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Geoarchaeology and zooarchaeology of Border Cave, South Africa: initial multiproxy considerations of stratigraphy and site formation processes from the Backwell et al. excavations.

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Abstract

Border Cave (BC) has accumulated over 200,000 years of archaeological deposits that document remarkable evidence of human behaviour during the Middle and Later Stone Age. For nearly fifty years, researchers have relied on the stratigraphic framework established by Peter Beaumont in 1973, in which the deposits are lithostratigraphically categorized into a sequence of alternating 'Brown Sand' (BS) and 'White Ash' (WA) members. Geoarchaeological work in the 1970s focused on stratigraphic sequencing of the anthropogenic assemblages, and proposed broad correlations between autogenic contributions and environmental conditions. The research presented here was undertaken as part of a new excavation campaign at Border Cave started in 2015 under the direction of Backwell et al.. Re-examining the stratigraphic context of the deposits and assessing site formation processes are among the key goals of this project; this will enable finer-scale intra- and inter-member comparative analyses of the artefacts and ecofacts recovered at the site. In this paper, we apply a facies and allostratigraphic analysis approach to assess the stratigraphic sequence exposed through the Backwell et al. excavations. We also provide an initial assessment of the prevailing site formation processes active in the deposition and modification of the sediments. The geoarchaeological data are integrated with new zooarchaeological and taphonomic evidence in order to explore inter- and intra-unit patterns throughout the sequence. Results of this work are: (1) exposed sediments can be broadly correlated to members of the Beaumont sequence; (2) we clearly define member boundaries, re-assess member stratigraphic complexity and recognise finer intra-member layering; (3) geoarchaeological and taphonomic studies demonstrate that the sediments have been subjected to greater post-depositional disturbance than was previously recognized and affect all levels of the sequence; (4) overall, faunal density at BC appears to be much lower than that at other Middle Stone Age sites such as Blombos and Sibudu; (5) multiproxy analysis suggests that WA and BS members have distinctive taphonomic histories that cross-cut the identified archaeological industries. As such, caution is warranted when combining BS and WA members for analysis of artefacts and ecofacts.

Keywords

Border Cave; Geoarchaeology; Zooarchaeology; Stratigraphy; Middle Stone Age; southern Africa; Facies analysis; Allostratigraphy; Taphonomy; Fourier transform infrared spectroscopy

1. Introduction

Border Cave (27°1'19"S, 31°59'24"E) occupies a precarious position near the top of a steep west-facing escarpment in the rhyolitic Lebombo Mountains overlooking the Eswatini Lowveld. Based on previous (Grün and Beaumont, 2001; Grün et al., 2003; Millard, 2006) and recent dates (Tribolo et al., this volume), it is a rare example of a shelter located in the interior of South Africa hosting a sequence of deposits spanning Marine Isotope Stage (MIS) 7 (that starts about 240 ka ago) to 2 (that starts about 24 ka ago). The semi-circular rock shelter is approximately 50 m wide at its mouth, 35 m deep, and is accessed either via a narrow, precipitous ledge at its northern edge, or a 450 m climb up a steep scree slope from Eswatini. Geologically and geomorphologically, Border Cave is atypical of other shelters and caves in southern Africa that host Middle Stone Age (MSA)-bearing deposits (Stratford et al., 2021). Geologically, the rock shelter formed in the Lower Jurassic felsic extrusive Jozini Formation (Lebombo Group) (Cooke, 1941; Butzer, et al., 1978), generally represented by a variety of igneous rhyolitic facies with interbedded sandstones (Cooke, 1941; Backwell et al., 2018). The development of localised flow-banding, variable igneous lithological textures, volcanoclastic breccias and sandstone/rhyolite agglomerate beds provides a unique context not only for the formation of the shelter, but also for the processes driving autogenic (internally generated) sedimentation and the resulting clastic/chemical sediment suite accumulating within the site. Geomorphologically, Border Cave occupies an uncommon context in southern Africa. The rock shelter is only 82 km from the Indian Ocean and yet resides in a highly irregular topographic setting, with the extensive Lebombo Mountain range stretching to the north, south and east and the fertile plains of the Eswatini Lowveld spreading westwards, below the shelter. The close proximity of the shelter mouth to the edge of the cliff and the challenging access route may have encouraged occupants to conduct a wider range of activities inside this shelter than at other sites. Activities that took place inside the shelter include the burial of an infant with associated ornamentation (Cooke et al. 1945; d'Errico and Backwell, 2016), plant food preparation (Wadley et al., 2020a), and the construction of grass bedding and other forms of site management (Wadley et al., 2020b).

The history of excavations at the shelter and an overview of results of the ongoing investigations, led by Lucinda Backwell, Lyn Wadley and Francesco d'Errico, are summarised in Backwell et al. (2018; this

volume). Here we review only the geoarchaeologically-pertinent information. Figure 1A presents a map of the shelter floor with the imperially-calibrated excavation grid established by Cooke (Beaumont, 1973), the location of the informal bat-guano pit dug by W.E. Horton in 1940 that uncovered a large artefact assemblage and fossil human remains (Cooke et al., 1945; Wells, 1950; de Villiers, 1973), and the locations of each of the five dedicated archaeological excavation projects - from Dart's initial trench to the most recent investigations by the Backwell et al. team. In 1934, Raymond Dart opened a test trench spanning the dripline (EXC. 1 in Figure 1A). Dart's records of the excavation are unpublished, but Cooke reports on Dart's discovery of "a definite stratum containing Middle Stone Age artefacts" (Cooke, 1941:1). Cooke, Malan and Well's 1941-1942 excavation extended Dart's E-W trench 16 yards (14.6 m) into the shelter and added a perpendicular trench in rows 15 and 16, exposing long sections of *in situ* deposits in the northern areas of the shelter and along the margins of Horton's Pit¹ (Cooke et al., 1945). Analyses of excavated material focused heavily on the human remains (Wells, 1950; de Villiers, 1973; Sillen and Morris, 1996; d'Errico and Backwell, 2016). Beaumont's initial excavations were extensive (3A Front and Rear and 3B; Beaumont, 1973, 1978), and further excavations with colleagues Todd and Miller (Excavations 4A and 4B) yielded large assemblages of lithics, fauna, botanical remains and sediments. These materials have been the subject of various reports and syntheses (e.g., Beaumont and Boshier, 1972; Beaumont, 1973, 1978, 1994; Thackeray, A., 1992; Backwell et al., 2018) and specialist studies focusing on a range of topics, from hominin behaviour (e.g., Klein, 1977; Beaumont et al., 1978; d'Errico et al., 2012; Villa et al., 2012; d'Errico and Backwell, 2016), palaeoenvironments (e.g., Klein, 1977; Butzer et al., 1978; Avery, 1982, 1992; Thackeray, J., 1987; Beaumont et al., 1992), and the chronology of the deposits and specific finds (e.g., Beaumont, 1980; Grün et al., 1990; Grün and Beaumont, 2001; Grün et al., 2003; Bird et al., 2003; Millard, 2006; and recalibration of samples, e.g., d'Errico et al., 2012; Villa et al., 2012). Despite the wide range of topics researched, large proportions of the excavated assemblages remain unstudied.

Studies of material remains and geochronology have generally been structured around recognised Middle Stone Age (MSA) lithic industrial complexes represented by the stone tool assemblages yielded from

¹Horton's Pit is a large, irregular and informal excavation conducted in 1940 for 'agricultural fertiliser'. It is likely that exposures of fine white ash were mistaken for bat guano, motivating the attempted exploitation. New excavations have not found intact bat guano deposits. Horton's Pit was dug to a depth of 173 cm near the rear of the shelter and 30 cm near the front of the shelter (Cooke, 1941; Beaumont, 1978). Photographs included in Cooke's (1941) unpublished excavation report shows the front part of Horton's Pit extended into Member 2 BS and photographs of the eastern wall of Horton's Pit suggest the pit perhaps extended into 3 BS but didn't reach bedrock in any locations.

deposits that were organised according to the stratigraphic framework established by Beaumont (1973, 1978)². The stratigraphic framework presented the deposits as a series of major alternating 'Brown Sand' (BS) and 'White Ash' (WA) members, with variations to this sequence determined by differing sediment colour or textural characteristics, e.g., 'Grey Brown Sand' (GBS), or 'Rubbly Grey Brown Sand' (RGBS). Within this framework, Beaumont noted significant complexity that was not necessarily captured in the BS/WA framework. Most notably, this is apparent in the abundant WA members, which Beaumont (1973, 1978) and Butzer et al. (1978) acknowledged as comprising multiple superimposed black and white ash lenses and strata considered indicative of intense occupational phases. The WA members generally yielded the highest abundance and diversity of artefacts, and yet intra-WA stratigraphy and formation history has not been explored in detail. Consequently, intra-member analyses of material culture have been limited by a lack of stratigraphic resolution.

Finer control of stratigraphic, depositional and palaeoenvironmental contexts enables more nuanced interpretations of human behavioural change. As a contribution to the increasingly integrative investigations of human behavioural evolution, and to aid re-analysis of the large Border Cave assemblages (e.g., d'Errico et al., 2012; Villa et al., 2012), the team sought to resample, through high-resolution excavation, Beaumont's stratigraphic sequence. Two of the priorities of this research campaign have been "to reassess the stratigraphic context of the sedimentary and cultural sequence" and "gain insights into the site formation processes" (Backwell et al., 2018:417).

In this paper, we address these issues using geoarchaeological and zooarchaeological data from the Backwell et al. excavations. First, we present a comprehensive description of the stratigraphic sequence exposed through new excavations. Our goal is to reassess the stratigraphic framework and provide additional resolution where possible, and where it is needed, to enable finer-resolution analyses of the assemblages. We draw on facies, allostratigraphic, zooarchaeological and taphonomic analyses to explore characteristics that distinguish BS and WA units and evaluate intra-WA heterogeneity. We also briefly consider the stratigraphic evidence with reference to new chronological data (Tribolo et al., this volume) and microbotanical remains (Esteban et al., this volume). We present data from zooarchaeological and taphonomic studies to augment our perspectives on changing site formation processes and assemblage

²Lithic industry nomenclature has changed since Beaumont's first attributions and here we follow established MSA industry terminology. To enable inter-site comparative perspectives, which often structure chronostratigraphic sequences by lithic industry, we use both Beaumont's original stratigraphic framework terminology as a base and the main lithic industry attributions of stratigraphic members. It is noted that ongoing lithic analysis may revise the lithic industry attributions at Border Cave.

integrity through time at Border Cave; this analysis focuses on the macrofaunal remains. The faunal remains are a key component of this project that allow us to assess analytical resolution within process-sensitive stratigraphic frameworks. For example, if the fauna is differentially preserved across the BS and WA members, it may not be appropriate to combine them for analysis—this is particularly salient because some of the identified archaeological units (based on lithic industry) span BS and WA deposits (e.g., the Early Later Stone Age (ELSA) spanning Members 1 BS and 1 WA, and MSA 3 spanning 2 BS and 2 WA). Finally, although the sample of identified bone is small—the total Number of Identified Specimens (NISP) reported here is 335—we briefly discuss the taxonomic data.

FIGURE 1 ABOUT HERE

Figure 1. Schematic of the Border Cave boundary and floor (A) with historical and current excavation locations, and the yard-calibrated excavation grid established by Cooke (11 yard grid squares is equivalent of 10 m) (Cooke, 1941). Excavations are colour coded by relative location within the shelter; yellow indicating northern excavations; green indicating central excavations; and blue indicating southern excavations. Mean deposit dip (from 0° horizontal) is also represented from literature and section drawings (Cooke, 1941; Beaumont, 1973, 1980; Butzer et al., 1978). In all cases, deposit dip can be considered apparent, not true. (B) Presents a composite, synthetic stratigraphy of the complete depositional sequence compiled from Beaumont (1973, 1980), Butzer et al. (1978) and Backwell et al., (2018) — ‘BS’ = Brown Sand; ‘WA’ = White Ash. The E-W inclination reflects the dominant dip direction of deposits (Cooke, 1941; Beaumont, 1973, 1978, 1980). Thicker unit boundary black lines in the composite sequence represent major hiatuses proposed by Butzer et al. (1978). Beaumont’s stratigraphic nomenclature is presented on the right of the column and the numbered units presented in Butzer et al. (1978) are on the left. On the left-hand edge of Panel B, colour-coded columns represent where parts of the composite sequence have been exposed. Bedrock was not reached in all excavations and no representative profile or sequence description has been published for excavation 4B. Unit nomenclature and correlation across the different excavations is presented in Table S1 and Backwell et al., this volume). (C) Relative stratigraphic positions and locations of ‘*éboulis*’ (roof spall) units described in Butzer et al. (1978). In the central deposits, ‘*éboulis*’ units grade laterally from the north and terminate in excavation 3A exposures.

1.1. Previous stratigraphic and geoarchaeological research at Border Cave

Cooke (1941 and 1945)

No stratigraphic record was published from Dart's 1934 excavation of Border Cave (EXC. 1 in Figure 1) and Cooke (1941) only reported Dart's observations of the cultural sequence. Dart's cultural sequence, from top to bottom, comprised a disturbed unit bearing Iron Age artefacts overlying a Middle Stone Age-bearing deposit. In reports on subsequent excavations in 1941 and 1942 by Cooke, Malan and Wells (EXC. 2 in Figure 1), a stratigraphic sequence for the shelter was first described, drawn and photographed (Cooke, 1941), with profile drawings redrawn and presented by Beaumont (1978, 1980) and Beaumont et al. (1978). Cooke (1941) described a complex series of deposits. At the top, a superficial layer varying in thickness contained a variety of Iron Age materials, including potsherds, maize cobs, goat pellets and cow dung, with a sporadic appearance of white, grey and black discontinuous lenses and dry grasses. Immediately below this, two laterally associated units appeared: to the south is a rubbly deposit with yellow dust fines, patches of 'chocolate-coloured earth', and 'thin layers and erratic lenticular bodies of ash'. To the north was a 'red loamy material', partially cemented by calcite that graded laterally and vertically into the chocolate-yellow unit. Below both was an 'almost continuous' 'fine chocolate-coloured earth' unit in which roof spall was almost absent. Interdigitating the chocolate-coloured units were laterally discontinuous sequences and patches of ash. Regarding the general geometry of the deposits, Cooke (1941) noted that deeper units in the sequence sloped in a more south-western direction as compared to later west-sloping deposits, that "there are indications that the deposits in the north-eastern part of the cave have been truncated", and that "individual layers are wedge-shaped and thin out towards the front of the cave" (Cooke, 1941; 5). Of the clastic component in the sequence, Cooke proposed that fragments up to 'matchbox' size and some 'dust' derived from the breakdown of the highly irregular cave roof. Cooke also identified units with higher 'rubble' abundance. Of the ash layers, Cooke (1941; 4) states that "...its nature and origin are not yet clear" and comments that it is not known if the ashy units represent single events or series of superimposed occupations.

Beaumont (1972, 1973 and 1978)

Beaumont's work at the site in the early 1970s (EXC. 3A and 3B; Figure 1) stimulated new stratigraphic documentation. Short unit descriptions, techno-cultural contents and broad chronostratigraphic

correlations with other sites were presented in 1972 (Beaumont and Boshier, 1972), and the first schematic sequence proposing a Brown Sand (BS) and White Ash (WA) stratigraphic framework was proposed in 1973 (Beaumont, 1973). Here, vertical correlations, and member thicknesses from the surface to the basal deposit were presented and accompanied by more detailed, but relatively brief, lithostratigraphic descriptions. Member distinction was largely based on sediment colour, roof spall abundance and artefact contents. It is not clear on what basis member subdivisions were made, but subdivision boundaries seem to be associated with stone lines and changes in roof spall abundance. Beaumont's progress report (1973) presented numerous observations and suggestions regarding the origin of the sediments and formation of the deposits. These can be summarised as follows: (1) deposit gradients result from a 15-20° westward sloping shelter floor; (2) deposits are composed of differing combinations of charcoal (represented largely by fine black and white ash), sand and roof spall; (3) sands are mostly fine-grained and "perhaps largely introduced by wind action" (p. 41); (4) roof spall increases significantly towards the north-eastern area of the shelter, reflecting differential integrity of the roof; (5) preserved grass in "fairly continuous lenses may represent bedding material" (p. 45); and (6) preservation of the vegetation may be a result of the shelter and deposits being "virtually impervious to moisture" (p. 45).

Further description of members, including those extending below 4 WA (originally named Basal Complex, 'BACO', units) were presented in Beaumont (1978). In this work, additional observations were made, including: (7) a southward (8-10°) slope of the shelter floor has affected the "immediately overlying strata" (p. 20); (8) the abruptness of unit contacts is a consequence of the "low human numbers and rhythmic alternation of periods of occupation and absence." (p. 23); (9) BS members are usually thicker near the walls of the cave, where autogenic weathering is more active; (10) the majority of the BS-associated autogenic spall in the north-east formed after the deposition of 3 WA spall-rich facies (named *éboulis* by Butzer *et al.*, 1978) and these thin from the northeast to the south and east (i.e. from EXC. 2 to 3A Front and Rear); (11) WA members 'invariably' thin from the centre of the shelter towards the walls and rear of the cave, a geometric pattern resulting from "gravitational effects of trampling" (p. 22), with the thickest WA units being found in the centre of the shelter and representing more regular occupation areas; and (12) primary sources of water are salt-carrying mists with minor contributions of animal urine. Consequently, Beaumont (1978) proposed 'negligible' impacts of biogenic post-depositional processes are limited to localised disturbances that are frequently associated with dense vegetation layers and are interpreted as small mammal nests and burrows. It is noted that some excavation sections presented in Beaumont (1978) are incorrectly orientated, complicating stratigraphic correlations across space.

Butzer et al. (1978)

Butzer et al. (1978) presented largely the same sequence within a composite stratigraphic column with supporting quantitative sedimentological data (summarised in Appendix 54 of Beaumont, 1978). Some of the variability in the presence and correlation of members exposed across Beaumont's excavations is demonstrated in Beaumont (1980; Table S1). The 'type' sequence is represented by deposits exposed in the central excavation 3A (Figure 1A, B) and variation from that sequence is most notable in the northern excavation 3B. In the north, Butzer et al. (1978) identified a significant episodic rubble contribution evidenced by four *éboulis* horizons that thin from north to south (Figure 1C) and that are attributed to the development of a 'spall cone' in the north-east of the shelter. It should be noted that minor differences in the stratigraphic position of the *éboulis* exist between Butzer et al. (1978) and Beaumont (1980).

In terms of the processes of sediment accumulation and modification, proposals by Butzer et al. (1978) can be summarised as follows: (1) WA units are often associated with a proportional increase in silts and rise in calcium carbonate; (2) an absence of rounded quartz grains challenges earlier proposals of a fine sand aeolian contribution (Beaumont, 1973); (3) allogenic (externally derived) mineral sediment accumulation through wind or water is prohibited by the entrance position and shape on the cliff face; (4) all biological components are essentially cultural in origin and have resulted in the accumulation of sand- to silt-sized particles and primary and secondary aggregates; (5) eight significant sedimentary hiatuses, or disconformities are documented in the sequence (Figure 1B); (6) intra-member disconformities are present (but not discussed); (7) major sedimentary hiatuses are associated with *in situ* weathering and correlate with comparatively warm, wet conditions, in contrast to *éboulis* formation, which is attributed to frost-weathering during colder conditions; (8) disconformities are attributed to local anthropogenic mobilisation of sediments and "it is probable that no natural, erosional breaks exist in Border Cave" (Butzer et al., 1978: 327); (9) since the deposition of Member 3 WA, the cave environment has remained 'hyperarid'; (10) evidence of chemical weathering in deposits older than 4 WA suggest these were significantly altered by *in situ* weathering during sedimentary breaks during wetter external and internal environments.

It is important to note that member and sub-member boundaries within the Beaumont and Butzer et al. (1978) sequences were not clearly defined in drawings or photographs for the northern limit of EXC. 3A. It is also clear that even member-scale deposits were inconsistently represented N-S and E-W across the

site. Both factors make correlation between Beaumont's previous members, sub-members and member boundaries and recent exposures challenging.

1.2. Previous zooarchaeological investigations at Border Cave

Despite the extensive history of research at Border Cave, the macrofaunal remains have seen relatively limited study. Cooke et al. (1945: 9) provided a list of taxa present in the assemblage, although they present no quantitative data or other information. The most noteworthy publication was produced by Klein (1977), who reported on the analysis of macrofaunal remains recovered from Beaumont's excavations. Based on his description, Klein's analysis appears to have focused on remains from the 1971-2 seasons. Data are reported only as minimum number of individual (MNI) counts, so the total number of identified specimens is unknown. Klein does not provide information on the non-identifiable faunal remains, beyond noting that most of the remains were "small, non-diagnostic fragments which could not be identified to body part or taxon" (1977: 17). Beaumont's thesis provided some detail on the non-identifiable fraction of the assemblage, highlighting the heavy fragmentation and the presence of burned bone (Beaumont, 1978). Finally, no faunal data have been published from the 1987 excavation with Todd and Miller. Given this, revisiting the old collections would no doubt be profitable; however, the focus here is on the material yielded from the excavations led by Backwell et al. (including remains excavated between 2015-18).

2. Materials and Methods

2.1. Stratigraphy and sedimentology

Facies analysis

Facies analysis is applied in a broad spectrum of sedimentary contexts (e.g., Anderton, 1985; Miall, 2013) and utilised to identify spatial and temporal changes in depositional and post-depositional processes as defining contributions to the composition and structure of deposits and sequences at multiple scales. It is founded on the premise that genetic equivalence is suggested in deposits with similar sedimentary structures, compositions, and particle organisation (e.g., Pirrie, 1998). Here, facies analysis was employed in order to: (1) provide consistent, detailed descriptions of sediments through the recently exposed Border Cave sequence; (2) aid in the distinction of units and their lateral and vertical extents; (3) provide

insight into the formation history of individual units; (4) assess spatial and temporal patterns of site formation processes in the shelter; and (5) develop a process-sensitive multiproxy and multiscale approach to stratigraphic analysis compatible with ongoing microscopic sedimentological research (e.g., Wadley et al., 2020b). This application differs from previous stratigraphic research at the site (Beaumont, 1978; Butzer et al., 1978) by increasing intra-member resolution and formation process sensitivity by drawing on extensive experimental research and previous sedimentological and facies analyses applied to sites with similar depositional features and contexts (e.g., Schiegl et al., 1996; Meignen et al., 2007; Goldberg et al., 2009; Mallol, 2013a, b, 2017; Mentzer, 2014, 2016; Miller et al., 2013; Karkanas, 2000, 2021; Karkanas and Goldberg, 2019; Haaland et al., 2020).

Facies were identified and described from *in situ* excavation profiles and open exposures across the site during excavations and dedicated visits between 2017 and 2020. Each profile was drawn and identified unit boundaries were surveyed with a Nikon Nivo 5C reflectorless total station. Photographs were taken of each profile and open sequence to construct 3D photogrammetric models that were georeferenced using total station-calibrated points in CloudCompare. These allow visualisation of the deposits, surveyed artefacts, and features in an integrated 3D space. Twenty-seven variables across four sedimentary component categories were described in the field and used to characterise each facies. Standard qualitative and semi-quantitative sedimentological variables were documented, including: colour (Munsell), support, void space, structure, consolidation, stratification, upper and lower contact type, and precipitate presence; clast frequency, size range, sorting, grading, association, shape, fabric, and *in situ* fragmentation; matrix origin, texture, and grading; and anthropogenic component composition, shape, frequency, association, size range, fragmentation, and fabric. Facies are grouped into seven major types (I to VII). Facies sub-types are recognised (e.g., I.I and I.II) that reflect minor, but important variations in sediment composition or structure. In addition, examples of turbation and localised deposit modification were drawn, photographed and described.

Allostratigraphy

Although Butzer et al. (1978) identified eight major depositional hiatuses within the Border Cave stratigraphic sequence, their stratigraphic units were packaged according to the initial lithostratigraphic member definitions by Beaumont (1973, 1978). Only BS members were formally subdivided, despite recognition of internal stratigraphic complexity in WA deposits. Quantitative sedimentological data (Butzer et al., 1978) do not strongly support the presence of distinct stratigraphic subdivisions within BS members, but do identify significant differences between BS and WA members. Allostratigraphy is a

common method of dividing depositional sequences into units and packages by the presence of sedimentary discontinuities. It provides the opportunity to identify sequences and breaks within compositionally-similar sediments. Here, an allostratigraphic approach was applied to test major and minor unit designations in the sequence and provide additional stratigraphic sensitivity to the recognised, but unexplored, complexity in WA members. Accordingly, units were identified first by their facies and then packaged by their bounding contacts. Below, exposed profiles are presented in order of excavation in accordance with the stratigraphic nomenclature of Beaumont. Within profiles, sequences are described in order of deposition, from bottom to top.

Stratigraphic contact type

Butzer et al. (1978) suggested that all disconformities in the Border Cave stratigraphic record are 'cultural' in origin, and that "no natural, erosional breaks exist in Border Cave" (p. 327). To explore this suggestion, facilitate an allostratigraphic approach, and clarify the nature of facies changes within and between units, major stratigraphic boundaries and changes between facies were classified according to three contact types, as described below. For each contact type, solid lines represent clearly observable boundaries, while dashed contact lines represent boundaries that have been obscured but can be projected based on deposit morphology.

1. Gradational contact types (green solid and dashed lines) are diffuse transitions between facies that indicate a gradual change in depositional regime over a period of time. Contacts that have been diffused through post-depositional processes are not considered gradational unless they are associated with a change in autogenic sedimentary component contribution. For example, a transition between Facies VI.I (homogeneous anthropogenic components within clast-poor massive silty sand) and Facies I.I (clast poor massive silty sand) may be diffuse, but is considered a post-depositional phenomenon and not reflective of a change in depositional environment. These contacts remain unlabelled.
2. Paraconformities (yellow solid and dashed lines) are abrupt changes in facies that indicate the development of a stable surface and a break in sedimentation. Paraconformities generally conform to the geometry of the underlying deposit and do not indicate significant alteration of the underlying sediments. However, contact morphology can also be irregular and reflect both topographically complex deposit surfaces and post-depositional deformation.
3. Disconformities (red solid and dashed lines) are abrupt contacts that have developed new surface morphologies through the significant physical alteration of underlying sediments and potentially

represent significant breaks in the sedimentary record. In instances where extensive grass mats³ (laminated organic matter facies – see below and Supplementary Information for descriptions) form disconformities, they constitute two contact types, a lower disconformity and an upper paraconformity. For ease of visualisation, grass mat disconformities are illustrated as a single red line representing the sedimentary implication of its presence. Irregular disconformity morphology can be reflective of an eroded and altered underlying surface, post-depositional deformation, or both. Where the extent of underlying surface erosion or physical modification is not clear, paraconformities are labelled to indicate an abrupt change, surface establishment and a unit boundary.

Fourier transform infrared spectroscopy (FTIR)

FTIR spectroscopy measurements were performed directly at the site or at the Evolutionary Studies Institute (ESI) using a portable Bruker Alpha spectrometer set with an Attenuated Total Reflectance (ATR) module equipped with a diamond crystal. Two sampling strategies were applied. To explore intra-member lateral and vertical variability, systematic sampling focused on the southern excavation area (Beaumont's EXC. 4A). Profile sampling columns were chosen to allow for sampling of vertical and lateral variation within the identified BS and WA members and were generally 40 to 50 cm deep and several centimetres wide. Three to four samples were taken vertically every 5 to 10 cm from the bottom to the top. To acquire data from individual features during excavation, spot samples were taken from the Backwell et al. excavation profiles and *in situ* features. Accordingly, target surfaces were cleaned and a few milligrams of sediment were taken from features and profiles. All samples were finely ground in an agate mortar to obtain a homogeneous composition and optimal contact with the crystal. Spectra were acquired in the mid-IR range between 400 and 4000 cm^{-1} (Deuterated TriGlycine Sulfate detector) with 64 scans and a resolution of 4 cm^{-1} . The spectra were corrected with an atmospheric compensation using OPUS 7.5 software.

2.2. Zooarchaeology

This initial faunal study incorporates the total sample of piece-plotted bones excavated between 2015-2018; piece-plotted bones are referred to as the 'single finds'. The sample reported here also includes all bone recovered during the 2017 campaign, including remains recovered from the sieve, which are

³ The use of 'mat' in this paper does not imply grasses were woven.

referred to as the ‘bucket finds’. Taxonomic and taphonomic analysis of the faunal remains was undertaken by JLC. Data collection took place at the University of the Witwatersrand and the Ditsong National Museum of Natural History in 2018. In analysing the fauna, single finds and bucket finds were processed separately. Both categories include identified (ID) and non-identified remains. A small number of potentially worked pieces were discovered during sorting. These were set aside for specialized analysis and will be discussed in a future publication.

In order to be considered identifiable, a specimen had to be identifiable to taxon (at least to class and a size category within that class, such as ‘small bird’) and to skeletal element. As such, long bone fragments were only incorporated in the identified sample if they preserved diagnostic features that allowed them to be identified to a particular element. Bones were identified using the comparative collection at the Ditsong National Museum of Natural History. Bovids are the most common taxa at the site. Given the degree of fragmentation and the relatively small number of diagnostic elements, most of the bovid remains could only be identified to size class, using a modified version of Brain’s (1974) classification scheme (Table 1). Following Klein (1977), because two species of hyrax may be present—rock hyrax (*Procavia capensis*) and tree hyrax (*Dendrohyrax arboreus*)—and because it is often difficult to distinguish between the two, these remains were simply identified as ‘hyrax’.

Table 1. Bovid size classes (adapted from Brain, 1974).

Size Class	Live Weight (kg)	Species (list not inclusive)
Bov I	<23	<i>Raphicerus campestris</i> (steenbok), <i>Cephalophus natalensis</i> (red duiker)
Bov II	23-84	<i>Pelea capreolus</i> (grey rhebok), <i>Tragelaphus scriptus</i> (bushbuck)
Bov III	85-300	<i>Hippotragus equinus</i> (roan antelope)
Bov IV	300-950	<i>Syncerus caffer</i> (African buffalo), <i>Tragelaphus oryx</i> (eland)

All identified specimens were weighed and measured, and cortical preservation was coded as good, fair or poor. Bones with 'fair' cortical preservation showed some degree of cracking and/or flaking of the cortical surface and/or the surface was partially obscured by adhering sediment (often concreted ash). Bones with 'poor' cortical preservation either did not preserve any of the original cortical surface (for instance, it had flaked away) or the bone surface was >75% obscured. Bones were assigned to a burning category using a modified version of the coding scheme presented in Stiner et al. (1995) (Table 2). Identified specimens were examined under a binocular microscope at 8-40x magnification for signs of surface damage, including cut marks, percussion damage, tooth scores/gnawing, insect damage, trampling, rodent gnawing, and root damage, following the diagnostic criteria of Andrews (1990), Blumenschine and Selvaggio (1991), Lyman (1994), Milo (1994), Blumenschine et al. (1996), Pickering and Egeland (2006), Dominguez-Rodrigo et al. (2009), Backwell et al. (2012), Fernandez-Jalvo and Andrews (2016), and Reynard and Henshilwood (2018). In analysing the identified long bone shaft fragments, fracture plane, angle and surface were coded following Outram (2001). Specimens showing recent breaks (likely reflecting breakage during excavation or transport to the lab) were excluded from this analysis.

Table 2. Categories used in classifying burned bone (modified after Stiner et al., 1995).

Burning Code	Description
0	Not burned (typically cream/tan in colour)
1	Localized burning (<50% black)
2	Moderate burning (>50% black)
3	Carbonized (100% black)
4	Localized calcination (<50% white)
5	Moderate calcination (>50% white)

Specimens that could not be identified to a specific skeletal element were analysed separately; these were assigned to fragment type (long bone shaft, skull, rib, vertebra, enamel, miscellaneous-spongy and miscellaneous-other). Among the single finds, wherein each fragment had a unique specimen number, each bone was weighed and measured independently—these specimens were also assessed for burning and cortical preservation. Procedures differed slightly for the bucket finds. Bones were still sorted into fragment type, but they were counted and bulk weighed within each fragment category based on fragment size (less than and greater than 2 cm) and the degree of burning. For the bucket finds, the following burning categories were used: non or lightly burned (NB/LB, equivalent to burn codes 0-1), moderately burned (MB, burn codes 2-4), or highly burned (HB, burn codes 5-6). The NB/LB category exists because it was sometimes difficult to tell whether discolouration was due to burning or some other factor (manganese staining, bacterial activity, etc.), especially for the smallest fragments. A conservative treatment of these data would be to consider the NB/LB category unburned.

3. Results

3.1. Facies analysis

3.1.1. General sedimentary constituents

Autogenic particles

Lithologies found in the host rock determine the clastic autogenic constituents of the shelter. Lithofacies exposed on the Lebombo Mountain landscape and those associated more directly with the shelter were previously described by Cooke et al. (1945), Butzer et al. (1978) and Backwell et al. (2018). Host rocks are generally described as a suite of rhyolitic extrusive lithologies and pyroclastic breccias with textural changes in the matrix representing different rates of lava cooling. Exposed across the majority of the walls and roof is a clast-supported, strongly lithified rhyolitic breccia incorporating pebble to boulder-size clasts of rhyolite and sandstone. In the southern areas of the shelter, an interbedded matrix-supported breccia with friable silt and clay-rich sandstone matrix and clasts of variably textured rhyolite is exposed. Internal breakdown of the roof and walls of the shelter contributes the vast majority of sediments to the Border Cave clastic sequence. The rhyolitic component of the host rock breaks down as poorly sorted, angular,

elongated, equant (similar dimensions in three axes) and platy shards along zones of flow banding and textural transitions. Sub-angular and occasionally rounded clasts of rhyolite can be released from the host breccias. *In situ* fragmentation reduces elongated pieces to angular equant or platy shards. Weathered rhyolites release red and yellow clays and siliciclastic particles. Included sandstones release sand, silt and clay as aggregates and single grains. Quartz grains are frequently angular and irregular (Wadley et al., 2020b). Occasionally larger, pebble to small cobble-size rounded sandstone clasts incorporated within host-rock breccias are released and decay *in situ*, forming smaller aggregates and concentrations of single grains.

Anthropogenic particles

Anthropogenic clastic components include a range of lithic, botanical, faunal and soil materials accumulated through human activity. These components contribute tangibly, but variably, to the matrix and clast fractions and to the chemical composition of the deposits. Each component of the archaeological record (e.g., seeds, phytoliths, charcoal) is being analysed individually as part of a broad multi-proxy research programme (e.g., Wadley et al., 2020a; Zwane and Bamford, 2021; Sievers et al., 2022; Esteban et al., this volume; Lennox et al., this volume). Significant anthropogenic contributions to the sediments include diffuse and dense deposits of burnt and unburnt vegetation, charcoal, bone and wood ash, and aggregated soil particles of various shapes and sizes. Although the majority of botanical remains are considered anthropogenic, alternative biological agents may have been responsible for accumulating some material (e.g., phytoliths and diatoms).

3.1.2. Identified facies

Seven major facies were identified from excavation profiles and open sediment exposures across the site. Table 3 presents a summary of the sedimentary characteristics of each facies and their respective formation interpretation. Examples of facies are illustrated in Figure 2 (Facies II is illustrated in Figure 3). Facies interpretations are based on FTIR analysis and facies/process associations established by various researchers at macro and micro scales (e.g., Butzer, 1979; Schiegl et al., 1996; Meignen et al., 2007; Goldberg et al., 2009; Mallol et al., 2013a, b, 2017; Miller et al., 2013; Mentzer, 2014, 2016; Karkanas et al., 1999, 2000, 2015; Karkanas and Goldberg, 2019; Haaland et al., 2020; Karkanas, 2021). It must be noted that geochemical make-up and proportions of major minerals vary at intra-facies and intra-stratum scales. We present only representative spectra at this stage. Comprehensive sedimentary descriptions of facies are presented in Supplementary Information, together with FTIR spectra for each facies (Figure S1).

Table 3. Facies identified, their major sedimentary characteristics and their respective formation interpretation.

Facies Label	Full Name	Main sedimentary characteristics	Mineralogical composition	Formation interpretation
Facies I (F I)	Massive Sand	Matrix is massive, poorly sorted, single-grained, unconsolidated silty sand to sandy silt with an open structure. Clasts are dispersed, poorly sorted and angular to subangular.	Silicates, including quartz; gypsum; calcite; iron oxides; organic matter; hydroxyapatite; kaolinite	Gradual geogenic and autogenic sediment accretion process potentially occurring locally and contemporaneous with occupation in other areas of the site (see SI for further details and FTIR interpretation and references). Fluctuations between F I.I and F I.II represent local or shelter-wide changes in roof breakdown but not to a degree that forms F II.
Facies I.I (F I.I)	Clast-poor silty sand (upper Figure 2a)	Matrix as above. Clasts are <50 mm, infrequent, poorly sorted, dispersed, angular to subangular, platy to equant rhyolite shards and blocks. Includes infrequent isolated patches and lenses of ash and/or fibrous vegetation; isolated and dispersed micro- and macrofauna; shell fragments; lithic flakes and knapping debris.		
Facies I.II (F I.II)	Clast-rich silty sand (Lower Figure 2a)	Matrix as above. Clasts are <100 mm, frequent, poorly sorted, angular to subangular platy to equant rhyolite blocks with frequently developed planar fabric. Occasionally clasts occur in stone lines and are directly associated.		
Facies II (F II)	Clast-supported silty sand (Centre of Figure 3)	Clast-supported facies with silty sand matrix. Clasts are <100 mm, poorly sorted, directly associated, angular platy to equant rhyolite blocks occasionally fragmented <i>in situ</i> . Fabric varies locally between isotropic and planar. Imbricated clasts found at contact with shelter floor.	As above	More significant, rapid roof spall contribution either locally or shelter-wide (e.g., Butzer et al., 1978).
Facies III (F III)	Ash	Variable in thickness and lateral extent. Thickness ranges between 40 cm (4 WA) and filamentous lenses. Frequently overlies F VI and burnt F V constituting combustion feature packages. Facies is a variably structured matrix-supported sandy silt to silty loam. Includes poorly sorted burnt bone, shell, ochre grains, micro-charcoal and lithics dispersed or accumulated in lenses.	Calcite; silicates; hydroxyapatite; occasionally quartz, organic matter, aragonite	Ash deposits associated with the construction and preservation of largely <i>in situ</i> combustion features (e.g., Schiegl et al., 1996; Karkanas et al., 1999, 2000; Goldberg et al., 2009; Karkanas, 2021).
Facies III.I (F III.I)	Stratified ash (Centre Figure 2b)	Frequently associated with F III.II. Stratification is often convoluted and deformed. Matrix is single-grained and powdery, granular or platy in structure and occasional includes lightly consolidated crusts.		
Facies III.II (F III.II)	Massive ash (Centre Figure 2c)	Matrix is generally single-grained and unconsolidated with pockets of lightly consolidated aggregates of ash. Clasts are <50 mm, infrequent, poorly sorted, isolated and dispersed. Clast fabrics range from isotropic to planar.		
Facies IV (F IV)	Massive charcoal (Centre of Figure 2d)	Macro- and micro-charcoal-supported; frequently underlies F III; massive matrix comprising poorly sorted micro-charcoal and silty sand; single grained, open structured. Abundant subrounded to rounded fragmented charcoal blocks of 2-30 mm; chaotically organised or occasionally laterally and vertically graded. Anthropogenic components include burnt bone, lithic flakes and debris.	Amorphous carbon; Silicates; gypsum; occasionally calcite, kaolinite, iron oxides	Basal unit of a largely <i>in situ</i> combustion feature (e.g., Goldberg et al., 2009; Miller et al., 2010, 2013).
Facies V (F V)	Laminated organic matter (Centre of Figure 2e; Figure 2a; Figure 2g; Figure 2c)	Variable in distribution and extent, ranging from isolated lenses and patches to densely superimposed, laminated layers up to 10 cm thick. Frequently associated with F III, F VI and F VII. Primarily consists of fibrous to woody matted vegetation in compact, diffuse, burnt, partially burnt, unburnt, desiccated or fragmented states. Matrix includes sands, silts, clays and aggregates. Anthropogenic components include ochre grains and nodules, lithic flakes and debris, burnt and unburnt bone, wood and charcoal.	Organic matter; amorphous carbon; quartz; calcite; gypsum; when silicified can contain amorphous silica, hydroxyapatite, quartz, gypsum (Wadley et al., 2020b)	Largely <i>in situ</i> bedding constructed and altered in a variety of ways (see Sievers et al., 2022 for analysis and discussion).
Facies VI (F VI)	Homogeneous anthropogenic components (HAC)	Highly variable in thickness and lateral extent. Facies is matrix-supported with single-grained, open in structure and unconsolidated. Frequently associated with F III and F V. Characteristically grey in colour. Occasionally includes patches and lenses of ash. Autogenic and anthropogenic components are poorly sorted, dispersed, ungraded and unorganised. Anthropogenic particles include isolated strands of fibrous vegetation, small pieces of wood, lithic debris, ochre grains, fragmented micro-charcoal, microfauna bones, and burnt and unburnt macrofauna bones.	Silicates, including quartz; gypsum; kaolinite; organic matter; iron oxides; amorphous carbon; and a variety of components depending on proximity to other facies, e.g., close to F III, Calcite and hydroxyapatite are prevalent.	Homogenised turbated sediment that originally comprised structured anthropogenic components and features (e.g., Goldberg et al., 2009; Miller et al., 2013; Karkanas et al., 2015).
Facies VI.I (F VI.I)	HAC with F I.I (Centre of Figure 2g)	As above associated with an F I.I autogenic component.		
Facies VI.II (F VI.II)	HAC with F I.II (Figure 2f)	As above associated with an F I.II autogenic component.		
Facies VII (F VII)	F VI with stratified anthropogenic components (Lower Figure 2f)	Similar in composition and association to F VI but structurally distinguished by its stratification.	As above	Mixed facies of anthropogenic components with residual stratification indicating primary anthropogenic features existed prior to turbation, but only isolated remnants remain preserved.

FIGURE 2 ABOUT HERE

Figure 2. Identified facies present in the profiles exposed through the Backwell et al. excavations (see Figure 1 for locations of excavations) and described in Table 3. In most panels multiple facies are visible and demonstrate frequent stratigraphic associations. Not all facies visible in each panel are labelled. Full facies descriptions, FTIR results and formation interpretations are presented in Supplementary Information.

3.2. Stratigraphy

3.2.1. Squares N109 E119 to N109 E120, Members 1 BS Lower to 2 BS Lower

Figure 3 presents the major facies and stratigraphic contacts through the 1 BS Lower to 2 BS Lower sequence exposed in excavation squares N109 E119 to N109 E120 (about 150 cm E-W; See Figure 1 for location of excavation). Stratigraphic associations of those facies and contact types in schematic form are presented in Figure S2. From bottom to top, the sequence starts with a clast-poor sandy silt (Facies I.I) grading into a clast-rich silty sand (Facies I.II). In the region of the change, a laterally extensive mat of laminated organic matter (Facies V; Grass Mat 'GM' Cassidy) represents a discrete anthropogenic feature emplaced during the accretion of early Facies I.II sediments, and a paraconformity. GM Cassidy-bounding clast-rich homogeneous anthropogenic components (Facies VI.II) represent dispersed anthropogenic elements within a Facies I.II depositional regime. In the centre of the profile, an isolated exposure of Facies II represents localised spall accumulation near the end of Facies I.II deposition. Several large, isolated clasts laterally associated with the Facies II occurrence on the deposit slope may have formed during the same period of local rapid roof breakdown. A locally abrupt paraconformity in the east and west indicates the commencement of combustion feature construction, attributed to Member 1 WA. Abrupt (in the west and east) and diffuse (in the centre) transitions between Facies I.II and VI.I indicate a change to a lower clast accretion autogenic regime (Facies I.I) and locally variable extents of mixing at the base of the 1 WA combustion features (Facies VI.I; dashed yellow line), which were initially laid down on a clast-poor surface with a gentle E-W slope. The construction of combustion features very close to the change in Facies I type has obscured that contact.

Although closely associated, unconformities in Member 1 WA indicate numerous distinct phases of combustion feature construction and alteration. Essentially, 1 WA can be separated into four largely *in situ* combustion features (represented by a combination of Facies III overlying Facies IV; labelled 1-4 in Figure 3) separated by clear unconformities. From bottom to top, a small remnant combustion feature (circle 1) with stratified ashes (Facies III.I) on the eastern end of the profile is truncated by the construction of a thick combustion feature (circle 2) with homogenised ashes (Facies III.II). This, in turn, is truncated and overlain by a relatively steeply dipping stratum of Facies VI, representing a hiatus and period of trampling and reworking, that underlies the third and fourth, superimposed, combustion features (circles 3 and 4) on the left of the profile. Layers of Facies V and Facies VI.I overlay Facies III of combustion features 3 and 4 with irregular and abrupt contacts (unconformities), indicating the establishment of stable surfaces and disturbance of the underlying feature. Stratified and massive ashes (Facies III.I and III.II) in all combustion features imply turbulence and compression.

Overlying all combustion features and representing a significant unconformity ending the 1 WA unit is an extensive stratum of laminated organic matter (Facies V) attributed to 1 BS Lower. Above this, a thick unit of Facies VI.I, representing mixed and reworked anthropogenic components within a Facies I.I regime, with occasional grass mat lenses, grades up into Facies I.I. On the far right, Facies VII overlies the 1 WA-capping grass mat and grades laterally west into Facies VI.I, indicating a removal of previously stratified anthropogenic features in the centre of the profile. In combustion feature 3, attributed to 1 WA, several burrows have mixed and vertically migrated Facies VI.I sediments into the underlying Facies I.II, significantly deforming the lower contact.

FIGURE 3 ABOUT HERE

Figure 3. Northern excavation E-W profile in squares N109 E119, N109 E119.5 and N109 E120 exposing the upper four members of Beaumont's stratigraphic sequence 1 BS Lower (1 BS.LR), 1 WA, 2 BS Upper (2 BS.UP) and 2 BS Lower (2 BS.LR) (see Figure 1 for location). Distance between boundary gridlines of N109 E119.5 is 50 cm. (A) Profile illustrated with Beaumont's stratigraphic attributions on the left and their boundaries as identified by here (white dashed lines). Total station calibrated depths are presented in boxes on the right. The transition between 2 BS Upper and 2 BS Lower is dashed and indicates the boundary as suggested by the facies change (discussed in text). Yellow labels are excavator-attributed

layers and features. Table S1 presents correlations between units recognised here and excavator-named units. (B) Northern excavation profile with major facies and stratigraphic contacts labelled (see text for definitions and descriptions). Numbered circles label *in situ* combustion features (1 - 4) in stratigraphic order. Green lines represent gradational stratigraphic contacts, yellow lines represent paraconformities, and red lines represent disconformities.

3.2.2. Squares N109 E117 to N109 E118.5, Members 2 BS Lower to 1 RGS / 4 BS

Figure 4 presents the major facies and stratigraphic contacts through the 2 BS Lower to 4 BS sequence exposed in excavation squares N109 E117 to N109 E118.5 (about 150 cm E-W; See Figure 1 for location of excavation). Stratigraphic associations of those facies and contact types in schematic form are presented in Figure S3. From bottom to top, the sequence starts with Facies VI.I sediments with interstratified deformed and eroded anthropogenic lenses and an isolated patch of Facies VI.II. A largely *in situ* combustion feature (circle number 1) composed of Facies IV underlying a massive ash unit (Facies III.II) has been eroded and locally reworked at its upper contact with another unit of Facies VI.I. These lower units, below Grass Mat Eaton (Facies V), represent a unit that can be attributed to Beaumont's Member 4 BS, which underlies 1 RGS, but the boundary between the two is unclear since no observable stratigraphic contact extends across the exposure or can be projected across the profile with confidence. Unit Grass Mat Eaton (Facies V) represents an extensive paraconformity in this exposure and a boundary between 1 RGS and the overlying 3 BS. It must be noted that 4 BS, 1 RGS and the lower reaches of 3 BS are largely composed of the same facies type, Facies VI.I. Evidently, post-depositional mixing has resulted in the homogenisation of most of the sediments. Mixing seems to have been constrained within units, with some bounding features (e.g., Grass Mat Eaton) remaining intact. Grass Mat Eaton is directly overlain and truncated at the western extremity of the profile by the margin of a combustion feature with a heavily altered upper surface disconformity (named by excavators 'combustion feature in Ebony'). This discontinuous combustion feature, with an eroded upper surface, expands into the northern profile of the excavation square immediately west (N108 E116.5; Figure 5) and may represent a limited exposure of Member 3 WA in this area. We have not located Member 3 WA with certainty anywhere in the Backwell et al. excavation.

Member 3 BS is primarily made up of Facies VI.I sediments but presents important lateral facies variation in its upper regions that extends into the western exposures of 3 BS (N108 E116.5). In the eastern side of

the 3 BS exposure, several Facies VI.I units with diffuse boundaries are exposed (Very Dark Yellowish Brown Easy; Dark Yellowish Brown Dossy) and contain ephemeral lenses of dispersed combustion features (e.g., Charcoal Layer in Very Dark Yellowish Brown Easy). In the upper western part of 3 BS, Facies VI.I sediments overlie the heavily eroded combustion feature that truncates Grass Mat Eaton, itself overlain by an *in situ*, but truncated and deformed, Facies V (Grass Mat Dossy). Grass Mat Dossy underlies a patch of massive, clast-poor sands (Facies I.I; Dark Yellowish Brown Dossy), within which occurs the eastern margin of a largely *in situ* combustion feature (circle number 2). The sequence in the western exposure of 3 BS in this profile represents the state of the unit prior to turbation. The boundary between 3 BS and 2 WA is represented by an abrupt paraconformity and facies change from Facies I.I (on the left) and VI.I (on the right) to Facies IV and III, representing a laterally extensive, but eroded and deformed combustion feature (circle number 3; White Dubbin).

Member 2 WA can be allostratigraphically divided into three sub-units (Figures 4 and S3), each characterised by different combustion feature assembly and frequency. The lower division (LR), starting with the base of combustion feature 3 (Strong Brown Duby) overlain by White Dubbin (Facies III.I) comprises two laterally extensive combustion features that have been deformed, fragmented and significantly altered by overlying grass mats (Facies V). The combustion features are interstratified by wedges of sand sloping from E-W, indicating episodic and perhaps variable use of this part of the shelter at this time. A middle division (MD) is represented by three laterally associated, largely *in situ* combustion features (circles 4, 5 and 6), the bases of which cut into the underlying 2 WA.LR sediments. The contact is an abrupt disconformity in the east and is more diffuse in the west where Facies IV sediments from 2 WA.LR and MD co-mingle. In each of these combustion features, thin lenses of rubified sand lie between the base of the combustion feature (Facies IV) and overlying ash (Facies III.I and III.II). The direct lateral association of the three combustion features suggests a period of intense anthropogenic activity in this area of the cave. These three combustion features are heavily truncated by a significant, consistently abrupt 10° E-W dipping disconformity that represents the lower contact of 2 WA Upper (UP). The upper division of 2 WA is characterised by a thick collection of homogeneous ashy packets (Facies III.II), intermingled with diffuse lenses and patches of Facies IV, rubified sands (Facies I) and charcoal-rich ash (Facies IV). The presence of highly weathered phytolith morphotypes in the ash units suggests exposure to high temperatures (Esteban et al., this volume). Some patches of ash show convoluted stratification (Facies III.I). In all cases, lateral and vertical contacts within this division are diffuse. An extensive ash packet on the right (circle number 7), underlain by Facies IV, may represent a relatively intact combustion feature despite its Facies III being massive and indicative of post-depositional homogenisation. A general

absence of structure in the centre of 2 WA.UP suggests that it may have been formed through the redistribution of combustion feature bases and ashes through rake-out or dumping, with potentially a later hearth being constructed over the mass of the unit (circle number 7). Based on exposures of 2 WA in the southern excavations (squares V21, W21 and W20 in Figure 1), 2 WA dips from S-N at approximately 5°. Correlations between identified 2 WA sub-units and excavated layers and plans (layer sub-units) are challenging because fine, diffuse and low angle lateral contacts between similarly composed and coloured sediments are very difficult to identify in the field. Consequently, some excavator-identified layers and plans may extend beyond the contacts recognised in clean profiles. We have attempted to correlate most excavator-identified layers through photographs and GIS-plotted artefact data (Table S1) and ongoing spatial analyses will provide further resolution in this regard.

Member 2 WA is truncated and capped by a thick succession of Facies V grass mats that directly overlay the ashy packets. Abundant lithic artefacts are directly associated with these F V units. Overlying Facies V is Facies I.I, which extends up to the vertical limit of the profile. Interstratifying the lower exposures of Facies I.I are several ephemeral grass mats and charcoal-rich Facies VI.I units that represent isolated and sporadic use of the same area of the cave or margins of occupation areas. Abundant lithic artefacts are associated with these F VI.I sediments and occur as vertically-constrained lenses within dispersed F VI.I fines.

The key stratigraphic differences between the excavator-assigned member boundaries and those suggested here are as follows: the inclusion in 1 RGBS of the part of unit Ebony that lies below Grass Mat Eaton; and a division of the thick unit Dossy into two – a lower Dossy (Dark Yellowish Brown Dossy), attributed to 3 BS that is below combustion feature 3, and an upper Dossy (Brown Dossy), attributed to 2 WA.LR, which lies between White Dubbin (attributed to combustion feature 3) and Dijon and Dino – see Table S1.

FIGURE 4 ABOUT HERE

Figure 4. Northern excavation E-W profile in squares N109 E117, N109 E117.5 and N109 E118 exposing the middle members of Beaumont's stratigraphic sequence 2 BS Lower (2 BS.LR), 2 WA, 3 BS, 1 RGBS and 4 BS (see Figure 1 for location; Table S1 for unit distribution and nomenclature across literature and correlation with excavator-named units). Distance between boundary gridlines of N109 E117.5 is 50 cm.

(A) Profile illustrated with Beaumont's stratigraphic attributions on the left and their boundaries as identified by excavators (white dashed lines). Total station calibrated depths are presented in boxes on the left. Yellow labels are excavator-attributed layers and features. (B) Northern excavation profile with major facies and stratigraphic contacts labelled (see text for definitions and descriptions). An alternative location for major member boundaries based on allostratigraphic boundaries is presented on the left with proposed subdivisions of 2 WA. The contact between 1 RGS and 4 BS is dashed and indicates that the boundary is unclear (discussed in text). Numbered circles label *in situ* combustion features in stratigraphic order (1 - 7). Yellow lines represent paraconformities, and red lines represent disconformities.

3.2.3. Squares N108 E115 to N108 E116.5, Members 3 BS to 4 WA

Figure 5 presents the major facies and stratigraphic contacts through the 2 BS Lower to 4 WA sequence exposed in excavation squares N108 E115 to N108 E116.5 (See Figure 1 for location of excavation). Stratigraphic associations of those facies and contact types in schematic form are presented in Figure S4. From bottom to top, a horizontally bedded thick ash deposit representing 4 WA is the basal unit of this profile (lower right panel in Figure 5A and B). The ash that comprises 4 WA is massive, bright white to yellow and light grey in colour with a single-grained to granular structure (Facies III.II). Intra-4 WA bedding in this profile is defined by faint, thin, horizontally interstratifying concentrations of poorly sorted pebble to sand-sized rounded charcoal particles and rubified sand particles floating within a fine, diffuse, darker grey ash matrix. Consolidation can occur in irregular patches or in laterally extensive strata suggestive of prolonged exposure of surfaces during its formation. The surface of 4 WA in this exposure is compacted, consolidated relatively heavily, and shows clear evidence of anthropogenic modification, creating an abrupt, irregular disconformity (see lower right panel in Figure 5B). To the west (N108 E114), the upper contact of 4 WA is largely horizontal and abrupt.

Overlying the irregular surface morphology of 4 WA is a clast-rich sediment with mixed anthropogenic components (Facies VI.II) attributed to 4 BS. Clast fabric near the 4 WA contact is planar and conforms to the underlying surface morphology. Further above the contact, clasts retain their planar fabric but develop an E-W apparent dip of about 15°, suggestive of a slowly, naturally accumulating sloped deposit. The autogenic component is laterally graded, with clast-poor sediments (Facies VI.I) replacing Facies VI.II from the centre of the profile eastwards, upslope. Within 4 BS, several important features occur: (1) an isolated, partially eroded combustion feature (circle number 1) with reworked margins and a horizontal to slightly

concave base is composed of a fragmented grass mat (Grass Mat Ega) underlying a poorly preserved Facies IV, which directly underlies a thin, partially dispersed Facies III.II; and (2) a significant, irregular truncation and fill sequence in the far west of the profile (N108 E115). Here, the contact between two units of Facies VI.II is abrupt and marked by compacted underlying sediments with a richer clay content and ephemeral, wave-like clay lenses interdigitating at the upslope margin of the cut-filling sediments. Clasts within the cut- fill are poorly sorted, appear roughly graded and show a planar fabric dipping E-W at about 15°. The eastern extent of the disconformity is not preserved. Neither the underlying sediments nor the cut-fill show clear anthropogenic features or organised anthropogenic contents and it is possible that this is a geogenic feature.

In the centre and east of the profile (N108 115.5 to N108 E116.5), 4 BS has been truncated in a E-W sloping disconformity in which clast-rich sediments with homogeneous anthropogenic components (Facies VI.II) abruptly overlie Facies VI.I and Facies VI.II sediments of 4 BS. These overlying sediments are attributed to 1 RGS of Beaumont's sequence. The eastern extremity of the contact is not preserved, but it appears at about E116.25, after which the contact slopes west at about 15° with minor undulations in underlying surface morphology. In the centre, the disconformity forms a concave shape associated with the base of combustion feature 2 (circle number 2). The western edge of the disconformity rises to meet the 3 BS disconformity.

At the base of 1 RGS are the remnants of an *in situ* combustion feature package (circle number 2) with Facies IV underlying a laminated, relatively clast-rich, ashy packet (Facies III.I). The base and internal stratigraphy of the combustion feature are slightly concave, but generally horizontal, unlike the underlying 4 BS deposit bedding, and the immediately overlying Facies VI.II sediments that abruptly truncate the upper surface of the combustion feature. In several instances, clasts from the overlying Facies VI.II are pressed into the ash surface, deforming laminations. The overlying body of 1 RGS contains notably larger clasts with occasional, directly-associated particles fragmented *in situ*. Clast fabric is planar and dipping at about 15° E-W. Anthropogenic components are abundant, but dispersed and highly fragmented. Occasional larger fragments of grass mat are preserved, suggesting minimal lateral mobilisation within the clast-rich sediment. This is exemplified in combustion feature 3, where a compacted series of laterally extensive burnt grass mats and charcoal and ash layers have been locally deformed, fragmented and dispersed at the margins, but remain largely *in situ*. Unlike combustion features 1 and 2, this combustion feature dips at the same gentle E-W inclination as the deposit fabric and the nearby major stratigraphic contacts. The eastern extremity of 1 RGS in this profile grades laterally into Facies VI.I, attains a darker

grey colour, and the lower and upper contacts are obscured by mixing (see stratigraphy for N109 117 for description). In the east of the profile, combustion feature 4 overlies 1 RGS in a locally abrupt disconformity.

Stratigraphically located between 1 RGS and 3 BS, combustion feature 4 is exposed in the western extremity of N109 E117 and it truncates Grass Mat Eaton. The combustion feature consists of a thick base of Facies IV and a thin, irregular, heavily eroded massive ash (Facies III.II). It is unclear if this feature represents what Beaumont would have called Member 3 WA. In the current exposures, combustion feature 4 is laterally discontinuous.

Truncating combustion feature 4 in the east, 1 RGS in the centre, and 4 BS in the west, is a significant and abrupt disconformity sloping at about 15° E-W, signifying the transition to 3 BS. In the west of the profile, the disconformity truncates the upper facies of a combustion feature in 4 BS (combustion feature in Eba; Figure 5). Above the contact, autogenic components change abruptly to clast-poor Facies I.I, demonstrating a change in the rate of roof spall generation in this part of the shelter. Localised pockets of Facies I.II downslope may reflect slope process-related longitudinal facies grading (clast-rich lobe development) or highly localised continuation of breakdown that characterised the underlying 4 BS and 1 RGS autogenic component. Facies I.I grades up into a clast-rich Facies I.II that extends across the profile, indicating a return to greater spall generation in this part of the shelter. In the east, the gradational contact is obscured by mixing. At the F I.I to I.II contact, a highly diffuse, thin and discontinuous unit of Facies VI.II is exposed and may represent a dispersed, discrete anthropogenic feature in 3 BS formed at the onset of F I.II sedimentation.

FIGURE 5 ABOUT HERE

Figure 5. Northern excavation E-W profile in squares N108 E115 (including insert), N108 E115.5, N108 E116 and N108 E116.5 exposing Members 2 BS.LR, 2 WA, 3 BS, 1 RGS, 4 BS and 4 WA of Beaumont's stratigraphic sequence (see Figure 1 for location; Table S1 for unit distribution and nomenclature across literature and correlation with excavator-named units). Distance between boundary gridlines of N108 115.5, N108 E116 and N108 E116.5 is 50 cm. (A) Profile illustrated with Beaumont's stratigraphic attributions on the right and their boundaries as identified by excavators (white dashes). Total station calibrated depths are presented in boxes on the right and a single depth reference is presented on the

left. Yellow labels are excavator-attributed layers and features. The lower right panel with dashed outline presents the exposed contact between 4 BS and 4 WA (corresponding to the features exposed in the dashed box on the lower left). The topography of the exposed 4 WA surface represents a concave, anthropogenic feature cut into 4 WA. (B) Northern excavation profile with major facies and stratigraphic contacts labelled (see text for definitions and descriptions). Numbered circles label *in situ* combustion features in stratigraphic order (1 - 4). Combustion feature 4 may represent part of Member 3 WA. Because no other deposits can be attributed to that member from Backwell et al. exposures, combustion feature 4's stratigraphic attribution is unclear. The lower right panel with dashed outline presents the exposed disconformity between 4 BS and 4 WA (corresponding to the features exposed in the dashed box on the lower left). Green lines represent gradational stratigraphic contacts, yellow lines represent paraconformities, and red lines represent disconformities.

3.2.4. Squares N108 E113.5 to N109.7 E113.5, Member 4 WA to cave floor

Figure 6 presents the major facies and stratigraphic contacts from Member 4 WA to the cave floor as exposed through the excavation of squares N108 E113.5 and N109.7 E113.5 (about 170 cm N-S; See Figure 1 for location of excavation). Stratigraphic associations of those facies and contact types in schematic form are presented in Figure S5. From bottom to top the entire sequence described in this study rests on a clast-supported (Facies II) decayed rhyolite deposit representing the shelter floor. The relatively limited surface exposure of the floor suggests in this area it is largely horizontal N-S and dips at about 10-15° E-W. The facies consists of variably piled, directly associated, very poorly sorted angular to sub-angular platy shards of rhyolite of different sizes (up to 75 mm). No obvious clast orientation is evident and clast fabric ranges locally between planar, imbricated and isotropic. *In situ* clast fragmentation is evident throughout the exposed facies and in many cases fragments remain directly associated. *In situ* clast weathering is increasingly abundant towards the upper contact and red and yellow silt/clay-rich powders have formed on clast surfaces and edges. Interstitial voids are filled with decayed, poorly sorted, sub-angular rhyolite fragments, and poorly sorted yellow sandy silt. Gypsum and calcite accumulation throughout the unit is frequent, but not abundant and occurs mostly in isolated interstitial voids and on upper surfaces of clasts and takes the form of powder and small crystals. The upper contact of Facies II is irregular and strongly influences the morphology of the lower sediments of the overlying unit, especially in the south (right in Figure 6), where the overlying unit reduces to a thin stratum before being truncated by a steep disconformity representing the base of 5 BS Lower.

Sediments overlying the irregular shelter floor consist of Facies VI.I with isolated pockets of Facies VII attributed by excavators to 6 BS. Centrally, Facies VII sediments form directly from the floor up to a paraconformity that represents the base of combustion feature 1. This short sequence of Facies VII underlying combustion feature 1 represents an isolated patch of largely *in situ* sediments. Facies VII sediments are finely laminated with frequent, dispersed, micro-charcoal particles and grade laterally north and south into Facies VI.I massive units. At the upper contact of 6 BS in the south of the exposure, some fine lamination is present in the Facies VI.I sediments directly underlying stratified ash (Facies III.I). Here, the ashy packets comprise thin layers of Facies III and IV that have been significantly deformed through compression and upper surface erosion. The base of combustion feature 1 is well defined and abrupt in the north, deformed and locally diffuse in the south. Internal stratification is deformed through compression and clasts have been pressed into the upper, eroded surface. Unconformably overlying the eroded combustion feature 1 and truncating the underlying Facies VII sediments is a coarser Facies VII (6 BS Brown Lad), the base of which is highly irregular (potentially a result of soft-sediment deformation) and partially obscured. 6 BS is abruptly truncated in the south by the 5 BS disconformity. The upper contact of 6 BS is a horizontal paraconformity representing the base of combustion feature 2.

Combustion feature 2, the basal unit of Member 5 WA, is characterised by finely laminated Facies III.I, IV and VI.I. The basal contact is sharp in the north and similar to combustion feature 1, is diffuse and more deformed in the south, near the steep 5 BS disconformity. Combustion feature 2 is eroded at its upper contact and deformed laminations are truncated locally by an irregular disconformity overlain by Facies VII sediments (Dark Brown Kevin). Another paraconformity represents the base of combustion feature 3, a thicker unit of Facies III ashes with gently undulating internal stratification and clear inclusion of lithics. The combustion feature is partially mixed in its centre and abruptly truncated in the south by the steep 5 BS disconformity. The upper contact of combustion feature 3 is also eroded and overlain by a thin unit of Facies VI.I sediment rich in coarse sands and small clasts, which represents the uppermost unit of 5 WA. Member 5 WA is heavily eroded by an irregular and steeply south-dipping disconformity that truncates all 5 WA and 6 BS layers. The recurrent pattern of facies and stratigraphic contact type presented through the 6 BS and 5 WA sequence, suggests that both may be one stratigraphic unit - 5 WA, and this indicated by the dashed black boundary label on the left of Figure 6B and Figure S5.

The abruptness and irregularity of the 5 BS disconformity suggest partial consolidation of at least the Facies III.I components in 5 WA (including 6 BS), while the interstratifying Facies VI.I and VII show some

limited mixing at the contact. Member 5 BS can be divided into three sub-units based on significant stratigraphic contacts and facies representation.

A lower unit, 5 BS Lower (LR) is defined at the base by the major disconformity that truncates 5 WA and 6 BS. Unit Brown Larry, attributed by excavators to 6 BS, is identified here as the basal unit of 5 BS based on the location of the unit-defining disconformity. Overlying layers include (from bottom to top) Brown Jolly, Brown John, Very Dark Greyish Brown Jim, Very Dark Grey Jez (Wadley et al., 2020b). The lower 5 BS unit consists of Facies VI.I sediments with two structured areas attributed to Facies VII. The lower example of Facies VII conforms generally to the morphology of the disconformity and stratification that is most obvious towards the base of 5 BS (Brown Larry to the base of Brown Jolly 3), a result of gradual filling of the eroded space. An upper area of Facies VII occurs within unit Brown Jolly and is identified by a slight increase in clast abundance with a consistent planar fabric dipping gently N-S and a layer of silicified organic matter (Wadley et al., 2020b). Apart from limited examples of Facies VII, Facies VI.I dominates the rest of 5 BS Lower. Isolated clasts throughout 5 BS dipping from N-S suggest a consistent bed dip in this direction, and remnant bed structure, as recognised by excavators.

A middle unit, 5 BS Middle (MD), is defined by a laterally extensive paraconformity representing the base of a sequence of compressed stratified combustion features, collectively labelled combustion feature 4. More frequent larger clasts (imbricated and isolated) at the lower contact suggests a depositional hiatus and surface development punctuated by the accumulation of roof spall. 5 BS.MD generally contains a higher abundance of isolated ('floating'), and directly associated larger clasts - indicative of Facies I.II autogenic sedimentation, or a deflated, time-averaged deposit. 5 BS.MD combustion features consist of Facies III.I sediments with convoluted internal stratification, deformed most intensively around included clasts. Inter-combustion feature boundaries have been obscured by compression, deformation and localised dispersion. White ashy packets are interstratified by lenses of fine, diffuse Facies IV and VI. Member 5 BS.MD is truncated to the north by a sharp S-N dipping disconformity representing the base of 5 BS Upper. This disconformity also truncates an ash and charcoal-filled small pit (P in Figure 6) dug into the body of 5 BS.MD. To the south, 5 BS.MD is abruptly truncated by a large pit and fill structure. Another higher-density accumulation of clasts occurs at the upper contact between 5 BS.MD and 4 WA. Here, clast fabric is more isotropic. Directly overlying the clast-rich ash of 5 BS.MD and extending across 5 BS Upper is a thin, diffuse stratum of Facies I.I sands. Together, these suggest the formation of a stable trampled combustion feature surface followed by a hiatus in anthropogenic activity and continuation of autogenic sedimentation closing the 5 BS deposit.

5 BS Upper (UP), is stratigraphically defined by a steep S-N sloping disconformity that truncates 5 BS.MD and the upper layers of 5 BS.LR, and the Facies I.I sands that cap 5 BS. Member 5 BS.UP sediment consists of homogeneous Facies VI.I in the lower and middle reaches. A slight increase in clast abundance lining the basal disconformity suggests this unit is graded. Facies VI.I grades into Facies I.I in the upper 5 cm. Member 5 BS.UP may also represent an ancient pit.

The sediments of 4 WA in this exposure compare closely with those described in the previous profile (Section 3.2.3) with some additional features. The lower contact is abrupt and gently dips N-S. Facies III.II sediments dominate the deposit with only faint bedding suggestive of punctuated accumulation. Patches of charcoal fragment-rich Facies III.II suggest dumping of loose combustion feature bases - similar to 2 WA.UP. A single structured combustion feature (circle number 5) occurs in the centre of the unit with a well-defined concave Facies IV base overlain by a charcoal fragment-rich partially mixed ash packet and a covering of dark coarse sand. Also noteworthy is a patch of partially indurated mixed rubified sands and ash that occurs as a wedge in the southern lower area of 4 WA (Unit RB in Wadley et al., 2020b). The patch is slightly graded with small rubified aggregated particles accumulated at its base and shows fine stratification at its southern edge. Some of the aggregates show post-depositional deformation and lateral dispersion into fine lenses, suggestive of minor fluid-induced reworking at the unit's periphery. The increased consolidation and partial induration of the ash components in 4 WA and 5 BS.MD is well demonstrated by their capacity to remain intact after being undercut through the formation of the large pit structure to the south, the age, formation and function of which is still being investigated. The upper contact of 4 WA is an abrupt and locally irregular disconformity overlain directly by a thin stratum of Facies I.I and VI.I with higher clay/silt content and reworked lenses of ash and charcoal attributed to the base of 4 BS.

FIGURE 6 ABOUT HERE

Figure 6. Northern excavation N-S profile in squares N109 E11.5 and N108 E113.5 exposing the lower members of Beaumont's stratigraphic sequence 4 BS, 4 WA, 5 BS, 5 WA and 6 BS to the contact with the shelter floor (see Figure 1 for location; Table S1 for unit distribution and nomenclature across literature). Distance between boundary gridlines of N108 E113.5 is 50 cm. (A) Profile illustrated with Beaumont's stratigraphic attributions on the left and their boundaries as identified by excavators (white dashed lines).

Total station calibrated depths are presented in boxes on the left. Yellow labels are excavator-attributed layers and features. (B) Northern excavation profile with major facies and stratigraphic contacts labelled (see text for definitions and descriptions; Table S1 for correlations with excavator-named units). An alternative location for major member boundaries based on allostratigraphic boundaries is presented with proposed subdivisions of 5 BS. The contact between 5 WA and 6 BS is dashed and indicates the boundary may be revised, resulting in a stratigraphic conflation of 6 BS into 5 WA (discussed in text). Numbered circles label *in situ* combustion features in stratigraphic order (1 - 5). Combustion feature 4 represents several combustion features within the 5 BS Middle unit (MD). Yellow lines represent paraconformities, and red lines represent disconformities. Encircled 'B' indicates a burrow. 'P' indicates the location of the pit in 5 BS.MD. The disconformity-bound F VI.I unit on the right of the profile is a pit of unknown age or function.

3.3. Post-depositional processes

Anthropogenic and non-anthropogenic post-depositional processes are evident throughout the recently exposed Border Cave depositional sequence. Anthropogenic activity can be identified at various scales and, apart from the presence of cultural items, they include: (1) trampled and mixed sediments (Facies VI, and HAC in Wadley et al., 2020b); (2) burnt bedding (e.g., Wadley et al., 2020b); (3) dumped and redistributed combustion features (Facies III.II); (4) surface modification through grass bedding and combustion feature construction; and (5) excavated ancient and modern pits. These processes, and associated features, are the subject of ongoing dedicated study. Here, we highlight some of the non-anthropogenic post-depositional processes in light of Butzer et al.'s (1978) suggestion that non-anthropogenic erosional processes were essentially absent in the Border Cave sequence and that disconformities were created as a result of deliberate or incidental mobilisation of sediments through cultural activities.

3.3.1. Non-anthropogenic processes

Clean sequence profiles exposed during excavations provided an opportunity to observe the nature of disturbance and contact formation. The descriptions above document evidence of both biogenic and geogenic deposit modification. Biogenic activity is evident from ancient and modern burrows through all levels of the sequence, with a particularly extensive network excavated in Member 2 WA. Geogenic post-depositional processes include extensive examples of deposit compression and deflation, exemplified by

deformation of unit boundaries and internal stratification, and *in situ* fragmentation of features and artefacts (particularly bone - see below). Of particular importance are numerous instances of clear, localised and laterally extensive fluid/sediment interactions of varying intensity and form, resulting in the truncation and removal of anthropogenically-rich strata, reworking and homogenisation of sediments, and dispersion of cultural remains (Figure 7). Presented examples focus on fluid-created features for three reasons: (1) previous stratigraphic work did not identify them; (2) previous research suggested that fluid accumulation in the shelter was restricted to mist-derived condensation or urine - significantly restricting the potential of fluid-associated deposit modification; and (3) understanding fluid/sediment interactions is crucial for clarifying sediment and chemical mobilisation, which directly affects artefact and feature taphonomic histories and assemblage integrity. Figure 7A presents the longitudinal, E-W, profile along the southern limit of excavation 4A (Figure 1). In this example, medial areas of the multi-layered 2 WA have been reworked into ephemeral lenses and, in the centre of the image, removed entirely by laterally extensive, shallow, braided channels. Erosion of superimposed strata in 2 WA indicates a recurrence of this process in this area. Figure 7B presents a transverse, N-S, profile exposed in a section of the eastern limit of Horton's Pit (Square P16 in Figure 1). In this example, a deep localised channel has been eroded into 3 BS and filled with heavily mixed sediments representing Facies VI.II. Figure 7C presents an excavation surface of 2 WA in square N109 E117. In this example, a localised high viscosity silty loam mud flow has moved downslope (west) incorporating macroscopic vegetation, charcoal and lithics. Compressed flow bands oriented perpendicular to flow direction formed at the toe of the deposit as it slowed. Directly underlying this is another mud flow, the toe of which is partially exposed. Additional evidence of fluid-influenced sediments can be seen in 1 RGS/4 BS and numerous eroded upper contacts and margins of combustion features throughout the sequence. Evidently, fluids have played a spatially and temporally recurrent role in unit integrity, and stratigraphic contact formation and preservation. The chemical implications of these processes are the subject of ongoing study. Questions remain as to the possible geogenic, anthropogenic and biogenic sources of fluids considering the geological and geomorphological context of the shelter.

FIGURE 7 ABOUT HERE

Figure 7. Examples of observed deposit modification and stratigraphic contact alteration associated with fluid interactions. (A) Laterally extensive erosion of strata of 2 WA evident in a longitudinal, E-W, profile along the southern limit of excavation 4A. (B) Channel erosion and fill within 3 BS evident in a transverse, N-S, profile exposed in a section of the eastern limit of Horton's Pit (Square P16 in Figure 1). (C) Two high viscosity mudflows evident in the excavation of 2 WA in square N109 E117.

3.4. The faunal sample

The total number of single finds analysed was 1,280; of these, 238 were identifiable. Samples were processed from stratigraphic Members 1 BS to 5 BS. The sample of bucket finds included 8,487 fragments, of which 93 were identifiable, for a total number of identified specimens (NISP) of 335 (full count and weight data are presented in Table 4). Given that processing of the bucket finds was limited to those remains excavated in 2017, these data suggest that analysing the remainder of the bucket finds could more than double the identified sample. From a methodological perspective, it is worth noting that the bucket finds included 877 fragments that were >20 mm in maximum dimension. While the bucket finds were not individually measured, a majority of these fell between 20-40 mm. As per the excavation strategy practiced at Border Cave, specimens >20 mm were meant to be piece-plotted. There are numerous reasons why this threshold has not been consistently applied. Given that the total number of single finds from the 2015-18 campaigns was only 1,280, this implies that a majority of the small bone fragments between 20 and 50 mm have not been piece plotted, prompting discussion about future piece plotting practices.

Because analysis of the total faunal sample (including the bucket finds) was limited to material from the 2017 season, we can only address faunal density using that dataset; furthermore, because not all members were excavated in 2017, we begin by considering the data in aggregate (variation in faunal density in 2 BS and 2 WA will be discussed later in this paper). In 2017, a total of 793.15 litres of sediment (0.793 m³) were excavated (Backwell et al., this volume); 8910 bones, weighing 4.134 kg, were recovered. The density of faunal remains was thus ~ 5.21 kg/m³. This number is significantly lower than that evidenced at other Late Pleistocene sites in South Africa; for instance, faunal density in the Still Bay (SB) deposits at Blombos ranged from 15-34 kg/m³ (Reynard and Henshilwood, 2018), while faunal density was as high as 60 kg/m³ in the Howiesons Poort (HP) and SB deposits at Sibudu (Clark, 2017, 2019). Whether this reflects a lesser degree of occupational intensity, reduced reliance on faunal resources, sampling bias

(in which faunal processing happened in areas away from the excavation unit), a greater rate of autogenic sedimentation, or some combination of all of these, is worthy of further inquiry. The relatively large size of the shelter may also have provided opportunities for occupants to use different areas of the site, potentially reducing absolute artefact density. As the faunal sample from the new excavation campaign expands, we will be able to better evaluate how faunal density varies through time.

Table 4. Count and weight data for the BC fauna. Lithic industry identification follows Beaumont (1978).

Industry	Member	Single Finds (2015-2018)				Bucket Finds (2017 season only)						
		Count	Weight (g)	Count	Weight (g)	ID	Non-ID >20 mm	Non-ID <20 mm	Count	Weight (g)	Count	Weight (g)
ELSA	1 BS	13	137.7	65	212	-	-	-	-	-	-	-
	1 WA	10	31.8	84	308.4	2	1.7	45	44.7	199	38.3	
	ELSA Total	23	169.5	149	520.4	2	1.7	45	44.7	199	38.3	
MSA 3	2 BS	58	410.7	126	572.7	29	10.3	175	142.9	2133	197.2	
	2 WA	81	554.7	349	1627.2	23	29.6	516	457.1	3253	468.3	
	MSA 3 Total	139	965.4	475	2199.9	52	39.9	691	600	5386	665.5	
HP	3 BS	27	139.7	73	353.8	30	18.2	76	62.4	1091	156.9	
	3 WA	10	92.5	66	282.6	-	-	-	-	-	-	
	1 RGBS	8	53.8	22	77.6	-	-	-	-	-	-	
	HP Total	45	286	161	714	30	18.2	76	62.4	1091	156.9	
MSA 1	4 BS	8	64.8	46	221	-	-	-	-	-	-	
	4 WA	19	79.2	170	409.6	1	0.3	4	1	29	2.8	
	5 BS	4	7.9	31	81.7	8	1.9	61	42.2	811	118.5	
	MSA 1 Total	31	151.9	247	712.3	9	2.2	65	43.2	840	121.3	
Grand Total		238	1572.8	1032	4146.6	93	62	877	750.3	7516	982	

Previous analyses of the Border Cave fauna (Klein, 1977; Beaumont, 1978) highlighted the fragmentary nature of the assemblage. Again, looking at the 2017 sample, wherein all faunal specimens were analysed, ~ 2% of the faunal specimens were identifiable (182/8897 fragments); by weight, that number rises to 17.7% (731.6 g for identified specimens and 3381 g for non-identified specimens). Complete count and weight data are rarely presented for the full sample of non-identified bone, so it is somewhat difficult to evaluate this metric relative to other MSA assemblages; however, based on weight, Clark (2019) reports that 8% of the Still Bay and pre-Still Bay fauna at Sibudu was identifiable, suggesting a somewhat lesser degree of fragmentation at Border Cave.

Evidence suggests that the assemblage suffered from significant post-depositional fragmentation; excavators noted that many of the single finds were splintered *in situ* but remained closely associated, observations that are supported by the widespread compression-related stratigraphic features documented above. During excavation, these were often removed in several pieces that were bagged together, although in some cases, a preservative was applied so that the specimens could be removed whole. The friability of shaft fragments is illustrated by the fact that 16 of 30 limb shaft fragments coded for fracture patterns displayed recent breaks.

3.4.1 Taxonomic Data

While the primary focus of this study relates to site formation and disturbance, it is worth briefly addressing the taxonomic data. A species list is presented in Table 5. While the table shows NISP data, MNI counts were also calculated; however, these were not included in the table as almost all values were 1. The following members/taxa had an MNI of two (typically representing an adult and a juvenile or foetal/neonate individual)—2 BS: suid and Bov II; 2 WA: suid and Bov III; 4WA: Bov I. As was the case in Klein's (1977) sample, mammals (particularly ungulates) dominate the sample; birds were included in the analysis but were present in very low frequencies (NISP = 21 or ~ 6.3% of the total identified sample). The sample includes one specimen identified as human; this is reported in Jashashvili et al. (this volume). No mammalian carnivores were identified as part of this study. Carnivores were also rare in Klein's (1977; 23) study; he proposed that this could reflect a "mutual avoidance" between the human occupants of Border Cave and larger carnivores.

Table 5. Species list (values reflect the number of identified specimens, or NISP). Lithic industry identification follows Beaumont (1978).

Member	Industry	ELSA		MSA 3		HP			MSA 1		
		1 BS	1 WA	2 BS	2 WA	3 BS	3 WA	1 RGBS	4 BS	4 WA	5 BS
Birds											
	<i>cf. Tyto alba</i>					1					
	Columbiformes			1							
	Passeriformes medium			2	1	1					1
	Bird small			1		2					
	Bird medium (dove/pigeon size)	1		8							
	Bird large			2							
Reptiles											
	Tortoise			1							2
	Reptile			1							
Mammals											
	Hyrax	1		2							
	Lagomorph			3		5		1			
	<i>cf. Homo</i>	1									
	<i>Equus quagga</i> (zebra)				1						
	<i>Equus</i> sp.	1		2	2						
	<i>Potamochoerus larvartus</i> (bushpig)					3					

Suid			11	11	12	1			1	
<i>Syncerus caffer</i> (African buffalo)				2						
<i>Tragelaphus scriptus</i> (bushbuck)								1		
<i>Tragelaphus oryx</i> (eland)	1									
cf. <i>Damaliscus pygargus</i> (blesbok)								1	1	
Alcelaphine small						1				
cf. <i>Hippotragus equinus</i> (roan)								1		
<i>Pelea capreolus</i> (grey rhebok)				3						
cf. <i>Raphicerus</i>				1						
cf. <i>Aepyceros melampus</i> (impala)									1	
Bov I	1	2	3	27	6	1		1	8	4
Bov I/II									1	
Bov II	3	3	12	21	11	2	2		2	5
Bov II/III			1		1					
Bov III	1	2	6	21	6	3	2	2	3	
Bov III/IV	1		1	4					1	
Bov IV	3	1	7	5	3			4		
Medium ungulate		1	14	4	3				2	
Large ungulate			2			1				
Mammal small		1	3	1	3					
Mammal medium		1	4			1				

Mammal large								1		
Grand Total	13	12	87	104	57	10	8	8	20	12

Specimens preserving unambiguous evidence of human or carnivore interaction with the assemblage are rare; this likely relates to the generally low degree of surface preservation (discussed in more detail below). Only five specimens bear cut marks: a lumbar vertebra of a medium ungulate and two Bov II cranial elements from 2 BS; a suid tibia from 2 WA; and an ulna assigned to cf. *Hippotragus equinus* from 1 RGBS. One specimen preserves percussion damage in the form of a percussion pit with striae (a Bov II metatarsal from 3 WA). A single specimen from layer 2 WA bears evidence of raptor damage (a passerine humerus with a perforation on the distal end). Seven specimens bear acid etching associated with digestion; all derive from 2 BS and all were birds: one assigned to Columbiformes, one small bird, and five specimens identified as medium birds (dove/pigeon size)—all but one of these were wing elements (one tibiotarsus, four humeri and two ulnae). No termite damage was identified.

Given the degree of fragmentation and the rarity of diagnostic specimens (only 26 teeth were identified as part of this study), most of the bovid remains could only be identified to size class. Figure 8 presents the ungulate size class data, broken down by member (small ungulates include the Bov I specimens, medium ungulates include the Bov II specimens and all suid remains, and large ungulates include Bov III/IV specimens and equids). Given the small sample sizes for several of the members—six members have an NISP of 10 or less—caution is warranted when interpreting variation in these data. Members 2 BS and 2 WA are the only ones in which the sample size is sufficient for inter-member statistical comparison; the differences between 2 BS and 2 WA are significant ($\chi^2 = 14.677$, $p = 0.0007$), with 2 WA showing a higher frequency of small ungulates.

FIGURE 8 ABOUT HERE

Figure 8. Ungulate size class data (NISP). Lithic industry identification follows Beaumont (1978).

Unfortunately, the present faunal dataset is insufficient for reconstructing paleoenvironmental conditions. In most members, only one or two specimens could be assigned to species (and thus to a preferred habitat type). The largest sample comes from 2 WA, which also had the largest overall sample

size; even there, the NISP that could be assigned to species/genus was only 19— all of the remains identifiable to genus/species from that member derive from animals that prefer open habitats, but a larger sample of identifiable bones will be necessary to establish the meaning of this finding.

3.4.2 Variation in faunal preservation throughout the sequence

In order to evaluate whether the fauna is similarly preserved throughout the sequence, particularly between WA and BS members, we first explored variation in fragment size, using both maximum length (mm) and fragment weight (g). Because the bucket finds were treated in bulk, the available sample is limited to the single finds. While piece plotting only encompassed the larger fragments, we believe that the available sample should still reflect overarching variation in fragment size. Table 6 presents summary data from the analysis of the single finds. The smallest fragments are found in the deepest deposits of the site; only the lower members (4 WA and 5 BS) have an average maximum length of less than 30 mm. These members not only have the smallest average length and weight, they also show the lowest standard deviations for each measure, suggesting that the fragments from 4 WA and 5 BS are consistently small. However, fragment size does not show a directional decrease over time, which may be expected if fragmentation was primarily a result of deposit compression.

Table 6. Summary data for the piece plotted fauna (referred to as the 'single finds').

Industry	Member	n	Fragment length (mm)		Fragment weight (g)		% MB/HB (>50% carbonized)	% with poor cortical preservation
			Mean	Standard Deviation	Mean	Standard Deviation		
ELSA	1 BS	78	39.9	21.1	4.5	8.1	15.8%	56.4%
	1 WA	94	36.8	20	3.6	7.4	32.6%	46.8%
MSA 3	2 BS	183	42.9	20.2	5.6	7.9	30.6%	48.9%
	2 WA	430	37.3	20.7	5.1	10.3	68.3%	69.4%
HP	3 BS	98	38.9	21.2	5	6.5	3.2%	29.5%
	3 WA	76	36.2	13.7	4.9	5.1	43.2%	33.3%
	1 RGBS	30	39.1	28.5	4.4	5.8	3.4%	31.0%
MSA 1	4 BS	54	40.2	19.9	5.3	6.2	4.0%	22.6%
	4 WA	188	29.7	12.4	2.6	4.2	86.5%	84.9%
	5 BS	35	29.9	14.6	2.6	2.7	29.4%	63.6%

MB: moderate burning, HB: heavily burned

As indicated in Table 6, the BS members tend to preserve larger fragments than the WA members; however, when comparing mean fragment size for the BS and WA members within each industry using the nonparametric Wilcoxon method (analysis conducted using JMP Pro 13.2), the differences in mean length were only significant between 2 BS and 2 WA (MSA 3) and 4 BS and 4 WA (MSA 1; see Table S2 for

statistical results). The BS members also tend to have a higher fragment weight (which may again suggest larger overall fragment size in those layers); however, many of these differences are not statistically significant. Notably, 4 BS and 4 WA again show significantly different mean values. However, 1 BS and 1 WA also show a significant difference in fragment weight (whereas they did not for fragment length). This may be attributed to bone denaturation processes associated with combustion features (e.g., Kalsbeek and Richter, 2006), or, feasibly, a combination of increased susceptibility of smaller fragments to demineralisation through weathering and heat exposure (e.g., Stiner et al., 1995)

Given that the WA members have typically been associated with a greater degree of combustive activity, the lack of significant variation in average fragment size across many of the BS/WA pairings is intriguing. Several studies have documented that burned assemblages also tend to be highly fragmentary—this could reflect the fact that burning makes bones more friable and thus more prone to post-depositional fragmentation (see discussions in Knight, 1985; Stiner et al., 1995; Costamagno et al., 1998, 2005; and Villa et al., 2004). At Border Cave, the fauna from the WA members shows a consistently greater degree of burning than that from the BS members. Figure 9 presents data on the distribution of the different burning categories by member, Table 6 presents summary data on the overall frequency of moderately or highly burned bone by member (defined as bone that is at least 50 percent carbonized), and Table S2 shows the results of the statistical comparison of the relative frequency of moderately or highly burned bone between the BS and WA members within each industry.

FIGURE 9 ABOUT HERE

Figure 9. Burned bone, by member/industry (single finds + ID bone).

However, it is important to note that the overall proportion of burned bone also varies across the BS and WA members; for instance, while more than 70% of the assemblage from 2 WA and 4 WA show at least some degree of heat damage, less than 40% of the assemblage from 1 WA is burned. Similarly, although the BS assemblages typically show a lesser degree of burning than the WA members, some BS members show more burning than others—while less than 20% of the assemblage from 1 BS, 3 BS and 4 BS is burned, roughly 40% of the assemblage from 2 BS is burned to some degree. However, across members attributed to the same lithic industry, the variation in the frequency of moderately and highly burned bone across the BS and WA members is highly significant, with the WA members showing a greater degree

of burning. Again, given the fact that burned bone has been associated with a greater degree of fragmentation, the lack of a significant variation in fragment size across many of the BS/WA pairings is unexpected.

Because burning can negatively impact cortical preservation (see Clark and Ligouis, 2010 and sources therein), it is also worth evaluating variation in cortical preservation throughout the sequence. If the WA members show a higher frequency of bone with poorly preserved cortical surfaces, caution is warranted when comparing the occurrence of various forms of surface damage across the members. Figure 10 presents data on surface preservation. Bones with well-preserved cortical surfaces are rare throughout the assemblage, even where the relative frequency of burning is low. Despite the fact that the WA members are burned to a greater degree, they do not consistently show a higher frequency of bones with poor cortical preservation—however, the two assemblages with the highest frequency of calcined bone, 2 WA and 4 WA, also have the highest frequency of fragments with poor cortical preservation (>60% of the specimens from each). 2 WA and 4 WA are members with significant representation of Facies III.II, suggestive of pronounced combustion feature modification. While 1 BS and 4 BS both show a low frequency of burned bone (<20% of the assemblage), cortical preservation in the two members is vastly different—nearly 60% of the bones from 1 BS were coded as having poor cortical preservation versus just over 20% in 4 BS. Several specimens from 1 BS show exfoliation or a complete lack of the outer cortical surface—the reasons for this deserve further discussion in light of an absence of evidence of intense particle movement or saturation of the sediments with fluids, although Butzer et al. (1978) do document a slight reduction in pH in 1 BS. An additional possibility is invertebrate activity—experimental work by Backwell et al. (2022) demonstrates that both millipedes and land snails can remove the outer cortical surface of bone. Land snail (*Achatina* sp.) shell has been identified in the deposits at Border Cave, and millipede casings found in the upper units (above 4 BS). Unfortunately, excavators were not consistent in recording the presence of millipede casings, but field notes indicate they were frequent in some of the BS deposits. Future work should explore the potential for a co-occurrence of land snail shell and poor cortical preservation; excavators will also more clearly document the prevalence and distribution of millipede casings. It may also be the case that multi-stage taphonomic histories may be responsible for the complex taphonomic evidence. Taken as a whole, the low frequency of specimens with good cortical preservation and the variation in cortical preservation throughout the sequence suggest that it is not appropriate to compare the frequency of various forms of surface damage (like cut marks) across the members.

FIGURE 10 ABOUT HERE

Figure 10. Bone surface preservation by member (single finds + ID bone).

While we explicitly address the nature and extent of variation between a BS and WA unit (comparing 2 BS and 2 WA) and within a given member (2 WA) later in this paper, the faunal assemblage is also valuable for exploring whether there is any broader patterning in the data. For instance, it is possible that the BS members and WA members share certain characteristics that cut across the named archaeological industries. If such patterning exists, it suggests that there may be some overarching taphonomic factors at play, as it is difficult to conceive of periodicity in human behaviour that would tie the BS and WA members together, given that they are present over a period spanning more than 150,000 years. Alternatively, variability in the fauna may be structured primarily by archaeological industry. In order to evaluate this, we conducted a hierarchical cluster analysis (analysis conducted in JMP Pro 13.2, using Ward's method). Included in this analysis are the taphonomic data summarized in Table 6 (average length, average weight, % MB/HB bone, % of the sample with poor cortical preservation) as well as the frequency of small ungulates. Figure 11 presents the resulting dendrogram.

FIGURE 11 ABOUT HERE

Figure 11. Results of hierarchical cluster analysis (conducted in JMP Pro 13.2, using Ward's method).

With the exception of 4 WA and 5 BS, which form a distinct cluster (likely reflecting the fact that these layers have the smallest fragment length and weight, the smallest ungulates, and are among the most burned), within the primary cluster, the BS members and the WA members group separately. In other words, the clusters, based on faunal assemblage attributes, are structured by member type and not by archaeological industry. Future analyses focusing on variation within 5 BS may provide additional insight into the unit's variable taphonomic and site formation history and the underlying cause of its similarities with 4 WA. The clustering supports the proposal that the WA and BS units are distinct in their formation history and composition. These distinctions are borne out by the geoarchaeological data, which demonstrate that there are significant differences in their respective stratigraphic complexities and the

representation of autogenic and allogenic facies between WA and BS members. Dedicated inter- and intra-unit comparisons provide some additional insight into the nature of the similarities and differences.

3.5. Comparison of BS and WA deposits: 2 BS vs. 2 WA

Given that the bulk of the deposits from 2 BS and 2 WA were excavated during 2017, the year for which all bucket finds were processed by JLC (giving us a complete faunal sample), a comparison of the two is informative about potential variation across BS and WA deposits. This is also a useful comparison as these were assigned by Beaumont to the same archaeological industry (post-Howiesons Poort/MSA 3), although, as previously discussed, the current project is also re-evaluating this framework, and new analyses may lead to a re-interpretation of the lithic sequence. There are a number of ways in which the faunal assemblages from 2 BS and 2 WA are distinct. Fragments from 2 WA are, on average, smaller than those from 2 BS (the difference in mean length was statistically significant, although the difference in mean weight was not). 2 WA also shows a significantly higher frequency of moderately to highly burned bone, and there is a significant difference in the representation of different ungulate size classes, with 2 WA showing a higher frequency of small ungulates. While specimens coded as having good cortical preservation are rare in both members, 2 WA shows a higher frequency of fragments with poor cortical preservation ($\chi^2 = 22.703$, $p < 0.0001$). Some of these trends are no doubt interrelated. For instance, the smaller fragment size and poor cortical preservation in 2 WA likely relate to the higher degree of burning as indicated by the abundance of Facies III and IV sediments. Given that Backwell et al. (this volume) provide volumetric data by member/year, we can also compare faunal density in 2 BS and 2 WA (Table 7). Whether expressed by the number of specimens (here including identified and non-identified bone) or by total bone weight, faunal density is ~ 3 times higher in 2 WA than in 2 BS. This could be due to a variety of factors; among these, it may reflect variation in occupational intensity between 2 BS and 2 WA, indicated in the comparatively high frequency and close association of combustion features. It may also imply that faunal processing took place close to combustion features.

In a larger sense, the marked variation in the fauna deriving from these members suggests that the members were formed through different sedimentation processes and were affected by different post-depositional processes. This is clearly supported by the representation of facies between 2 BS and 2 WA. In 2 BS, relatively few stratigraphically isolated primary anthropogenic features, like combustion features or grass mats, occur within a dominant Facies I depositional regime. In 2 BS, Facies VI sediments are closely

associated with isolated anthropogenic features and indicate localised dispersion, but not a consistent or significant contribution from peripheral anthropogenic activity. Lower in the sequence, BS units are dominated by Facies VI sediments, but taphonomic data still associates them (Figure 11). In Facies VI, anthropogenic input is limited to dispersed components within a prevailing autogenic regime. The above evidence suggests that there are significantly different taphonomic processes affecting fauna between WA and BS members, discussed in more detail below. In light of this evidence, we consider it inappropriate to combine BS and WA members for analysis at the level of the archaeological industry.

Table 7. Faunal density by count/weight for Members 2 BS and 2 WA (2017 excavations only).

Member	Count (NSP)	Weight (kg)	Vol (m ³)	Faunal density	
				NSP/m ³	kg/m ³
2 BS	2409	0.806	0.3162	7618.6	2.5
2 WA	4020	1.4321	0.1731	23223.6	8.3

3.6. Intra-member variation: 2 WA

Member 2 WA also serves as an appropriate sample for an exploration of variation within a given member. Below, we present faunal data deriving from each 2 WA sub-unit described above, and explore the recognised patterns in relation to the geoarchaeological evidence.

Stratigraphic and facies data distinguish three units within 2 WA: 2 WA.UP, 2 WA.MD, and 2 WA.LR. Most faunal remains could be assigned to one of these discrete layers; however, some specimens located at the contact points could not be confidently assigned to a sub-layer and were excluded from the analysis. The distinctiveness of each unit is supported by the faunal assemblage. Given the notable variation in the frequency and structure of combustion features across the three sub-units of 2 WA, we begin with a consideration of variation in the intensity of burning damage (Figure 12). In each case, the bucket finds show a slightly lower intensity of burning damage than the single finds. This may reflect the fact that the smallest fragments were at times difficult to characterize, resulting in them being assigned to the NB/LB

category. In any case, both the single finds and the bucket finds show the same pattern—the intensity of burning damage is the highest in 2 WA.UP, where >50% of the single find/ID bone and >25% of the bucket finds are calcined. More than 50% of the sample from 2 WA.MD also shows heat damage, but at a lower intensity, as most burned bones were categorized as moderately burnt (>50% carbonized). 2 WA.LR shows the lowest intensity of heat damage, with a vast majority of specimens identified as being non or lightly burned (<50% carbonized). This pattern is well supported by the stratigraphic evidence, which demonstrates a progressive increase in the frequency of combustion feature-related facies from 2 WA.LR to 2 WA.UP.

FIGURE 12 ABOUT HERE

Figure 12. Intensity of burning damage within 2 WA. NB/LB = non or lightly burned (<50% carbonized); MB= moderately burned (>50% carbonized); HB = highly burned (>50% calcined).

The summary data (Table 8) suggest some additional distinctions within 2 WA, in that 2 WA.MD shows a much lower representation of small (<20 mm) fragments—this is particularly noticeable when comparing 2 WA.MD and 2 WA.LR, which otherwise have a similar quantity of remains. This does not appear to be a sampling artefact and there is no clear geoarchaeological evidence indicative of processes that would lead to more intense *in situ* decay of bone in 2 WA.MD when compared to the UP and LR units. It is possible that the difference in fragment abundance may reflect a pre-depositional behavioural factor.

Table 8. Summary data for within member analysis of the fauna from 2 WA.

	ID bone		Single Finds (non-ID)		Bucket Finds <20 mm		Bucket Finds >20 mm		Total Count
	Ct	Wt (g)	Ct	Wt (g)	Ct	Wt (g)	Ct	Wt (g)	
2 WA.UP	56	175.8	196	842.6	1152	222.4	312	304.8	1716
2 WA.MD	20	107.4	54	311	237	40.7	58	47.2	369
2 WA.LR	14	135.3	71	331.6	1160	105.9	67	36.3	1312

Ct: count, Wt: weight

The data presented in Table 8 again illustrate a lack of consistency in piece plotting, in that nearly as many (if not more, as in the case of 2WA.UP) of the bone fragments that were >20 mm were recovered from the bucket finds. The fact that the average fragment weight for the >20 mm bucket finds is 3-5 grams less than the average weight of single finds (Table 9) further suggests it was the smaller fragments (i.e., those just above 20 mm) that were not piece-plotted. Among the single finds/ID bone, 2 WA.MD shows the largest average fragment weight, followed by 2 WA.LR; on average, specimens from 2 WA.UP weighed 1.5-1.7 grams less than those from the other deposits. A comparison of average fragment length for the sample of single finds/ID bones shows the same pattern—2 WA.MD has the highest average fragment length (44.1 mm), followed by 2 WA.LR (36.0 mm) and 2 WA.UP (33.6 mm). The lower fragment size in 2 WA.UP may relate to the higher frequency of calcined bone in that layer and more intense bone denaturation. This is well supported by the dominance of Facies III and IV sediments in the unit, indicative of combustion feature activity.

Table 9. Average fragment weight (in grams), single find + ID bone versus >20 mm bucket finds.

Average fragment weight (g)		
	Single Finds + ID	Bucket Finds >20 mm
2 WA.UP	4.0	1.0
2 WA.MD	5.7	0.8
2 WA.LR	5.5	0.5

As previously discussed, the WA deposits typically show poor cortical preservation. While bones coded as having “good” cortical preservation are rare throughout the 2 WA deposits, there is marked variation in the representation of bones with fair/poor surface preservation (Figure 13); poorly preserved bones are more frequent in 2 WA.UP and 2 WA.LR than in 2 WA.MD. And yet, the underlying cause of poor cortical preservation varies between these units. Calcination often results in a chalk-like outer surface; as such, bones that were intensely burned also often had poor cortical preservation. Beyond this, specimens were generally coded as poorly preserved for two reasons: (1) surfaces were obscured due to adhering sediment, or (2) the bone was exfoliated/lacking the outer cortical surface. Given that 2 WA.UP shows a high frequency of calcined bone, the dominance of specimens with poor cortical preservation in 2 WA.UP is not unexpected (e.g., Clark and Ligouis, 2010). Member 2 WA.UP also contains a number of specimens encrusted with cemented ash (n=34, or 17.3% of the total sample of poorly preserved bone). Only ~ 6% of the poorly preserved bones from 2 WA.UP were coded as being exfoliated. In contrast, the majority of specimens in 2 WA.LR were coded as non- or lightly burned, and only two of 54 (3.7%) of the specimens from 2 WA.LR were coded as being encrusted. Within 2 WA.LR, 65.8% (n=35) of the sample was exfoliated or preserved none of the outer cortical surface (these were often cortical fragments that had broken into planes across the thickness of the bone, with the outer surface completely gone/flaked away). As discussed above, this type of preservation was also noted in the BS layers, particularly in 1 BS.

Of the 2 WA sub-units, 2 WA.LR is most closely associated with Facies I sediments, with several Facies I strata interdigitating more anthropogenically-associated Facies (III, IV and VI). Poor bone preservation associated with Facies I deposits could reflect a number of site formation scenarios: (1) significantly

different depositional processes prevailed, leading to intense bone mobilisation and abrasion, a process unsupported by the sedimentological, stratigraphic and zooarchaeological evidence; (2) sedimentation rates were significantly lower during the accumulation of Facies I units, leading to longer bone exposure and weathering times; and (3) an incidental anthropogenic contribution in Facies VI has aided bone preservation. It is noteworthy that non-combustion feature sediments in lower BS units (3 BS, 1 RGS and 4 BS) are predominantly Facies VI (rich in dispersed ashes) and yield better preserved bone, despite being significantly older and prone to cumulative weathering processes - 2 WA.MD, with better preserved bone than 2 WA.UP or LR- is dominated by Facies VI sediments associated with isolated combustion features. FTIR analysis indicates lower calcium carbonate mineral content in Facies I than Facies VI (Supplementary Information 1; Figure S1), in which dispersed ashes may enrich sediments with alkaline minerals, mitigating a more acidic autogenic mineral suite. Additionally, pH data from excavation 3A suggest more acidic sediments in 1 BS (Butzer et al., 1978), a unit without significant Facies VI representation but with higher bone surface degradation. It is also of interest that F I sediments contain well-preserved (favoured by lower pH's) but highly fragmented phytoliths - potentially indicative of slow sedimentation rates and lower autogenic sediment pH (Esteban et al., this volume). This possibility is relevant to patterns in the faunal evidence presented earlier, which suggests a consistent taphonomic difference between the BS and WA members (e.g., Figure 11).

FIGURE 13 ABOUT HERE

Figure 13. Bone surface preservation within 2 WA (single finds + ID bones only).

The faunal data from 2 WA thus demonstrates that there can be marked variation in faunal preservation within members, not just between them- and the reasons for this variation is integrally tied to the formation history of each identified sub-unit. As such, members should not be considered as homogeneous, and when possible, analyses should be undertaken on a finer scale. Identifying the appropriate resolution will require continued collaboration between geoarchaeologists and those studying the artefacts and ecofacts from the site.

4. Discussion

4.1. Stratigraphy and facies representation

The results of the allostratigraphic analysis of the Border Cave sequence provide a view of the deposit stratigraphy that contrasts with that proposed by Beaumont (1973, 1978). In Beaumont's framework, unit subdivision was only applied to BS members and generally focused on variability in autogenic component contribution. As a result, intra-member resolution is biased toward BS members, which appear to contain a greater frequency of stratigraphic contacts. Consequently, BS members and their sub-units have been subjected to higher resolution analysis and interpretation, which, in turn, have focused on the palaeoenvironmental implications of BS variability (Butzer et al., 1978). Evidence presented here demonstrates that WA members are significantly more stratigraphically complex than BS members. Counter to BS member variability, WA stratigraphic complexity is associated largely with the preservation of more structured anthropogenic features, like combustion features and grass mats. A complex history of human activity is suggested by numerous stratigraphic features: inter-combustion feature paraconformities and disconformities (e.g., Facies V construction over each combustion feature in 1 WA, in 2 WA between 2 WA.MD and 2 WA.UP; erosion of upper surfaces of combustion features in 5 WA); intra-WA hiatuses in anthropogenic activity (e.g., 1 WA between combustion features 2 and 3, and 2 WA.LR interstratifying units of Facies I); and variability in combustion feature frequency and organisation. Consequently, analyses of artefacts should be conducted with as much stratigraphic sensitivity as possible. The complexity implies repeated and frequent establishment and modification of anthropogenically-developed surfaces, supporting Beaumont's proposal that WA members document relatively intense human activity.

Whether or not BS members document less intense human activity is an interesting question. From a stratigraphic perspective, BS members preserve fewer clear intra-member contacts, but are generally dominated by Facies VI sediments, the formation of which may have blurred previous contacts. The occurrence of Facies VII in various levels from 1 BS to 5 BS suggests previous structural complexity, and the stratigraphic clarity observed in the upper west portion of 3 BS also suggests greater stratigraphic integrity (and complexity) prior to disturbance in BS-attributed units. Feasibly, the clear distinction we now see between BS and WA members may be related to structural preservation as much as occupation intensity – facies representation and faunal evidence suggest a mixture of both.

We have identified some distinctive patterns in stratigraphic contact types throughout the sequence. (1) Combustion features are commonly truncated or directly overlain by grass mats, evidenced in both BS and WA members. (2) In numerous instances, several *in situ* combustion features or units of reworked Facies III and IV are vertically and/or laterally directly associated - common in units attributed to WA

members. In this respect, most intra-WA contacts are anthropogenic in nature (as proposed in Butzer et al., 1978). (3) Where not directly overlain by grass mats, the upper surface of combustion features is frequently eroded, mixed, and shows reworking at their margins, indicative of both biogenic and geogenic modification. (4) Some upper contacts between WA and BS members and some intra-BS disconformities are geogenic in nature (e.g., 1 RGS/3 BS; intra-4 BS erosion). Considered in light of clear evidence of fluid/sediment interaction, these geogenic erosional features allude to a greater impact of non-anthropogenic processes in shaping the sequence than has been previously acknowledged. (5) Numerous steep disconformities may represent ancient pits (e.g., cross-cutting disconformities in 5 BS), although the function of these is not yet clear.

The presence of frequent disconformities throughout the sequence has implications for the chronology of the deposits and for the interpretation of the associated assemblages. The chronological synthesis and new dates presented by Tribolo et al. (this volume) indicate that some deposits may be more complex in their depositional history than others. A major disconformity is documented between 4 BS and 4 WA. In this case, ESR data (Grün et al., 2003; see Tribolo et al., this volume for discussion of chronological modelling) suggest a break of up to 20 ka, between 80 and 100 ka, traversing the 4 BS, 4 WA boundary. Also noteworthy are the dates for 4 WA, which cover a significant amount of time bracketed by generally coherent chronological sequences above and below. This thick ash unit may, therefore, have taken a long time (40 - 50 ka) to form and potentially includes both intra-unit formational hiatuses (indicated by the faint bedding, and sporadic laterally extensive crusts) and significant ash compression, deflation and boundary mixing (indicated by the dominance of Facies III.II sediments), resulting in a strongly time-averaged unit. Caution should be exercised in the interpretation of the assemblages yielded from 4 WA. Butzer et al. (1978) identified a major hiatus between 5 BS and 5 WA and we identify a correspondingly major truncation event at this interface. Chronological data is inconclusive about the duration of this sedimentary break but suggests the formation of the disconformity represents a duration shorter than the 5-10% error margin of ESR and OSL/TL ages. Future dating efforts may seek to clarify the duration of the disconformities and sub-unit contacts identified here because they may have significant implications for comparative analyses at the inter- and intra-member scale. The refined stratigraphic sequences and locations of member and sub-member contacts stemming from this research are presented in a simplified manner in figures S6 to S9.

Facies representation through the sequence demonstrates several interesting patterns relating to the formation and modification of the Border Cave sequence. (1) Although the recently exposed E-W

orientated profiles do not allow correlation between geogenic sediment fluctuations and the *éboulis* layers identified by Butzer et al. (1978), which thicken from N-S (Figure 1), similarities were observed that imply periodic changes in the rate of autogenic roof spall production (F I.I and I.II). For example, laterally extensive clast-rich facies were identified in 2 BS, 3 BS and 1 RGS/4 BS. However, some exposures of clast-rich facies may relate to isolated roof breakdown (e.g., 2 BS.UP) and slope process-related lateral grading (e.g., 1 RGS/4 BS). N-S orientated deposit exposures will help test the lateral continuity of these facies and clarify their association with shelter-wide processes and their palaeoenvironmental sensitivity.

(2) Facies VI is closely associated with combustion features in WA units and generally dominates lower BS unit sediments. Localised examples of Facies VII, and diffuse transitions between F VI and F VII, indicate that at least in some cases Facies VI units previously preserved better structure, as opposed to being initially formed as massive sediments – as supported by phytolith evidence (Esteban et al., this volume) and instances of vertically-constrained lenses of lithic artefacts within diffuse F VI sediments (de la Peña et al., this volume). This suggests that pervasive destructuring of deposits through various processes has taken place throughout the sequence, but that destructuring mostly affected the fine fraction of the matrix. Mixing in the BS units created different taphonomic conditions from those seen in WA-attributed units, but potentially also facilitated better preservation of some artefacts than is expected in a Facies I sediment dominated by lower pH igneous lithologies; for example, these conditions may have favoured phytolith preservation but caused greater bone weathering. Within BS-attributed Facies VI units, autogenic components dominate the matrix, suggesting that even prior to destructuring and dispersion, anthropogenic features were less frequent and less dense than other deposits (that were, by their nature, attributed to WA members). Where structures remain, and fortuitous chemical conditions prevail (higher pH), extraordinary organic preservation has been achieved, as evidenced by the organic remains that included desiccated wood documented in 5 BS.

4.2. Zooarchaeological data

The preliminary faunal study suggests that caution is warranted when combining material from the BS and WA members in order to explore change across archaeological industries. While this is evident in the phytolith study in particular (Esteban et al., this volume), and may apply to other material classes, as well, it particularly applies to the faunal remains, as variation in the taphonomic history of these assemblages could impact the taxonomic data and result in differential preservation of skeletal elements in a way that complicates interpretations of human behaviour. It may be better to treat the members independently;

in this case, larger samples will be key to exploring questions relating to human subsistence and landscape use. However, as evidenced in the consideration of variation within 2 WA, treating members as homogeneous samples may also mask important variability. Smaller units were excavated by Backwell et al. and future analyses will explore variability at this scale if unit sample sizes are sufficient. Extending excavations laterally both along and across the deposit slope in a stratigraphically sensitive manner will supplement assemblage sizes for individual sub-units and facies and allow us to continue to explore spatial variability in unit formation and preservation.

Faunal data suggest that 4 WA and 5 BS share certain traits that distinguish them from the other deposits. These members preserve the smallest fragments (on average), and the least variation in fragment size, suggesting consistently small fragments. Smaller fragment size could reflect a greater degree of fragmentation due to burning—more than 70% of the single finds from 4 WA are calcined. However, burning is rare in 5BS, where nearly 70% of the single finds are unburned. Smaller fragments could also reflect an assemblage dominated by smaller animals, and while small ungulates account for more than 40% of the ungulate sample from each, the small sample size makes it difficult to evaluate the relative importance of this measure. From the geoarchaeological evidence presented here, 5 BS consists of three sub-units, only one of which (5 BS.MD) is associated directly with combustion features (combustion feature 4; Figure 6), perhaps accounting for the 30% burned bone in the assemblage. The two other 5 BS units are composed primarily of Facies VI sediments. The presence of Facies VII suggests prior structure and perhaps a limit to the mobility of particles contributing to the units. Consequently, degree of fragmentation may be attributed more to *in situ* compression related breakage, or human selection, and less to burning or post-depositional sorting. Supplemental faunal samples and other dedicated analyses (e.g., micromorphology, botanical, etc.) will be key in exploring these patterns and their significance.

4.3. Site formation processes

The seven major facies and facies sub-types identified here attest to the wide range of site formation processes that have cumulatively contributed to the preservation and integrity of the assemblages and anthropogenic and non-anthropogenic stratigraphic features at Border Cave. Each facies is interpreted following established process/feature associations (e.g., Schiegl et al., 1996; Meignen et al., 2007; Goldberg et al., 2009; Mallol et al., 2013a, b, 2017; Miller et al., 2013; Mentzer, 2014; Karkanas, 2000, 2021; Karkanas et al., 2015; Karkanas and Goldberg, 2019; Haaland et al., 2020), but it can be assumed (as

is evident from phytolith analysis) that variability in formation history exists in all facies, and at this scale, the facies approach suffers some degree of interpretative equifinality. However, as a first step in establishing a process-sensitive framework, it does provide greater site formation resolution than is possible using the previous BS/WA system and further resolution will be achieved through ongoing micromorphological studies.

As feature and facies dedicated analyses continue, several observations are made regarding the formation of the deposits:

1. Beaumont (1973, 1978) proposed a generalised geometric pattern for BS and WA units - BS members thickened towards the walls of the shelter and WA members thickened downslope, towards the centre of the shelter. This is not always the case and it is clear that WA sub-unit geometry is not consistent, suggesting different formation histories. While Facies III.II sediments do conform to this pattern, suggestive of gravity-aided redistribution of ashes, upper and lower boundaries of Facies III.I units tend to conform to the underlying gradient. Detailed fabric analysis will help explore the interaction between slope and anthropogenic activity, which, based on the deposit geometry and nature of erosional features, should provide some evidence of a geogenic directional influence on the deposits and assemblages. It is an interesting note that some underlying sloped deposits have been cut to create horizontal bases for combustion features (e.g., combustion features 1 and 2 in 1 RGS, and the upper surface of 4 WA).

2. Periods of increased autogenic spall production (evidenced by laterally extensive beds of Facies I.II) are attributed to BS attributed units and although there are isolated combustion features and grass mats associated with F I.II sediments, there are no units attributed to WA members that have a clast-rich autogenic component. The process of increased spall generation may contribute to the destructuring and mixing of sediments, helping create Facies VI and VI.II. This may be the case in 1 RGS and 4 BS, but not the case in the 1 BS to 2 BS sequence, where 1 WA is associated with a distinct reduction in spall production. Spall fluctuations are apparent within BS-attributed units (e.g., 2 BS and 3 BS), and anthropogenic contributions are distinctively less frequent in Facies I sediments, suggesting potentially significant periods of time passed between intense occupations. Potentially slower sedimentation rates in F I units are also suggested by poor bone preservation, high phytolith abundance and high phytolith fragmentation (Esteban et al., this volume) resulting from longer surface exposure times and greater cumulative turbative influences. The close correlation between WA-attributed units and lower spall production suggests a pattern of more intense occupation during periods of reduced autogenic breakdown and that Facies III, IV, and V were formed faster than F I units of equivalent volume –

potentially indicated by less fragmented phytolith assemblages in WA-associated facies (Esteban et al., this volume).

3. Combustion feature construction generally follows prior observations from archaeological and experimental examples (e.g., Schiegl et al., 1996, Miller et al., 2010; Bentsen, 2012; Mallol et al., 2013a; Mentzer, 2014; Karkanas, 2021), however, some interesting observations are made that require more detailed examination. First, in some instances, basal units of combustion features (Facies IV) are separated from ashes by thin layers of sands, perhaps suggestive of punctuated formation (e.g., Mallol et al., 2013b). Second, emplacement of grass mats directly over combustion feature ashes throughout the sequence (from 5 BS to 1 WA) suggests this was a standard practice in human occupational space management over the last 200,000 years at Border Cave.

4. Many feature and unit contacts are abrupt even in the oldest units, where pits and steep disconformities are preserved. The integrity of pit boundaries and potential for organic preservation in lower levels is particularly relevant to discussions of the integrity and context of the BC 3 infant skeleton burial attributed to the 1 RGBS unit (Cooke et al., 1945; de Villiers, 1973; Beaumont et al., 1978; d'Errico and Backwell, 2016). Abrupt contacts and combustion features preserved in the 1 RGBS exposures studied here suggest a potential for the preservation of a well-defined burial pit, while minimal large particle movement suggests the potential for associated remains to be preserved within bounded features. Pit boundaries are also well-defined in 4 WA and 5 BS.

5. Conclusions

Through the application of a facies and allostratigraphic analysis approach, we present a comprehensive description of the Border Cave stratigraphic sequence exposed through the Backwell et al. excavations, and provide an initial assessment of the prevailing site formation processes active in the deposition and modification of the sediments. We also present new zooarchaeological and taphonomic evidence and integrate these data with geoarchaeological evidence in order to explore inter- and intra-unit patterns through the sequence. In doing so, we evaluate previously published stratigraphic and site formation observations and hypotheses (Beaumont and Boshier, 1972; Beaumont, 1973, 1978; Butzer et al., 1978). Key findings from this work are summarized below.

Conclusions stemming from the geoarchaeological evidence include:

1. The deposits exposed through new excavations can be broadly correlated to the Beaumont members. Here, we clearly define member boundaries, re-assess published BS member stratigraphic complexity and recognise finer intra-member layering. We argue that a facies and allostratigraphic approach offers greater sequence and formational resolution than division into generic members based on lithological attributes. In Table S1, we correlate units identified here with units named during excavations, and work continues to refine the intra-unit stratigraphy to provide fine-scale correlations. Disconformities help to separate most members and we correlate excavator-named layers to a refined framework. We also suggest that based on combustion feature structure and pattern, and a lack of clear contact between 5 WA and 6 BS, one member, rather than two, is represented immediately above bedrock. Simplified stratigraphic sequences of the studied profiles are presented in Figures S6 – S9.

2. The geoarchaeological and taphonomic studies demonstrate further that the sediments have been subjected to greater post-depositional disturbance than was previously recognised and affected all levels of the sequence. Apart from burrows, pits and channels, there is evidence of turbation within unit boundaries. This takes the form of fine fraction dispersion and destructuring of ephemeral and isolated structures in BS units and homogenisation of WA sediments. Spatial, fabric and micromorphological analyses will help clarify the nature of the turbation processes. Considered with the taphonomic data presented, the combination of geogenic, biogenic and anthropogenic processes have created complex assemblage histories in each unit, making inter-member comparisons challenging. Integration of additional taphonomic data deriving from botanical remains and lithics will provide additional perspectives on inter-proxy and multi-scale process effects (e.g., Esteban et al., this volume) and offer data to investigate hypotheses regarding occupational intensity.

3. While post-depositional alteration of sediments often has a geogenic origin that can be related to the geological and geomorphological context of the shelter, the geometry of the deposits and the autogenic sedimentary component, anthropogenic activities also play a part, with the two interacting in complex ways over the depositional history of the shelter. Combustion feature construction and redistribution introduced significant volumes of ash and charcoal to the site. In addition to being modified by geogenic processes, these features were often the focus of anthropogenic post-depositional activity, perhaps an indication of intensified use of the shelter. This created complex sequences of units separated by paraconformities and disconformities that attest to repeated behaviours and changes in how the area was used. Upper surfaces of combustion features were sometimes reworked and redistributed, possibly as

part of site maintenance practices, and clearly the construction of bedding directly over ashes was a long-standing behaviour at Border Cave.

Conclusions stemming from the zooarchaeological evidence include:

1. The sample of identifiable fauna is currently small (<350); however, the results are broadly consistent with previous analysis (Klein 1977), in that the assemblage is highly fragmented and dominated by ungulate remains that could only be identified to size class. Carnivore remains are largely absent—when combined with the low frequency of evidence for carnivore modifications (gnaw marks, tooth punctures, etc.), this may suggest that the portions of the cave utilised by humans were not frequently occupied by mammalian carnivores.

2. Overall, faunal density at BC appears to be much lower than that at other MSA sites such as Blombos and Sibudu. In looking at variation in density through time, the current sample only allowed for a comparison of faunal density from 2 BS and 2 WA. Faunal density was nearly three times higher in 2 WA than in 2 BS. As the sample is enlarged, we will be better able to evaluate whether this pattern applies more generally (i.e., higher density in WA vs. BS members). Analysis of artefact densities will also be important in assessing whether higher faunal densities reflect a greater degree of occupational intensity.

3. As discussed above, our analysis suggests that the WA and BS members have distinct taphonomic histories that cross-cut the identified archaeological industries. As such, BS and WA members should not be combined for future zooarchaeological analyses. Caution is also warranted when combining these members for analysis of other classes of artefacts and ecofacts.

Our work has provided new stratigraphic resolution and insight into site formation processes at Border Cave, and shown that there is clearly great potential for further multi-proxy and multi-scale research on specific features and units. Expanding excavations laterally, particularly in a N-S direction, will provide a wealth of new information on lateral variability of anthropogenic features, deposit geometry, and the nature of the *éboulis* units of Butzer et al. (1978). Given the complexities of the deposits, this work requires an integrative multi-resolution stratigraphic and sedimentological framework; which we have attempted to establish in this contribution.

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References

- Anderton, R., 1985. Clastic facies models and facies analysis. Geological Society, London, Special Publications 18, 31–47.
- Andrews, P.J., 1990. Owls, Caves and Fossils. University of Chicago Press, Chicago.
- Avery, D.M., 1982. The micromammalian fauna from Border Cave, KwaZulu, South Africa. *J. Archaeol. Sci.* 9, 187–204.
- Avery, D.M., 1992. The environment of early modern humans at Border Cave, South Africa: Micromammalian evidence. *Palaeogeog. Palaeoclimat. Palaeoecol.* 91, 71–87.
- Backwell, L.R., Parkinson, A.H., Roberts, E.M., d'Errico, F., Huchet, J.-B., 2012. Criteria for identifying bone modification by termites in the fossil record. *Palaeogeogr. Palaeoclimat. Palaeoecol.* 337-338, 72–87.

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

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

Backwell, L.R., Wadley, L., d'Errico, F., Banks, W.E., de la Peña, P., Stratford, D., Sievers, C., Laue, G., Vilane, B., Clark, J., Tribolo, C., Beaudet, A., Jashashvili, T., Carlson, K., Lennox, S., Esteban, I., Mauran, G., This volume. *Border Cave: A 227,000-year-old archive from the southern African interior*.

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

Beaumont, P.B., 1978. Border Cave. MA Thesis. University of Cape Town.

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

Beaumont, P.B., 1994. Report to the KwaZulu Monuments Council on excavations at Border Cave near Ingwavuma in July–August 1987 and on the results of related investigations up until December 1993. Kimberley: McGregor Museum.

Beaumont, P.B., Boshier, A.K., 1972. Some comments on recent findings at Border Cave, northern Natal. *S. Afr. J. Sci.* 68, 22–24.

Beaumont, P.B., de Villiers, H., Vogel, J.C., 1978. Modern Man in Sub-Saharan Africa prior to 49,000 years B.P.: A review and evaluation with particular reference to Border Cave. *S. Afr. J. Sci.* 74, 409–419.

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

Bentsen, S.E., 2012. Size matters: preliminary results from an experimental approach to interpret Middle Stone Age hearths. *Quat. Internat.* 270, 95–102.

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 to 60 ka BP at Border Cave, South Africa. *Quat. Sci. Rev.* 22, 943–947.

Blumenschine, R.J., Marean, C.W., Capaldo, S.D., 1996. Blind test of inter-analyst correspondence and accuracy in the identification of cut marks, percussion marks and carnivore tooth marks on bone surfaces. *J. Archaeol. Sci.* 23, 493–507.

Blumenschine, R.J., Selvaggio, M., 1991. On the marks of marrow bone processing by hammerstones and hyaenas: their anatomical patterning and archaeological implications, in: Clark, J.D. (Ed.), *Cultural Beginnings: Approaches to Understanding Early Hominid Lifeways in the African Savanna*. Dr. R. Habelt GMBH, Bonn, pp. 17–32.

Brain, C.K., 1974. Some Suggested Procedures in the Analysis of Bone Accumulations from Southern African Quaternary Sites. *Annals of the Transvaal Museum* 29, 1–7.

Butzer, K.W., 1979. Geomorphology and geo-archeology at Elandsbaai, Western Cape, South Africa. *Catena*, 6, 157–166.

Butzer, K.W., 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, 317–341.

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. Paleol. Archaeol.* 2, 26–73.

Clark, J.L., Ligouis, B., 2010. Burned bone in the Howieson's Poort and post-Howieson's Poort Middle Stone Age deposits at Sibudu (South Africa): behavioral and taphonomic implications. *J. Archaeol. Sci.* 37, 2650–2661.

Cooke, H.B.S. 1941. Unpublished reports presently housed at the National Archives and Records Service (NARS) in Tswane (formerly Pretoria), South Africa (<http://www.national.archives.gov.za/>), where they are kept in Archaeological Survey Files (source ASW, volume 60, reference 20/1/A and B20/1/2A).

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* 3, 6–13.

Costamagno, S., Griggo, C., Mourre, V., 1998. Approche expérimentale d'un problème taphonomique: utilisation de combustible osseux au Paléolithique. *Préhistoire Européenne* 13, 167–194.

Costamagno, S., Théry-Parisot, I., Brugal, J.-P., Guibert, R., 2005. Taphonomic consequences of the use of bones as fuel. Experimental data and archaeological applications, in: O'Connor, T. (Ed.), *Biosphere to Lithosphere: New studies in vertebrate taphonomy* Oxbow Books, Oxford, pp. 51–62.

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

d'Errico, F., Backwell, L., Villa, P., Degano, I., Lucejko, J.J., Bamford, M.K., Higham, T.F.G., Colombini, M.P., Beaumont, P.B., 2012. Early evidence of San material culture represented by organic artifacts from Border Cave, South Africa. *P. Nat. Acad. Sci.* 109, 13214.

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

de Villiers, H., 1973. Human skeletal remains from Border Cave, Ingwavuma District, Zululand. *Annals of the Transvaal Museum* 28, 229–256.

Dominguez-Rodrigo, M., De Juana, S., Galan, A.B., Rodriguez, M., 2009. A new protocol to differentiate trampling marks from butchery cut marks. *J. Archaeol. Sci.* 36, 2643–2653.

Esteban, I., Stratford, D.J., Sievers, C., de la Peña, P., Backwell, L., d’Errico, F., Wadley, L. This volume. Plants and Fire: phytolith and FTIR analyses of the post-Howiesons Poort occupations at Border Cave. *Quat. Sci. Rev.*

Fernandez-Jalvo, Y., Andrews, P., 2016. *Atlas of Taphonomic Identifications: 1001+ Images of Fossil and Recent Bone Modification*. Springer, Dordrecht.

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. Anthropol. Sci.* 1, 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, 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.

Haaland, M.M., Miller, C.E., Unhammer, O.F., Reynard, J.P., van Niekerk, K.L., Ligouis, B., Mentzer, S.M., Henshilwood, C.S., 2020. Geoarchaeological investigation of occupation deposits in Blombos Cave in South Africa indicate changes in site use and settlement dynamics in the southern Cape during MIS 5b-4. *Quat. Res.* 1–54.

Jashashvili, T., Carlson, K., Zipfel, B., Clark, J., Wadley, L., d’Errico, F., de la Peña, P., Stratford, D., Backwell, L. This volume. New human remains from Border Cave, South Africa. *Quat. Sci. Rev.*

Kalsbeek, N., Richter, J., 2006. Preservation of burned bones: an investigation of the effects of temperature and pH on hardness. *Stud. Conserv.* 51, 123–138.

Karkanas, P., 2021. All about wood ash: Long term fire experiments reveal unknown aspects of the formation and preservation of ash with critical implications on the emergence and use of fire in the past. *J. Archaeol. Sci.* 135, 105476.

Karkanas, P., Goldberg, P., 2019. *Reconstructing archaeological sites: understanding the geoarchaeological matrix.* John Wiley & Sons.

Karkanas, P., Kyparissi-Apostolika, N., Bar-Yosef, O., Weiner, S., 1999. Mineral assemblages in Theopetra, Greece: a framework for understanding diagenesis in a prehistoric cave. *J. Archaeol. Sci.* 26, 1171–1180.

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.

Karkanas, P., Brown, K.S., Fisher, E.C., Jacobs, Z. and Marean, C.W., 2015. Interpreting human behavior from depositional rates and combustion features through the study of sedimentary microfacies at site Pinnacle Point 5-6, South Africa. *J. Hum. Evol.* 85, 1–21.

Klein, R.G., 1977. The mammalian fauna from the Middle and Later Stone Age (Later Pleistocene) levels of Border Cave, Natal Province, South Africa. *South Afr. Arch. Bull.* 32, 14–27.

Knight, J.A., 1985. *Differential preservation of calcined bone at the Hirundo Site, Alton, Maine, Quaternary Science.* University of Maine at Orono, Orono.

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

Lyman, R.L., 1994. *Vertebrate Taphonomy.* Cambridge University Press, Cambridge.

Milo, R.G., 1994. Human-animal interactions in southern African prehistory: A microscopic study of bone damage signatures. PhD Thesis. University of Chicago.

Mallol, C., Hernández, C.M., Cabanes, D., Machado, J., Sistiaga, A., Pérez, L., Galván, B., 2013a. Human actions performed on simple combustion structures: an experimental approach to the study of Middle Palaeolithic fire. *Quat. Int.* 315 (Suppl. C), 3–15.

Mallol, C., Hernández, C.M., Cabanes, D., Sistiaga, A., Machado, J., Rodríguez, Á., Leopoldo, P., Galván, B., 2013b. The black layer of Middle Palaeolithic combustion structures. Interpretation and archaeostratigraphic implications. *J. Archaeol. Sci.* 40, 2515–2537.

Mallol, C., Mentzer, S.M., Miller, C.E., 2017. Combustion features. In: Nicosia, C., Stoops, G. (Eds.), *Archaeological Soil and Sediment Micromorphology*. Wiley, Hoboken, New Jersey, pp. 299–326.

Meignen, L., Goldberg, P., Bar Yosef, O., 2007. The hearths at Kebara Cave and their role in site formation processes. In: Bar Yosef, O., Meignen, L. (Eds.), *Kebara Cave, Mt. Carmel, Israel: the Middle and Upper Paleolithic Archaeology, Part 1*. Peabody Museum of Archaeology and Ethnology, Cambridge, pp. 91–122.

Mentzer, S.M., 2014. Microarchaeological approaches to the identification and interpretation of combustion features in prehistoric archaeological sites. *J. Archaeol. Method & Theory* 21, 616–668.

Mentzer, S.M., 2016. Hearths and combustion features. In: Gilbert, A.S. (Ed.), *Encyclopaedia of Geoarchaeology*. Springer, Dordrecht, pp. 411–424.

Miall, A.D., 2013. Facies Analysis. In *Principles of Sedimentary Basin Analysis*. Springer, Berlin, Heidelberg.

Millard, A.R., 2006. Bayesian analysis of ESR dates, with application to Border Cave. *Quat. Geochron.* 1, 159–166.

Miller, C.E., Conard, N.J., Goldberg, P., Berna, F., 2010. Dumping, sweeping and trampling: experimental micromorphological analysis of anthropogenically modified combustion features. *P@lethnologie* 2010, 25–37.

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

Outram, A.K., 2001. A new approach to identifying bone marrow and grease exploitation: Why the "indeterminate" fragments should not be ignored. *J. Archaeol. Sci.* 28, 401–410.

Pickering, T.R., Egeland, C., 2006. Experimental patterns of hammerstone percussion damage on bones and zooarchaeological inferences of carcass processing intensity by humans. *J. Archaeol. Sci.* 33, 459–469.

Pirrie, D., 1998. Interpreting the record: facies analysis. *Unlocking the Stratigraphical Record: Advances in Modern Stratigraphy*. Wiley and Sons, Chichester, pp. 395–420.

Reynard, J., Henshilwood, C.S., 2018. Using trampling modifications to infer occupational intensity during the Still Bay at Blombos Cave, Southern Cape, South Africa. *Afr. Archaeol. Rev.* 35, 1–19.

Schiegl, S., Goldberg, P., Bar-Yosef, O., Weiner, S., 1996. Ash Deposits in Hayonim and Kebara Caves, Israel: macroscopic, microscopic and mineralogical observations, and their archaeological implications. *J. Archaeol. Sci.* 23, 763–781.

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. *Quat. Sci. Rev.* 275, 107280.

Sillen, A., Morris, A., 1996. Diagenesis of bone from Border Cave: implications for the age of the Border Cave hominids. *J. Hum. Evol.* 31, 499–506.

Stiner, M.C., Kuhn, S.L., Weiner, S., Bar-Yosef, O., 1995. Differential burning, recrystallization, and fragmentation of archaeological bone. *J. Archaeol. Sci.* 22, 223–237.

Stratford, D., Braun, K., Morrissey, P., 2021. Cave and rock shelter sediments of southern Africa: a review of the chronostratigraphic and palaeoenvironmental record from Marine Isotope Stage 6 to 1. *South Af. J. Geol.* 2021. 124, 879–914.

Thackeray, A.I., 1992. The middle stone age south of the Limpopo River. *J. World Prehist.* 6, 385–440.

Thackeray, J.F., 1987. Late Quaternary environmental changes inferred from small mammalian fauna, southern Africa. *Climatic Change* 10, 285–305.

Villa, P., Castel, J.-C., Beauval, C., Bourdillat, V., Goldberg, P., 2004. Human and carnivore sites in the European Middle and Upper Paleolithic: Similarities and differences in bone modification and fragmentation. *Revue de Paleobiologie, Geneve* 23, 705–730.

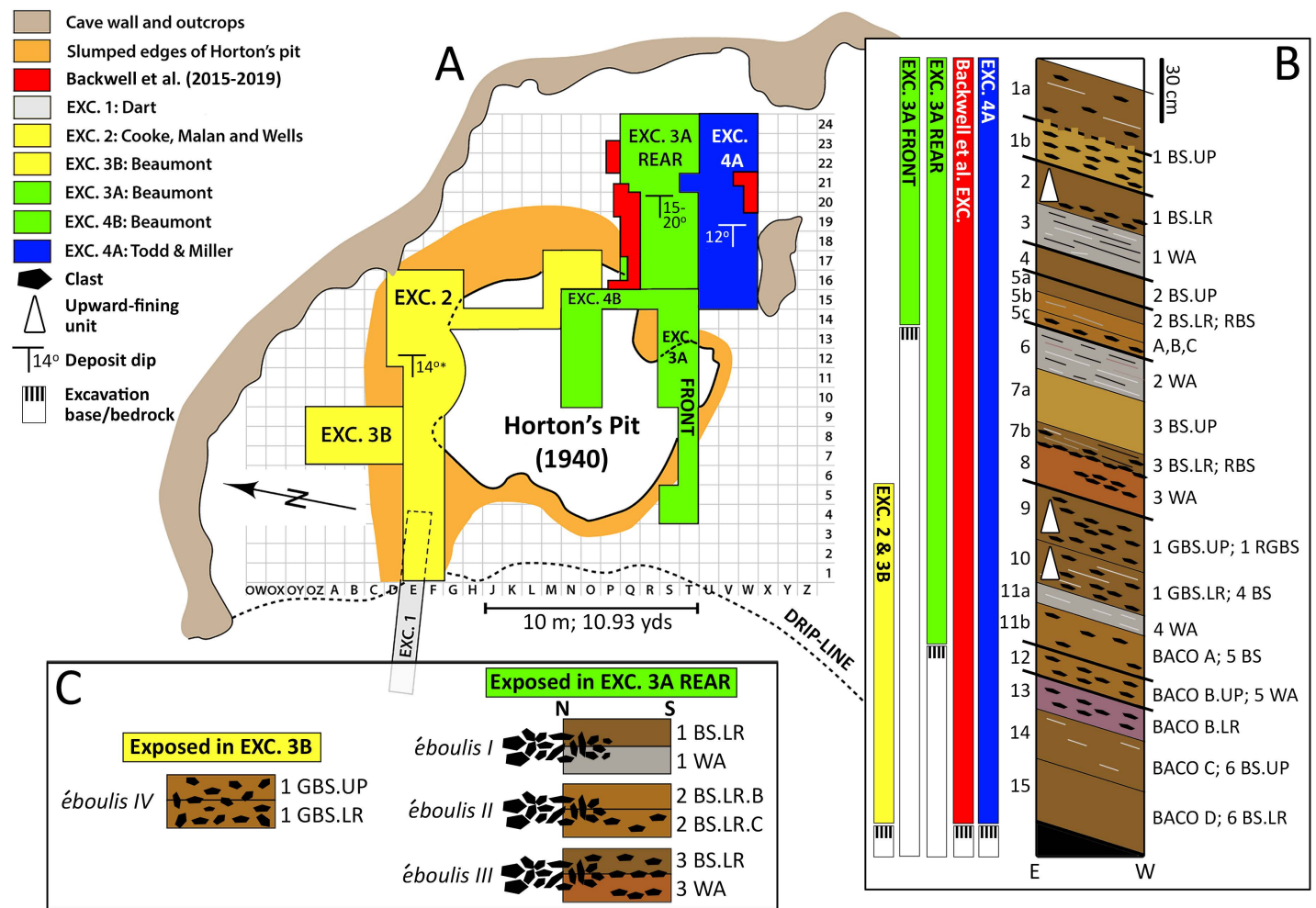
Villa, P., Soriano, S., Tsanova, T., Degano, I., Higham, T.F.G., d’Errico, F., Backwell, L., Lucejko, J.J., Colombini, M.P., Beaumont, P.B., 2012. Border Cave and the beginning of the Later Stone Age in South Africa. *P. Nat. Acad. Sci.* 109, 13208.

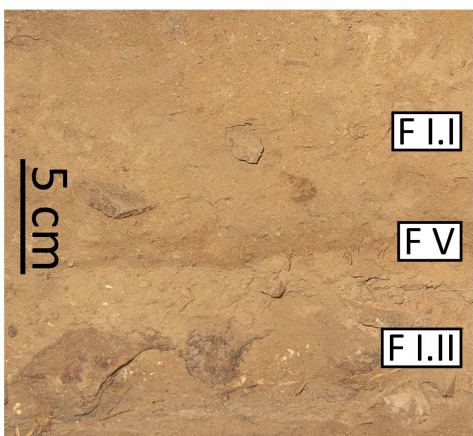
Wadley, L., Backwell, L., d’Errico, F., Sievers, C., 2020a. Cooked starchy rhizomes in Africa 170 thousand years ago. *Science* 367, 87–91.

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

Wells, L.H., 1950. The Border Cave skull, Ingwavuma District, Zululand. *Am. J. Phys. Anth.* 8, 241–243.

Zwane, B., Bamford, M., 2021. A reconstruction of woody vegetation, environment and wood use at Sibudu Cave, South Africa, based on charcoal that is dated between 73 and 72 ka. *Quat. Int.* 593, 95–103.

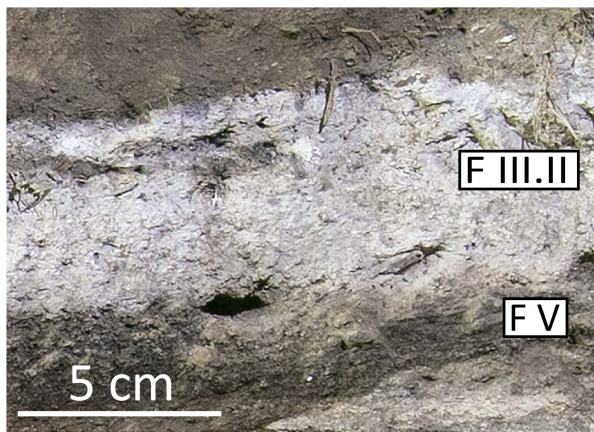




A



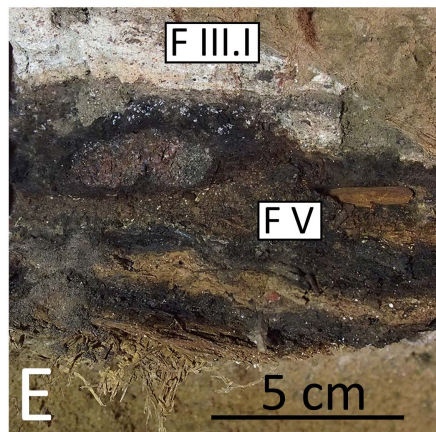
B



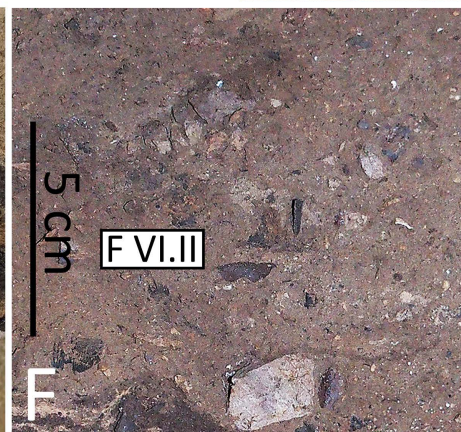
C



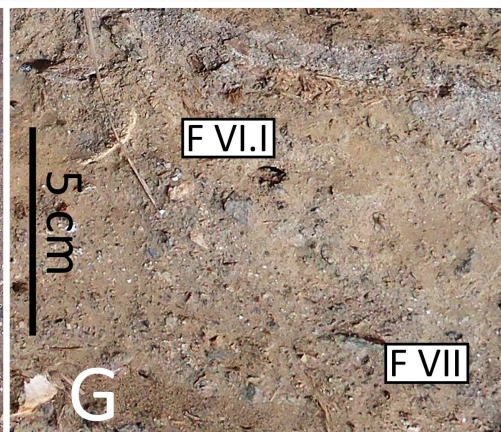
D



E



F



G

N109 E119

N109 E119.5

N109 E120

A

1 BS.LR

1 WA

2 BS.UP

2 BS.LR

104.600

104.400

104.300

104.200

10 cm

B

F.I.I

F.VII

F.III.II

F.VI.I

F.V

F.IV

F.V

F.III.I

4

F.V

F.VI.I

F.VI.I

F.V

F.V

F.III.I

1

F.I.II

F.V

F.V

F.III.II

F.VI.I

F.VI.I

F.III.I

F.II

F.I.II

F.I.II

F.VI.II

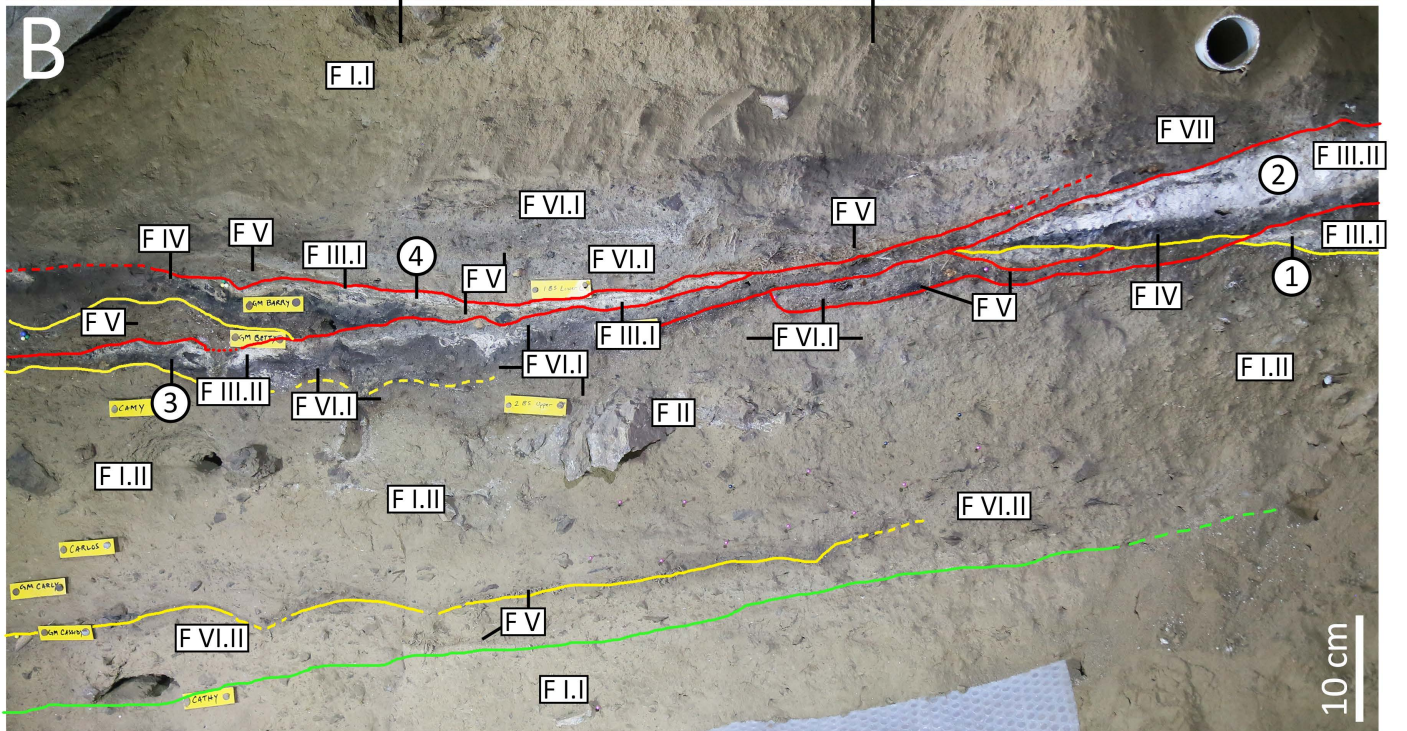
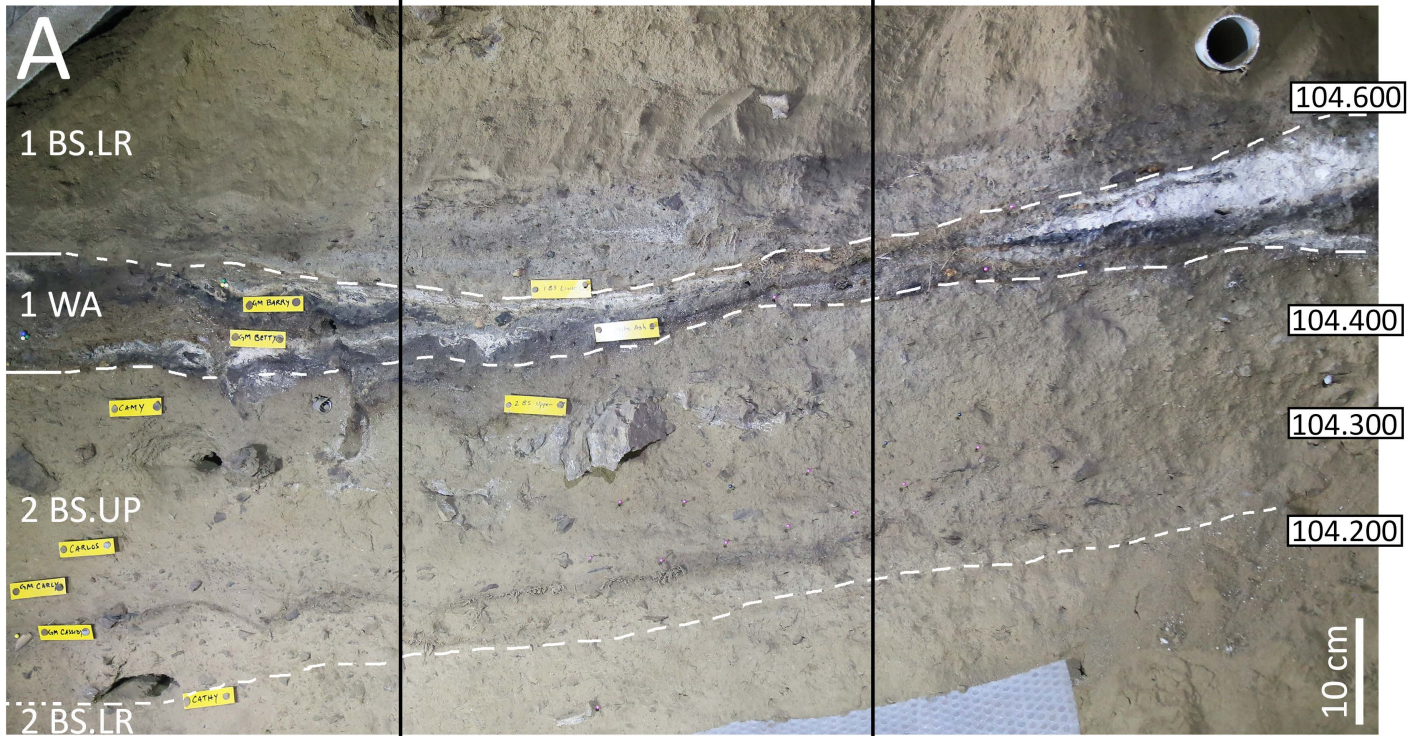
F.VI.II

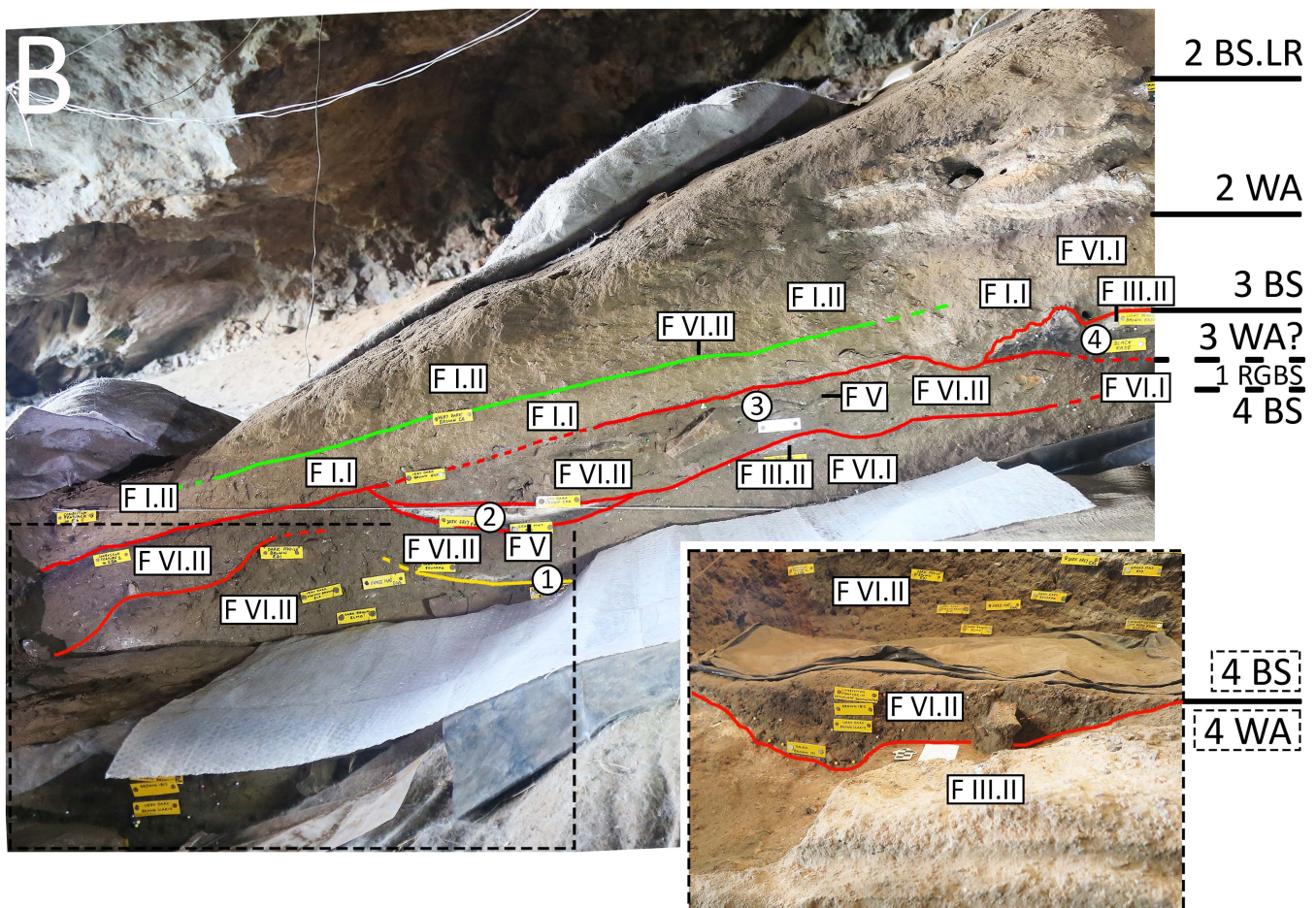
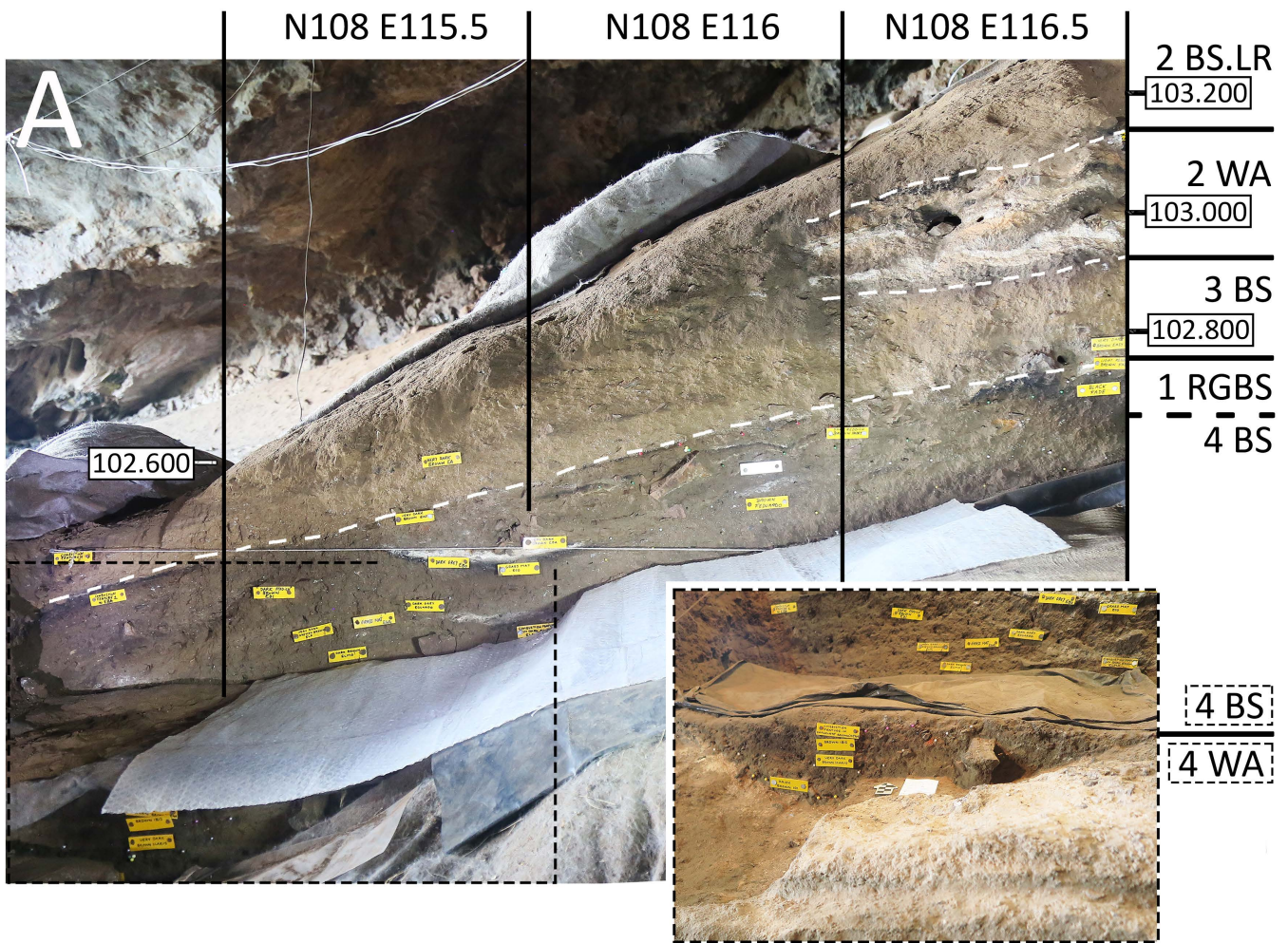
F.VI.II

F.V

F.I.I

10 cm





N109 E113.5

N108 E113.5

4 BS
102.070

4 WA

5 BS

101.500

5 WA

6 BS

101.200
floor

A

4 BS

4 WA

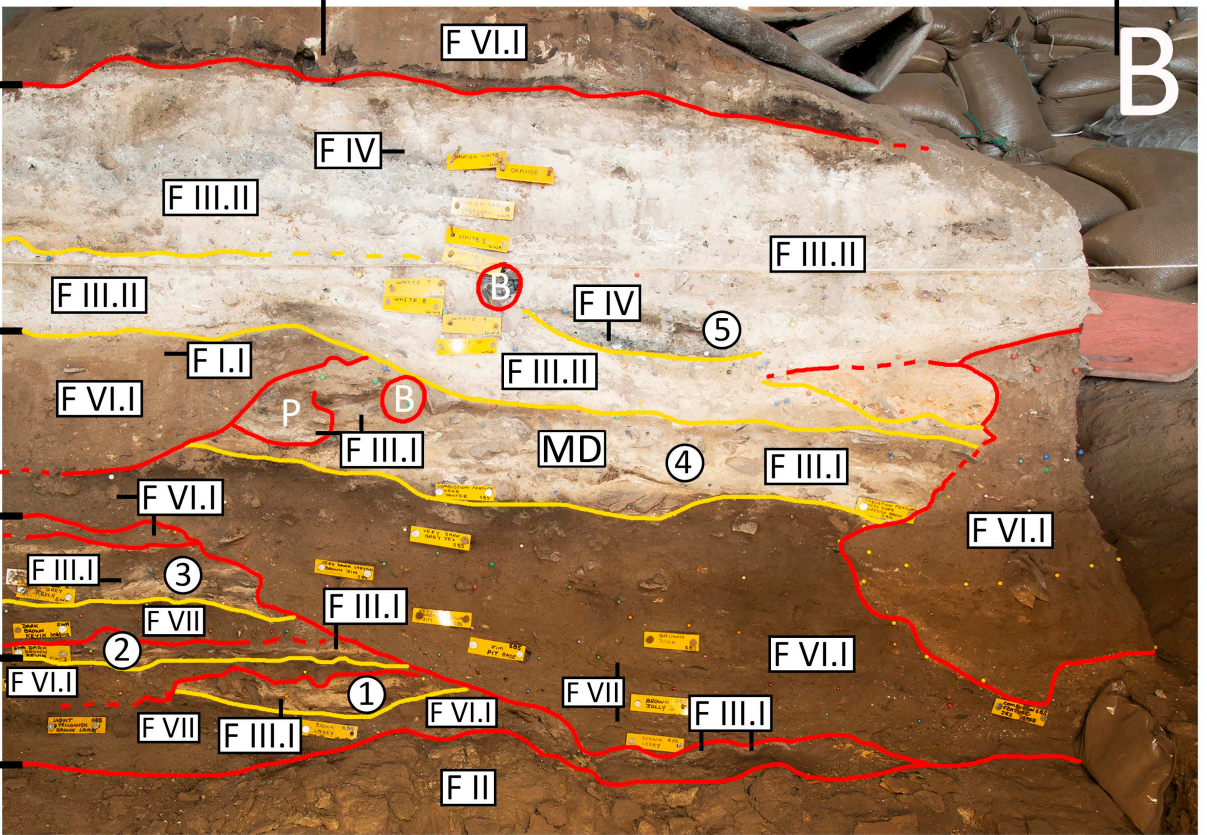
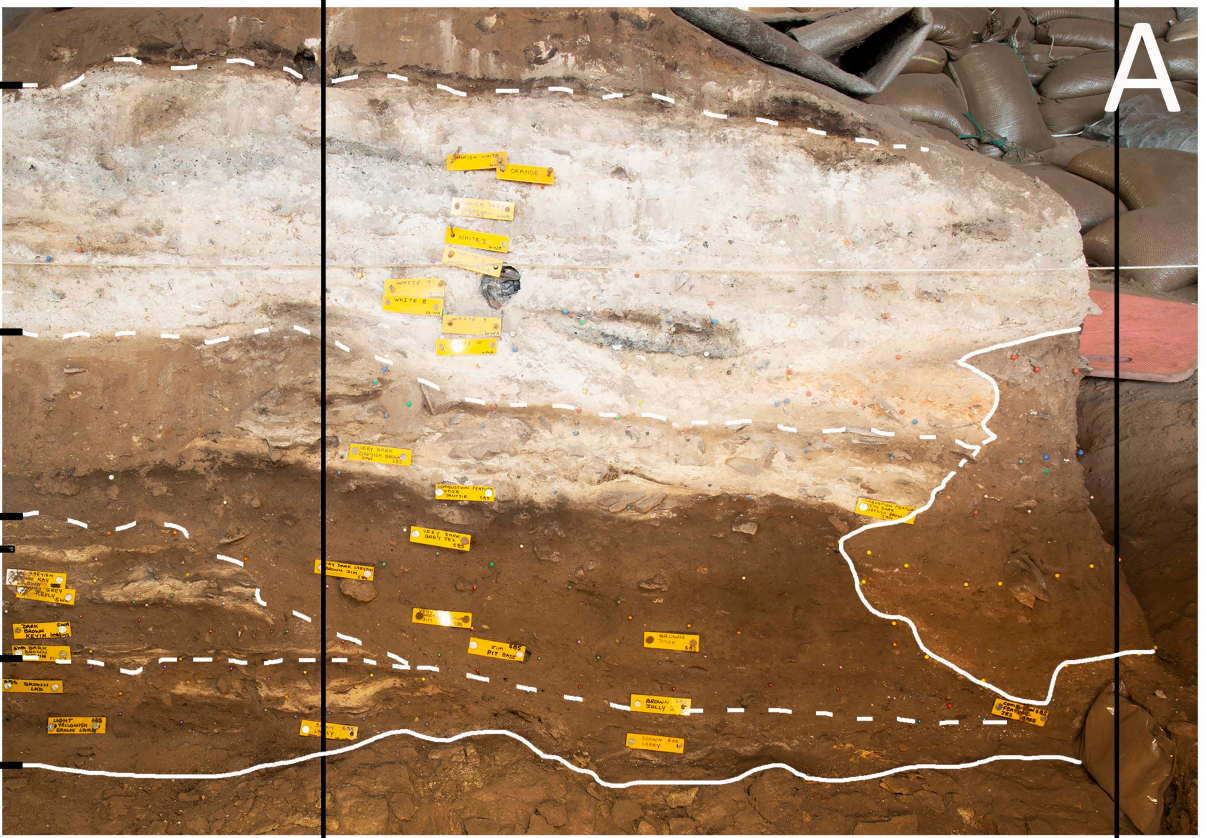
5 BS
UP
LR

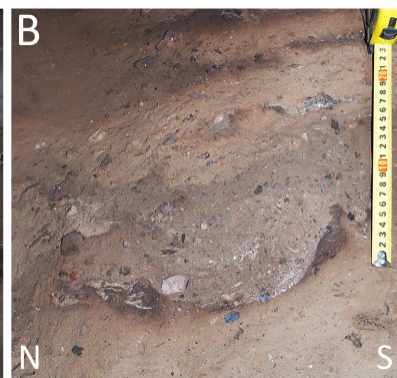
5 WA

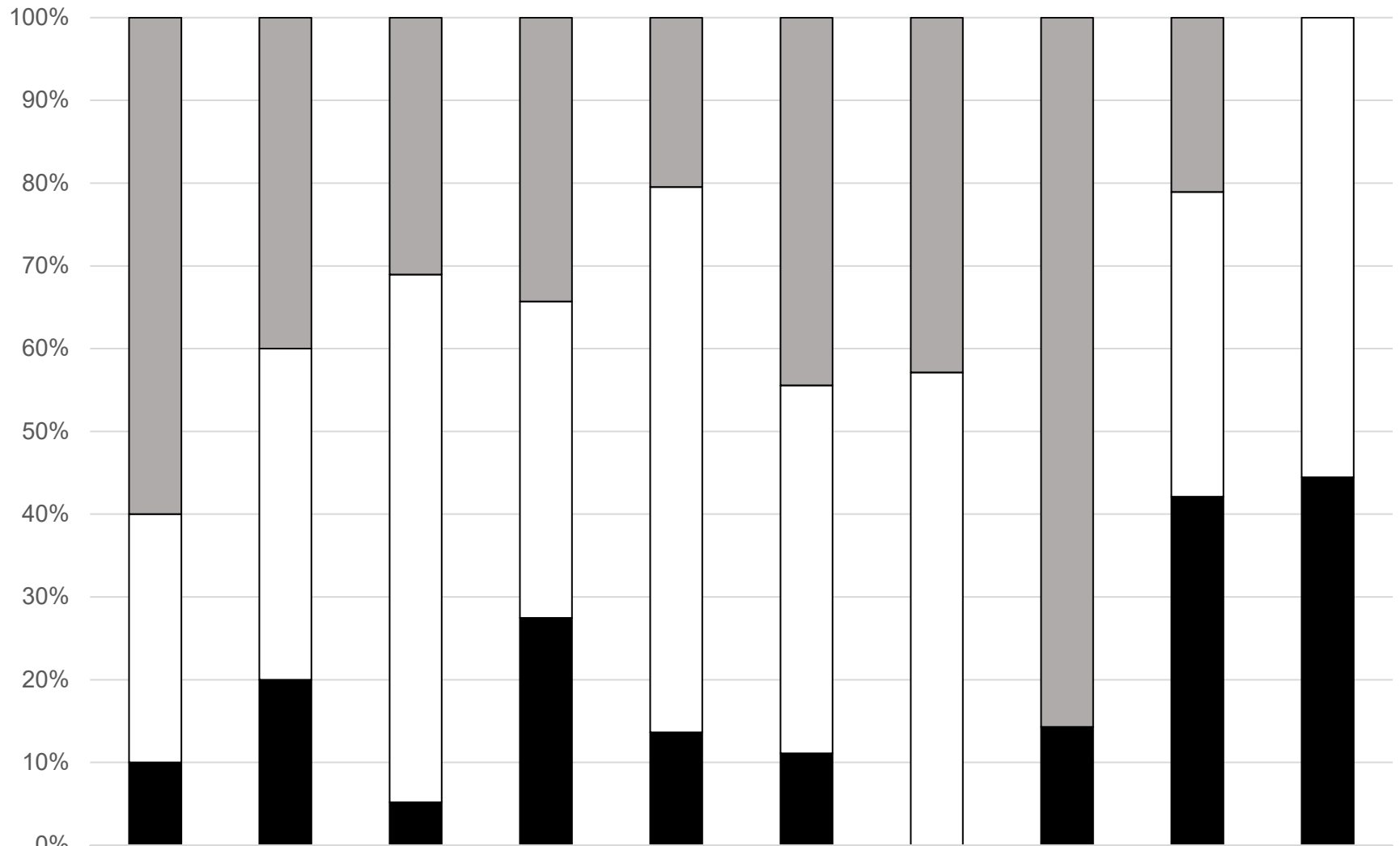
6 BS

floor

B

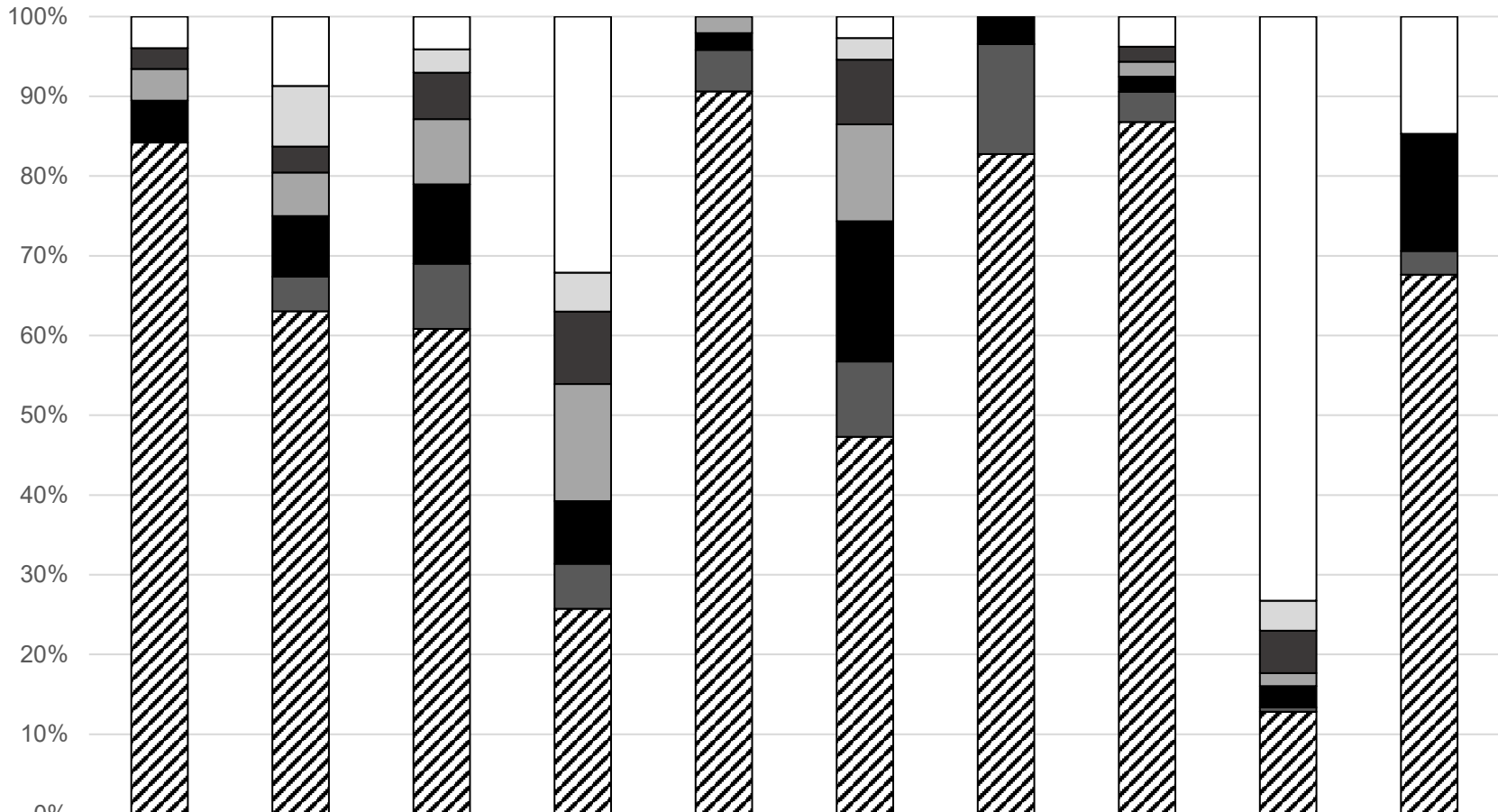






	1 BS	1 WA	2 BS	2 WA	3 BS	3 WA	1 RGBS	4 BS	4 WA	5 BS
	ELSA		MSA 3						MSA 1	
■ Large Ungulate	6	4	18	35	9	4	3	6	4	0
□ Medium Ungulate	3	4	37	39	29	4	4	0	7	5
■ Small Ungulate	1	2	3	28	6	1	0	1	8	4

Industry	Member	Small Ungulate	Medium Ungulate	Large Ungulate
ELSA	1 BS	1	3	6
	1 WA	2	4	4
MSA 3	2 BS	3	37	18
	2 WA	28	39	35
HP	3 BS	6	29	9
	3 WA	1	4	4
	1 RGBS	0	4	3
MSA 1	4 BS	1	0	6
	4 WA	8	7	4
	5 BS	4	5	0



	1 BS	1 WA	2 BS	2 WA	3 BS	3 WA	1 RGBS	4 BS	4 WA	5 BS
ELSA				MSA 3					MSA 1	
HP										

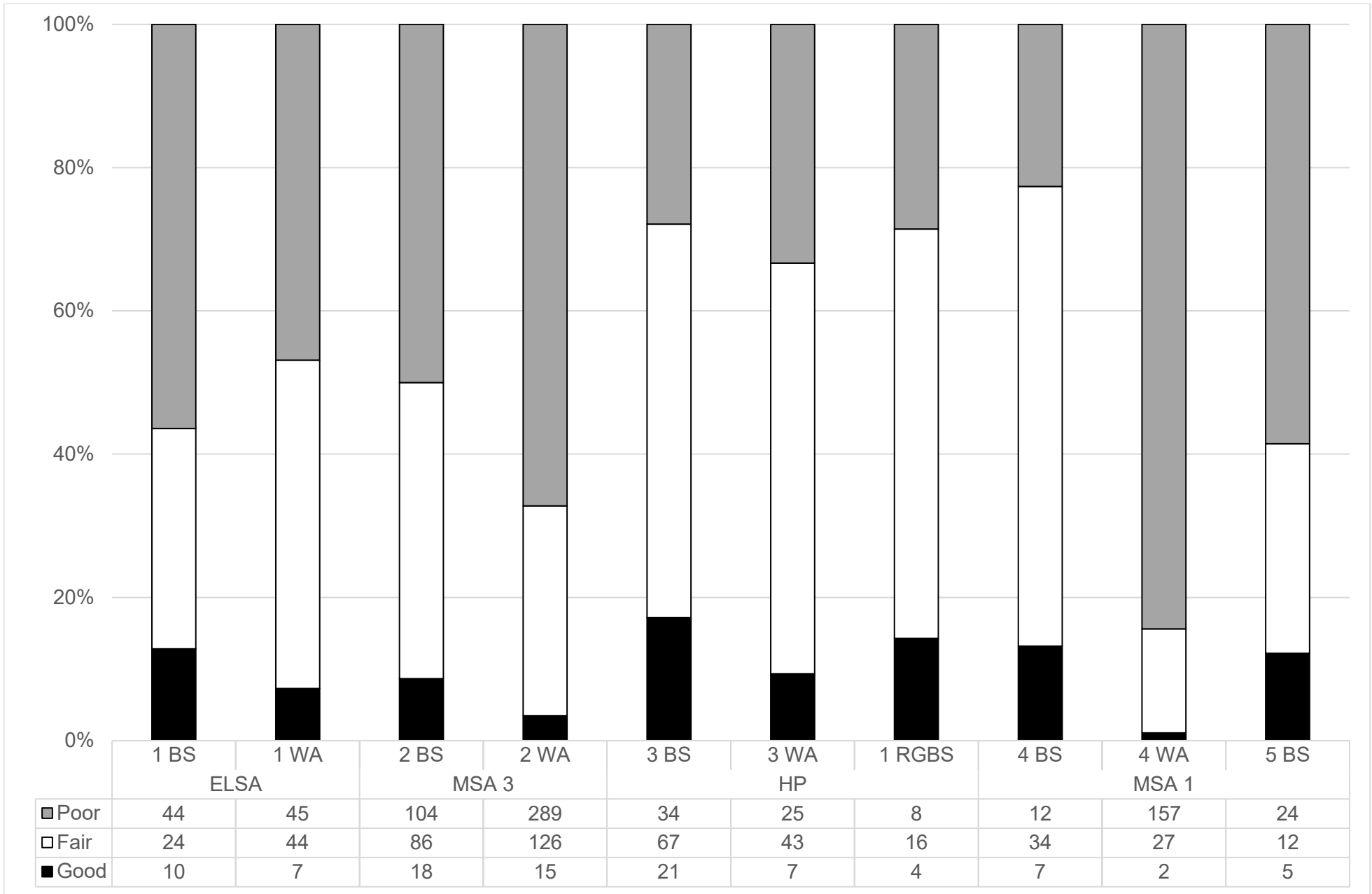
□6- Calcined	3	8	7	131	0	2	0	2	137	5
□5- Moderate calcination	0	7	5	20	0	2	0	0	7	0
■4- Localized calcination	2	3	10	37	0	6	0	1	10	0
■3- Carbonized	3	5	14	60	2	9	0	1	3	0
■2- Moderate burning	4	7	17	32	2	13	1	1	5	5
■1- Localized burning	0	4	14	23	5	7	4	2	1	1
▨0- Not burned	64	58	104	105	87	35	24	46	24	23

0- Not burned 1- Localized b 2- Moderate l 3- Carbonized 4- Localized c

ELSA	1 BS	64	0	4	3	2
	1 WA	58	4	7	5	3
MSA 3	2 BS	104	14	17	14	10
	2 WA	105	23	32	60	37
HP	3 BS	87	5	2	2	0
	3 WA	35	7	13	9	6
	1 RGBS	24	4	1	0	0
MSA 1	4 BS	46	2	1	1	1
	4 WA	24	1	5	3	10
	5 BS	23	1	5	0	0

5- Moderate (6- Calcined

0	3
7	8
5	7
20	131
0	0
2	2
0	0
0	2
7	137
0	5



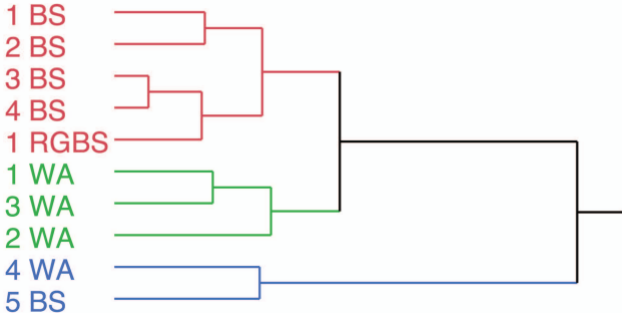
ELSA

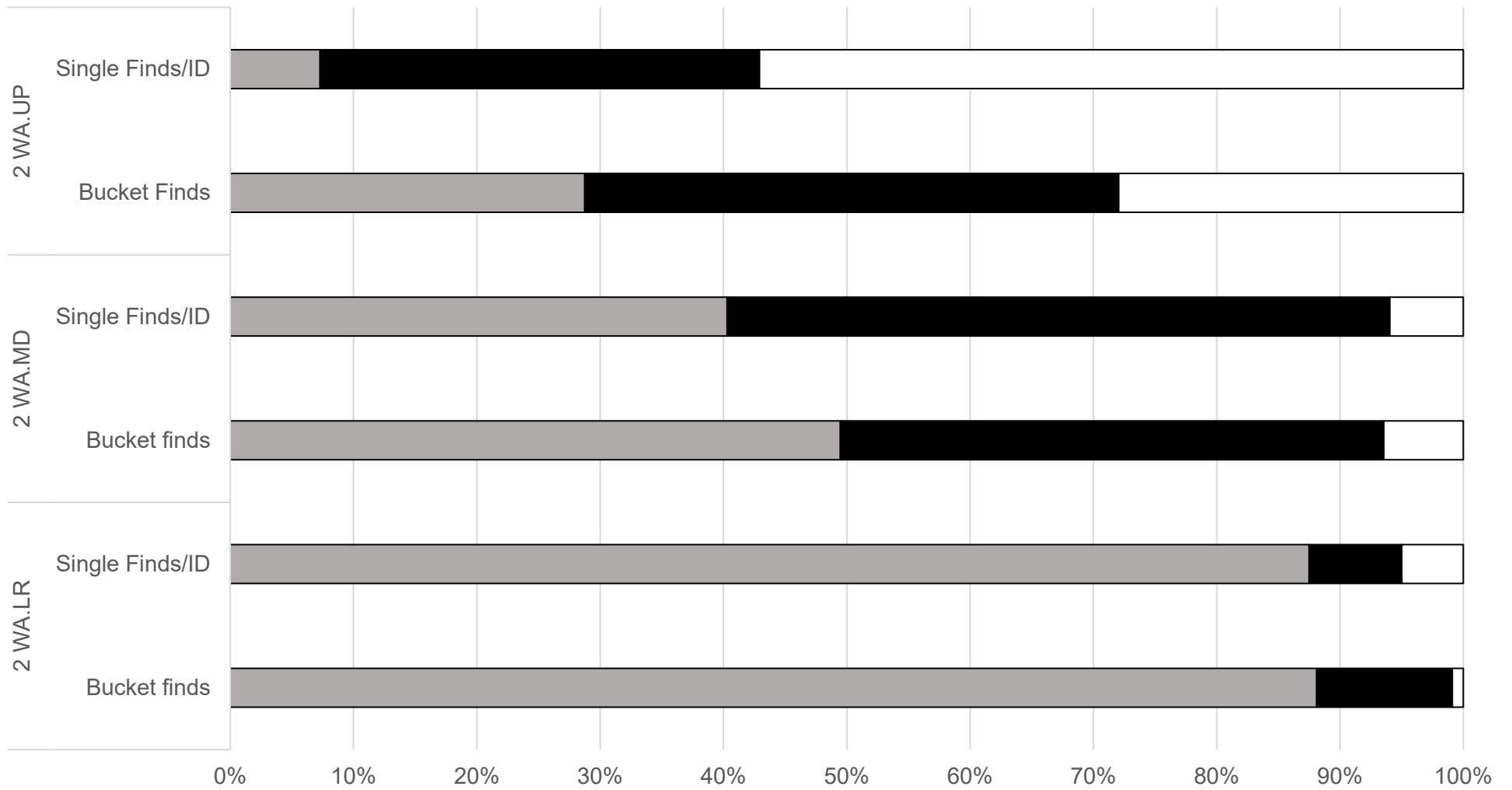
MSA 3

HP

MSA 1

		Good	Fair	Poor	
ELSA	1 BS		10	24	44
	1 WA		7	44	45
MSA 3	2 BS		18	86	104
	2 WA		15	126	289
HP	3 BS		21	67	34
	3 WA		7	43	25
	1 RGBS		4	16	8
MSA 1	4 BS		7	34	12
	4 WA		2	27	157
	5 BS		5	12	24





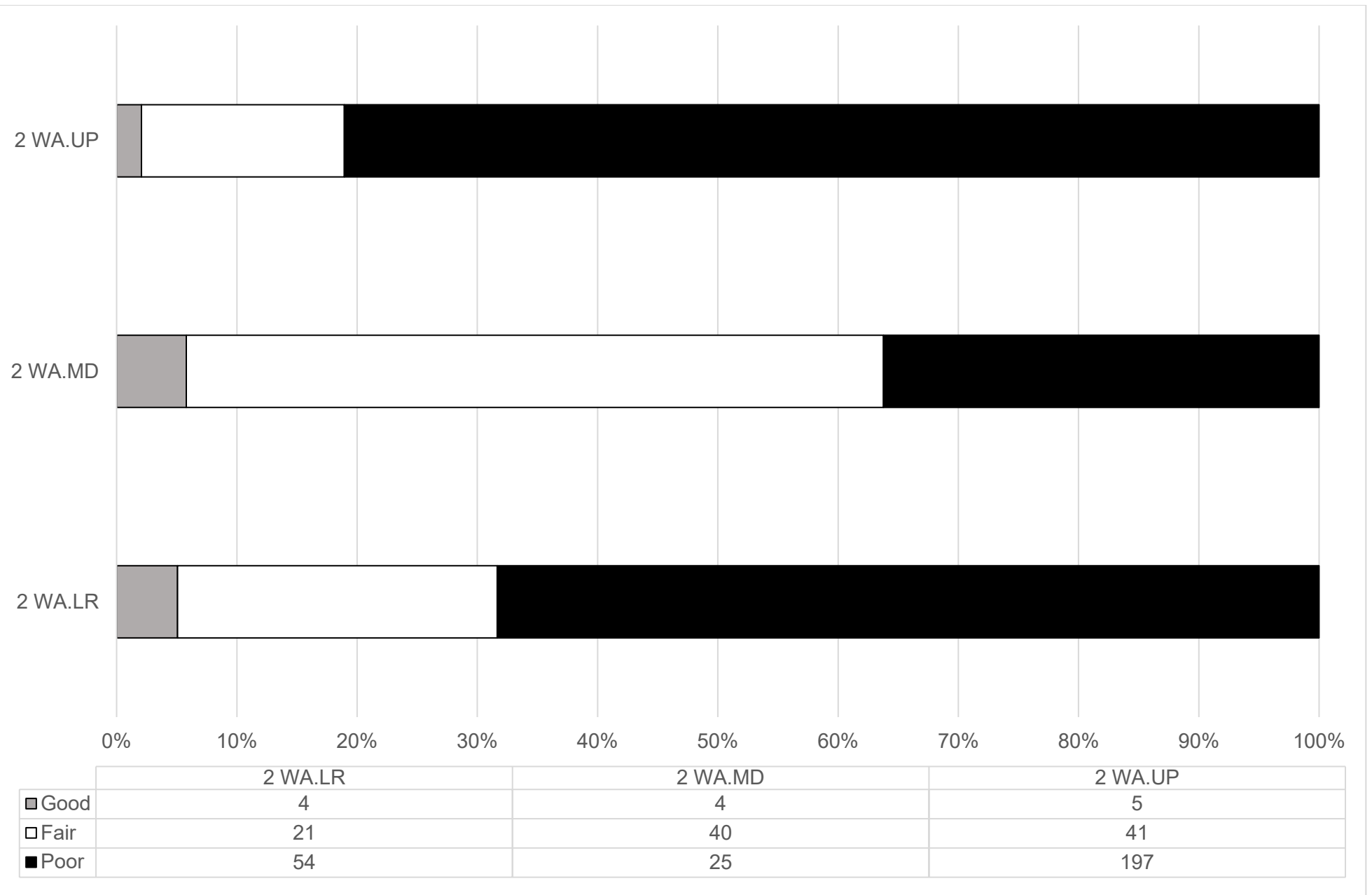
	2 WA.LR		2 WA.MD		2 WA.UP	
	Bucket finds	Single Finds/ID	Bucket finds	Single Finds/ID	Bucket Finds	Single Finds/ID
■ NB/LB	1081	70	146	27	421	18
■ MB	135	6	130	36	634	88
□ HB	11	4	19	4	409	141

	2 WA.LR		2 WA.MD	
	Bucket finds	Single Finds/ID	Bucket finds	
NB/LB	1081		70	146
MB	135		6	130
HB	11		4	19

2 WA.UP

Single Finds/ Bucket Find: Single Finds/ID

27	421	18
36	634	88
4	409	141



	Good	Fair	Poor	
2 WA.LR		4	21	54
2 WA.MD		4	40	25
2 WA.UP		5	41	197