Border Cave: A 227,000-year-old archive from the southern African interior

Lucinda Backwell[a, b, c *], Lyn Wadley[b], Francesco d'Errico[d, e], William E. Banks[d, f], Paloma de la Peña[b, c, g], Dominic Stratford[h], Christine Sievers[h], Ghilraen Laue[h, i], Bawinile Vilane[j], Jamie Clark[b, k], Chantal Tribolo[l], Amélie Beaudet[h, m, n], Tea Jashashvili[o, p], Kristian J. Carlson[o, b], Sandra Lennox[b], Irene Esteban[q, b, r], Guilhem Mauran[b]

[a] *Instituto Superior de Estudios Sociales (ISES-CONICET), San Lorenzo 429, San Miguel de Tucumán, CP4000, Tucumán, Argentina*

[b] *Evolutionary Studies Institute, University of the Witwatersrand, Private Bag 3, WITS, 2050, South Africa*

[c] *Centre of Exploration for the Deep Human Journey, University of the Witwatersrand, Private Bag 3, WITS, 2050, South Africa*

[d] *Université de Bordeaux, CNRS, MCC, PACEA, UMR 5199, Allée Geoffroy Saint Hilaire, CS 50023, F - 33615, Pessac CEDEX, Talence, France*

[e] *Centre for Early Sapiens Behaviour, Øysteinsgate 3, Postboks 7805, 5020, University of Bergen, Norway*

[f] *Biodiversity Institute, University of Kansas, Lawrence, KS, 66045-7562, United States of America*

[g] *McDonald Institute for Archaeological Research, University of Cambridge, Downing Street, Cambridge CB2 3ER, United Kingdom*

[h] *School of Geography, Archaeology and Environmental Studies, University of the Witwatersrand, Private Bag 3, WITS, 2050, South Africa*

[i] *KwaZulu-Natal Museum, 237 Jabu Ndlovu Street, Pietermaritzburg, KwaZulu-Natal, 3201, South Africa*

[j] *Amafa Heritage AkwaZulu Natali, 195 Langalibalele Street, Pietermaritzburg, 3201, South Africa*

[k] *Department of Sociology and Anthropology, George Mason University, MSN 3G5, Fairfax, Virginia 22030-4444, United States of America*

[l] *Archéosciences Bordeaux, UMR 6034, CNRS-Université Bordeaux Montaigne, Maison de l'Archéologie, Esplanade des Antilles, 33607, Pessac, France*

[m] *Department of Archaeology, University of Cambridge, Downing Street, Cambridge CB2 3DZ, United Kingdom*

[n] *Institut Català de Paleontologia Miquel Crusafont, Universitat Autònoma de Barcelona, Edifici ICTA-ICP, Campus de la UAB. c/ de les columnes s/n, 08193 Cerdanyola del Vallès, Barcelona, Spain*

[o] *Department of Integrative Anatomical Sciences, Keck School of Medicine, University of Southern California, Los Angeles, CA, 90033, USA*

[p] *Department of Geology and Paleontology, Georgian National Museum, Rustaveli Avenue 3, Tbilisi, 0105, Georgia*

[q] *ERAAUB, Dept. de Història i Arqueologia, and Institut d'Arqueologia de la Universitat de Barcelona, Carrer de Montalegre 6-8, 08001, Universitat de Barcelona, Barcelona, Spain*

[r] *African Centre for Coastal Palaeoscience, Nelson Mandela University, Port Elizabeth, South Africa*

* Corresponding author: lucinda.backwell@wits.ac.za

Abstract

In 2015, which marked 35 years since Beaumont had worked at the site, we renewed excavations at Border Cave. Our primary aims were to reassess the stratigraphic context of the sedimentary and cultural sequence, gain insight into site formation processes, make a detailed study of organic remains, identify long term cultural trends, and characterize expressions of complex behaviour and innovation. This contribution serves as an update on activities conducted in 2018 and 2019 and provides an overview of our research findings to date, placing them in the broader context of the Middle Stone Age in southern Africa. New luminescence ages based on feldspar grains in the sedimentary sequence are in broad agreement with the previous chronology established for the site. Geoarchaeology and faunal taphonomy have started to elucidate site formation processes, showing that the members should not be considered as homogeneous units, and that associated formation interpretations established by Beaumont are simplifications that are not representative of the diverse site formation processes active in the shelter. This finding is supported by lithic analysis of the Member 2 WA assemblage that shows differences in technology between artefacts from the top, middle, and lower part of the same member. In addition, the lithic artefacts from the middle and lower part of Member 2 WA show continuities with the lithics from the underlying Members 3 BS and 1 RGBS, which were attributed by Beaumont to a different industry. Grass mats/bedding layers are preserved throughout the sequence, the oldest of which dates to ~200 ka. The use of ash and leaves with insecticidal properties in the bedding construction reflects complex cognition, as does the cooking of starchy rhizomes that come from layers dated to 170 ka. In addition to a rich mammal fauna found in all of the deposits, the remains of a new individual, a 3–4-year-old child, were recovered from Member 1 BS.LR C that has an ESR date of 42.6 ka.

Keywords: Middle Stone Age, cave deposit, excavation, organic preservation, behavioural complexity, cultural innovation, modern human remains

1. Introduction

Symbolic and abstract thought, planning and technological innovation certainly developed in Africa in Middle Stone Age (MSA) contexts, but the criteria used to identify complex cognition, the timing and geographic distribution of its emergence, mode and tempo of its evolution, and whether it is specific to anatomically modern humans are the subject of ongoing debate (e.g. Chazan and Horwitz, 2009; d'Errico et al., 2009, 2012a, 2017; d'Errico and Stringer, 2011; Henshilwood et al., 2002; Klein, 2001; McBrearty and Brooks, 2000; Zilhão et al., 2010; Villa and Roebroeks, 2014; Brooks et al. 2018; Mellars, 1991; Stringer, 2002; Marean et al., 2007; Wadley, 2013; Kissel and Fuentes, 2018; Wilkins and Chazan, 2012; Wilkins et al., 2021). Early evidence of complex behaviour and symbolism is found at a handful of sites dotted across the African continent and in the Near East from about 100 ka in the form of pigment use, beads, formal bone tools and burials. Border Cave records all of these lines of evidence in older and younger deposits. With an intermittent Stone Age sequence that spans ~227 thousand years ago (ka) to 24 ka (Vogel and Beaumont, 1972; Beaumont et al., 1978; Beaumont, 1980; Vogel et al., 1986; Miller and Beaumont, 1989; Miller et al., 1999; Beaumont et al., 1992; Grün and Beaumont, 2001; Bird et al., 2003; Grün et al., 2003; Millard, 2006; d'Errico et al., 2012a; Villa et al., 2012; Backwell et al., 2018), the site has recently added entries to the list of criteria that can be considered as evidence of behavioural complexity: grass and ash bedding construction at ~200 ka (Wadley et al., 2020a) and transport and sharing of cooked starchy rhizomes at 170 ka (Wadley et al., 2020b). Our research at the site supplements previous work carried out since 1934 by Dart, Malan, Beaumont and their colleagues. It presents evidence that behaviour similar to our own emerged in the archaeological record earlier than was previously thought.

Our ongoing excavations, which commenced in 2015, are located mostly along the North section of Beaumont's excavation 3A rear (Figure 1). Most of the upper layers were excavated by Beaumont, which enabled us to sample from the youngest sediments with cultural material that Beaumont interpreted as Early Later Stone Age (ELSA) to the oldest deposits on bedrock near Horton's pit in the centre of the cave. Our long-term aims are to (1) identify when complex behaviour emerged at the site, and examine how it was expressed through time; (2) produce a high-resolution multi-proxy record of climate change and contemporaneous human behaviour that extends from MIS 7 to MIS 2; (3) contribute to an understanding of the impact of climate change on subsistence strategies in this region through time; (4) gain further insight into site formation processes; (5) identify cultural trends within a secure chronological framework; (6) document the emergence of cultural innovations, and (7) characterise the nature and variability of burial practices in the Stone Age. Here we report on the new excavations and research, and investigate the vertical distribution of finds to gain insight into site formation processes, occupation intensity, and elements of cultural expression through time. This contribution, which serves as an update on Backwell et al. (2018), also highlights the potential of the site to answer standing and new scientific questions.

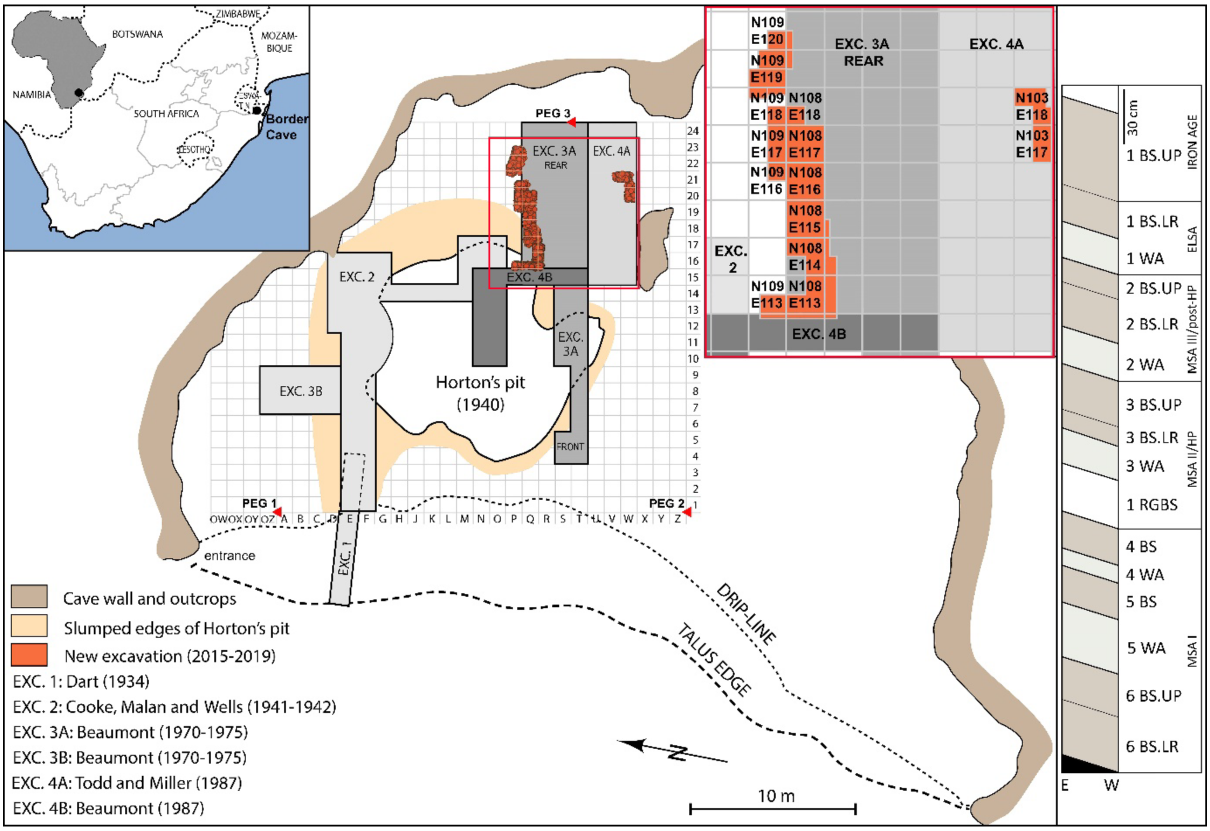

Fig. 1. Location of Border Cave and a site plan showing the position of the various excavations from 1934 to 2019. The orange overlay shows the position of point-plotted artefacts in excavations conducted by us from 2015 to 2019 along the North wall of excavation (EXC.) 3A and South wall of EXC. 4A. The red frame demarcates the area shown in the inset (top right), which provides the square names excavated by us according to North and East lines. The grid is the original one established by Cooke et al. (1945) in yards and followed by Beaumont (1973, 1978, 1980), Beaumont et al. (1978), Butzer et al. (1978), Grün and Beaumont (2001) and Grün et al. (2003). Our work is metrically calibrated, so it does not follow the original grid precisely. Stratigraphic members and associated cultural attributions (Beaumont et al., 1992) are shown in the column on the right. The alternating tan and off-white colours denote Brown Sand and White Ash members, and the sloped dividing lines represent the dip of the deposit. See Table 1 for the layers found within each member. **Double column figure**

1.1. *Site location*

Border Cave is situated in KwaZulu-Natal (27°1'19"S, 31°59'24"E) 82 km from the Indian Ocean (Figure 1). Located in the Lebombo mountain range below the rim of an escarpment at an elevation of *c*. 600 m above sea level, the cave faces West, overlooking eSwatini (formerly Swaziland). The shelter is semi-circular in shape and approximately 50 m wide by 35 m long. The cave formed in the Lower Jurassic felsic extrusive rocks of the Jozini Formation, Lebombo Group, approximately 182.1 ± 2.9 mya (Riley et al., 2004). Two volcaniclastic facies of the Jozini Formation are exposed in the cave: a clast- and a matrix-supported flow breccia. The cave formed through the weathering of these rocks (Cooke et al., 1945; Backwell et al., 2018).

1.2. *Pre-2015 excavations*

The first excavation campaign took place in 1934 when Dart dug a narrow East-West trench to bedrock at the entrance to the shelter (Figure 1, EXC. 1). The 168 cm-thick sequence and the material it yielded were never published. From what was published later (Cooke et al., 1945), it seems that some Iron Age (IA) artefacts were recovered at the top of the sequence, while MSA ones were retrieved in the layers below. There is no record stating where this material is stored. In 1940 W. E. Horton dug an enormous pit in the centre of the cave deposit, ostensibly to extract bat guano. He removed most of the upper layers down to what is now called Member 4 WA. In this non-archaeological excavation, Horton uncovered archaeological and human remains, namely BC1, an adult partial cranial vault and the shafts of two femora and tibiae, likely belonging to the same individual, and BC2, a partial adult mandible (Cooke et al., 1945; Beaumont, 1978). The femora and tibiae have since been lost (de Villiers, 1973), but the cranial remains are stored in the Evolutionary Studies Institute at the University of the Witwatersrand in Johannesburg, South Africa.

These discoveries prompted a second archaeological excavation, conducted by Cooke, Malan and Wells (1945), which linked Dart's trench and Horton's pit (Figure 1, EXC. 2). They discovered an infant burial (BC3) with a *Conus* shell originally covered in ochre (d'Errico and Backwell, 2016), and recovered additional human remains from Horton's dump, which they attributed to the MSA. Because Cooke et al. (1945) excavated after Dart, the stratigraphy they provided followed Dart's (Table 1). According to Beaumont (1978), the material recovered was transferred to the University of the Witwatersrand. The BC3 infant and other human remains still reside there, but the rest of the Cooke et al. collection was later moved to the McGregor Museum in Kimberley, Northern Cape Province, South Africa, where it is currently housed (Table 2). There are 25 boxes named "Malan". Apart from Beaumont, who included some of it in his work after inferring its likely stratigraphic context within the sequence (Beaumont, 1978), this assemblage has not been studied.

The third excavation episode, carried out by Beaumont between 1970 and 1975, took place in three different areas (EXC. 3A Front, EXC. 3A Rear and EXC. 3B, Figure 1). It revealed a 4 m-deep sedimentary sequence comprising alternating units of brown sand (BS) and white ash (WA) (Beaumont, 1973; Butzer et al., 1978). From the bottom to the top the sequence includes MSA lithic assemblages initially attributed by Beaumont to the Pietersburg Industry but later assigned to MSA I, MSA II/Howiesons Poort (HP) and MSA III/post-HP, and an unusually early Later Stone Age assemblage termed ELSA. The ELSA layers are overlain by a thick, virtually sterile deposit, itself capped by Iron Age deposits. BC4, an Iron Age skeleton missing the skull, was found in layer 1 BS.UP outside the grid area and near the surface in the southern part of the cave and has been directly dated to 340 ± 45 ^{14}C BP (Pta-777) and 480 ± 45 ^{14}C BP (Pta-1318) (Beaumont et al., 1978; Beaumont, 1980; Vogel et al., 1986). BC5 is a nearly complete adult mandible found by Powell and Beaumont in 1974 while collecting sediment samples. It comes from the South section of excavation 3A, just above the base of undisturbed 3 WA (Figure 1). It was found close to a sub-circular shallow depression apparently dug into lower level 4 BS with an electron spin resonance (ESR) age of 74 ± 4 ka (Grün et al., 2003). BC6 (humerus), BC7 (proximal ulna), BC8a and BC8b (two metatarsals) were recovered from disturbed deposits (Grün and Beaumont, 2001) and have since been lost. All human remains retrieved from Border Cave are anatomically modern (Rightmire, 1989; Grün and Beaumont, 2001; Grün et al., 2003). As with the faunal remains, the bones are not fossilised. The human remains are housed at the Evolutionary Studies Institute, together with 72 boxes of material. Of the 72 boxes, one contains feathers (excavation 3A Rear and Front), one contains a basket (excavation 3A Rear) and 70 contain animal bones. Among these 70 boxes, 61 come from excavation 3A Rear, three from excavation 3A Front, and six from excavation 3B. The rest of the material recovered from this excavation campaign is stored at the McGregor Museum in Kimberley, where there are 97 boxes under the name of Beaumont for the period 1970-1975.

The fourth excavation episode (EXC. 4A and EXC. 4B, Figure 1), conducted in 1987 by Beaumont, Todd and Miller significantly expanded excavation 3A (Beaumont et al., 1992). Excavation 4A focused on expanding the upper layers of Beaumont's sequence, while excavation 4B mainly focused on connecting excavation 3A to excavation 2. These excavations led to some name changes in the stratigraphic sequence. BACO layers A-D, initially named by Beaumont during his first campaign, were refined into units referred to as Members 5 WA, 5 BS, 6 BS.UP and 6 BS.LR (Table 1). The BACO A unit was divided in two, with the upper part corresponding to 4 WA and the lower part forming the new Member 5 BS. BACO B was renamed 5 WA and BACO C and D were respectively renamed 6 BS.UP and 6 BS.LR (Beaumont et al., 1992). Other name changes were 1 BS.UP.S to 1 BS.LR A, and 1 GBS to 4 BS. During these excavations, tooth enamel from the sequence was extensively dated (Grün and Beaumont, 2001; Grün et al., 2003; Millard, 2006; Bird et al., 2003). MSA and ELSA lithic assemblages from these excavations have been documented by Villa and colleagues (2012), and d'Errico and colleagues (2012a) have described contemporaneous organic artefacts. The material excavated during this episode is stored at the McGregor Museum in Kimberley. There are three boxes named Beaumont 1987 and seven boxes named Todd 1987, as well as 137 unmarked boxes that are either from the 1987 campaign or Beaumont's 1970s excavations.

The Border Cave sequence has been dated by ESR (Grün and Beaumont, 2001; Grün et al., 2003; Millard, 2006), amino acid racemisation (Miller and Beaumont, 1989; Miller et al., 1999), and radiocarbon methods (Vogel and Beaumont, 1972; Beaumont et al., 1978; Beaumont, 1980; Vogel et al., 1986; Beaumont et al., 1992; Bird et al., 2003; d'Errico et al., 2012a; Villa et al., 2012; Backwell et al., 2018), see Table 3. A new chronology for the site is presented by Tribolo and colleagues (this volume) and we refer to the new dates in the Discussion section of this manuscript. ESR results indicate that the members that Beaumont assigned to MSA I (5 WA, 5 BS, 4 WA, 4 BS) span 238 ka to 71 ka when minimum and maximum standard deviations are included. Beaumont's MSA II/HP members (1 RGBS, 3 WA, 3 BS) range between 82 ka and 54 ka, and the MSA III (post-HP) members (2 WA; 2 BS.LR C, B and A; 2 BS.UP) fall between 63 ka and 42 ka (Table 3). Although the radiocarbon ages for the lower post-HP members 2 WA, 2 BS.LR C and 2 BS.LR B (60–49 ka C14 BP) fall outside the range of the IntCal09 calibration curve, which makes it problematic to interpret them in terms of calendar years, they appear in broad agreement with the range proposed by ESR for these deposits. Member 2 WA is dated to 60 ka BP. Bayesian modelling of calibrated radiocarbon ages indicate that Member 2 BS.LR A is older than 49 ka BP, and Member 2 BS.UP accumulated between 49 ka and 45 ka BP (d'Errico et al., 2012a).

Cultural material from 1 WA and 1 BS.LR has previously been attributed to the ELSA (Beaumont, 1978; Villa et al., 2012). Recent studies, conducted before the new excavation campaign, have implied the onset of the ELSA at the site around 44 ka (d'Errico et al., 2012a;

Villa et al., 2012; Backwell et al., 2018). Member 1 BS.LR C is dated 42.6 ka, 1 BS.LR B is dated 42.3 ka, and 1 BS.LR A dates to between 41.5 ka and 24 ka (Table 3). Bayesian modelling of calibrated radiocarbon ages suggests that Member 1 WA accumulated between 44 ka and 43 ka BP, 1 BS.LR C and B between 43 ka and 42 ka BP, and 1 BS.LR A between 41 ka and 22 ka BP (d'Errico et al., 2012a).

Excavations by Cooke, Malan and Wells (1945), and later by Beaumont (1978) document the presence of Iron Age deposits. The Iron Age deposits correspond to Member 1 BS.UP.IA with some possible local intrusion into Member 1 BS.UP.S in EXC. 2 and EXC. 3 (Beaumont, 1978). Excavation in arbitrary spits prevented appropriate isolation of the Iron Age stratigraphic units. These deposits have yielded ceramic sherds, smelted artefacts, metal and glass beads, matting, basketry, bovid faeces, and goat pellets. The Iron Age is dated by radiocarbon to 590 ± 70 BP (Beaumont, 1978).

1.3. *2015-2017 excavations*

Excavation activities conducted from 2015 to 2017 are reported in Backwell et al. (2018), and briefly summarised here. To reassess the stratigraphic context of the sedimentary and cultural sequence, we decided to excavate part of the northern face of Beaumont's excavation 3A because it provided a good lateral profile of the upper members and was stepped down from the back to the front of the cave, which enabled us to sample the sequence without having to excavate each square from surface level (Figure 1). We also decided to excavate part of the eastern edge of excavation 4B, which preserved the lower members to bedrock (Figure 1). Once the profiles had been cleaned, we were able to identify the alternating brown sand and white ash units to which Beaumont (1973) and Butzer et al. (1978) attributed member names. We established a new grid tied into the original datum (pegs 1, 2 and 3 in Figure 1), which is now mapped with a total station theodolite. Our grid is aligned with the previous excavation grid, but it is not a perfect fit due to the change in 1965 from the British Imperial System (inches, feet, yards) to the Metric one (metres and centimetres). The difference can be seen in Figure 1 in the number of grid squares between the two areas that we have excavated. If one counts the squares in yards in ascending order to the left, one will see that the distribution of point-plotted artefacts does not correspond with the original grid squares. We introduced different square names from those used by Cooke and Beaumont. Our squares are named according to North and East lines. All layers, finds, and features were recorded using a total station theodolite calibrated to a local spatial grid. The total station was used in conjunction with digital photographs of excavated areas and profiles for conversion into 3D models (photogrammetry). Each specimen measuring over 2 cm in maximum dimension was surveyed with the total station and allocated a unique total station number that serves as the catalogue number. Artefacts smaller than 2 cm were collected with the excavated sediment in buckets and each bucket was allocated a total station point number. In our database they are referred to as bucket points (BP). Our excavations were in seven squares: E120, E119, E118, E117 and E113 on line N109, and E115 and E113 on line N108 (Figure 1). Squares E120 and E119 were at the top of the sequence in deposits that Beaumont had called Member 1 BS.LR C, 1 WA (ELSA) and 2 BS (MSA III/post-HP). Squares E118 and E117 in the middle portion of the North profile, were in Beaumont's Members 2 BS.LR, 2 WA (MSA III/post-HP), and 3 BS (HP). Square E115 sampled the base of Member 3 BS and 1 RGBS (HP). The E113 squares on the East profile sampled Members 4 BS, 4 WA and 5 BS (MSA I).

In Backwell et al. (2018) we report that the lithic sample retrieved was small and thus it was not possible to determine to what extent the industries named in previous publications correspond with the newly excavated material. We did find, however, that the highest number of blades and blade fragments were found in Members 4 WA, 5 BS and 2 BS.LR, and that fewer blades occur in 3 BS, 3 WA and 1 RGBS which Beaumont described as HP members.

However, one would expect to encounter a bladelet and blade-rich technology in the HP, and we did not find such an assemblage. In Square N108 E115 in Member 3 BS, there were several *Levallois* cores, but because of the small sample size it was not possible to determine whether *Levallois* technology is chronologically restricted. A preliminary study showed technological differences within the same member, for example, the Lower and Upper layers in Member 2 BS have different lithic profiles. The differences might correspond to functional variability within the same cultural tradition, but it could also mean that the original grouping of layers into larger members was incorrect. This finding highlighted the need to study the lithic material according to groups of stratigraphically related layers rather than by Beaumont's member classification. The analysis showed that the main rock types knapped at the site are rhyolite, quartzite, basalt, agate, chalcedony, and quartz (automorphic and xenomorphic). Rhyolite is the most abundant rock knapped in all of the members.

Insight into site formation processes was provided through evidence of erosion in the form of channels caused by low energy water flow in Member 2 WA. A number of examples were observed in profiles showing that they originated at the back of the cave and flowed downslope. Other disturbance to the sediments included rodent and insect burrows, trampling, and sedimentary contacts indicative of active slope processes. Micromorphology samples of the sequence were taken from refreshed profiles using gypsum jackets. Once in the laboratory, the samples were impregnated with resin to produce thin sections for study. Fourier Transform Infrared Spectroscopy (FT-IR) analysis using a portable instrument was conducted at the site and in the laboratory, and the results of sediment samples analysed were reported in Backwell et al. (2018). The preliminary results showed variation in gypsum and calcite content within and between layers in Members 5 BS, 2 WA and 2 BS, indicating that the sediments have different moisture regimes spatially and chronologically, and demonstrating that FT-IR is a good complement to geoarchaeological techniques used to study site formation processes (Karkanas et al., 2000).

Palaeobotanical remains in the form of grass, seeds, rhizomes, wood, and charcoal were retrieved throughout the sequence. Seventeen grass mat/bedding layers were excavated, some of which were burnt. Three came from Member 1 BS.LR C, three from 1 WA, five from 2 BS, three from 2 WA, and five from 3 BS. No bedding was found in Members 4 WA or 5 BS, but 55 charred rhizomes of unknown taxon at the time of excavation were recovered from these members. A preliminary study of charcoal fragments from Members 4 WA and 5 BS identified the taxa as the same as those growing in the region today. In order to know what types of vegetation the inhabitants of Border Cave may have used, and to supplement the inventory of Anderson (1978), a survey of modern woody taxa in the area was conducted by Lyn Wadley and Christine Sievers and resulted in a list of 47 species that is given in Backwell et al. (2018).

2. Materials and methods

Excavations were conducted with pastry brushes, leaf trowels and camera lens puffers, which were particularly useful to clean profiles, excavate ash deposits, and expose plant remains. While perfectly preserved, organic remains are extremely fragile, and can turn to dust when touched. Therefore, some wood, bone and bedding were impregnated with a weak glue solution (Paraloid™), for which acetone is the solvent. We do not excavate in spits, we excavate in layers, which are differentiated by colour and texture. Each excavator completed a worksheet for each *décapage* (plan/sub-unit) within a layer. Sediments and artefacts from each *décapage* were excavated, documented, sieved, and processed separately. Worksheet information for each *décapage* or layer included the square number (e.g. N103 E118), Member (e.g. 2 BS), layer name (e.g. Brown Caby), Munsell description of sediment colour (e.g. Brown 7.5YR 4/4), texture (e.g. silty), coherence (e.g. none), content (lithic, bone, tooth, seed, charcoal, shell, ostrich eggshell, wood, ochre, roof spall, other), specimen number and description, orientation and dip of lithics >4 cm, volume of sediment removed in litres, and plotting of finds on graph paper. Layers are named alphabetically by member, starting with layer Abba in Member 1 BS, layer Barry in Member 1 WA, layer Camy in Member 2 BS, layer Dabby in Member 2 WA, etc. The naming system was introduced in 2017, so layers from earlier years are named according to their description only. There is no strict alphabetical order within the members because new names starting with the same letter were introduced by excavators working in different parts of the deposit, and the relationship between them was unknown. Plan photographs were taken of each metre square, including a scale and North arrow, with close-ups of features. Sediment samples were taken for each layer. The volume of all excavated sediment was measured in litres and then sieved using 2 mm and 1 mm mesh, and the contents carefully sorted into categories such as microfauna, bone flakes, seeds, ochre, and lithic fragments. Field notes were kept by all excavators in notebooks dedicated to each square opened. All finds and data pertaining to our research at Border Cave, including total station theodolite data concerning finds (specimen number, type, provenience), notebooks, stratigraphic drawings, photographs, and worksheets are lodged with the curator of the Border Cave collection at the Evolutionary Studies Institute at the University of the Witwatersrand, and electronic versions with the South African Heritage Resource Agency (SAHRA).

We have systematically recovered grass mats/bedding from all the layers when this feature appeared, and during our 2018 field trip 15 blocks of grass mats/bedding and a horncore feature were jacketed with plaster bandages and lifted *in toto* for excavation and analysis under the microscope. The excavation and preservation of plant remains relies on the plaster jacket technique of reinforcing a block of deposit (Wadley, 2020a), rather than coating or impregnating the specimen with glue, which prevents microscopic analysis (see Sievers et al., 2022). Micromorphology blocks of the strata associated with bedding layers were also jacketed with plaster bandages, and later impregnated with resin for making thin sections. Two experimental catch trays set up in 2017 were cleaned of their contents. One is located at the foot of the South wall of the cave to monitor the rate of weathering of the pyroclastic breccia that constitutes the roof of the cave, and the other is in an open area to the South of the excavation to document bat guano accumulation per annum. To increase their reference collection, in 2018 and 2019 Christine Sievers and Lyn Wadley collected botanical samples from the Border Cave region. A permit was obtained from Ezemvelo Wildlife KwaZulu-Natal (OP4367/2017) for these collections and vouchers were lodged with the Durban Herbarium and the C. E. Moss Herbarium at the University of the Witwatersrand. Their main aims were to identify grasses, leaves and seeds represented in grass mats/bedding found throughout the sequence, as well as charred rhizomes originating from Members 4 WA and 5 BS. Scanning electron microscopy was used to study the rhizomes and photograph them and plant structures preserved in the bedding. In 2018 optically stimulated luminescence (OSL) dosimeters were inserted in the deposit, and sediment, agate, mollusc, and tooth enamel samples were taken for dating. During our field trip in 2019 we retrieved the dosimeters for analysis. No excavations were conducted in 2020 because our field trip was abandoned after three days due to the coronavirus pandemic, which also prevented excavations in 2021.

3. Results

3.1. *Areas excavated*

In 2018-19, excavations continued in squares N108 E113 and N109 E113 (Figure 1), sampling the oldest deposits, including Members 4 WA, 5 BS, 5 WA and 6 BS to bedrock. This area is shown in Figure 2a on the extreme left. We also excavated square N108 E114 to increase the artefact sample size for Member 4 WA and bring us closer to two large ancient pits exposed in the North section in Member 5 BS (Figure 1). We dug deeper in N108 E115 to better understand

Member 4 BS. We continued our work in N108 E117 to sample deposits attributed by Beaumont to the HP. We sampled Members 2 BS and 2 WA (both MSA III), Members 3 BS, 3 WA, 1 RGBS (all purported HP) and Member 4 BS (MSA I), in other words before, during and after the HP, but found no diagnostic artefacts. In attempting to sample HP material, excavations were also conducted in N108 E116, including Members 3 WA, 1 RGBS and 4 BS. We also excavated N109 E117, where we sampled Members 2 WA, 3 BS, 3 WA, 1 RGBS and 4 BS, but only two backed lithic artefacts were found. Excavations in N109 E117-120 sampled the post-HP (Members 2 WA, 2 BS.UP, 2 BS.LR) and so-called ELSA (Member 1 WA) deposits (Figure 1). To increase the artefact sample size for the ELSA (Members 1 BS.LR, 1 WA) we opened two squares on the South face of Beaumont's EXC. 3A trench (Figure 1), namely N103 E117 and E118. The spatial link between our excavation squares and EXC. 3A Rear by Beaumont enables us to discuss our results in relation to his. We compare our results with those of Beaumont in squares R/S 18 to 21 (Figure 1), which he excavated to bedrock (Beaumont, 1978). To our knowledge, and based on a lack of any diagnostic evidence, we did not excavate any Iron Age deposits. This is not the focus of our research, and thus no comparison is made with the Iron Age material recovered by Beaumont. The uppermost layer that we have excavated is from Member 1 BS.LR C.

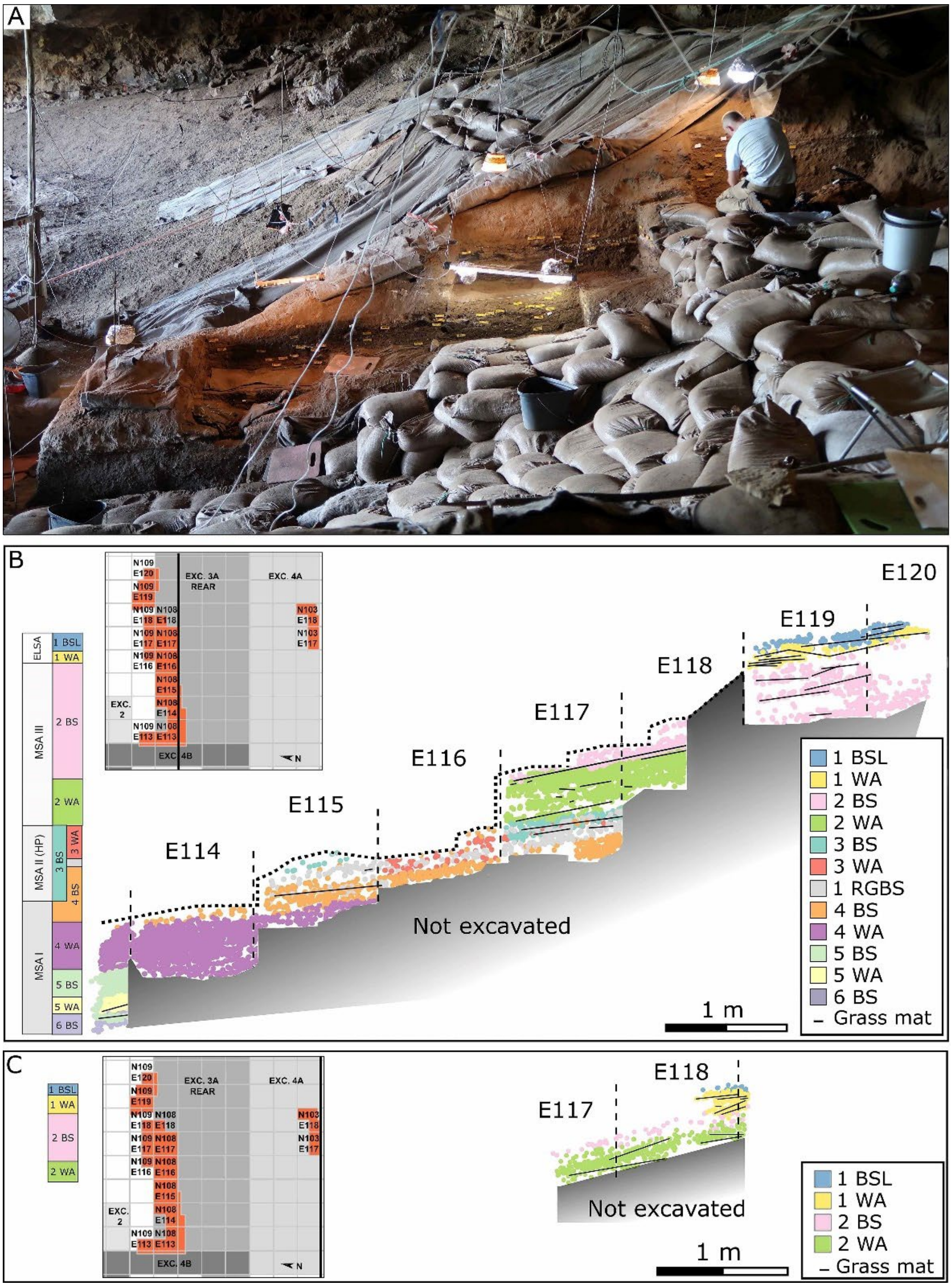

Fig. 2. A, Photograph of excavations conducted from 2015 to 2019 along the North face of Beaumont's excavation (EXC.) 3A trench. The youngest deposits are towards the back of the cave on the right, and the oldest towards the centre of the cave on the left. **B,** Stratigraphic sequence along the north wall with plotted grass mats/bedding shown as dipping horizontal black lines. The dashed line indicates the bottom limit of Beaumont's excavations. **C,** Stratigraphic sequence along the South wall with grass mats/bedding shown as black lines. The

bold vertical lines in the plan insets indicate the position of the sections shown. **Double column figure**

Our fine-resolution excavation methods have enabled us to expose layer upon layer of remnants of occupational surfaces as moments captured in time. The preservation at the site is such that intact layers of grass and hearths remain relatively fresh and uncompressed and can therefore be isolated for study (Wadley et al., 2020a; Sievers et al., 2022). Our fine-scale approach identifies 10 layers where Beaumont saw one for Member 1 BS, and 15 in Member 1 WA. We identify 69 layers within his single Member 2 WA and 51 in 4 WA. Stratigraphic layers identified and excavated to date number 237 and are listed with their host member in Table 1. A reappraisal of the sedimentary sequence is presented by Stratford and colleagues (this volume) who use a facies and allostratigraphic approach (the definition of stratigraphic units based on bounding discontinuities). Updated section drawings of profiles were made of N103 E118 and N109 E117 and 118. New profiles were drawn for N103 E117 and N108 E114 and the adjacent squares N108 E113.5-115. At the end of the 2018 excavations 547.70 litres of sediment were removed and in 2019 285.85 litres. The volume of sediment removed by member since 2015 is given in Table 4 and shown in Figure 3a. The relatively high volume of sediment removed from Members 2 BS and 4 WA correspond in some cases with an increased number of finds. Member 2 BS is a thick deposit and was excavated in six of our eight squares opened along the North profile (Figure 2b). Member 4 WA is also a thick unit and was sampled in three squares. In other instances, the data show that even though very little sediment was excavated, a great deal of archaeological information was retrieved, as in the recovery of grass bedding in Members 5 BS and 5 WA (>140 ka). Here we present data based on piece-plotted artefacts only, as bucket finds continue to be processed. All numbers will be subject to some later revision, especially seeds, ochre, and charcoal. We also compare the trends from the material we have collected with trends observed in material recovered by Beaumont in EXC. 3A Rear.

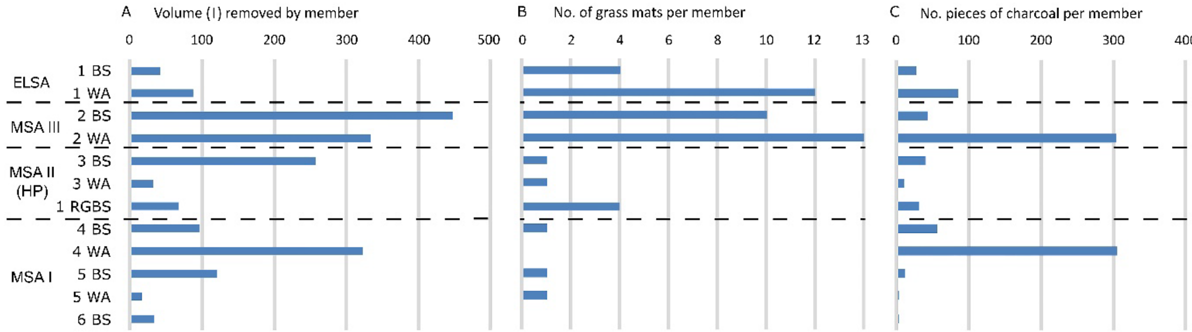

Fig. 3. Histograms showing **A,** volume in litres of sediment removed per member; **B,** number of grass mats/bedding per member, and **C,** number of plotted pieces of charcoal per member excavated from 2015 to 2019. **Double column figure**

3.2. *Organic remains*

Desiccated complete leaves are preserved in 2 WA, in layers Dark Brown Dijon (Figure 4) and Dark Yellowish Brown Dossy, dated to *c*. 60 ka. Sievers et al. (2022) provide information on leaves and other plant remains preserved at the site, and their contribution to plant bedding construction between 60 ka and 40 ka years ago. A total of 48 layers of grass mats/bedding have been identified in the squares excavated between 2015 and 2019 (Table 1 highlighted in grey, Figure 2b, c). They are exceptionally well preserved and are rich in seeds, ochre and lithics (see Wadley et al., 2020a). Figure 3b shows the number of mats by member, with four from 1 BS, 12 from 1 WA, 10 from 2 BS, 13 from 2 WA, one from 3 BS, one from 3 WA, four from 1 RGBS, one from 4 BS, none from 4 WA, and one each from 5 BS and 5 WA. Even though relatively little sediment was excavated from 1 BS and 1 WA, many mats are still recorded. Their abundance decreases sharply in the layers dated 82–56 ka (1 RGBS, 3 WA, 3BS), with the last of the desiccated mats recorded in 4 BS dated 91–71 ka. The oldest grass bedding was found in N109 E113 in 5 BS (Brown Jolly plan 2) dated at 161–144 ka, and 5 WA (Dark Brown Kevin), dated to >227 ka. Unlike the bedding in the younger members, which is entirely organic and retains pigmentation, the grass in 5 BS and 5 WA is white because organic material decayed completely, releasing the silica phytoliths (Wadley et al., 2020a). Microscopic analysis identified an unusually high number of grass phytoliths associated with these deposits, supporting the interpretation that it was intentionally introduced as a floor cover. Charcoal in the bedding includes *Tarchonanthus trilobus* (broad-leaved camphor bush) that has aromatic leaves like those from *T. camphoratus*, which is used as an insect repellent in modern plant bedding in Africa (Beentje, 1999). Thin sections of the microstratigraphy show silicified, laminar bedding underlain with phosphatic ash. The grass mats/bedding found throughout the sequence occur on layers of ash, which suggests that ash was intentionally spread before grass and aromatic leaves were laid down, and that the ash and leaves may have served as an insect repellent (Wadley et al., 2020a). A study by Esteban and colleagues (this volume) of the phytolith assemblage at Border Cave focuses on Members 2 BS and 2 WA (~60 ka) and shows that while grass phytoliths occur in all of the layers examined, eudicot broadleaf phytoliths predominate in most bedding layers. These results indicate a shift in the strategies for bedding construction of past site occupants with broadleaf-based bedding being more widely used 60 ka years ago. Esteban and colleagues (this volume) also found a high frequency of diatoms in layer Light Reddish Brown in Member 2 WA.UP, suggesting the presence of water in the vicinity during the accumulation of this unit. The oldest charcoal that we have found at Border Cave comes from a hearth in Member 6 BS, dated to >227 ka. Notably high numbers of charcoal are found in Members 4 WA and 2 WA (Figure 3c), corresponding to the large volume of sediment excavated from these ash units. Charcoal from Member 1 RGBS shows that *Tarchonanthus* sp. was the most abundant taxon collected at the site at 74 ka, possibly for medicinal and cosmetic purposes, followed by *Euphorbia* species that were perhaps collected for their latex (Zwane and Bamford, 2021). Nine species identified by these authors have known medicinal properties (e.g., *Tarchonanthus* sp., *Euphorbia* sp., *Lannea discolor*, *Senegalia caffra*, *Searsia chirindensis*), while three species have nutritional value (*Sclerocarya birrea*, *Lannea discolor*, *Vachellia tortilis*) for which they are still harvested (Coates-Palgrave, 1981; van Wyk and van Wyk, 2013). The taxa represented in Member 1 RGBS imply that at 74 ka there was more Savanna/Bushveld mixed with Grassland vegetation within the foraging distance of the site. Anthracology results presented by Lennox and colleagues (this volume) suggest that the present-day Lebombo Bushveld and Summit Sourveld probably persisted throughout the sequence, with more bushveld/open woodland than forest/closed woodland represented in all members.

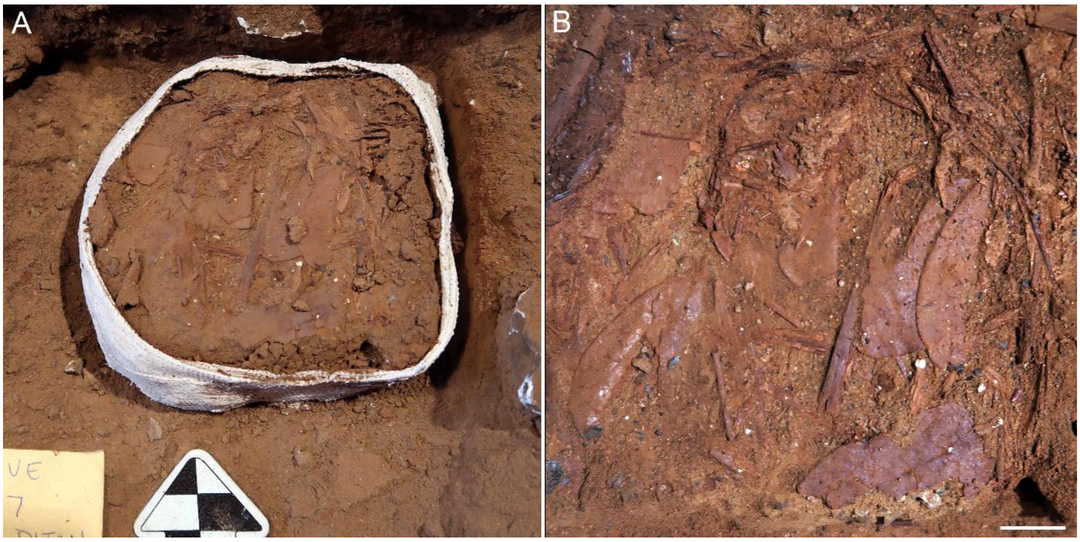

Fig. 4. A bed of desiccated *Chionanthus foveolatus* leaves found in square N118 E109 in Member 2 WA in layer Dark Brown Dijon, aged ~60 ka years. **A,** Plaster jacket made around the feature *in situ*. **B,** Close-up view showing leaf colour, margins and ribs. Scale in B = 1 cm. **Double column figure**

Fifty-five charred underground storage organs, identified as *Hypoxis angustifolia*, were described (Wadley et al., 2020b). Forty-four come from 4 WA and 11 from 5 BS, making them the oldest known examples of cooked starchy rhizomes at 170 thousand years old. To date, 140 seeds have been found *in situ* and double that amount in the sieve. Figures 5a-b show the number of plotted seeds found by Beaumont in EXC. 3A Rear compared to the number of *in situ* plotted seeds found by us. Beaumont recovered around 1,400 seeds within EXC. 3A Rear, most of them coming from the Iron Age layers (Beaumont, 1978). None were recorded below Member 2 WA though he mentions that seeds were found in older layers. Our excavations yielded seeds throughout the sequence, with the oldest in 5 BS (Figure 5c). The highest number of plotted seeds (n = 48) comes from Member 4 WA, and this could be due to the long period that it covers (168–113 ka), the fact that a relatively large volume of sediment has been excavated from this thick unit, and because the seeds from 4 WA are charred and come from ash layers. Forty-three come from Member 2 WA at ~60 ka, and this may be due to their also being charred and found in ash layers, and because a high volume of sediment was removed from this member. Twenty-seven have been found in Member 2 BS and one in 1 BS. Seed identification is being conducted by Christine Sievers and is work in progress. The phytolith study by Esteban and colleagues (this volume) identified *Commelina* seeds in Members 2 BS and 2 WA.

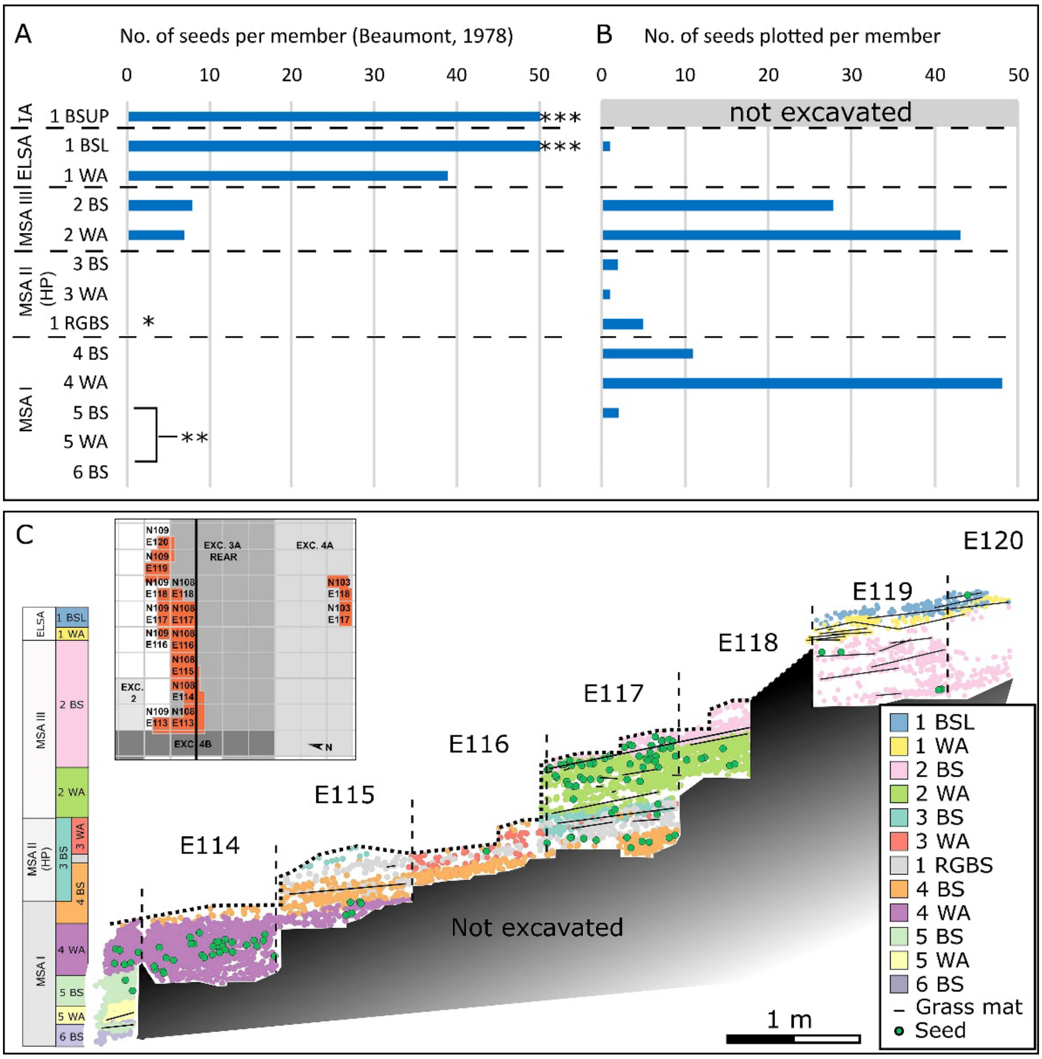

Fig. 5. Histograms showing **A,** number of seeds per member excavated by Beaumont (1978), and **B,** number of plotted seeds per member excavated from 2015 to 2019. *Not identified by Beaumont in excavation (EXC.) 3. Rear, **Grouped under BACO member, ***>50. **C,** Stratigraphic distribution along the north wall of plotted seeds recovered from members excavated from 2015 to 2019. The dashed line indicates the bottom limit of Beaumont's excavations. The bold vertical line in the plan inset indicates the position of the section shown. **Double column figure**

In our excavations, wood was abundant in the upper members (2 BS, 2 WA). The plotted distribution of wood is similar to that of the grass mats/bedding (Figure 6a). This pattern is likely a function of volume of sediment removed from each member (Figure 3) and better preservation in younger deposits. Wood is present in Member 4 WA, dated ~168–113 ka, where a very long piece of it occurs in Pit 1 and Pit 2 in square N108 E114 (Figure 6b). Two pieces are recorded in Member 5 BS, dated 161–144 ka. Of particular interest is the discovery of one notched piece of wood coming from 2 WA Brown Daria, dated ~60 ka. It increases the collection found by Beaumont (1978), consisting of a potentially shaped piece in Member 2 WA and four notched pieces originally belonging to a single stick recovered from 1 WA, interpreted as a poison applicator (d'Errico et al., 2012a). A second find of interest that is currently under investigation is an organic container-like object associated with a stick. They were found inside a pit lined with cemented ash in Member 5 BS. The find is exceptional given its age and provides rare insight into organic material culture and technology ~150 ka years ago.

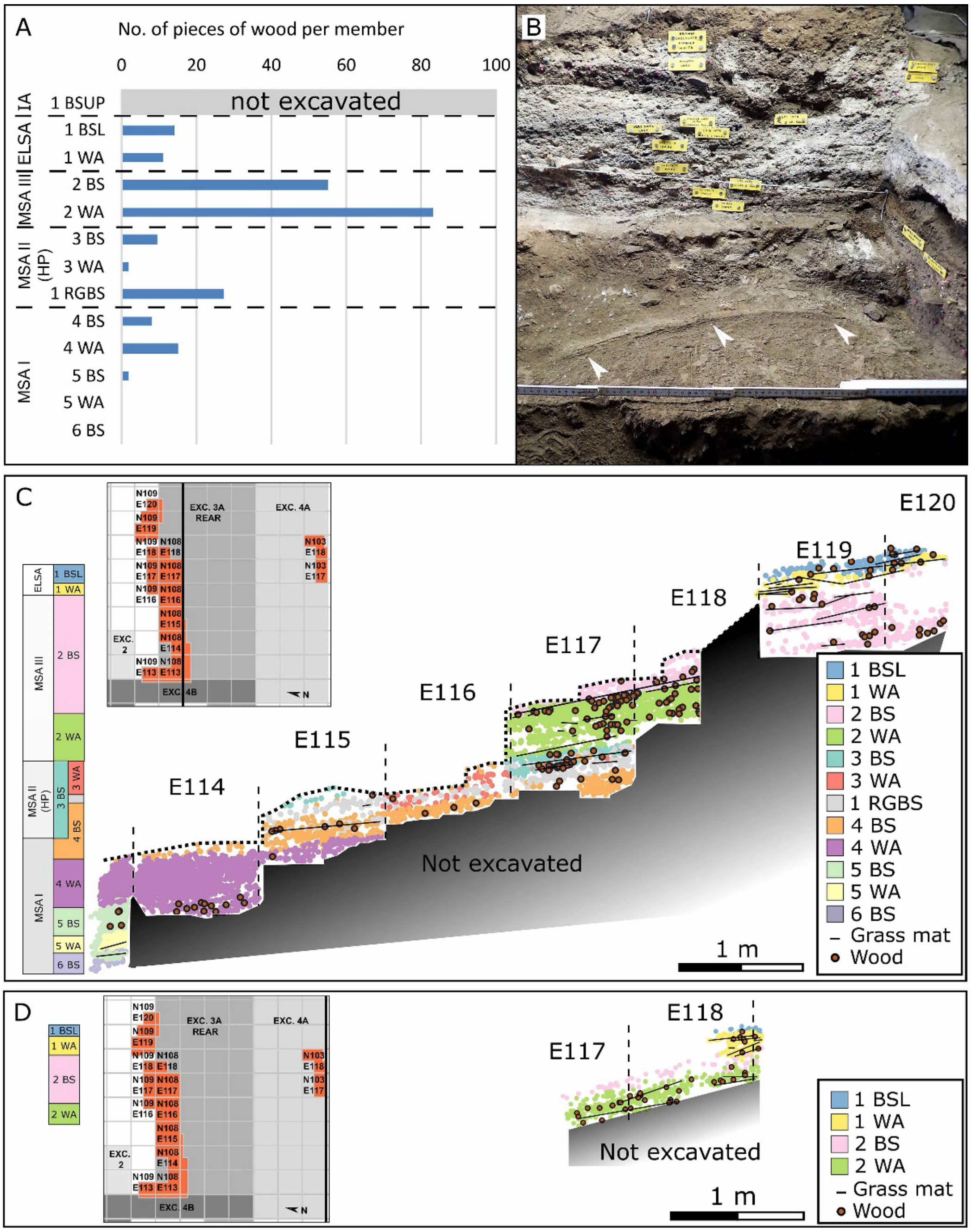

Fig. 6. A, Histogram showing the number of pieces of plotted wood per member excavated from 2015 to 2019. **B,** Photograph of an approximately 40 cm-long piece of pedestalled wood (arrows) recovered in N108 E114, in Member 4 WA (168–113 ka), in Pit 1 and Pit 2 in layer White 8 Idaho, plan 6. **C-D,** Stratigraphic distribution of the recorded pieces of plotted wood recovered along the North **(C)** and South **(D)** walls from members excavated from 2015 to 2019. The dashed line in C indicates the bottom limit of Beaumont's excavations. The bold

vertical lines in the plan insets indicate the position of the sections shown. **Double column figure**

The remains of giant land snails (*Metachatina kraussi*) were found in relatively high numbers in Members 4 BS, 4 WA, 3 WA, and 1 RGBS (Figure 7). While the highest number of plotted shells in 4 BS may be a function of the volume of sediment removed from this thick unit, the low numbers in the younger deposits do not match this pattern. From all of the excavations conducted by Beaumont, he found 3,529 pieces of *Achatina* shell, representing a minimum number of 84 individuals (Beaumont, 1978), with the highest number in 4 BS (n = 1,076), as is the case with our excavations. It appears therefore that between 168 ka and 77 ka land snails may have been part of the diet of visitors to the cave, and that more recent occupants ate them only occasionally. *Achatina* are most active during the warm wet summer months. During the cold and dry winter months they bury themselves deep in the soil at the base of trees and shrubs, amongst dense clumps of herbaceous plants or under logs (Herbert and Kilburn, 2004), which may suggest that they were consumed seasonally, in summer. It is possible that the land snails buried themselves in the cave deposit, but the shells are fragmented with mixtures of burned and unburned pieces, so human intervention seems more likely to account for their presence. For Members 1 WA and 1 BS our data and Beaumont's diverge. For the *Achatina* remains we only rely on a general count of the shells from excavations 3A and 3B as Beaumont's results include some of the younger layers that were capping part of the sequence we excavated.

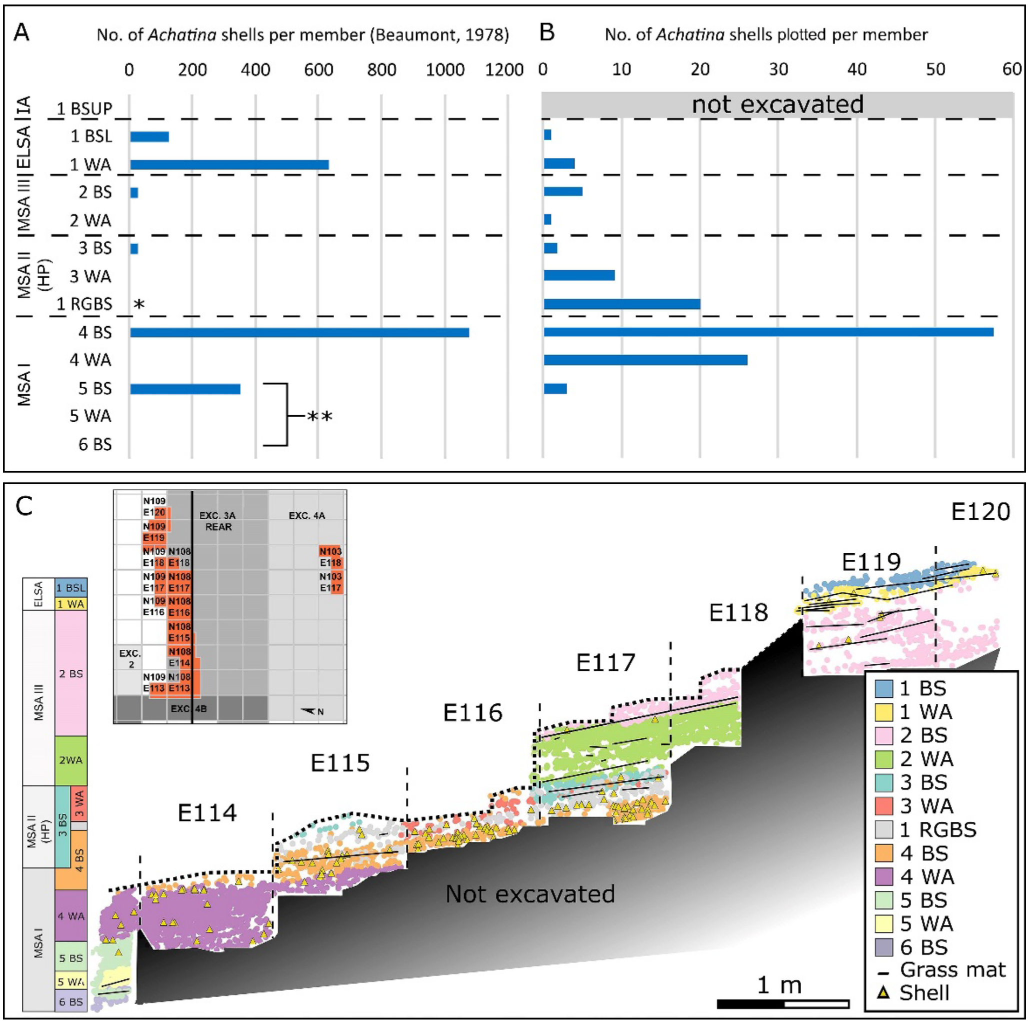

Fig. 7. Histograms showing **A,** number of *Achatina* shells per member excavated by Beaumont (1978), and **B,** from 2015 to 2019. *Not identified by Beaumont in excavation (EXC.) 3. Rear, **Grouped under BACO member. **C,** Stratigraphic distribution of the plotted *Achatina* shells recovered along the North wall from members excavated from 2015 to 2019. The dashed line indicates the bottom limit of Beaumont's excavations. The bold vertical line in the plan inset indicates the position of the section shown. **Double column figure**

In 2018 the fauna excavated from 2015 to 2018 was analysed, including all piece-plotted bone and the bucket finds from the 2017 campaign (see Stratford et al., this volume). Along with the mammalian fauna, the remains of a human were identified; a child, represented by the centrum of an upper or mid thoracic vertebra from 1 BS.LR C dated 42.6 ka (see Jashashvili et al., this volume). The identified fauna includes three bird taxa, tortoise, and one reptile. Apart from the human remains, no primates are represented in the current assemblage, and no carnivores either. Bovids are the most common taxa identified, and all bovid size classes are represented. Small mammals are rare and include hyrax and lagomorphs. Figure 8 shows the number of pieces of bone plotted per member compared with what Beaumont found in squares R/S 18 to 21. Macroscopic faunal remains are present throughout the sequence, except in the oldest Members 5 WA and 6 BS (>227 ka), though microscopic fragments of calcined bone were found in Member 5 WA. A spike in bone recovered occurs in Member 2 WA at ~60 ka. Similar trends can be seen in Beaumont's excavation of squares R/S 18 to 21. This may reflect the relatively high volume of sediment removed from this member, but it could also reflect variation in site formation processes or human behaviour. The members above (2 BS) and below (3 BS) had a relatively high volume of sediment removed, yet the bone densities are less than half that of Member 2 WA. The relatively small volume of deposit sampled from Members 3 BS, 3 WA, and 1 RGBS yielded a similarly small sample of bone. The earlier members (4 BS, 4 WA, 5 BS, 5 WA, 6 BS) reflect the same density as the volumes of sediment removed from these members, with a spike in 4 WA (168–113 ka). Despite this being a thick ash unit representing multiple combustion features, bone was still preserved.

The absence of bone tools and recovery of only a few personal ornaments (three ostrich eggshell beads) from our sample may be explained by the fact that we have excavated very little from Members 1 BS.LR C and 1 WA. In addition to the three ostrich eggshell beads previously described from 1 BS.LR C (d'Errico et al., 2012a), seven pieces of ostrich eggshell have been found, three in Member 1 BS.LR C (42 ka), one in 2 WA (~60 ka), two in 3 BS (~72–56 ka), and one piece in 4 BS in Dark Brown Hayley (91–71 ka), and the piece from Dark Brown Hayley is stained red with ochre.

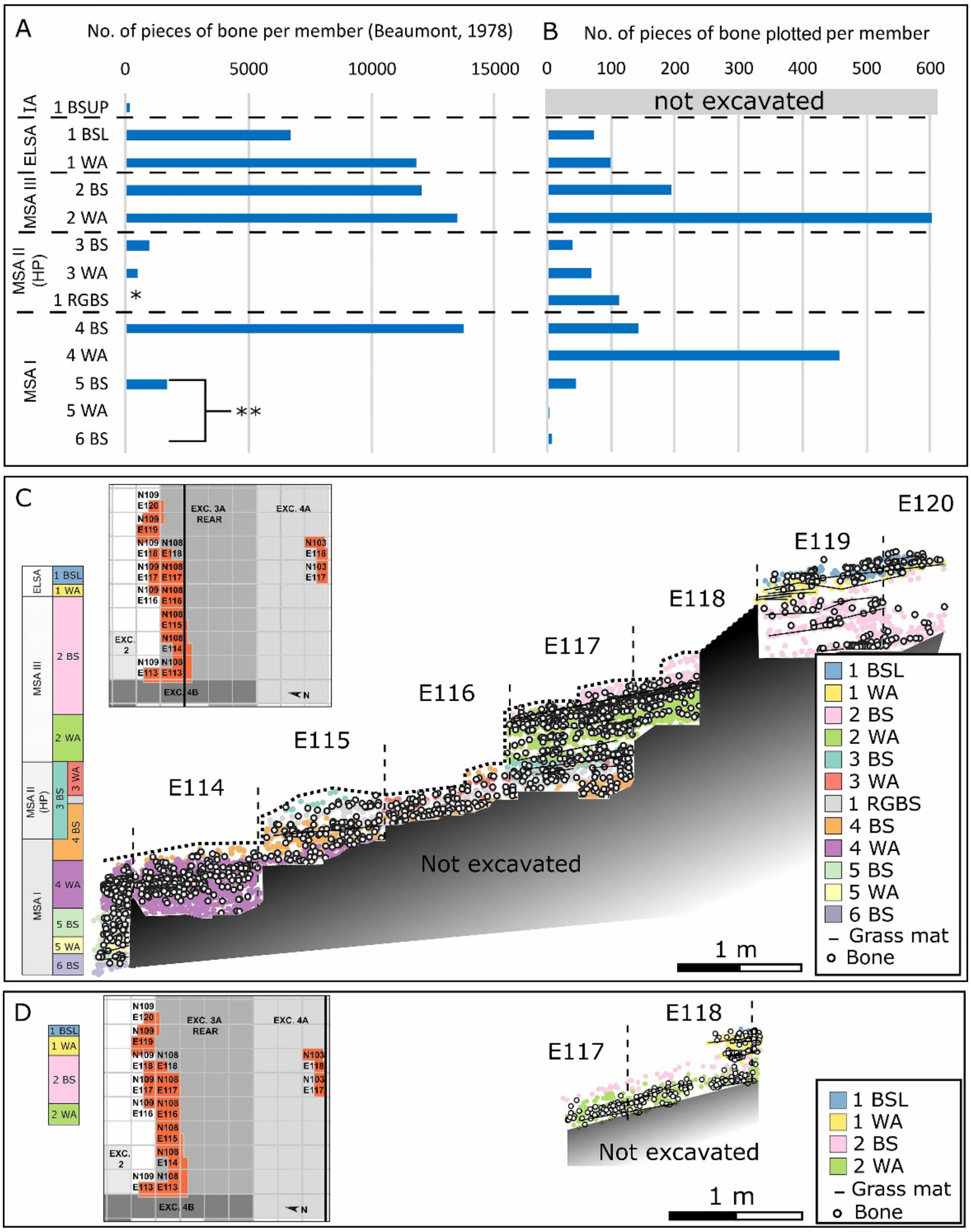

Fig. 8. Histograms showing **A,** number of pieces of bone recorded per member excavated by Beaumont (1978), and **B,** plotted from 2015 to 2019. *Not identified by Beaumont in excavation (EXC.) 3. Rear, **Grouped under BACO member. **C-D,** Stratigraphic distribution of the plotted pieces of bone recovered along the North **(C)** and South **(D)** walls from members excavated from 2015 to 2019. The dashed line in C indicates the bottom limit of Beaumont's excavations. The bold vertical lines in the plan insets indicate the position of the sections shown. **Double column figure**

3.3. *Ochre and lithic artefacts*

Figure 9 shows the number of plotted ochre pieces found by member compared with what Beaumont found in squares R/S 18 to 21. The numbers are low, below 20 for most members, except for Member 4 WA with 33 pieces representing the period 168–113 ka, a peak in 2 WA with 82 pieces at approximately 60 ka and a lessening trend from 2 BS.UP (*n.* 43) to 1 BS.LR, where only nine pieces were found. A similar trend is visible in Beaumont's numbers from his excavation of squares R/S 18 to 21. The main difference lies in the upper layers. Most of the upper layers of the squares we excavate were excavated by Beaumont, so they were not included in our comparison. The higher number of pieces associated with MSA III (2 BS, 2 WA) corresponds with the high volume of sediment removed from these layers. In the silicified Member 5 WA bedding layer Dark Brown Kevin, red and orange ochre grains are up to 37 times more frequent than 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 (Wadley et al., 2020a). Non-human taphonomic processes may be responsible for the colour and shape differences. Nonetheless, we hypothesise that the ochre particles were processed anthropogenically and became detached from objects or human skin when people used the bedding. Element and mineral analyses using scanning electron microscopy coupled with energy-dispersive X-ray spectroscopy and μ-Raman spectroscopy cannot distinguish grains from bedding and those from over- and underlying layers (Wadley et al., 2020a), which could suggest that people used ochre from within the cave. Future research will investigate further the nature and provenance of these ochre grains. During his excavation, Beaumont recovered some specular haematite. He thought that it could have come from the Ngwenya haematite mine (Eswatini), which has potentially been mined for over 40,000 years (Vogel, 1970;

Beaumont, 1978). If confirmed, these two behaviours would highlight different strategies in ochre procurement that might be related to socio-cultural behaviours of these populations.

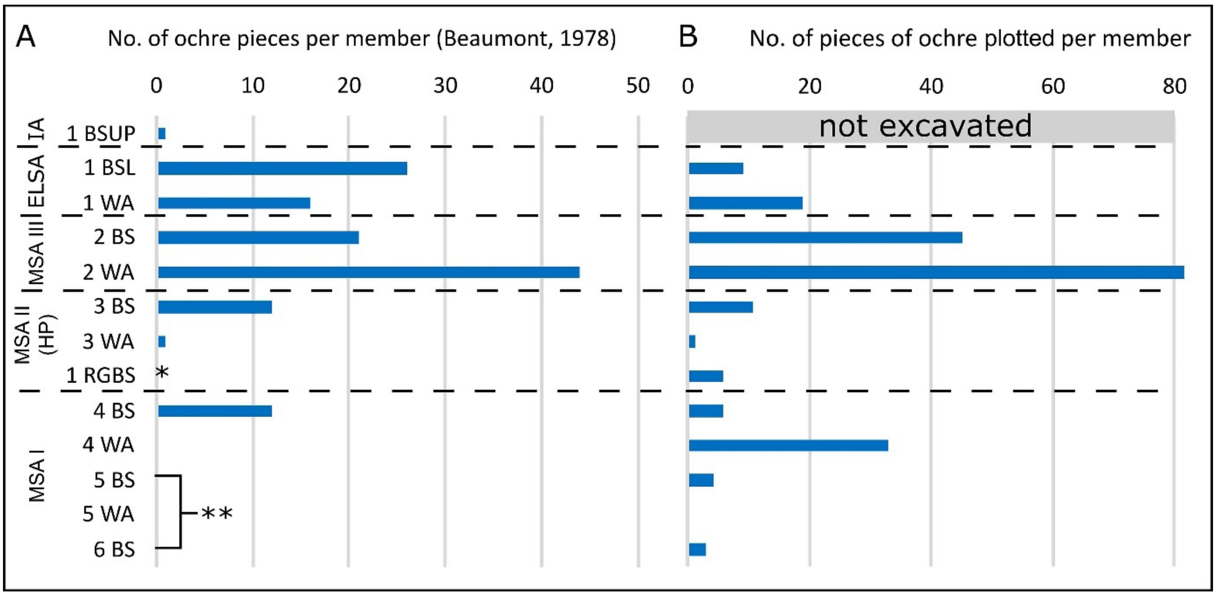

Fig. 9. Histograms showing **A,** number of pieces of ochre recorded per member excavated by Beaumont (1978), and **B,** plotted from 2015 to 2019. *Not identified by Beaumont in excavation (EXC.) 3. Rear, **Grouped under BACO member. **Double column figure**

Figures 10a-b show the number of lithics by member and the comparison with the material Beaumont recovered in squares R/S 18 to 21. Starting at the bottom of the sequence, stone flake and blade manufacture is associated with the Member 5 WA bedding layer Dark Brown Kevin. The lithics described cannot be assigned to a specific industry, but they resemble those in the 1987 Member 5 WA collection of Beaumont, labelled MSA I/Pietersburg (Wadley et al., 2020a). The highest number of lithics retrieved come from Members 5 BS and 4 WA, while relatively few lithics were found in Member 4 BS.

de la Peña and colleagues (this volume) studied lithic material from the new excavations from Members 1 RGBS and 3 BS, and Members 2 WA and 2 BS (lower and upper) that Beaumont et al. (1992) and Grün and Beaumont (2001) described as HP and MSA III (post-HP), respectively. In the recent study, Member 2 WA was divided into 2 WA.LR, 2 WA.MD (middle) and 2 WA.UP. Lithics from Members 2 BS.UP, 2 BS.LR and 2 WA.UP are characterized by discoidal and *Levallois* reduction, and by an abundance of unretouched triangular blanks. However, the three units have notable differences regarding raw material percentages and frequencies of technical features, and in the multivariate statistical analysis they were clearly separated from each other. Member 2 WA.MD and 2 WA.LR have a much lower percentage of chordal flakes (typical of discoidal reduction) in comparison with the upper lithic assemblages. In these units a specific variant of *Levallois* reduction was deduced from core-related by-products, the aim of which was to produce elongated blanks with two opposed platforms. These two units also have triangular blanks, but they are different from the 2 BS triangular blanks regarding dorsal scar pattern and elongation. Indeed, the highest elongated index between 1 RGBS and 2 BS.UP was recorded in 2 WA.LR (showing no statistical distinction with 3 BS). Member 2 WA.LR also has crested blades, which are typical of initiation of the cores in some blade reduction knapping methods. In 3 BS discoidal and *Levallois* recurrent reduction methods were also documented on two cores. Member 1 RGBS did not have any cores (except two tested nodules), but the attribute analysis of the flakes demonstrates continuities with Member 3 BS. Regarding raw material distribution, different varieties of rhyolite were dominant in all four members. The multivariate analysis showed three distinct groups in this regard: 2 BS, 2 WA.UP and 2 WA.MD to 1 RGBS.

Concerning retouched pieces, 1 RGBS and 3 BS yielded two backed pieces. This is in accordance with Beaumont's HP attribution to these members (Beaumont, 1978). However, it must be borne in mind that backed pieces are not exclusive to the HP. Member 2 WA.MD and LR yielded trimmed base elongated points (which were also described in Beaumont, 1978). Nonetheless, the number of retouched pieces from 1 RGBS to 2 BS. UP is low (in all members it is less than 1% of the artefacts). The other retouched pieces from 2 BS. UP to 1 RGBS are retouched flakes, notches and retouched points. Points from Members 3 BS, 2 WA and 2 BS are the subject of a technological and geometric morphometric analysis conducted by Timbrell and colleagues (this volume). They found that unretouched points from Members 2 BS, 2 WA and the top of 3 BS were manufactured using a range of reduction sequences that were not necessarily targeting triangular shapes, and that Sibudan morphotypes (Conard et al., 2012; Will et al., 2014) are recorded in the Border Cave sample. In 2 WA the lithic distribution is clearly stratigraphically associated with grass mats/bedding. Quartz crystals were found complete in Member 2 WA (~60 ka) and shattered in Member 1 WA (43 ka). Relatively few lithics have been retrieved from the 1 WA and 1 BS.LR deposits.

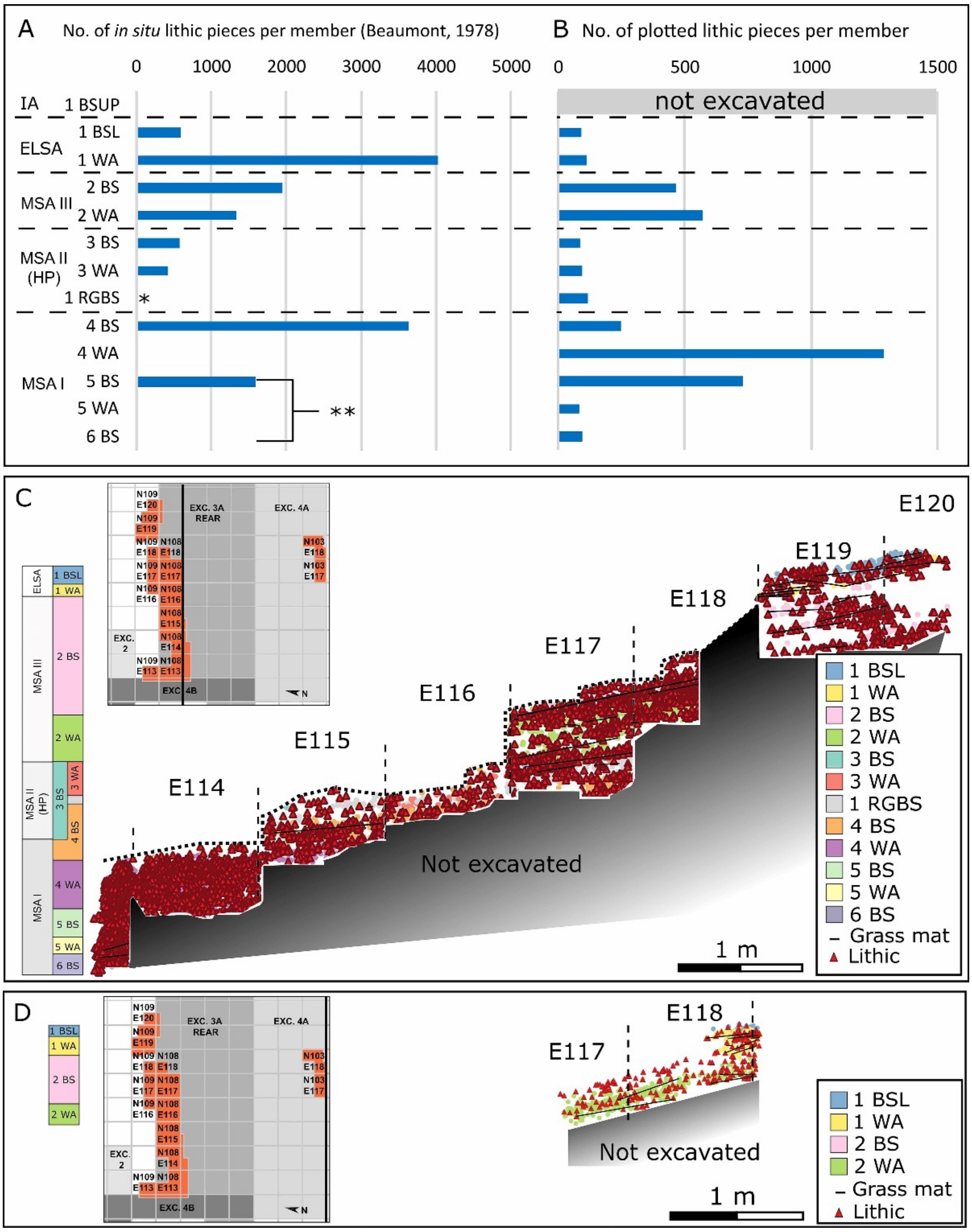

Fig. 10. Histograms showing **A,** number of lithics recorded per member excavated by Beaumont (1978), and **B,** number of plotted lithics from 2015 to 2019. *Not identified by Beaumont in excavation (EXC.) 3. Rear, **Grouped under BACO member. **C-D,** Stratigraphic distribution of the plotted lithic artefacts recovered along the North **(C)** and South **(D)** walls from members excavated from 2015 to 2019. The dashed line in C indicates the bottom limit

of Beaumont's excavations. The bold vertical lines in the plan insets indicate the position of the sections shown. **Double column figure**

3.4. *Horncore feature*

A horncore in Member 2 BS.LR, dated 60–49 ka, was found lying with the distal half on a mat of burnt grass bedding towards the edge of a fireplace (Figure 11a). The tip was covered with a shiny black residue, which was also present on nearby stone tools (Figure 11b). Knowing that variation exists in modern and archaeological glue recipes (Villa et al., 2012, 2015; d'Errico et al., 2012a; Wadley et al., 2015), we wanted to know if the black residue was melted keratin, and if it was, whether it had been used as a substitute for beeswax or latex for hafting. We set out to test the hypothesis by conducting a heating experiment with a modern sheathed horncore. Experimental results showed that keratin does not transform into viable glue when heated. Instead, it reduces immediately to a glassy brittle black residue. Our finding strongly supports a scenario of incidental deposition of residue on the archaeological stone tools (Backwell et al., 2020). Previous combustion experiments have shown that the sediment below a fire can reach 300+°C through vertical heat transfer (Aldeias et al., 2016; Sievers and Wadley, 2008; Werts and Jahren, 2007). This implies that horn sheaths in archaeological deposits, separated from overlying combustion features by thousands of years, can transform into a black residue that may deposit on nearby stone and bone tools.

Fig. 11. A, Horncore in Cilla combustion feature 1 in square N109 E119-120 showing the calcined basal half of the horncore in the centre of the white ash and the tip on a burnt grass mat. A shiny black substance covers the tip and surrounding area. A narrow trench was excavated around the feature to facilitate the construction of a plaster jacket. **B,** Lithics uncovered close to the tip of the horncore showing a shiny black substance adhering to their surfaces. The shiny black substance has tiny charcoal and ash inclusions. **C,** Horncore feature in a plaster jacket. Scale in B = 10 mm, scale in C = 30 mm. **Double column figure**

Finally, about 250 ml of sediment and roof spall were collected from the one catch tray in 2018 and again in 2019, supporting our hypothesis that roof degradation is a significant part of the site formation process (Backwell et al., 2018). No bat guano was found in the other tray. Bats occupy the back of the shelter in the vicinity of the East wall and at times one can smell guano present there.

4. Discussion

4.1. *Chronology*

The acquisition of new dates for the sedimentary sequence at Border Cave (Tribolo et al., this volume) has, in some instances, supported the previous chronology established for the site. The new ages derive from feldspar grains in MSA sediments. Two sets of ages were determined, one that is shown to overestimate the target ages, and the other that is expected to underestimate or be close to the target ages. The lower set of ages is in accordance with those obtained by Grün twenty years ago on bovid teeth using the electron spin resonance method (Grün et al., 1990; Grün and Beaumont, 2001; Grün et al., 2003). Hence, research published on material from MSA deposits based on Grün's dates need not be reappraised in terms of age. The new luminescence ages are given in Tribolo et al. (this volume) using a single standard error (c. 65%). New Bayesian models, based on the Event concept (Chronomodel, Lanos and Dufresne, 2019; Lanos and Philippe, 2018) including new C14 results and all the ESR results, have also been calculated (Tribolo et al., this volume). They are given at 2 sigma (95%) and show little difference; we mention here the one with the largest confidence interval. Member 5 WA was ESR dated by Grün to 220 ± 11–183 ± 20 ka, consistent with the luminescence age of 181 ± 43 ka. The Bayesian analysis indicates 252–198 ka for Member 5 WA layer 2, and 202-154 ka for 5 WA layer 1. Member 5 BS was dated by Grün to 161 ± 10 and 144 ± 11 ka, consistent with the low luminescence age at 179 ± 49 ka. The Bayesian modelled ages are 182–142 ka for Member 5 BS layer 5, and 174–140 ka for 5 BS layer 2. Member 4 WA was dated by ESR to between 168 ± 5 and 115 ± 8 ka, while the low luminescence age is 108 ± 8 ka. Three Bayesian ages for Member 4 WA range between 169 ka and 96 ka. Grün dated Member 4 BS to 77 ± 2 ka, while the new Bayesian age model is 99–69 ka. The new Member 1 RGBS/4 BS (the sample analysed in the new study straddles Members 1 RGBS and 4 BS) low range luminescence age is 111–89 ka including sigma. Member 1 RGBS was dated by Grün to 74 ± 4 ka, and the new Bayesian age for 1 RGBS is 80–67 ka. There are no new ages for Member 3 WA, which is dated by Grün to 64 ± 2 ka. The new Bayesian model age is 75–62 ka. Grün dated Member 3 BS to between 72 ± 4 and 56 ± 2 ka. The Bayesian age of Member 3 BS layer 3 is 71–61 ka, Member 3 BS layer 2 is 68–59 ka and Member 3 BS layer 1 is 65–57 ka. Member 2 WA was dated by ESR to 60 ± 3 ka, and 14C to between 60 ka and 53 ka BP. New luminescence ages for 2 WA.LR range between 70 ± 8 and 58 ± 7 ka. The new Bayesian model age is 63–54 ka. The new luminescence ages for Member 2 BS, within 73–44 ka (low range), are very close to the C14 ages of Bird et al. (2003), which range between 60–44 ka BP ago. The Bayesian age of Member 2 BS.LR C is 59–51 ka, Member 2 BS.LR B is 55–49 ka, Member 2 BS.LR A is 53–47 ka and Member 2 BS.UP is 51–43 ka.

4.2. *Site formation*

Previous research conducted by Beaumont (1973, 1978) and Butzer and colleagues (1978) used an alternating Brown Sand (BS) and White Ash (WA) member system for the deposits. The allostratigraphic and facies approach of Stratford and colleagues (this volume) reassesses the boundaries of the BS-WA member system, while providing finer resolution subdivisions of the members in formal allostratigraphic units, and identifies intra-unit facies variation to establish a process-sensitive framework. The allostratigraphically-defined sub-units and facies diversity identified within the members indicate that members should not be considered as homogeneous. Faunal data from the upper, middle, and lower parts of Member 2 BS corroborate this finding, with marked variation in faunal preservation between the three units.

In this regard, the data presented here by member will no doubt be the last time that finds are lumped according to BS and WA members. Periods of increased autogenic roof-spall production, evidenced by laterally extensive beds of clast-rich sediment occur in BS units, and while there are isolated combustion features and grass mats/bedding associated with these sediments, there are no units attributed to WA members that have a clast-rich autogenic component, suggesting more intense anthropogenic activities were concurrent with low roof spall production periods.

Disconformities help to separate most members, but there is no disconformity between Members 5 WA and 6 BS, implying that one member (5 WA), rather than two, is represented immediately above bedrock. Major disconformities in the stratigraphic sequence have implications for the chronology of the deposits and the interpretation of finds. Butzer and colleagues (1978) report a hiatus between Members 5 WA and 5 BS, and we too identify a major truncation event at the contact between these two members (Stratford et al., this volume). Another major disconformity is recorded between Members 4 WA and 4 BS, which may represent a break of up to 100 ka. Hiatuses and erosion phases that are observed in the stratigraphy are not reflected in the current chronological data, partly because Bayesian models assume a continuous sedimentation rate, leading to the artificial filling of chronological gaps (Tribolo et al., this volume). More focused dating is needed to clarify the nature and duration of the sedimentary breaks in the sequence for controlling technological and palaeoenvironmental calibrations and changes.

The geoarchaeological study demonstrates that the sediments have been subjected to greater post-depositional disturbance than was previously recognised. Apart from identifying mudflow and water channels in Member 2 WA, burrows and pits, there is also evidence of widespread turbation that has affected mostly the fine fraction of the sediments, as evidenced by units with dispersed ashes and charcoal constrained within well-preserved unit boundaries.

High phytolith fragmentation and poor bone preservation within BS-attributed units suggests slow deposit accumulation rates and cumulative turbative processes homogenising sediments. The chemical consequences of facies development on the preservation of artefacts and ecofacts is intriguing and requires further study. While post-depositional alteration of sediments often had an environmental origin (natural chemical and mechanical processes), anthropogenic activities also played a part. The edges of combustion features are sometimes reworked, and this may be due to raking of hearths for site maintenance, and the spreading of ash to create clean surfaces on which to work and sleep.

4.3. *Hominin remains*

Recent research on hominin remains from Border Cave has provided novel palaeoanthropological information. In addition to the eight individuals found in earlier excavations described in the introduction, our new excavations have recovered the remains of a 3–4-year-old child from Member 1 BS.LR C, layer Very Fine Silt, dated 42.6 BP ka (Jashashvili et al., this volume). The thoracic vertebra is attributed to a modern human. It was not buried or found close to a pit, unlike the BC3 infant (Grün and Beaumont, 2001; Grün et al., 2003; d'Errico and Backwell, 2016; Tommy et al., 2021). The different contexts for Border Cave human remains suggest differential treatment of the dead in contemporaneous populations. Formal burials are almost unknown in MSA contexts, which makes comparisons and interpretations difficult. It is possible that people in the MSA disposed of their dead using social conventions appropriate for the time, but that the method of interment made the skeletons archaeologically invisible (Wadley, 2015) or barely discernible, and may be the case for the new individual given that it was found in association with elements typical of a living floor, such as a grass mat/bedding, faunal remains, lithics, and a piece of ochre.

The cranial morphology of BC1, which was attributed to the MSA, albeit that it was found out of context (Cooke et al., 1945; Beaumont et al., 1978; Beaumont, 1980), is characterised by a broad frontal, glabellar protrusion, and prominent superciliary eminences (Beaudet et al., 2022). It has been interpreted as similar in morphology to extant *Homo sapiens* (de Villiers, 1973; Rightmire, 1979; Houghton and Thackeray, 2011) and different from them (Campbell, 1984; Ambergen and Schaafsma, 1984; Van Vark et al., 1989; Corruccini, 1991). Reappraisal of BC1 (Beaudet et al., 2022) shows that the overall morphology of its endocast approximates the derived globular shape of the modern human brain, and that the bony labyrinth displays some ancestral features observed in *Homo erectus*, which are also recorded in variable proportions in modern humans. As such, the cranial morphology of BC1 is within the range of variation expected for an early or later age and cannot be used to date the specimen. Gamma spectrometric U-series dating is the only non-destructive method available for dating the cranium (Simpson and Grün, 1998) and will soon be used to date this specimen.

4.4. *Organic remains*

The Border Cave deposits are unparalleled in terms of MSA plant preservation. Desiccated grass bedding is found throughout the sequence, except in Member 4 WA which comprises a thick stack of ash lenses (Wadley et al., 2020a; Sievers et al., 2022). In the oldest layers, bedding is silicified, and the fact that it was preserved in layers dated 200 ka is extraordinary. MSA plant bedding is scarce in the archaeological record, reported from only a few other sites, namely Sibudu, which has the oldest bedding after Border Cave (Wadley et al., 2011), Apollo 11 (Vogelsang et al., 2010), Wonderwerk Cave (Beaumont and Vogel, 2006), Diepkloof (Miller et al., 2013) and Strathalan Cave B (Opperman and Heydenrych, 1990; Opperman, 1996). Grass bedding throughout the sequence overlies a layer of ash, suggesting that ash was intentionally used as a clean surface that may also have deterred crawling insects (Wadley et al., 2020a). Comprehending that ash deters insects and using it as a tool that provides delayed gratification following planning and strategizing, decision-making, and organisation that entails a sequence of events (Coolidge, 2019; Wadley, 2021), implies complex cognition in Border Cave inhabitants 200 thousand years ago. Leaves with insecticidal properties were incorporated in the bedding, as was the case at Sibudu, where bedding was made from sedge culms (Wadley et al., 2011). All great apes construct bedding in the form of sleeping platforms that entail the manipulation of foliage (Sampson, 2012), but while pathogen and parasite avoidance have been proposed as a possible function of sleeping platforms (Fruth and Hohmann, 1996; Anderson, 1998; Nunn and Heymann, 2005), there are no reports of the intentional selection of foliage with insecticidal properties for inclusion in the bedding. Insecticidal properties may explain the increase in the use of broadleaf-based bedding observed by Esteban and colleagues (this volume) in phytolith composition at 60 ka. Bedding at Border Cave and Sibudu is occasionally burnt, and while it may have been accidental, it may also have been intentional, as a means of ridding the living area of pests (Goldberg et al., 2009; Wadley et al., 2011).

The discovery of 55 cooked *Hypoxis angustifolia* rhizomes in layers aged 170 ka at Border Cave (Wadley et al., 2020b) provides the earliest known evidence for the consumption of underground storage organs. Only three other MSA sites have yielded geophytes: Strathalan Cave B (Opperman and Heydenrych, 1990), Boomplaas and Klasies River (Deacon, 1995). Seeds are found through most of the Border Cave sequence, whereas few other MSA sites record them, namely Sibudu (Wadley 2004, 2006; Sievers, 2006) and Bushman Rock Shelter (Plug, 1981).

Unburnt wood is rarely preserved at MSA sites, and yet wood occurs throughout the Border Cave sequence, except in the oldest Members 5 WA and 6 BS. The only other southern

African Stone Age sites that have yielded wood are Florisbad (Clark, 1955; Bamford and Henderson, 2003), Amanzi (Deacon, 1970) and Kalambo Falls in Zambia (Clark, 1954).

Pieces of charcoal are found throughout the Border Cave sequence. Charcoal remains of camphor bush trees (*Tarchonanthus* sp.) are found in the ancient bedding in Members 5 BS and 5 WA (>227–144 ka) and in 1 RGBS (74 ka). Nowadays the leaves are used medicinally, for cosmetic purposes, and to produce perfumed smoke that can repel insects, but the wood is rarely used for making fires (Gandar, 1982; van Wyk and van Wyk, 2013). Hence, the presence of *Tarchonanthus* sp. at Border Cave and in a hearth at Sibudu dated 60–50 ka (Lennox, 2016) suggests that the use of these trees for purposes other than fuel was known and employed by MSA people (Zwane and Bamford, 2021). Charcoal in the Border Cave deposits represents wood that was selected for medicinal properties, possible tool use and combustion so it represents only a small sample of the flora in the vicinity of the cave. Nonetheless, trees are sensitive environmental indicators, and so the taxa identified provide some data on the local palaeoenvironment. The cultural changes observed in the lithic assemblages at Border Cave may not be linked to environmental change because the vegetation profile suggests relative environmental stability (Lennox et al., this volume). Only a few other MSA sites in southern Africa preserve charcoal, namely Melikane (Stewart et al., 2016), Apollo 11 (Vogelsang et al., 2010), Strathalan Cave B (Opperman and Heydenrych, 1990), Boomplaas (Scholtz, 1986), Diepkloof Rock Shelter (Cartwright, 2013), Elands Bay Cave (Cartwright and Parkington, 1997; Cowling et al., 1999) and Sibudu (Wadley, 2004; Allott, 2004, 2006; Sievers, 2006; Bamford, 2021).

Fragmented bone is preserved throughout the Border Cave sequence, representing small and very large animals, and in this regard is not unlike most MSA sites in southern Africa. The only noteworthy differences are the relatively high number of human remains preserved in the Border Cave deposits, and the relatively low density of faunal remains. The density of faunal remains is significantly lower than that in the Still Bay deposits at Blombos Cave (Reynard and Henshilwood, 2018), and in the Still Bay and HP deposits at Sibudu (Clark, 2017, 2019), suggesting less occupational intensity at Border Cave (Stratford et al., 2022). Unlike the excellent plant preservation at Border Cave, bone surface preservation is fair to poor, irrespective of whether the bone comes from a white ash or brown sand member (Stratford et al., 2022). Given the generally neutral pH of the sediments down to Member 4 WA (Butzer et al., 1978), it may be that the bone surfaces have been removed by invertebrates and microorganisms. Beaumont (1978) reports insects from the following families: Curculionidae (weevil), Tettiganidae (bush cricket), Carabidae (ground beetle), Cerambycidae (longhorn beetle), Ptinidae (spider beetle), Tenebrionidae (darkling beetle), Melolonthidae and Scarabaeidae (both scarab beetles). The remains of millipede exoskeletons were found by us in abundance in the later members, particularly in Member 2 BS, and the shells of giant land snails were found throughout the sequence. Arthropods reminiscent of very large woodlice were observed to live under sandbags, and a modern grasshopper was encountered in a small tunnel during excavations. Backwell et al. (2022) report that all of these invertebrates and microorganisms remove bone surfaces, so their potential contribution to bone modification at the site will be explored in future.

4.5. *Cultural innovations*

Only one piece of worked bone has been found in MSA layers at Border Cave. It is a notched piece in Member 2 WA dated to 60 ka. Seven worked warthog or bushpig tusks were found in Members 2 WA and 2 BS.LR C dated 58–48 ka, and Member 1 WA dated 44–43 ka. Four tusks bear evidence of having been used as awls. It is only at the onset of what Beaumont called the ELSA at Border Cave at about 44 ka (Beaumont and Vogel, 1972; Vogel and Beaumont, 1972; Villa et al., 2012; d'Errico et al., 2012a) that bone points, bone awls and notched pieces of bone enter the archaeological record (d'Errico et al., 2012a). A notched baboon fibula dated 44–42 ka is interpreted as the earliest known system of notation, in which notches were added at different times using different stone tools (d'Errico et al., 2018). A warthog or bushpig tusk from 1 BS.LR B-C (dated 43–42 ka) is modified at one end for hafting and use as a spear point (d'Errico et al., 2012a). Other organic artefacts include ostrich eggshell beads, a lump of beeswax, resin used to haft microliths, a poison applicator and a digging stick (d'Errico et al., 2012a). Given that fauna and flora are recorded throughout the sequence, poor preservation does not explain the dearth of worked bone in MSA layers at the site. The faunal assemblage from Border Cave indicates that bovids of all size ranges were hunted, from Member 4 WA, dated ~168–113 ka, to the youngest MSA layers (Stratford et al., this volume), so there was no shortage of bone as a raw material for tool production, which suggests that stone may have been used as a substitute for bone in the production of spear points. Either MSA people at Border Cave were careful in their curation of bone artefacts and did not lose them in the deposit, or they were a negligible part of their material culture, which could be explained in terms of regional traditions (d'Errico et al., 2012b). A range of bone artefacts have been found at other MSA sites in southern Africa. Blombos has yielded awls on long bone shafts from mammals and birds, a bone retoucher with incised lines, two bone fragments with possible engravings, and large bone points that were scraped and polished (Henshilwood and Sealy, 1997; Henshilwood et al., 2001a; d'Errico and Henshilwood, 2007; Henshilwood, 2012). Worked bone from Sibudu includes retouchers, awls, spatulas, wedges, scrapers, a possible needle (Backwell et al., 2008; d'Errico et al., 2012b) and a notched rib fragment (Cain, 2004; d'Errico et al., 2012b). Notched rib fragments were also preserved at Apollo 11 (Wendt, 1972; Vogelsang, 1998; Vogelsang et al., 2010), and bone fragments with serrated edges were found at Klasies River Cave 1 (Singer and Wymer, 1982). d'Errico and Henshilwood (2007) have interpreted the serrated Klasies pieces as possible tools, while Bradfield and Wurz (2020) propose their use as possible musical instruments.

4.6. *Ochre*

Beaumont (1978) reports the discovery of ochre fragments at Border Cave. The number of pieces that he recorded by member are similar to those found by us (Figure 9). The only notable differences are that he retrieved three times the amount from 1 BS.LR, and none from 1 RGBS or the older Members 6 BS to 4 WA in EXC. 3A Rear. A count of the ochre fragments found at Border Cave is given by Watts (2002), who identifies 111 pieces for the whole site, gives information on the colours, and from a visual examination proposes the mineral composition. In a more recent publication Watts (2014) reports the presence of one piece in Member 6 BS, three in 5 WA, three in 5 BS, 30 in 4 WA, 35 in 4 BS and four pieces in the upper layers of the sequence. Beaumont (1978) mentions the presence of ochre 'crayons', but without making an inventory of this material, indicating the layers of origin, or presenting evidence that these fragments bore traces of modification. A small slab of red ochre from 1 BS.LR, dated ~42 ka, tentatively interpreted as composed of haematite, is figured in an article devoted to the lithic assemblage from Border Cave (Villa et al., 2012). The authors observe that the edges of the slab are rounded, and that the rounding seems to be the result of rubbing the edge in a longitudinal motion, as indicated by long grooves. The purpose seems to have been to make red marks on a soft material, possibly human skin or animal hide. A thin bone point from 1 WA, dated to 43 ka, is decorated with a delicate incision that spirals around the piece and that is filled with red pigment. It is interpreted as a mark of ownership, and as such the ochre-filled incision served a symbolic purpose (d'Errico et al., 2012a). Traces of ochre on the *Conus* shell associated with the BC3 infant burial (d'Errico and Backwell, 2016) suggest that ochre was used for symbolic purposes at Border Cave 74 ka.

Preliminary analysis of the ochre recovered by us shows that it was apparently not used as a soft hammer for knapping, and neither was it incorporated in compound adhesives used for hafting. One side of a recently excavated piece of ostrich eggshell from Member 4 BS is stained with red ochre. Member 4 BS is dated 91–71 ka (Millard, 2006). Possible ochre grains in ancient bedding dated to 200 ka (Wadley et al., 2020a) suggest that it may have rubbed off from animal hides or human skin, in which case it was used in the tanning of hides (Audouin and Plisson, 1982) and possibly as a sunscreen (Rifkin, 2011), though a symbolic function for body paint cannot be ruled out. Border Cave records very little ochre compared with other MSA sites in South Africa, such as Blombos where over 8,000 pieces were excavated (Henshilwood et al., 2001b; Henshilwood et al., 2002), and Sibudu where over 9,000 pieces were retrieved (Wadley, 2007; Hodgskiss, 2012). One of the original aims of our excavations was to establish whether the relatively low number of ochre fragments reported from Border Cave is the consequence of techniques applied during previous excavations that might have failed to collect, or possibly destroyed, small or fragile fragments, either during excavation or sieving and sorting of the material. The new excavations convincingly show that the low number of ochre fragments and little evidence of modification is a reality and not an artefact of old excavation techniques. The scarcity of ochre at the site is difficult to explain in terms of a lack of availability because iron-rich rocks are present within and close to the Border Cave shelter. This suggests that the dearth of ochre in the Border Cave deposits is best explained in terms of cultural behaviour. MSA sites in southern Africa with worked ochre include nearby Sibudu Cave in KwaZulu-Natal (Wadley, 2007; Hodgskiss, 2012; Wojcieszak, 2018; Wojcieszak and Wadley, 2019), Blombos (Henshilwood et al., 2001b; Henshilwood et al., 2002), Pinnacle Point Cave 13B (Marean et al., 2007; Watts, 2010), Klipdrift (Henshilwood et al., 2014), Hoedjiespunt (Will et al., 2013), Klasies River (Singer and Wymer, 1982; Deacon, 1995; d'Errico, 2008), Die Kelders (Thackeray, 2000), Hollow Rock Shelter (Evans, 1994) and

Diepkloof (Rigaud et al., 2006; Dayet et al., 2013) in the Cape, Rose Cottage in the Free State (Hodgskiss and Wadley, 2017), Mwulu's Cave in Limpopo Province (de la Peña et al., 2018) in South Africa and Apollo 11 in Namibia (Wendt, 1972, 1976; Vogelsang, 1998). Grindstones bearing traces of ochre have been recovered from Sibudu (Wozcieszak, 2018) and Cave of Hearths in South Africa (Mason, 1988), ≠Gi in Botswana (McBrearty and Brooks, 2000: 528) and Pomongwe in Zimbabwe (Walker, 1987), indicating that the use of ochre was widespread in the MSA.

4.7. *Lithics*

In 2018 a preliminary analysis of the material from the 2015 to 2017 campaigns was reported and a general overview of the lithic technology in all of the members was given (Backwell et al., 2018). That preliminary analysis highlighted several technological aspects worth noting: the abundance of elongated blanks and *Levallois* points in Members 5 BS and 4 WA, the presence of *Levallois* reduction in Member 2 BS.LR., and the occurrence of large flake reduction in Members 1 WA and 1 BS.LR C. In this volume an in-depth analysis of the later phases of the Middle Stone Age is presented, including lithic assemblages from Members 1 RGBS, 3 BS, 2 WA and 2 BS (de la Peña et al., this volume), and a study that combines geometric morphometrics and technological analysis of the triangular blanks from Members 3 BS, 2 WA and 2 BS (Timbrell, et al., this volume). All of these members were attributed by Beaumont (1978) to the HP and post-HP/MSA III.

The new technological and taphonomic analysis of the lithics reveals different technological trends in the members attributed to the post-HP. The attribute analysis of lithics from Members 2 BS.UP, 2 BS.LR and 2 WA.UP shows technological differences between the three units, though they have in common *Levallois* recurrent centripetal and discoidal reduction methods. Moreover, lithics from Members 2 WA.MD and 2 WA.LR show similarities between them and are different from the upper layers. Lithics from Members 2 WA.MD and 2 WA.LR are characterized by elongated *Levallois* blanks probably produced from two opposed platform *Levallois* cores (already described by Villa et al., 2012). The attribute analysis shows similarities between lithics from 2 WA.MD and 2 WA.LR and those from Members 3 BS and 1 RGBS regarding raw material frequencies, some of the technological attributes of the blanks, and the lithics as taphonomic indicators. For example, lithics from Members 2 WA.LR and 3 BS show the highest elongation index on blanks in this group of members.

In terms of the presence/absence of *fossiles directeurs*, Member 2 WA.MD-LR and Members 3 BS−1 RGBS denote differences. Member 2 WA.MD-LR has two trimmed base points (also described by Beaumont, 1978), whereas Members 3 BS and 1 RGBS have provided two examples of backed pieces. As already highlighted, the presence of backed pieces is not necessarily an indication of the HP industry because, as shown in other sequences in southern Africa, backed pieces are not exclusive to this technological tradition. At Sibudu Cave there is evidence of backed artefact manufacture as early as 77 ka (Wadley, 2012) and at Pinnacle Point at 71 ka (Brown et al., 2012). In the same vein, there are several instances across southern Africa of backed pieces in MIS 3 and 2 contexts. Nonetheless, the HP constitutes without a doubt a period of proliferation of these pieces (Way et al., in press). At Border Cave, the highest frequency of these pieces was in Member 1 RGBS.A, though no more than 20 backed pieces and three fragments were documented as coming from EXC. 3A Rear (Beaumont, 1978 Vol. II: 273-280). According to Beaumont Members 3 BS, 3 WA and 1 RGBS are also associated with the HP, although the number of backed pieces from these members is even lower. The fact that Members 1 RGBS (80–67 ka) and 3 BS (71–57 ka) have quite old ages, and that the new technological analysis shows no evidence of clear blade production and a very low percentage of backed pieces in these members, caution should be exercised in attributing Members 3 BS and 1 RGBS to the HP. The most important findings of the new analysis are 1) that four sets of technological strategies are distinguished within Members 2 BS and 2 WA, attributed by Beaumont to the post-HP, and 2) that the multivariate analysis of the lithic attributes, raw material distribution and particle size analysis of all the artefacts studied shows continuities between stone tools from Members 2 WA.MD, 2 WA.LR, 3 BS and 1 RGBS, which Beaumont attributed to different industries: post-HP (2 WA) and HP (3 BS, 1 RGBS).

The number of lithics is particularly low in some of the BS members and the upper half of the Border Cave sequence compared to the density of lithics found at nearby Sibudu in KwaZulu-Natal and sites in other provinces with similar chronologies, such as Bushman Rock Shelter. Nonetheless, Border Cave offers on the one hand the rare opportunity of analysing high intensity occupations (such as in the contact of 2 BS.LR and 2 WA.UP) in which activities were conducted at specific moments in time, and on the other hand a long sequence that provides snapshots from MIS 7 to MIS 2 and the evolutionary changes that are poorly represented at most southern African sites.

5. Conclusion

5.1. *Summary of results*

New luminescence dating results for the sedimentary sequence at Border Cave have provided supplementary chronological evidence that is essentially in accordance with ages previously obtained using ESR. The allostratigraphy and facies study of the sequence broadly follows the BS-WA member system devised by Beaumont, but the recent study identifies finer intra-member layering, thus providing greater resolution than before. The sub-units within the members indicate that members should not be considered as homogeneous layers, and that data on finds should not be lumped according to BS and WA members. The study also identifies greater post-depositional disturbance than was previously recognised in the site formation process, including burrows, pits, mudflow, water channels and turbation. Stratigraphic layers and features identified and excavated to date number 237, of which 48 are grass mat/bedding features. The grass mats are extremely well preserved and are rich in seeds, ochre and lithics. Charcoal in the desiccated bedding includes wood from *Tarchonanthus trilobus* (broad-leaved camphor-bush), which has aromatic leaves that are used as an insect repellent in modern plant bedding. The grass mats/bedding found throughout the sequence mostly occur on layers of ash, which suggests that from 200 ka ash was intentionally spread on the ground before grass and leaves were laid down, and that the ash and leaves may have served as a repellent of crawling insects, ticks, scorpions, spiders, and mites. Leaves of eudicot trees form part of the bedding, at least those from Members 5 WA, 2 BS and 2 WA, as indicated by phytolith analysis and the preservation of macro-leaves. Fifty-five charred underground storage organs, identified as *Hypoxis angustifolia*, are the oldest known examples of cooked starchy rhizomes at 170 thousand years old. Seeds and wood are found throughout the sequence, as are the remains of giant land snails. The abundance of land snails in members dated to between 168 ka and 77 ka suggests that they may have been part of the diet of visitors to the cave, and that more recent occupants ate them only occasionally. Bone is also recorded throughout the sequence, except in the two oldest members, and includes small and very large animals, with bovids being the most common taxa identified. Among the bone assemblage was the vertebra of a human child. Ochre has been recovered throughout the sequence, but there is very little of it compared to other cultural remains. The highest number of lithics retrieved come from layers >100 ka. It is not yet possible to assign any of the Border Cave lithic assemblages to industries recognised elsewhere in southern Africa.

5.2. *Research perspectives*

One of our short-term aims is to excavate deposits on the South profile of excavation 4A to better understand the lithic technology and people represented at the site for the period currently attributed to the HP. The deposits that span the period 82–54 ka that we have excavated on the North profile have yielded only two stone tools, neither of which is backed, and this deserves further investigation. We plan to continue excavating sections of the entire stratigraphic sequence to retrieve more lithic artefacts because our sample size is small. This will enable us to check previous cultural attributions and look for regional features and affinities with other MSA sites in southern Africa. We plan to excavate two large ancient pits, one flat and the other round, which are exposed in Member 5 BS in the North section of N108 E114-115. We are going to evaluate different hypotheses based on their size and shape; including that the bowl-shaped one may preserve traces of use as a roasting pit, and that the other contains human remains. We plan to expand excavations on the South face of EXC. 4A, targeting the deposits that Beaumont called ELSA. Our analysis of lithic and organic remains from 44 ka deposits at Border Cave shows that, by this time, there were elements of a material culture similar to that found at younger LSA sites (d'Errico et al., 2012a; Villa et al., 2012). They take the form of ostrich eggshell beads, bone arrowheads, a poison applicator, a lump of beeswax, a digging stick, microliths that were hafted with tree resin and a bored stone, probably used as a weight on a digging stick. New excavations in Members 1 WA and 1 BS may help to address the doubts expressed by Bader and colleagues (2022) regarding the early transition from the MSA to LSA at Border Cave. New finds from these layers may clarify whether or not the 44 ka Border Cave artefacts are innovative LSA precursors that signal cultural continuity between MSA and LSA in a limited part of southern Africa.

In accordance with our interest in archaeological evidence of complex cognition before and after 100 ka, we will continue with existing excavations on the North wall of Beaumont's EXC. 3A rear, which spans Members 4 WA (~120 ka) to 3 BS (~60 ka). We plan to expand excavations in N109 E118 as only one quarter of the square has been excavated. Excavations in this square will serve to remove a column of unexcavated deposit, which will expose a continuous lateral profile of the sequence from the youngest to the oldest members. Future work will investigate the artefact density throughout the sequence, based on plotted artefacts and non-plotted bucket finds. Phytolith and FT-IR analyses will be expanded to compare phytolith preservation and composition in the remainder of the Border Cave sequence. One of our objectives is to understand the provenance of the ochre present at Border Cave, how it was modified and used, and whether these behaviours changed over time. This will be done through technological and physicochemical analyses of the ochre, combined with a characterisation of potential geological sources. Considering the relatively small volume of sediment removed during our excavations, our aim is to extend this analysis to all the ochre discovered by Beaumont, which is stored at the McGregor Museum in Kimberley. We aim to produce a high-resolution multi-proxy record of environmental change and contemporaneous human behaviour that extends from MIS 7 to MIS 2. This will contribute to our understanding of the impact of climate change on subsistence strategies in this region and provide a framework for our understanding of the emergence of behavioural modernity.

Author contributions

L.B, L.W and F.D. conceived the research. L.B. and G.M. analysed the data and wrote the paper, with input from L.W., F.D., D.S. and P.d.l.P. Figures were produced by L.B and G.M. W.B., C.S., G.L., B.V., J.C., C.T., A.B., T.J. and K.C. revised versions of the manuscript and made improvements to the text. All authors read and approved the final manuscript. Funding was acquired by L.B.

Declaration of competing interest

The authors declare that they have no competing financial interests or personal relationships that could have influenced the work reported in this paper.

Acknowledgements

This research was generously funded by a National Geographic Explorer grant (NGS-54810R-19) and DSI-NRF Centre of Excellence in Palaeosciences (Genus) grant (CEOOP2020-1) to Lucinda Backwell. Francesco d'Errico was supported by the European Research Council (ERC) under the Horizon 2020 program (QUANTA project, contract no. 951388), the Research Council of Norway through its Centres of Excellence funding scheme, SFF Centre for Early Sapiens Behaviour (SapienCE), project number 262618, the LaScArBx research programme (ANR-10-LABX-52), and the Talents Programme [grant number: 191022_001]. Francesco d'Errico, Chantal Tribolo and William Banks were supported by the *Grand Programme de Recherche* 'Human Past' of the Initiative d'Excellence (IdEx) of the University of Bordeaux. Financial support from the National Research Foundation (NRF) of South Africa is acknowledged by Dominic Stratford (NRF Y-Rated Researcher grant #116358), Amélie Beaudet (#129336) and Lucinda Backwell (#98824). Sandra Lennox received a post-doctoral fellowship funded by a NRF African Origins Platform grant awarded to Lyn Wadley (#98827). A DSI-NRF Centre of Excellence in Palaeosciences (Genus) grant (COE2021-GM) is acknowledged by Guilhem Mauran. Paloma de la Peña was supported by a Poroulis grant through Cambridge University and the action PID2019-1049449GB-I00 funded by the Spanish FEDER/Ministry of Science and Innovation. Irene Esteban received funding from the postdoctoral fellowship programme Beatriu de Pinós (2019BP00247), funded by the Secretary of Universities and Research (Government of Catalonia) and by the Horizon 2020 programme of research and innovation of the European Union under the Marie Sklodowska-Curie grant agreement No. 801370. Ghilraen Laue's field trips were sponsored by the KwaZulu-Natal Museum. We are grateful to Amafa for issuing us with the excavation permit (SAH 15/7645), and the Evolutionary Studies Institute at the University of the Witwatersrand for housing our field equipment and archaeological collections. David Morris and Bernhard Zipfel kindly provided information on the location of previously excavated Border Cave material. We thank the local Border Cave community for welcoming us into their homes during our field trips, and Len van Schalkwyk, Chris Thornhill and Amon Sokhela of eThembeni Cultural Heritage for logistical support in the field.

References

Aldeias, V., Dibble, H.L., Sandgathe, D., Goldberg, P., McPherron, S.J.P., 2016. How heat alters underlying deposits and implications for archaeological fire features: a controlled experiment. J. Archaeol. Sci. 67, 64–79.

Allott, L.F., 2004. Changing environments in Oxygen Isotope Stage 3: reconstructions using archaeological charcoal from Sibudu Cave. S. Afr. J. Sci. 100, 179–184.

Allott, L.F., 2006. Archaeological charcoal as a window on palaeo-vegetation and wood use during the Middle Stone Age at Sibudu Cave. South. Afr. Humanit. 18(1), 173–201.

Ambergen, A.W., Schaafsma, W., 1984. Interval estimates for posterior probabilities: Applications to Border Cave. In: van Vark, G.N., Howells, W.W. (Eds.), Multivariate Statistical Methods in Physical Anthropology. Reidel, Dordrecht, pp. 115–134.

Anderson, J., 1978. A survey of the extant flora in the vicinity of Border Cave. In: Beaumont, P., Border Cave. M.A. dissertation, University of Cape Town, pp. 195–213.

Anderson, J.R., 1998. Sleep, sleeping sites, and sleep-related activities: awakening to their significance. Am. J. Primatol. 46, 63–75

Audouin, F., Plisson, H., 1982. Les ochres et leurs témoins au Paléolithique en France: enquéte et expériences sur leur validité archéologique. Cah. Centre de Recherches Préhistoriques 8, 33–80.

Backwell, L., d'Errico, F., Wadley, L., 2008. Middle Stone Age bone tools from the Howiesons Poort layers, Sibudu Cave, South Africa. J. Archaeol. Sci. 35, 1566–1580.

Backwell, L., Wadley, L., d'Errico, F., Banks, W., de la Peña, P., Sievers, C., Stratford, D., Lennox, S., Wojcieszak, M., Bordy, E., Bradfield, J., 2018. New excavations at Border Cave, KwaZulu-Natal, South Africa. J. Field Archaeol. 43(6), 417–436.

Backwell, L.R., Wojcieszak, M., Wadley, L., 2020. The effect of heat on keratin and implications for the archaeological record. Archaeol. Anthrop. Sci. 12(8), 1–10.

Backwell, L.R., Huchet, J.-B., du Guesclin Harrison, J., d'Errico, F., 2022. Invertebrate modification of bone. In: Pokines, J.T., Symes, S.A. (Eds.), Manual of Forensic Taphonomy. CRC Press, Boca Raton, FL, pp. 631–666.

Bader, G.D., Mabuza, A., Price Williams, D., Will, M., 2022. Rethinking the Middle to Later Stone Age transition in southern Africa – A perspective from the highveld of Eswatini. Quaternary Sci. Rev. 286, 107540.

Bamford, M.K., 2021. Pollen, charcoal and phytolith records from the Late Quaternary of southern Africa: vegetation and climate interpretations S. Afr. J. Geol. 124(4), 1047–1054

Bamford, M.K., Henderson, Z.L., 2003. A reassessment of the wooden fragment from Florisbad, South Africa. J. Archaeol. Sci. 30, 637–651.

Beaudet, A., d'Errico, F., Backwell, L., Wadley, L., Zipfel, B., de la Peña, P., Reyes-Centeno, H., 2022. A reappraisal of the Border Cave 1 cranium (KwaZulu-Natal, South Africa). Quaternary Sci. Rev. 282, 107452.

Beaumont, P.B., 1973. Border Cave - A Progress Report. S. Afr. J. Sci. 69, 41–46.

Beaumont, P.B., 1978. Border Cave. M.A. dissertation, University of Cape Town. South Africa.

Beaumont, P.B., 1980. On the age of Border Cave hominids 1-5. Palaeontol. Afr. 23, 21–33.

Beaumont, P.B., Vogel, J.C., 1972. On a new radiocarbon chronology for Africa South of the Equator. Afr. Stud. 31, 65–89.

Beaumont, P.B., Vogel, J.C., 2006. On a timescale for the past million years of human history in central South Africa. S. Afr. J. Sci. 102, 217–228.

Beaumont, P.B., de Villiers, H., Vogel, J., 1978. Modern man in sub-Saharan Africa prior to 49 000 years BP: a review and evaluation with particular reference to Border Cave. S. Afr. J. Sci. 74(11), 409–419.

Beaumont, P.B., Miller, G., Vogel, J., 1992. Contemplating old clues to the impact of future greenhouse climates in South Africa. S. Afr. J. Sci. 88, 490–498.

Beentje, H.J., 1999. The genus *Tarchonanthus* (Compositae-Mutisieae). Kew Bull. 81–95.

Bird, M.I., Fifield, L.K., Santos, G.M., Beaumont, P.B., Zhou, Y., Di Tada, M.L., Hausladen, P.A., 2003. Radiocarbon dating from 40–60 ka bp at Border Cave, South Africa. Quat. Sci. Rev. 22, 943–947.

Bradfield, J., Wurz, S., 2020. A functional assessment of the notched bone artefacts from Klasies River Main site. S. Afr. Archaeol. Bull. 75(213), 128–136.

Brooks, A.S., Yellen, J.E., Potts, R., Behrensmeyer, A.K., Deino, A.L., Leslie, D.E., Ambrose, S.H., Ferguson, J.R., d'Errico, F., Zipkin, A.M., Whittaker, S., Post, J., Veatch, E.G., Foecke, K., Clark, J.B., 2018. Long-distance stone transport and pigment use in the earliest Middle Stone Age. Science 360, 90–94.

Brown, K.S., Marean, M.W., Jacobs, Z., Schoville, B.J., Oestmo, S., Fisher, E.C., Bernatchez, J., Karkanas, P., Matthews, Th., 2012. An early and enduring advanced technology originating 71,000 years ago in South Africa. Nature 491, 590–594.

Butzer, K., Beaumont, P.B., Vogel, J.C., 1978. Lithostratigraphy of Border Cave, KwaZulu, South Africa: a Middle Stone Age Sequence Beginning c. 195,000 B.P. J. Archaeol. Sci. 5(4), 317–341.

Cain, C.R., 2004. Notched, flaked and ground bone artefacts from Middle Stone Age and Iron Age layers of Sibudu Cave, KwaZulu-Natal, South Africa. S. Afr. J. Sci. 100, 195–197.

Campbell, N.A., 1984. Some aspects of discrimination and allocation. In: van Vark, G.N., Howells, W.W. (Eds.), Multivariate Statistical Methods in Physical Anthropology. Dordrecht, Reidel, pp. 177–192.

Cartwright, C.R., 2013. Identifying the woody resources of Diepkloof Rock Shelter (South Africa) using scanning electron microscopy of the MSA wood charcoal assemblages. J. Archaeol. Sci. 40, 3463–3474.

Cartwright, C.R., Parkington. J., 1997. The wood charcoal assemblages from Elands Bay Cave, southwestern Cape: principles, procedures and preliminary interpretation. S. Afr. Archaeol. Bull. 52, 59–72.

Chazan, M., and Horwitz, L.K., 2009. Milestones in the development of symbolic behaviour: a case study from Wonderwerk Cave, South Africa. World Archaeol. 41(4), 521–539.

Clark, J.D., 1954. An early Upper Pleistocene site at the Kalambo Falls on the Northern Rhodesia/Tanganyika border. S. Afr. Archaeol. Bull. 9, 51–56.

Clark, J.D., 1955. A note on a wooden implement from the level of Peat 1 at Florisbad, Orange Free State. Navorsinge van die Nasionale Museum (Bloemfontein) 1, 135–140.

Clark, J.L., 2017. The Howieson's Poort fauna from Sibudu Cave: documenting continuity and change within Middle Stone Age industries. J. Hum. Evol. 107, 49–70.

Clark, J.L., 2019. The Still Bay and pre-Still Bay fauna from Sibudu Cave: taphonomic and taxonomic analysis of the macromammal remains from the Wadley excavations. J. Paleolithic Archaeol. 2(1), 26–73.

Coates-Palgrave, K.C., 1981. Trees of Southern Africa. Struik Publishers.

Conard, N.J., Porraz, G., Wadley, L., 2012. What is in a name? Characterising the 'post-Howiesons Poort' at Sibudu. S. Afr. Archaeol. Bull. 67, 180–199.

Cooke, H.B.S., Malan, B.D., Wells, L.H., 1945. Fossil man in the Lebombo Mountains, South Africa: the 'Border Cave', Ingwavuma district, Zululand. Man 45(3), 6–13.

Coolidge, F.L., 2019. The enhanced working memory model: its origin and development. In Overmann, K.A., Coolidge, F.L. (Eds.), Squeezing Minds from Stones: Cognitive Archaeology and the Evolution of the Human Mind. Oxford University Press, Oxford, pp. 406–431.

Corruccini, R.S., 1991. Metrical reconsideration of the Skhūl IV and IX and Border Cave 1 crania in the context of modern human origins. Am. J. Phys. Anthropol. 87, 433–445.

Cowling, R.M., Cartwright, C.R., Parkington, J.E., Allsopp, J.C., 1999. Fossil wood charcoal assemblages from Elands Bay Cave, South Africa: implications for Late Quaternary vegetation and climates in the winter-rainfall Fynbos Biome. J. Biogeogr. 26, 367–378.

Dayet, L., Texier, P.-J., Daniel, F., Porraz, G., 2013. Ochre resources from the Middle Stone Age sequence of Diepkloof Rock Shelter, Western Cape, South Africa. J. Archaeol. Sci. 40, 3492–3505.

Deacon, H.J., 1970. The Acheulean occupation at Amanzi Springs Uitenhage District, Cape Province. Annals of the Cape Provincial Museums 8, 89–189.

Deacon, H.J., 1995. Two late Pleistocene-Holocene archaeological depositories from the Southern Cape, South Africa. S. Afr. Archaeol. Bull. 50, 121–131.

d'Errico, F., 2008. Le rouge et le noir: implications of early pigment use in Africa, the Near East and Europe for the origin of cultural modernity. South African Archaeological Society Goodwin Series 10, 168–174.

d'Errico, F., Henshilwood, C.S., 2007. Additional evidence for bone technology in the southern African Middle Stone Age. J. Hum. Evol. 52, 142–163.

d'Errico, F., Stringer, C., 2011. Evolution, revolution or saltation scenario for the emergence of modern cultures? Philos. T. Roy. Soc. B. 366, 1060–1069.

d'Errico, F., Backwell, L.R., 2016. Earliest evidence of personal ornaments associated with burial: the *Conus* shells from Border Cave. J. Hum. Evol. 93, 91–108.

d'Errico, F., Vanhaeren, M., Barton, N., Bouzouggar, A., Mienis, H., Richter, D., Hublin, J.-J., Shannon, P., McPherron, P.S., Lozouet, P., 2009. Additional evidence on the use of personal ornaments in the Middle Paleolithic of North Africa. P. Natl. Acad. Sci. USA. 107(3), 1023–1028.

d'Errico, F., Backwell, L.R., Villa, P., Degano, I., Lucejko, J., Bamford, M., Higham, T., Colombini, M.P., Beaumont, P., 2012a. Early evidence of San material culture represented by organic artifacts from Border Cave, South Africa. P. Natl. Acad. Sci. USA. 109(33), 13214–13219.

d'Errico, F., Backwell, L., Wadley, L., 2012b. Identifying regional variability in Middle Stone Age bone technology: the case of Sibudu Cave. J. Archaeol. Sci. 39, 2479–2495.

d'Errico, F., Banks, W.E., Warren, D.L., Sgubin, G., van Niekerk, K., Henshilwood, C., Daniau, A.L., Goñi, M.F.S., 2017. Identifying early modern human ecological niche expansions and associated cultural dynamics in the South African Middle Stone Age. P. Natl. Acad. Sci. USA. 114(30), 7869–7876.

d'Errico, F., Doyon, L., Colagé, I., Queffelec, A., Le Vraux, E., Giacobini, G., Vandermeersch, B. and Maureille, B., 2018. From number sense to number symbols. An archaeological perspective. Philos. T. R. Soc. B., 373(1740), p.20160518.

de la Peña, P., Colino, F., Stratford, D., Banks, W., Esteban, I., d'Errico, F., Wadley, L., Backwell, L., The lithic technology and spatial analysis of the final phases of the Middle Stone Age at Border Cave. Quaternary Sci. Rev

de la Peña, P., Val, A., Stratford, D.J., Colino, F., Esteban, I., Fitchett, J.M., Hodgskiss, T., Matembo, J., Moll, R., 2019. Revisiting Mwulu's Cave: new insights into the Middle

Stone Age in the southern African savanna biome. Archaeol. Anthrop. Sci. 11(7), 3239–3266.

de Villiers, H., 1973. Human skeletal remains from Border Cave, Ingwavuma district, KwaZulu, South Africa. Annls. Transv. Mus. 28, 229–256.

Esteban, I. Stratford, D., de la Peña, P., Backwell, L., d'Errico, F., Wadley, L., Plants, People and Fire: phytolith and FTIR analyses of the post-Howiesons Poort occupations at Border Cave (KwaZulu-Natal, South Africa). Quaternary Sci. Rev.

Evans, U., 1994. Hollow Rock Shelter, a Middle Stone Age site in the Cederberg. South. Afr. Field Archaeol. 3, 63–73.

Fruth, B., Hohmann, G., 1996. Nest building behavior in the great apes: the great leap forward? In: McGrew, W.C., Marchant, L.F., Nishida T. (Eds), Great Ape Societies. Cambridge, Cambridge University Press, pp. 225–240.

Gandar, M., 1982. Some social and environmental aspects of the use of fuel wood in Kwazulu. In: Bromberger, N., Lea, J.D., (Eds.), Rural Studies in Kwazulu. University of Natal, Pietermaritzburg, pp. 147–152.

Goldberg, P., Miller, C.E., Schiegl, S., Ligouis, B., Berna, F., Conard, N.J., Wadley, L., 2009. Bedding, hearths, and site maintenance in the Middle Stone Age of Sibudu Cave, KwaZulu-Natal, South Africa. Archaeol. Anthrop. Sci. 1(2), 95–122.

Grün, R., Beaumont, P., 2001. Border Cave revisited: a revised ESR chronology. J. Hum. Evol. 40, 467–482.

Grün, R., Beaumont, P.B., Stringer, C.B., 1990. ESR dating evidence for early modern humans at Border Cave in South Africa. Nature 344(6266), 537–539.

Grün, R., Beaumont, P., Tobias, P.V., Eggins, S., 2003. On the age of Border Cave 5 human mandible. J. Hum. Evol. 45, 155–167.

Henshilwood, C.S., 2012. Late Pleistocene techno-traditions in southern Africa: a review of the Still Bay and Howiesons Poort, c. 75–59 ka. J. World Prehist. 25, 205–237.

Henshilwood, C.S., Sealy, J.C., 1997. Bone artefacts from the Middle Stone Age at Blombos Cave, southern Cape, South Africa. Current Anthropology 38, 890–895.

Henshilwood, C.S., d'Errico, F., Marean, C.W., Milo, R.G., Yates, R., 2001a. An early bone tool industry from the Middle Stone Age at Blombos Cave, South Africa: implications for the origins of modern human behaviour, symbolism and language. J. Hum. Evol. 41, 631–678.

Henshilwood, C.S., Sealy, J.C., Yates, R., Cruz-Uribe, K., Goldberg, P., Grine, F.E., Klein, R.G., Poggenpoel, C., van Niekerk, K., Watts, I., 2001b. Blombos Cave, Southern Cape, South Africa: preliminary report on the 1992–1999 excavations of the Middle Stone Age levels. J. Archaeol. Sci. 28, 421–448.

Henshilwood, C.S., d'Errico, F., Yates, R., Jacobs, Z., Tribolo, C., Duller, G.A., Mercier, N., Sealy, J.C., Valladas, H., Watts, I., Wintle, A.G., 2002. Emergence of modern human behavior: Middle Stone Age engravings from South Africa. Science 295(5558), 1278–1280.

Henshilwood, C.S., van Niekerk, K., Wurz, S., Delagnes, A., Armitage, S.J., Rifkin, R., Douze, K., Keene, P., Haaland, M., Reynard, J., Discamps, E., Mienies, S., 2014. Klipdrift Shelter, southern Cape, South Africa: preliminary report on the Howiesons Poort layers." J. Archaeol. Sci. 45, 284–303.

Herbert, D., Kilburn, R., 2004. Field Guide to the Land Snails and Slugs of Eastern South Africa. Natal Museum.

Hodgskiss, T., 2012. Attribute analysis of the Sibudu Middle Stone Age ochre assemblage. South. Afr. Humanit. 24, 99–120.

Hodgskiss, T., Wadley, L., 2017. How people used ochre at Rose Cottage Cave, South Africa: Sixty thousand years of evidence from the Middle Stone Age. PLoS ONE 12(4), e0176317.

Houghton, K., Thackeray, J.F., 2011. Morphometric comparisons between crania of Late Pleistocene *Homo sapiens* from Border Cave (BC 1), Tuinplaas (TP 1) and modern southern African populations. T. Roy. Soc. S. Afr. 66, 159–162.

Jashashvili, T., Carlson, K., Zipfel, B., Clark, J., Wadley, L., d'Errico, F., de la Peña, P., Stratford, D., Sievers, C., Backwell, L. New human skeletal remains from Border Cave, South Africa. Quaternary Sci. Rev. Under review.

Karkanas, P., Bar-Yosef, O., Goldberg, P., Weiner, S., 2000. Diagenesis in prehistoric caves: the use of minerals that form *in situ* to assess the completeness of the archaeological record. J. Archaeol. Sci. 27, 915–929.

Kissel, M., Fuentes, A., 2018. 'Behavioral modernity' as a process, not an event, in the human niche. Time Mind 11(2), 163–183.

Klein R.G., 2001. Southern Africa and modern human origins. J. Anthropol. Res. 57, 1–16.

Lanos, P., Dufresne, P., 2019. ChronoModel version 2.0 User manual. https://hal.archives-ouvertes.fr/hal-02058018

Lanos, P., Philippe, A., 2018. Event date model: a robust Bayesian tool for chronology building. Commun. for Stat. Applications and Meth. 25(2), 131–157.

Lennox, S.J., 2016. Woody Taxa from Charcoal in Sibudu's Middle Stone Age Hearths. Ph.D. thesis, University of the Witwatersrand. South Africa.

Lennox, S., Backwell, L., d'Errico, F., Wadley, L., A vegetation reconstruction based on charcoal identifications from Border Cave, KwaZulu-Natal, South Africa, ~ 227 000 to ~ 43 000 years ago. Quaternary Sci. Rev.

Marean, C.W., Bar-Matthews, M., Bernatchez, J., Fisher, E., Goldberg, P., Herries, A.I., Jacobs, Z., Jerardino, A., Karkanas, P., Minichillo, T., Nilssen, P.J., 2007. Early human use of marine resources and pigment in South Africa during the Middle Pleistocene. Nature 449(7164), 905–908.

Mason, R.J., 1988. Cave of Hearths, Makapansgat, Transvaal. Archaeological Research Unit, University of the Witwatersrand.

McBrearty, S., Brooks, A., 2000. The revolution that wasn't: a new interpretation of the origin of modern human behaviour. J. Hum. Evol. 39, 453–563.

Mellars, P., 1991. Cognitive changes and the emergence of modern humans in Europe. Camb. Archaeol. J. 1, 63–76.

Millard, A., 2006. Bayesian analysis of ESR dates, with application to Border Cave. Quat. Geochronol. 1(2), 159–166.

Miller, G.H., Beaumont, P.B., 1989. Dating in the Middle Stone Age at Border Cave, South Africa, by the epimerization of isoleucine in ostrich eggshell. Geol. Soc. Am. 21, A235.

Miller, G.H., Beaumont, P.B., Deacon, H.J., Brooks, A.S., Hare, P.E., Jull, A.J.T., 1999. Earliest modern humans in Southern Africa dated by isoleucine epimerization in ostrich eggshell. Quaternary Sci. Rev. 18, 1537–1548.

Miller, C.E., Goldberg, P., Berna, F., 2013. Geoarchaeological investigations at Diepkloof Rock Shelter, Western Cape, South Africa. J. Archaeol. Sci. 40, 3432–3452.

Nunn, C.L., Heymann, E.W., 2005. Malaria infection and host behavior: a comparative study of Neotropical primates. Behav. Ecol. Sociobiol. 59, 30–37.

Opperman, H., 1996. Strathalan Cave B, north-eastern Cape Province, South Africa: evidence for human behaviour 29 000-26 000 years ago. Quatern. Int. 33, 45–53.

Opperman, H., Heydenrych, B., 1990. A 22 000 year-old Middle Stone Age camp site with plant food remains from the north-east Cape. S. Afr. Archaeol. Bull. 45, 93–99.

Plug, I., 1981. Some research results on the late Pleistocene and early Holocene deposits of Bushman Rock Shelter, eastern Transvaal. S. Afr. Archaeol. Bull. 36, 14–21.

Reynard, J.P., Henshilwood, C.S., 2018. Using trampling modification to infer occupational intensity during the Still Bay at Blombos Cave, southern Cape, South Africa. Afr. Archaeol. Rev. 35(1), 1–19.

Rifkin, R.F., 2011. Assessing the efficacy of red ochre as a prehistoric hide tanning ingredient. J. Afr. Archaeol. 9, 131–158.

Rigaud, J-P., Texier, P-J., Parkington, J., Poggenpoel. C., 2006. Le mobilier Stillbay et Howiesons Poort de l'abri Diepkloof. La chronologie du Middle Stone Age sud-africain et ses implications. CR. Palevol. 5, 839–849.

Rightmire, G.P., 1979. Implications of the Border Cave skeletal remains for Later Pleistocene human evolution. Current Anthropology 20, 23–35.

Rightmire, G.P., 1989. Middle Stone Age humans from Eastern and Southern Africa. In: Mellars, P., Stringer, C.B. (Eds.), The Human Revolution. Edinburgh University Press, Edinburgh, pp. 109–122.

Riley, T.R., Millar, I.L., Watkeys, M.K., Curtis, M.L., Leat, P.T., Klausen, M.B., Fanning, C.M., 2004. U–Pb zircon (SHRIMP) ages for the Lebombo rhyolites, South Africa: refining the duration of Karoo volcanism. J. Geol. Soc. London 161(4), 547–550.

Samson, D.R., 2012. The chimpanzee nest quantified: morphology and ecology of arboreal sleeping platforms within the dry habitat site of Toro-Semliki Wildlife Reserve, Uganda. Primates 53(4), 357–364.

Scholtz, A., 1986. Palynological and Palaeobotanical Studies in the Southern Cape. M.A. dissertation, University of Stellenbosch. South Africa.

Sievers, C., 2006. Seeds from the Middle Stone Age layers at Sibudu Cave. South. Afr. Humanit. 18(1), 203–222.

Sievers, C., Wadley, L., 2008. Going underground: experimental carbonization of fruiting structures under hearths. J. Archaeol. Sci. 35(11), 2909–2917.

Sievers, C., Backwell, L., d'Errico, F., Wadley, L., 2022. Plant bedding construction between 60,000 and 40,000 years ago at Border Cave, South Africa. Quaternary Sci. Rev. 275, 107280.

Simpson, J.J., Grün, R., 1998. Non-destructive gamma spectrometric U-series dating. Quaternary Sci. Rev. 17(11), 1009–1022.

Singer, R., Wymer, J., 1982. The Middle Stone Age at Klasies River Mouth in South Africa. Chicago, Chicago University Press.

Stewart, B.A., Parker, A.G., Dewar, G., Morley, M.W., Allott, L.F., 2016. Follow the Senqu: Maloti-Drakensberg paleoenvironments and implications for early human dispersals into mountain systems. In: Jones, S.C., Stewart, B.A. (Eds.), Africa from MIS 6-2: Population Dynamics and Paleoenvironments. Springer, Dordrecht, pp. 247–271.

Stratford, D., Clark, J., Wojcieszak, M., de la Peña, P., Wadley, L., d'Errico, F., Mauran, G., Sievers, C., Banks, W., Beard, T., Horn, M., Shadrach, K., Morrissey, P., Backwell, L., 2022. Geoarchaeology and zooarchaeology of Border Cave, South Africa: initial multiproxy considerations of stratigraphy and site formation processes from the Backwell *et al*. excavations. Quaternary Sci. Rev.

Stringer, C., 2002. Modern human origins: progress and prospects. Philos. T. R. Soc. Lon. B. 357, 563–579.

Thackeray, A.I., 2000. Middle Stone Age artefacts from the 1993 and 1995 excavations of Die Kelders Cave 1, South Africa. J. Hum. Evol. 38, 147–168.

Timbrell, L., Grove, M., Way, A., Hoggard, C., Backwell, L. d'Errico, F., Wadley, L., de la Peña, P. 2022. Technological and geometric morphometric analysis of 'post-Howiesons

Poort points' from Border Cave, KwaZulu-Natal, South Africa. Quaternary Sci. Rev. Under review.

Tommy, K.A., Zipfel, B., Kibii, J., Carlson, K.J., 2021. Trabecular bone properties in the ilium of the Middle Paleolithic/Middle Stone Age Border Cave 3 Homo sapiens infant and the onset of independent gait. J. Hum. Evol. 155, 102984.

Tribolo, C., Mercier, N., Dumottay, C., Cantin, N., Banks, W., Stratford, D., de la Peña, P., Backwell, L., Wadley, L., d'Errico, F., 2022. Luminescence dating at Border Cave: attempts, questions and new results. Quaternary Sci. Rev. Under review.

van Vark, G.N., Bilsborough, A., Dijkema, J., 1989. A further study of the morphological affinities of the Border Cave 1 cranium, with special reference to the origin of modern man. Anthrop. Préhist. 100, 43–56.

van Wyk, B., van Wyk, P., 2013. Field Guide to Trees of Southern Africa (2nd ed.). Struik Nature.

Villa, P., Roebroeks, W., 2014. Neandertal demise: an archaeological analysis of the modern human superiority complex. PLoS one 9(4), p.e96424.

Villa, P., Soriano, S., Tsanova, T., Higham, T., d'Errico, F., Backwell, L.R., Lucejko, J., Beaumont, P., 2012. Border Cave and the beginning of the Later Stone Age in South Africa. P. Natl. Acad. Sci. USA. 109(33), 13208–13213.

Villa, P., Pollarolo, L., Degano, I., Birolo, L., Pasero, M., Biagioni, C., Douka, K., Vinciguerra, R., Lucejko, J.J., Wadley, L., 2015. A milk and ochre paint mixture used 49,000 years ago in South Africa. PLoS One 10(6), e0131273.

Vogel, J.C., 1970. Groningen radiocarbon dates IX. Radiocarbon 12(2), 444–471.

Vogel, J.C., Beaumont, P.B., 1972. Revised radiocarbon chronology for the Stone Age in South Africa. Nature, 237(5349), 50–51.

Vogel, J.C., Fuls, A., Visser, E., 1986. Pretoria radiocarbon dates III. Radiocarbon 28(3), 1133–

1172.

Vogelsang, R., 1998. Middle Stone Age Fundstellen in Südwest-Namibia. Köln, Heinrich Barth Institut.

Vogelsang, R., Richter, J., Jacobs, Z., Eichhorn, B., Linseele, V., Roberts, R.G., 2010. New excavations of Middle Stone Age deposits at Apollo 11 Rock Shelter, Namibia: stratigraphy, archaeology, chronology and past environments. J. Afr. Archaeol. 8, 185–218.

Wadley, L., 2004. Vegetation changes between 61 500 and 26 000 years ago: the evidence from seeds in Sibudu Cave, KwaZulu-Natal. S. Afr. J. Sci. 100, 167–173.

Wadley, L., 2006. Partners in grime: results of multi-disciplinary archaeology at Sibudu Cave. South. Afr. Humanit. 18(1), 315–341.

Wadley, L., 2007. Announcing a Still Bay Industry at Sibudu Cave. J. Hum. Evol. 52,681–689.

Wadley, L., 2012. Two moments in time during Middle Stone Age occupations of Sibudu, South Africa. South. Afr. Humanit. 24(1), 79–97.

Wadley, L., 2013. Recognizing complex cognition through innovative technology in Stone Age and Palaeolithic sites. Cam. Archaeol. J. 23(2), 163–183.

Wadley, L., 2015. Those marvellous millennia: the Middle Stone Age of southern Africa. Azania 50(2), 155–226.

Wadley, L., 2021. What stimulated rapid, cumulative innovation after 100,000 years ago? J. Archaeol. Method Th. 28(1), 120–141.

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., Trower, G., Backwell, L., d'Errico, F., 2015. Traditional glue, adhesive and poison used for composite weapons by Ju/'hoan San in Nyae Nyae, Namibia. Implications for the evolution of hunting equipment in prehistory. PloS One 10(10), p.e0140269.

Wadley, L., Esteban, I., de la Peña, P., Wojcieszak, M., Stratford, D., Lennox, S., d'Errico, F., Rosso, D.E., Orange, F., Backwell, L.R., Sievers, C., 2020a. Fire and grass bedding construction 200 thousand years ago at Border Cave, South Africa. Science 369, 863–866.

Wadley, L., Backwell, L., d'Errico, F., Sievers, C., 2020b. Cooked starchy rhizomes in Africa 170 thousand years ago. Science 367(6473), 87–91.

Walker, N.J., 1987. The dating of Zimbabwe rock art. Rock Art Res. 4, 137–149.

Watts, I., 2002. Ochre in the Middle Stone Age of southern Africa: ritualised display or hide preservative? S. Afr. Archaeol. Bull. 1–14.

Watts, I., 2010. The pigments from Pinnacle Point Cave 13B, Western Cape, South Africa. J. Hum. Evol. 59, 392–411.

Watts, I., 2014. The red thread: pigment use and the evolution of collective ritual. In: Dor, D., Knight, C., Lewis, J. (Eds.), The Social Origins of Language. Oxford University Press, Oxford, pp. 208–227.

Way, A.M., de la Peña, P., de la Peña, E., Wadley, L. Howiesons Poort backed artifacts provide evidence for social connectivity across southern Africa during the Final Pleistocene. Scientific Reports. (In press)

Wendt, W.E., 1972. Preliminary report on an archaeological research programme in South West Africa. Cimbebasia Series B 2, 1–61.

Wendt, W.E., 1976. 'Art mobilier' from the Apollo 11 Cave, South West Africa: Africa's oldest dated works of art. S. Afr. Archaeol. Bull. 31, 5–11.

Werts, S.P., Jahren, A.H., 2007. Estimation of temperatures beneath archaeological campfires using carbon stable isotope composition of soil organic matter. J. Archaeol. Sci. 34(6), 850–857.

Wilkins, J., Chazan, M., 2012. Blade production~ 500 thousand years ago at Kathu Pan 1, South Africa: support for a multiple origins hypothesis for early Middle Pleistocene blade technologies. J. Archaeol. Sci. 39(6), 1883-1900.

Wilkins, J., Schoville, B.J., Pickering, R., Gliganic, L., Collins, B., Brown, K.S., von der Meden, J., Khumalo, W., Meyer, M.C., Maape, S., Blackwood, A.F., 2021. Innovative *Homo sapiens* behaviours 105,000 years ago in a wetter Kalahari. Nature 592(7853), 248–252.

Will, M., Parkington, J.E., Kandel, A.W., Conard, N.J., 2013. Coastal adaptations and the Middle Stone Age lithic assemblages from Hoedjiespunt 1 in the Western Cape, South Africa. J. Hum. Evol. 64, 518–537.

Will, M., Bader, G.D., Conard, N.J., 2014. Characterizing the Late Pleistocene MSA lithic technology of Sibudu, KwaZulu-Natal, South Africa. PLoS One 9(5), e98359.

Wojcieszak, M., 2018. Material processed with 58,000-year-old grindstones from Sibudu (KwaZulu-Natal, South Africa) identified by means of Raman microspectroscopy. J. Raman Spectrosc. 49(5), 830–841.

Wojcieszak, M., Wadley, L., 2019. A Raman micro-spectroscopy study of 77,000 to 71,000 year old ochre processing tools from Sibudu, KwaZulu-Natal, South Africa. Heritage Science 7(1), 1–14.

Zilhão, J., Angelucci, D.E., Badal-García, E., d’Errico, F., Daniel, F., Dayet, L., Douka, K., Higham, T.F., Martínez-Sánchez, M.J., Montes-Bernárdez, R. and Murcia-Mascarós, S., 2010. Symbolic use of marine shells and mineral pigments by Iberian Neandertals. P. Natl. Acad. Sci. USA. 107(3), pp.1023-1028.

Zwane, B., Bamford, M., 2021. Wood charcoal from Border Cave's Member 1RGBS: evidence for the environment and plant use during MIS 5. Afr. Archaeol. Rev. 38, 657–674.

Table 1. Stratigraphy according to the excavation episodes at Border Cave. Grass mats are indicated in light grey

Excavations 1 and 2 Cooke et al. 1945	Excavation 3B Beaumont 1978	Excavation 3A Front Beaumont 1978	Excavation 3A Rear Beaumont 1978	Excavation 4A Beaumont 1994	PB Member acronyms Beaumont et al. 1992	PB Industrial names	Backwell et al. Member acronyms	Backwell et al. layer names	Munsell colour	Sediment description
"Bantu"	1 BS	1 BS.UP.IA	1 BS.UP.IA	1 BS.UP	1 BS.UP	Iron Age	-	not excavated		
		1 BS.UP.S	1 BS.UP.S	1 BS.LR.A	1 BS.LR.A	ELSA	1 BS.LR (A)			
		1 BS.LR.	1 BS.LR.	1 BS.LR.B	1 BS.LR.B					
				1 BS.LR.C	1 BS.LR.C			Very Fine Silt	10YR 4/3	very fine silt
								Brown	10YR 4/3	very fine silt
								Light Brown	10YR 3/3	very fine silt
								Grass Mat 1	5YR 3/2	organic
								Greyish Brown	10YR 5/2	
								Grass Mat 2	7YR 4/2	organic
								Dark Brown/Brown	10YR 3/3 / 10YR 5/3	-
								Dark Reddish Brown	5YR 3/2	-
								Dark Reddish Brown Ally grass mat	5YR2.5/2	loose
								Brown (East)	10YR 4/3	-
								Grass Mat 3	-	organic
		1 BES	1 WA	1 WA	1 WA	ELSA	1 WA (B)	Light Brownish Grey	10YR 6/2	-
								Grass mat 2 Caramel mat 1	-	-
								Very Dark Brown Barry	10YR 2/2	fine silt
								Black burnt Grass Mat Barry	-	burnt organic
								Greyish Brown Ben	10YR 5/2	fine pebbles, coarse sand
								Grass mat Ben	-	-
								Unburnt grass mat Betty	-	organic
								Very Dark Greyish Brown Bill	10YR 3/2	ashy, loamy
								Burnt/Unburnt Grass Mat Bimba	-	burnt/unburnt organic
								Grass Mat Bingo	-	organic
								Grass Mat Bob	-	organic
								White Bifi grass mat	5YR8/1	powdery
								Dark Brown Bobby	7.5YR 3/3	loose
								Dark Brown Botha grass mat	7.5YR3/3	loose
								Grey Bride grass mat	7YR5/1	powdery and compact
			2 BS.UP	2 BS.UP	2 BS.UP	MSA IIIb / post-HP	2 BS.UP (C)	Brown Camy 1,2	10YR 4/3	clayey sand
								Yellowish Brown Carlos 1,2	10YR 5/4	clayey sand, loose
								Grass Bed 1	-	-
								Grass Mat Camilla 1,2	10YR 5/4	organic
								Yellowish Brown Carlos 3,4	10YR 5/4	sandy silt, loose
								Grass Mat Carly	-	organic, pebbly, sandy
								Grass Mat Carrol	-	-
								Yellowish Brown Case	10YR 5/4	silty, loose
								Light Grey Casey	-	-
								Grass Mat Cassidy	10YR 4/3	silty, loose
								Brown Caby	7.5YR 4/6	silty
								Dark Brown Caset	-	-
								Very Dark Brown Caso	-	-
Red Earth Band	1 RBS ?	1 ORS ?	2 BS.LR.A	2 BS.LR.A	2 BS.LR.A	MSA IIIb / post-HP	2 BS.LR A,B	Yellowish Brown Caz 1,2,3	10YR 5/4	silty (almost velvety), loose
								Brown Cathy 1,2,3,4,5	10YR 4/3	sandy silt, loose, almost sterile
								Dark Greyish Brown Cecil 1,2	10YR 4/3	ashy silt, loose, almost sterile
								Dark Yellowish Brown Cecilia 1,2	10 YR 4/4	silty, firm, moist
								Grass Mat Ceta	10YR 4/4	organic, very silty, compact
								Dark Yellowish Brown Chloe	-	-
								Combustion Feature Cilla 1	varied	ashy, cemented
			2 BS.LR.B	2 BS.LR.B	2 BS.LR.B	MSA IIIb	2 BS.LR C	Brown Sand Lower gravel	10YR 5/3	coarse sand, gravelly
			2 BS.LR.C	2 BS.LR.C	2 BS.LR.C	MSA IIIa / post-HP		Brown Sand Lower silt	10YR 5/3	silty, loose, uncemented
								Dark Greyish Brown	10YR 4/2	ashy, loose
								Orange silty	-	-
								Grass Mat 1	-	organic
								Grass Mat 2	-	organic
								Grass Mat with bone	-	-
			2 WA	2 WA	2 WA	MSA IIIa / post-	2 WA	White Ash	10YR 8/1	ashy, partly cemented
								Light Reddish Brown	2.5YR 6/3	powdery
								Brown with charcoal inclusions	10YR 5/3	ashy, loose
								Very Dark Greyish Brown David	10YR 3/2	ashy, soft, loose
								Brown Dawn	7.5YR 5/2	-
								White Dad	-	-
								Very Dark Brown Dax/Deve	7.5YR 2.5/2	ashy, loose
								Dark Grey Debi	-	-
								Black	10YR 2/1	ashy, loose
								Orange Compact Da	10YR 4/3	-
								Brown Dan grass mat	10YR5/3	-
								Black Dayo	10YR 2/1	-
								Greyish Brown Dobe	10YR 5/2	ashy, cemented
								Light Brown Dobe	-	-
								Very Dark Greyish Brown Derrik	10YR 3/2	-
								Reddish Black Desmond 1,2	2.5YR 2.5/1	ashy, loose
								Reddish Brown Des	5YR 4/4	powdery
								Pale Yellow Destiny	2.5YR 7/3	
								Reddish Yellow Detra	7.5YR 6/6	powdery
								Dark Brown Didi	-	-
								Yellowish Brown Dillon	-	-
								Dark Yellowish Brown Dino 1,2,3,4	10YR 4/4	silty, loose, roof spall
								Grayish Brown Dot	10YR 5/2	powdery
								Combustion Feature White Dubbin	10YR 8/1	silty, loose, partly cemented
								Dark Brown Dulce 1,2,3,4	7.5YR 3/2	silty, loose
								Greyish Brown Duran	10YR 5/2	compact
								Reddish Brown Dussy	5YR 4/4	silty, loose
								Yellowish Brown Dusty	10YR 5/4	sandy
								Dark Brown Devan	-	-
								Light Brown Dazy	7.5YR 6/4	silty, loose
								Grass Mat Decon	-	organic
								Greyish Brown Digby	10YR 5/2	silty, roof spall
								Dark Brown Dijon 1,2,3	7.5YR 3/3	silty, loose
								Dark Yellowish Brown Devo	10YR 4/4	sandy, loose
								Grass Mat Dark Brown Dijon	-	organic
								Brown Don grass mat	-	-

								Strong Brown Duby	-	-
								Very Dark Brown Dudi	10YR 2/2	silty
								Reddish Brown Dama	5YR 4/4	silty
								Brown Damel	7.5YR 4/4	silty
								Black Daoiz	7.5YR 2.5/1	organic
								Combustion feature 1 in Black Daoiz	-	silty
								Grass mat Denia	7.5YR 4/4	silty, organic
								Combustion feature 1 in Grass mat Denia	7.5YR 2.5/2	silty
								Dark Brown Dene	7.5YR 3/3	sandy, organic
								Combustion feature in Dark Brown Dene	7.5YR 2.5/1	sandy
								Detroit	7.5YR 4/4	-
								Combustion feature 1 in Detroit	7.5YR 2.5/1	organic
								Brown Grass mat Dia	7.5YR 4/3	organic
								Brown Daria	7.5YR 3/3	silty, gravelly
								Brown Daria combustion feature 1	7.5YR 2.5/3	-
								Grass mat Davos	7.5YR 4/3	silty, organic
								Combustion feature 1 Grass mat Davos	7.5YR 4/2	silty
								Combustion feature 2 Grass mat Davos	7.5YR 2.5/2	-
								Brown Delfin	7.5YR 3/3	silty
								Combustion feature 1 in Brown Delfin	7.5YR 3/2	silty, compact
								Combustion feature 2 in Brown Delfin	10YR 3/1	organic
								Combustion feature 3 in Brown Delfin	10YR 3/2	silty
								Black Depo	7.5YR 2.5/2	organic
								Combustion feature 1 in Black Depo	5YR 4/2	ashy, sandy, organic
								Combustion feature 2 in Black Depo	5YR 3/2	ashy
								Combustion feature 3 in Black Depo	5YR 3/2	ashy, silty
								Grass mat Delta	7.5YR 4/3	ashy, silty
								Combustion feature 1 in Grass mat Delta	-	-
								Combustion feature 2 in Grass mat Delta	7.5YR 2.5/2	-
								Greyish Brown Duran	-	-
								Brown Dossy 1,2,3,4,5,6,7	-	-
								Dark Yellowish Brown Dossy	10YR 3/6	fine sand, silty
								Dark Yellowish Brown Dossy grass mat	-	organic
			3 BS.UP	3 BS.UP	3 BS.UP	MSA IIb / HP	3 BS	Light Brownish Grey Dipsy'	10YR 6/2	ashy, loose
Roof collapse			3 BS.LR.A	3 BS.LR.A	3 BS.LR.A	MSA IIb / HP	(E)	Very Dark Brown Ea	7.5YR 2.5/2	gravelly, loose
			3 BS.LR.B	3 BS.LR.B	3 BS.LR.B	MSA IIb / HP		Very Dark Brown Easy	10YR 2/2	gravelly, roof spalls, loose
								Lens in Very Dark Yellowish Brown Easy	-	clay, some silt
								Hearth in Very Dark Brown Easy	7.5YR 2.5/2	-
								Grass Mat Eaton	5YR 3/3/3	clay and grass
								Grass Mat Eaton in Dark Reddish Brown	5YR 3/3/3	silty
								Combustion Feature Very Dark Brown Ebony	7.5YR 2.5/2	silty
	3 WA?		3 WA	3 WA	3 WA	MSA IIb / HP	3 WA	Black Fade grass mat	5YR 2.5/1	organic, powdery
							(F)	Light Reddish Brown Faba	5YR 6/4	silty, powdery
								Dark Greyish Brown Faddy	-	gritty
								Dark Brown Faddy	-	-
								Dark Reddish Brown Faddy	5YR 2.5/2	loose
								Dark Reddish Brown Face	5YR 2.5/2	loose
								Brown Feduardo	5YR 2.5/2	loose
	1 RGBS				1 RGBS	MSA IIa / HP	1 RGBS	Dark Grey Ebo grass mat"	10YR 4/1	ashy/silty, loose
							(G)	Grass Mat Ebu"	-	-
								Very Dark Brown Ebony"	7.5YR 2.5/2	silty
								Dark Brown Ebony"	10YR 3/3	gritty
								Dark Brown Ekhart"	7.5YR 3/2	silty, loose
								Very Dark Brown Eba 1,2,3,4,5"	10YR 2/2	silty/sandy, loose
								Grass Mat Eco"	-	burnt, organic
								Dark Reddish Brown Edi 1,2,3"	5YR 3/4	silty, loose
								Very Dark Greyish Brown Elf 1,2"	10YR 3/2	silty, loose, with shell
								Very Dark Brown Faan*	7.5YR 2/2	silty
								Very Dark Brown Faan grass mat*	-	-
								CF in Very Dark Brown Faan*	7.5YR 2.5/2	-
Ash band overlying BC3								White ash in Very Dark Brown Faan*	-	ashy
								Black lens in Faan*	10YR 2/1	clay and silty
Soft dark band BC1***								Very Dark Brown Feba*	5YR 2.5/2	very loose
	1 GBS		1 GBS	4 BS	4 BS	MSA I / late Pietersburg	4 BS (H)	Brown	10YR 4/3	silty, loose
								Orange	7.5YR 7/4	ashy, loose, weakly cemented
								Dark Brown (chocolate)	7.5YR 3/2	silty, loose, weakly cemented
								Very Dark Brown Easy^	7.5YR 2.5/3	silty, loose
								Dark Grey Eduardo 1,2,3,4^	5YR 4/1	fine sand
								Grass Mat Ega^	-	organic and silty
								Dark Brown Elmo 1,2^	10YR 3/3	silty, loose
								Brown Emu 1,2^	7.5YR 4/2	silty, loose
								Chocolate Brown Ena^	7.5YR 4/3	silty, loose
								Reddish Brown Heduardo	5YR 4/3	loose, granular
								Chocolate Brown Hena	7.5YR 5/3	-
								Combustion feature in Chocolate Brown Hena	5YR 2.5/1	fine, powdery
								Dark Brown Hayley	10YR 3/3/3	gravelly
								Brown Chocolate	5YR 3	silty, ashy, loose
	4 WA		4 WA ?	4 WA.UP	4 WA.UP	MSA I / late P.	4 WA	Pinkish White 1,2,3,4	7.5YR 8/2	ashy, cemented
				4 WA.LR.A	4 WA.LR.A	MSA I / early P.	(I)	Pinkish White	7.5YR 6.2	ashy, loose
				4 WA.LR.B	4 WA.LR.B	MSA I / early P.		Pinkish Grey 1,2,3,4	7.5YR 7/2	ashy, partly cemented
								Pinkish Grey	7.5YR 6.2	ashy, loose
								Pinkish Grey CF 1	-	ashy
								Pinkish Grey CF 2	7.5YR 7.2	ashy, loose
								Pinkish Grey CF 3	7.5YR 7.2	ashy
								Pinkish Grey with charcoal flecks	7.5YR 7/2	ashy, partly cemented
								Grey	5YR 6/2	ashy, loose
								Grey Igor	-	ashy
								Reddish Brown Ian 1,2,3,4,5,6,7	5YR 6/4	gritty/ashy, loose
								Very Dark Grey	5YR 3/1	ashy, loose
								White 1,2,3,4,5,6,7,8,9,10,11,12	10YR 8/1-10YR 7/2	ashy, strongly cemented
								White 1 Idaho	7.5YR 8.1	ashy, grainy, cemented
								White Idaho CF 3	-	ashy
								White 2 Idaho	7.5YR 8/1	ashy, gritty, some cementation
								White 2 Idaho CF 1	-	ashy, loose
								White 3 Idaho	7.5YR 8.1	ashy, gritty, cemented
								White 3 Idaho + CF 6 in White 1 Idaho	-	gritty, cemented

								White 4 Idaho	7.5YR 7/3	ashy, cemented
								White 4 Idaho + CF 6 in White 1 Idaho	7.5YR 6/3	-
								White 5 Idaho	7.5YR 7/2	ashy, cemented
								White 5 Idaho + CF 1 in White 5 Idaho	7.5YR 4/2	gritty, silty, loose, cemented
								CFs 5+6 in White 1 Idaho	-	-
								White 6 Idaho	7.5YR 7/2	ashy, cemented in parts
								White 6 Idaho CF 1.	7.5YR 2/5/2	ashy, some cementation
								White 7 Idaho	-	ashy, some cementation
								White 8 Idaho	10YR 7/2	ashy, cemented in parts
								Pit 1 in White 8 Idaho	7.5YR 3/1	ashy
								Pit 1 and Pit 2 in White 8 Idaho	7.5YR 3/1	silty, loose
								Pit 1 and Pit 2 Very Dark Grey	7.5YR 3/1	-
								Pit 1 and Pit 2 contact Dark Brown	7.5YR 3/2	silty, loose
								Pit 2 Very Dark Grey in White 8 Idaho	7.5YR 3/1	silty, gritty, loose
								Yellowish Red Pit 2 cap in White 8 Idaho	5YR 5/6	-
								White 9 Idaho	-	ashy
								Black Immy	7.5YR 2.5/1	fine, loose
								CF in Black Immy	-	ashy, loose
								Dark Brown Pit	7.5YR 7/2	ashy, silty, loose
								Dark Brown Ivan	10YR 3/3	loose
								Very Dark Greyish Brown Ihepic	10YR 3/2	fine, loose
								Very Dark Brown Ihera	10YR 2/2	fine, loose
								Dark Brown Iheos	7.5YR 3/2	fine, gritty, loose, crumbly
								Pinkish Grey Ianus	7.5YR 5/8	fine, cemented
								Very Dark Grey combustion feature 4	5YR 3/1	fine, loose
								Very Dark Brown Ihester	5YR 6/2- 7.5YR 6/3	fine, loose
								Brown Ibis	10YR 2/2	fine, powdery, gravelly
								Very Dark Brown Icarus	10YR 3/3	fine, loose, sandy, gravelly
	BACO.A		BACO.A					Dark Brown Idi	10YR 3/2	fine, silty, sandy, loose
								Brown Idi	5YR 3/2- 10YR 3/2	fine, gritty, weakly cemented
								Pink Icubo	7.5YR 4/2	silty ash, partly cemented
								Light Brownish Grey Icon	7.5YR 7/3	powdery with charcoal
				5 BS ?**	5 BS	MSA I / early Pietersburg	5 BS (J)	Very Dark Greyish Brown Jan 1,2,3,4	10YR 3/2	silty, loose
								Very Dark Grey Brown Jantjie	7.5YR 8/1	ashy
								Brown unconsolidated (N109 only)	10YR 4/3	sandy
								White Jet 1,2	7.5YR 8/1	ashy, loose/cemented
								Very Dark Grey Jez 1,2,3,4,5	7.5YR 3/1	ashy, loose
								Very Dark Greyish Brown Jim 1,2,3,4	10YR 3/2	ashy, loose
								Brown John 1,2	7.5YR 4/2	ashy, loose/cemented
								Brown Jim	-	-
								Brown Jolly grass mat	7.5YR 4/2	silty, partly cemented
								Brown Larry`	7.5YR 4/2	ashy, loose
	BACO.B			5 WA ?**	5 WA	MSA I / early Pietersburg	5 WA (K)	Dark Greyish Brown Kay	10YR 4/2	silty ash, loose
								Light Grey Kelly	10YR 7/2	powdery ash, partly cemented
								Dark Grey Ken	7.5YR 4/1	ashy, loose
								Brown Ken	7.5YR4/2	silty, ashy
								Dark Brown Kent	7.5 YR 5/2	ashy, partly cemented
								Dark Brown Kevin grass mat	5YR 3/2	silty, loose
								Pale Brown Kim	10YR 7/3	ashy, partly cemented
	BACO.C			6 BS.UP ?**	6 BS.UP	MSA I / early Pietersburg	6 BS (L)	Brown Lad	7.5YR 4/2	gritty, silty, sandy
	BACO.D			6 BS.LR ?**	6 BS.LR	MSA I / early Pietersburg		Light Yellowish Brown Lamb	10YR 6/4	ashy, partly cemented
								Brown Lassy	7.5YR 4/2	silty, loose

PB = Peter Beaumont; P. = Pietersburg; (A)-(L) denote the first letter given to layer names per member. ' Light Brownish Grey Dipsy was thought to come from 2 WA during excavations. " Layers starting with E in 1 RGBS were thought to come from 3 BS during excavations. * Faan and Feba in 1 RGBS were thought to come from 3 WA during excavations. ^ The layers starting with E in 4 BS were thought to come from 3 BS during excavations. ` Brown Larry was thought to come from 6 BS during excavations. ** Vague mention of layers below 3 WA but no details of which ones, and some of them might be absent. *** Previously thought to be part of 4 BS but appeared to be a 3 WA /1 RGBS intrusion into 4 BS. CF = combustion feature.

Table 2. Location of excavated Border Cave material. All human remains are housed at the Evolutionary Studies Institute, University of the Witwatersrand

Excavation episode	ESI	McGregor Museum
EXC. 1: Dart (1934)		
EXC. 2: Cooke, Malan and Wells (1941-1942)		x
EXC. 3A: Beaumont (1970-1975)	x	x
EXC. 3B: Beaumont (1970-1975)	x	x
EXC. 4A: Todd and Miller (1987)		x
EXC. 4B: Beaumont (1987)		x
EXC. 5: Backwell, Wadley and d'Errico (2015-2019)	x	

EXC.: Excavation; ESI: Evolutionary Studies Institute, University of the Witwatersrand.

Table 3. Chronology of the Border Cave stratigraphic sequence

Member	Sub-layer	Culture	Age BP ka*	Dating method	Laboratory Codes ****	Reference
1 BS	UP	ELSA	-	14C		
	Lower A		41.5 - 24	14C	Pta-4984, Pta-4986, Pta-4789, Pta-4784	1, 2, 3, 4
	Lower B		42.3	14C	Pta-4779, Pta-4758, Pta-4778, Pta-4744, Pta-4793, Pta-5015	1, 2, 3
	Lower C		42.6	14C	Pta-4711, Pta-4706, Pta-4700, Pta-4775, Pta-4776	1, 2, 3
1 WA	UP	ELSA	43	14C	Pta-4875, Pta-4880, Pta-4903, Pta-4856, ANUA-17304	1, 2, 3
	2			14C		2, 3, 5
2 BS***	UP	MSA III	49.0 - 44.2	14C	ANUA-17307, ANUA-15805, ANUA-17302, ANUA-17306	2, 3, 4, 5
	Lower A		60.0 - 49.0 **	14C	ANUA-17304, ANUA-15814,	2, 3, 5
	Lower B			14C	ANUA-16305, ANUA-17308, ANUA-17504, ANUA-15813	2, 3, 5
	Lower C			14C	ANUA-16304, ANUA-17505	2, 3, 5
2 WA		MSA III	60 ± 3 **	ESR-14C	ANUA-17303, ANUA-18626, ANUA-19010	2, 3, 5
3 BS	1	HP	56 ± 2	ESR		6, 7
	2		64 ± 3	ESR		6, 7
	3		72 ± 4	ESR		6, 7
3 WA		HP	64 ± 2	ESR		6, 7
1 RGBS		HP	82 - 74	ESR		6, 7, 8
4 BS		MSA I	91 - 71	ESR		6, 7, 8
4 WA	1	MSA I	115 ± 8	ESR		6, 7, 8
	6		113 ± 5	ESR		6, 7, 8
	7		168 ± 5	ESR		6, 7, 8
5 BS	2	MSA I	161 ± 10	ESR		6, 7, 8
	5		144 ± 11	ESR		6, 7, 8
5 WA	1	MSA I	183 ± 20	ESR		6, 7, 8
	2		227 ± 11	ESR		6, 7, 8

* 14C ages were performed at the Pretoria Radiocarbon Laboratory, the Australian National University Radiocarbon Laboratory, the Oxford Radiocarbon Accelerator Unit and Kiel Radiocarbon Laboratory. 14C ages were calibrated with the INTCAL09 calibration curve.
** The nine 14C ages for Members 2 WA and 2 BS.LR B-C, ranging from 58 to 48 ka 14C BP, fall outside of the range of the IntCal09 calibration curve. Ages attributed to each sub-layer are estimations resulting from Bayesian modeling of ESR and 14C ages based on Millard (2006) and d'Errico et al. (2012a).
*** Five additional 14C ages were obtained directly on archaeological objects from Members 2 BS.LR B-C: OxA-23173; OxA-23172; OxA-X-2418-47, KIA 44423, OxA-W-2455-52.
**** Information on the dated material is given in 1, 2, 3, 4 and 5.
1: Beaumont et al. (1992); 2: Villa et al. (2012); 3: d'Errico et al. (2012a); 4: Backwell et al. (2018); 5: Bird et al. (2003);
6: Grün and Beaumont (2001); 7: Grün et al. (2003); 8: Millard (2006).

Table 4. Volume (litres) of sediment removed by member by year

Year	1 BS	1 WA	2 BS	2 WA	3 BS	3 WA	1 RGBS	4 BS	4 WA	5 BS	5 WA	6 BS	
2015	23.70	12.50	14.50	0.00	5.50	0.00	0.00	0.00	39.25	0.00	0.00	0.00	95.45
2016	10.52	4.80	59.70	12.40	0.00	0.00	0.00	0.00	39.30	17.05	0.00	0.00	143.77
2017	0.00	52.50	316.20	173.10	135.60	0.00	0.00	0.00	29.50	86.25	0.00	0.00	793.15
2018	4.00	20.20	57.00	102.25	100.50	33.50	64.50	85.00	12.00	17.00	16.75	35.00	547.70
2019	0.00	0.00	0.00	47.00	17.50	0.00	4.00	13.50	203.85	0.00	0.00	0.00	285.85
Total	38.22	90.00	447.40	334.75	259.10	33.50	68.50	98.50	323.90	120.30	16.75	35.00	1865.92