of formation proposed by Goldberg et al. (2009) was that during the MSA the occupants of Sibudu collected sedges from the adjacent uThongathi River and placed them on the surface of the rock shelter floor to prepare an area for sitting, resting or working. The constant trampling and compaction of the vegetal material created the laminated microstructure seen in thin section. The presence of stringers of crushed bone (Miller et al., 2009) and chipped stone within the laminated fibrous charcoal suggested that in some instances, sedges were repeatedly brought to the site and laid down to refresh the bedding surface. At some point the shelter occupants ignited the bedding, possibly as a form of site maintenance to remove pests (Goldberg et al., 2009). Sievers and Wadley (2008) also noted that the evidence for bedding at the site was carbonized, and suggested that the carbonization of the sedge nutlets was serendipitous below subsequently constructed, yet unrelated hearths. Other examples of inadvertent heat treatment, as well as deliberate burning at Sibudu have been noted: Wadley (2009) cited post-depositional heating of ochre, possibly resulting in the over-representation of red ochre in MSA sites. Clark and Ligouis (2010) refer to incidental burning in their analysis of the taphonomy of bone at Sibudu and mention intentional burning of bone, as previously proposed by Cain (2006), as a possible site maintenance activity.

2. Methods and materials

2.1. Experimental goals

We designed the experiments to address the following questions:

- Does the experimental placement, trampling, and subsequent burning of sedge or grass bedding, as proposed by Goldberg et al. (2009), produce micromorphological characteristics similar to those seen in archaeological examples from Sibudu? Can multiple experimental phases of bedding construction and burning be detected micromorphologically?
- Is the micromorphological signature of bedding dependent on the type of plants used?
- Were the bedding layers at Sibudu directly ignited, or were they carbonized by overlying hearths?

2.2. Experimental design

We conducted seven fire experiments to address these questions (Table 1). Fires 1, 6 and 7 were designed to address the issue of direct versus indirect burning of the bedding. Fires 2–5 were designed to test the model for the formation of burnt bedding proposed by Goldberg et al. (2009), and to determine if different types of plants would produce different micromorphological signatures that could be recognized in archaeological samples.

2.2.1. Fire 1

The aim of Fire 1 was to investigate whether the carbonization of buried bedding material by an overlying fire produced the micromorphological signature of the archaeological bedding layers. Previous burning experiments showed that seeds, buried up to 10 cm deep, were affected by the heat of a fire lit directly above them (Sievers and Wadley, 2008). At 5 cm below the center of the hearth, seeds of various sizes and testa hardness, with or without fruit adhering, and of varying oil and moisture content, became carbonized (black throughout). At 10 cm some seeds became black, whereas others were less affected and were altered to a dark

Table 1
Materials, methods and aims of the experimental fires.

Fire	Plant type	Name	Heat treatment	Replication aim
1	Sedge	*Cyperus involucratus*	Single wood fire above buried sedge culms	Accidental carbonization of buried bedding
2	Sedge	*Cyperus involucratus*	5 fires, one above the other	Signature of repeatedly burned sedge bedding
3	Sedge	*Schoenoplectus litoralis*	3 fires, one above the other	Signature of repeatedly burned sedge bedding
4	Grass	*Panicum deustum*	3 fires, one above the other	Signature of repeatedly burned grass bedding
5	Grass	*Setaria plicatilis*	3 fires, one above the other	Signature of repeatedly burned grass bedding
6	Sedge	*Cyperus involucratus*	Single fire	To test the possibility of accidental fire
7	Sedge	*Cyperus involucratus*	Single fire	To test the possibility of accidental fire

brown. These results indicated that it is possible that the sedge nutlets and therefore sedge bedding layers at Sibudu, once buried, could have been later carbonized by fires made above them some time after their entry into the deposits. The presence of numerous hearths and the overwhelmingly ashy deposits at Sibudu (Schiegl et al., 2004, Schiegl and Conard, 2006) support this possible scenario.

For Fire 1, *Cyperus involucratus* Rottb. culms, including attached inflorescences, were cut into 30 cm lengths and laid down and compacted in a hole of the same lateral dimensions and approximately 8 cm deep. The culms were then covered by 5 cm of lightly compacted fine sediment recovered from Sibudu 1 mm screening. Seven pieces (3 kg total mass) of *Casuarina equisetifolia* L., a firewood that produces relatively hot, long-lasting coals, were stacked directly above the buried sedges and ignited using commercially available fire-starter to produce a fire of 30 cm diameter. After 30 min the wood had burned down and six more pieces of wood (also 3 kg) were added. Temperatures were recorded with a Major-Tech digital thermometer (MT 632) and a K-type thermocouple with a 50 cm probe positioned as close as possible to the base of the buried sedges without disturbing them (the thermaprobe could not be inserted when the sedges were laid down, because of possible damage during compaction of the sedges). Recordings were noted every 15 min for the first three and a half hours, at 30 min intervals for the next three hours, and at hourly intervals for the rest of a 24 h period, apart from four hours in the early hours of the morning. The measurement intervals were determined by the rate and degree of observed temperature change, particularly those registered by a second probe which became available two and a half hours after the fire was started. This probe was inserted to record temperatures in the coals at the base of Fire 1.

After Fire 1 had cooled, the area was covered for protection from wind and rain, left undisturbed for one week, and then excavated following conventional archaeological procedures. During excavation, a 10 cm square column sample was removed from the center of the hearth area.

2.2.2. Fires 2–5

Fires 2–5 were designed to reproduce the model of burnt bedding formation proposed by Goldberg et al. (2009). Both Cyperaceae (sedge) and Poaceae (grass) pollens and phytoliths have been identified at Sibudu (Schiegl et al., 2004; Renaut and Bamford, 2006; Schiegl and Conard, 2006; Goldberg et al., 2009) and so two sedge species, *Cyperus involucratus* Rottb. and *Schoenoplectus litoralis* Palla and two grass species, *Panicum deustum* Thunb. and *Setaria plicatilis* (Hochst.) Engl. were chosen for the experimental fires (Fig. 3). At the time of the experiments (February 2010) no grass species had been identified by macrobotanical studies at Sibudu, and *Schoenoplectus* cf. *brachyceras* had been suggested as a possible identification for the sedge nutlets (Sievers, 2006). This sedge is not available for harvesting in the Durban area, but a similar sedge *S. litoralis* is available and it, like *Cyperus involucratus* is regularly used for the manufacture of sleeping mats (CS, pers. observation, Van Wyk and Gericke, 2000). The grasses for the experiment were chosen to provide variety in the possible characteristics of the bedding: *Setaria plicatilis* has soft leaves and culms, whereas *Panicum deustum* has firm long culms and is sturdier. All four taxa were collected in the Durban area: *Cyperus involucratus* from a suburban garden in Durban North (approximately 45 km from Sibudu), *Panicum deustum* from a roadside bank also in Durban North, *Schoenoplectus litoralis* from ponds in Umbilo-Umhlatazana River Park, and *Setaria plicatilis* from coastal forest in Virginia Nature Reserve. The sedges and grasses were laid down on newsprint, under cover, to dry naturally.

The selected grass and sedge species were also chosen because the habitats in which they occur can be found near Sibudu, which is situated in a forested cliff above the perennial uThongathi River, overlooking a north-facing slope of grassland. *Cyperus involucratus*

Fig. 3. Sedges and grasses used in the fire experiments. A) *Cyperus involucratus* growing in the uThongathi River below Sibudu. B) *Schoenoplectus litoralis* in Umbilo Ponds, Durban. C) CS collecting *Panicum deustum* alongside Crusader's Field, Durban North. D) *Setaria plicatilis* in Virginia Nature Reserve, Durban North.

occurs in moist situations, whereas *Schoenoplectus litoralis* grows only in standing water. The grass, *Panicum deustum*, known as reed panicum, occurs in shade, in moist situations such as river banks and also on stony slopes (Gibbs et al., 1990; Van Oudtshoorn, 1992). *Setaria plicatilis*, known as folded leaf tussock grass (although it is only loosely caespitose/occurring in tufts), occurs in semi-shade, along forest margins and occasionally in woodland (Gibbs et al., 1990). Both the tussock grass and panicum occur in coastal forests and also in savanna. Reed panicum has long stiff culms used in the weaving of grass mats (Gibbs et al., 1990), whereas tussock grass is a soft leafy plant, which can make up a comfortable and springy resting area.

For Fire 2, dried *Cyperus involucratus* (sedge) culms, including inflorescences, were cut into 30 cm sections and placed in a hole of the same lateral dimensions and approximately 6 cm deep, layer upon layer at 90 degrees to each other. When the layering extended above the ground surface a 30 cm by 30 cm piece of cardboard was placed on the pile and the sedges were compacted under repeated rolling of a tennis court roller, which was then left to compress the bedding for 45 min. This was done to simulate repeated human trampling and compaction of the bedding. A thermaprobe was placed at the base of the sedges and the sedges were ignited using commercially available fire-starter. Temperatures were recorded every 15 min for two and a half hours, and then the thermaprobe was removed (to prevent damage to it during the next part of the experiment). A second series of layers of sedges was placed on the 30 cm × 30 cm designated area and compacted once the layers threatened to topple. After 45 min under the roller, the sedges were ignited. The thermaprobe was not re-inserted because of possible disturbance of the sediments. The layering, compacting and igniting process was repeated five times in total, to replicate repeated burning of bedding. The area was then covered with fine sand and compacted for one week by the stationary weight of the roller. This phase of compaction was conducted to simulate compaction and settling that would have occurred over time following burial at Sibudu. Excavation followed and a block was removed from the center of the experimental area for micromorphological analysis (Fig. 4). For Fire 3 (*Schoenoplectus litoralis* – sedge), Fire 4 (*Panicum deustum* – reed panicum) and Fire 5 (*Setaria plicatilis* – tussock grass) the dimensions of the fires were as for

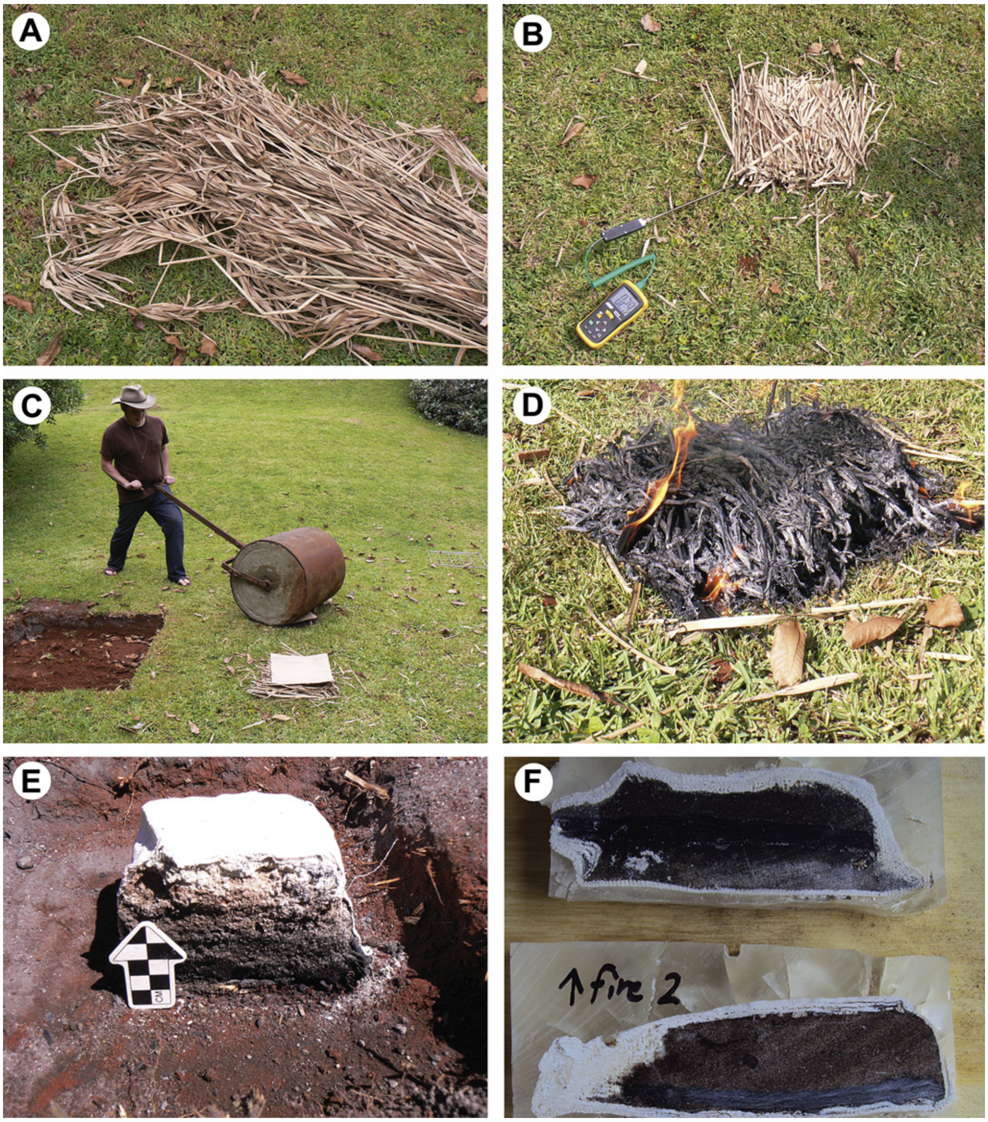

Fig. 4. Fire experiment methods. A) Dried *Cyperus involucratus* culms. B) Cut culms in 30 cm × 30 cm × 8 cm hole. C) Compaction of culms with garden roller. D) Burning of culms. E) Sediment block from center of excavated Fire 1. F) Resin-impregnated blocks from fire experiments (photo. Silje Bentsen).

Fire 2, 30 cm × 30 cm, and five pieces of fire-starter were used to ignite each fire, one piece in each corner and one in the center. Three sets of layers were ignited and the material was compacted between each fire. After the final fires had cooled, they were covered by 5 cm of sand before compaction for three days. Circumstance of timing and the amount of available sedges and grasses governed the slight differences in number of layering and timing of compaction between the different fires.

The blocks of intact sediment from Fires 1–5 were covered in plaster bandages to facilitate removal and to preserve the integrity of the samples. The samples were dried on-site overnight at 60 °C and then impregnated with polyester resin (NCS Resins, New Germany, KwaZulu-Natal, South Africa) mixed with styrene and hardener. After the resin had set following several days of air drying, the samples were heated at 60 °C overnight to complete the hardening. They were cut using a rock saw and the resulting blocks were thin sectioned by Spectrum Petrographics (Vancouver, WA, USA). Thin section descriptions were conducted on a Zeiss AxioImager petrographic microscope using plane polarized light (PPL), cross-polarized light (XPL) and oblique incident light (OIL) and followed the procedures described by Stoops (2003) and Courty et al. (1989).

2.2.3. Fires 6 and 7

The aim of Fires 6 and 7 was to investigate whether the bedding material at Sibudu could have ignited accidentally, for example, from a coal or spark of a nearby fire or if direct ignition by humans was more likely. Culms of *Cyperus involucratus* were used in the experiments. The culms used in Fire 6 had previously been harvested and had been drying for 15 months in Sibudu. The sedges were laid horizontally and were ignited with fire-starter after matches proved unsuccessful. The fire-starter was positioned at one end of the stack of sedges to observe whether the flames would move across the mass of sedges. The methods for Fire 6 were repeated for Fire 7 which used a large stack of sedges that had been sundried at Ballito, a coastal town approximately 15 km directly east of Sibudu.

3. Results

3.1. Fire 1

The maximum temperature at the base of the buried sedges in Fire 1 was 253 °C, which was reached nine and a half hours after the fire was ignited and at least 3 h after the last glimmer of light could be seen glowing in the coals (Table 2). The temperature recorded by the second thermaprobe, positioned in the coals at the base of the fire, also continued to rise long after the flames had died down and the embers had stopped glowing. It reached a maximum of 489 °C seven and a half hours after the fire was ignited.

The fuel in Fire 1 combusted completely and the remains of the fire consisted of lenticular layers, shallower at the edges and thicker towards the center and were composed of a white ashy layer underlain by a pinkish layer grading into a reddish colored layer, all above a black layer. These layers overlay the sieved Sibudu sediments and the sedges themselves (Fig. 5). All sedges were carbonized except for those towards the perimeter and at the base of the sedge layer, which was 4.5 cm thick (Fig. 6).

The layer of sedges is marked by the preservation of distinct culms, roots and leaves forming a loose structure (Fig. 5). The sedges appear carbonized, based on their opacity in plane polarized (PPL) and cross-polarized light (XPL). The lowermost sedges, however, do not exhibit evidence of carbonization. Furthermore, the occurrence of interference colors in XPL in the culms indicates that original cellulose remained. Most importantly, the characteristic phytolith layers found in bedding at Sibudu are not evident.

3.2. Fire 2

After ignition, the *Cyperus involucratus* burned and then rapidly subsided after 9 min. The embers continued smoldering and the maximum temperature, 603 °C, was recorded at the base of the sedges 18 min after ignition of the fire (Table 2). Excavation of the experiment revealed a centimeter-thick consolidated deposit consisting of fused, burnt culms, some black but others white, that exhibited preserved anatomical structures of the original plants.

The alternating direction in which the sedges were laid is distinguishable in thin section, usually from the carbonized sedges that were sectioned transversally. The culms were compressed from circular to lenticular in transverse section and as a result, the vascular bundles were packed closely together. The bracts from the sedge inflorescences can also be identified in transverse section and longitudinal sections of culms are visible. In XPL, the charcoal is opaque and the phytoliths are isotropic, as would be expected; however, some zones of micron-sized birefringent material, most likely calcite, are present.

Fire 2 produced micromorphological structures and features most similar to the archaeological examples found at Sibudu. The layer of experimentally-produced burnt bedding consisted largely of compacted and laminated phytoliths (approximately 60%), many of which were still articulated and retained anatomical characteristics of the original plant. The remainder of the layer consisted of laminated fibrous charcoal, which is found in distinct zones within the laminated phytoliths. The fibrous charcoal is found throughout the layer. The distribution of the fibrous charcoal in relation to the phytoliths does not resemble the distribution found in archaeological samples from Sibudu. Importantly, it is not possible to distinguish individual burning events in the thin sections of Fire 2.

Table 2
Results of the experimental fires. Time refers to the time from the lighting of the fire until the maximum temperature recorded (at the base of the fire) was reached. Temperatures were recorded only for the first of the series of fires in each experiment because the thermometer probes were removed to prevent damage during compaction of material in subsequent fires.

Fire	Plant name	Max. temp.	Time	Comments
1	*Casuarina equisetifolia*	489 °C	7½ h	Temp. measured at base of fire.
	Cyperus involucratus (buried)	253 °C	9½ h	Max. reached 2 h after temp. of fire above began decreasing.
2	*Cyperus involucratus*	603 °C	18 min	Flames lasted 9 min
3	*Schoenoplectus litoralis*	554 °C	31 min	
4	*Panicum deustum*			Temperatures not recorded.
5	*Setaria plicatilis*	157 °C	30 min	Not fully dry.
6	*Cyperus involucratus*			Temperatures not recorded.
7	*Cyperus involucratus*	>800 °C	5 min	Thermometer and probe removed to prevent damage to them.

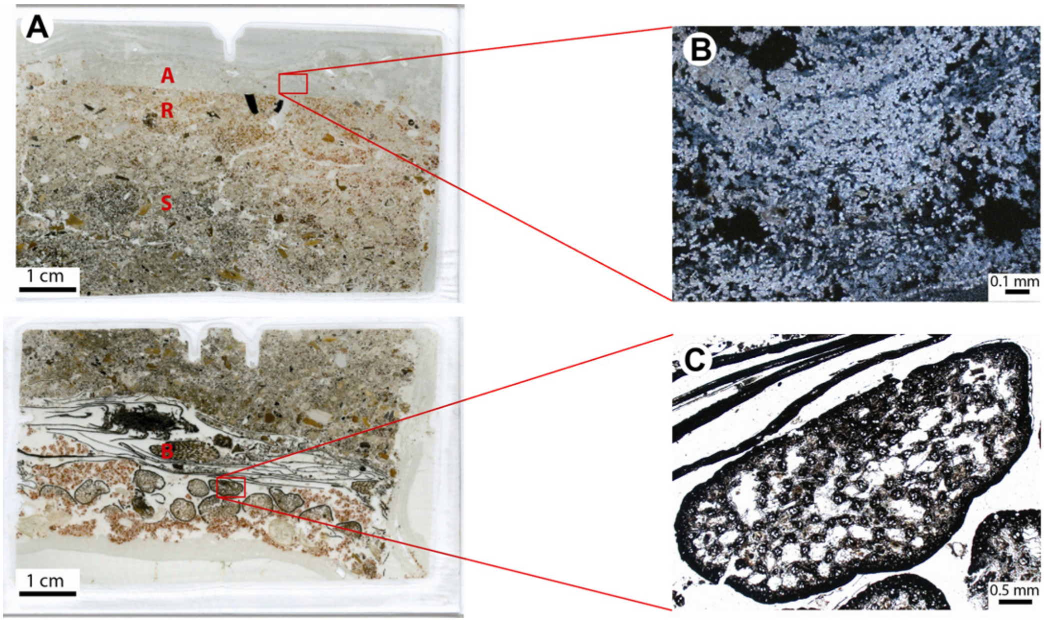

Fig. 5. Results of Fire 1. A) Two thin sections (each 50 mm × 75 mm) collected from Fire 1, showing the ash (A) produced from the overlying fire, the sieved Sibudu sediment (S) separating the fire from the sedge bedding layer (B), with a rubefied top (R). Notice that the rubefication does not extend to the bedding, but that the culms of the sedges were carbonized. Below the bedding layer (B) is consolidated red dune sand that makes up the natural substrate. B) Calcareous ash produced in the wood fire. Compare this to the burnt bedding layers (Figs. 6 and 7), where little calcareous material was found. C) A cross-section of a carbonized *Schoenoplectus litoralis* culm, clearly showing vascular bundles. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

3.3. Fire 3

The *Schoenoplectus* culms, once lit, burned well, and puffed and expanded. They continued smouldering as in Fire 2 and also produced a centimeter-thick consolidated deposit that preserved anatomical features of the original plants. A maximum temperature of 554 °C was reached after 31 min (Table 2).

In general, Fire 3 exhibited micromorphological characteristics similar to Fire 2 and to archaeological examples of burnt bedding at Sibudu. The bedding layer of Fire 3 consisted largely of compact laminated phytoliths (50%) and fibrous charcoal. Unlike Fire 2, the phytoliths in Fire 3 are not as clearly defined and appear relatively amorphous in morphology, making the laminated character of the phytoliths less distinct than in Fire 2. However, many individual phytoliths exhibit distinct morphological characteristics that would potentially lend themselves to identification in thin section. The fibrous charcoal, as in Fire 2, is located in distinct zones, but its distribution is not clearly related to individual burning events. The zones of fibrous charcoal are less well defined in Fire 3 than in Fire 2 and exhibit slightly diffuse boundaries with the surrounding laminated phytoliths. Carbonized plant material is located at the very base and also at the very top of the burnt bedding layer.

3.4. Fires 4 and 5

As noted for the sedges, the grasses also needed fire-starter to ignite. Residual moisture or absorption of excessive humidity are likely explanations for the difficulty in ignition, Nevertheless, compacted sections of burned material were obtained for analysis.

The grass fires produced results that are micromorphologically distinct from the sedge fires (Fires 2 and 3) (Fig. 7). The experiment with *Panicum* (Fire 4) contains a proportion of phytoliths to fibrous charcoal that is similar to the proportion found in Fires 2 and 3 (50–60%); however, the phytoliths and fibrous charcoal are not as clearly laminated here as in Fires 2 and 3. Furthermore, the structure of the layer is less compact than in the sedge fires. The relatively open structure and less obvious lamination appear to be a result of the *Panicum* anatomy. The burnt culms of the grass produced articulated phytoliths that display clear laminations similar to Fires 2 and 3. However, the *Panicum* leaves created a more irregular and open structure that does not appear similarly laminated.

Fire 5 appeared similar to Fire 4 in thin section, except that the proportion of phytoliths was the least of all fires (only 25% of the layer). Fibrous charcoal is dominant, and some weak laminations are present, but they are not as clear as in the sedge fires (Fires 2 and 3), or as in the *Panicum* fire (Fire 4). As in Fire 4, the leaves of the grass in Fire 5 produced a more open and irregular structure with a less-laminated appearance compared to the other experiments. Individual culms from the *Setaria* were preserved and visible in thin section, having not been extensively crushed and compacted as in the other experiments.

3.5. Fires 6 and 7

Upon ignition the fire did not move across the stack of sedges in Fire 6, and it died out before fully combusting the sedges. In Fire 7, where sundried sedges were used, the flames moved rapidly across the entire stack of sedges, fully combusting all the sedges.

4. Discussion

The main objective of the experiments was to determine if modern compacted and burnt sedges and grasses would produce a micromorphological signature similar to features identified at Sibudu and interpreted as burnt bedding (Goldberg et al., 2009). In particular, we were interested in investigating whether different types of plants produced different signatures, and if multiple episodes of bedding construction and burning could be detected micromorphologically. We were also interested in investigating whether we could distinguish between incidental carbonization and direct burning of plant bedding.

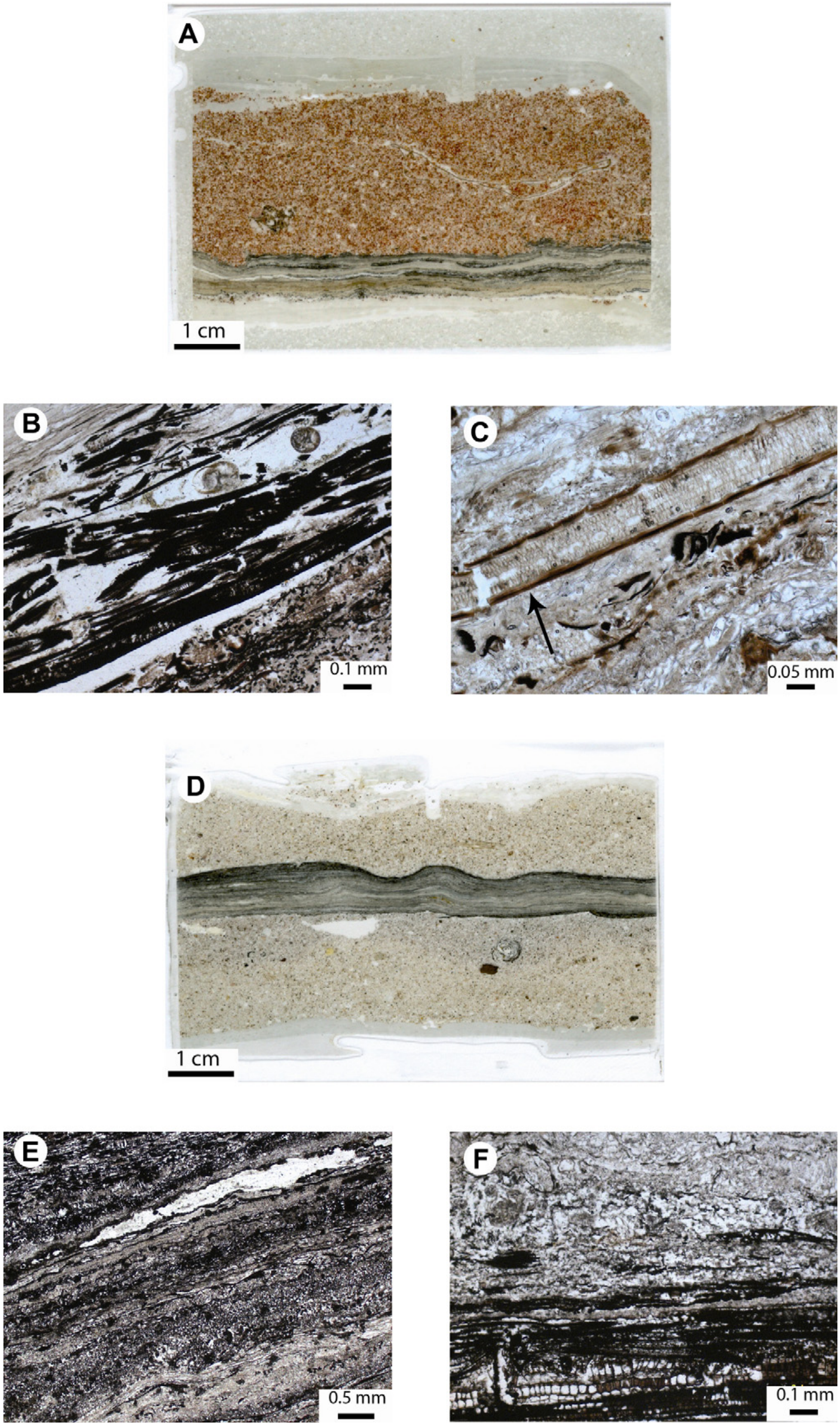

Fig. 6. Sedge fires: Fire 2 (A, B, C) and Fire 3 (D, E, F). A) Thin section (50 mm × 75 mm) collected from Fire 2. The reddish material is the Berea red soil which provided the substrate for this experiment. Notice the clear laminated structure of the experimental burnt bedding layer. While all experimental fires produced a laminated microstructure, Fire 2 exhibited the clearest laminations of all experiments. B) Carbonized sedge culm. C) articulated phytoliths (indicated with arrow). Similar carbonized culms and phytoliths in a laminated microstructure are found in the archaeological deposits of Sibudu. D) In this section (50 mm × 75 mm) collected from Fire 3, the over- and underlying material is sand from Ballito, South Africa, which was the substrate for this and Fires 4, 5 and 6. Notice the clear laminations present in this experimental burnt bedding layer. E) Example of laminated phytoliths and carbonized culms. F) A closer view of laminated carbonized culms (at base) overlain by laminated phytoliths. The phytolith-rich layers in this experiment (Fire 3) were not a clearly defined as in Fire 1. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

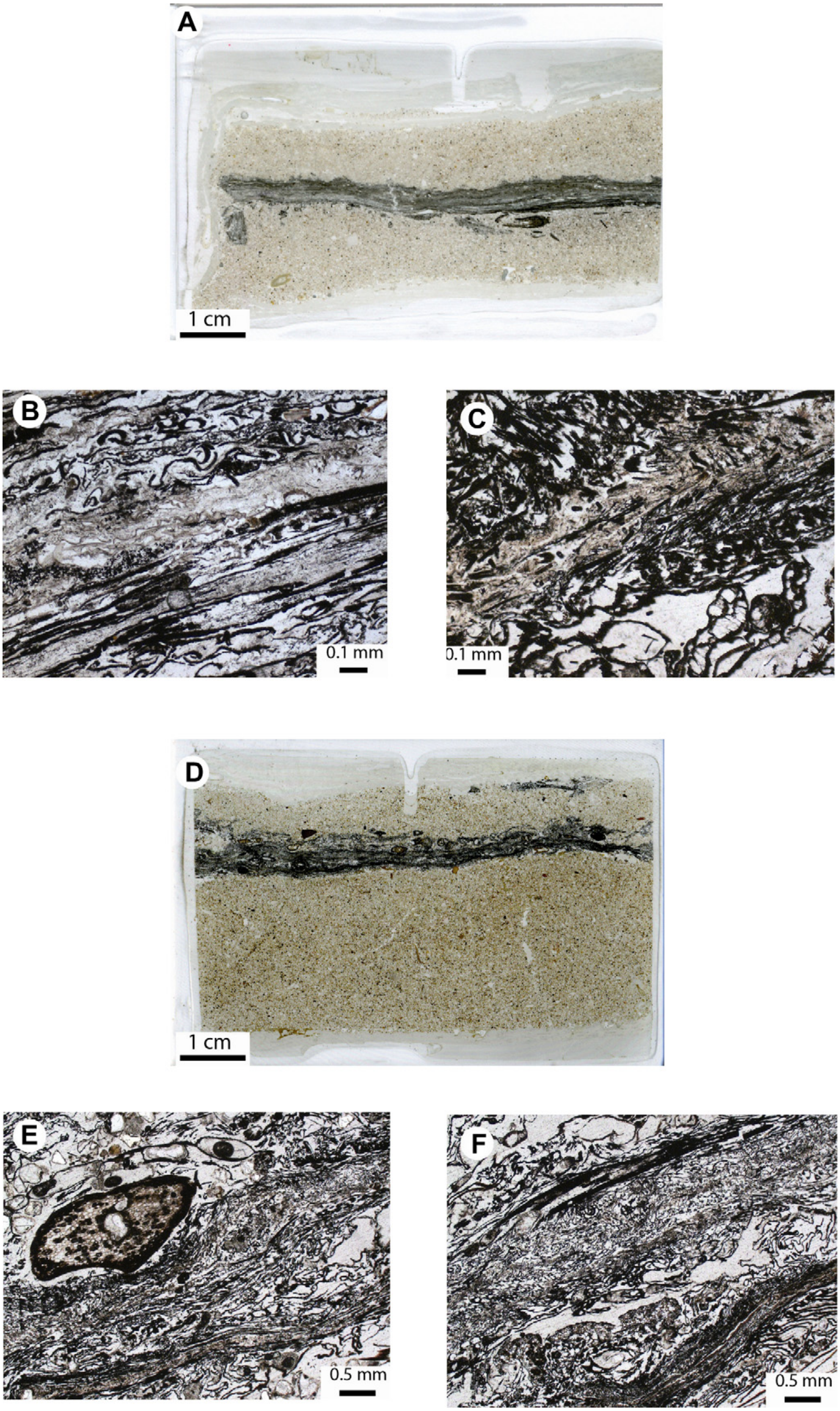

Fig. 7. Grass fires: Fire 4 (A, B, C) and Fire 5 (D, E, F). A) Thin section (50 mm × 75 mm) of Fire 4. Laminations are visible, but not as clearly as in the sedge fire experiments (Fires 2 and 3). B) While phytoliths and carbonized culms and leaves are clearly visible microscopically, they appear closely together, and not clearly separated into distinct zones as seen in the sedge fires and in archaeological examples. C) Laminated phytoliths and carbonized culms and leaves. D) Thin section (50 mm × 75 mm) of Fire 5. This fire experiment produced results that were least similar to the archaeological examples of burnt bedding. Laminations are not clearly visible, as in the sedge fires (1 and 2). E) Some grass culms were still clearly preserved, as seen here. F) Some laminations are visible microscopically, but no clear layers of laminated phytoliths were apparent.

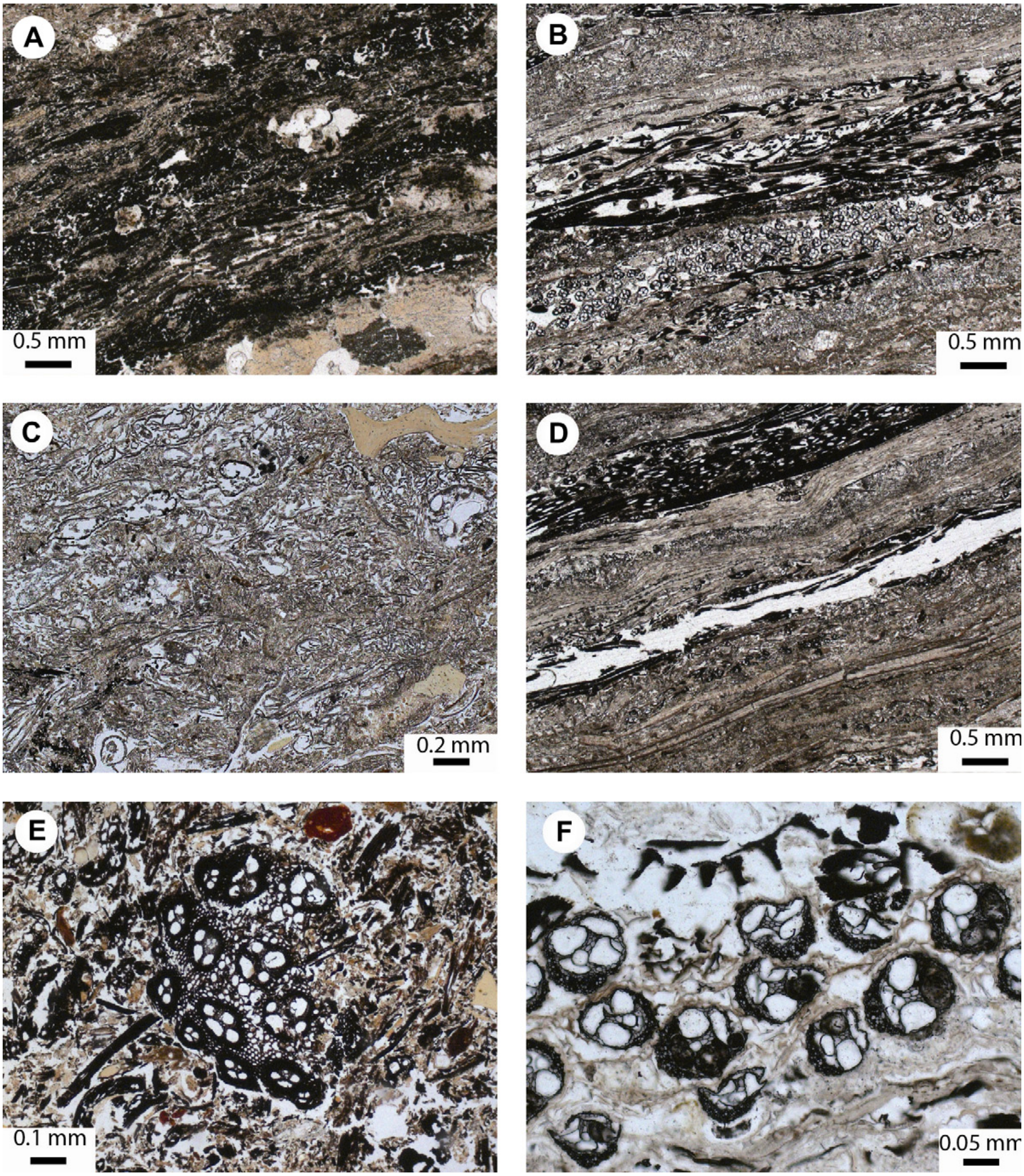

Fig. 8. Archaeological and experimental examples of burnt bedding. A) Archaeological example of burnt bedding from Sibudu, from ~59 ka layers (Brown under YA2(i)). Notice the distinct zones of laminated carbonized material separated by thin, light colored layers of phytoliths. B) Experimental example of laminated phytoliths and carbonized culms, Fire 2. Notice the similarity in appearance of the laminations compared to the archaeological example. C) Archaeological example of a laminated phytolith layer, Sibudu (OMOD). The different articulated phytoliths are clearly visible. D) Experimental example of laminated phytolith layer from Fire 2. While all experimental fires produced phytoliths to some extent, only the sedge fires produced distinct laminated layers of phytoliths. E) Vascular bundles preserved in archaeological sediments, Sibudu(OMOD). F) Experimental example of preserved vascular bundles. The arrangement of such bundles in cross-section of a culm may allow for the identification of different types of plants used for bedding. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

All four experiments (Fires 2–5) produced laminated fibrous charcoal and phytoliths that generally resembled the micromorphological characteristics observed in the Sibudu sediments (Fig. 8). Of the four experiments, the sedge fires, and in particular the *Cyperus* experiment (Fire 2), produced results most similar to the archaeological examples of burnt bedding. Most of the combustion remains of Fire 2 consisted of phytoliths that were predominantly articulated and clearly defined. Although phytoliths were present in the other sedge fire (Fire 3) and also in the grass fires, the clear articulation and laminations were not as well defined. In general, the results of these fires indicated that the model of formation for the types of layers as proposed by Goldberg et al. (2009) is plausible. Phytolith studies have the potential to provide detail on the composition of the bedding, and detailed phytolith studies at Sibudu are on-going. Pollen is not well preserved at Sibudu, but both grass and sedge pollens have been identified in the ~58 ka layers (Renaut and Bamford, 2006). These pollens are anemophilous, thus their presence is not necessarily connected to the bedding in the shelter.

Some micromorphological aspects of the experimental fires are different from those of the archaeological examples. All of the burnt bedding layers at Sibudu are defined by a basal unit of laminated fibrous charcoal that grades into an overlying layer of laminated phytoliths. The goal of conducting multiple firings of the sedge and grass experiments was to determine if multiple distinct burning events could be detected when they occurred directly on top of one another. Our experiments showed that this is not always the case. Although laminated phytoliths and fibrous charcoal were produced in the experiments, the distinct gradation from the charcoal to the phytoliths was not reproduced. For our experiments it seems that complete ashing (producing the laminated phytoliths) or carbonization (producing the laminated fibrous charcoal) varied in the different experiments, so that the sedges were largely burnt to completion (ashed), but the grasses were more likely carbonized.

A possible explanation for the lack of a clear vertical variation in proportions of charcoal and phytoliths is that our experimental beds were either too thin or not sufficiently compact. Particularly for the sedge experiments, enough oxygen was able to reach the base of the bedding so that the entire mass of material was able to burn largely to completion. If the beds were thicker, or if the beds were more compact, oxygen would have been less able to reach the base of the deposit, thereby promoting the carbonization rather than the complete ashing of the basal sedges. Although there was a lack of structuring in the fibrous charcoal and phytoliths in the experiments, we observed zones of laminated fibrous charcoal, which demonstrates that this type of charcoal can be formed during similar burning events.

One particularly striking result observed in the experiments was the reduction in volume of the collected and compacted plant material after burning. A total of 30 cm of compacted *Cyperus* and *Schoenoplectus* was used for the fire experiments and both produced layers that were on average 6 mm thick after burning and compaction. Up to 98% of the total thickness, before compaction, of the experimental bedding layers was lost during combustion. Most of the archaeological phytolith layers are around 1 cm thick, and some appear at least 3 cm thick (Goldberg et al., 2009). Our experiments suggest that the relatively thin burnt bedding deposits at Sibudu represent significant volumes of plant material that were brought to the site. Based on a 98% loss of bulk, some of the archaeological phytolith layers may represent compressed bedding deposits that were up to 150 cm thick, though it seems unlikely that any individual bedding unit was this thick at any given time. Albert et al. (2008) have also suggested that phytolith-rich layers represent a significant loss in volume, which can influence the taphonomic processes of a site. Micromorphological analysis of some of the Sibudu bedding layers has identified stringers of crushed bone and chipped stone that defined surfaces within the constructed bedding unit (Goldberg et al., 2009), suggesting that plant material was applied repeatedly to refresh the bedding surface. The fact that large volumes of plants are needed to form the archaeological phytolith layers may also explain why laminated fibrous charcoal is found below laminated phytoliths in archaeological examples, but not in the experimental examples. While our experiments produced layers approximately as thick as some archaeological examples, our experimental deposits were produced by several fires. It seems that the archaeological burnt bedding layers represent thicker accumulations of plant material, possibly as thick as our entire volume of plants for each fire. In the past, this large volume was possibly burnt at one time. Therefore, in the archaeological examples, the base of the burnt bedding layers was probably carbonized while the upper portion of the bedding layer was ashed, producing the laminated phytolith layers. In our experiments, the entire bedding layer was more or less ashed, producing laminated phytolith layers with stringers of fibrous charcoal throughout the entire deposit.

Fires 1, 6 and 7 addressed the question: was the burning of the bedding direct or indirect? Fire 1 was conducted to explore the possibility of accidental carbonization, by a post-depositional fire, of bedding that had been buried by the accumulation of overlying sediment; this scenario had been proposed by Sievers and Wadley (2008). If the results of Fire 1 replicated the signatures of the Sibudu deposits (layers of phytoliths and carbonized material) they could indicate serendipitous carbonization. Fire 1 confirmed that sedge culms carbonize when buried below 5 cm of sediment similar to that found at Sibudu. But, the carbonized sedges were not capped by a layer phytoliths as seen in the Sibudu microstratigraphy. This is not an unexpected result since the heating of plant material in a reducing environment is unlikely to allow full combustion and produce ash, or a layer of phytoliths.

Fires 6 and 7 addressed the burning of bedding exposed on the floor of the shelter. In Fire 6, it was not possible to ignite the sedges so that they combusted completely. However, in Fire 7, the sedges ignited quickly, with temperatures nearing over 900 °C, necessitating the removal of the thermaprobe. A likely explanation for the dichotomy of the results is the tendency of dried sedges to react to the amount of moisture in the atmosphere. This feature is successfully exploited in the north-western parts of South Africa where nomadic herders use sedge mats to cover the curved wooden frames of their “matjieshuise” (Afrikaans for “houses of mats”). During the dry summer months, sedge culms shrink and allow a breeze to pass between them, whereas in the wet winter months the sedges absorb moisture, expand and form a watertight covering (Van Wyk and Gericke, 2000).

While one cannot exclude the possibility that the MSA bedding of Sibudu was accidentally burnt, either naturally or from sparks from a nearby fireplace, there are several lines of evidence from the archaeological samples and from the experimental results that strongly suggest that the bedding was directly ignited. Whereas Fires 6 and 7 produced different results – one suggesting that it was difficult to ignite sedges, and one suggesting that sedges ignite and burn easily – it is important to note that the sedges which had spent 15 months in the rock shelter were difficult to light. It was only sedges which had dried in the sun that burnt easily and rapidly. The sedges from the shelter, while appearing relatively dry, may have held enough moisture to prevent them from easily igniting. In this scenario, it is possible to imagine that the MSA bedding material also retained some level of moisture that may have made it difficult to ignite accidentally and that the occupants of the shelter would have had to apply significant effort to light a laterally extensive layer of thick bedding. We suggest that the inhabitants directly ignited the bedding, in spite of possible difficulty it may have involved at times.

Another indication that the bedding was directly ignited comes from the archaeological examples of bedding. The repeated occurrence of burnt bedding throughout the sequence, particularly in the 58 ka occupations (Goldberg et al., 2009) suggests that the burning was not accidental. Furthermore, archaeological examples of similar types of sediment, albeit from a very different archaeological context, are quite common. In the Near East and the Mediterranean, pastoralists since the Neolithic have used caves for stabling, where straw is laid down and where dung accumulates over time (Brochier et al., 1992; Macphail et al., 1997). When the herd leaves the site, the shepherd will ignite the matted dung and straw in order to remove pests and parasites (P. Goldberg, personal communication, S. Heydari, personal communication). The micromorphological features of burnt stabling and other pastoralist deposits (Albert et al., 2008) are remarkably similar to the bedding deposits from Sibudu. Considering the difficulty of lighting some sedges (Fire 6), the repetition and common occurrence of burnt bedding in the site, and the similar appearance in thin section of the Sibudu burnt bedding with intentionally burnt stabling material at Near Eastern and Mediterranean sites, it seems probable that the Sibudu bedding was intentionally burned.

Another interesting result from the fire experiments was that the ash formed by fully combusting the sedges and grasses did not contain typical ash rhombs (Courty et al., 1989), but rather consisted almost exclusively of phytoliths. In this sense, phytoliths are the "ash" that is produced when burning sedges and grasses. Goldberg et al. (2009) had suggested that diagenetic processes were responsible for removing calcareous ash from the phytolith layers; however, it seems more likely, based on the results of this experiment, that calcite was never a significant component of the laminated phytolith layers. The lack of calcareous ashes does not seem to be a result of taphonomic processes occurring after the experiments, since calcareous ash was produced and preserved in the wood fire from Fire 1.

5. Conclusion

Our experiments suggest that the laminated fibrous charcoal and phytolith layers at Sibudu were most likely produced by the direct burning of compacted herbaceous plant material. The four burning experiments conducted with two species of sedges, *Schoenoplectus* and *Cyperus* and two species of grasses, *Panicum* and *Setaria*, all produced laminated charcoal and phytoliths. The sedges fires produced layers of laminated phytoliths, similar to numerous layers of laminations found in micromorphological samples from Sibudu. This finding lends support to the idea of Sievers (2006) who suggested that sedges were the dominant taxon used for the construction of bedding during the MSA at Sibudu. Our experiments also demonstrated that large volumes of plant material are required to produce the relatively thin layers of laminated fibrous charcoal and phytoliths, implying that the occupants of Sibudu invested significant amounts of energy to collect plants for the preparation of their living space. The collection of sedges and the construction of bedding, combined with evidence that the bedding was possibly burned as part of site maintenance, indicate not only a considerable expenditure of time and energy, but also forethought in the preparation and maintenance of domestic space. With respect to the issue of accidental or intentional burning of the bedding, our experiment indicated that it is unlikely that buried bedding was significantly carbonized by subsequent combustion activities.

These results also demonstrate the value of conducting experiments for calibration of micromorphological interpretations. Although many of the previous interpretations of the phytolith layers were supported by the result presented here, the experiments also provided some unexpected results: first, the large volume of dried plant material required to produce a layer of "burnt bedding" and, secondly, the lack of visible individual burning events. Through experiments and studies of individual microcontexts, geoarchaeological and archaeobotanical research can be combined to gain a more holistic picture of human activities in the past.

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CHAPTER EIGHT – MORE BURNING OF SEDGE BEDDING

An understanding of the taphonomic processes is vital for accurate interpretation of archaeobotanical remains (Pearsall 2000; Van der Veen 2007). The paper (Miller & Sievers 2012) in this chapter follows on the experiments described in Wadley et al. 2011, SOM) and in the previous chapter. I report on experimental fires (Fig. 8.1) to investigate the formation processes of the burned bedding identified at Sibudu. I pose various questions about the effect of the burning of bedding on the carbonisation of sedge nutlets and the factors which might affect the burning of bedding and the carbonisation of buried nutlets.

Figure 8.1 Burning of sedge bedding, experiment set-up and fire (Series 1 Bed 1).

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Thesis pages 138–162. Page numbers below refer to those in the submitted paper.

Introduction

Background

EXPERIMENTAL SEDGE BEDDING FIRES AND THE TAPHONOMIC IMPLICATIONS

INTRODUCTION

Sedges (Cyperaceae) are grass-like plants that generally grow in moist and wet situations. Most sedges have long straight, spongy culms (stems) which today are commonly used for making mats. The sedge fruits (nutlets) are single, indehiscent (do not split on ripening) and less than 3mm long. Sedge nutlets recovered from Middle Stone Age (MSA) occupations at Sibudu, KwaZulu-Natal (KZN), South Africa, are likely to have been introduced to the shelter on sedge culms harvested in the nearby uThongathi River. The sedge culms and leaves were placed on the shelter floor to provide a clean and comfortable surface ('bedding'). The nutlets have been preserved through carbonisation as a result of exposure to heat from fire, presumably to rid the site of fusty bedding. Carbonised nutlets and a culm of the sedge *Cladium mariscus* (L.) Pohl subsp. *jamaicense* (Crantz) Kük have been identified in the Sibudu deposits (Sievers & Muasya 2011; Wadley *et al.* 2011). Other sedges identified at Sibudu include mineralised nutlets of two *Scleria* species and a carbonised *Cyperus* sp. spikelet (part of the inflorescence). *Cladium* inflorescences produce prolific nutlets. The nutlets, up to 3 mm long, consist of a hard lignified mesocarp covered by an exocarp with large air-filled cells. When exposed to heat as from a fire, the exocarp becomes very fragile and in the Sibudu assemblage, remains very occasionally only as small adhering fragments. The Sibudu mesocarps, loosely referred to as carbonised, have become blackened and sufficiently transformed to prevent further chemical or biological decay, thus enhancing the likelihood of preservation in the deposits.

This paper reports the results of three series of open-air experiments in which a total of 18 individual sedge beds were burned to investigate questions about bedding and taphonomy at Sibudu. The sedge bundles burned in the experiments were intended to replicate bedding at Sibudu. In the experiments my first aim is to explore the taphonomy of carbonised sedge nutlets at Sibudu. Previous experiments with a variety of fruits, seeds and fuels (Sievers & Wadley 2008) suggest that sedge nutlets, placed in a wood fire and on the substrate surface directly below a wood fire, could not survive the flames, whereas buried sedge nutlets would be carbonised. In these experiments the survival rate of sedge nutlets below burnt sedge bedding is investigated. Secondly, I aim to investigate the role of different matrices, such as ash and coarse sediment, on the conduction of heat under a sedge bedding fire. Ash was chosen to cover the possibility that newly harvested bedding with nutlets attached was placed directly on the remains of previously burned bedding and the nutlets migrated down into the ash during use of the fresh bedding. The Sibudu 1 mm sievings discard, which includes stone and bone fragments and other material, such as tiny fragments of charcoal, was chosen as the most appropriate coarse sediment because it is the matrix in which the archaeological nutlets were recovered. The 1–2 mm dimensions of the particles of this matrix define it in geological terms as 'very coarse sand'. Thirdly, I aim to investigate the effect of the moisture content of sedges on temperatures under burning sedge bedding. Fourthly, I aim to investigate the variation in temperature across a sedge bedding fire because of the implications for the carbonisation of sedge nutlets and the burning of bedding. Temperature variation might explain, for example, the presence of both burnt and non-burnt laminated fibrous organic material identified in two Sibudu micromorphological samples (Goldberg *et al.* 2009).

The series of experiments were set up as follows: Series 1 aimed to test the effect of different matrices on the conduction of heat and carbonisation of sedge nutlets under burning sedge bedding. Series 2 aimed to test the effect of different moisture content of sedges on temperatures achieved while burning sedge bedding and Series 3 aimed to test temperature variation under individual burning sedge beds. The results of each of the experiments have taphonomic implications for the preservation of plant material.

BACKGROUND

Multidisciplinary research at Sibudu directed by Prof. Lyn Wadley of the University of the Witwatersrand between 1998 and 2011, has produced over 70 papers relating to the environment, technological accomplishments and adaptations of cognitively complex people inhabiting the shelter periodically between approximately 38 ka (1000 years) and 77 ka ago (see for example, Wadley & Whitelaw 2006; Wadley *et al.* 2011 and references therein). The clear, detailed stratigraphy and excellent preservation at Sibudu has allowed for fine resolution of distinct occupations and identification of mineralised sedge and other monocotyledonous bedding strewn with aromatic *Cryptocarya woodii* leaves at approximately 77 ka, and the repeated burning of bedding most likely for site maintenance in subsequent MSA layers (Goldberg *et al*. 2009; Wadley *et al*. 2011). In addition, carbonised seeds of many taxa have been recovered from the site (Sievers 2006; Wadley 2004) and vegetation communities have been identified through charcoal from fireplaces (Allott 2006). Various special purpose fires are present at Sibudu (Bentsen 2012), and heat from fire was used to alter ochre, most likely in buried situations where a constant temperature is easier to maintain and because ochre exposed directly to flames shatters (Wadley 2009). The burning of organic material for site maintenance is not restricted to plant material; bone too was repeatedly burned in the Howiesons Poort (65–62.5 ka) and post-Howiesons Poort (~59 ka) levels (Cain 2006; Jacobs *et al.* 2008a,b; Clark & Ligouis 2010). The informal lithic designation ‘post-Howiesons Poort’ is used here pending further study of the ‘Sibudu Technocomplex’, or ‘Sibudan’ which are possible alternative labels (Conard *et al.* 2012; Lombard *et al*. 2012).

Burning of bedding and carbonisation of sedge nutlets

Micromorphological analysis of slides made from resin-impregnated blocks of Sibudu deposit showed the presence of bedding repeatedly burned (Goldberg *et al*. 2009; Goldberg & Berna 2010; Wadley *et al*. 2011). Experimental micromorphological investigation of bedding construction, trampling and burning replicated the ancient signatures (Miller & Sievers 2012), confirming the presence of repeated and deliberate burning of bedding at Sibudu. The methods of the experiments reported here are appropriate for the specific aims set out and they differ in some respects from the previous methods, for example, here sedge nutlets were included and the bedding was not systematically trampled.

The micromorphological profile of burnt bedding has been likened to the profiles observed in burnt stabling (Miller & Sievers 2012) and an issue that requires further research is the effect of moisture content on the burning of bedding and stabling. Experiments concerning the phenological (moisture content) and physiological (healthy, dead or rotten) properties of wood (Théry-Parisot & Henry 2012) are relevant to this issue. In open combustion fires in laboratory conditions, the maximum temperatures reached by burning two samples each of green and seasoned (dry) wood were not notably different. One sample of green wood reached the highest temperature recorded and both green wood samples retained more heat for over an hour longer than the drier fuel (Théry-Parisot & Henry 2012: fig. 4). The implications are that once green fuel has been ignited and if the fire receives maintenance, it burns at least as well as seasoned wood and can have equal or greater impact on buried material.

The burning of fresh dry sedge leaves and culms produces soft ash, phytoliths and carbonised material (Miller & Sievers 2012). Sometimes the material resembles its pre-carbonised shape, but is delicate and mostly disintegrates on touch. No in-depth identification analyses of carbonised culms have been undertaken on archaeologically recovered material and the single *Cladium* culm that has been identified (Wadley *et al*. 2011) could be one of many in the deposit. Its presence indicates that the nutlets were introduced on culms. It is likely the nutlets were introduced unintentionally to the shelter. Harvesting of *Cladium* leaves by cutting near the base of the plant would automatically include any inflorescences further up the plant, if harvesting were during summer; by late autumn all nutlets have dropped from the mother-plants. Nutlets drying on harvested plants, laid out flat as for bedding, fall through the leaves to the surface below. When these fall onto a soft ash surface, they sink into the ash, particularly when sedges are placed upon them and trampled, even briefly. This pattern has been observed also with the preservation of goat dropping in dung ash where after recent burning of the dung, the goat droppings are trampled down into the porous ash and so are more likely to preserve their form (Brochier *et al*. 1997: 73).

METHODS

The methods were similar in all three series of experiments and every experiment involved the burning of sedge bedding. The beds were labelled consecutively, thus Beds1–3 are in Series 1, Beds 4–7 in Series 2 (Table 1) and Beds 8–13 in Series 3 (Table 2), but in Series 2, where two beds alongside each other burned at the same time, the beds are distinguished by lower case letters , for example, Bed 4a and 4b. Differences between experiments, such as type and mass of sedge, size of fire (lateral area covered by the bedding), ambient temperature, humidity, wind speed and wind direction are listed in Tables 1 and 2. Fire temperatures were recorded with two Major-Tech Digital Thermometers (MT 632) and two EXTECH HD 200 Differential Thermometer Data Loggers and eight K-type thermocouples with probes. Seven probes were 50 cm long and one probe was 70 cm long. The length of the probe does not affect the temperature reading. The ends of the probes were placed alongside the sedge nutlets in the experiments that included nutlets. An EXTECH Mini Hygro Thermo-Anemometer, or a Silva ADC Pro, measured temperature, wind speed, relative humidity and barometric pressure. A MC 7825S Moisture Meter set at code 3 was used for sedge moisture measurements and a Delta-T HH2 Soil Moisture Meter with ML2X thetaprobes was available for soil moisture measurements for the Series 1 and 2 experiments (Series 3 preceded Series1 and 2 chronologically).

The recording of accurate soil moisture measurements is complicated by factors such as the type of matrix, air bubbles and inclusions of different materials. Because of the effect of the presence of metals, namely the thermaprobes at 2 cm and 5 cm depths, the soil moisture readings were not read for the Series 1 and 2 experiments. The soil moisture meter probes would also have disturbed the placement of buried nutlets (the nutlets on the surface were placed directly above those buried below the surface). For all three Series 1 experiments the nutlets, or ash of the nutlets, could be removed without displacing the thermaprobes and the thermaprobes were left *in situ* to ensure standardization.

Experiments were carried out at various times of the year, in coastal suburban gardens in Durban North and at Ballito, approximately 45 km north of Durban North. The substrate in Durban North is Berea Red, a clayey decomposed ancient dune, and at Ballito the substrate is sand, varying from pale to dark grey. The darker hue incorporates some fine, claylike particles and in midsummer, the surface temperature on this dark substrate can reach up to 50°C.

Series 1: To test the effect of different matrices on the conduction of heat and carbonisation of sedge nutlets

In each of the three experimental bedding fires in this series, one bed of sedges was positioned to cover two different matrices in which *Cladium mariscus* nutlets were buried at different depths. The experiment was designed, as much as possible, to limit the variables to the different matrices. Dry bundles of *Cladium mariscus* leaves and culms were selected to replicate the bedding. The bedding was laid down in a north/south orientation over one column each of i) 'very coarse sand', the discard after the sorting of the 1 mm sievings of Sibudu excavations, ii) ash from previous experimental fires (Fig. 1a). Each column had a 10 cm diameter and extended to 10 cm below ground surface. The columns were positioned 10 cm apart in a north/south direction so that they would be equally covered by the bedding. Thirty *Cladium* nutlets respectively were placed in the centre of each matrix on the ground surface under the bedding and at 2 cm and 5 cm below the ground surface.

TABLE 1. Date and ambient conditions for Series 1 and 2 experiments. Mass of bedding and bed dimensions are recorded for *Cladium mariscus* beds. Mass, number of culms and month of harvesting are recorded for *Cyperus involucratus.* Culms harvested in March were dry and culms harvested August and October were 'green'. The number of culms refers to the number of culms laid side by side perpendicular to a carpenter's rule, to cover a distance of 1m. ()=harvest time in 2012; % RH= relative humidity percentage; °C=ambient temperature in degrees Celsius; m/s (metres/second)=wind speed.

Series 1	Date (2012)	Ambient conditions	*Cladium mariscus*
Bed 1	3 Nov	Gusts 0.8m/s, 61% RH, 22°C	5kg 150x70x35cm
Bed 2	4 Nov	No wind, 80% RH, 22°C	5kg 150x60x35cm
Bed 3	5 Nov	Overcast, no wind, humid, 22°C	5kg 150x55x40cm
Series 2			*Cyperus involucratus*
Bed 4a 4b	10 Nov	Light gusts not registering on anemometer, 55% RH, 26°C	550g 200 culms (March) 580g 200 culms (March)
Bed 5a 5b	12 Nov	Gusty 0.07-1.3 m/s SE to SW, 80% RH, 23°C	440g 165 culms (March) 410g 177 culms (March)
Bed 6a 6b	15 Nov	Light gusts not registering on anemometer, 94% RH, 23°C	435g 162 culms (March) 415g 183 culms (March)
Bed 7a 7b	16 Nov	Gusts not registering on anemometer, 76% RH, 27°C	515g 192 culms (Aug) 680g 188 culms (Oct)

TABLE 2. Bedding material, bed size (lateral area), air temperature, wind speed and direction, maximum temperature reached, time taken to reach maximum temperature and duration of specific temperatures in Series 3 experiments to test variation of temperatures under a single burning sedge bed. Bed/fire numbers follow consecutively on those of the previous Series. Burning of Beds 8, 9, 10 (September 2011) and 14 (June 2012) was in Durban, and Beds 11, 12 and 13 (February 2012) in Ballito. Beds 8, 11 and 12 contained dry *Cyperus involucratus* culms and bracts; Bed 13 was 'green' *C. involucratus.* Dry *Cladium mariscus* was used in Bed 9 (leaves and culms) and Bed 10 (leaf bases and rhizomes). Abbreviations: **Bold**=temperature measured by a probe positioned **upwind**; V=variable wind direction; [1]humidity 82.3%, pressure 1004 hPa; [2] humidity 81.3%, pressure 1005.4 hPa; [3] humidity 82.3%, pressure 1004.2 hPa.

Bed	Bedding	Area (cm)	Air temp. (°C)	Wind (m/s)	Probe #	Max. fire temp. (°C) and specific time	Duration of fire temperatures					
							>100°C	>200 °C	>300 °C	>400 °C	>500 °C	>600 °C
8	*Cyperus*	250 x 60	20.4	6m/s NE	1	552 at 6 min		6½ min	4 min	-	-	-
					2	**377** at 5½ min		7 min	4½ min	-	-	-
9	*Cladium*	250 x 60	21.3	8,6m/s NE	1	531 at 5 min		19½ min	9½ min	5 min	1½ min	-
					2	**540** at 5½ min		8½ min	6 min	4 min	2½ min	-
10	*Cladium*	50 x 50	24.5	6,5m/s NE	1	606 at 10 min		54 min	28 min	15 min	8½ min	1 min
					2	**654** at 11 min		68 min	29 min	19 min	12½ min	4 min
11	*Cyperus*	180 x 80	36[1]	<1m/s SW	**1**	**336** at 2 min	6½ min	3½ min	1 min	-	-	-
					2	**271** at 3 min	9 min	2½ min	-	-	-	-
					3	453 at 7 min	17 min	8 min	4½ min	3½ min	-	-
					4	333 at 4 min	14 min	5½ min	1 min	-	-	-
12	*Cyperus*	210 x 60	27[2]	No wind	1	369 at 4 min	9 min	3½ min	1 min	-	-	-
					2	428 at 4½ min	19 min	7½ min	3½ min	1 min	-	-
					3	682 at 4½ min	18 min	8½ min	4½ min	3½ min	2½ min	1½ min
					4	311 at 4 min	8½ min	3½ min	½ min	-	-	-
					5	359 at 5 min	11½ min	4½ min	2 min	-	-	-
					6	340 at 8 min	17½ min	7 min	2½ min	-	-	-
					7	560 at 6 min	15 min	6½ min	4½ min	2 min	1 min	-
					8	309 at 6 min	11 min	3½ min	½ min	-	-	-
13	*Cyperus*	210 x 70	28[3]	No wind	1	487 at 6 min	21 min	7½ min	4½ min	2 min	-	-
					2	601 at 11 min	30 min	5½ min	6½ min	5 min	3 min	<½ min
					3	575 at 12 min	22 min	9½ min	5½ min	4 min	2½ min	-
					4	398 at 11 min	15½min	6 min	3½ min	-	-	-
					5	515 at 5½ min	20 min	9 min	5 min	3 min	1 min	-
					6	178 at 5½ min	20½ min	-	-	-	-	-
14	*Cyperus*	100 x 60	24	<0.6m/s V	1	426 at 8 min	42 min	17 min	7 min	3½ min	-	-
					2	453 at 13 min	41 min	22½ min	13 min	8 min	-	-
					3	522 at 10 min	34 min	21 min	13 min	6½ min	2 min	-
					4	519 at 11 min	40½ min	19 min	12 min	6 min	1 min	-

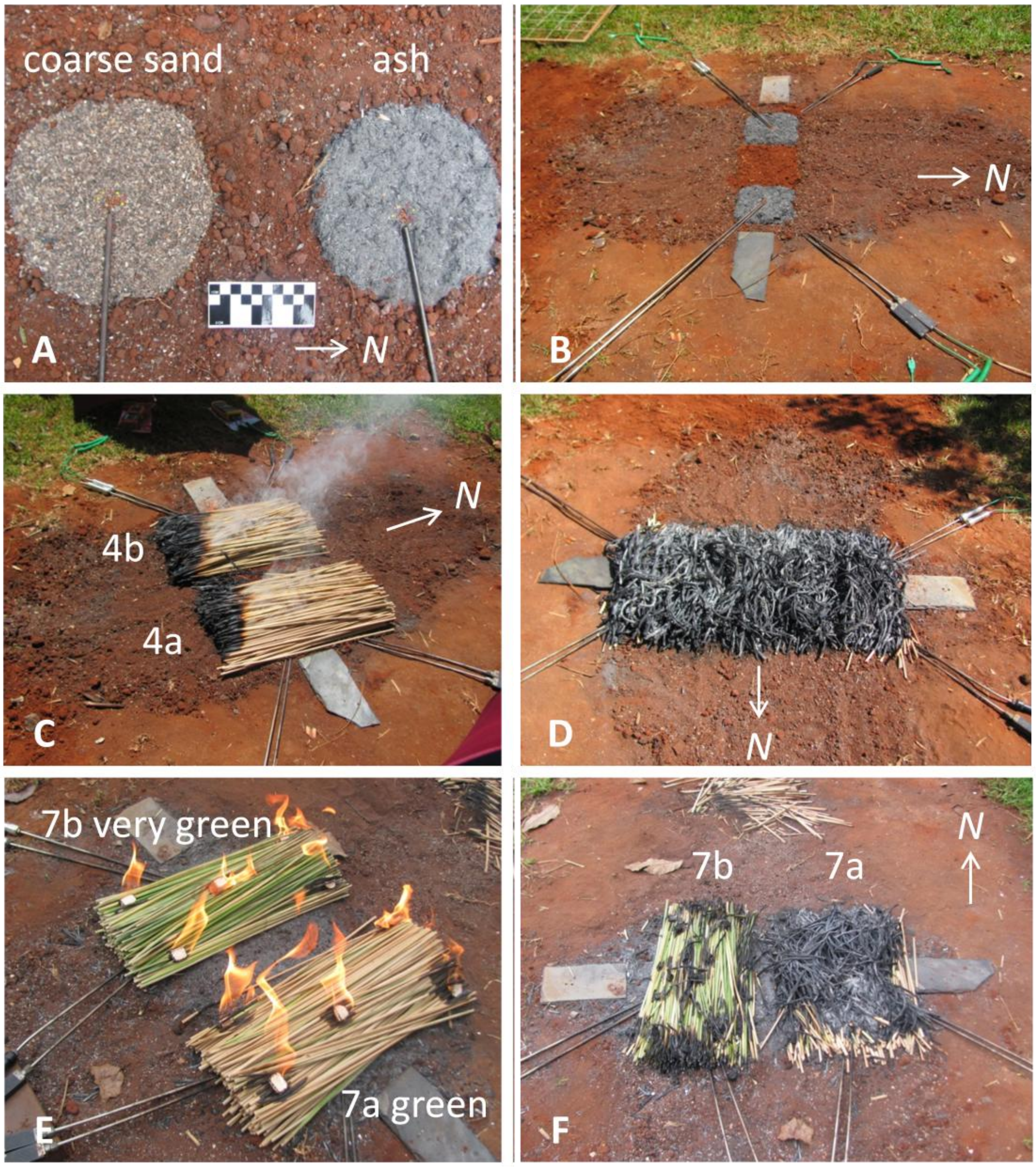

FIG.1. Series 1 (A) and Series 2 (B–F) experiments. (**A**) Bed 1: The nutlets and beads were placed in the centre of a column, 10 cm radius and 5 cm depth, of ash (right) and very coarse sand (left). The points of thermaprobes were placed next to the nutlets. Scale: 100 mm; (**B)** Series 2 set-up: Two probes each connected to thermocouples at 2 cm depth and on the surface of ash-filled areas 20 cm x 20 cm (20 cm apart) and 5 cm deep; (**C**) Beds 4a,b smouldering, rather than burning brightly. Scale: In all the Series 2 beds the fresh culms are 50 cm long; (**D**) Ashes of Beds 4a and 4b have merged; (**E**) Bed 7b did not burn (**F**). The ashes of Bed 7a have spread across to Bed 7b.

The nutlets had been undercover since they were harvested during the previous fruiting season, seven months before the experiment. Glass beads were placed at compass points around the nutlets to demarcate their location for excavation. During the burning of the bedding, temperatures were recorded at the location of every cache of 30 nutlets. A single K-type thermaprobe connected to the Major MT 632 Digital Thermometer was positioned adjacent to the nutlets on the ground surface and at 5 cm depth, and two K-type thermaprobes connected to EXTECH HD 200 Temperature Data Loggers, were placed with recording points 1 cm apart, at 2 cm depth alongside the nutlets.

The ash substrate for Bed 1 was prepared on 31/10/2012 and when the bed was laid down three days later, a crust on the ash had formed. The prepared area had been covered by a large tray and sheet of plastic, which protected it from the heavy rain of the intervening period. The preparation for the second experiment in the Series and the burning of Bed 2 was completed on one day. The same applied for Bed 3.

Series 2: To test the effect of different moisture content of sedges on temperatures achieved while burning bedding

Each experiment in this series involved two beds positioned next to each other on an ash substrate. Temperatures were recorded the under each of the eight sedge beds, which were made up of *Cyperus involucratus* culms that had been harvested at different times during 2012. The sedges in Beds 4, 5 and 6 were dry, whereas the sedges in Beds 7a and 7b were ‘green’, particularly in Bed 7b, which contained the most recently harvested sedges. Apart from the different moisture content of the bedding, all other variables were held constant as far as is possible for fires lit in the open.

The basic premise in this series of experiments was, first, that dry and green sedges burn at different temperatures. Secondly, that it should be possible to measure the different moisture contents of sedges by using mass as a proxy. Mass should be an appropriate proxy if sedges are of the same taxon harvested from the same source, but at different times, and thus dried for longer or shorter periods. Green culms of *Cyperus involucratus* growing in a suburban garden in Durban

North, were harvested in March (autumn), August (the end of winter), and October (mid-Spring) and the expectation was that the March culms that had been drying undercover for the longest period, would be the driest and have the lowest mass. Culms of 50 cm length were prepared and the mass of 200 culms from each harvest was noted. Surprisingly, the August sample (500g) weighed less than the March samples (Bed 4a, 580g and Bed 4b, 550g), which had been drying longer. Although Durban experiences summer rainfall, the mild winters allow year-round growth of the sedge and because all the culms were green when harvested, I assumed that the method of making up equivalent samples was incorrect rather than that the August culms were drier than the March culms. A different sample preparation was suggested: I placed the 50 cm long culms closely adjacent to each other so that the diameters of the culms covered a distance of 1 m along a metre rule. I then weighed the samples and recorded the number of culms in each sample (Table 1, Series 2). This method showed a general trend of increasing mass from the driest sedges, harvested in March (Beds 5–6), to the 'greener' sedges harvested in August (Bed 7a) and the 'greenest' sedges harvested in October (Bed 7b), containing the most moisture. Four 'March' samples were prepared using this method and the difference in mass between the bundles (Beds 5a,b and 6a,b) varied from 5g to 30 g; the average mass was 425g (Table 1). Factors to consider here are variations in culm diameter, culm density and different moisture contents within the March harvest sample. Using a moisture meter, MC 7825S set at code 3, different moisture readings across a single culm were recorded and showed variation. It appears that determining precisely the moisture content of sedge culms is not possible under actualistic conditions. However, a general trend of increasing mass corresponding to increasing moisture in the more recently harvested samples was observed (Table 1, Beds 4a–7b).

As for the four Series 1 experiments (Beds 1–4), sets of 30 *Cladium mariscus* nutlets with outer covering intact were placed centrally on the ground surface under the bedding and were buried 2 cm below the surface under each bed. The nutlets were buried in ash-filled rectangular areas 20 cm x 20 cm and 5 cm deep (Fig. 1b) constructed 20 cm apart in an east/west orientation so that neither situation would be upwind or downwind in the prevailing north/south wind direction. Temperatures were recorded for each set of nutlets: two thermaprobes were placed immediately alongside each other on the surface under the bedding and connected to the thermometer data loggers, and two thermaprobes connected to the digital thermometers were placed at 2 cm depth. The preparation of the first experiment in this series (Beds 4a,b) was interrupted by rain. The ash substrate for Beds 4a and 4b (Fig. 1b) was covered by a tray and tent for protection and when the bedding was laid down three days later a crust had formed on the surface of the ash.

In each of the four experiments, the two adjacent beds, for example, Beds 4a and 4b (Fig. 1c), were ignited simultaneously so that the ambient conditions would be constant for both fires. Beds 4a and 4b were ignited at a single point and smouldered slowly until both beds were almost fully combusted (Fig. 1d). Small pieces of fire starter were placed at five points on the other beds in the series because they did not ‘take’ sufficiently from one point even to smoulder.

The maximum temperature under Bed 6b was not recorded because I did not realise that the data logger was not recording (flat battery). No temperatures were measured for Bed 7b because even slightly larger pieces of fire-starter positioned in five places across the bundle of sedge culms could not ignite this closely packed ‘very green’ bedding (Figs 1e and 1f).

Series 3: To test temperature variation under individual burning sedge beds

The sedges *Cyperus involucratus* and *Cladium mariscus* were used in this series of experiments involving 7 sedge bedding fires (Beds 8–14). A bed of *Cyperus* culms with bracts attached were placed in a bed approximately 2,5 m long and 60 cm wide (Table 2 Bed 8; Fig. 2a), positioned in line with the wind direction (NE at approximately 6 m/s). Two probes were positioned towards the centre of the bed and approximately 70 cm from each end, with Probe 1 on the downwind side 1 m from Probe 2.

A second bed (Table 2 Bed 9; Fig. 2b) of approximately the same dimensions, but of the leaves and culms of the sedge *Cladium*, was made on the same day, on the same site and following the same procedures as described above. In a third experiment (Table 2 Bed 10), also using *Cladium*, but with rhizomes and leaf bases exclusively, and covering 50 x 50 cm, the probes ends were placed only 2 cm apart. A fourth experiment (Table 2 Bed 12; Fig. 2c) involved four probes and a

Cyperus bed. Three more beds to test temperature variation across a bedding fire were constructed using *Cyperus* and four to eight probes in each fire (see details for all Series 3 experiments in Table 2 and Figs 2a–f).

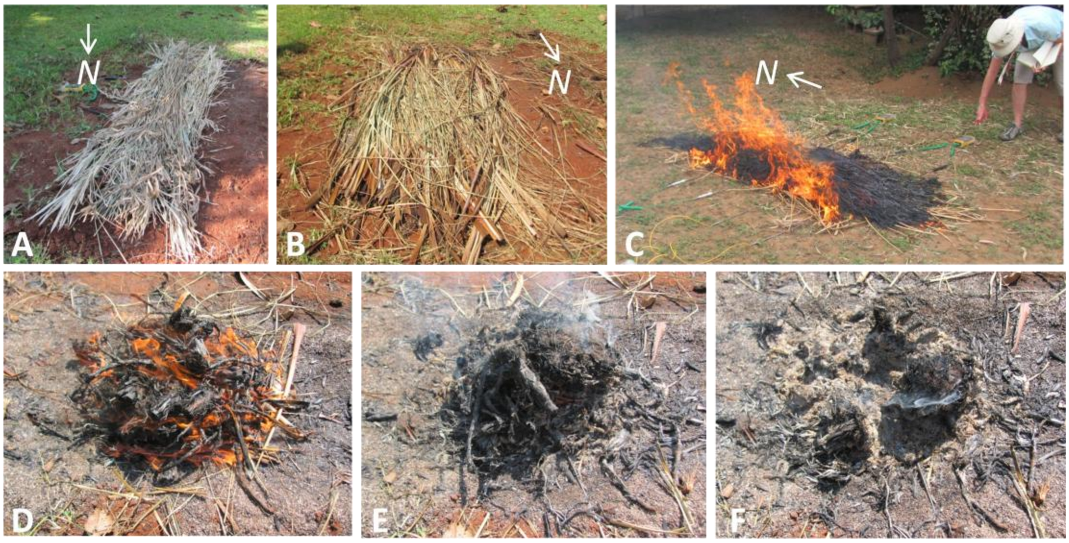

FIG. 2. Series 3 experiments. (A) Bed 8, *Cyperus involucratus* leaves and bracts (250 x 60 cm); (B) Bed 9, *Cladium mariscus* leaves and culms (250 x 60 cm); (C) Bed 12, *Cyperus involucratus* (210 x 60 cm) with eight probes; (D) Bed 10, *Cladium mariscus* leaf bases and rhizomes (50 x 50 cm), 2 minutes after ignition; (E) Bed 10, 5 minutes after ignition, last whisps of smoke visible at top right; (F) Bed 10, ashes and carbonised remains 13 minutes after ignition. Maximum temperature recorded, 654°C, was reached at 11 minutes.

RESULTS

Series 1: To test the effect of different matrices on the conduction of heat

Eight temperature readings were recorded under each of the three burning sedge beds in this experiment (Table 3). The maximum temperatures on the ash substrate directly below the burning bedding were above 600°C (average 659°C) for all three beds, whereas the maximum temperature was 526°C (average 486°C) on the coarse sand substrate. The maximum temperatures reached at a depth of 2 cm in the ash were between 171°C and 461°C, whereas in the sand they all were between 90°C and 99 °C (Table 3). Ash conducts heat better than coarse sand and the effects are also apparent on the nutlets. All 90 nutlets buried at 2 cm in the sand remained uncharred after the three fires, whereas all 90 nutlets recovered from 2 cm depth in the ash were charred. A low proportion of sedge nutlets survived on the surface directly under the bedding fires. Six nutlets of the original 90 nutlets (30 in each fire) survived on the ash, and 17 out of 90 survived on the sand. The recovered nutlets were fragile and many that I picked out from the deposit with tweezers, disintegrated during dry sieving. The frequencies quoted above are after sieving.

TABLE 3. Maximum temperatures reached in specific times in the three Series 1 experiments to test the effect of ash and coarse sand matrices on temperatures recorded under burning sedge bedding. In both matrices two probes to record temperatures were placed at 2 cm depth, one probe was placed on the ground surface below the bedding and one probe at 5 cm depth. Each bed contained 5 kg of *Cladium mariscus* (see Table 1 for details). [#] This probe was accidentally dislodged at the start of the fire.

Series 1

		Bed 1	Bed 2	Bed 3
Surface				
	Ash	667°C in 4 min	698°C in 21 min	612°C in 16 min
	Sand	496°C in 8½ min	526°C in 11 min	436°C in 9 min
2 cm depth				
	Ash	189½°C in 18 min	461°C in 28 min	366°C in 23 min
	Ash	171½°C in 19½ min	425°C in 29 min	274°C in 25 min
	Sand	90°C in 24½ min	92°C in 22½ min	92°C in 19 min
	Sand	[#]286°C in 14 min	99°C in 22 min	90°C in 19 min
5 cm depth				
	Ash	57°C in 21 min	105°C in 61 min	46°C in 25 min
	Sand	41°C in 110 min	40°C in 105 min	36 in 55 min

These experiments also provided an unexpected result. There was a decrease in temperature under the surface of the bedding after ignition. The greatest decrease in temperature was 8°C, which was recorded at 5 cm beneath the ash. At 2 cm below the ground surface the maximum decrease was 4.5°C, in the sand. Whereas the decrease at 5 cm depth was greater in the ash matrix, at 2 cm depth the decrease was consistently higher for the sand matrix. The minimum temperature was maintained for less than a minute in every instance.

Series 2: To test the effect of different moisture content of sedges on temperatures while burning bedding

The maximum temperatures recorded on the substrate below the dry sedge beds (Beds 4a–6a) varied from 182°C in Bed 4a to 436°C in Bed 4b (Table 4). It was not possible to ignite or burn green Bed 7b, but temperature on the ground surface beneath the 'less green' Bed 7a reached a maximum of 516°C, which was 80°C more than the maximum temperature under a dry sedge bed (Bed 4b) (Table 4). This result and the different maximum temperatures achieved under the various dry beds from the same harvest were unexpected, particularly the difference of 254°C between dry Beds 4a and 4b. Variables were kept to a minimum and Beds 4a and 4b both consisted of two hundred 50 cm long culms from the same harvest, were prepared in the same way, experienced the same ambient conditions, smouldered rather than burned, reached maximum temperatures only five minutes apart (24 minutes vs. 18 minutes) and had most of the bedding reduced to ashes (Fig. 1c and d). Sedges from the same harvest were used for all the dry bed fires (Beds 4–6), but the sample preparation for Beds 4a and 4b, was different from the sample preparation used for the other dry beds (Beds 5–6), but the variation between the temperatures achieved for Beds 4a and 4b, was less that the variation between these beds and the other dry beds. The maximum temperatures reached in Beds 5a and 5b under the same ambient conditions varied by 91°C.

Temperatures reached on the ground surface under both dry and green burning bedding were sufficient to carbonise the sedge nutlets and to reduce most of them to indistinguishable ages. Recovery of nutlets was low under all the fires (an average of just under 4 of the 30 original nutlets at each location survived after excavation and dry sieving), all nutlets were carbonised and no obvious pattern distinguished the effects of burning dry or green bedding.

Two incidental observations were made during the experiments. First, the ashes of Beds 4a and 4b had merged by the end of the fire (Fig. 1d), covering the 15 cm gap that had existed between the beds before combustion. The spreading of carbonised material during the combustion of bedding was evident during the burning of other beds too, for example, Bed 7a (Fig. 1f). Secondly, cementation of the ash substrate was evident in a fine crust under Bed 4a, (but less so under Bed 4b) and approximately 2 cm sections of the surface up to 5 mm thick could be removed as a unit. The maximum temperature reached in Bed 4a was approximately 240 °C less than in Bed 4b (Table 3), but the role of temperature in the cementation process is not clear. The ash surface under the burned bedding of Beds 5a and 5b also formed a crust. Moisture might be implicated in the formation of a crust: the excavation of Bed 7a, delayed by nightfall and one day of rain, revealed that the ash from the burnt bedding was damp in spite of the protection provided by a tent. It appeared that the ashes had absorbed humidity from the surrounding air.

TABLE 4. Maximum temperatures reached in specific times on the ground surface under ± 0.5 kg *Cyperus* culms (see Table 1 for details) in the Series 2 Bedding Fires to test the effect of different moisture content of sedges on temperatures achieved while burning bedding. The points of Probes 1 and 2, which provided the temperatures in the table, were placed alongside each other on the surface under the bedding. Both beds in Bedding Fires 4, 5 and 6 (numbered consecutively after those in Series 1) were made of dry sedges and Beds 7a and 7b contained 'green' sedges. Bed 7b d did not burn under the protocols applied to the other bedding fires.

Series 2

	Bed 4a	**Bed 5a**	**Bed 6a**	**Bed 7a**
Probe 1	192°C in 24 min	325°C in 3 min	397°C in 2 min	513°C in 18 min
Probe 2	182°C in 24 min	329°C in 3 min	362°C in 2½ min	516°C in 18 min
	Bed 4b	**Bed 5b**	**Bed 6b**	**Bed 7b**
Probe 1	436°C in 19 min	393°C in 25 min	recording problem	no ignition
Probe 2	433°C in 19 min	416°C in 25 min	recording problem	no ignition

Series 3: To test temperature variation beneath a single burning sedge bed

Different maximum temperatures were recorded at all points on the ground surface under the bedding in all the Series 3 experiments (Table 2 Beds 8–14). There was a difference of 273°C between the lowest and highest maximum temperatures recorded at eight points on the ground surface under Bed 12 (Fig. 2c). Probes placed only 2 cm apart recorded different temperatures in Bed 10. This consisted of *Cladium* rhizomes and leaf bases and Figures 2d, 2e and 2f illustrate that the distribution is not uniform across the fire, which is a possible explanation for the temperature variation.

During the burning of Beds 8, 9 and 10 there was wind between 6–8.6 m/s in a north-east direction. For Bed 9 the upwind temperature recorded was higher, by a hardly notable 9 °C, whereas in Bed 8 the upwind temperature was lower (Table 2). During the burning of Bed 11 with very slight south-west air movement, the upwind temperature was also lower. There was no wind during the burning of Beds 12 and 13 and the difference between the lowest temperature and highest temperature recorded on the surface under the beds was 273°C for Bed 12 and 423°C for Bed 13. These differences, in the absence of wind, exceeded the largest upwind/downwind variation of 182°C (for Bed 4). For Bed 14, under conditions of variable wind direction, the highest and lowest temperatures on the surface under the burning bedding varied by 96°C. Beds 12 and 13 had eight and six readings respectively, widely spaced under the bedding, whereas Beds 8–11 and 14 had two to four readings.

DISCUSSION

Effect of different matrices on the conduction of heat and carbonisation of sedge nutlets

The effects of different matrices on the temperatures and the conduction of heat during the burning of bedding are discussed together with the taphonomy of sedge nutlets because of the close correlation between temperatures and the post-burning condition of the nutlets. Different matrices conduct heat disparately, thereby affecting the preservation of the nutlets differently: a lower proportion of sedge nutlets (7%) survived on an ash matrix surface under the bedding fires than on a coarse sand surface (19%) (Fig. 3). This result is unsurprising considering that all the temperatures on the ash matrix were over 600°C (average 659°C) whereas on sand the maximum temperature under any of the three bedding fires was 526°C (average 486°C). In both circumstances nutlets recovered from the surface were consistently fragile and many disintegrated during dry sieving; their long-term survival possibilities are uncertain. This result supports the observation from previous fire experiments (Sievers & Wadley 2008) that seeds become ashed on the surface under a fire.

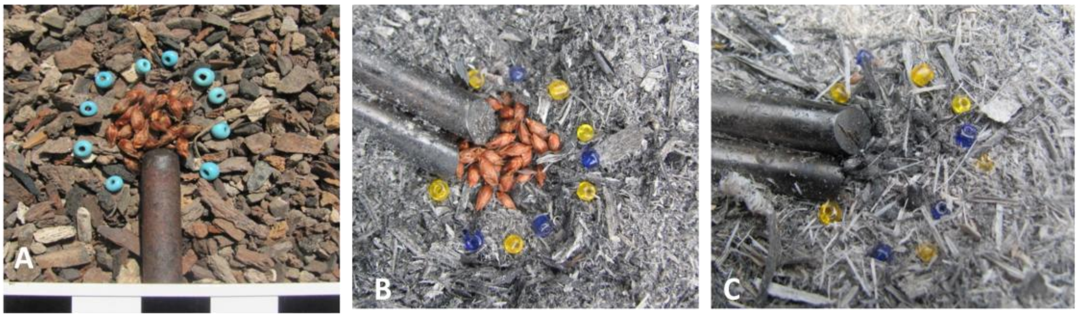

FIG. 3. (**A**) *Cladium mariscus* nutlets surrounded by beads on the very coarse sand matrix of Bed 1, before firing. Scale in cm.; Bed 5a nutlets on the surface before (**B**) and after (**C**) the burning of the bedding. Five of the original 30 nutlets survived the burning, excavation and sieving. The diameter of each thermaprobe is 5 mm.

The effect of the matrix on conduction of heat and consequently on nutlet preservation is more obvious on buried material. Ash conducted heat sufficiently well to char nutlets buried at 2 cm below the surface, whereas it was difficult to tell whether nutlets buried at 2 cm below coarse sand had been altered at all.

Apart from being a more efficient conductor of heat than a coarser matrix, it is possible that ash had an additional effect on the nutlets at Sibudu and protected uncarbonised nutlets against insect infestation until such time as they were exposed to heat and were carbonised. The Valley Trust Social Plant Use Project in Botha's Hill, KZN, uses a mixture of ash and chilli powder to prevent insect infestation of stored agricultural seeds (pers. obs.) and ash is used as an insecticide against many types of insects in the upper north-west Himalayas of India (Verma 1998). The ash abrades the epicuticular waxes and leads to desiccation of the insects. It acts as a deterrent to foliage feeders and also interferes with the chemical signals of the plants, obscuring their location.

Effect of different moisture content of sedges on the burning of bedding

Everyday experience, at least for many Third World people, indicates that moister fuel is more difficult to ignite. The October harvest experiment (Series 2 Bed 7b) suggests that this observation also applies to moist sedges. Even when additional fire-starter was added at each corner and in the centre of the bedding, the culms did not burn independently (Figs 1e and 1f). An observation in the other bedding fires was that the sedge culms twisted and curled while they burned, facilitating airflow, and allowing expansion of the sedge beds so that the ashes of two beds, placed 15 cm apart at the start of the experiment, merged by the end of the experiment (Fig. 1d). For standardization in the subsequent experiments (Beds 5–7) extra fire-starter was added and once the fire got going, the displacement of culms as they burned encouraged further combustion, except for Bed 7b which was particularly moist and did not catch fire using this protocol. It appears that once sedge bedding is burning well, the fire is likely to be sustained and temperatures will be sufficient to carbonise sedge nutlets under the bedding irrespective of the original moisture content of the bedding. A consideration affecting the maximum temperatures achieved, as well as the preservation of the nutlets, is the amount of oxygen available. This is influenced by the compaction of the sedge bedding and the wind presence and strength. Wind is known to fuel fire and increase temperatures: this is the reason that bellows are used.

Variation in temperature across the surface under burning bedding

Common sense suggests that there will be variation in temperature across a fire and the Series 3 experiments confirmed this. The results of the experiments were inconclusive with respect to wind direction as a factor for higher temperatures in certain areas of the bedding fires. Probes placed only 2 cm apart under *Cladium* rhizomes and leaf bases (Series 3, Bed 10) recorded different temperatures. Figures 2d–f illustrate that the placement of the *Cladium* was not uniform, which is the likely explanation for the temperature variation. An even distribution of bedding is difficult to achieve, even with ‘uniform’ material such as sedge culms and leaves. An uneven distribution of sedges is also likely to have been present when bedding was burned in the past and temperature variation across space is likely to have resulted.

The general pattern of fire temperatures is of rapid heating to maximum temperature, which is maintained for a short time, followed by a gradual decrease in temperature (Table 2; Sievers & Wadley 2008; Bentsen 2012; Gur-Arieh *et al.* 2012). Maintenance of maximum temperature for a few minutes is observed not only in sedge fires, but also in wood fires where temperatures may soar as high as 1000 °C. Even without added wood fuel, temperatures of 400–500 °C may be maintained for several hours during the cooling process (Bentsen 2012; Gur-Arieh *et* *al*. 2012). Wood forms coals whereas sedge culms and leaves do not; they simply ash. Burning *Cladium* rhizomes and leaf bases (Table 2 Bed 10) mimic wood fires more closely and achieve higher and more sustained temperatures than burning bedding consisting exclusively of leaves and culms.

The presence of flames can be very brief: flames lasted for 3 to 3½ minutes in the burning *Cladium* bedding (Series 3 Bed 9) and flames were observed up to 7 minutes after the *Cladium* rhizomes and leaf bases were ignited (Series 3 Bed 10). Flames are the visible evidence of the ignition of volatiles which are released when plant material is heated. In the presence of oxygen and a pilot heat source the ignition of these volatiles takes place at about 350°C (Braadbaart & Poole 2008). The life of flames is consistently brief in the burning sedge bedding, but as may be expected, flames that 'die down' may flare up again when a gust of wind provides added oxygen. Smoke production also is of short duration and whisps of smoke were not visible after 20 minutes. The trend noted in other experimental work (Sievers & Wadley 2008; Bentsen 2012) that underground temperatures increase after the flames have died down is found in burning sedge beds, too, and maximum below ground temperatures are reached after those above ground have started decreasing (Table 3).

Heuristic value of the experiments

Some observations do not have direct bearing on the aims or results of the experiments reported on here, but may have other taphonomic implications and warrant further investigation, for example, the initial decrease in temperature on the ground surface under a sedge bedding fire after it is ignited. The decrease varies between less than 1°C to up to 8°C, which was recorded at 5 cm depth in the ash matrix of the fires testing for the conduction of heat in different matrices. At 2 cm depth the decrease was consistently higher for the sand matrix. The results need supplementation from a larger sample size.

An incidental observation, during both the Series 1 and Series 2 experiments here described, was that ash absorbs moisture from the atmosphere and forms a crust, the beginning of cementation. The implications for the preservation of bedding at Sibudu are that high humidity acts to preserve burnt bedding by cementing the ashes and preventing their dispersal by strong wind. Cementation of ashes was first reported by Wadley (2010) and the processes warrant further investigation. In Series 2, cementation was evident in a fine crust under Bed 4a and less so under Bed 4b and under Beds 5a and 5b. Rather than fire temperature, causality may be primarily linked to moisture and a tendency by ash to absorb moisture from its surroundings. A crust formed on the ash matrix for Series 1 Bed 1 in the three days between the preparation of the substrate and the placement and burning of the bedding, although the experiment area had been protected from the intermittent rain of the intervening period. The excavation of Series 2 Bed 7a was delayed for one day and although the excavation area had been thoroughly protected from heavy rain, the air moisture penetrated and the ash of the bedding become damp.

Another observation was that the bedding was seldom all combusted, particularly towards the outer edges of the beds. This could explain the small pieces of unburnt bedding observed at Sibudu (Goldberg *et al*. 2009). In the Series 2 experiments the sedge culms were closely packed (e.g., Figs 1c and e), but generally when they started burning they buckled, allowing previously covered culms access to oxygen and more successful combustion. It is difficult to gauge the condition of the Sibudu bedding when it was set alight, but the experiments described here suggest that considerable effort would be necessary to fully combust bedding if it were tightly packed. Also, the lateral movement during the combusting of tightly packed bedding here described, indicates that ashes from bedding fires could cover a larger area than the original extent of the bedding.

The interplay of variables in the burning of sedge bedding and the dispersal of ashes reflects the multiplicity of factors and countless combinations that produce the archaeological record. In terms of carbonisation of material, the rate of heating, the maximum temperature reached and the length of exposure to heat are important factors (Wright 2003; Braadbaart & Poole 2008; D’Andrea 2008) and these parameters, external to the affected plant material itself, are dependent on the type of fuel, fuel load, fuel moisture content and environmental conditions. Of the many possible variables, these experiments have clearly demonstrated the effect on temperature exerted by the matrix on which fuel is placed and in which plant material may be buried.

CONCLUSIONS

Particle size of the matrix forming the substrate on which a sedge bedding fire is lit affects the surface temperature and the conduction of heat below the surface. In turn this has an effect on buried organic matter. A low percentage of carbonised sedge nutlets survives on the substrate immediately below burnt sedge bedding. The recovery rate is further reduced during handling such as dry sieving. The ability of these fragile carbonised nutlets to survive in an inhabited shelter like Sibudu over tens of millennia is questionable. When buried nutlets are carbonised, the likelihood of preservation increases.

An ash matrix conducts heat more effectively than a matrix of very coarse sand (1–2 mm particle size). In these experiments the heat was sufficiently well-conducted in ash to carbonise sedge nutlets buried in 2 cm of ash, but not those buried at 2 cm in a coarse sand matrix. Nutlets buried at 5 cm under either matrix survived apparently unaltered. These conclusions are relevant to Sibudu where the sediments are predominantly ashy and layers are invariably at centimetre scale.

The issue of the effect of the moisture content of the sedges on the burning of the bedding was not resolved. Common sense and personal experience suggests that moist material is more difficult to ignite, but once a fire is burning strongly and if it is vigilantly tended, the fire will continue to burn. Research on wood (Théry-Parisot & Henry 2012) indicates that this is the case with green wood. It is likely that it would apply to moist bedding too, depending on the degree of moisture.

Variation of temperatures on the surface below burning bedding was undoubtedly demonstrated in these experiments and the implications for the burning of the bedding itself and buried material are clear. Unburnt material remained even at the edges of beds that burnt well: this can explain the unburnt bedding observed in the micromorphological profiles at Sibudu (Goldberg *et al.* 2009). Wind direction was not clearly shown to be a factor in temperature variation, but this conclusion needs corroboration from further experiments.

These experiments drew attention to a multiplicity of variables that arise during the burning of bedding and by extension, other fuel. Some of the variables could be controlled, such as the degree of compaction in the Series 2 beds of neatly packed culms. Other variables such as the wind direction and strength could not be controlled. It is difficult to control all the possible permutations of the active variables in 'natural' situations. However, results from laboratory experiments are not always confirmed in open combustion situations (Théry-Parisot & Henry 2012). Moreover, the "field situation is where creative solutions are found" (L. Wadley, pers. comm. 2012), and useful observations are made during focussed experiments of any kind. In some cases the observations are incidental to the aims of the experiments and they lead to further insights and questions. One instance here is the accidental discovery of conditions leading to ash cementation.

The experiments have produced observations of taphonomic relevance, for example, different sediment matrices conduct temperature differentially, thus affecting the potential for carbonisation of plant material. The experiments confirm the problems determining causality where multiple variables exist. This complexity likely operated in ancient times as well. Further, the experiments allow the creation of scenarios to explain the life-cycle of sedge bedding in the past.

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CHAPTER 9 – DISCUSSION AND CONCLUSIONS

The research on sedges as bedding in Middle Stone Age Sibudu demonstrates the need for multi-stranded research and the value of collaboration in addressing an archaeological issue. The 'seed' for the study was the presence of sedge nutlets throughout the MSA layers at Sibudu (Sievers 2006). The multidisciplinary expertise and participation, and the use of a variety of technical and experimental techniques, led to the conclusion that sedges were harvested in the uThongathi River below Sibudu, and were placed on the shelter floor to provide informally constructed 'bedding' for sleeping, resting, eating or working.

Evidence that led to this conclusion was identification of the sedge nutlets, confirmation that people were the most likely reason for sedge nutlet presence in the deposits, the identification of bedding at Sibudu and the presence of sedges in the bedding. Discussion on these topics follows.

9.1 Identification of sedges at Sibudu

Previous published identifications reported the presence of sedge (Cyperaceae) nutlets, *Albildgaardia ovata, Schoenoplectus* cf. *brachyceras* and *Scleria* cf. *angusta* in the Sibudu MSA deposits (Sievers 2006). Except for the tentative identification of *Albildgaardia ovata* (Chapter Four – Identification of Sedges at Sibudu) the presence of the other sedge taxa at Sibudu could not be confirmed in the detailed studies that resulted in the present research project. Mineralised sedge nutlets of the species *Scleria natalensis* and *S. melanomphala* have been positively identified in the ~77 ka layers (Wadley et al. 2011) and carbonised *Cladium mariscus* (saw-sedge) nutlets have been identified in post ~77 ka layers (Sievers & Muasya 2011). SEM provided detail for the identifications. Surface features of the ancient carbonised material are not well-preserved and an alternative method, scrutinising the internal morphology of sedge nutlets, was used in the identifications. Mineralisation preserved the nutlet characteristics far more clearly than carbonisation and SEM images of the outer surfaces of mineralised, ~ 77 ka *Scleria* nutlets show at least as much detail as those of modern nutlets. For example, whereas the morphology of the ancient nutlet (Fig. 9.1) suggests it is *Scleria poiformis*, the small scars from hair bases, seen as circles on the surface, identify it as *S. melanomphala.* This detail, not evident in the SEM images of modern *S. melanomphala* nutlets and not published elsewhere, was kindly indicated by Professor Esmé Franklin-Hennesy (Franklin-Hennesy 1985; pers. com. 2011). As discussed in the next chapter, more work on the Sibudu seeds and fruits of similar size and shape is needed, and, as in the ~77 ka layers, it is possible that more than one species of sedge was used in an individual 'bed' in the more recent layers.

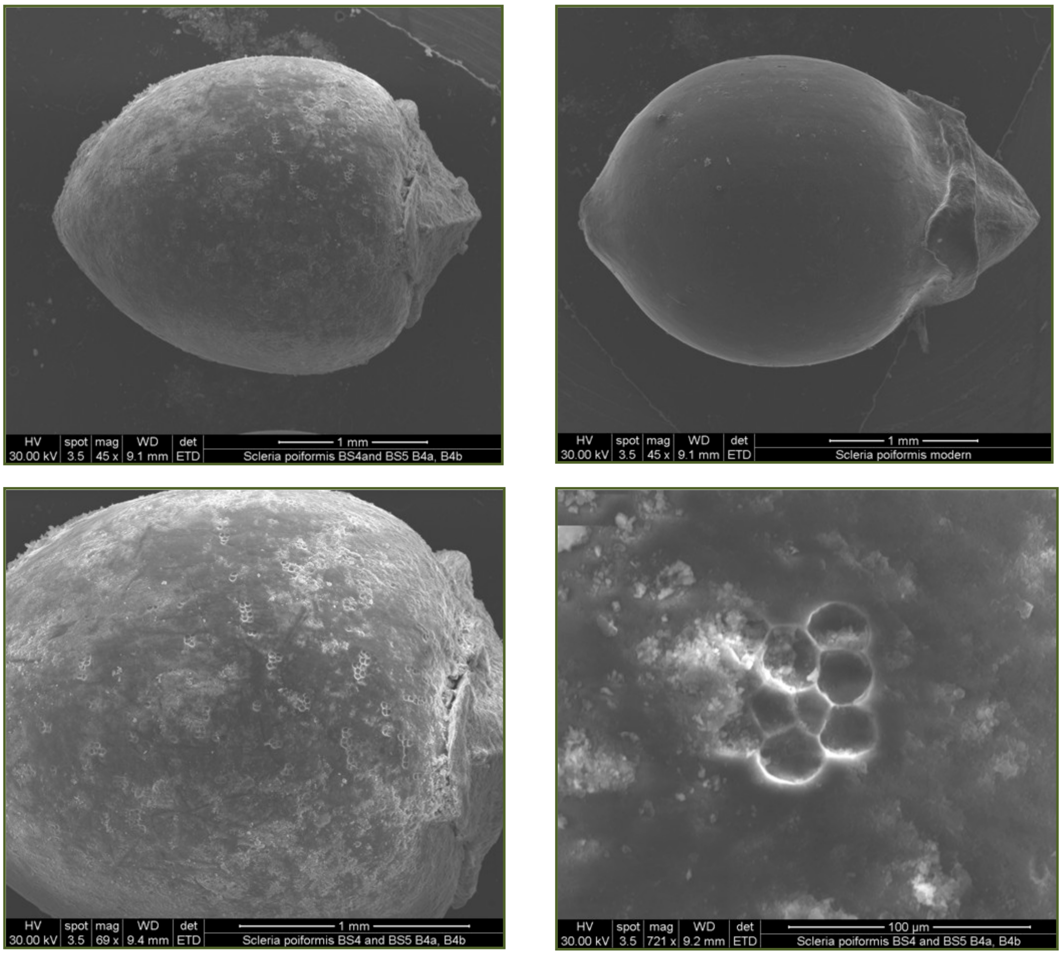

Figure 9.1 ESEM (Environmental Scanning Electron Microscope) image of an ancient mineralised nutlet from layer BS4/BS5 quadrant B4b (upper left) and modern *Scleria poiformis* (upper right). Detail on the surface of the ancient nutlet (lower left) is magnified (lower right) and is not a function of preservation or mineralisation. The rings represent the scars where hairs grew. This identifies the

nutlet as *Scleria melanomphala* and not *S. poiformis*, which was my original identification.

Sedge pollen (Renaut & Bamford 2006) and sedge phytoliths (Schiegl et al. 2004; Scheigl & Conard 2006; Wadley et al, 2011) have been identified, but only to family level. There is a *Cyperus* sp. spikelet in layer LBG under Hearth (Fig. 9.2). Layer LBG, dated to ~73 ka, contains the oldest evidence of burnt bedding at Sibudu (Wadley et al. 2011). There is a *Cladium mariscus* culm in Brown under Yellow Ash2(i), which is one of the ~58 ka bedding layers (Wadley et al. 2011 figure 2a). The presence of sedges is definitely established at Sibudu, but how and why did the nutlets, the predominant evidence of sedge presence (Sievers 2006), enter the Sibudu deposits?

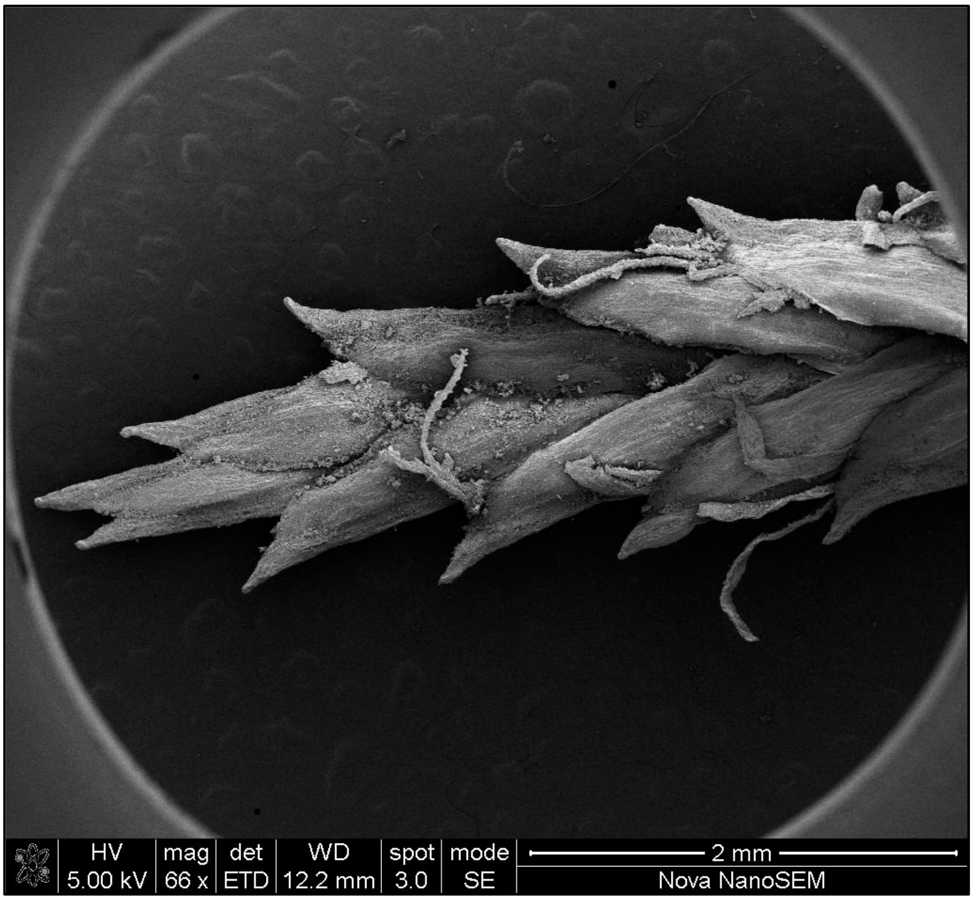

Figure 9.2 Carbonised *Cyperus* sp. spikelet from layer LBG under Hearth, quadrant B4d, ~72.5 ± 2.0 ka (Jacobs et al. 2008a).

9.2 Identification of routes of entry of sedge nutlets

The sediments at Sibudu exhibit none of the features of water-borne materials (Pickering 2006) and water can be dismissed as a possible route of entry for the sedge nutlets. Although there are exceptions, sedges are generally plants of moist habitats and the sedges identified at Sibudu follow this preference. In particular, *Cladium mariscus* thrives in shallow standing water and will die off when the water table sinks below 15 cm (Conway 1942). Sibudu was back-cut into a steep cliff below the crest of a hill and, topographically, the only location suitable for the growth of *Cladium mariscus* is in the uThongathi River, which flows in the valley about 20 m below the shelter. This situation rules out natural agencies such as gravity and wind as routes of entry for the nutlets.

The most compelling evidence that sedge nutlets did not enter the Sibudu deposits via the digestive systems of birds or other animals is that the nutlets are invariably whole, an unlikely condition for nutlets that have been eaten: nutlets by definition contain nourishment within a hard covering, rather than on their outer surface. Moreover, rodents, small mammals and water fowl that frequent the type of habitat that supports *Cladium* are unlikely to inhabit the shelter or store nutlets there. These animals may, however, have been targeted by raptors and carnivores and their stomach contents discarded in the shelter, for example, from a raptor nest on the cliff, but this would not explain the frequencies of nutlets that have been recovered.

The large air-filled cells that form the outer layer of *Cladium* nutlets (Fig. 4.2) and keep them floating (for at least one year in a jar of water in a laboratory situation) are evidence of their strategy of using water as a primary means for dispersal of nutlets. The *Cladium* and *Scleria* nutlets lack the classic reproductive features required for attachment to animals and people, but could they have entered the deposits in the dung of grazing animals? The tough leaves of *Cladium* discourage grazing (Ellery & Ellery 1997) and even if it were grazed, the large grazing ungulates would be unable to negotiate the steep climb to leave their dung in the shelter. Moreover, when *Cladium* is grazed it is the new growing shoots that are targeted, and these do not bear mature inflorescences and fruits. The collection of dung as fuel is unlikely because of the ready availability of wood; the charcoal evidence suggests riverine and evergreen forest environments throughout the Sibudu sequence (Allott 2006). The Sibudu *Scleria* species grow in dappled shade along rivers and likely make good grazing. However, the *Scleria* nutlets, which are mineralised, have been found only in association with the mineralised bedding, which suggests they were introduced along with the soft green leaves of the taxon when they were harvested for bedding material. Archaeological and ethnographic records report the use of sedges for bedding and the next section addresses this.

9.3 Ethnographic and archaeological records of sedge uses

Many modern and ancient uses of sedges have been recorded and are summarised in Sievers (2011) and Sievers & Muasya (2011). The ethnographic records of the use of sedges in southern Africa cover a diverse range from food, medicines and poisons to basketry and woven artefacts. These provide analogies that may be used with caution to suggest past use. It is possible that some of the properties that encourage the modern uses may have been recognised in the past, such as the anti-bacterial properties of *Kyllinga* (Van Wyk & Gericke 2000) and the high silica content in sedges that may retard mildew build-up and predators (Rosen 2005).

9.4 Sedge bedding at Sibudu

Multiple sources point toward the presence of bedding at Sibudu (Wadley et al. 2011). Furthermore, the construction, maintenance, and deliberate burning of bedding were major activities at the site from about ~73 ka (Sievers 2006; Sievers &Wadley 2008; Goldberg et al. 2009; Wadley et al. 2011). Particularly at ~58 ka (post-Howiesons Poort), bedding evidence constitutes a significant component of the sedimentary units. The different lines of evidence are reviewed here: 1. micromorphological analysis of thin sections of the Sibudu deposit, 2. sand-sized and slightly larger clay aggregates, some gleyed and others containing diatoms, 3. macrobotanical and microbotanical remains of sedge and other herbaceous plants in the proposed bedding layers and, 4. the corroborative evidence of experimental micromorphology.

9.4.1 Micromorphological evidence

In thin section, the microstratigraphy at ~77 ka (pre-Still Bay) consists of finely laminated phytoliths and siliceous plant material, such as monocotyledonous leaves and sedge nutlets *(*Wadley et al. 2011 figures 1b, 2b,c,e, S11a, S16), which are capped with *Cryptocarya woodii* leaves (Wadley et al. 2011 figure 4). The earliest carbonised laminations occur at ~73 ka (Wadley et al. 2011 figure S7) and they exhibit the pattern that also occurs in the more recent layers: laminated fibrous charcoal lies at the base of the features, grading into micro-laminated phytoliths nearer the surface of the features (Miller & Sievers 2012 figures 2, 8). As will be shown in the section on experimental morphology below, the plant material would have been ashed on top and carbonised below where less oxygen is available to promote full combustion.

The ancient bedding layers vary between three to four mm thick to a 1200 mm thick multi-component combustion feature in the ~58 ka layers. This feature contains at least five sets of laminations made up of phytolith layers two to five mm thick grading into carbonised material five to ten mm thick (Wadley et al. 2011 figures 1c, S6, S9). The phytoliths and carbonised material in the microstratigraphy preserve anatomical features typical of monocotyledonous plants (Wadley et al. 2011 figures 1c, S6, S9; Miller & Sievers 2012 figure 8). Carbonised *Cladium mariscus* nutlets are also recovered from these layers. The layers are compacted and micro-laminated, and many contain numerous stringers and traceable surfaces. This and the presence of crushed bone (Wadley et al. 2011 figures S8, S12) suggests extensive trampling, repeated placement of fresh plant material upon older material and burning of the material, presumably to get rid of pests.

9.4.2 Experimental micromorphology

A comparison of the micromorphological signatures produced by experimental construction and burning of sedge and grass bedding, and the micromorphological signatures of the Sibudu deposits that Goldberg et al. (2009) postulated were burned bedding, suggest that the laminated fibrous charcoal and phytolith layers at Sibudu were most likely produced by the direct burning of compacted monocotyledonous plant material. Modern experimental construction, burning and compaction of sedge and grass bedding produces laminated phytoliths and fibrous charcoal (Miller & Sievers 2012 figure 6). In a series of experiments, two species of grass and two species of sedge were used to construct the informal bedding. The burnt sedge bedding, particularly the *Cyperus involucratus* bedding, produced burnt remains most similar to those in the Sibudu micromorphological samples.

The experiments showed it is not always possible to distinguish multiple burning events that have taken place one above the other. Although laminated charcoal and phytoliths were produced in the experiments, the gradation seen in the Sibudu microfacies succession identified by Goldberg et al. (2009) was not reproduced in the experiments. As described above, the Sibudu succession consists of a lower microfacies unit of laminated fibrous charcoal, overlain by laminated fibrous charcoal and laminated phytoliths, and an uppermost microfacies consisting only of laminated phytoliths. In the experiments the sedges were largely reduced to ashes, whereas the grasses were mostly carbonised. The relative moisture retained in the samples and amount of oxygen available, dependent on the thickness and the compaction of the bedding, may be implicated in these results.

Large amounts of bedding are needed to reproduce centimetre thick layers such as those found in the Sibudu bedding deposits. In the experiments there was a 98% loss of bulk during the repeated compaction and burning of bedding. This indicates that some of the ancient phytolith layers may represent bedding of up to 150 cm thickness, though it is unlikely that any individual bedding unit was this thick at any one time. The multiple episodes of construction and burning of bedding at Sibudu represent considerable expenditure of time and energy in the preparation and maintenance of living space.

An incidental observation was that no calcareous ash rhombs were produced in the experiments. These are also absent from archaeological examples of burned bedding. In the experiments, the ‘ash’, fully combusted sedge and grass bedding, consisted almost entirely of phytoliths. Goldberg et al. (2009) suggested that diagenetic processes removed calcareous ash from the phytolith layers, but the experiment results suggest that calcite was never a significant component of the laminated phytolith layers.

9.4.3 Clay aggregates

Within many of the layers of laminated carbonised material and phytoliths, there are clay aggregates that have been burned and are reddish-brown. These can be seen as sand-sized grains in micromorphological section of the sediments (Wadley et al. 2011 figure 3) and were found as small fragments in sieved deposits. Some aggregates appeared gleyed (‘gley’ refers a clayey soil formed under intermittent or permanent water-logging) and others contained numerous diatoms (diatoms are minute algae that live in water or damp places). The uThongathi River below Sibudu is the obvious source for the aggregates, and the monocotyledonous leaf impressions on the clay fragments suggest the clay came into the shelter on sedges, grasses or rushes harvested in and along the river. The leaf impressions await detailed identification, but the parallel venation is characteristic of monocotyledons.

9.4.4 Botanical remains

Macro- and microbotanical remains have been mentioned above in the sections outlining the sources of evidence for bedding at Sibudu. Briefly, the microbotanical evidence in the sediment micromorphology consists of phytoliths, including articulated phytoliths, from monocotyledons, at least including grasses and sedges (Wadley et al. 2011 figures 2b, S11; table S2). These phytoliths are within the laminated layers and their laminated position above carbonised material indicates that they are *in situ* and that the evidence of burned layers of organic material is intact. The bone fragments and stone chips within these stratified layers imply that some domestic activities took place here.

The macrobotanical remains consist of monocotyledonous stems and fruits. One stem has been identified (Wadley et al. 2011 figure 2a) as *Cladium mariscus* and more identifications are likely. Particularly, the carbonised monocotyledonous stems from the ~58 ka layer, Brown under Yellow Ash 2(i), (Wadley et al. 2011 SOM) show promise (Fig. 9.3).

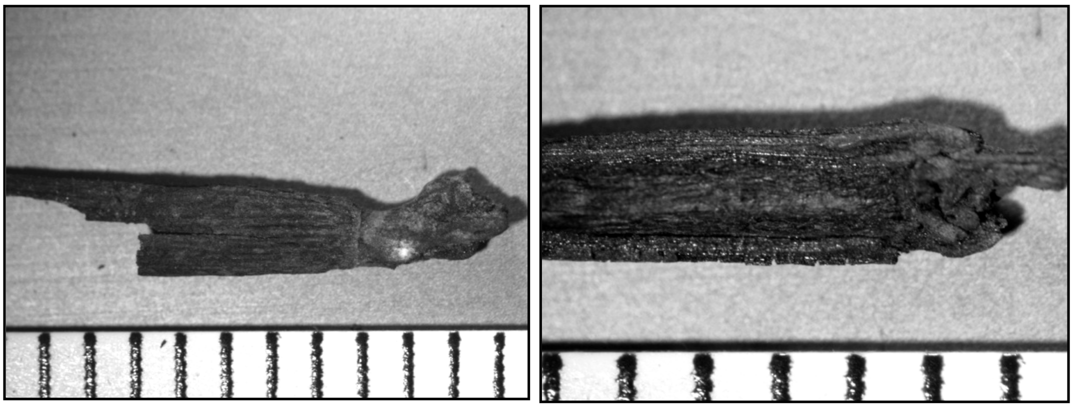

Figure 9.3 External view of ~58 ka old carbonised fragment from H1 (base) Brown under Yellow Ash 2(i) showing parallel veins indicative of a monocotyledon (left). The internal view (right), hollow with nodes, suggests it is a grass. Scale in mm.

Carbonised sedge nutlets, *Cladium mariscus,* (Sievers &Muasya 2011 figures 1, 2 and Wadley et al. 2011 figure 2d) were recovered throughout the MSA at Sibudu. One *Cladium mariscus* nutlet has been identified in a sediment section in the late MSA. The oval rather than round cross-section of the nutlet indicates that trampling has flattened the nutlet and also abraded most of the fibrous exocarp or outer layer of the fruit (Fig. 9.4).

Two carbonised *Juncus* sp. capsules (rushes) were recovered from ~ 73 ka sediments (Wadley et al. 2011 figure 2f) and mineralised *Scleria natalensis* and *S. melanomphala* nutlets (sedges) (Wadley et al. 2011 figure 2e; Fig. 9.1) were recovered from the laminated layers of mineralised herbaceous material at about ~77 ka. This brief summary of the botanical remains is included here as one of the strands making up the evidence which supports the hypothesis of sedges as bedding in MSA Sibudu.

Figure 9.4 Cross-section of carbonised *Cladium mariscus* nutlet from layer MOD, quadrant 6a. The single seed within is visible and the normally circular outline has become oval through trampling. Most of the exocarp of the nutlet is no longer present, possibly as a result of abrasion during trampling. Reproduced with kind permission of C.E. Miller.

One might ask the question: why *sedge* bedding? When I began this research, the evidence of sedge nutlets prompted the title *Sedges as Bedding in Middle Stone Age Sibudu.* As research progressed, it become clear that exclusive sedge use for bedding was unlikely, and that rushes and grasses, and possibly other plants, may have been used too. The grass phytoliths and pollens could have been brought in by the wind, but the presence of articulated grass phytoliths in the mineralised ~77 ka old bedding suggest that the grasses formed part of the bedding. Grasses and sedges could easily have been harvested simultaneously, but deliberate harvesting of grasses and sedges respectively may also have occurred. The presence of the *Cryptocarya* leaves confirm the presence of more than one type of plant collected for bedding. The pattern of combining more than one plant in bedding is also is found in the Later Stone Age at De Hangen shelter (Parkington & Poggenpoel 1986). Less elaborate collections of bedding materials are reported at Saulspoort Shelter. The bedding is described only as ‘grass bedding’ and has the delightful commentary by Schofield (1950: 42):

> “None of us, I fancy, who has spent any length of time in the veld is ever likely to forget the luxury of a properly staked grass bed, nor would it be

> unreasonable to assume that the Stone Age hunters who occupied such shelters as that at Saulspoort were as much alive to their creature comforts as we are.”

Goodwin (1950: 42), as editor of the Bulletin in which Schofield’s statement was published, notes that there is *Zostera capensis* bedding at Oakhurst Shelter and “bedding of other materials” at Kalk Bay Cave. I have sat upon a thick mattress of *Zostera* or ‘seagrass’ exposed by sinking water-levels, and drying on the banks of De Hoop Vlei in the southern Cape and I can attest to its comfort; but, having laid myself down at Sibudu on a newly harvested, cool and fresh-smelling bed of the sedge *Cyperus involucratus*, I can echo also Schofield’s praise, for a sedge bed.

At Sibudu, the use of particular sedges and the presence of stratigraphically distinct bedding with different sedges deserve more scrutiny. The use of *Scleria* spp. at ~77 ka and subsequently the use of *Cladium mariscus* were deliberate choices by the Sibudu inhabitants. The reason for the choices and the replacement of one type of bedding component by another is unclear: was the availability of the sedges the determining factor, or were particular properties of the sedges favoured? There is presently insufficient environmental data at ~77 ka to provide definite answers to these questions, but there is potential to explore these issues further, given the richness of the Sibudu record.

Another issue to explore in terms of human behaviour at Sibudu concerns the sharp projections on the margins and midribs of *Cladium mariscus* leaves. These razor-sharp projections imply that a *Cladium* mattress would need some sort of covering. This could have consisted of one or more soft plants, but possibly also of animal hides. The presence of hides would imply hide-processing expertise. The processing and use of hides is a likely scenario, considering the sophisticated technological capabilities of the Sibudu inhabitants.

9.5 Conclusions

This study is important because it has produced

- identification of the earliest archaeological bedding materials used by *Homo sapiens*
- sets of micrographs that provide a comparative collection for the identification of sedge nutlets
- methodology employing analysis and comparison of experimental and ancient material on a micromorphological scale to answer an archaeological question
- successful application of GIS-based coexistence analysis of southern African archaeobotanical data to interpret past climate
- answers to new questions about aspects of human behaviour in the past

Experimental micromorphology replicated the micromorphological signatures in thin sections of the Sibudu deposit indicating that these are likely to have been caused by the burning of sedge bedding. The presence within these ancient laminated layers of charcoal and phytoliths, of clay aggregates and macrobotanical and microbotanical remains of wetland plants provides strong support for the hypothesis that sedges were harvested in and along the uThongathi River below Sibudu and brought into the shelter to provide a floor covering that was used for more than one purpose. In the pre-Still Bay ~77 ka layers the bedding was supplemented with aromatic and insect-repelling leaves of *Cryptocarya woodii*, the River Wild-quince, and during subsequent occupations of the shelter, the bedding was repeatedly replenished with fresh material and regularly burned. Experiments with fresh bedding suggest that the burning of the ancient bedding was deliberate.

The construction of bedding is not peculiarly human; many species instinctively construct sleeping areas and maintain their living space. All great apes construct sleeping areas and furthermore, the process might not be entirely instinctual amongst primates (Van Casteren et al. 2012). Therefore, the presence of informally constructed bedding at Sibudu is not necessarily another indication of complex cognition at the site. Yet, the deliberate addition of the leaves of a plant that acts as an insect deterrent and the intentional, repeated burning of bedding in subsequent occupations of the site imply calculated strategies to maintain the living area.

CHAPTER TEN – FUTURE RESEARCH

The research for this thesis has engendered many questions and opened several avenues for further investigations and analysis. Some of these are listed below and are likely to form the basis for post-doctoral research and publications.

10.1 Distribution of sedge nutlets in time and space

The distribution and frequency of sedge nutlets spatially and through time needs to be updated. Since the original frequency analysis (Sievers 2006), the excavation at Sibudu has been extended deeper, into older deposits, and also laterally to uncover more of the layers identified in the original test pit. Identification and quantification has been ongoing, but has been hampered by the difficulty of precise identification of the sedge nutlets. Whereas *Cladium mariscus* was positively identified in *Paper1,* this identification was through SEM images of the internal structure of the nutlet, which is obviously an impractical approach for the whole assemblage. I have begun dedicated measurement of *Cladium* nutlets carbonised under sedge bedding fires to assess the changes in shape and size as a result of exposure to heat, and to get precise limits for the size range of modern carbonised *Cladium* nutlets. The internal morphology of *Cladium* appears similar to that of the waxy fruit, *Morella serrata*. *M. serrata* occurs along rivers in conditions similar to around Sibudu. The hard endocarp of this fruit has a variable size range, the lower end of which overlaps with the size of *Cladium* mesocarps. This requires further investigation and the quantification of the morphology of carbonised fruits of *Cladium* and *Morella* under different heating regimes. A possible approach is geometric morphometrics, which uses multivariate statistical analyses to assess the shape of the object under scrutiny. This method has been used successfully in archaeobotany, for example, to trace the origins and history of the Egyptian olive (Newton et al. 2006).

I have been recording the frequency of sedge nutlets in different parts of hearths (top, middle and base) and I would like to quantify their frequency under hearths;

according to matrix; in and under bedding and in other activity areas; and compare these results with patterns identified in the fire experiments.

10.2 The other possible uses of *Cladium mariscus*

The use of the sedge *Cladium mariscus* as bedding has been addressed in this thesis, but the investigation of other possible uses of the sedge should also be conducted.

10.2.1 Sedges for breakfast?

The presence of bone chips intimately associated with the Sibudu bedding (Wadley 2012a) has prompted quips about ”breakfast in bed” (L. Wadley, pers. com. 2011). A related query could be, ”your bed for breakfast?”. The eating of sedge nutlets and rhizomes has been recorded ethnographically and archaeologically (*Paper 2*) and begs the question: was *Cladium mariscus* harvested for food, as well as bedding? Samples of the nutlets, rhizomes and base of *Cladium mariscus* culms from two different geographical locations and at different seasons were submitted to the CSIR (Council for Scientific and Industrial Research) Food and Beverage Laboratory for analysis of nutritional content, including carbohydrate, energy, moisture, ash, total fat and protein content. Further research would involve assessment of bioaccessiblity and bioavailability of these nutrients. Bioaccessibility is the proportion of a nutrient that is released from a food matrix, and impacts on bioavailability, which is the proportion of a food or nutrient capable of being absorbed into the human body (Wollstonecroft 2011, Wollstonecroft et al. 2012). Tests for lignin and subarin, which would influence these issues, would be first steps in the research. Lignin confers strength to cell walls and suberin, a lipid (fatty substance), repels water.

10.2.2 Insecticide?

Insecticidial properties of plants are recognised by birds (Wimberger 1984; Clark 1990) and not suprisingly, also by people as long ago as ~77 ka (*Paper 3*). In many plants it is the aromatic essential oils that are effective insect repellents, for example, citronella and eucaplytus oils. In sedges too, the essential oils from the rhizomes and tubers have insecticidal and lavicidal properties (Ameen et al. 2011; Kempraj &Bhat 2008; Van Wyk & Gericke 2000). The volatile oils in the leaves of sedges are released during harvesting and are unlikely to survive, even in fresh bedding (K. Gordon-Gray, pers. com. 2010). However, there might be properties other than volatile oils in *Cladium* that repelled pests and samples of *Cladium* rhizomes, leaves and nutlets have been submitted for analysis to Professor Fanie van Heerden of the Chemistry Department at the University of KwaZulu-Natal, Pietermaritzburg Campus. An unnamed alkaloid was listed in a Kew Gardens entry for *Cladium* (Burkill 1985). The planned chemical analyses will address the possible presence of alkaloids and oxalates in *Cladium*.

Preliminary results suggest there are no alkaloids nor oxalate crystals present in *Cladium* (Fanie van Heerden, pers. com. 2012). However, there are irritants other than alkaloids in plants and the quest continues for an explanation for the itchiness caused by a *Cladium* cut. The scabrid leaf edges can draw blood, the irritation persists for a couple of days, and the scars of even superficial scratches last for about two weeks. Protective clothing was worn to harvest sedges in seventeenth century England (Rowell 1986) and is still worn today (Len van Schalkwyk, pers. com. 2013)

The preservative properties of ash have been mentioned (*Paper 6*) and it is possible that *Cladium* ash may be useful, particularly if this was a base on which to lay futher bedding. The experimental bedding fires made with *Cladium* ignited easily and burnt furiously and it is possible that this too could have been an incentive to use *Cladium*: unwanted bedding would have been easy to burn. An incidental bonus provided by *Cladium* bedding would be that an efficient fire-starter was available in times of need.

Sedges (and grasses) have high silica content, which may retard mildew build-up and rodent predation (Rosen 2005). This is suggested as a possible interpretation of a thick layer of *Scirpus* sp. (sedge) phytoliths lining a storage bin at Çatalhöyük

(Rosen 2005) and may be a useful line of investigation to develop with respect to the Sibudu bedding.

10.3 SEM images of *Juncus* fruits and seeds

Juncus sp. from the Sibudu ~73 ka layers was identified in *Paper 3* and SEM images were made of the fruits and seeds of 12 possible *Juncus* taxa that might identify the *Juncus* species. A positive identification was not forthcoming. More SEM work is required. An incidental outcome of the work so far has bearing on a debate over the specific identity of *Juncus mollifolius* Hilliard & Burt, which is listed as a separate species by Glen and Cook (2003), but not by SIBIS (http://sibis.sanbi.org), the South African National Biodiversity Institute's (SANBI) Integrated Biodiversity Information System. The SEM images indicate that *Juncus mollifolius* may indeed be a separate species. This could prove to be an unusual situation in which archaeobotanical research can inform on a botanical issue. Apart from providing images for the identification of the specific species, a paper with images of all the taxa will be of use to botanists generally, because no such published images exist in the botanical literature.

10.4 Selection of bedding materials

An issue that needs further investigation is whether more than one type of bedding material was selected after ~77 ka. The bedding in the ~77 ka layers consisted of at least two sedge species, a panicoid grass and possibly a rush, topped with a leaf with insecticidal properties. These were identified from macrobotanical and microbotanical remains, mineralised fruits and phytoliths (*Paper 3*) and there is scope for more identifications through SEM and study of the micromorphological images. In the more recent MSA occupations at Sibudu, the only sedge nutlet securely identified is *Cladium mariscus*. The sharp projections on the midrib and leaf margins of *Cladium* are irritating and can easily cut, but a bundle of *Cladium* covered with a sheet is very comfortable. Although an animal like my short-haired dog (Staffordshire terrier) lies happily directly on the leaves, a person is unlikely to be safe from scratches. At Sibudu, *Cladium* is likely to have been an informal

’mattress’ below a covering of some other material. This could be other sedges, grasses, rushes, soft herbaceous plants, and possibly even skins. There is no evidence for the latter suggestion, but micromorphological slides of the carbonised bedding layers have provided many examples of potentially identifiable botanical material. I should like to develop comparative material of sedge, grass, rush and restio leaves and culms for comparison and identification of the ancient material.

10.5 When was the bedding burned?

Micromorphological analysis of slides made from resin-impregnated blocks of Sibudu deposit showed the presence of bedding repeatedly burned (Goldberg et al. 2009; Goldberg & Berna 2010). Experimental micromorphological investigation of bedding construction replicated the ancient signatures (*Paper 4*), but did not address the question of when the bedding was burned. Was the bedding burned when people arrived at the site, while they were living at the site or when they left the site? An answer to this question might be found through further experimentation and observation of the residues produced by burning bedding.

The burning of sedges and grasses produces soft ash, phytoliths and carbonised material (*Paper 4*). Sometimes the material resembles its pre-carbonised shape, but even so it is delicate and mostly disintegrates on touch. The scenarios that can be reconstructed to explain the survival or disintegration of burnt bedding are various and I formulated them partly in response to the experience I gained through my experiments:

- If bedding was burned when people left the site, the ashes and light carbonised remains might have blown away or disintegrated as a result of animal activity in the shelter. This scenario would have prevented the formation of the superimposed layers of phytoliths and carbonised material identifiable in micromorphological sections of the Sibudu deposits
- Alternatively, thicker vegetation around the shelter in the past may have provided a shield against the strong winds that occasionally rush through the shelter today, blowing sand and light debris. Thus protected from the elements, light combustion products may have been undisturbed for some

time. Ash is better preserved in sheltered sites with minimal humidity (Shahack-Gross 2011) and the deposits at Sibudu are dry, with locally arid conditions confirmed by gypsum growth in certain layers. A small amount of moisture is required for gypsum formation, but it can survive only in arid conditions

- Wadley (2010d) reports the cementation of the white ash of hearths at Sibudu through phosphatization and gypsum formation. It is possible that moisture, even from humid air, contributed to the cementing of ash, and prevented ash dispersal (*Paper 6*)
- If bedding smouldered for days when it was burnt, concurrent occupation of the site and placing of fresh bedding above the burning or newly burned bedding is extremely unlikely
- If combustion of bedding was rapid and the residues did not produce sustained heat, the burning of bedding and placing of fresh bedding could easily be completed within half a day

The burning time and retention of heat in the ashes are thus important factors when considering when the Sibudu bedding was burned. Similarities in the micromorphological signatures of burnt stabling and pastoralist deposits in the Mediterranean and Near East (Albert *et al.* 2008) and the Sibudu deposits were suggested previously (*Paper 4*). The stabling burns slow and long and before comparing this to the Sibudu situation, I note the reasons for the burning of pastoralist deposits. The fires and smouldering goat dung and organic material observed in many parts of the Middle East are primarily aimed at getting rid of ticks (Goldberg *et al*. 2009); a shepherd in Sicily stated that dung was burnt to reduce the risk of disease for the herd (Brochier *et al*. 1992) and other ethnographic records also document burning to destroy disease and insects (Cameron 1990, 1991). It is not unreasonable to suggest that Sibudu bedding may have been burned to get rid of pests.

Studies of post-Mesolithic burnt dung in Croatia report “layer-cake units” where there was repeated burning of dung (Boschian & Miracle 2007: 176). The litter and dung was compact from trampling and the resultant lack of oxygen, combined with residual moisture, produced a slow burning fire. For dung to burn, the upper centimetres need to have dried thoroughly and the shepherd in Sicily stated that dung was burnt at the end of the hot summer, long after the herd had departed (Brochier *et al*. 1992). Moisture is obviously a factor to consider and the implication is that the dung had dried over the summer. With the burning of dung and stabling, other variables affecting the burning are the depth and extent of the organic matter, the degree of decomposition and particle size.

When compared to straw stabling, it is likely that bedding used by people for whatever purpose would not become as moist or as decomposed as the stabling with its inclusions of dung (macerated plant material) and moisture from animal urine. The processed and more compact texture of trampled dung and stabling is also likely to produce a slower smouldering fire than burning sedge or grass bedding.

Cattle-owning subsistence farmers in southern Africa (pers. obs. 1960s; Green 2012) process cow dung into patties, which are dried and used as fuel. Clay is included in the patties and produces longer and hotter fires (Green 2012). Dung and prepared dung cakes are also used as fuel in India and the Near East (Shahack-Gross 2011). Dung has qualities similar to wood because it is high in lignin (the cellulose and hemicellulose are digested more easily, enriching the lignin content), and open-air dung fire experiments (Shahack-Gross *et al*. 2005) exhibited glowing embers as from wood. The temperatures did not fall below 400 °C for two to three hours. Maximum temperatures reached were 630 °C (Shahack-Gross 2011). These results are included here to indicate the high and sustained temperatures from burning dung and stabling. Where thick accumulations of dung are burned, high temperatures may cause partial or complete melting of phytoliths and vitrification of the dung. Heat-altered phytoliths indicative of intense heat are present at Sibudu and suggest long-burning wood fires or reuse of the same hearth; heavily altered phytoliths were not produced in experimental small camp fires (2-3 kg wood) (Schiegl *et al*. 2004). The issue of phytolith preservation at Sibudu has been addressed again (*Paper 3 SOM*). Further detailed phytolith studies are likely to provide more clues on the mineralogy, diagenesis and preservation of the record at Sibudu.

Whereas many of the carbonised bedding layers at Sibudu are defined by a basal unit of laminated fibrous charcoal that grades into an overlying layer of laminated phytoliths, in two micromorphological samples the sequence begins with laminated nonburnt fibrous organic material grading into laminated burnt fibrous organic material with phytoliths (microfacies laminated type 2B) and finally a layer of laminated phytoliths (Goldberg *et al*. 2009). Does this provide any clue to questions posed earlier?

As stated earlier two approaches to answering the question of when the bedding was burned could be to explore the temperature and duration of heat retention during the burning of bedding and secondly, to determine whether ash residues would persist if they were left uncovered. The premise here is that ash layers would be preserved if fresh bedding were laid upon newly ashed bedding and that if newly burned bedding were left exposed, the ash would blow away. The burning of bedding was deliberate (*Paper 4*); persistent evergreen forest in the immediate vicinity of Sibudu, indicated by wood species in the charcoal analyses (Allott 2006), also argues against accidental burning, caused by a passing bush fire. Fires do not penetrate beyond a few metres into thick evergreen forest. Furthermore, the areas of burnt plant material at Sibudu are restricted and where excavation has exposed them, are situated in the centre and to the rear of the shelter, beyond the reach of a bush fire. In this situation, would the ash of burned bedding persist or be blown away, unless covered immediately by more bedding?

Strong winds pass through Sibudu Cave at times and unless precautions are taken, these are strong enough to cause small seeds and charcoal fragments to be lost from sorting trays. Accordingly it is possible that the wind could blow away ashes from fires. Mallol *et al*. (2007), studying ethnoarchaeological signals of Hadza fires, observe that ephemeral surface fires may be difficult to detect after wind action, “but when the earth is scooped out very deeply and fires burn for a long time, it is easier to detect and recognize.” (Mallol *et al.* 2007: 2036). Movement of ash is evident at Sibudu, in the scraping out of hearths (Bentsen 2012), but the stratigraphic profiles show no evidence of deep scooping for hearths or bedding areas. Although the Hadza fuel types are dry wood-sticks and logs, the Hadza impala-cooking fire, tuber-roasting fire and torch-making fire to get honey closely resemble the sedge fuel experiments in this paper, in that the authors describe them as short-duration. The tuber-roasting fire had flames lasting eight minutes, similar to the duration of flames observed in sedge fires *(Paper 6*), which varied from three to six minutes. These Hadza fire types are described as brief low intensity (<300°C) fires. Temperatures were not measured directly and it is unlikely that the fires described reached only 300°C; laboratory experiments with wood show that in the presence of oxygen and a pilot heat source, ignition will occur at 350°C (Braadbaart & Poole 2008). Very rare traces of ash were found on the surface of the Hadza impala-cooking fire when it was sampled 10 days later. The tuber-roasting fire was sampled the day after it was made and the remains consisted of a thin layer of ash and a thin layer of black organic material (2 cm) which were moist at the time of sampling. Heavy rain had fallen overnight and could have caused the possible cementation and thus, preservation, of the ashes.

Intact undisturbed remains of burnt sedge bedding are preserved at Sibudu. Whether this is because the remains were protected, for example, by the immediate superimposition of fresh bedding or for any other reason, is likely to remain hypothetical because of the unknowns that cannot be accounted for, such as wind direction and velocity during and after the fire, protection provided by dripline vegetation and disturbance by animals or people.

The experimental fires reported in *Paper 6* were quick, high temperature events and within a few hours the surface temperatures below the fires were low enough to touch. Therefore, it would seem possible that new bedding could be laid upon recently burned bedding. But, the experimental beds were uncompacted and free of contaminating debris, which was not the case at Sibudu where at least, bits of bone and stone were present. Further experiments involving the inclusion in the bedding of bone fragments and possibly other food debris, stone chips and fine dust, could accommodate these many variables. The moisture content of the bedding is another important variable that would affect the duration the burning. Both undercover and open dung deposits are wet and ethnographic accounts report that the dung has to dry at least on the surface before it can be combusted; even then, it smoulders as it burns. Body fluids as well as moisture from food debris could have moistened Sibudu bedding, but it seems highly unlikely that the bedding would have been used until it became as wet as dung. The question of when the bedding was burned remains unanswered.

10.6 The effect of fires on below ground moisture content

During the Series 1 Experimental Bedding Fires (*Paper 6*), I recorded the soil moisture at 15 cm below the ground surface before and after lighting a fire on the surface directly above the measurement point. A slight increase in soil moisture was registered. The amount of moisture in deposits affects the preservation of organic materials and it would be useful to test the effect of fires on the moisture content in the ground below them. If my single observation is corroborated, this could be a source of the moisture required for gypsum to grow below the burning events in the post-Howiesons Poort and more recent layers at Sibudu.

10.7 More evidence for MSA vegetation change at Sibudu

The many types of evidence at Sibudu allow for more robust vegetation interpretations than those based on the evidence from fruits and seeds alone. Identification of the presently unidentified plant taxa and possibly more that are recovered, combined with insights from other analyses, is likely to refine the current vegetation interpretations. This will also impact the results of the coexistence analysis (*Paper 5*), which is based on taxonomic identifications. In the approach, more precise identification leads to more accurate and precise results.

10.8 Concluding remarks

Ex Africa semper aliquid novi (always something new from Africa), a well-used and probably over-used phrase generally attributed to Pliny the Elder, applies aptly to Sibudu, and the conclusions of this thesis, *Sedges as Bedding in Middle Stone Age Sibudu*, are unlikely to be the last word on sedges or bedding at Sibudu.

APPENDIX A – MODERN VEGETATION IN THE SIBUDU AREA

List of plant taxa for the Sibudu Cave area and cliff supplied by G.R. Nichols (2005) and supplemented with records by D. Styles and C.J. Ward

* = Introduced Plant
\# = Recorded by D. Styles (Autumn 2002)
$^{\text{CJW}}$ = Recorded by C.J. "Roddy" Ward (29/03/2012 and 22/04/2010)
Underlined = Plants collected by G.R. Nichols (Jan. 2001)
$^{\underline{\text{CJW}}}$ = Plants collected by C.J. "Roddy" Ward and CS (29/03/2010 and 22/04/2010)

PTERIDOPHYTA (Ferns)
EQUISETACEAE
Equisetum ramossimum Desf.$^{\text{CJW}}$

NEPHROLEPIDACEAE
**Nephroleptis exaltata* (L.) Schott

POLYPODIACEAE
Microsorum punctatum (L.) Copel.

PTERIDACEAE
Adiantum capillus-veneris L.
Cheilanthes viridis (Forssk.) Sw.var. *macrophylla* (kunze) Schelpe & N.C.Anthony
Doryopteris concolor (Langsd. & Fisch.) Kuhn

SELAGINELLACEAE
Selaginella kraussiana (Kunze) A.Braun

THELYPTERIDACEAE
Cyclosorus interruptus (Willd.) H.Itô$^{\underline{\text{CJW}}}$
**Macrothelypteris torresiana* (Gaudich.) Ching$^{\underline{\text{CJW}}}$

SPERMATOPHYTES (The seed-bearing plants)
ACANTHACEAE
Dicliptera heterostegia Nees$^{\underline{\text{CJW}}}$
#Duvemoia adhatodoides E.Mey. ex Nees
Justicia campylostemon Nees T.Anderson

AMARANTHACEAE
Aerva lanata (L.) Juss. ex Schult.$^{\underline{\text{CJW}}}$
**Achyranthes aspera* L. var. *sicula* L.
Pupalia lappacea (L.) A.Juss. var. *lappacea*

AMARYLLIDACEAE
Clivia miniata Lindl.
Haemanthus albiflos Jacq.
Scadoxus membranaceus (Baker) Friis & Nordal

ANACARDIACEAE
#*Harpephyllum caffrum* Bernh.
ProtoSearsia longifolia Bernh.
#Searsia chirindensis Baker f.
Searsia gueinzii Sond.
Searsia pentheri Zahlbr.
* *Schinus terebinthifolius* Raddi

ANNONACEAE
#*Monanthotaxis caffra* (Sond.) Verdc.
Uvaria caffra E.Mey. ex Sond.

APIACEAE
Centella asiatica (L.) Urb.$^{\text{CJW}}$

APOCYNACEAE
#*Acokanthera oppositifolia* (Lam.) Codd
Carissa bispinosa L. Desf. Ec Brenan
Carissa macrocarpa Eckl.
**Catharansis roseus* (L.) G.Don
Secamone filifolia (L.f.) J.H.Ross
Tabernaemontana ventricosa Hochst. ex A.DC.
Tacazzea apiculata Oliv.
Wrightia natalensis Stapf

ARALIACEAE
#*Cussonia zuluensis* Strey

ASPARAGACEAE
Asparagus falcatus L.
Asparagus suaveolens Burch.
Asparagus virgatus Baker$^{\text{CJW}}$

ASPHODELIACEAE
Aloe arborescens Mill.
Bulbine latifolia (L.f.) Schult. & Schult.f.

ASTERACEAE
**Ageratum conyzoides* L.
**Ageratum houstonianum* Mill.
**Bidens pilosa* L.$^{\text{CJW}}$
Brachylaena discolour DC.
**Chromolaena odorata* (L.) R.M.King & H.Rob.
Cotula DC. var. *nigellifolia*
Distephanus angulifolia DC.
Pulicaria scabra (Thunb.) Druce$^{\text{CJW}}$
Senecio brachypodus DC.
Senecio macroglossus DC.

**Tagetes minuta* L.^{CJW}
**Tithonia diversifolia* (Hemsl.) A. Gray

BORAGINACEAE
#*Ehretia rigida* (Thunb.)

BURSERACEAE
Commiphora harveyi (Engl.) Engl.
Commiphora woodii Engl.

CACTACEAE
Rhipsalis baccifera (J.Mill.) Stern subsp. *mauritania* (DC.) Barthlott
**Pereskia aculeata* Mill.

CAPPARACEAE
Capparis sepiaria L.var. *citrifolia* (Lam.) Tölken
Capparis tomentosa Lam.
Maerua racemulosa (A.DC.) Gilg & Gilg-Ben.

CELASTRACEAE
#*Lauridia tetragona* (L.f.) R.H.Archer
Mystroxylon aethiopicum (Thumb.) Loes.
Putterlickia verrucosa (E.Mey. ex Sond.) Szyszyl.
#*Salacia gerrardii* Harv. ex Sprague

CELTIDACEAE
Celtis africana Burm.f.
Celtis mildbraedii Engl.
#*Trema orientalis* (L.) Blume

COMBRETACEAE
#*Combretum krausii* Hochst.
#*Combretum molle* R.Br. ex G.Don

COMMELINACEAE
Aneilema aequinoctiale (P.Beauv.) Loudon
Commelina benghalensis L.

CONVOLVULACEAE
Ipomoea carnea Jacq. subsp. *fistulosa* (Mart. ex Choisy) D.F.Austin^{CJW}
Ipomoea mauritania Jacq.

CRASSULACEAE
Crassula sarmentosa Harv.
Kalanchoe rotundifolia (Haw.) Haw.

CYPERACEAE
Cyperus albostriatus Schrad.
Cyperus nrst. *Cyperus compressus* L.^{CJW}

Cyperus distans L.f.^{CJW}
Cyperus dives Delile ^{CJW}
Cyperus involucratus Rottb.
Cyperus latifolius Poir.^{CJW}
Cyperus prolifer Lam.^{CJW}
Cyperus sphaerospermus Schrad.^{CJW}
Fimbristylis bisumbellata (Forssk.) Bubani^{CJW}
Killinga cf. *brevifolia* Rottb.^{CJW}
Killinga melanosperma Nees^{CJW}
Pycreus mundi Nees ^{CJW}
Pycreus polystachos (Rottb.) P.Beauv. var. *polystachos*

DIOSCOREACEAE
Dioscorea cotinifolia Kunth.

EBENACEAE
Diospyros natalensis (Harv.) Brenan
#*Euclea natalensis* A.DC.

EUPHORBIACEAE
#*Acalypha glabrata* Thumb.
#*Acalypha sonderiana* Müll.Arg.
Andrachne sp. L.
#*Antidesma venosum* E. Mey. ex Tul.
Bridelia micrantha (Hochst.) Baill.
Clutia pulchella L.
#*Croton sylvaticus* Hochst.
Dalechampia capensis A.Spreng.
#*Drypetes arguta* (Müll.Arg.) Hutch.
#*Drypetes gerrardii* Hutch.
Macranga capensis (Baill.) Benth. ex Sim
**Ricinus communis* L.
Tragiella natalensis (Sond.) Pax & K.Hoffm.

FABACEAE
Acacia robusta Burch.
Albizia adianthifolia (Schumach.) W.Wight
#*Baphia recemosa* (Hochst.) Baker
Crotalaria pallid Aiton
#*Dalbergia obovata* E.Mey.
Desmodium incanum DC.
Dichrostachys cinerea (L.) Wight & Arn.
#*Millettia grandis* (E.Mey.) Skeels
**Mimosa pudica* L.^{CJW}
Schotia brachypetala Sond.

FLACOURTICEAE
#*Dovyalis rhamnoides* (Burch. ex DC.) Burch. ex Harv.
Rawsonia lucida Harv. & Sond.

#*Xylotheca kraussiana* Hochst.

GESNERIACEAE
Streptocarpus prolixus C.B.Clarke

HYACINTHACEAE
Ornithogalum longibractiatum Jacq.
Resnova humifusa (Baker) U.Müll.-Dublies & D. Müll.-Dublies

ICACINACEAE
#*Apodytes dimidiate* E.Mey. ex Arn.
Pyrenacantha scandens Planch. ex Harv.

JUNCACEAE
Juncus effusus L.[CJW]

LAMIACEAE
#*Clerodendrum glabrum* E.Mey.
Plectranthus fruticosus L.
Plectranthus madagascariensis Pers. Benth. var. *woodii* Benth.
Plectranthus petiolaris E.Mey. ex Benth.[CJW]
Plectranthus verticillatus (L.f.) Druce
Tetradenia riparia (Hochst.) Codd
Teucrium cf. *kraussii* Codd[CJW]

LAURACEAE
#*Cryptocarya woodii* Engl.
**Litsea sebifera* Lam.

MALPIGHIACEAE
#*Acridocarpus natalitius* A.Juss. var. *natalitius*

MALVACEAE
Hibiscus cannabinus L.[CJW]

MELIACEAE
#*Ekebergia pterophylla* (C.DC.) Hofmeyr
**Melia azedarach* L.
Trichilia emetica Vahl
#*Turrea floribunda* Hochst.

MESEMBRYANTHEMACEAE
Aptenia cordifolia (L.f.) Schwantes

MORACEAE
Ficus glumosa Delile
Ficus ingens (Miq.) Miq.
Ficus lutea Vahl

Ficus natalensis Hochst.
#*Ficus polita* Vahl
Ficus sur Forssk.
#*Ficus thoningii*
**Morus alba* L.

MYRTACEAE

#*Eugenia natalitia* Sond.
#*Eugenia* sp. no. (rare endemic)
**Psidium guajava* L.
#*Syzygium cordatum* Hochst. ex C.Krauss.

OCHNACEAE

#*Ochna natalitia* (Meisn.) Walp.

OLEACEAE

#*Schrebera alata* (Hochst.) Welw.

ONAGRACEAE

Ludwigia octovalvis (Jacq.) P.H.Raven

OXALIDACEAE

**Oxalis corniculata* L.[CJW]

PHYTOLACCACEAE

Phytolacca dodecandra L'Hér.

POACEAE

**Coix lacrymaljobi* L.[CJW]
Digitaria cilaris (Retz.) Koeler [CJW]
Digitaria eriantha Steud.
Eleusine indica (L.) Gaertn.[CJW]
Ischaemum fasciculatum Brongn.[CJW]
Eragrostiscurvula (Schrad.) Nees[CJW]
Miscanthus capensis (Nees) Anderson[CJW]
Oplismenus hirtellus (L.) P.Beauv.[CJW]
Panicum aequenerve Nees[CJW]
Panicum hymeniochilum Nees[CJW]
Panicum maximum Jacq.
Panicum schinzii Hack [CJW]
Paspalum distichum L.[CJW]
**Paspalum urvillei* Steud.[CJW]
Paspalum scrobiculatum L.[CJW]
Pennisetum natalense Stapf[CJW]
Phragmites australis (Cav.) Steud.
Pseudochinolaena polystachya (kunth) Stapf[CJW]
Setaria megaphylla (Steud.) T.Durand & Schinz
Sporobous africanus (poir.) Robyns &Tournay [CJW]
Stenotaphrum secundatum (H.Walter) Kuntze[CJW]

POLYGONACEAE
Persicaria decipiens (R.Br.) Wilson [CJW]
*<u>*Persicaria hydropiper*</u> (L.) Spach

RHIZOPHORACEAE
#*Cassipourea malosana* (Bak.) Alston

RUBIACEAE
Burchellia bubalina (L.f.) Sims
#*Canthium ciliatum* (Klotzsch) Kuntze
<u>*Canthium inerme*</u> (L.f.) Kuntze
Kraussia floribunda Harv.
<u>*Lagynias lasiantha*</u> (Sond.) Bullock
#*Pachystigma macrocalyx* (Sond.) Robyns
#*Pavetta bowkeri* Harv.
Pentodon pentandrus (Schumach. & Thonn.) Vatke[CJW]
#*Psychotria capensis* (Eckl.) Vatke
#*Psydrax locuples* (K.Schum.) Bridson
#*Rothmannia globosa* (Hochst.) Keay
Rubia cordifolia L.
#*Tricalysia capensis* (Meisn. Ex Hochst.) Sim
#*Tricalysia lanceolata* (Sond.) Burtt Davy
#*Vangueria infausta* Burch.
<u>*Vangueria randii* S.Moore subsp. *chartacea*</u> (Robyns) Verdc.

RUTACEAE
<u>*Calodendrum capense*</u> (L.f.) Thunb.
#*Clausena anisata* (Willd.) Hook.f. ex Benth.
#*Oricia bachmanii* (Engl.) I.Verd.
<u>*Ptaeroxylon obliquum*</u> Eckl. & Zeyh.
#<u>*Teclea gerrardii*</u> I.Verd.
<u>*Vepris lanceolata*</u> (Lam.) G.Don
Zanthoxylum davyii (I.Verd.) P.G.Waterman

SAPINDACEAE
#*Allophylus africanus* P.Beauv.
#*Allophylus dregeanus* (Sond.) De Winter
#<u>*Hippobromus pauciflorus*</u> (L.f.) Radlk.

SAPOTACEAE
#*Englerophytum natalense* (Sond.) T.D.Penn.
Manilkara discolor (Sond.) J.H.Hemsl.
#*Mimusops caffra* E.Mey. ex A.DC.
<u>*Mimusops obovata*</u> Sond.
#<u>*Vitellariopsis marginata*</u> (N.E.Br.) Aubrév.
<u>*Sideroxylon inerme*</u> L.

SCROPHULARIACEAE

#Annastrabe integerrima E.Mey. ex Benth.

SOLANACEAE
**Solanum mauritianum* Scop.
**Solanum nigrum* L.^{CJW}

STERCULIACEAE
#Cola natalensis Oliv.
<u>*Dombeya tiliacea*</u> (Endl.) Planch.

STRYCHNACEAE
<u>*Strychnos decussate*</u> (Pappe) Gilg
<u>*Strychnos gerrardii*</u> N.E.Br.
#Strychnos henningsii Gilg
#Strychnos unsambarensis Gilg

THYMELACEAE
#Peddiea africana Harv.

TILIACAEAE
#Grewia lasiocarpa E.Mey. ex Harv.
#Grewia occidentalis L.

TYPHACEAE
#Typha capensis (Rohrb.) N.E.Br.

URTICACEAE
Obetia tenax (N.E.Br.) Friis

VERBENACEAE
**Lantana camara* L.

VITACEAE
Cissus fragilis E.Mey. ex Kunth
Cyphostemma hypoleucum Harv. Desc. ex Wild & R.B.Drumm.
<u>*Rhoicissus digitata*</u> (L.f.) Gilg & M.Brandt
#Rhoicissus tomentosa (Lam.) Wild & R.B.Drumm.
#Rhoisissus tridentate (L.f.) Wild & R.B.Drumm.

Total taxa: 243 indigenous plus 24 alien plants (not all alien plants noted)

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