PALEOANTHROPOLOGY

Fire and grass-bedding construction 200 thousand years ago at Border Cave, South Africa

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Early plant use is seldom described in the archaeological record because of poor preservation. We report the discovery of grass bedding used to create comfortable areas for sleeping and working by people who lived in Border Cave at least 200,000 years ago. Sheaves of grass belonging to the broad-leafed Panicoideae subfamily were placed near the back of the cave on ash layers that were often remnants of bedding burned for site maintenance. This strategy is one forerunner of more-complex behavior that is archaeologically discernible from ~100,000 years ago.

About 1 million years ago, an ephemeral fire was lit in Wonderwerk Cave, South Africa (*1*), and traces of fire have been dated to 1.5 million years ago at the open campsite FxJj20 in Koobi Fora, Kenya (*2*). Fire was used in the Spanish rock shelter Cueva Negra del Estrecho del Río Quípar 800,000 years (800 ky) ago (*3*), and it was used 780 ky ago at the open-air site Gesher Benot Ya'akov, Israel (*4*). These rare early occurrences suggest the expedient harvesting of fire—for example, from lightning strikes—whereas stacked hearths and evidence for multiple uses of heat imply the ability to produce fire at will. After ~400 ky ago, fire appeared regularly in archaeological sites (*5*–*8*), where it was probably used for cooking, heating, light, socializing, and protection from predators.

In this work, we present evidence for other uses of fire, and its products, before 200 ky ago. People inhabiting Border Cave, South Africa, systematically placed floor coverings (bedding) of broad-leafed grass above ash layers, set hearths nearby, and occasionally burned their bedding. Before this discovery, the oldest-known plant bedding was 77 ky old from Sibudu, South Africa (*9*), and younger examples were found to occur in other archaeological sites (*10*–*12*). At Sibudu, layered sedge was garnished with medicinal plants, and stale bedding was sometimes burned (*9*). Border Cave data indicate that such practices began far earlier.

Border Cave is located in the Lebombo Mountains of KwaZulu-Natal, on the eSwatini border (fig. S1). Excavations between 2015 and 2019 (*13*) (Fig. 1A) have yielded archaeobotanical data (*14*) not retrieved previously (*15*). The cave was occupied intermittently from before 227 ky ago until ~1000 CE (*16*) (table S1), and it is made up of alternating brown sand (BS) and white ash (WA) stratigraphic members (*15*). Member 6 Brown Sand (6 BS) rests on cave bedrock (Fig. 1B and fig. S2). Above this is Member 5 White Ash (5 WA), the base and top of which have ages of 227 ± 11 and 183 ± 20

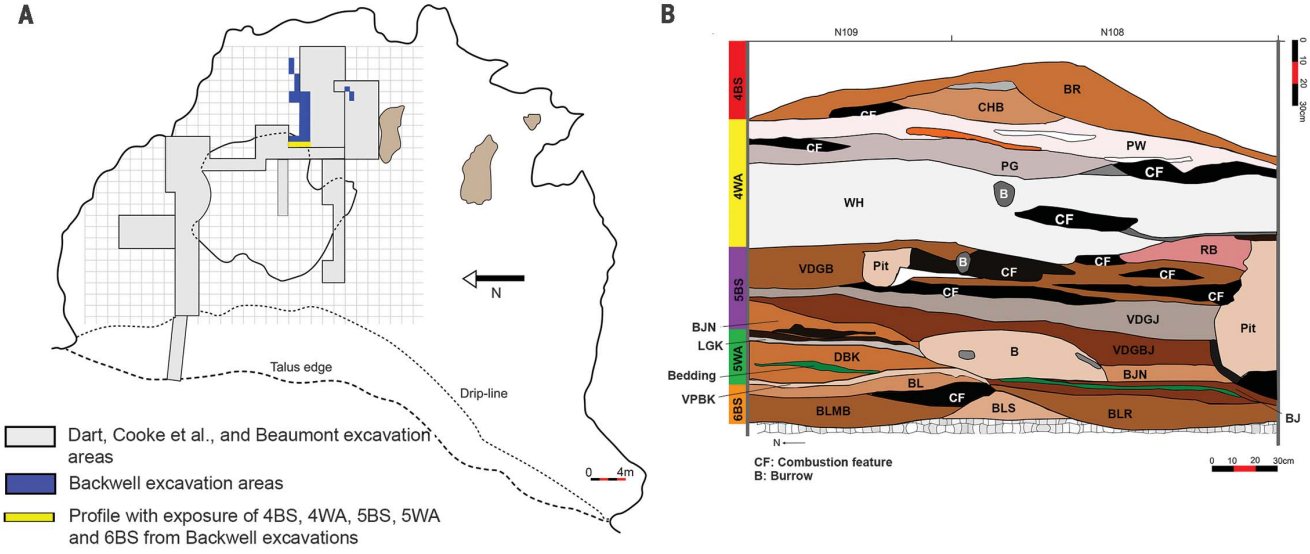

Fig. 1. Border Cave plan and stratigraphy. (**A**) Plan of Border Cave marking excavation areas. The profile featured in (B) (*13*) is shown in yellow. (**B**) East profile stratigraphy in squares N109, E113 and N108, E113. The thickest 5WA-DBK bedding is green, but the entire layer contains silicified grass fragments (see Fig. 4). Large combustion features (CFs), but not small ones (as shown in Fig. 4), are illustrated here. 4WA-WH comprises 12 superimposed layers of ash. Scale bar, 30 cm. For greater detail, see fig. S2; for profiles of more recent layers, see (*13*). B, burrow; BR, Brown; CHB, Chocolate Brown; PW, Pinkish White; PG, Pinkish Gray; WH, White; RB, Reddish Brown; VDGB, Very Dark Grayish Brown; VDGJ, Very Dark Grayish Jez; VDGBJ, Very Dark Grayish Brown Jim; BJN, Brown John; LGK, Light Gray Kelly; DBK, Dark Brown Kevin; VPBK, Very Pale Brown Kim; BJ, Brown Jolly; BL, Brown Lad; BLR, Brown Larry; BLS, Brown Lassy; BLMB, Brown Lamb.

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(means and standard error) ky ago, respectively (*17*). 6 BS is undated, so the start date of >300 ky ago for 5 WA that has been suggested by Bayesian modeling may be overestimated (*18*). Hearths, ash layers (fig. S2), and grass bedding (table S2) are visible throughout the Border Cave sequence (*13*). Stratigraphic profiles (*13*) show that bedding of all ages is generally located in the warm rear of the cave, and hearths often abut beds so that grass ends are scorched. Nonetheless, accidental incineration of beds was probably infrequent because most are desiccated, not burned (table S2). Thick ash in the cave center [for example, 4WA-WH (Member 4 White Ash, layer White) in Fig. 1B] confirms repeated fire making there by 170 ky ago, perhaps for protection from predators, but likely also for domestic uses, such as cooking and sharing *Hypoxis* rhizomes (*14*).

The oldest recovered bedding is from Member 5 WA, layer Dark Brown Kevin (5WA-DBK). In large-scale, rapid excavations of the past century, this material was largely removed but not recorded; therefore, site-wide spatial inferences must be made cautiously. Organic material degrades over time (*19*, *20*), so 5WA-DBK bedding survives as visually ephemeral fragments of silicified plant (Fig. 2, A, B, and C, and fig. S3). Its original appearance is exemplified by younger bedding features that are better preserved (Fig. 2D).

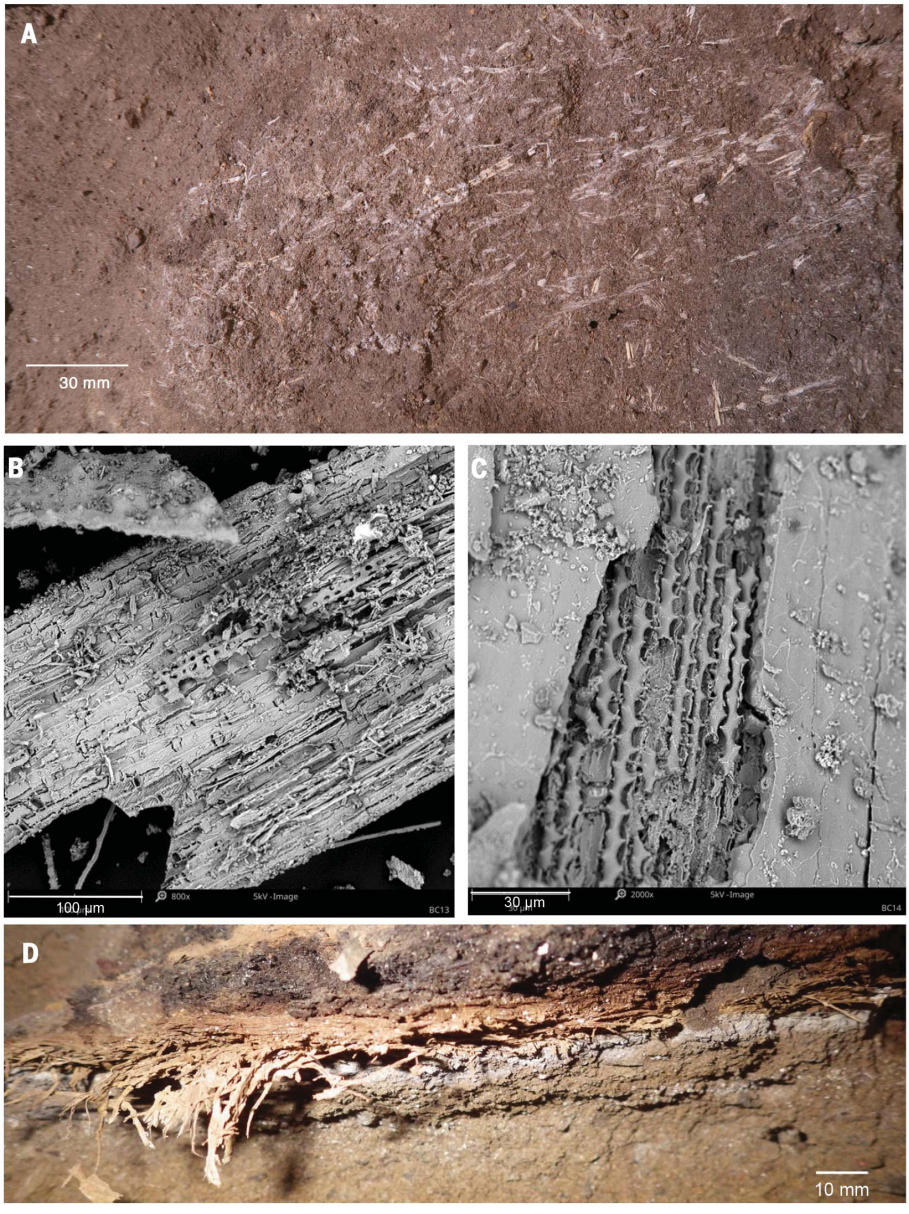

Fig. 2. Border Cave plant bedding from 5WA-DBK and 1 WA. (**A**) Horizontal field view of silicified bedding in 5WA-DBK. Scale bar, 30 mm. (**B** and **C**) SEM images of grass fragments from (A). Scale bar in (B), 100 µm. Scale bar in (C), 30 µm. (**D**) Vertical field section of desiccated bedding grass on Member 1 WA ash (~43 ky old). 5WA-DBK bedding may have looked like this 200 ky ago. Scale bar, 10 mm.

Grass in 5WA-DBK bedding was identified further by Fourier transform infrared (FTIR) spectroscopy, scanning electron microscopy (SEM), and phytolith analysis (*16*) (Fig. 3, figs. S4 to S14, and tables S3 to S6). Silicified plant fragments viewed at high magnification using SEM (*16*) reveal grass anatomy (Fig. 3, A and C). Phytolith analysis confirms the presence of prickles, stomata, and epidermal long and short cell bilobates that characterize the Panicoideae subfamily of grasses (Poaceae), especially *Melinis repens* (Willd.) Zizka, *Setaria pallide-fusca* (Schumach.) Stapf & C.E. Hubb., *Panicum maximum* Jacq., *Panicum deustum* Thunb., and *Themeda triandra* Forssk. (*16*) (Fig. 3, B and D, and fig. S14). The Border Cave phytolith concentration exceeds that from other archaeological sites (*12*, *16*) (tables S5 and S7), and we infer intentional, intensive grass accumulation. Moreover, dicotyledonous epidermal leaf fragments, mostly lying on grass as articulated phytoliths, comprise at least three cell shapes, which implies the presence of several unidentifiable species. Charcoal in bedding (table S8) includes *Tarchonanthus trilobus* DC (broad-leaved camphor-bush) that has aromatic leaves like those from *T. camphoratus*, which is used as insect repellent in modern plant bedding in Africa (*21*). The identified grass and woody species still grow in woodland near the cave (supplementary text).

Thin sections made from 5WA-DBK sediment reveal details of the layered ash and plant material at millimeter scale (Fig. 4, C, D, E, and F, and fig. S15), which implies multiple phases of hearth and bed construction. Charred grass, charcoal, ash, and calcined bone fragments in some 5WA-DBK bedding phases (*16*) (Fig. 4, fig. S15, and supplementary text) imply that these beds were occasionally burned for site maintenance before being refreshed [as described in (*22*, *23*)]. 5WA-DBK sediments are compressed against underlying ashy layer 5WA-VPBK (Member 5 WA, layer Very Pale Brown Kim). Both layers, especially 5WA-VPBK, are silicate- and apatite-rich (this includes carbonated hydroxyapatite) (figs. S5 to S7). The ash of *Panicum maximum*, one likely bedding grass at Border Cave, contains apatite among other minerals (*16*, *24*) (fig. S9). The chemical content and high phytolith concentration in 5WA-VPBK (tables S3 to S5) imply burning of grass bedding there too (*16*). The chemistry might also signal the presence of bone, guano, or diagenetically altered calcite (*16*, *25*, *26*). Calcite is a better-known component of ash than apatite, and in bedding younger than that found in 5WA-DBK, layers of calcitic ash underlie desiccated grass bedding (*16*) (fig. S8). Although this is probably wood ash, we must be circumspect because ash studied

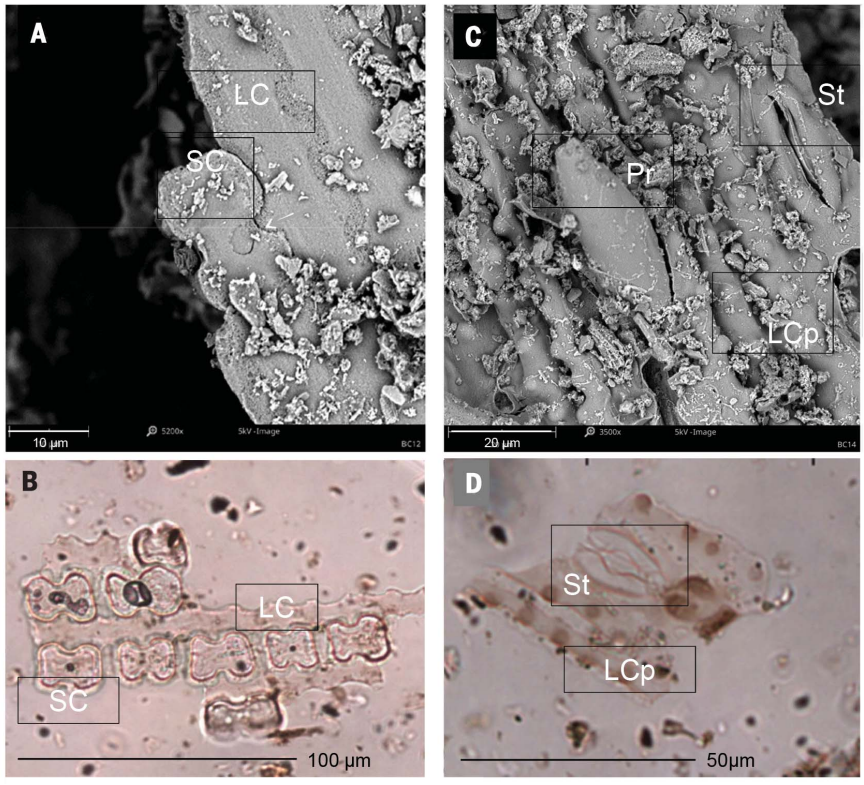

Fig. 3. Silicified Panicoideae grass remains from plant bedding in 5WA-DBK. (**A**) SEM image of silicified grass epidermis showing articulated short cell bilobate and epidermal ong cells. Scale bar, 10 µm. (**B**) Microphotograph of silicified grass epidermis showing articulated short cell bilobate and epidermal long cells. Scale bar, 100 µm. (**C**) SEM image of silicified grass epidermis showing articulated epidermal long cells with papillate ornamentation, prickle, and stomata. Scale bar, 20 µm. (**D**) Microphotograph of silicified grass epidermis showing articulated epidermal long cells with papillate ornamentations and stomata. Scale bar, 50 µm. LC, long cell; LCp, long cell papillate; SC, short cell; Pr, prickle; St, stomata.

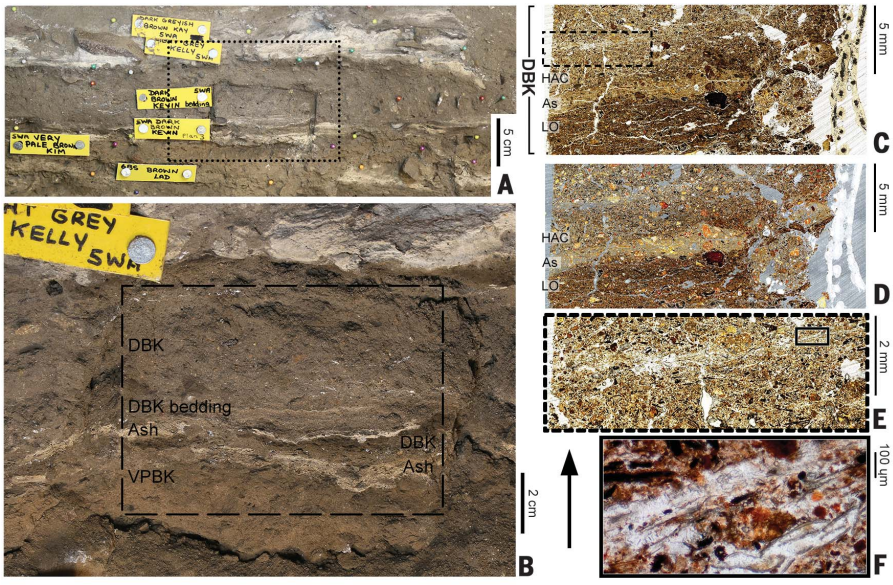

Fig. 4. Border Cave plant bedding observed in the field and in thin sections of 5WA-DBK sediment. (**A**) East profile of part of the stratigraphy from Fig. 1B. Scale bar, 5 cm. (**B**) Magnified image of 5WA-DBK stratigraphy showing the position of the micromorphological sample (black-dashed square). Scale bar, 2 cm. (**C** and **D**) Microphotographs of 5WA-DBK thin section 1/1. Microfacies include homogeneous anthropogenic components (HACs), ash (As), and dark brown laminar units rich in organic matter (LOs) (*16*). Image in (C) was taken with plane polarized light (PPL) and that in (D) with cross-polarized light (XPL) (*16*). Scale bars, 5 mm. (**E**) Magnified microphotograph of silicified, laminar bedding in black-dashed square in (C), taken with PPL. Scale bar, 2 mm. (**F**) Magnified image of plant remains in solid black square in (E), taken with PPL. Further detail is available in the supplementary text and fig. S15. Scale bar, 100 µm.

from 35 European plant species revealed diverse chemical compositions (*27*). Ash was possibly raked from hearths to create a clean, odor-controlling base for bedding. We speculate that such placement of bedding, as well as that on the ashes of previously burned bedding, was deliberate, because several ethnographies report that ash repels crawling insects, which cannot easily move through fine powder because it blocks their breathing and biting apparatus and eventually leaves them dehydrated (*28*).

Stone flake and blade manufacture (tables S9 and S10 and figs. S16 and S17) on 5WA-DBK bedding surfaces demonstrate their occasional use as workspace. The lithics described here cannot be assigned to a specific industry, but they resemble those in the 1987 Member 5 WA collection, labeled MSA 1 (*29*), from which a few pieces of ochre were also recovered. In 5WA-DBK bedding, red and orange ochre grains are up to 37 times as frequent as in over- and underlying layers, and they are smaller and rounder than the dark red, angular fragments from cave roof detritus that provides an ochre source (figs. S18 and S20 and tables S11 to S13). This evidence, together with reports of regular ochre use in Africa from ~300 ky ago (*30*), supports the hypothesis that 5WA-DBK ochre particles were processed

anthropogenically and became detached from objects or human skin when people used the bedding. Elemental and mineralogical analyses cannot distinguish grains from bedding and those from over- and underlying layers (figs. S20 to S22 and tables S14 to S17), so either people collected and processed ochre from the cave rock or the 5WA-DBK grains have a natural origin that we cannot explain.

Modern hunter-gatherer camps have fires as focal points; people regularly sleep alongside them and perform domestic tasks in social contexts (*31*, *32*). People at Border Cave also lit fires regularly, as seen throughout the sequence (*13*) and not only in the layered ash and grassy sediment of 5WA-DBK. Before 200 ky ago, close to the origin of our species, people could produce fire at will and used fire, ash, and medicinal plants to maintain clean, pest-free camps. Although hunter-gatherers are characteristically mobile, cleansing camps can extend their potential for occupancy. The simple strategies inferred from the Border Cave data not only broaden our knowledge of lifeways in the remote past, but they also suggest an early potential for the cognitive, behavioral, and social complexity that is more widely evident in innovative material culture from ~100 ky ago (*33*).

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SUPPLEMENTARY MATERIALS

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Materials and Methods
Supplementary Text
Figs. S1 to S22
Tables S1 to S17
References (*34*–*96*)

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Bedding of grass and ashes

The Border Cave site in the KwaZulu-Natal region of South Africa has been a rich source of archaeological knowledge about Stone Age humans because of its well-preserved stratigraphic record. Wadley *et al.* now report the discovery of grass bedding in Border Cave, dated to approximately 200,000 years ago. The bedding, identified with a range of microscopic and spectroscopic techniques, was mingled with layers of ash. It also incorporated debris from lithics, burned bone, and rounded ochre grains, all of which were of clear anthropogenic origin. The authors speculate that the ash may have been deliberately used in bedding to inhibit the movement of ticks and other arthropod irritants. These discoveries extend the record of deliberate construction of plant bedding by at least 100,000 years.

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