Reassessing the stratigraphy and formation of the basal deposits at Klasies River Main Site with a multiscale and multiproxy approach

Peter Morrissey

676930

A thesis submitted to the Faculty of Science, University of Witwatersrand in fulfilment of the requirements for the degree of Doctor of Philosophy

School of Geography, Archaeology and Environmental Studies

DECLARATION

I, Peter Morrissey, declare that this thesis is my own original work except for the clearly stated contributions of my co-authors in the case of chapters which have been published or submitted. It is submitted for the degree of Doctor of Philosophy in the School of Geography, Archaeology and Environmental Studies at the University of Witwatersrand, Johannesburg. This work has not been previously submitted for another degree or examination at any other university.

Signed by: Peter Morrissey on this the 28th day of March 2024

Student number: 676930

ABSTRACT

The basal deposits at Klasies River Main site, associated with the MSA I and II lithic cultural phases and dating from >120 ka to ~80 ka, have yielded highly significant archaeological assemblages and human fossils across multiple phases of excavation since the late 1960s. These finds have contributed to a growing understanding of the appearance and intensification of modern human behaviours and provide rare insight into *Homo sapiens* anatomy during the early parts of the Late Pleistocene.

The three recesses occupied during this period represent distinct depositional environments with differing degrees of attractiveness for human activities. Significant climatic, environmental, and geomorphic changes, including large fluctuations in sea level, occurred, impacting formation processes within the site complex. Stratigraphic relationships across a space like this would always be complicated but understanding them here is even more difficult because there are not continuous deposits between the recesses for all or part of their respective sequences.

Geoarchaeological research has taken place alongside all three phases of excavation at Klasies. Until Sarah Wurz began her field programme in 2013, this work entailed macroscopic descriptions of standing sections (at differing resolutions) and the sedimentological analysis of bulk samples. Given the finely laminated nature of many of the deposits, even higher resolution bulk sampling resulted in the incorporation of multiple visible deposits into individual samples in many cases. More recently, archaeological micromorphology and other microscale analyses have been applied to deposits in the site complex by Susan Mentzer and colleagues. This work has provided important new insights into human behaviour and the spatially and temporally variable impacts of different diagenetic processes.

Here, field observations of standing sections and microcontextual analysis are used to provide greater insight into the formation of deposits in two areas of the site complex. This information is used, along with unpublished field notes and profile drawings and critical engagement with the extensive, but seldom detailed, literature to assess and refine stratigraphic correlations of the basal deposits both between different recesses and different stratigraphic systems (the layers used in the initial

excavations and the excavation units grouped into members and sub-members in subsequent work).

The results demonstrate that the formation of any particular deposit could involve any number of combinations and relative intensities of different depositional and post-depositional processes. Furthermore, the interplay between geogenic, biogenic, and anthropogenic processes is often significant. Anthropogenic deposition has long been recognised as being highly significant at Klasies, but it is now also clear that humans played a major role in reworking sediment through daily activities during occupations, very likely including trampling and site maintenance activities. Chemical diagenesis had a major impact on the preservation of anthropogenic features, but variations in the intensity and frequency of anthropogenic deposition also influenced how susceptible deposits were to diagenesis.

It has proven possible to correlate between the two stratigraphic systems in Cave 1B, a particularly understudied area of the site complex, providing clarity on the cultural association of a highly significant human fossil. The overall stratigraphic system used at the site complex is now also better understood, both in terms of correlations and the nature of the system.

Finally, this study highlights the utility of a multiscale geoarchaeological approach to site complexes like Klasies for understanding site formation and stratigraphy. It also highlights the vital, but often ignored or underplayed, connection between site formation processes and stratigraphy, especially in such a complicated context.

ACKNOWLEDGEMENTS

As with any PhD project, there are many people and entities who helped me in various important ways during this project.

I am extremely grateful to my supervisors, Prof. Sarah Wurz and Dr Susan Mentzer, for their guidance, valuable input and suggestions, and their patience and understanding throughout the delays caused by the pandemic and other factors. Prof. Wurz also provided access to the incredible Klasies River Main site complex and to important archival materials and shared a great deal of her extensive knowledge of Klasies and its excavation history, and Dr Mentzer provided vital training in microscale analysis and interpretation and created extremely useful elemental maps for all the thin sections studied in this thesis.

Dr Bertrand Ligouis conducted organic petrology analysis on the deposits in one my thin sections, which provided some important insights into a significant anthropogenic feature and broader patterns within Cave 1.

Dr Kathryn Croll provided invaluable assistance during fieldwork, including helping with collecting micromorphology samples and taking numerous photographs of samples and deposits.

Panagiotis Kritikakis processed my block samples into thin sections and taught me about the practicalities of the process.

Comments made by reviewers and editors at *Journal of Paleolithic Archaeology* and *Journal of Human Evolution* on the two published papers included in this thesis were very helpful and led to the improvement of these portions of the thesis.

Carl Holmes helped with identifying several mollusc species in my thin sections.

Sonia Varandas organised the transport of my samples to Germany and played a huge role in the logistics of my three months in Tübingen. Her support during my time there is also enormously appreciated.

I am grateful to the late Prof. Hilary Deacon and his excavation team members for unpublished notes, drawings, and photographs from the 1984-1995 excavations at Klasies which have proven invaluable for this thesis.

Liezl van Pletzen Vos produced digital re-drawings of many of the Deacon team's profile drawings, several of which appear in this thesis.

I was supported financially during this project by GENUS (DSI-NRF Centre of Excellence in Palaeosciences) through a PhD bursary (UID 86073). The Palaeontological Scientific Trust (PAST) provided a grant which made it possible to complete my fieldwork. Finally, the Baden-Württemberg Ministerium für Wissenschaft, Forschung und Kunst funded a research fellowship at Eberhart Karls University of Tübingen. Opinions expressed and conclusions arrived at are mine (and those of my co-authors where relevant) and are not necessarily to be attributed to any of these funders.

On a more personal note, I thank my parents, my siblings, and Jenny Croll for their incredible support and understanding throughout this period. My dogs provided important endorphins and perspective, along with getting me away from my desk for much needed fresh air and sunlight. Finally, I have no idea how I would have reached this point without the support of my partner Kathryn Croll. Thank you for everything Kate.

DEDICATION

To my mother Gillian, my stepfather Gordon, my late father Norman, and Kathryn Croll.

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GLOSSARY

Allogenic Sediment derived from outside a site and subsequently transported into it. Synonymous with allochthonous.

Allostratigraphy The division and grouping of deposits based on disconformities or unconformities which can be tracked across space or are inferred to have occurred in multiple locations.

Anthropogenic Deposition of various materials, and the disturbance, erosion, and alteration of existing deposits (of whatever origin) by human activities.

Autogenic Sediment derived from inside a site (such as the breakdown of the bedrock in a cave) which can be transported to varying degrees within the site. Synonymous with autochthonous.

Biogenic Deposition of sediment, and the disturbance, alteration, and erosion of deposits as a result of non-human biological activity.

Biostratigraphy The division and grouping of deposits based on the presence/absence or relative abundance of the remains of particular faunal and/or floral species.

Clast A grain of sediment (of widely varying sizes and origins) which are typically the product of the weathering or breakage of rocks or other materials as opposed to precipitated chemical sediments like speleothem (although a fragment of broken speleothem is considered a clast). In macroscopic descriptions in this thesis, clast is used to refer to material >2 mm, with smaller clasts (sand-, silt-, and clay-sized) considered part of the matrix. There are clasts of anthropogenic, biogenic, and geogenic origin in the deposits at the Klasies River Main site complex.

Clast-supported	Deposits in which clasts >2 mm constitute enough of the volume of the deposit that they are in contact with each other, with finer material only filling the void space.
Diagenesis	The alteration of sedimentary deposits by physical and/or chemical processes after deposition.
Facies	A particular set of sedimentary characteristics (both compositional and structural) which allow deposits to be grouped based on a shared (inferred) formation history. Macrofacies (sometimes used in the micromorphological literature) is a synonym.
Geogenic	Deposition of sediment, and the disturbance, alteration, and erosion of deposits by geological processes.
Lithology	The physical properties of sediment or rocks, including their texture (the size of grains within them) and colour.
Lithostratigraphy	The grouping and division of deposits based on similarities or differences in their lithology.
Matrix-supported	A deposit in which clasts >2 mm are contained within a matrix of finer sediment (sand, silt and clay) such that the clasts do not (or seldom) touch one another. While these deposits may contain numerous clasts, they are proportionally less common than in a clast-supported deposit.
Member	A lithostratigraphic grouping of deposits within the site complex's sequence.
Microfacies	A particular set of sedimentary characteristics (both compositional and structural) observable at the microscale which allow microstratigraphic units to be grouped based on a shared (inferred) formation history. Individual facies (or macrofacies) may contain multiple microfacies.

Pedogenic	Physical and chemical processes which form soils through the alteration of sediments.
Soil mesofauna	A diverse range of invertebrate taxa ~0.1 to 2.0 mm in size which feed on organic material in soils and sediments.
Sub-member	A sub-division of a member, based on (often localised) variation in lithologies within a member which necessitate distinguishing these deposits from the rest of the member, but which are not considered significant enough to warrant placing them into a distinct member.

CHAPTER 1. INTRODUCTION

Klasies River Main site (KRM) is the name given to a group of associated recesses eroded into a quartzite cliff along South Africa's southern Cape coast (Figures 1.1 & 1.2). Although varying in size, shape, elevation, and exposure, four of the five recesses have been found to contain archaeological deposits (Singer & Wymer, 1982). The site complex was first excavated in 1967 and has continued to attract research attention, including two long-term field programmes (Table 1.1), due to the length of the sequence and the sheer volume of significant archaeological evidence recovered from deposits which exceed 20 m in thickness in places (Singer & Wymer, 1982; Deacon, 1995; Wurz et al., 2018; Wurz, 2023).

Figure 1.1. A view of Klasies River Main site from the southeast.

KRM was occupied repeatedly by Middle Stone Age (MSA) people over tens of thousands of years, from at least ~120 ka before present to between 60 ka and 40 ka (Grine et al., 2017; Wurz et al., 2018, 2022). After a long hiatus, Later Stone Age (LSA) occupations occurred between ~4.7 ka and ~2.5 ka (Singer & Wymer, 1982; Binneman, 1995; Nami et al., 2016). Archaeological assemblages excavated from the

site complex have allowed reconstructions of human behaviour and environmental conditions across this period (e.g., Klein, 1976, 1989; Thackeray, 1988; Deacon, 1995; Milo, 1998; Wurz, 2002; Von den Driesch, 2004; Villa et al., 2010; Langejans et al., 2012, 2017; Nel et al., 2018; Reynard & Wurz, 2020; Brenner et al., 2022), and human fossils have provided important information on the anatomy of early Late Pleistocene *Homo sapiens* populations (e.g., Singer & Wymer, 1982; Rightmire & Deacon, 1991; Smith, 1992; Bräuer & Singer, 1996; Lam et al., 1996; Royer et al., 2009; Grine, 2016; Bergmann et al., 2021).

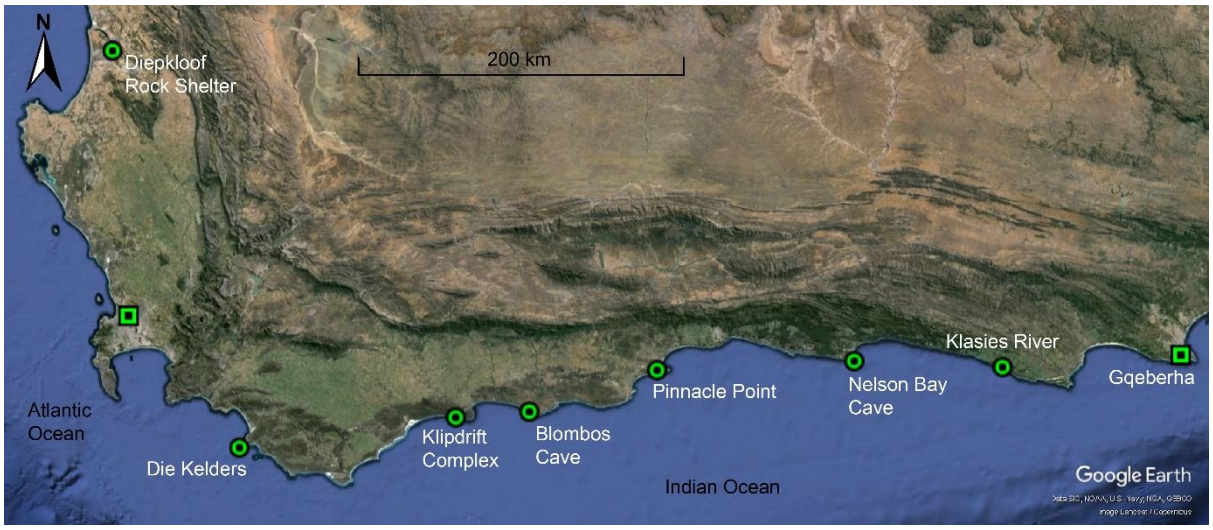

Figure 1.2. The location of Klasies River Main site (KRM) and some other significant Middle Stone Age sites along South Africa's southern and western Cape coasts. The relationship of KRM to other sites of geoarchaeological significance in South Africa and Lesotho is provided in Chapter 2.

The KRM sequence spans a period of extreme significance for understanding human behavioural and cognitive evolution (McBrearty & Brooks, 2000; Wadley, 2015, 2021; Scerri & Will, 2023) which coincided with multiple stages of marked changes in climatic and environmental conditions, including significant changes in sea level (Fisher et al., 2010; Marean et al., 2014; Cawthra et al., 2018). Unsurprisingly then, assemblages from KRM have contributed significantly to debates around the modernity of human anatomy and behaviour during the MSA (e.g., Thackeray, 1992; McBrearty & Brooks, 2000; Deacon, 2001; Klein, 2001; Henshilwood & Marean, 2003; Marean, 2014; Wadley, 2015).

Table 1.1. A summary of the three phases of field investigation (including excavation and the description and sampling of standing sections) at Klasies River Main site.

Leader and period	**Excavation approach**	**Stratigraphic model**	**Geoarchaeological research**	**References**
John Wymer 1967 – 1968	Large areas at low spatial resolution. Excavation layers included multiple distinct deposits	Layers grouped based on cultural stratigraphy	Field observations and bulk sample analysis. Focus on palaeoenvironments and linking local sequence to regional/global ones	Butzer, 1982a; Singer & Wymer, 1982
Hilary Deacon 1984 – 1995	Small areas at high spatial resolution. Excavation units contain as few deposits as possible/practical given the microlamination	Units grouped into members and sub-members based primarily on lithostratigraphy and cultural stratigraphy. Some sub-members are equivalents of Wymer layers	Field observations and bulk sample analysis. Greater focus on impacts of site formation on the integrity of excavated materials, and some interpretation of human behaviour from anthropogenic features and deposits	Deacon & Geleijnse, 1988; Henderson, 1992; Deacon, 1995, 2008
Sarah Wurz 2013 –	Same as Deacon but benefits from technological and methodological advances	Deacon model, but with on-going revision of some members and sub-members	Field observations and microcontextual analysis. Greater attention paid to characterising diagenetic processes and interpreting human behaviour from anthropogenic features and deposits	Wurz et al., 2018, 2022; Larbey et al., 2019; Wurz, 2023

All three phases of archaeological investigation at KRM have involved geoarchaeological research (Table 1.1), even though the earliest fieldwork pre-dated the formal definition of the discipline (Butzer, 1982a; Deacon & Geleijnse, 1988; Wurz et al., 2018, 2022). Naturally, field and laboratory techniques, interpretive approaches, and research questions have all changed to varying degrees over the past six decades, but there has been continuous recognition of the potential for geoarchaeology to contribute to understanding this incredible site complex.

This thesis, which focuses on the basal MSA I and II deposits across the site complex, will address some of the gaps in our understanding of the stratigraphy and formation of these significant deposits, helping to better contextualise archaeological finds and provide greater insight into human behaviour during these two lithic cultural phases. This work involves engagement with published and archival material, and the collection and interpretation of multiscale geoarchaeological data.

1.1. Background

1.1.1. The Middle Stone Age

The Middle Stone Age (MSA) is characterised by a focus on the use of prepared-core technologies to produce flakes, blades, and points (Wurz, 2013; Lombard et al., 2022). In southern Africa, the MSA is typically viewed as starting around 300 ka (Wadley, 2015; Lombard et al., 2022). However, significant continuities in lithic technologies from the latter stages of the Earlier Stone Age into the early MSA mean that this division is somewhat unclear (Wilkins & Chazan, 2012; Wurz, 2013; Lombard et al., 2022). The exact end of the MSA and start of the subsequent Later Stone Age (LSA) is also ambiguous, but this transition is generally placed in the period between 30 ka and 20 ka (Wurz, 2013; Wadley, 2015; Lombard et al., 2022).

The earlier part of the MSA is associated with the appearance of *H. sapiens* and the species' dispersals across Africa (Grine, 2016; Hublin et al., 2017; Richter et al., 2017). However, the period has become increasingly synonymous with research into the evolution of modern human behaviour and cognition (Wadley, 2021; Scerri &Will, 2023). A wide range of behaviours or behavioural patterns (and variation therein) are now used as proxies for gauging cognition (Wadley, 2021, Table 1; Scerri & Will, 2023, Table 1). These behaviours have been identified through the analysis of a variety of

different types of archaeological evidence, including through microscale interpretations of anthropogenic features and deposits (e.g., Henshilwood et al., 2004, 2009, 2011; Wadley et al., 2011, 2020a,b; Lombard & Haidle, 2012; Clark & Kandel, 2013; Marean, 2014; Wadley, 2015; Larbey et al., 2019).

The appearance of modern cognitive abilities has previously been hypothesised to have occurred around 50 ka, in association with the appearance of the first LSA assemblages in Africa and/or the start of the Upper Palaeolithic in Europe (e.g., Mellars, 1989; Klein, 2001, 2008). However, it has now become clear that modern or near-modern levels of cognition have existed in *H. sapiens* populations for considerably longer (see Scerri & Will, 2023 for a recent and comprehensive review). Hilary Deacon (1992, 1993, 1995, 2001) was an early proponent of recognising signs of cognitive modernity in MSA populations and, unsurprisingly, evidence from KRM featured heavily in his arguments. Evidence for many fairly complex behaviours first appears in the archaeological record during the early stages of the MSA and Middle Palaeolithic, but there is a significant increase in the frequency of innovation and behavioural variability after ~100 ka (McBrearty & Brooks, 2000; Wadley, 2021; Scerri & Will, 2023).

The MSA coincided with a series of Marine Isotope Stages (MIS), each of which were characterised by comparatively low or high global temperatures driven primarily by orbital changes (Wadley, 2015, Table 2). These temperature patterns, combined with resulting changes in atmospheric and oceanic circulation and sea level, led to variation in climatic and environmental conditions both within and between different stages (e.g., Blome et al., 2012; Carr et al., 2016). Along with changes (and variation) in temperature and the amount and seasonality of rainfall which could impact any area (to the benefit or detriment of human occupation) coastal populations also faced multiple periods of sea level change (Chase, 2010; Blome et al., 2012; Ziegler et al., 2013; Carr et al., 2016; Cawthra et al., 2018; Timbrell et al., 2022). Sea level change resulted in the gain or loss of land and associated resources along with changing distances between sites and marine food resources (Fisher et al., 2010; Dusseldorp & Langejans, 2013; Marean et al., 2014, 2020). Furthermore, resulting geomorphic changes impacted what shellfish species were available for exploitation (Langejans et al., 2017).

Naturally, resource availability has significant implications for Stone Age human behaviour. People may respond to changing conditions in many ways, including (re)occupying or abandoning areas, increasing or decreasing the frequency and duration of visits to certain locations, developing new technologies, changing how and how often some technologies or resources are used, and even changing the size and structure of groups (McCall & Thomas, 2012; Dusseldorp & Langejans, 2013; Mackay et al., 2014, 2022; Marean, 2014; Wadley, 2015, 2021; d'Errico et al., 2017; Roberts & Stewart, 2018; Scerri & Will, 2023).

Climatic and environmental changes are not the only factors affecting human behaviour. Group sizes, population densities, social structures, cumulative culture, and other cultural factors also play significant roles and may be independent of environmental conditions (Conard & Will, 2015; Wadley, 2015, 2021; Kandel et al., 2016; Scerri & Will, 2023). Furthermore, some extremely important resources (such as some lithic raw material) may be available in high enough quantities regardless of palaeoenvironmental conditions, and various resources may be reduced or become unavailable through other processes, including intensity of human exploitation. Therefore, behavioural changes in the MSA have been linked to a variety of different factors, many of which are not exclusive and likely co-occurred and even influenced one another (Wadley, 2021; Scerri & Will, 2023).

1.1.2. Context and the Middle Stone Age

Southern African cave and rockshelter MSA sites are often finely stratified, generally including microlaminated deposits under a centimetre in thickness (Mentzer, 2023). Although it is typically impossible to excavate distinct microlaminae individually, the fine stratification has resulted in the need for high resolution excavation with a significant focus on recording the three-dimensional provenience of individual excavated finds and features whenever possible (Wadley & Jacobs, 2006; Mackay, 2010; Oestmo & Marean, 2015; Porraz et al., 2016; Backwell et al., 2018; Mentzer, 2023). Given the potential significance of these finds and features, it is vital that associations with specific deposits and other features or finds (including dated materials) can be demonstrated.

An artefact's context is far more than just its three-dimensional provenience, and so there has been considerable interest in understanding how deposits in these sites form. Determining how deposits formed allows an assessment of whether excavated finds are in situ or if they were disturbed or altered (including in situ alteration) by natural or anthropogenic processes, and (if they have been disturbed) to what extent and in what ways (e.g., Goldberg et al., 2009; Miller et al., 2013, 2016; Karkanas & Goldberg, 2019; Wurz et al., 2022). This information allows greater confidence in associations with dated materials and other significant finds and provides the means to consider what these relationships might have originally been in cases where disturbance has occurred. Anthropogenic site formation processes have also received growing attention in the MSA as they provide insight into a range of behaviours, including different types of pyrotechnology, the structuring and maintenance of living spaces, and occupational intensities and frequencies (Goldberg et al., 2009; Miller et al., 2013; Karkanas et al., 2015; Wadley et al., 2020b; Haaland et al., 2021a; Mentzer, 2023).

The frequent occurrence of microlaminated deposits, along with regular evidence for a complex mix of site formation processes, means that a high-resolution approach is vital when studying the formation histories of most MSA sites in southern Africa (Mentzer, 2023). A microcontextual approach combining multiple micro-analytical techniques centred around archaeological micromorphology (e.g., Goldberg & Berna, 2010) has consequently become common, to the point that most geoarchaeological research programmes at MSA sites in the region incorporate some degree of this approach.

1.1.3. Geomorphic context

The geomorphology of the KRM site complex and its surrounds have influenced the formation (and erosion) of the deposits in the various recesses. Karl Butzer (1982a) provides a comprehensive overview of the regional geomorphology and geology of the broader landscape. This is summarised here (also drawing on other relevant sources), but the major focus of this sub-section is on introducing allogenic sediment sources and their relationships to the site complex, and on describing the morphology of the site complex itself along with the geomorphology of the immediate area.

The KRM site complex is located at (and within) the base of a cliff (Figure 1.1) at the seaward edge of the 8–10 km wide coastal platform. As is typical along the southern Cape coast (Marker & Holmes, 2010), the platform comprises several distinct surfaces of differing ages and elevations (Butzer, 1982a). They are at 90–120 m, 140–160 m, and 200–250 m, with the latter meeting the roughly coast parallel Tsitsikamma mountains which mark the landward edge of the platform (Butzer, 1982a).

The underlying geology falls within the Cape Supergroup, and comprises Table Mountain quartzite, with associated slate and shales which are less resistant to weathering by a variety of processes, and younger Bokkeveld metashales, which are also less resistant than the quartzite (Butzer, 1982a). The site complex itself is one of many locations along the southern Cape coast where contorted rocks of the Cape Fold Belt meet the sea, providing significant potential for the formation of caves and rockshelters during sea level highstands as coastal erosion exploits the faults within the hard quartzites (e.g., Karkanas & Goldberg, 2010). The rivers in the region are deeply incised, following the less resistant shales, and have likely had similar courses throughout the Quaternary (Buzter, 1982a; Marker & Holmes, 2010).

Aeolianites of varying ages cover parts of the coastal platform, and have undergone differing degrees of lithification, weathering, and pedogenesis (Butzer, 1982a). The deposits and soils along the coastal margin, above the quartzite cliffs, are of particular significance as they are important sources of colluvial sediment (Deacon & Geleijnse, 1988). The aeolianites are also the primary source of the secondary calcite which was precipitated within the site complex in the form of tufa, speleothems, and flowstones (Deacon & Geleijnse, 1988).

The most significant colluvial landform in the immediate vicinity of the site is a cone which originates at a point along the cliffs to the north of the site complex (Figure 1.1). The land surface slopes steeply down along the cliff towards the sea and the site complex from this point. The angle of the slope nearer the sea has been influenced by Holocene coastal erosion, and it would have been gentler in the vicinity of the site as the deposits built up during the MSA (Deacon, 1995). This slope is the most likely route for much of the colluvial sediment which entered the site complex (Deacon & Geleijnse, 1988; Deacon, 1995).

Given its location, aeolian and marine depositional and erosional processes are important aspects of the formation history of the KRM deposits, and global sea level changes during the Quaternary would have played a significant role (Carr et al., 2016; Cawthra et al., 2018). Associated changes in shoreline position and coastal geomorphology (including the presence or absence dunes in the area, and their size and geomorphic types, and whether beaches were rocky or sandy) would have impacted availability of sand for aeolian deposition in and around the site complex. A hypothesised barrier dune system between KRM and the shoreline during parts of the MSA occupations would have had significant impacts on aeolian deposition (Deacon, 1995).

The geomorphic and shoreline changes would also have exerted some control over the types of erosional processes which occurred, and their intensities. The formation of a ~5–6 m wave cut bench in the quartzite seaward of the site (Figures 1.3 & 1.4) has been attributed to the Last Interglacial (Buzter, 1982a; Deacon & Geleijnse, 1988), but (as is often the case with these features) this has not been confirmed through any form of dating. However, the elevation of this feature is consistent with this highstand (Cooper & Green, 2021). This highstand would have resulted in significant erosion of deposits in the site complex, barring the presence of a barrier system like the one proposed for later periods by Deacon (1995). Erosion during Holocene sea level highstands removed significant quantities of sediment from the site, and altered the morphology of Cave 1A and the associated cone of (largely) colluvial sediment.

Although the five recesses which make up the KRM site complex are very closely associated and are all hosted in the same quartzite cliff (Figures 1.3 & 1.4), their differing orientations, elevations, and morphologies (Appendix A, Figure 1) mean that they represent distinct depositional contexts with their own site formation histories. The relationships between the different recesses and the immediate landscape are illustrated from multiple perspectives in Figures 1.4 to 1.7.

The cliff provides protection from the westerly winds which have been dominant along the southern Cape coast since the Middle Pleistocene (Roberts et al., 2014), making the site more attractive for human occupation and significantly reducing the potential for aeolian erosion (Deacon, 1995). This is most pronounced on the eastern side of the site complex – in Caves 1, 1A, 1C, and 2, and their surrounds (Figure 1.4). This

side of KRM faces the adjacent valley, with southeast-facing cliffs to the north of the complex. The cone of (mostly) colluvial deposits here is banked against the wall of the Cave 1A rockshelter (Figure 1.4) and slopes down over the cliffs to the north before turning towards the site complex (Figure 1.1). Therefore, the areas on the eastern side of the complex are more susceptible to colluvial deposition and erosion.

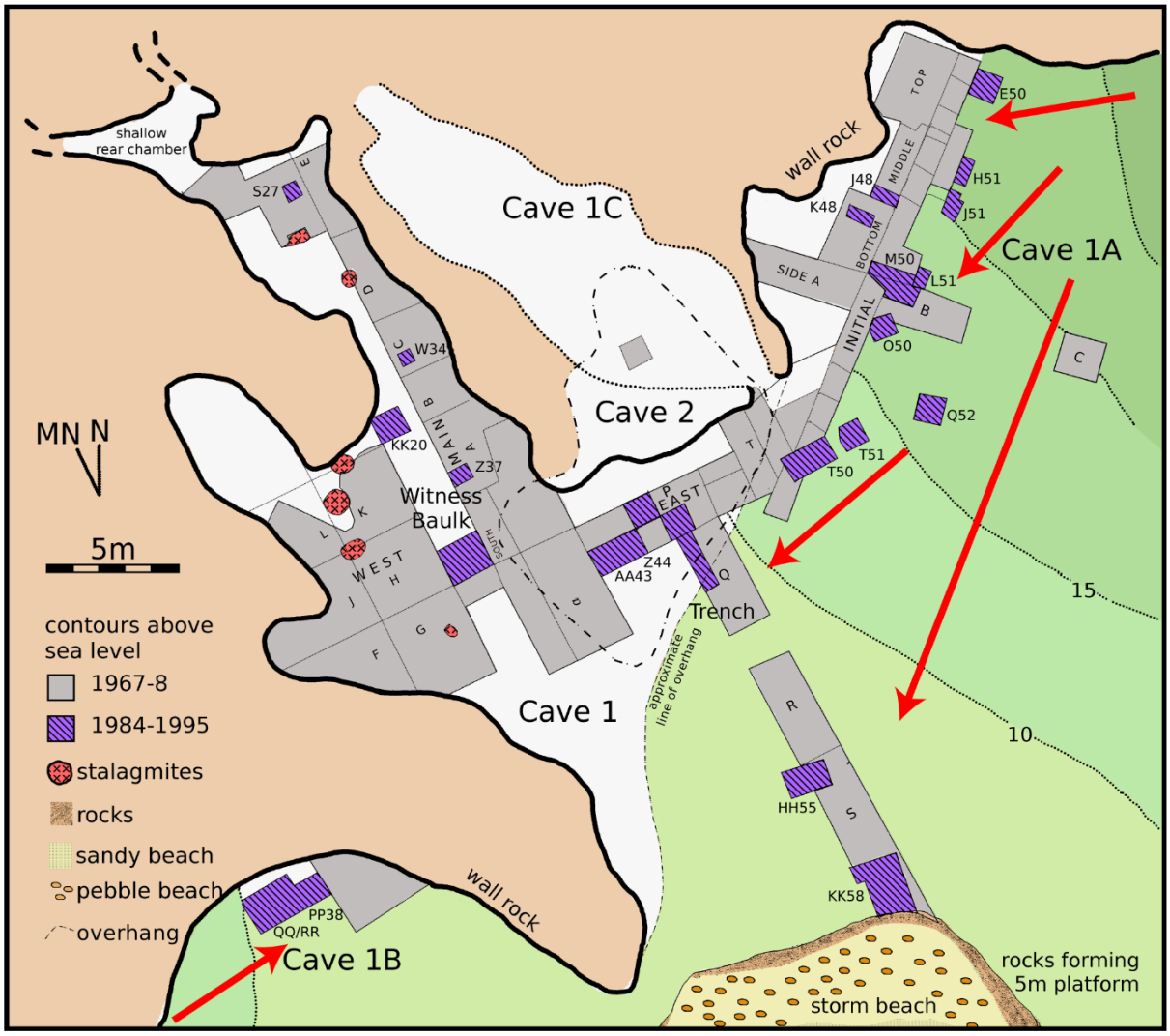

Figure 1.3. A map of the KRM site complex (after Wurz et al., 2018). The red arrows show the general direction of slopes around the complex. Note that Cave 2 overlies Caves 1 and 1C (Figure 1.4). The lowest points in Caves 1, 1A, and 1B are all around 6 m above sea level. Cave 1C appears to have a similar elevation, while Cave 2 is at ~18 m.

Cave 1C is the only recess which does not appear to have been occupied during the MSA, likely because it was too damp (Singer & Wymer, 1982). It also appears to have played little to no role in affecting sedimentation or erosion in other recesses. Therefore, it is not discussed here.

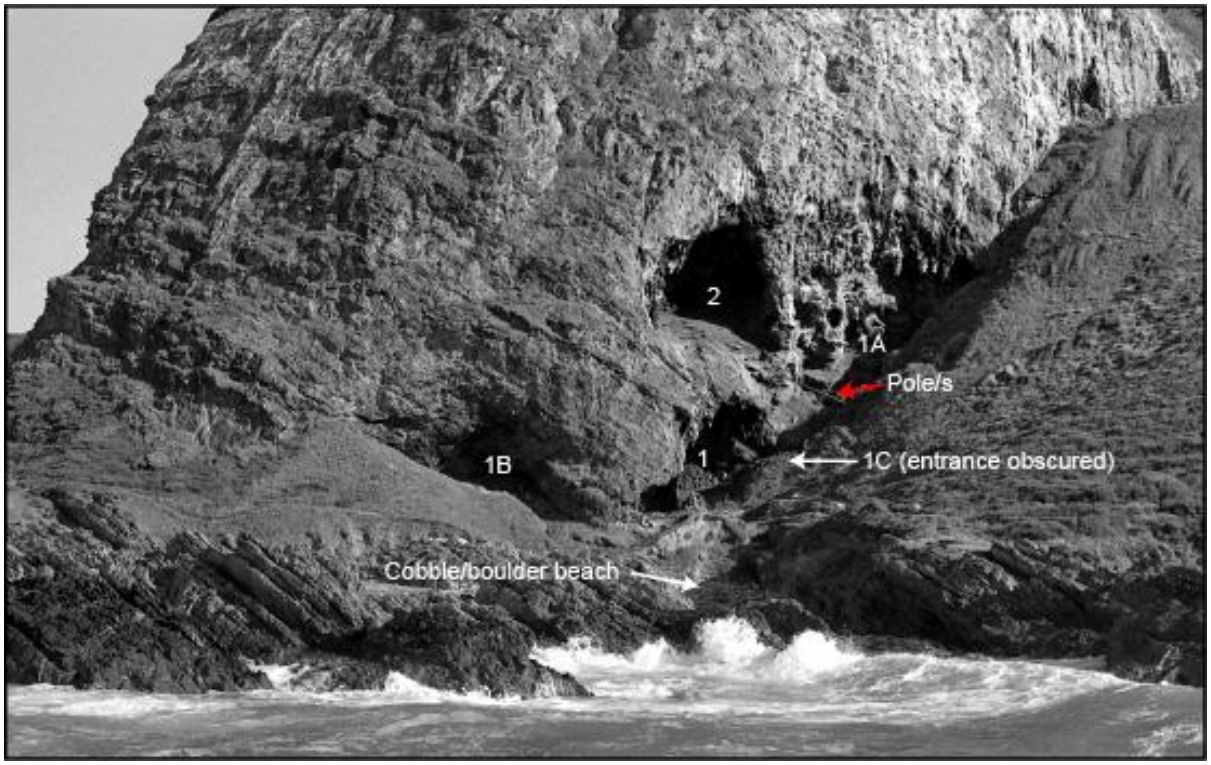

Figure 1.4. The main site complex viewed from the south (from the Deacon archive). The pole visible in the photograph (part of a crude ladder used to access Cave 2) appears in several of the following figures, providing a landmark for situating the different perspectives relative to each other. Note the steep slope to the east of the complex and the gentler slope within Cave 1B.

Cave 1 is a relatively deep cave, extending roughly 25 m back into the cliff (Figure 1.3). It is around 10 m wide at the entrance (which faces southeast), where the floor is about 6 m above mean sea level. The elevation of the roof and floor and the overall morphology of the cave vary significantly across its length and breadth (Figure 1.3 and Appendix A). The opening is fairly large, with the area immediately under the overhang being relatively exposed as a result (Figures 1.5 & 1.6).

Cave 1A is a rockshelter which makes up much of the eastern side of the site complex. The archaeological deposits formed under an overhang against the cliff face, which initially (at the entrance to Cave 1) runs roughly east-northeast before turning to run approximately north-northeast after the entrance to Cave 1C (Figure 1.4). The exact division between Cave 1A and the entrance of Cave 1 is somewhat arbitrary, and the two areas can be considered continuous, although a variety of depositional environments occur. Bedrock has seldom been reached in the excavations in Cave 1A, but the shelter floor may rise moving landward along the cliff (Appendix A, Figure 1).

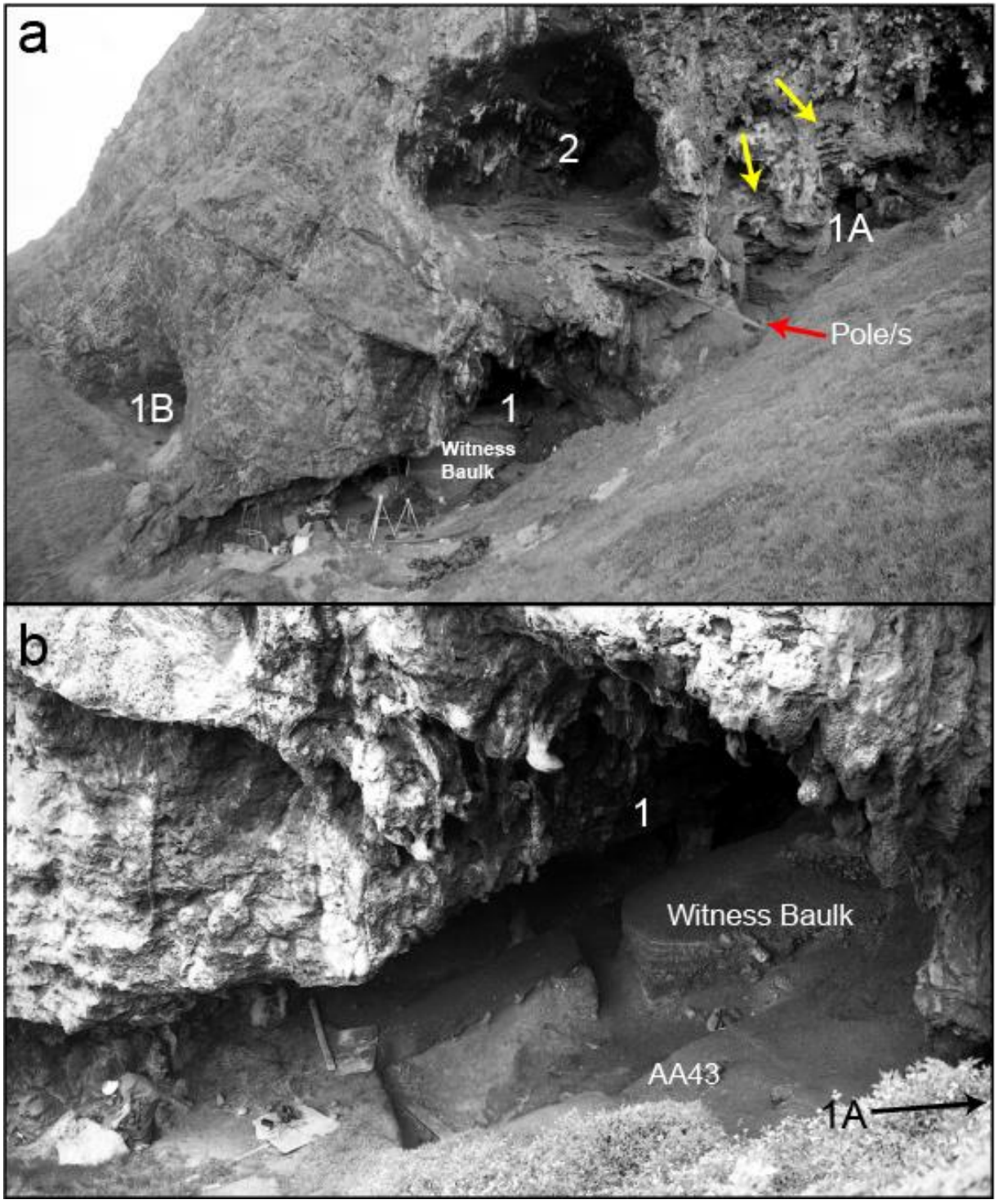

Figure 1.5. Two photographs of the KRM site complex from the Deacon archive. a) A view from the east near the base of the steep slope. The protection the cliff provides from the dominant westerly winds is obvious here, as is Cave 1B's relative exposure in this respect. The yellow arrows indicate cemented remnants of otherwise eroded deposits which formed part of former ground surfaces within Cave 1A. b) A closer view of the entrance to Cave 1 from the east prior to the excavation of AA43.

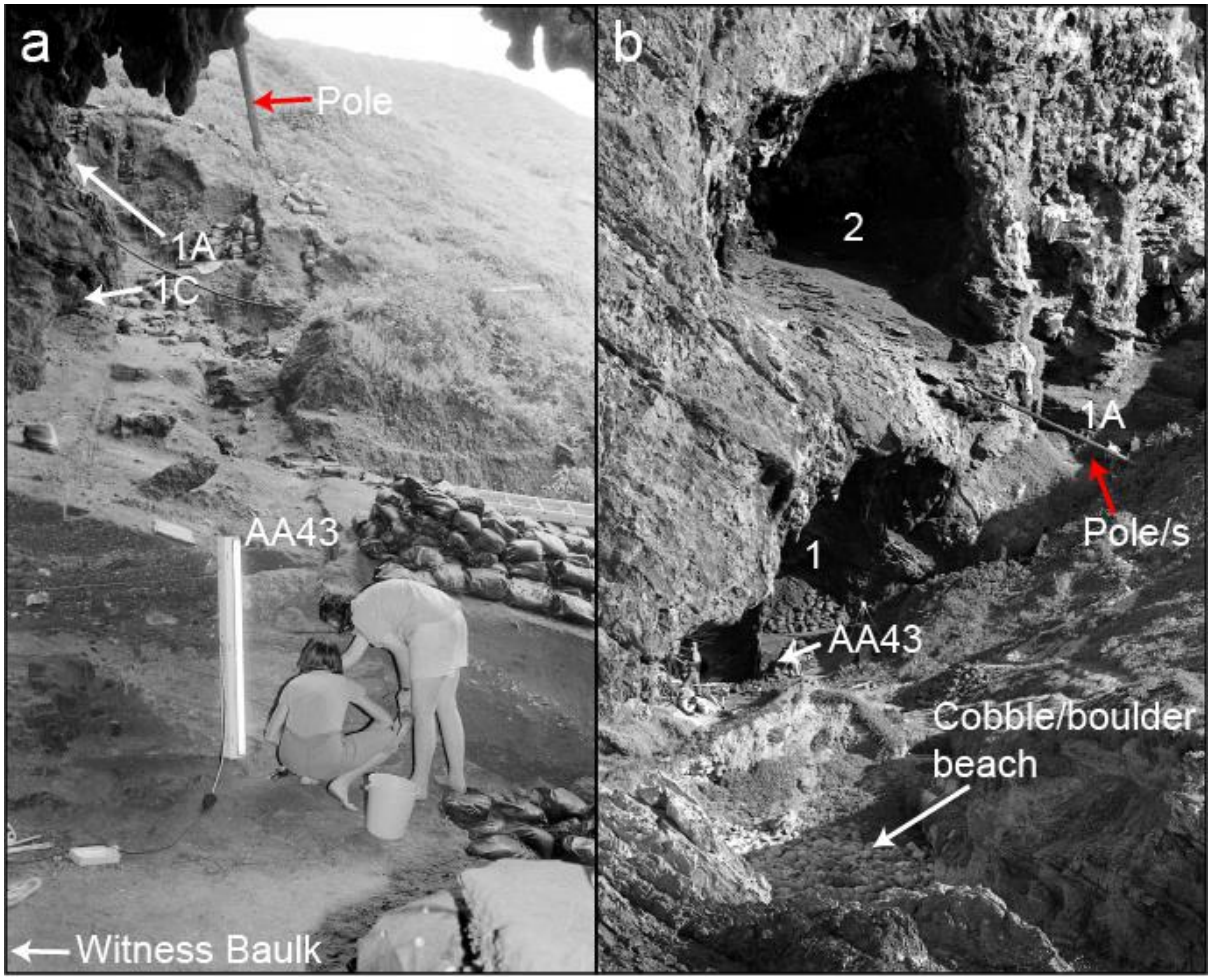

Figure 1.6. Two different views of the site complex, both from the Deacon archive. a) Looking west from a position just south of the Witness Baulk, prior to the excavation of AA43. Note the change in the angle of the rock just after the entrance to Cave 1C. The steep slope is largely parallel to the wall of Cave 1A, but the dip down towards Cave 1 is also visible. b) A southerly perspective, again showing the angles of the steep slope and the "corner" prior to the steeper rise of the deposits in Cave 1A.

The land surface within Cave 1A (prior to excavation) and adjacent to the shelter slopes seaward and towards Cave 1 at a steep angle (Figures 1.4 to 1.7). Cuttings through the slope (Figures 1.3 & 1.7) reveal that the archaeological deposits generally do not dip at the same angle as the slope, and that there is a clear succession of older material near the base of the slope and younger material at the top (Singer & Wymer, 1982; Deacon & Geleijnse, 1988; Deacon, 1995). This indicates that erosion has removed much of this sediment, creating a slope onto which some colluvial scree was subsequently deposited (Singer & Wymer, 1982; Deacon, 1995).

Figure 1.7. Different views of the slope to the east of the site complex (from the Deacon archive). a) Looking down towards Cave 1 from a position to the east of the Cave 1A overhang. b) Looking back up the same slope, with the protected area of Cave 1A to the left (the cuttings) and the adjacent slope to the right.

Cave 2 is notably shallower than Cave 1, but their entrance widths are similar (both ~10 m) (Figure 1.3). The southeast-facing entrance is around 18 m above sea level, meaning that a considerable quantity of sediment had to accumulate against the cliff for it to be accessible (Figure 1.4). The opening in the cliff is roughly triangular (Figures 1.4 & 1.5a), meaning that the deposits are relatively exposed despite the protection provided by the cliff and the overhang. The cave is currently inaccessible without ladders or ropes due to the erosion of the seaward portion of the sediment cone in Cave 1A and outside Cave 1 but would have formed a continuous area with Cave 1A at times in the past (Singer & Wymer, 1982). The cemented (but now largely eroded) deposits in the mouth of Cave 2 (Figures 1.5a & 1.6b) indicate that land surfaces were fairly horizontal or gently sloped across this space and that people could have walked into Cave 2. The floor of Cave 2 dips relatively steeply towards Cave 1A, meaning that

the accumulation of sediment in Cave 1A not only eventually enabled access to Cave 2, but also allowed the retention of sediment within Cave 2, and the subsequent build-up of deposits there, by effectively holding the sediment in place. It is possible that people may have accessed Cave 2 earlier in the history of KRM, when it had become possible to climb up into the cave from the land surface in Cave 1A, but that any cultural material they may have deposited was eroded out of the cave along with any geogenic or biogenic sediment.

The south-facing (seaward) Cave 1B is the most exposed to both the westerly and onshore winds, but still receives significant protection from the former (Figure 1.3). It is a small rockshelter, about 10 m wide and only a few metres deep. As with Cave 1, it is about 6 m above sea level at its lowest point. It is the only recess which is completely separated from the others by the bedrock (Figure 1.3). It is also separated from the slope (and associated colluvial sediment) to the east of the site complex, potentially reducing the amount of colluvial sedimentation. However, there is a slope within the shelter which, while notably gentler than that in Cave 1A (Figures 1.4 & 1.5a), also seems to be the product of erosion of one end of the shelter and subsequent formation of a capping scree deposit (Henderson, 1992).

1.1.4. The Klasies River Main site sequence

The current stratigraphic model used at KRM (Figure 1.8) is based on the grouping of identified sedimentary units (defined based on lithology and allostratigraphy) into members and (in some cases) sub-members using a complex combination of lithology, sedimentary and geomorphic properties, absolute and relative dating, archaeological stratigraphy, and biostratigraphy (Deacon & Geleijnse, 1988; Wurz et al., 2018). This system is used in tandem with the series of numbered layers excavated by Singer and Wymer (1982) due to the need to understand stratigraphic relationships between finds recovered during the different excavations and to contextualise these finds using all available geoarchaeological observations (Figure 1.8 & Table 1.1).

Deacon and Geleijnse (1988) recognised the following five members (in stratigraphic order from the base): Light Brown Sand (LBS), Shell and Sand (SAS), Rockfall (RF),

Upper, and White Sand (WS). The Rubble Brown Sand[1] (RBS), first published as a basal sub-member of the SAS, is now sometimes considered to be a distinct member between the LBS and SAS (e.g., Grine et al., 2017).

Typological and technological studies of the lithic assemblages excavated from KRM have allowed the grouping of deposits into a series of cultural phases (Singer & Wymer, 1982; Wurz, 2002). From oldest to youngest, they are the MSA I, MSA II, Howiesons Poort (HP), MSA III, and MSA IV. The MSA II, also known as the Mossel Bay, is divided into the MSA II lower and MSA II upper due to technological changes (Wurz, 2002), while three divisions are recognised in the HP (Villa et al., 2010). The MSA III and IV are also referred to as the Post-Howiesons Poort (Volman, 1984; Wurz, 2002).

MSA I assemblages have been recovered from the LBS and RBS, with both pre-dating 110 ka (Wurz, 2002; Wurz et al., 2022). The LBS is found across Caves 1, 1A and 1B (Deacon and Geleijnse, 1988). The RBS is present in Cave 1, but potentially correlating deposits have been identified in Caves 1A and 1B (Deacon and Geleijnse, 1988; Grine et al., 2017). The SAS (>110 – 64 ka) is associated with the MSA II and has been excavated in Cave 1, where it is split into several sub-members (Figure 1.8), and in Caves 1A and 1B. The RF (~80 – 53 ka) and Upper (~65 – 45 ka) Members are present in Caves 1A and 2, with the former seemingly associated with the MSA II and the latter yielding HP and Post-HP lithics (Deacon & Geleijnse, 1988; Wurz, 2002). Finally, the MSA IV-bearing WS (~70 – 56 ka) is restricted to Cave 1 (Deacon & Geleijnse, 1988).

It is important to note that the members have overlapping age ranges. This is due to the use of a wide variety of dating techniques, with differing degrees of accuracy depending on the specific material dated, the known or assumed provenience of the material, the general limitations of the technique, and how technologically and/or theoretically advanced the state of the dating technique was when the study was

[1] As will be discussed in later chapters, the deposits that Hilary Deacon assigned to the RBS are now referred to as the Silty Black Soils (SBLS) due to new observations and interpretations. Both terms are used in different parts of this thesis as thinking about this problem evolved over time, and RBS is still often used in literature written by workers external to the Wurz team based on past publications about the deposits. As will also be discussed, the term “soil” has often been applied to deposits at KRM which are not pedogenic in nature.

conducted. This has implications for the use of chronostratigraphy to correlate deposits across space, and for linking the KRM sequence to global and regional events.

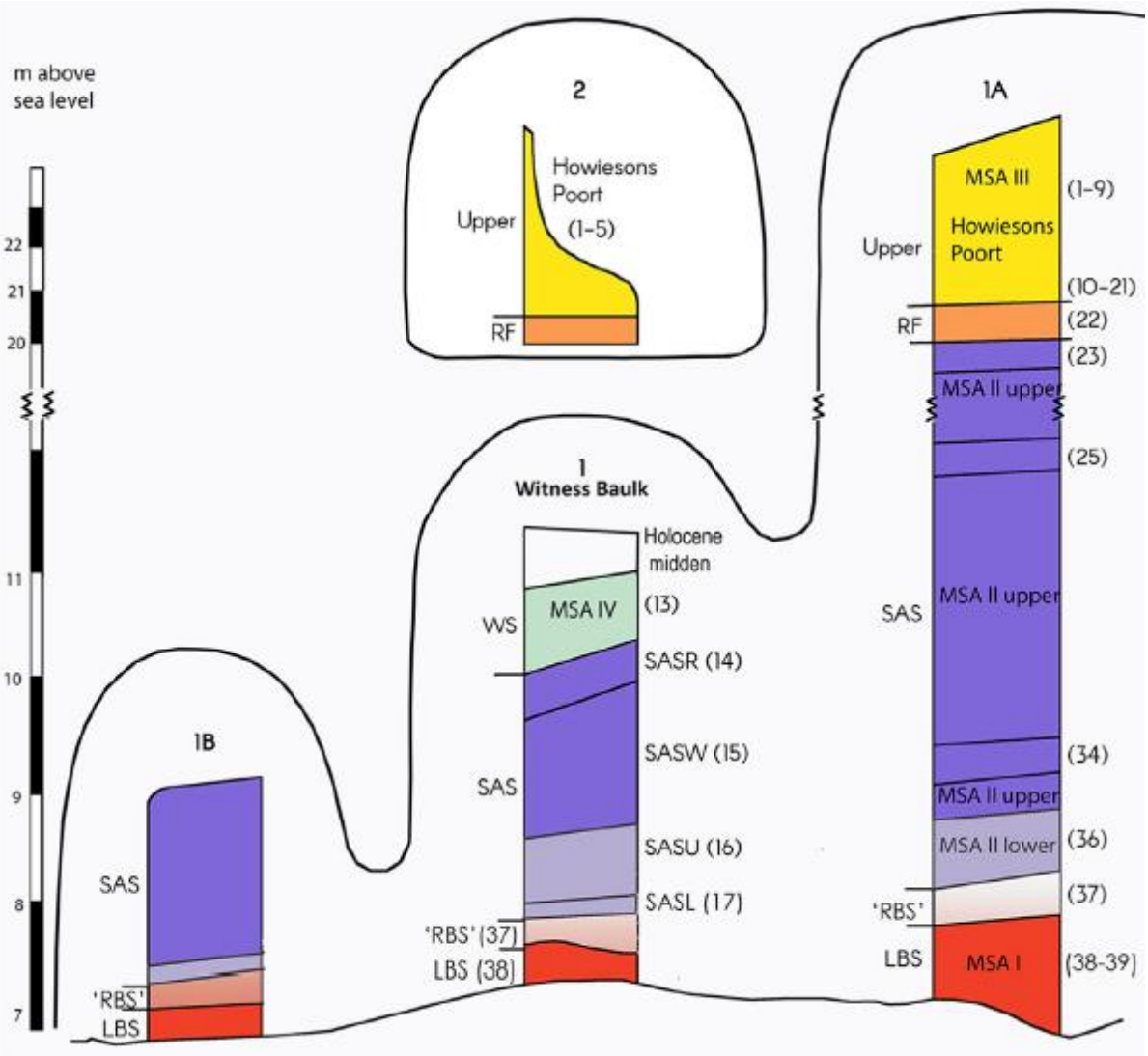

Figure 1.8. Simplified stratigraphy of the Klasies River Main site complex (Wurz et al., 2022). Numbers in brackets indicate the layers from the original excavations (Singer & Wymer, 1982) which are associated with the members or sub-members. Note that there are few direct correlations between SAS deposits in Cave 1 and Cave 1A, and Cave 1B is physically separated from the other recesses. SASL = SAS Lower; SASU = SAS Upper; SASW = SAS Wedge; SASR = SAS Rubble.

Faunal assemblages, including shell, have been recovered from all the members and sub-members and have been used to varying degrees for different members to reconstruct human diet and palaeoenvironmental conditions (Klein, 1976; Voigt, 1982; Thackeray, 1988; Langejans et al., 2017; Reynard & Wurz, 2020). These proxies include the analysis of oxygen isotopes from *Turbo sarmaticus* opercula (Shackleton,

1982; Loftus et al., 2017; Thackeray, 2018). Palaeoenvironmental interpretations have also been made from the properties of the sediments in many, but not all, members (Butzer, 1982a; Deacon & Geleijnse, 1988). The same is true for micromammal assemblages (Avery, 1987; Nel et al., 2018).

The palaeoenvironmental research has provided information on a wide range of environmental variables, including: moisture levels inside Cave 1, sea levels (and distance between the site complex and the shoreline), sea surface temperatures, the geomorphology of the shoreline near the site, and the vegetation in the vicinity of the complex (with implications for the climatic conditions and geomorphic factors, including the amount of land exposed or covered due to sea level change). The general environmental sequence is summarised in Figure 1.9.

This paleoenvironmental work has not only provided vital context for understanding the human occupations at KRM during these changing conditions. A recent reconstruction of conditions during the MSA I using large mammal assemblages has led to the recognition that the conditions around KRM were more consistent with the colder MIS 6 than with the interglacial MIS 5e (Reynard & Wurz, 2020). Subsequent absolute dating of the basal MSA II deposits to older than 110 ka now suggests that an older date for the MSA I is highly likely (Wurz et al., 2022).

1.2. Rationale

The finds from KRM dating to the MSA I and II have been excavated from different areas across the site complex which can seldom be linked stratigraphically due to erosion and the removal of sediment during the 1967-68 excavations (Singer & Wymer, 1982; Deacon & Geleijnse, 1988). Although there are (or more often, were) continuous deposits between some of the excavated recesses, each is effectively an individual site with varying degrees of exposure to the elements and differing chances of various types of sediment entering them at different times in the past. Beyond potential differences in natural sedimentation and post-depositional processes, these recesses would have differed in their degree of attractiveness for various human activities. Intra-site variation in conditions is also an important factor, as there are different depositional and diagenetic environments within each cave or shelter.

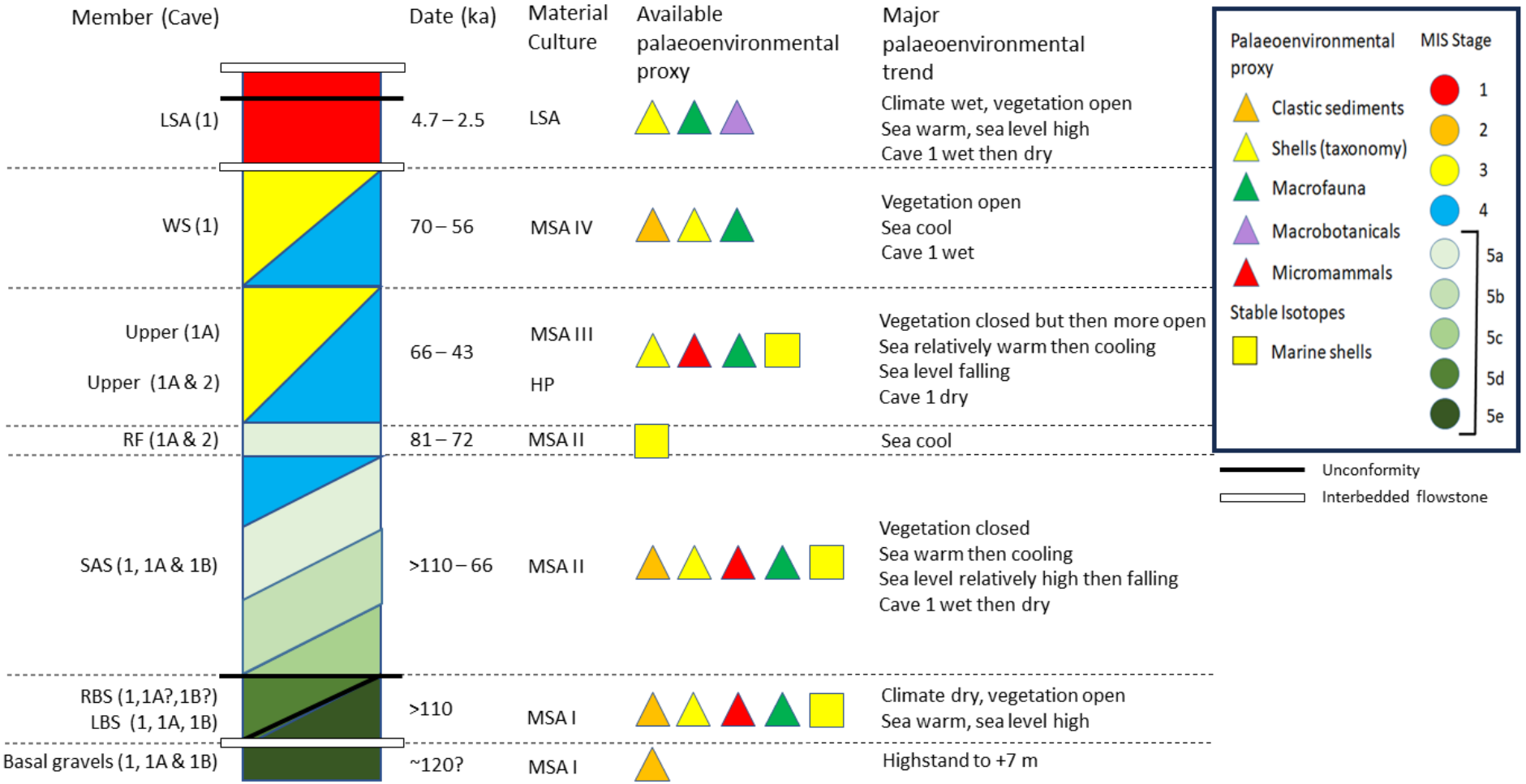

Figure 1.9. A simplified single stratigraphic column for Klasies River Main site, with the Marine Isotope Stage associations for each member, the lithic cultural phases, palaeoenvironmental proxies, and major paleoenvironmental interpretations for each member (modified from Stratford et al., 2021). Growing evidence for the MSA I starting to form prior to 120 ka suggests that the basal gravels may date to an older highstand, as suggested by Hendey and Volman (1986).

A lack of detailed recording, and the paucity of published data relative to the scale of the site complex and sequence mean that there are significant uncertainties regarding stratigraphic correlations that have been made between these areas, and between recorded profiles and some excavated materials. This means that spatial (both within and between the different recesses) and temporal patterns in the excavated material cannot be explored securely. Absolute dates are also comparatively limited given the time depth of the sequence and the number of separate areas, and it is common for potentially contemporaneous deposits in different parts of the site complex to have been dated with different techniques or for absolute dates to only be available in one area per lithostratigraphic member (see Grine et al., 2017 for a review of the dates).

Most of the research into the formation of deposits at KRM has been broadly focused, with the goal of elucidating site-scale processes which acted over long periods of time (e.g., Butzer, 1982a; Deacon & Geleijnse, 1988). The site complex's numerous anthropogenic features and deposits have been recognised as highly significant for understanding human behaviour for more than three decades, but only macroscale analysis and description was possible as microscale approaches were not yet widely available in South Africa (Henderson, 1992; Deacon, 1993, 1995). Depositional and post-depositional processes in contexts like KRM can be extremely complex and vary considerably through time and space, with a variety of geogenic, biogenic and anthropogenic inputs potentially playing a role (Goldberg & Sherwood, 2006; Goldberg & Berna, 2010; Mallol & Goldberg, 2017). Recent microcontextual analysis of thin sections collected from deposits across much of the site complex has provided a detailed understanding of the formation and diagenesis of the sampled deposits (Larbey et al., 2019; Wurz et al., 2022). As these studies focused on anthropogenic features, they have also provided evidence for a range of behaviours which cannot be identified at the macroscale.

The LBS, RBS, and SAS deposits in the Witness Baulk in Cave 1 are the focus of on-going excavation and multidisciplinary research (Wurz et al. 2018, 2022; Brenner et al., 2022). Hilary Deacon began excavating a 1.5 m by 1.5 m portion of the baulk in the 1990s (Deacon, 1995), with Sarah Wurz resuming the excavation of this area in 2015 (Wurz et al., 2018). The goal was/is to excavate assemblages at very high spatial and stratigraphic resolution in order to provide more nuanced understandings of

human behaviour and site formation processes, and to aid in interpreting the assemblages recovered at lower resolution from around the Witness Baulk by John Wymer.

Despite research conducted since the 1960s, several stratigraphic uncertainties hinder intra-site correlations, and little detailed information is available on their formation (Butzer, 1982a; Singer & Wymer, 1982; Deacon & Geleijnse, 1988; Rightmire & Deacon, 1991, 2001; Deacon & Schuurman, 1992; Deacon, 2008; Grine et al., 2017; Wurz et al., 2018) except for a few anthropogenic features which have been studied at the microscale (Larbey et al., 2019; Wurz et al., 2022). There has also been limited consideration of how spatial patterns in site formation processes may impact the stratigraphy. This hampers interpretations of assemblages from the Witness Baulk as it is unknown if they have been modified by site formation processes, and nuanced comparisons with assemblages from different areas of the site are difficult or impossible.

The current field research programme would benefit from an improved understanding of the stratigraphic relationships between the deposits in the Witness Baulk and in other parts of KRM. It is also vital to understand if, and how, the assemblages that have been (and will be) excavated from there have been modified by post-depositional processes, and how spatial variation in these processes might hinder stratigraphic correlation. Whilst recent high-resolution work targeting the formation of hearth features within the Witness Baulk is highly informative (Larbey et al., 2019; Wurz et al., 2022), more work is needed to better understand natural and anthropogenic site formation processes in other parts of the baulk at a higher resolution than the published macroscale work currently allows.

Cave 1B is a particularly problematic area of the site from the perspective of stratigraphic correlation as there are no extant linking deposits and it is physically separated from Caves 1 and 1A by the bedrock (Singer & Wymer, 1982; Deacon & Geleijnse, 1988). The sedimentary characteristics and stratigraphy of this small rockshelter have been published in far less detail than the rest of the site, even though the relationships between the Cave 1B deposits and those in the rest of the site complex have proven to be particularly contentious (Binford, 1984, 1986a,b; Singer &

Wymer, 1986; Thackeray, 1986; Deacon & Geleijnse, 1988). Furthermore, correlations between the stratigraphy of the 1967-1968 excavation and that carried out by the Deacon team have never been published in detail (Deacon & Schuurman, 1992; Henderson, 1992; Wurz, 2002; Deacon, 2008; Grine et al., 2017). Clarifying the stratigraphy and formation of these deposits would contribute significantly to improving our understanding of inter-area stratigraphic correlations while also providing insight into spatial variation in site formation processes across the site complex.

1.3. Research questions and aims

Ultimately, this project intends to answer the following three research questions:

1. What are the stratigraphic relationships between the basal deposits (layers assigned to the LBS, RBS and SAS Members/Sub-members) at Klasies River Main site, both within and between Caves 1, 1A and 1B?

2. What geogenic, biogenic and anthropogenic processes were involved in the formation and post-depositional alteration of the deposits in Cave 1B?

3. What geogenic, biogenic and anthropogenic processes were involved in the formation and post-depositional alteration of the basal deposits in the Witness Baulk of Cave 1?

This project is developed around three basic aims:

1. To clarify the stratigraphy of the basal deposits (LBS, RBS and SAS Members/Sub-members) at Klasies River Main site across Caves 1, 1A and 1B using published information and/or new observations of lithostratigraphy, allostratigraphy, cultural stratigraphy, chronostratigraphy, and biostratigraphy.

2. To determine – using data from micro- and macroscale analyses – what depositional and post-depositional processes were involved in the formation of the deposits in Cave 1B.

3. To determine – using data from micro- and macroscale analyses – what depositional and post-depositional processes were involved in the formation of the layers assigned to the LBS, RBS and SAS in the Cave 1 Witness Baulk.

1.4. Thesis structure

This thesis comprises three co-authored papers and three chapters which contextualise and expand on the papers. The two published papers are presented as published.

Chapter 2 is a review of the history of geoarchaeological research in the MSA of South Africa, detailing changes in approaches and research foci and the introduction of new techniques. Along with providing context to the work presented here, this also introduces the approach and techniques I used. This chapter will be converted into a paper and submitted for review.

Chapter 3 is a published journal article (Morrissey et al., 2022):

Morrissey, P., Mentzer, S. M. & Wurz, S. (2022). A critical review of the stratigraphic context of the MSA I and II at Klasies River Main site, South Africa. *Journal of Paleolithic Archaeology*, 5, 5.

Morrissey et al. (2022) is a review of the extensive and often confusing body of literature relating to the stratigraphy of the site complex, with a particular focus on the more complicated MSA I and II deposits. This work leads to a better understanding of the stratigraphic system in use, identifies areas or deposits in particular need of study, and lays a platform for the following chapters and future stratigraphic work. This paper is reproduced with permission from Springer Nature.

I conducted the research and wrote most of the manuscript, with suggestions and small contributions to the text from Dr Mentzer and Prof. Wurz.

Chapter 4 is a published journal article (Morrissey et al., 2023):

Morrissey, P., Mentzer, S. M. & Wurz, S. (2023). The stratigraphy and formation of Middle Stone Age deposits in Cave 1B, Klasies River Main site, South Africa, with implications for the context, age, and cultural association of the KRM 41815/SAM-AP 6222 human mandible. *Journal of Human Evolution*, 183, 103414.

Morrissey et al. (2023) is a multiscale study of deposits in the understudied rockshelter known as Cave 1B. The results provide a significantly more nuanced understanding of the formation and stratigraphy of the deposits, including insight into the structuring of space in the shelter and differing occupational intensities. Correlations between two different stratigraphic systems (of very different resolutions) also address a long-running debate over the age of a significant human fossil.

I described the deposits in the field and analysed thin sections of samples collected by Dr Mentzer, who also created elemental maps of the thin sections and oversaw my analysis. I interpreted the results and wrote most of the manuscript, with input and suggestions in both regards from Dr Mentzer and Prof. Wurz.

Chapter 5 is a submitted journal article (Morrissey et al., submitted):

Morrissey, P., Wurz, S., Ligouis, B., & Mentzer, S. M. (submitted). Burning, cleaning, dumping and dissolution: insights into the role of human behaviour and diagenesis in the formation and stratigraphy of pre-110 000-year-old MSA I deposits in Cave 1, Klasies River Main site, South Africa. *Geoarchaeology*.

This paper reports on the microscale analysis of MSA I deposits in the Cave 1 Witness Baulk. The samples were collected further into the cave than those previously published (Larbey et al., 2019; Wurz et al., 2022) to include a greater variety of deposits. The results reveal the significant role human activities and diagenetic processes played in forming the deposits and allow insights into how spatial patterning in both influences lithostratigraphy. Temporal patterns in the frequency and intensity of occupations may reflect behavioural adaptations to changing conditions before and/or during the Last Interglacial. This chapter is presented as a manuscript with

some minor formatting changes for the thesis. The supporting information is included in the chapter.

I described the deposits in the field and collected micromorphology samples. Dr Mentzer scanned the thin sections to make elemental maps, and Dr Ligouis conducted organic petrology analysis on one of the samples. I analysed the thin sections and collected micro-FTIR spectra from them. I interpreted the results (other than the organic petrology) and wrote most of the manuscript, with Dr Mentzer and Prof. Wurz providing input and suggestions regarding both interpretations and writing. Dr Mentzer adapted the organic petrology results (presented in the Supporting Information for the paper) from a report written by Dr Ligouis.

Chapter 6 is a synthesis and discussion of the results of the study, with a focus on general site formation patterns and their implications for understanding human behaviour and for stratigraphic correlation of the studied deposits. The chapter also includes a discussion of limitations and possibilities for future research. Finally, the conclusions of the study are presented.

CHAPTER 2. GEOARCHAEOLOGICAL APPROACHES TO THE MIDDLE STONE AGE OF SOUTH AFRICA

2.1. Geoarchaeology

The definition of geoarchaeology in the first edition of *Encyclopedia of Geoarchaeology* is, “the archaeological subfield that uses the methods of geological investigation to gather information and solve problems in the exploration of the human past” (Gilbert et al., 2017, p. xxvii). Such a broad definition is not without its drawbacks and is not universally accepted (see discussion in Cannell, 2012). However, a broad definition for geoarchaeology is also useful, as it does not restrict geoarchaeologists to specific time periods, contexts, or questions (Miller, 2011). Instead, we are only constrained by the limitations of our techniques and approaches, and by the nature of the (geo)archaeological record itself.

The term geoarchaeology was first used in a published work in 1973 in a study of the open-air Acheulian site at Amanzi Springs, South Africa (Butzer, 1973a). However, the general concept of the application of geological techniques and ideas to the archaeological record is much older (Butzer, 1982b, pp. 35–36; Hill, 2017). Since geoarchaeology first emerged as a distinct discipline within archaeology, it has been used to address a variety of questions relevant to the study of past human behaviour, using a wide range of analytical techniques at different scales. A non-exhaustive list includes: 1) identifying human behaviours from the study of anthropogenic features and deposits (e.g., Goldberg et al., 2009; Sherwood & Kidder, 2011; Karkanas et al., 2015; Macphail et al., 2022); 2) determining the impacts of site formation processes on the integrity of archaeological assemblages and anthropogenic deposits (e.g., Petraglia & Potts, 1994; Schiegl et al., 1996; Fowler et al., 2004); 3) helping to clarify stratigraphic relationships between sites or deposits within sites (e.g., Butzer, 2004; Karkanas & Goldberg, 2010); and 4) reconstructing past climatic and/or environmental conditions associated with human occupations of individual sites or broader landscapes (e.g., Butzer et al., 1978; Courty & Vallverdu, 2001; Morrissey et al., 2020; Sulas et al., 2022).

In South Africa, research by specialist geoarchaeologists is largely limited to Stone Age sites. Only a handful of studies of Iron Age sites or landscapes have been

published (e.g., Fowler et al., 2004; Sulas et al., 2022), and I am only aware of one study of a historical context (Berna, 2017a).

Microscale geoarchaeological approaches (primarily micromorphology) have been applied to Earlier Stone Age (ESA) and Later Stone Age (LSA) deposits (e.g., Berna et al., 2012; Herries et al., 2022; Rhodes et al., 2022; Wurz et al., 2022), and have been used to understand an important landscape occupied by farming communities during the Iron Age (Sulas et al., 2022). However, they have been used most widely and regularly in the study of the Middle Stone Age (MSA) (Mentzer, 2023).

This chapter describes the evolution of geoarchaeological research in the MSA of South Africa. Klasies River Main (KRM) site (Figure 2.1) has seen multiple generations of geoarchaeological analysis since the late 1960s, with differing research foci, analytical techniques, scales of analysis, and ways of thinking about the (geo)archaeological record (Singer & Wymer, 1982; Deacon, 1995; Wurz et al., 2018). This pattern is common in the research histories of MSA sites in the country (see Figure 2.1 for the locations of South African sites named in the text), many of which have seen multiple phases of investigation and re-investigation, often due to improvements in the scale of excavation and recording techniques (e.g., Porraz et al., 2013, 2015; Backwell et al., 2018; Val et al., 2021).

Here I divide the history of the field in South Africa into two rough periods, falling before and after the first published application of archaeological micromorphology in the country by Paul Goldberg (2000). The timing of Goldberg's seminal (for the region) publication on site formation at Die Kelders conveniently places this split at the turn of the millennium. Although the latter period is associated with the paradigm shift brought about by the introduction of the microscale approach to geoarchaeology, there are also important continuities in thought and technique from the twentieth century.

2.2. Twentieth Century geoarchaeology in South Africa

Early geoarchaeological research in South Africa was dominated by Karl Butzer. Starting in the 1960s, he studied deposits at numerous Stone Age sites (Figure 2.1), including Border Cave, Diepkloof, Die Kelders, Elands Bay Cave, Florisbad, KRM, Montagu Cave, Nelson Bay Cave, and Wonderwerk (Butzer, 1973b,c, 1978, 1979a,b,

1982a, 1984a, b, 1988; Butzer et al., 1978). Studies on Bushman Rock Shelter, Heuningneskrans, and Rose Cottage Cave were carried out and presented at a conference, but never published (Butzer & Vogel, 1979). However, some observations were presented in published works (e.g., see Butzer, 1984a cited in Porraz et al., 2015).

Butzer's work was conducted at the site-scale, with the major goal being to identify and characterise major lithostratigraphic units within the site sequence. Field descriptions were supplemented with data from various standard sedimentological analyses conducted on bulk samples (e.g., particle size and shape, and carbonate content). Distinct facies (including potential anthropogenic features) were reported within the coarser lithostratigraphic units, but typically only those deemed to be geogenic (or to contain sufficient geogenic input) were described and incorporated into the overall interpretation of each major unit. The large bulk samples he analysed appear to have often incorporated sediment from multiple facies, especially at finely stratified sites.

Butzer's focus was typically on understanding the lithostratigraphy of the sites he studied. He then used these lithostratigraphic sequences to reconstruct palaeoenvironmental conditions within the site, and to attempt to link the local sequence to regional or even global environmental records (e.g., Butzer, 1973b, 1979a, 1982a; Butzer et al., 1978). Placing sites within these broader records was identified as being a major goal for geoarchaeological research (Butzer, 1982b: 69–76), as was common in Europe and the Levant at the time (e.g., Laville, 1973; Farrand, 1979). However, his work in South Africa seldom considered other common geoarchaeological questions, such as the effects of site formation processes on archaeological assemblages, and the role of anthropogenic sedimentation (Goldberg & Macphail, 2006). His study of the KRM sequence stands out from this pattern as he explicitly discussed anthropogenic sedimentary components and facies and provided some interpretation of their presence or formation, although this was still not a major focus of the work (Butzer, 1982a, p. 41).

Die Kelders was one of the few MSA cave sites studied from a geoarchaeological perspective by someone other than Karl Butzer during this period. Tankard and

Schweitzer (1974, 1976) used a similar theoretical and analytical approach, and focused mainly on reconstructing the palaeoenvironmental sequence of the site, with a particular emphasis on sea level fluctuations. However, they also identified alternating types of deposit which they interpreted as being the product of periods of occupation and abandonment.

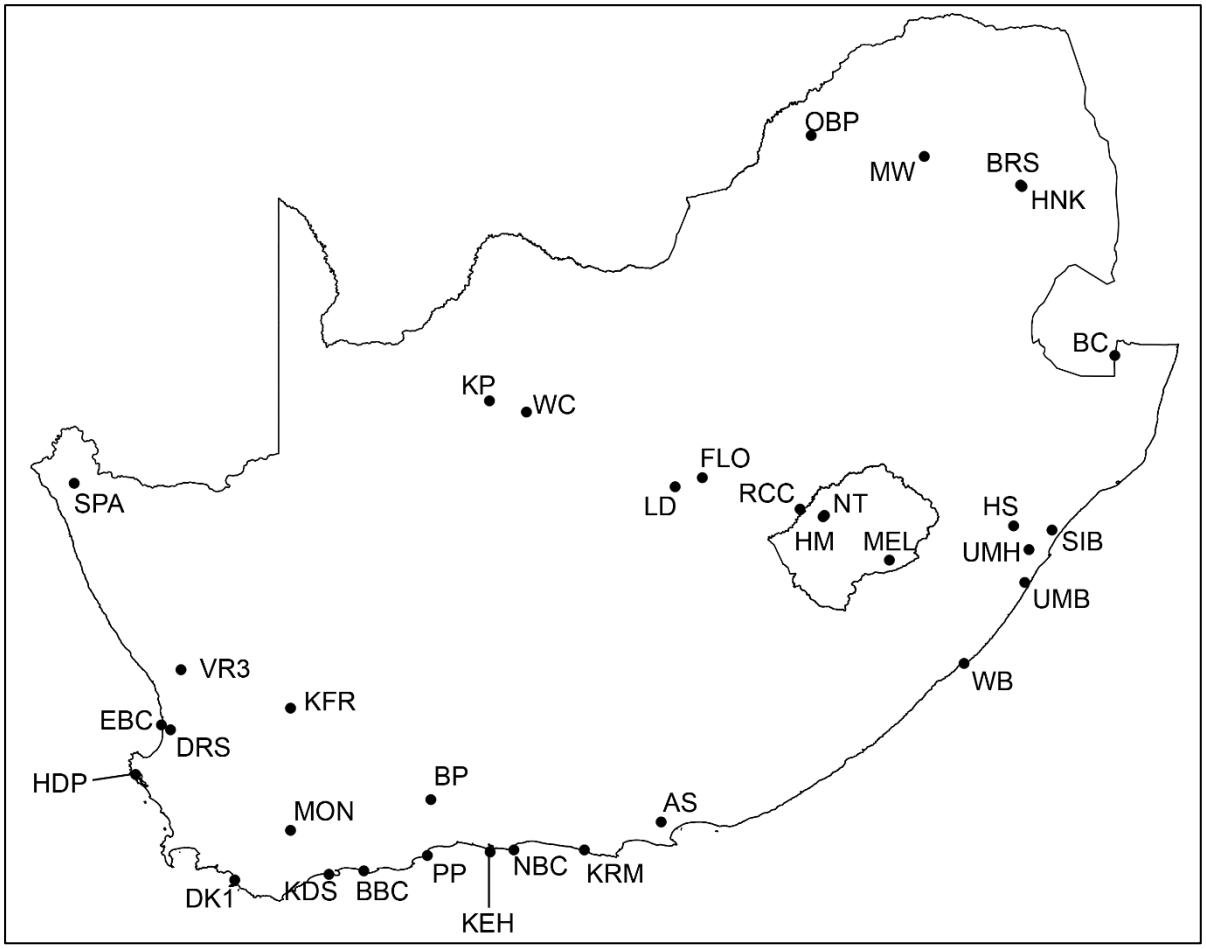

Figure 2.1. Map of South African sites mentioned in the text of Chapter 2. AS = Amanzi Springs, BBC = Blombos Cave, BC = Border Cave, BP = Boomplaas, BRS = Bushman Rock Shelter, CK = Canteen Kopje, DK1 = Die Kelders Cave 1, DRS = Diepkloof Rockshelter, EBC = Elands Bay Cave, FLO = Florisbad, HA = Ha Makotoko, HNK = Heuningneskrans, HDP = Hoedjiespunt 1, HS = Holley Shelter, KP = Kathu Pan, KRM = Klasies River Main site, KDS = Klipdrift Shelter, KFR = Klipfonteinrand, KEH = Knysna Eastern Heads, LD = Lovedale, MEL = Melikane, MON = Montagu Cave, MW = Mwulu's Cave, NBC = Nelson Bay Cave, NT = Ntloana Tsoana, OBP = Olieboomspoort, PP = Pinnacle Point, RCC = Rose Cottage Cave, SIB = Sibhudu Cave, SPA = Spitzkloof A, UMB = Umbeli Belli, UMH = Umhlatuzana, VR3 = Varsche Rivier 003, WB = Waterfall Bluff, WC = Wonderwerk Cave.

In 1982, Butzer published *Archaeology as human ecology*, in which he considered methodological and theoretical approaches to studying the relationships between past human populations and the environments they occupied (Butzer, 1982b). Drawing on his large body of work in South Africa, Egypt, Ethiopia, Europe, the Middle East, and

the United States, he made important observations on the practice and theory of geoarchaeology at the time, including critiquing his own approach to some studies (e.g., Butzer, 1982b, p. 37), and suggested a framework for future work. He also placed greater emphasis on anthropogenic and biogenic sedimentation, and the modification of the archaeological record by site formation processes, than in his previous work.

Two significant aspects of the geoarchaeological approach he recommended were the recognition of the need to focus on identifying and interpreting the facies which form in distinct "depositional microenvironments" (Butzer, 1982b, p. 44), and the importance of clarifying the detailed "microstratigraphy" of archaeological sites as a starting point of geoarchaeological research which would involve integration with multiple levels of stratigraphic resolution (Butzer, 1982b, p. 69). His use of these terms differs from how they would be understood now – as entities which would be identified and studied under magnification using micromorphology and other micro-analyses (Courty, 2001; Goldberg & Berna, 2010) – but the recognition of the potential for multiple scales of analysis was significant, even if those scales were all macroscopic in nature. It is important to note that the idea of starting from detailed "microstratigraphy" and then working up to more generalised lithostratigraphy is at odds with the approach he typically used in South Africa where he had to base his studies on the coarser excavation units delineated by the archaeologists who excavated the sites (e.g., Butzer et al., 1978; Butzer, 1982a).

Butzer (1982b, pp. 79–87) was also, along with Paul Goldberg (1979a), one of the earliest geoarchaeologists to recognise the significant role humans play in forming deposits in occupied caves. Importantly, this included the fact that they can alter natural and anthropogenic deposits after their deposition through a variety of different processes. However, the presence of anthropogenic materials and the possible mixing of deposits (e.g., through trampling) was viewed more as a complicating factor for understanding natural sedimentation (and thus, palaeoenvironmental conditions) than as an opportunity to study human behaviour (Butzer, 1982b, pp. 82–87).

Butzer stopped doing fieldwork in South Africa around 1982, with his final twentieth century publications on the South African MSA coming out later in the 1980s (Butzer,

1984a,b, 1988). However, geoarchaeological research into the MSA did not come to a complete stop. Deacon and Geleijnse's (1988) study of the sequence at KRM used the same general approach as Butzer had used in South Africa, with data collected through field descriptions and the sedimentological analysis of bulk samples. In contrast to Butzer's approach at KRM, individual macroscopically distinguishable deposits were studied within broader groupings, with a greater focus on the differences between deposits interpreted as occupational and non-occupational. This study and subsequent work by Deacon and various colleagues at KRM did include some focus on palaeoenvironmental conditions, but there was far greater consideration of the impacts of post-depositional processes on artefacts and features, and more interest in anthropogenic deposits and features (Deacon & Geleijnse, 1988; Henderson, 1992; Deacon, 1993, 1995, 2008). Significant behavioural interpretations of hearths and shell middens were made, culminating in the argument that MSA people at KRM structured and managed space within the site in the same way that LSA populations had at several studied sites (Deacon, 1989, 1993, 1995).

Despite Deacon's interest in anthropogenic deposits, and the information they could provide about the people who produced them, he lacked the methodological means to better understand their formation. However, by the time his fieldwork programme at KRM came to an end in 1995 there was a growing recognition of the need to view deposits at archaeological sites as the product of human behaviour (to varying extents), and that studying them accordingly would reveal behavioural insights (Shahack-Gross, 2017). Consequently, the development of a high-resolution approach to the study of anthropogenic features was already underway (Courty et al., 1989; Goldberg & Berna, 2010; Mentzer, 2014; Goldberg et al., 2017), and the first microscale study of an archaeological site in South Africa had begun (Goldberg, 2000).

2.3. New millennium; new approaches

Paul Goldberg's (2000) study at Die Kelders utilised the microscale technique most frequently applied in microscale geoarchaeological studies: archaeological micromorphology. This technique entails the microscopic analysis of thin sections cut from resin-impregnated oriented block samples (Goldberg & Macphail, 2003) and allows the in situ identification of the components and structures within sediments at

high resolution (Courty et al., 1989; Macphail & Goldberg, 2018; Karkanas & Goldberg, 2019). Unlike with the analysis of bulk samples, micromorphology makes it possible to determine the arrangement of sedimentary components within deposits (Goldberg & Berna, 2010; Macphail & Goldberg, 2018; Stoops, 2021). This allows for the interpretation of a wider range of depositional and post-depositional processes, including those represented by deposits or features too small to be identified and studied at the macroscale (Goldberg & Berna, 2010; Mallol & Mentzer, 2017; Macphail & Goldberg, 2018).

Archaeological micromorphology is an offshoot of soil micromorphology, a discipline dating back to the 1930s (Kubiëna, 1938). The first applications of soil micromorphology to archaeological sites took place in the 1950s (Cornwall, 1958; Dalrymple, 1958), but it was only from the late 1970s/early 1980s that they started to become more common (Goldberg, 1979a,b,c, 1980, 1983; Macphail, 1983), eventually resulting in the emergence of archaeological micromorphology as a distinct, but closely related, field (Courty et al., 1989).

Early applications of micromorphology to cave sediments were presented as a means to provide greater nuance and account for anthropogenic site formation processes and natural post-depositional processes when attempting to obtain 'pure' palaeoenvironmental signals (Goldberg, 1979a,b). Butzer (1982b, Table 3.2) acknowledged the potential of micromorphology, even if it was only considered "complementary" to the more established analysis of bulk samples. By the time archaeological micromorphology was established, however, it was recognised that there was significant potential for studying human behaviour and assessing the integrity of archaeological deposits using the technique (Courty et al., 1989).

Unsurprisingly given its origins, archaeological micromorphology draws heavily on descriptive and interpretive guidelines from soil micromorphology (e.g., Bullock et al., 1985; Stoops et al., 2018; Stoops, 2021). However, the presence of anthropogenic components and/or deposits and the common occurrence of non-pedogenic geogenic (and biogenic) sediments have necessitated the development of distinct terminology and interpretative approaches tailored to differing contexts and research goals (Courty et al., 1989; Nicosia & Stoops, 2017; Macphail & Goldberg, 2018). Archaeological

micromorphology has proven to be an extremely powerful tool for studying anthropogenic deposits, especially when they are poorly preserved or difficult to distinguish at the macroscale (Goldberg & Berna, 2010; Goldberg et al., 2017).

Goldberg's (2000) micromorphological work at Die Kelders confirmed some conclusions of the macroscale research conducted by Tankard and Schweitzer (1974, 1976). However, the new microscale approach revealed that some previously identified 'occupational' and 'non-occupational' units had more nuanced formation histories, involving geogenic, biogenic, and anthropogenic processes. This, along with a greater understanding of post-depositional processes, helped to improve interpretations of human behaviour and the modification of behavioural proxies in different parts of the sequence (Goldberg, 2000; Marean et al., 2000). Furthermore, it challenged previous palaeoenvironmental interpretations (Tankard & Schweitzer, 1974, 1976) by demonstrating that the proportion of marine shell fragments in aeolian sand deposits was influenced by post-depositional dissolution of calcite and thus, was not an accurate proxy for the distance between the cave and the shoreline.

Although the publication of the Die Kelders study (Goldberg, 2000) was a significant moment in the history of geoarchaeology in South Africa, the subsequent work at Sibhudu Cave expanded the development of microscale geoarchaeological research in the country (and the broader southern African region) to include several other techniques. Fourier transform infrared spectroscopy (FTIR) analysis of small bulk samples was used to identify different minerals within the sediments in order to characterise diagenetic processes and determine their impacts on the archaeological record within the site (Schiegl et al., 2004; Schiegl & Conard, 2006). Microscale analyses of phytoliths (Schiegl et al., 2004; Schiegl & Conard, 2006) and plant materials (Wadley et al., 2011) were also carried out. However, (unlike earlier work at Hayonim Cave and Kebara Cave in Israel [Schiegl et al., 1996]) the micromorphology (Goldberg et al., 2009) and other analyses at Sibhudu Cave were not integrated to form a single unified microcontextual approach (Mentzer, 2023).

The other major difference between Sibhudu and Die Kelders was that the identification and interpretation of anthropogenic site formation processes received far greater attention at Sibhudu. The microscale analysis of features provided evidence –

invisible or ambiguous at coarser resolution – for multiple human activities, including several distinct site maintenance behaviours such as sweeping out hearths and burning stale bedding, and gave insight into changes in occupational intensity through the sequence (Goldberg et al., 2009; Wadley et al., 2011).

The results from Sibhudu are also notable for contributing (along with insights from other sites) to the formal articulation of an important geoarchaeological theoretical and methodological perspective. This is the recognition that many deposits at archaeological sites are partly or wholly formed by human behaviour and thus, are themselves artefacts, rather than simply a sedimentary matrix within which artefacts can be found (Miller, 2011). Significantly, this extends beyond deposits of obvious anthropogenic origin, like well-preserved hearths, to include a wider variety of anthropogenic site formation processes and deposits which have been altered after deposition. Viewing deposits as artefacts, and studying their formation accordingly, allows the inference of various human behaviours which might not be discernible from the analysis of other artefact types (Miller, 2011). Given the complexity of site formation processes and the need to disentangle natural and anthropogenic site formation processes in the (geo)archaeological record, micromorphology (and supporting micro-analyses) is vital for achieving the potential of this way of thinking about deposits. As demonstrated in the rest of this section, this approach has become the norm in research at MSA sites in South Africa.

The work at Sibhudu (and almost all subsequent micromorphological studies in South Africa) benefitted from the introduction of the microfacies approach to archaeological micromorphology (Courty, 2001). This approach allows the grouping of deposits with similar microscopic properties (what sedimentary components are present and how they are arranged within the deposit) into microfacies, which can then be interpreted as the products of a specific mix of depositional and post-depositional processes acting within a particular environment of deposition (Courty, 2001; Flügel, 2004). Interpretations are made based on comparison to published descriptions and photographs of deposits from archaeological (e.g., Goldberg et al., 2009; Mallol & Goldberg, 2017), geo-ethnoarchaeological (e.g., Mallol et al., 2007; Berna, 2017a), and experimental contexts (e.g., Miller et al., 2010; Miller & Sievers, 2012; Karkanas, 2021). An individual microfacies can then be associated with the occurrence of specific

environmental conditions, biogenic activities, human behaviours, or a combination of any or all of these (Macphail & Goldberg, 2018).

The microfacies approach has proven to be a powerful tool for studying the deposits at cave and rockshelter sites in South Africa, as they are often microlaminated (Mentzer, 2023) and it is common for a range of natural (geogenic and biogenic) and cultural (anthropogenic) processes to have played a role in the formation and alteration of deposits within a single site (Goldberg et al., 2009; Miller et al., 2013, 2016; Karkanas et al., 2015; Haaland et al., 2021a). It has also seen use at open-air sites, where anthropogenic deposits are less commonly preserved (particularly at older sites) but pedogenic processes are a significant factor in reconstructing environmental conditions and evaluating the integrity of archaeological assemblages (e.g., Tofollo et al., 2017, 2019; Lukich et al., 2020).

Following the microscale study of Sibhudu, micromorphology has been utilised at many South African MSA sites and some in Lesotho (Table 2.1). Naturally, the goals of individual studies and the techniques applied vary depending on the context of the site, the nature of the overall archaeological research project, the availability of funding and equipment, and the skillsets of the scientists involved. However, two related trends can be identified, particularly for cave and rockshelter sites (Mentzer, 2023). The first is that almost all published studies integrate another microarchaeological technique with micromorphology, and the second is that there is a strong focus on studying anthropogenic site formation processes and associated human behaviours.

The technique most commonly applied alongside micromorphology is FTIR. This includes both the analysis of very small quantities of powdered sediment from bulk samples (e.g., Karkanas & Goldberg, 2010; Miller et al., 2013; Sifogeorgaki et al., 2020; Wadley et al., 2020b; Wroth et al., 2022), and the collection of spectra directly from materials in thin sections using µFTIR (e.g., Toffolo et al., 2015; Miller et al., 2016; Haaland et al., 2017, 2021a; Larbey et al., 2019; Mackay et al., 2020; Wurz et al., 2022). The use of µFTIR provides greater contextual resolution for spectra over even very small bulk samples and allows far greater integration of results with micromorphological observations (Goldberg & Berna, 2010; Berna, 2017b; Goldberg et al., 2017; Mentzer, 2023). Spectra collected for South African cave and rockshelter

sites using both FTIR and µFTIR have been used to characterise diagenetic processes and their implications for archaeological integrity, and to study human behaviours (e.g., through identifying the presence and distribution of burnt or heated materials).

Table 2.1. Archaeological sites in South Africa and Lesotho where Middle Stone Age deposits have been sampled for micromorphology, with varying stages of analysis and publication (see Figure 2.1 for site locations). Note that the detail in which results have been published, and coverage of sequences, vary considerably between sites. *Sites which have been reported as being sampled, but for which analysis has not been completed or published. †Sites for which it is explicitly stated that only preliminary results have been published. ‡Archer et al. (2023) report microcontextual results for ESA deposits but also appear to have sampled MSA deposits for which analysis is on-going.

Site/Complex	**Context**	**Reference/s**
Blombos Cave	Cave	Haaland et al., 2017, 2021a,b
Border Cave	Cave	Wadley et al., 2020b
Boomplaas	Cave	S. Mentzer, pers. comm., 2023*
Bushman Rock Shelter	Rockshelter	Porraz et al. 2018*
Die Kelders	Cave	Goldberg, 2000
Diepkloof Rockshelter	Rockshelter	Miller et al., 2013; Dinckal, 2020
Elands Bay Cave	Rockshelter	Miller et al., 2016
Florisbad	Open-air	Toffolo et al., 2015, 2017
Ha Makotoko	Rockshelter	Patalano et al., 2023*
Heuningneskrans	Rockshelter	S. Mentzer, pers. comm., 2023*
Hoedjiespunt 1	Open-air	Göden, 2014
Holley Shelter	Rockshelter	S. Mentzer, pers. comm., 2023*
Kathu Pan	Open-air	Lukich et al., 2020
Klasies River Main site	Multiple caves and rockshelters	Larbey et al., 2019; Wurz et al., 2022; this thesis
Klipdrift Rockshelter	Rockshelter	Haaland et al., 2019*

Site/Complex	Context	Reference/s
Klipfonteinrand	Rockshelter	Mackay et al., 2020
Knysna Eastern Heads 1	Cave	S. Mentzer, pers. comm., 2023*
Lovedale	Open-air	Wroth et al., 2022
Melikane	Rockshelter	Stewart et al., 2012
Montagu Cave	Cave	Archer et al., 2023‡
Mwulu's Cave	Cave	de la Peña et al. 2019*
Ntloana Tsoana	Rockshelter	Roberts et al., 2013*
Olieboomspoort	Rockshelter	Val et al., 2021*
Pinnacle Point	Multiple caves and rockshelters	Karkanas and Goldberg, 2010, Karkanas et al., 2015, 2021
Rose Cottage Cave	Cave	Kloos, 2014
Sibhudu Cave	Rockshelter	Goldberg et al., 2009; Wadley et al., 2011
Spitzkloof A	Rockshelter	Dewar and Stewart, 2012*
Umbeli Belli	Rockshelter	Bader et al., 2018
Umhlatuzana	Rockshelter	Reidsma et al., 2021†
Varsche Rivier 003	Rockshelter	Steele et al., 2016; Mackay et al., 2022
Waterfall Bluff	Rockshelter	Esteban et al., 2020*
Wonderwerk Cave	Cave	*ESA*: Berna et al., 2012; Goldberg et al., 2015, 2023; Thibodeau, 2016 *MSA*: Chazan et al., 2020 *LSA*: Rhodes et al., 2022

Micro-x-ray fluorescence spectroscopy (µXRF) has been used less frequently than FTIR and µFTIR (Larbey et al., 2019; Haaland et al., 2021a,b; Wurz et al., 2022), but is significant for this thesis as it is one of the techniques utilised in the microcontextual

work presented in Chapters 4 and 5. As with typical XRF analysis, this technique is used to identify the elemental composition of a sample, but the focused beams allow sampling spot sizes of a few µm (Mentzer, 2017). In combination with a motorised sample stage and specialist mapping and recording software, this allows for the collection of readings across a defined area and the production of high-resolution maps for different elements (Mentzer, 2017). In the South African studies cited above, µXRF has largely been used to understand the distribution of different minerals within part, or all, of a thin section, typically by producing a combined elemental map with several elements relevant for that study. For example, Wurz et al. (2022, Figure 10) use combined maps of calcium, phosphorus, and silicon to clearly show the distributions of ash and shell (calcium), bone (calcium and phosphorus), and quartz sand and quartzite fragments (silicon), allowing easier identification of different types of deposit, and an understanding of the density and distribution of significant inclusions. This data format also allows for clear communication of these findings, especially for readers who are less familiar with micromorphology.

The application of micromorphology to South African MSA sites has allowed the identification of several distinct anthropogenic depositional processes. Hearths and other combustion features (in varying states of preservation) have been recorded at many sites (e.g., Miller et al., 2013; Karkanas et al., 2015; Larbey et al., 2019; Haaland et al., 2021a). In contrast, the construction of grass bedding layers has only been confirmed at Sibhudu Cave, Diepkloof Rockshelter, and Border Cave (Goldberg et al., 2009; Miller et al., 2013; Wadley et al., 2020b). However, it appears that preservation is a major factor in this relative scarcity as macroscopically identifiable grass bedding has been reported more frequently from South African LSA sites and some younger MSA deposits (Grobbelaar & Goodwin, 1952; Parkington & Poggenpoel, 1971; Opperman & Heydenrych, 1990; Opperman, 1996; Van Rijssen & Avery, 1992; Binneman, 1997, 1998, 1999, 2000; Wadley et al., 2020b). Shell middens are also comparatively under-represented in micromorphological work, with Blombos Cave and KRM the only two sites with published studies describing MSA shell midden deposits (Haaland et al., 2021a; Wurz et al., 2022).

Anthropogenic modification of features and deposits has also been regularly identified. Trampling has often impacted deposits within the confined occupational spaces in

caves and rockshelters, resulting in the reworking of anthropogenic materials into more geogenic sediments and the deformation or destruction of some deposits or features (e.g., Miller et al., 2013; Haaland et al., 2021a; Wurz et al., 2022). Maintenance of hearths, in the form of sweeping or raking out of hearth materials has been identified at many sites such as Sibhudu, Diepkloof, Border Cave, and Blombos (e.g., Goldberg et al., 2009; Miller et al., 2013; Wadley et al., 2020b; Haaland et al., 2021a). All three sites in South Africa where grass bedding has been studied microscopically have also yielded evidence for the burning of stale bedding (Goldberg et al., 2009; Miller et al., 2013; Wadley et al., 2020b).

These anthropogenic site formation processes are important indicators of the organisation of space within occupational sites, the maintenance of these spaces, and the intensity and/or frequency of occupation (Mallol et al., 2017; Clark et al., 2022). The diachronic and synchronic comparison of these behaviours within and between sites provides the opportunity to observe potential changes or continuities in how human populations structured and maintained living spaces across the span of the MSA (Clark et al., 2022). Perhaps more importantly, it also presents the means to identify factors which may influence these behaviours, such as climatic differences, the specific environmental context of occupations (both within and around a site), and demographic change (Karkanas et al., 2015; Haaland et al., 2021a).

Arguably the greatest limitation of the existing micromorphological research into human behaviour in South Africa is the fact that very few experimental studies have been conducted in local conditions and/or with a specific focus on understanding microfacies identified at sites in the country. Miller et al. (2010) focused on the sweeping out and dumping of hearth materials, and the trampling of in situ hearths and the reworked materials. These experiments were conducted in Germany but were partly aimed at understanding patterns observed at Sibhudu by Goldberg et al. (2009). Miller and Sievers (2012) tested several potential combinations of different human behaviours which could have formed the grass bedding microfacies identified at Sibhudu by Goldberg et al. (2009) using local plant materials. All other experimental studies used to interpret microfacies at MSA sites in South Africa (e.g., Villagran et al., 2011; Mallol et al., 2013a,b; Villagran, 2014; Karkanas, 2021) are more generally focused, or were conducted to understand processes at sites in other regions. This

does not mean that they are not relevant for understanding microfacies here, or that their use means the interpretations made from them are incorrect. However, experimental work aimed at replicating observed microfacies on matching substrates and using local materials could help to provide more nuanced interpretations of the South African (geo)archaeological record.

2.4. A diverse geoarchaeology of the Middle Stone Age

Although the introduction of the microscale approach is highly significant and has allowed insights into site formation which were previously unattainable, macroscale geoarchaeological work has continued to provide important information for understanding the context of the MSA in South Africa. Studies published in the new millennium have a greater focus on site formation impacts on archaeological assemblages and anthropogenic processes than the largely palaeoenvironment-focused geoarchaeology practised during the twentieth century.

Cave and rockshelter sediments are still viewed as an important source of palaeoenvironmental information for South Africa as a whole, with due recognition of spatial and temporal biases and the fact that these deposits reflect very localised conditions which may or may not relate to broader climatic or environmental states (Stratford et al., 2021). However, sediments have been used far less commonly than other palaeoenvironmental proxies (primarily macro- and microfauna), particularly since the last of Butzer's studies in these contexts (Stratford et al., 2021).

In contrast, landscape to regional scale palaeoenvironmental reconstructions, predominantly of coastal areas, are relatively common. These studies place archaeological sites and/or human footprint localities into stratigraphic and palaeoenvironmental context within broader palaeo-landscapes, generally with an emphasis on sea levels (e.g., Butzer, 2004; Fuchs et al., 2008; Roberts, 2008; Jacobs & Roberts, 2009; Cawthra et al., 2016, 2018; Helm et al., 2018; Jacobs et al., 2020; Morrissey et al., 2020). This work tends to be more geological in character (few are explicitly presented as geoarchaeological studies) and involves the field description and bulk sampling of multiple exposed sections (some of which may be within archaeological or palaeoanthropological sites) to characterise the geomorphic history of the study area. Offshore studies of previously exposed landscapes utilise sonar to

map the seafloor, and geologists describe and sample deposits during scuba dives (Cawthra et al., 2018). Luminescence dating of various aeolian and marine deposits plays a vital role in providing chronostratigraphic control for both onshore and offshore work. These studies are only distinguished from purely geological work on similar environments (e.g., Illenberger, 1996; Carr et al., 2010; Bateman et al., 2011) by the emphasis on contextualising archaeological or palaeoanthropological evidence.

Macroscale studies of site formation published this century have been far more focused on evaluating the integrity of the archaeological record compared to Butzer's work (e.g., Kandel et al., 2003; Lotter et al., 2016; de la Peña et al., 2019; Ames et al., 2020; Sifogeorgaki et al., 2020; Reidsma et al., 2021; Val et al., 2021; Stratford et al., 2022; Phillips et al., 2023). As with Hilary Deacon's work at KRM (Deacon & Geleijnse, 1988; Deacon, 1993, 1995), these studies are typically conducted at the highest possible spatial and stratigraphic macroscale resolution, but results and interpretations are generally reported more fully than in Deacon's work, even in preliminary papers. Geoarchaeological work is now often included in broader multidisciplinary publications on sites due to greater recognition of the importance of understanding site formation processes and their impacts on excavated (and surface) assemblages.

Although field descriptions and the sedimentological and chemical analysis of bulk samples remain major sources of data in South African MSA sites, new methods have been adopted which provide more information for understanding site formation. Following important geoarchaeological studies of deposit fabric at Stone Age/Palaeolithic archaeological sites in East Africa and Europe (e.g., Schick, 1991; Petraglia & Potts, 1994; Bertran & Texier, 1995; Dibble et al., 1997, 2006; Lenoble & Bertran, 2004; McPherron, 2005; Enloe, 2006), total station plotting of artefacts and natural clasts is now routinely carried out at MSA sites in South Africa. This provides high resolution spatial data which can be used to interpret depositional and post-depositional processes in several ways. The dip and orientation (sometimes determined with a Brunton compass rather than total station plots) and vertical and horizontal distribution of artefacts have been used to infer if, and to what degree, an assemblage has been disturbed after deposition, including if it has been transported to a secondary context (e.g., Bernatchez, 2010; Oestmo et al., 2014; Lotter et al.,

2016; de la Peña et al., 2019; Sifogeorgaki et al., 2020; Wilkins et al., 2020). Experimental and modelling work has been conducted to understand how different shapes and sizes of lithic artefacts within an exposed assemblage are moved over time in an open-air context (Phillips et al., 2019). Greater emphasis has also been placed on the use of allostratigraphy as a complementary approach to lithostratigraphy (Stratford et al., 2022).

It is important to note that (as is the norm globally) microscale studies of context in the South African MSA have all been supported or informed to some degree by macroscale field observations and descriptions, particularly the identification and grouping of facies using lithology and/or allostratigraphy (e.g., Goldberg et al., 2009; Karkanas & Goldberg, 2010; Miller et al., 2013, 2016; Karkanas et al., 2015; Toffolo et al., 2017; Haaland et al., 2021a). The degree to which these data have been integrated with the results of microanalyses varies based on the context of the site and the goals of the researchers. However, a number of these studies can be considered effectively multiscalar in approach. Perhaps the most clearly articulated multiscalar study in the region was conducted by Panagiotis Karkanas et al. (2015) at Pinnacle Point 5-6. In the approach they describe, the macroscopic identification and description of facies in the field (based on lithology and allostratigraphy) forms the anchor for a study. It is inherently recognised that each facies will almost certainly contain distinct microfacies, which can only be identified and described using micromorphology. The microfacies represent distinct short-term events in the formation of a facies, in the same way that several facies may cumulatively form a lithostratigraphic unit. This hierarchical system allows for multiple integrated levels of understanding of the formation of deposits, ranging from single events that may have lasted just minutes, to the cumulative results of different natural processes and human actions over thousands of years.

2.5. Conclusion

The geoarchaeology of the South African MSA has matured and expanded since the earliest studies, in line with global changes in the discipline (e.g., see Shahack-Gross, 2017). The introduction of the microscale approach, and the resulting interest in studying anthropogenic site formation processes (and associated behaviours) has not

led to a lack of interest in palaeoenvironmental conditions and the impacts of site formation processes on archaeological assemblages and anthropogenic features/deposits. Instead, the discipline has become broader and more diverse, with the application of different techniques best suited to answering specific research questions in differing geomorphic and occupational contexts. The recognition of the potential geoarchaeology provides for contextualising the archaeological record and identifying and studying human behaviours has also grown significantly over the past three decades.

Geoarchaeological research at KRM spans the full history of the discipline in South Africa, from Butzer's fieldwork in the late 1960s (Butzer, 1982b) to the collection of micromorphology block samples from the site from 2013 onwards (Larbey et al., 2019; Wurz et al., 2022). Scales of analysis and interpretation, analytical techniques, and research foci have all changed over this period – at KRM, across South Africa, and globally. The following chapters review the approaches to stratigraphy and site formation applied at KRM during three different periods of field and laboratory work (Chapter 3) and present the results of new macro- and microscale analyses of deposits aimed at better understanding stratigraphy and site formation in two areas of the site complex (Chapters 4 and 5).

CHAPTER 3. PUBLISHED PAPER #1

Thesis pages: 43–92

Morrissey, P., Mentzer, S.M. & Wurz, S. Published in 2022

Journal of Paleolithic Archaeology 5, 5, 1–47 (page numbers below reflect publication page numbers)

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Journal of Paleolithic Archaeology (2022) 5:5
https://doi.org/10.1007/s41982-022-00110-2

A Critical Review of the Stratigraphic Context of the MSA I and II at Klasies River Main Site, South Africa

Peter Morrissey[1] · Susan M. Mentzer[2] · Sarah Wurz[1,3]

Accepted: 3 January 2022
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Abstract

Klasies River Main site, on South Africa's southern Cape coast, has contributed significantly to understanding Late Pleistocene human evolution. Excavations across this complex of caves and rock shelters have uncovered important assemblages of human fossils, faunal remains and lithic artefacts which have allowed interpretations of human anatomy and behaviour, and the palaeoenvironmental context of human occupations. The stratigraphy of the site is complicated, and the deposits have been recorded and published at varying degrees of resolution and detail over three phases of fieldwork. This paper is the first detailed review of the stratigraphy of any part of the sequence, and considers the different stratigraphic approaches used at Klasies and the published data and interpretations for the basal deposits. These units have been assigned to the Light Brown Sand, Rubble Brown Sand and Shell and Sand Members, and have yielded MSA I and MSA II lithic assemblages and most of the human fossils. We argue that some of the published stratigraphic interpretations need to be reconsidered, that a purely lithostratigraphic approach to the deposits at Klasies is not currently viable and that further field description and micromorphological work is needed. More broadly, this review demonstrates potential complications for stratigraphic correlation during the reinvestigation of previously excavated sites. These include the importance of understanding site formation processes in a lithostratigraphic system, and the need to think about how, why and at what resolution we make correlations between different stratigraphic systems or different areas within a site or site complex.

Keywords Klasies River Main site · Archaeological stratigraphy · Geoarchaeology · Middle Stone Age · Late Pleistocene archaeology

✉ Peter Morrissey
Peter.Morrissey@students.wits.ac.za

[1] School of Geography, Archaeology and Environmental Studies, University of the Witwatersrand, Johannesburg, South Africa

[2] Senckenberg Centre for Human Evolution and Palaeoenvironment, Institute for Archaeological Sciences, Eberhard Karls Universität Tübingen, Tübingen, Germany

[3] SFF Centre for Early Sapiens Behaviour (SapienCE), University of Bergen, Bergen, Norway

Published online: 01 March 2022

Introduction

Klasies River Main (KRM) site is a complex of five closely associated caves and overhangs within a quartz arenite cliff on the southern coast of the Eastern Cape Province (Fig. 1). Archaeological deposits within Caves 1, 1A, 1B and 2 (Fig. 2) have yielded evidence for human occupation of the site during parts of the Middle Stone Age (MSA) and Later Stone Age (LSA) (Deacon & Geleijnse, 1988; Singer & Wymer, 1982; Wurz, 2002; Wurz et al., 2018). Published ages for the MSA deposits range from ~120 thousand years before present (ka) to between 60 and 40 ka (Grine et al., 2017; Wurz et al., 2018). KRM is widely considered to be among the most important MSA sites in South Africa, and Africa as a whole, due to the recovery of early *Homo sapiens* fossils, lithic assemblages representing multiple cultural phases and rich faunal assemblages (Brenner et al., 2020; Deacon, 1989, 1992, 1995, 2001; Grine, 2016; Henshilwood & Marean, 2003; Klein, 2001; Marean, 2014; McBrearty & Brooks, 2000; Reynard & Wurz, 2020; Thackeray, 1992; Wadley, 2015; Wurz, 2008, 2013).

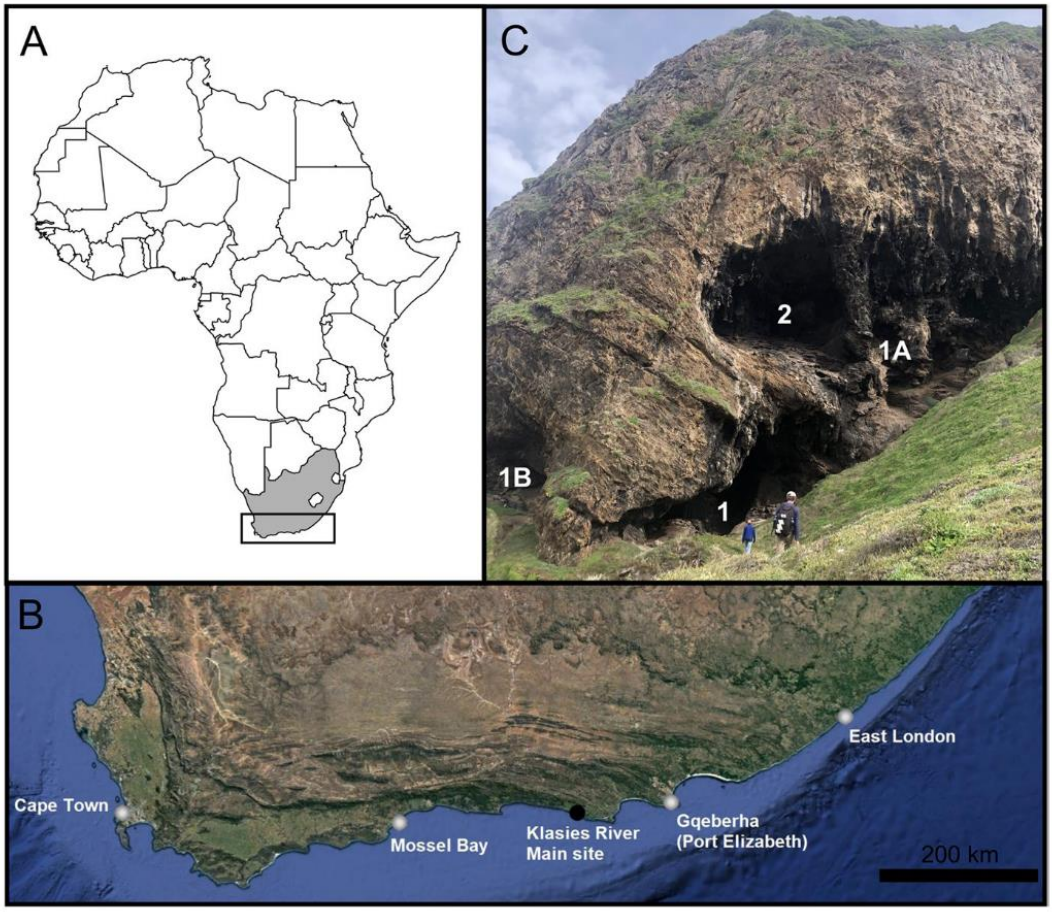

Fig. 1 Location and layout of Klasies River Main site. **A** The location of South Africa's southern coastline and **B** the location of Klasies River Main site along the coastline. **C** A view of the site from the east (photograph by K. Croll)

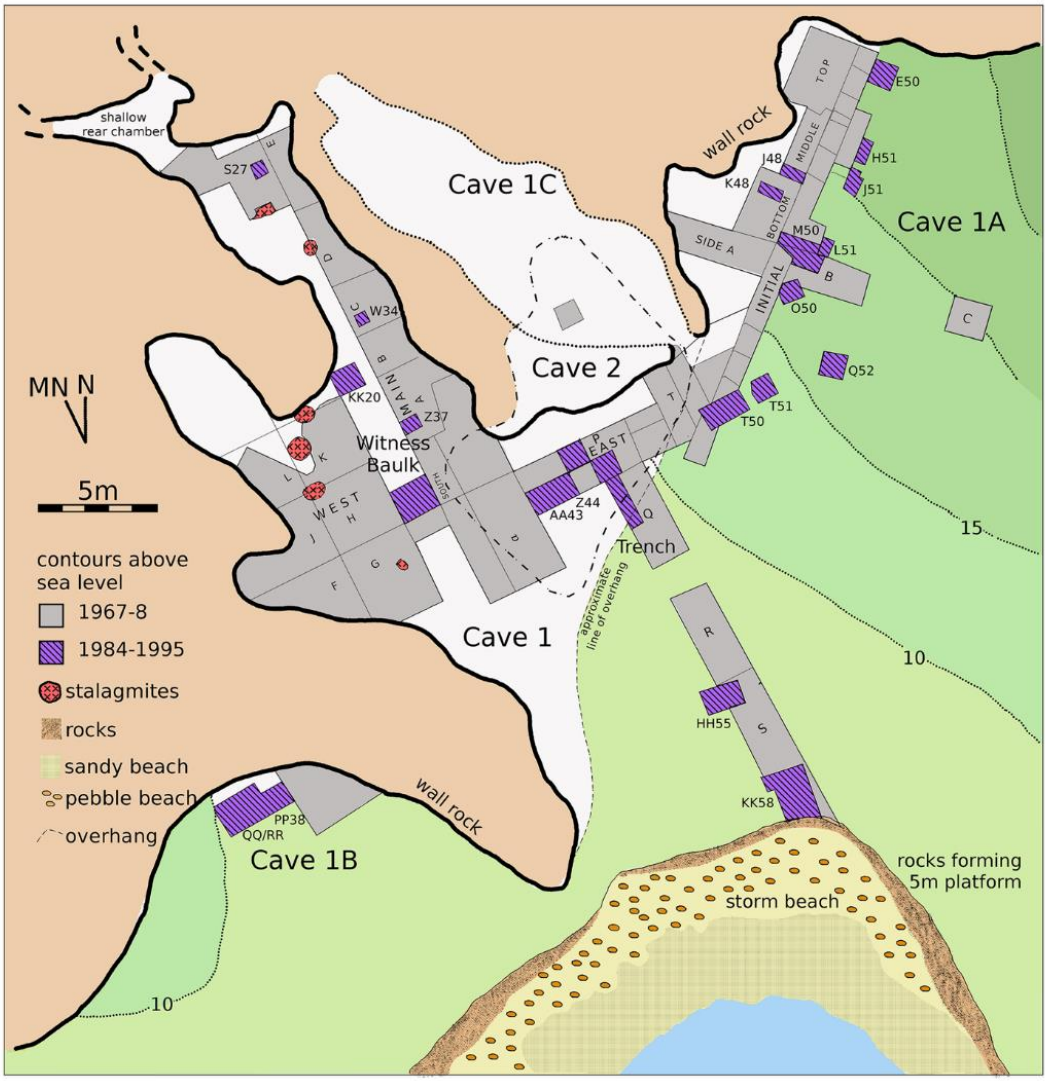

Fig. 2 Map of Klasies River Main site. Note that many of the Deacon excavations (blue) and some of Wymer's (grey) did not reach bedrock, and that Wymer used a system of squares within cuttings

Excavations conducted at the site in 1967–8 by John Wymer (Fig. 2) removed large volumes of deposit and yielded significant fossil and artefact samples from five MSA cultural phases (Singer & Wymer, 1982). Hilary Deacon's subsequent excavations and geoarchaeological fieldwork resulted in the grouping of the deposits into lithostratigraphic members and attempts to correlate these members with the layers excavated by Wymer (Deacon, 2008; Deacon & Geleijnse, 1988). This stratigraphic system, still in use at the site today, has evolved somewhat since it was first published but has also retained many of its original characteristics (Deacon, 2008; Deacon & Schuurman, 1992; Rightmire & Deacon, 1991). The MSA deposits have been grouped into the following six members (Table 1; Fig. 3): the Light Brown Sand (LBS) at the base of the sequence in Caves 1, 1A and 1B; the Rubble Brown Sand (RBS) in Cave 1, and associated deposits in Caves 1A and 1B (but see discussion below); the Shell and Sand (SAS) in Caves 1, 1A and 1B; the Rockfall (RF) and

Table 1 The lithostratigraphic members present in Caves 1, 1A 1B and 2 at Klasies River Main site, with inter-cave correlations, correlations with Wymer's layers in brackets, and lithic phases

Cave 1	Cave 1A	Cave 1B	Cave 2
White Sand (13) MSA IV			
	Upper (1–9) MSA III		
	Upper (10–21) Howiesons Poort		Upper (1–5) Howiesons Poort
	Rockfall (22) MSA II		Rockfall (–) MSA II
SAS R (14) MSA II U SAS W (15) MSA II U	SAS upper (23–35) MSA II U	SAS/DC upper (1–5) MSA II U	
SAS U (16) MSA II L SAS L (17) MSA II L	SAS lower (36) MSA II L	SAS/DC lower (6–11) MSA II L	
RBS (37) MSA I	RBS[a]	RBS[a]	
LBS (38) MSA I	LBS (38–39) MSA I	LBS/RS (12–15[b]) MSA I	
Layer 40 MSA I	Layer 40 MSA I	Layer 15[b] MSA I	

[a]Deposits which have been argued to correlate with the RBS (but see discussion below)

[b]Layer 15 in Cave 1B has been variously grouped with Layer 40 and with the LBS/RS

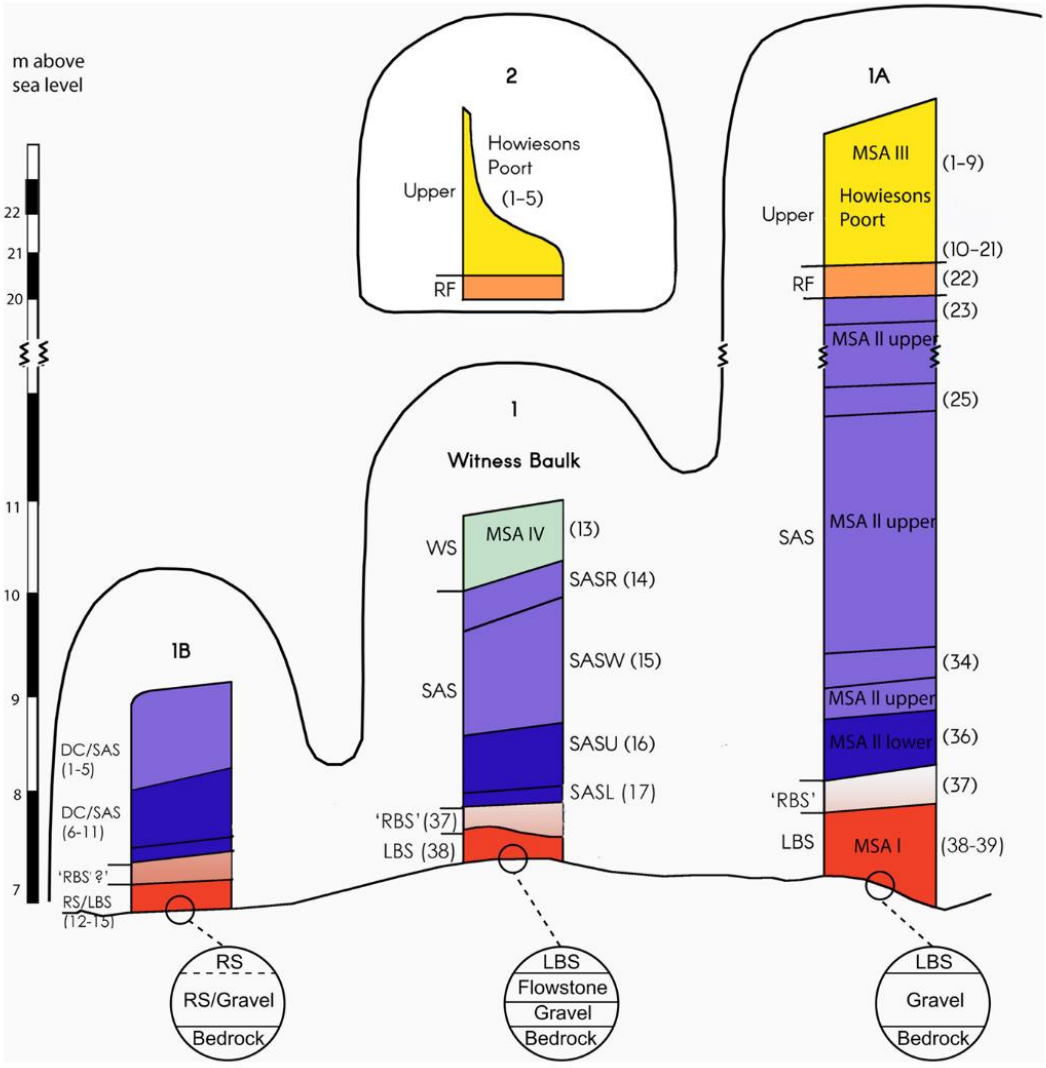

Fig. 3 The published cultural and lithostratigraphy of Klasies River Main site (after Deacon & Geleijnse, 1988, Grine et al., 2017, and Wurz et al., 2018). The insets indicate some of the spatial variation in the relationships between the basal gravels and the overlying archaeologically richer deposits, including in Cave 1B where the gravels are sometimes included in the RS/LBS Member. The presence of the RBS or deposits correlated with it in Caves 1A and 1B is not certain, and the RBS itself is a potentially problematic lithostratigraphic grouping (see discussion in text)

Upper Members, both in Cave 1A and Cave 2; and the White Sand (WS) Member in Cave 1. Beach gravels which underlie the LBS across the site (Table 1) and have yielded 'numerous' MSA artefacts in Cave 1B (Singer & Wymer, 1982, p. 25) and isolated lithics in Caves 1 and 1A (Singer & Wymer, 1982, pp. 22, 83) have not been grouped into a named member (except in Cave 1B).

Despite the significance of KRM and the complexity of the stratigraphy at the site, a detailed review of the published data on the stratigraphy of the site, and the interpretations of stratigraphic correlations across the site, is lacking. A recent review of the human fossils recognised that they had not been 'contextualized within the spatial and strato-chronological framework of the site' (Grine et al., 2017, p. 76).

Grine et al. (2017) placed all the published specimens into such a framework but did not critically engage with the data and interpretations behind the framework.

Almost all the existing published interpretations of the stratigraphy of the members and their correlation with the layers of the original excavations can be attributed to Hilary Deacon. Several recent publications continue with these stratigraphic interpretations (e.g. Brenner & Wurz, 2019; Brenner et al., 2020; Langejans et al., 2017; Nel et al., 2018; Reynard & Wurz, 2020; Wurz et al., 2018). Careful reading of the works published and guided by Deacon reveals changes in interpretation, not always acknowledged in publications that follow each other. It is possible to miss these changes without an in-depth and focused comparative reading of these papers. A detailed review of the published research is presented here in order to clarify the existing interpretations prior to the publication of on-going multiscale geoarchaeological studies which may refine our understanding of the stratigraphy of the site. This review is focused on the LBS, RBS and SAS Members due to the complex stratigraphy of these deposits and the significance of the human fossils they have yielded (Deacon, 2001, 2008; Grine, 2016; Rightmire & Deacon, 1991, 2001). Site formation will seldom be discussed in this paper because little detailed information has been published, and interpretations of how layers formed have not often been used in stratigraphic correlation. Any reference to the interpretation of stratigraphy refers to groupings of deposits at individual locations and/or correlations across the site rather than the formation of each layer (unless specified otherwise).

Site Description

The morphology and locations of the different recesses at KRM (Figs. 1C and 2) are significant for understanding both the stratigraphy and formation of the deposits at the site. Cave 1 is a deep cave (approximately 25 m from the dripline to the back wall) at roughly 6 m above sea level which hosts some of the oldest occupational deposits. Cave 1C is a deep chamber (~19 m) which was closed off relatively early in the site's history. It is the only recess which has not revealed any evidence for human occupation, perhaps because it was too wet (Singer & Wymer, 1982, p. 25). Cave 2 is set in the cliff at ~18 m above sea level and is far less deep (~6 m) than Caves 1 and 1C below. Cave 1A refers to the area under a large overhang which shelters much of the site, including the entrances of Caves 1, 1A and 2. Finally, Cave 1B is a smaller rock shelter which is separated from the other recesses by the hosting outcrop.

During the period of interest, only Caves 1, 1A and 1B were occupied. Human occupation of Cave 2 was not possible as the deposits in Cave 1A had not yet built up sufficiently to allow access to the cave. There is no clearly defined boundary point between Cave 1 and Cave 1A, and these areas form part of a single sedimentary repository (Deacon & Geleijnse, 1988). As such, there was considerable potential for continuous deposits to form between these areas. In contrast, the physical separation between Cave 1B and the Cave 1/1A depository means that the formation of continuous deposits was virtually impossible.

Different areas of the site afford differing degrees of protection from the elements, with implications for what human activities would have taken place at each, and which natural depositional and post-depositional processes would have been involved in site formation. The interior of Cave 1 was the most sheltered, followed by the entrance of Cave 1 at the boundary with Cave 1A. Caves 1A and 1B are significantly more exposed, but face different directions and have differing topography, suggesting they would have been affected differently by wind and rain (and associated aeolian and colluvial processes).

A variety of different anthropogenic and geogenic deposits are preserved at KRM (Fig. 4). Anthropogenic units include discrete deposits of ash, carbonaceous material and marine shell which are just millimetres thick in many cases but can be

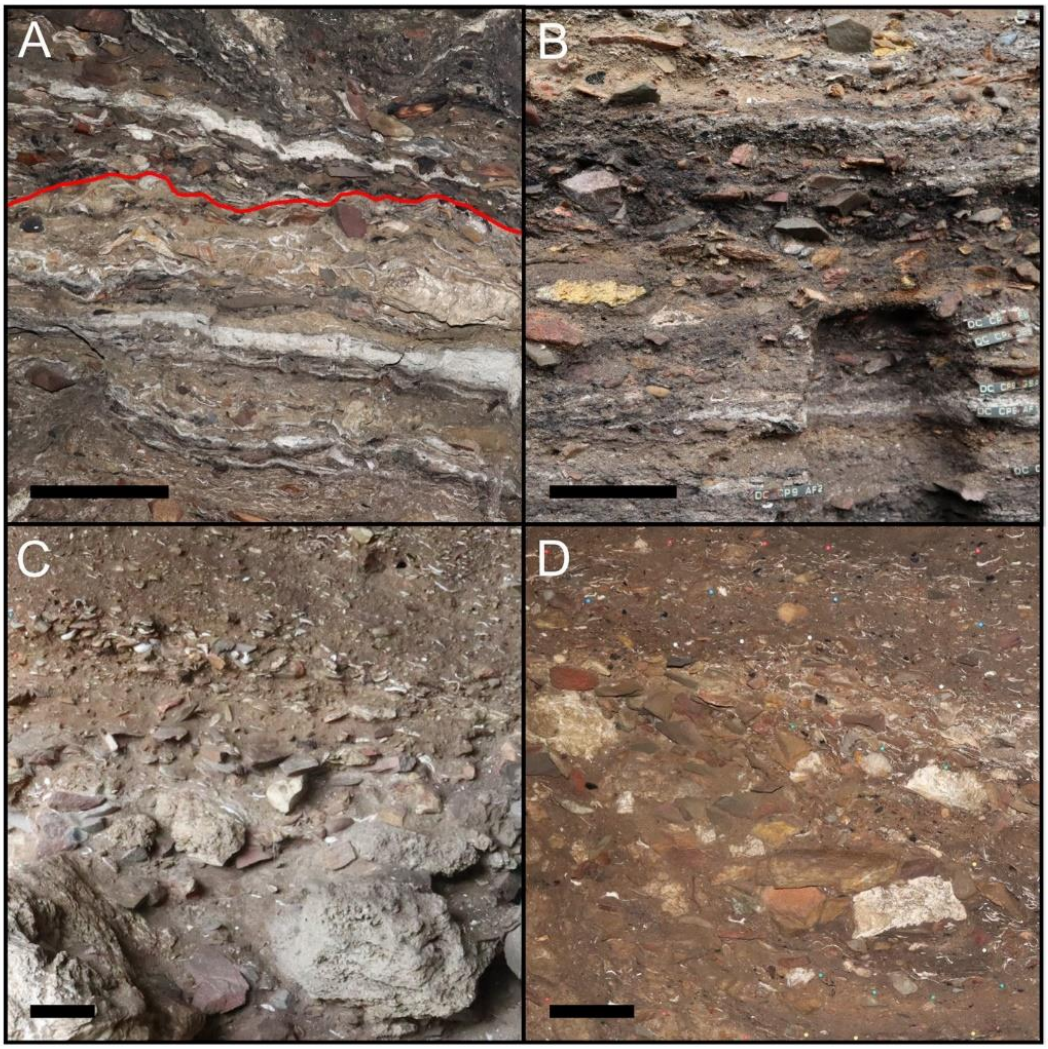

Fig. 4 Examples of deposits at Klasies River Main site (photographs by K. Croll; scale bars are all 10 cm). **A** Finely stratified deposits assigned to the LBS (below red line) and RBS (above red line), Cave 1. **B** Finely stratified deposits assigned to the DC/SAS, Cave 1B. **C** Clast-rich deposits overlain by finer talus deposits, both assigned to the SAS, Cave 1. **D** Clast rich deposits bounded by relatively poorly stratified deposits, all assigned to the SAS, Cave 1/1A boundary

significantly thicker. They are often found as dense packages of associated deposits. The surrounding geogenic deposits are predominantly medium to fine sands with thicknesses of up to tens of centimetres (Deacon & Geleijnse, 1988, p. 12). There are several clast-rich deposits (generally referred to as rubble or gravel) in Cave 1 which appear to have very different depositional and post-depositional histories (Deacon, 2008). The morphologies of both anthropogenic and geogenic deposits were strongly influenced by existing topographies, with the most obvious example being the formation of sloped deposits rich in secondary context archaeological material on the talus which extended from Cave 1A down into Cave 1 (Deacon & Geleijnse, 1988).

Stratigraphic Approaches

Stratigraphy in Archaeology

Stratigraphy is perhaps the most fundamental concept in archaeological excavation and interpretation regardless of the age or context of the excavated site. Archaeologists primarily use stratigraphy to group material of presumed similar age into distinct occupational/depositional periods and to establish relative chronologies for these periods within a site's history, but stratigraphy also plays a significant role in understanding the roles of human behaviour and natural processes in the formation of the deposits at a site (Fedele, 1984; Stein, 1987). Despite, or perhaps because of, the importance of stratigraphy, the approaches and terminology used to distinguish, describe and group deposits during and after excavation vary widely (e.g. Croix et al, 2019; Fedele, 1984; Harris, 1989; Mallol & Mentzer, 2017, Table 2). The broad categories of stratigraphic units utilised in archaeological research are summarised below (following Gasche & Tunca, 1983; Goldberg et al., 2017; Mallol & Mentzer, 2017, Table 2; Stein & Holliday, 2017), with references for their use at archaeological/palaeoanthropological sites.

Lithostratigraphic units are defined based on the physical properties of the sediments within deposits, such as their texture or colour (e.g. Bruxelles et al., 2019; Marean et al., 2010). Allostratigraphic units (utilised in sequence stratigraphy) are deposits bounded by disconformities or unconformities at their upper and lower contacts (e.g. Edwards et al., 2020; Stanistreet et al., 2018). Soil stratigraphic units are deposits which can be identified as one or more horizons of a buried soil (e.g. Holliday et al., 2017; Pietsch & Kühn, 2017). They are especially useful as 'marker horizons' for temporal correlation. Biostratigraphic units are groupings of deposits made using the presence/absence or relative abundance of the remains of particular faunal or floral species within the deposits (e.g. Braun et al., 2013; Urban & Bigga, 2015). Chronostratigraphic units are defined using absolute dates, where different deposits can be grouped or separated based on their ages (e.g. Jacobs et al., 2008; Loftus et al., 2016). Cultural stratigraphic (or ethnostratigraphic) units are defined based on culturally significant changes in the artefact assemblages excavated from a site (e.g. Lombard et al., 2012; Wurz, 2002). Finally, spits are arbitrary units excavated based on depth below a defined point. These may be excavated within

lithostratigraphic units to create finer artificial groupings of material (e.g. Lotter et al., 2016), but they are often excavated across multiple deposits (e.g. Davies, 1975). Each of these approaches have advantages and disadvantages for intra-site and inter-site correlations with archaeological and geological deposits and various proxy records depending on the context and content of the deposits (Goldberg et al., 2017; Stein & Holliday, 2017). Therefore, it is common for multiple approaches to be used in developing a stratigraphic model for a site or group of sites (e.g. Butzer, 2004; Jacobs et al., 2020; Porraz et al., 2013).

Stratigraphic Approaches to Cave and Rock Shelter Deposits in the Southern African Middle Stone Age

The MSA archaeological record of southern Africa has proven to be vital to understanding the evolution of complex cognitive abilities in human populations (Marean et al., 2014; Wadley, 2015). The most informative assemblages from this period have been recovered from cave and rock shelter sites throughout the region, such as Blombos Cave (d'Errico et al., 2005; Henshilwood et al., 2011) and Pinnacle Point (Esteban et al., 2018; Jerardino et al., 2014), which have higher rates of preservation of organic materials and stratigraphic integrity relative to most open-air sites. The fine stratigraphy preserved at many of these sites allows archaeologists to isolate individual short-term occupational events. An excellent example of this remarkable preservation is the discovery of distinguishable layers of grass bedding in deposits as old as ~ 200 ka at Border Cave (Wadley et al., 2020).

The excavation, recording and interpretation of these deposits can present significant challenges, and approaches have evolved with changing technologies and techniques and a growing understanding of the significance of finely stratified deposits. Many early excavations were conducted largely using arbitrary spits, with little or no relationship to lithostratigraphy (e.g. Cooke et al., 1945; Tobias, 1949) but this approach was gradually replaced by the use of gross lithostratigraphic changes to define excavation units (e.g. Beaumont, 1978; Opperman, 1996; Tankard, 1976). More recently, there has been movement towards a 'standard' high-resolution approach to excavation where finely stratified deposits are excavated and recorded individually as far as practically possible (e.g. Backwell et al., 2018; Deacon, 1979; Deacon & Geleijnse, 1988; Mackay, 2010; Oestmo & Marean, 2015; Porraz et al., 2016; Wadley & Jacobs, 2006).

The reinvestigation of previously published sites in South Africa is becoming increasingly common as archaeologists seek to apply new technologies and approaches at sites which have yielded significant (or potentially significant) assemblages and sequences, but for which we have relatively limited stratigraphic and contextual information by current standards. Sites with recent or on-going reinvestigations include Border Cave (Backwell et al., 2018), Bushman Rock Shelter (Porraz et al., 2015), Diepkloof Rock Shelter (Porraz et al., 2013), Elands Bay Cave (Porraz et al., 2016), Grassridge Rock Shelter (Ames et al., 2020), Mwulu's Cave (de la Peña et al., 2019), Olieboomspoort (Val et al., 2021) and Umhlatuzana (Sifogeorgaki et al., 2020). Therefore, the issues involved in correlating stratigraphic units (and

the assemblages they have yielded) across multiple stratigraphic systems—with differing approaches to excavation and/or recording and varying stratigraphic resolution—is currently highly relevant to MSA archaeological research in the region.

Approaches to the Stratigraphy at Klasies River Main Site

Field research at KRM can be divided into three phases, each of which have involved different approaches to the stratigraphy of the site. This has implications for understanding the relationships between assemblages excavated during different field campaigns and for integrating the data collected from these assemblages.

Initial Excavation by Wymer

The first phase of fieldwork was the excavation of large areas of Caves 1, 1A and 1B, and a smaller area of Cave 2 by John Wymer in 1967–68 (Fig. 2). This work was conducted at relatively low spatial and stratigraphic resolution, with recording that was limited by current standards (Singer & Wymer, 1982). In Wymer's stratigraphic system, the deposits were divided into numbered layers based on what were believed to be significant changes in lithology or important unconformities (Fig. 3). At the same time, some relatively thick and homogenous deposits were divided into spits based on depth. This resulted in a situation where many of the layers included several (and sometimes many) distinct sedimentary units with differing lithology which were formed by different anthropogenic and/or geogenic processes (Singer & Wymer, 1982, pp. 9–32), while some layers were the product of the arbitrary splitting of deposits despite similarities in lithology and sedimentology (Deacon, 2008; Deacon & Geleijnse, 1988; Grine et al., 2017).

Typological analysis of lithic artefacts recovered from the layers was used to group layers into cultural phases, namely the MSA I, MSA II, Howiesons Poort, MSA III and MSA IV, and two overlying LSA industries. Stratigraphic correlations between Caves 1, 1A, 1B and 2 were made primarily based on this cultural stratigraphy, as were interpretations of human behaviour and palaeoenvironmental change (Singer & Wymer, 1982).

Due to the fine stratigraphy of many of the deposits at KRM (Fig. 4), the combined excavation of distinct sedimentary units within the layers resulted in considerable loss of stratigraphic information. Artefacts and faunal and human remains excavated from units formed by a variety of anthropogenic and geogenic processes were ultimately lumped into larger but less informative assemblages, effectively creating artificial palimpsests (Fig. 5).

Information on the nature of the deposits within each layer is vital for anyone attempting to link new excavations or stratigraphic recording to the original stratigraphic system. Singer and Wymer (1982, pp. 9–27) present relatively detailed field descriptions of the basic properties of the layers compared to many archaeological studies, but these descriptions are fairly homogenised for each layer. However, there

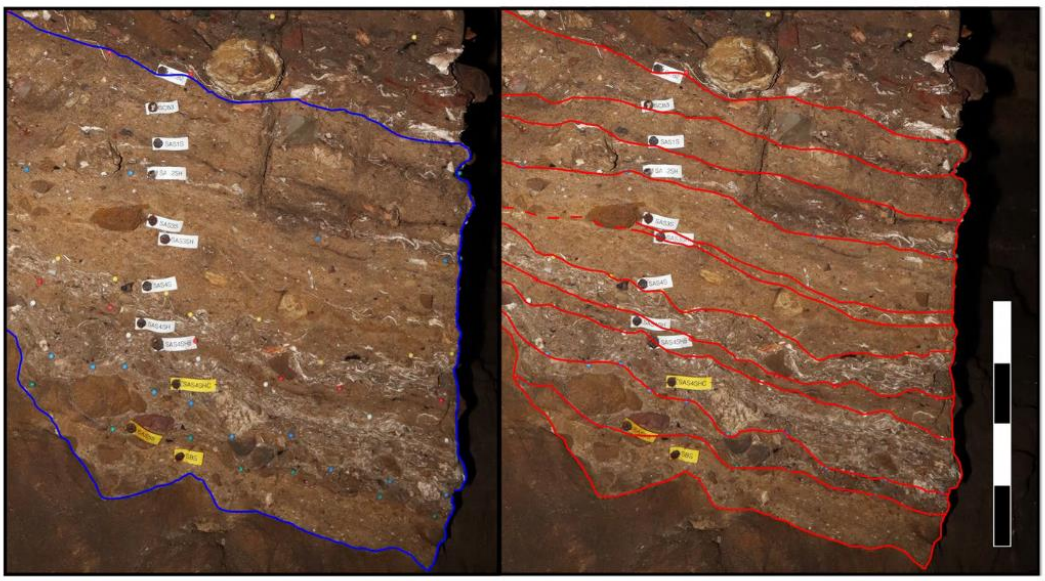

Fig. 5 A direct visual comparison of the differences in resolution between the stratigraphic approaches utilised by John Wymer and Hilary Deacon (photograph by K. Croll; scale bar is 40 cm). The image to the left indicates the vertical extent of deposits excavated as a single stratigraphic entity—Layer 38—at the eastern edge of Wymer's excavations in Cave 1. In the image to the right, the same deposits—grouped into the LBS Member—with the unit boundaries corresponding to the excavations conducted by Deacon's team in the lower section of square AA43 (to the right of the photograph). Each of these units were excavated and recorded as distinct entities

is significant variation in the amount of detail provided for different layers and different parts of the site. For example, layer thicknesses were provided for Cave 1, but not for Caves 1A, 1B and 2. The field and laboratory descriptions published in Butzer's (1982a) sedimentological study differ from Wymer's in some of the types of information presented, but they also reflect a homogenised approach to the deposits. Furthermore, these descriptions are only available for Cave 1 and the upper part of the Cave 1A sequence (the Howiesons Poort and MSA III deposits). Butzer did not comment on intra-site correlations of deposits, but instead focused on linking the sequence to global and regional environmental records (e.g. Butzer, 1982a, Table 4.1), a common feature of his geoarchaeological work (Butzer, 1982b).

Renewed Excavation and Recording by Deacon

The second phase of field research at KRM was led by Hilary Deacon, who conducted numerous small excavations across the site from 1984 to 1995 (Fig. 2) at significantly higher resolution and with more detailed recording (Deacon, 1995, 2008; Deacon & Geleijnse, 1988). These included excavations in Cave 1A and Cave 1B, and in the baulk which Singer and Wymer (1982) used to arbitrarily divide Cave 1 from Cave 1A. Excavation of the Cave 1 Witness Baulk began in the 1990s, after the initial publication of a revised stratigraphic model by Deacon and Geleijnse (1988). Initial stratigraphic data for the Witness Baulk was collected through the recording of standing sections left by Wymer's excavations.

The stratigraphic approach differed notably from that utilised previously. Each discernible sedimentary unit was treated as a distinct entity and excavated and recorded separately from other units so far as practically possible (Deacon & Geleijnse, 1988). This allowed the recovery of individual assemblages from distinct units, in sharp contrast with the grouped excavation of units within layers (Fig. 5). Three-dimensional plotting of excavated finds was carried out for some, if not all, units (such data are available for some units in Deacon's unpublished notes). The units were predominantly named descriptively, based on observed sedimentary properties or inferred formation processes. Commonly used abbreviations in the unit names include CP (carbonised parting: dark layers containing burnt material), SH (shell), SM (shell midden), AF (ash feature) and S (sand: usually with a colour identifier, e.g. YS for yellow sands or BS for brown sands). Non-descriptive names were only used for some of the deposits in the Cave 1 Witness Baulk.

Excavated units, and those viewed in the standing sections, were then grouped into several named lithostratigraphic members and (in some cases) sub-members (Table 1). This system of units, sub-members and members is an evolution or adaptation of the stratigraphic system of sub-units, units and members Deacon employed during his earlier excavations of Boomplaas Cave (Deacon, 1979). As with the units, the naming of the members was mostly descriptive, with all except the Upper Member being named for sedimentary properties.

While the lithology of the units is presented as the primary means by which units were grouped into members (Deacon & Geleijnse, 1988), several other stratigraphic approaches have also been used to correlate deposits across the site (see 'The Stratigraphy of the MSA I and II at Klasies River Main Site' section). These include the use of unconformities or 'marker horizons' (interpreted as palaeosols) to correlate erosional events and depositional hiatuses (allostratigraphy and soil stratigraphy), absolute or relative dates (Table 2) for different deposits (chronostratigraphy), the techno-typological characteristics of assemblages excavated from units across the site (cultural stratigraphy) and the vertical distribution of ostrich eggshell within excavations (biostratigraphy).

Despite the use of a significantly higher resolution stratigraphic approach, little information is available for the deposits excavated or recorded by Deacon and his team. The published descriptions (e.g. Deacon & Geleijnse, 1988) largely comprise the general properties of the members and sub-members, with even the most basic unit-specific information available in only a few cases.

Considerable effort was put into determining the relationship between Wymer's numbered layers and the new members and sub-members (Deacon, 2008; Deacon & Geleijnse, 1988; Rightmire & Deacon, 1991, 2001; and see Fig. 3). This task was complicated by the relatively limited and homogenised information provided by Singer and Wymer (1982), but also by the difference in the scale of the stratigraphic data. As will be demonstrated in this review, assessing the reliability of both the published correlations between Deacon's members and Wymer's layers and the grouping of deposits between caves in Deacon's system is complicated by several factors. There is considerable variation in the level of detail of both published sedimentary descriptions, and the evidence for and reasoning behind different

Table 2 Age estimates for the basal deposits at Klasies River Main site. Where available, layer correlations and sample provenience are included

Cave	Member	Layer	Provenience	Age (ka)	Technique	Reference
1A	SAS	27	K48	60.5 ± 4.9 65.8 ± 7.0 72.8 ± 6.4	LU ESR	Grün et al., 1990
1A	SAS	30	–	77.4 ± 7.0	U-series	Vogel, 2001
1	SASR	14	Square D	85.2 ± 2.1	U-series	Vogel, 2001
1	SASR	14	Square D	94.6 ± 3.2	U-series	Vogel, 2001
1	SASR	14	Square M	100.8 ± 7.5	U-series	Vogel, 2001
1	SASW	15	WB	70.9 ± 5.1	TL-OSL	Feathers, 2002
1	SASW	15	–	MIS 5c or 5a	δ^{18}O shell	Shackleton, 1982
1	SASU	16	–	89	AAR	Bada & Deems, 1975
1	SASU	16	WB	< 126.0 ± 1.5	U-Th	Wurz et al., 2018
1/1A	SASU[a]	16[a]	Cave 1/1A boundary	68.4 ± 6.5	TL-OSL	Feathers, 2002
1	SASL	17	WB	88.3 ± 7.8 93.5 ± 10.4	LU ESR	Grün et al., 1990
1	SASL	17	WB	101 ± 12	U-series + ESR	Eggins et al., 2005
	SAS[b]			104–64	LU ESR	Millard, 2008
1	RBS	37	–	90	AAR	Bada & Deems, 1975
1	LBS	38	–	110	AAR	Bada & Deems, 1975
1	LBS	38	–	MIS 5e	δ^{18}O shell	Shackleton, 1982
1	LBS		–	> 110	U-series	Deacon et al., 1988
1	LBS	40	Square K	108.6 ± 3.4	U-series	Vogel, 2001
1/1A	LBS		AA43	MIS 5e	δ^{18}O shell	Deacon et al., 1988
1/1A	LBS		AA43	106.8 ± 12.6	TL-OSL	Feathers, 2002
1B	LBS	12	–	MIS 5e	δ^{18}O shell	Shackleton, 1982
	LBS[b]			> 101	LU ESR	Millard, 2008

WB = Witness Baulk; LU ESR = late uptake electron spin resonance; U-series = Uranium–Thorium dating; TL-OSL = thermoluminescence and optically stimulated luminescence; δ^{18}O shell = marine shell oxygen isotopes; AAR = amino acid racemisation. The relative ages determined by Goede and Hitchman (1987) are not included here but are discussed in the text

[a]This sample was collected from SM5, a deposit correlated with Layer 36, but was published with the details listed in the table

[b]Age estimates presented by Millard (2008) are based on statistical analysis of published dates for entire members

correlations. Furthermore, there have been changes in stratigraphic interpretations over time, but these have generally been published without sufficient reference to past ideas, resulting in a complex and confusing narrative.

Current Fieldwork Programme of Wurz

The third phase of fieldwork at KRM began in 2013, with an ongoing programme led by Sarah Wurz (Brenner & Wurz, 2019; Brenner et al., 2020; Wurz et al., 2018).

This work has largely focused on the continuation of high-resolution excavation and recording of deposits in the Cave 1 Witness Baulk. While Deacon's stratigraphic system of units, sub-members and members has been retained, multiscale geoarchaeological work is being undertaken which is aimed at evaluating and refining this approach and providing microstratigraphic data (Larbey et al., 2019; Mentzer et al., 2014; Mentzer, in press).

The Stratigraphy of the MSA I and II at Klasies River Main Site

Basal Gravels

The stratigraphically lowest units at KRM are a variety of gravelly and/or shingly deposits, in places capped by crusts or flowstones. Singer and Wymer (1982) grouped them into Layer 40 in Caves 1 and 1A and Layer 15 in Cave 1B. Layer 40 was reported across most of Cave 1 (Singer & Wymer, 1982, Fig. 3.26), but changes from a thin cemented gritty shingle with angular clasts near the entrance to an uncemented predominantly sub-rounded pebbly gravel at the rear of the cave (Butzer, 1982a, pp. 35–37; Deacon & Geleijnse, 1988, p. 7; Singer & Wymer, 1982, p. 17). In Cave 1A, Layer 40 comprises uncemented gritty sand (shingle) with angular gravel (Deacon & Geleijnse, 1988, p. 7; Singer & Wymer, 1982, pp. 22, 26). A single rolled handaxe was recovered from Layer 40 in Cave 1 (Singer & Wymer, 1982, p. 83), while the corresponding deposits in Cave 1A yielded two lithic artefacts (Singer & Wymer, 1982, p. 22).

Layer 15 in Cave 1B differs from Layer 40 in that the deposits are reportedly sandier and are considerably richer in lithic artefacts (Singer & Wymer, 1982, p. 25). Deacon and Geleijnse (1988) did not include Layers 40 and 15 in the overlying LBS Member, nor did they assign these deposits to a distinct member. However, as discussed below, Layer 15 in Cave 1B has subsequently been considered part of the LBS (e.g. Wurz, 2002).

Layer 40 was initially assigned an age of ~ 120 ka and equated with the Marine Isotope Stage (MIS) 5e highstand (Butzer, 1982a). This interpretation, although initially questioned (Hendey & Volman, 1986), continues to be supported by similar elevations for dated MIS 5e highstand deposits along South Africa's coastline (e.g. Cawthra et al., 2018; Jacobs & Roberts, 2009; summarised by Cooper & Green, 2021).

The Light Brown Sand Member

Layer 38 in Cave 1

The lowermost deposits containing archaeological materials in Cave 1 were grouped into Layer 38 by John Wymer (Singer & Wymer, 1982, p. 17). This layer was found over much of the excavated area of Cave 1, from the front of the cave to Square B or C in the Main Cutting and Squares K-L in the West Cutting (Singer & Wymer, 1982,

Fig. 3.25). Layer 38 capped the (almost) culturally sterile beach deposits of Layer 40 but in a few places capped either bedrock or calcite crusts (Singer & Wymer, 1982, p. 17). Layer 38 was overlain by Layer 37 wherever the latter deposits were identified (Singer & Wymer, 1982, Figs. 3.2–3.5), with isolated mixing occurring in the extreme west of the cave (Singer & Wymer, 1982, Fig. 3.25).

Layer 38 was described as a 15- to 45-cm-thick set of brown silty sand deposits containing numerous hearths which were often densely concentrated (Singer & Wymer, 1982, p. 17). The deposits were sandier near the entrance becoming rich in clay along the walls (Singer & Wymer, 1982, p. 17, Fig. 3.25). Hearths were most common nearer the entrance, apart from a significant concentration to the west of the Witness Baulk (Singer & Wymer, 1982, p. 17). Large quantities of bone and lithic artefacts were recovered, along with heavily fragmented shell (Singer & Wymer, 1982, p. 17). Butzer (1982a, p. 37) states that the artefacts were generally associated with the hearths.

Layers 38 and 39 in Cave 1A

Wymer was able to track Layer 38 from Cave 1 across into Cave 1A where it was excavated in Squares P and Q of the East Cutting (Singer & Wymer, 1982, Figs. 3.1 and 3.6). There, the deposits are similar in composition—with common lithics, bone and shell—but are thicker, generally coarser in texture, and contain fewer hearths (Singer & Wymer, 1982, p. 22).

In Square Q, Layer 38 was found over a culturally sterile deposit of beach sand and rare pebbles (Singer & Wymer, 1982, p. 22). This deposit was underlain by a succession of sandy sterile and artefact-bearing deposits. These sets of deposits were grouped together as Layer 39. The artefact-bearing sands in Layer 39 preserved some evidence of hearths and yielded relatively rare lithics, bones and poorly preserved shell.

The LBS

Deacon and Geleijnse (1988) grouped Layers 38 and 39 in Caves 1 and 1A into the Light Brown Sand (LBS) Member based on inspection and description of the then-unexcavated Witness Baulk (Fig. 6) in Cave 1, excavations in Cave 1/1A (AA43/Z44) (Fig. 7) and the analysis of sediment samples from both locations. This member is defined by a geogenic matrix of light brown sandy sediments with relatively thin interbedded layers of concentrated cultural debris, including hearth features and shell middens (Deacon & Geleijnse, 1988, p. 8). An unconformity truncating Layer 38 in Caves 1 and 1A was also noted in the definition and recorded in the stratigraphic drawings provided for both areas (Figs. 4 and 5). At the Cave 1/1A boundary (squares AA43 and Z44), the LBS includes units SBS to SCB3. The LBS has not been excavated by either Deacon or Wurz in Cave 1 itself.

Deacon and Geleijnse (1988, p. 11) included the basal archaeological deposits in Cave 1B (units RS BCH to RS YS1) in the RS (Rubble Sand) Member (Fig. 8) and equated these deposits with the LBS Member. Correlations with Wymer's original layers were published without justification (Wurz, 2002, Table 2). As with the LBS in Caves 1 and 1A, Layers 12 to 14 are alternating sandy deposits and finer

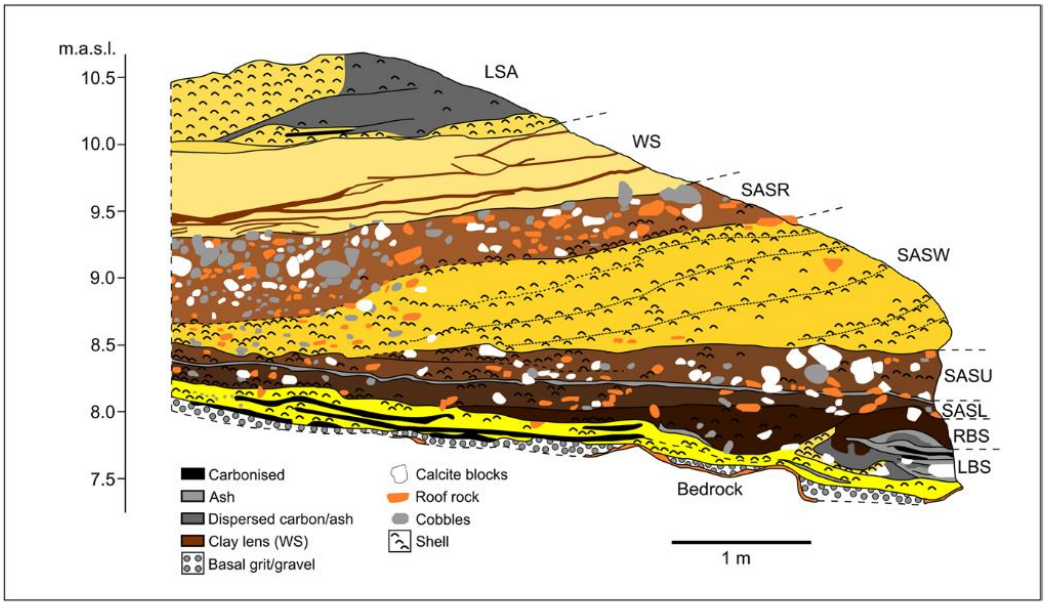

Fig. 6 The stratigraphy of the west face of the Witness Baulk (redrawn from Deacon & Deacon, 1999). As this profile was recorded prior to Deacon's excavations in Cave 1, no excavation units are shown

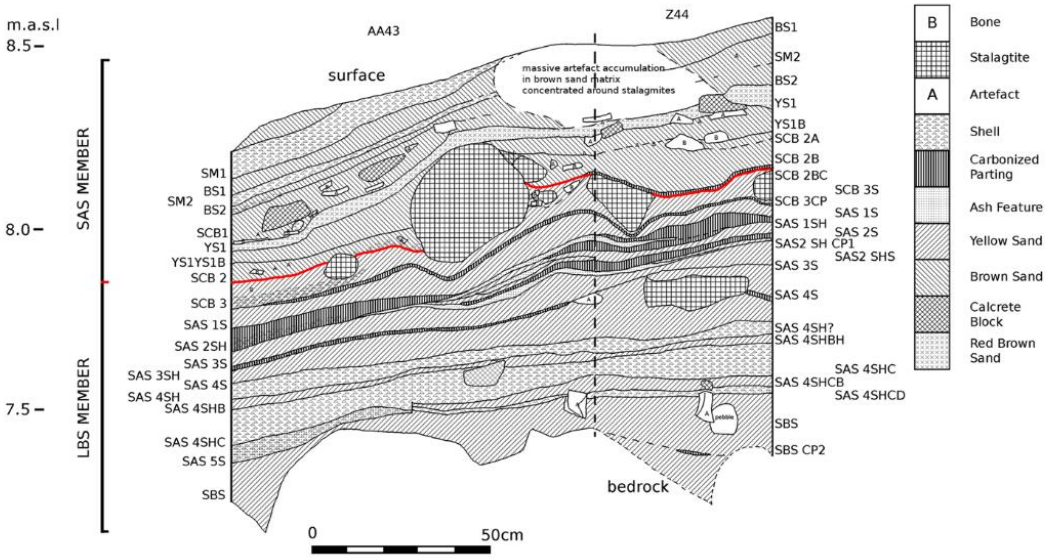

Fig. 7 The stratigraphy of the excavated units in the north face of squares AA43 and Z44 at the Cave 1/1A boundary (profile redrawn by L van Pletzen Vos from the original field drawings by the Deacon team). The red line indicates the contact between the LBS and SAS deposits proposed by Deacon

artefact-rich deposits which lie directly on beach deposits and are truncated by an unconformity (Deacon & Geleijnse, 1988, p. 11; Singer & Wymer, 1982, pp. 24–25). Layer 15, a sandy beach gravel which yielded 'numerous' lithics from its upper portion (Deacon & Geleijnse, 1988, p. 11; Singer & Wymer, 1982, p. 25) was initially excluded from the LBS (Deacon & Geleijnse, 1988). However, it was subsequently included in the Cave 1B LBS as published in Wurz (2002, Table 2), based on the

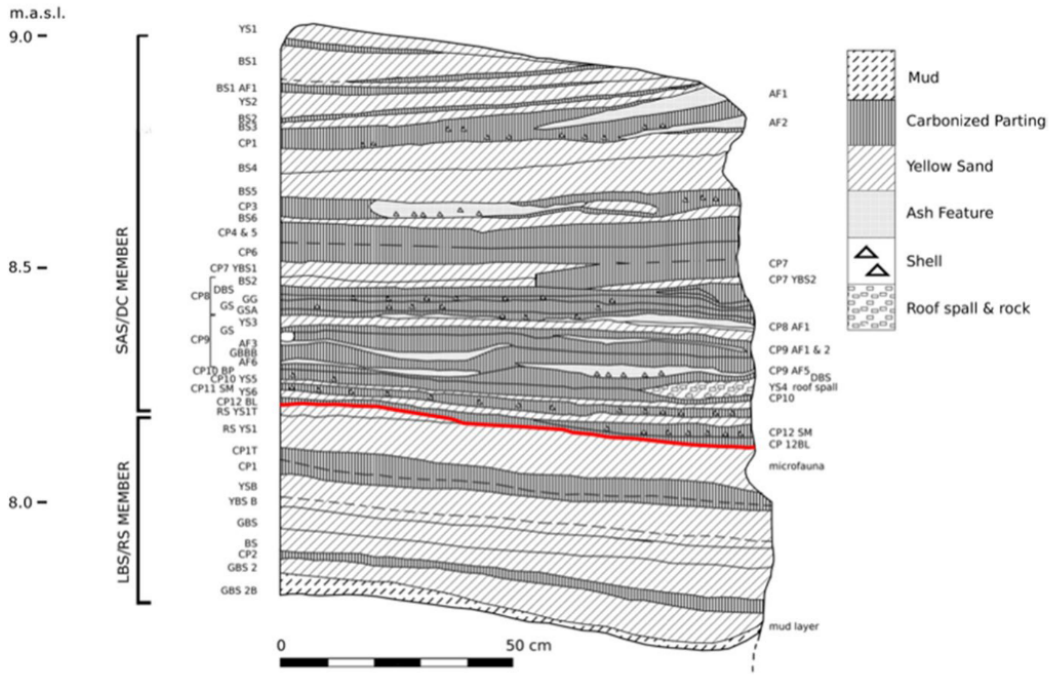

Fig. 8 The stratigraphy of the excavated units in the north wall of square PP38, Cave 1B. Note that this excavation has not reached bedrock (profile redrawn by L van Pletzen Vos from the original field drawings by the Deacon team). The red line indicates the contact between the LBS/RS and SAS/DC deposits proposed by Deacon

presence of MSA 1 lithics. The name RS has seldom been used in the literature, and there has been no discussion of the significance of the difference in descriptive meaning of the RS and LBS.

The unconformable upper surface of the LBS deposits across the site (Figs. 4, 5, and 6) suggests that they were truncated by erosion (Deacon & Geleijnse, 1988; Singer Wymer, 1982). However, the nature of this event or events is unclear, as is the temporal relationship between the LBS and the overlying RBS.

Lithic artefacts from Layers 38 and 39 in Caves 1 and 1A, and Layers 12 to 15 in Cave 1B were classified as MSA I by Singer and Wymer (1982). This attribution has been confirmed through detailed technological analysis of artefacts from the original excavations and those led by Deacon (Thackeray, 1989; Wurz, 2002, 2010, 2012; Wurz et al., 2003).

Age estimates for the LBS (Table 2) have been obtained through various means. Bone from Layer 38 in Cave 1 was dated to ~ 110 ka using amino acid racemization (AAR) (Bada & Deems, 1975), and Shackleton's (1982) analysis of oxygen isotope values in shells from Layer 38 in Cave 1 and Layer 12 in Cave 1B gave results consistent with global levels during MIS 5e (~ 130–115 ka). Subsequent isotopic analysis on shell from AA43 yielded results consistent with MIS 5e for the LBS in Cave 1/1A (Deacon et al., 1988). However, Deacon and Wurz (2001) refer these results to MIS 5d. These ambiguities need clarification that will be fully addressed in future publications and analyses. Two phases of speleothem growth have been associated with the LBS Member in Cave 1, which are argued to respectively pre-date

and post-date these deposits (Deacon & Geleijnse, 1988; Deacon et al., 1988; Vogel, 2001). However, no evidence has been provided to confirm these relationships. A Uranium-Thorium (U-series) date on speleothem from the second phase suggests a minimum age of ~ 110 ka for the LBS (Deacon et al., 1988), but an estimate from the base of a stalagmite which overlies the Layer 40 beach gravel in Square K in the west of Cave 1 places the maximum age of the LBS at 108.6 ± 3.4 ka (Vogel, 2001). Finally, thermoluminescence (TL) and optically stimulated luminescence (OSL) dating of a sample from units SAS4S-SAS3S from AA43 in Cave 1/1A yielded a result of 106.8 ± 12.6 ka (Feathers, 2002).

Statistical analysis of the U-series and luminescence ages suggests that the LBS can confidently be considered to pre-date 101 ka (Millard, 2008). The available evidence suggests that the LBS formed during MIS 5e/5d, but the wide variety of results from different techniques rule out a more secure age estimate. It has recently been suggested that the LBS could pre-date MIS 5e (Reynard & Wurz, 2020), and this hypothesis cannot currently be ruled out.

The Rubble Brown Sand Member

Layer 37 in Cave 1

During the 1967–1968 excavations in Cave 1 Wymer exposed and excavated deposits—designated as Layer 37—which were very different in colour and texture than the over- and underlying sediments. Layer 37 was found to cover a large area of Cave 1, including the width of the mouth and some distance (up to Square B or C in the Main Cutting and Squares J-K in the West Cutting) back into the cave (Singer & Wymer, 1982, Figs. 3.2 and 3.24). It was overlain unconformably in different areas by Layers 17a, 17b, 16, 15 and 14 (Singer & Wymer, 1982, p. 17). In several areas to the west of the Witness Baulk, Layer 37 was reported to be mixed with or disturbed by other layers (Singer & Wymer, 1982, p. 16). It is currently exposed in the southern and eastern profiles of the Witness Baulk (Singer & Wymer, 1982, Figs. 3.2 and 3.3, Plate 8). The distribution of Layer 37 indicated in Singer and Wymer's (1982) Fig. 3.24 suggests that it would also be exposed in the western profile of the Witness Baulk, but no drawing of this profile was published.

Singer and Wymer (1982, pp. 16–17) describe Layer 37 as a very carbonaceous 'black, greasy occupational soil' with 'clear and even' bedding which was sometimes contorted due to the irregular surface on which beds were deposited or due to the 'nature of the soil'. The layer had a maximum thickness of 0.5 m and contained pebbles and small stones and rare larger pieces of calcite and bedrock. Elsewhere, however, Singer and Wymer (1982, p. 208) remark on the presence of 'abundant angular rock fragments in layer 37'. Archaeological material was very common, but distinct hearths were not recognised, and shell was generally very degraded (Singer & Wymer, 1982, p. 16–17). There is some evidence for horizontal variation in Layer 37 across Cave 1, including a significant fining of sediments at the eastern wall, and an apparent concentration of contorted bedding and relatively good shell preservation in

the general area of the Witness Baulk (Singer & Wymer, 1982, p. 32, Fig. 3.24). The lithic artefacts were assigned to the MSA I (Singer & Wymer, 1982, p. 27).

Evidence for the age of Layer 37 is limited (Table 2). An estimate of 90 ka was obtained using AAR on bone from the original excavations (Bada & Deems, 1975). Goede and Hitchman's (1987) electron spin resonance (ESR) dating of marine gastropod shells collected by Deacon yielded only relative ages. These suggest potentially significant age differences between Layer 37 and its under- and overlying deposits (Layer 38/39 and Layers 14–17 respectively) and a possible similarity between Layer 37 and Layer 10 in Cave 1B. However, there is evidence that the analysed shells were enriched with uranium at differing rates in different parts of the sedimentary sequence, which could skew the results, especially for stratigraphically-lower samples (Goede & Hitchman, 1987, p. 171–172).

Layer 37 in Cave 1A

Wymer excavated a Layer 37 in Cave 1A which was a 'dark, sandy occupational soil with lines of carbonaceous soil and a few lumps of calcite' and yielded many lithics and bone pieces, but little shell (Singer & Wymer, 1982, p. 22). Clay content was observed to increase nearer Cave 1. It was correlated with Layer 37 in Cave 1 as the sediments were observed to be similar on either side of the ~ 3 m baulk between Square a (Cave 1) and East Cutting (Cave 1A) (Singer & Wymer, 1982, Fig. 3.1). It is not clear from Figs. 3.1 & 3.1A in Singer and Wymer (1982) if Layer 37 was excavated during limited excavations of the upper surface of this baulk.

It is difficult to estimate the distribution of Layer 37 in Cave 1A as little data are provided. It appears to mainly occur closer to the cave/cliff wall, and not extend as far out as Layers 38 and 39, but it has likely been truncated in some locations (Singer & Wymer, 1982, Figs. 3.1A & 3.6). The deposits are overlain by Layer 36 in places, but in others they are covered by seemingly significantly younger scree deposits (Singer & Wymer, 1982, Figs. 3.1, 3.6 & 3.15).

The MSA lithics from the Cave 1A Layer 37 were not described by Singer and Wymer (1982) unless they were grouped with the Cave 1 assemblage without this being stated. Layer 37 was ultimately assigned to MSA I (Singer & Wymer, 1982, p. 11), but it is not clear if this was due to the perceived stratigraphic correlation with Layer 37 in Cave 1 or due to unpublished analysis of the lithics.

The RBS in the Witness Baulk, Cave 1

The deposits lying above the truncated LBS deposits in the Witness Baulk were named the Rubble Brown Sand (RBS) sub-member and considered to be the base of the Shell and Sand (SAS) Member (Deacon & Geleijnse, 1988, pp. 8–9). Subsequently, the RBS has been viewed first as a sub-member of the LBS (Deacon, 2008, p. 145) and later as a distinct member (Wurz et al., 2018, p. 104). These deposits were not excavated by Deacon, who observed them in section in the Witness Baulk.

Deacon and Geleijnse (1988, p. 8) equated the RBS with Layer 37 due to its stratigraphic position and similarities in the described sediments (Fig. 6). Given the wide distribution of Layer 37 and its apparent exposure across much of the Witness

Baulk, if is not clear why the 'type' description of the RBS was made from the south-eastern corner of the Witness Baulk. Here, it is a fine-grained dark sediment rich in organic carbonaceous material with well-defined beds and laminae which are often heavily contorted. No sedimentary description of stratigraphic equivalents within the Witness Baulk was provided.

Despite the name assigned to these deposits, no mention was made of the presence or significance of rubble in them. Drawings of the eastern and western faces of the Witness Baulk published by Deacon suggest that the RBS is significantly less rubbly than the overlying deposits (e.g. Deacon, 2008, Fig. 3; Deacon & Deacon, 1999, Fig. 6.9; Deacon & Geleijnse., 1988, Fig. 7; Rightmire & Deacon, 2001, Fig. 2). Singer and Wymer's (1982, Figs. 3.1–3.5) illustrations appear to show a similar pattern for Layer 37 across Cave 1.

The extremely limited description of the RBS means that it is not possible to assess how representative the described portion is of the rest of deposits in the Witness Baulk assigned to this entity. In turn, this hampers any consideration of how representative of Layer 37 the RBS is.

'RBS Correlates' in Cave 1A and 1B.

The RBS *sensu stricto* in Cave 1 was correlated with deposits in Caves 1A and 1B by Deacon and Geleijnse (1988). In AA43 and the trench (Fig. 2), the shelly sand deposit of SCB2 (Fig. 7) is considered the 'stratigraphic equivalent' of the RBS/Layer 37 as it lies on the truncated surface of the LBS deposits (unit SCB3 in AA43) (Deacon & Geleijnse, 1988, p. 8). Units YS1B, dark sands with a number of lenses, and YS1, a 'marker' horizon of rubified sand, lie above SCB2 (Deacon & Geleijnse, 1988, p. 8). Overlying YS1 is a lag deposit named SCB1 (Deacon & Geleijnse, 1988, p. 8). Its description as 'the base of a considerable thickness of conformable sediments making up the SAS member' (Deacon & Geleijnse, 1988, p. 8) suggests a distinction between SCB1 and the underlying units SCB2-YS1. However, it is then stated that 'Layer 37 and the correlates SCB2-SCB1 are interpreted here as the truncated and drip eroded base of the younger SAS member and are not included in the LBS member' (Deacon & Geleijnse, 1988, p. 8). No truncation of these deposits is described in Cave 1A, so it is unclear if this is referring to the unconformable upper surface of the RBS or an unconformity in AA43 or the trench.

The RBS and the Cave 1A 'correlates' cannot be grouped lithostratigraphically due to significant differences in the limited information provided on their lithology. As the RBS in Cave 1 and SCB2 in Cave 1A lie on the truncated surface of the LBS, they clearly both post-date these deposits. However, this does not necessarily confirm a temporal correlation beyond a shared maximum age. Deacon and Geleijnse (1988) do not state explicitly why they consider SCB2-SCB1 distinct from the overlying Cave 1A SAS deposits, and thus, equivalent to the RBS. It may be that they viewed a possible hiatus represented by the formation of YS1 and/or the SCB1 lag as being caused by the same event as the apparent hiatus indicated by drip eroded pools at the top of the RBS, but this is unclear. On the data currently available, allostratigraphy cannot be used to correlate these deposits between Cave 1 and 1A.

The stratigraphic relationship between the 'RBS correlates' and Layer 37 in Cave 1A has yet to be explored in the literature, and Deacon and Geleijnse (1988, p. 8) seemingly pointedly avoid referring to the correlates as 'Layer 37'. Not enough detail has been published on the sedimentary properties of these layers to allow meaningful comparison to the RBS *sensu stricto* or Singer and Wymer's (1982) descriptions of Layer 37 and overlying deposits in Cave 1A.

Deacon and Geleijnse (1988, p. 11) correlate part of the sequence in Cave 1B (Fig. 8) with the RBS because ESR dating of shell associated with a human mandible (KRM 41815) in Layer 10 of Cave 1B yielded a similar relative result to that of a shell from Layer 37 in Cave 1 (Goede & Hitchman, 1987). However, as discussed previously, these relative dates have likely been influenced by differing rates of uranium enrichment and do not necessarily prove a temporal correlation. The very basic description of Layer 10 as 'dark grey clayey soil' which was 'flecked with charcoal but had no clear hearth spreads' given by Singer and Wymer (1982, p. 24) is broadly similar to their descriptions of Layer 37 in Cave 1 and 1A (pages 16–17 and 22 respectively), but there is too little detail to assess their similarity in the context of lithostratigraphic correlation.

Deacon and Geleijnse (1988, p. 11) suggest that a rubified sand unit which overlies the truncated LBS in Cave 1B correlates with YS1 in Cave 1A and represents the same depositional hiatus. This deposit was equated to Singer and Wymer's (1982, pp. 24–25) Layer 13b. Layer 10's position above this 'marker horizon' was used as evidence for correlating it with the 'RBS correlates' in Cave 1A and, indirectly, the RBS/Layer 37 in Cave 1. However, this ignores the fact that the 'RBS correlates' (other than SCB1) in 1A underlie the rubified 'marker horizon', while Layer 10 overlies its equivalent in 1B. This places these deposits on either side of an apparent depositional hiatus.

Wurz's (2000, 2002) analysis of the lithics from the PP38 excavation demonstrated that the assemblages from deposits immediately overlying RS YS1 at the top of the LBS (which contained MSA I lithics) fell within the MSA II lower. Based on Deacon's unpublished work, the units which yielded MSA II lower artefacts (DC CP12–DC CP7) were equated with Layers 11–6 of the original excavation. This was used to place Layer 10 within the SAS Member proper and to suggest a temporal correlation with the SASU and SASL in Cave 1 (Deacon, 2008). The apparent contradiction of the 'marker horizon' both overlying the LBS and being correlated with Layer 13b (which has subsequently been included in the LBS) has not been addressed. Furthermore, the very basic description of this unit (Deacon & Geleijnse, 1988, p. 11) does not seem to correspond with the only slightly more detailed description of Layer 11 provided by Singer and Wymer (1982, p. 24).

The analysis of the lithics from Cave 1A yielded similar results to Cave 1B (Wurz, 2000, 2002). The LBS deposits (from SCB3 down to the base of the AA43/Z44 sequence) yielded MSA I lithics. The assemblages from the 'RBS correlates' SCB2-SCB1 were classified as MSA II lower, along with the rest of the overlying deposits in AA43/Z44. Also placed in the MSA II lower were the lithics from SM5 in square T50 (Wurz, 2000, 2002). These deposits, in the lower portion of the SAS Member, have been equated to Layer 36 of the original excavation (Deacon, 2008; Wurz, 2002). In contrast to the MSA II lower assemblages

of the 'RBS correlates' in Caves 1A and 1B, the Layer 37 lithic assemblage in Cave 1 was assigned to the MSA I by Singer and Wymer (1982) and, following a more thorough analysis, by Wurz (2000, 2002). This strengthens the case against a stratigraphic correlation between the RBS *sensu stricto* and its 'correlates'.

The lithics from Layer 37 in Cave 1A have not been described, but Singer and Wymer (1982, p. 11) placed these deposits into the MSA I cultural grouping (perhaps based on unpublished analysis). While it would appear that SCB2-SCB1 therefore do not correlate with Wymer's Cave 1A Layer 37 deposits, they could be contemporaneous if the latter deposits *were* erroneously assigned to the MSA I rather than the MSA II lower. Further lithic analysis could clarify this.

The 'RBS correlates' in Caves 1A and 1B have also been related to each other based on the presence of ostrich eggshell (Deacon & Schuurman, 1992; Rightmire & Deacon, 1991). Ostrich eggshell, however, is present in many places throughout the site, including the 'RBS correlates' and overlying SAS deposits in Cave 1A (Deacon & Schuurman, 1992, Fig. 3; Rightmire & Deacon, 1991, Fig. 2), the MSA II of Cave 1 (Layers 14–17) (Singer & Wymer, 1982, p. 117) and from the SASL (Layer 17) (Wurz et al. 2018, p. 107). Furthermore, unpublished tallies of shell recovered during the Deacon excavations indicate the presence of ostrich eggshell in the LBS deposits underlying the 'RBS correlates' in Cave 1A. Ostrich eggshell is therefore not a valid biostratigraphic marker.

Careful reading of the literature shows that Deacon was aware of the difficulties with correlating the RBS with deposits outside the Witness Baulk. The RBS was initially considered lithologically distinct enough to be a member in its own right (Deacon, 1987). However, Deacon and Geleijnse (1988, p. 8) ultimately categorised it as the basal sub-member of the SAS because the deposits in Cave 1A (and presumably Cave 1B) were similar to the rest of the SAS. It was first suggested by Rightmire and Deacon (1991, p. 136) that Layer 10 could be penecontemporaneous with the lower parts of the SAS (Layers 16 and 17) which overlie the RBS in Cave 1, although they retained the stratigraphic correlation with Layer 37. Deacon then abandoned the correlation with Layer 37, and equated Layer 10 with Layers 16 and 17 in Cave 1 (Deacon, 1995, 1998; Deacon & Schuurman, 1992). He advised Wurz—his then-PhD student—to include the 'RBS correlates' in both Cave 1A and 1B within the SAS. When this work was published in 2000 (Wurz, 2000), the LBS in Cave 1B (Layers 12–15) was erroneously referred to as the RBS (Wurz, 2002, Table 2; see also comment in Grine et al., 2017, p. 57). In his final paper on the stratigraphy of KRM, Deacon repeated his argument for Layer 10 being the equivalent of the basal SAS (Deacon, 2008, p. 148).

Grine et al. (2017, p. 57) have subsequently stated that 'the layers for the RBS Member in Cave 1B should be 10–11, and SAS Lower in Cave 1B should correspond to Layers 6–9'. However, as the Cave 1B sequence is so poorly published, it is difficult to assess this reinterpretation.

Unsurprisingly given the different arguments Deacon made about the stratigraphic relationships between the RBS *sensu stricto* and its 'correlates' in Caves 1A and 1B, and the lack of a review clarifying them, the situation is somewhat confusing. On the current balance of published evidence, it seems that the

'correlates' should be considered the base of the SAS Member in both locations but that significantly more work is required to confirm this in Cave 1B.

The SAS Member

Layers 14–17b in Cave1

The 1967–1968 excavations in Cave 1 yielded material classified as MSA II from Layers 14, 15, 16, 17a and 17b (Singer & Wymer, 1982).

Layer 17 was excavated across a relatively small area of Cave 1 which stretched across the cave mouth and back to Squares B/C in the Main Cutting but included only a small part of the West Cutting (Singer & Wymer, 1982, Fig. 3.23). The published profiles suggest that it lay almost exclusively on Layer 37 while it was overlain by Layer 16 (and perhaps 14) and scree deposits (Singer & Wymer, 1982, Figs. 3.1–3.3). Towards the interior end of its distribution, Layer 17 was composed of a dark grey brown matrix with a relatively minor rubble component which included pebbles and fragments of calcite (Singer & Wymer, 1982, p. 16). Towards the eastern side of the entrance, distinct upper and lower sub-layers were recognised: the occupational deposits of Layer 17a and the underlying rubbly Layer 17b (Singer & Wymer, 1982, p. 16). Both contained the same organic silty sand matrix with no apparent bedding which, in Layer 17a, gradually became clay along the eastern wall (Butzer, 1982a, p. 37; Singer & Wymer, 1982, p. 16). The rubble of Layer 17b was predominantly composed of pieces of 'soft calcite' (Singer & Wymer, 1982). This appears to be either tufa or phytokarren/photokarren, calcite deposits formed by dripping water and biophysical/biochemical activity respectively (Vanara & Maire, 2006; Viles, 1984). Layer 17 yielded a high density of artefacts throughout, which were apparently well-preserved except for shell (Singer & Wymer, 1982, p. 16). Artefacts in the rubble were found to dip at a wide range of angles.

Layer 16 was recorded from just inside the mouth back to Square B of the Main Cutting, and in most of the eastern half of the West Cutting (Singer & Wymer, 1982, Fig. 3.22). It may extend further back into the cave along the Main Cutting, but it could not be distinguished from the lithologically similar Layer 14 in this area (Singer & Wymer, 1982, pp. 14–16). These deposits lay on Layer 37 or Layer 17 and were overlain by both Layer 15 and Layer 14 (Singer & Wymer, 1982, Figs. 3.2–3.5). Singer and Wymer (1982, pp. 14–16) state that it is likely that there was mixing between Layer 14 and Layer 16 in some excavated areas, and they could not be differentiated during excavation of some areas, resulting in excavated material being attributed to Layer 14 when Wymer was uncertain of its context. Near the cave entrance, Layer 16 was an organic silty sand with notable clay content, but it soon merged into a dense rubble comprising 'pebbles, angular rock fragments, large lumps of soft and hard calcite, broken stalagmites, and many large and small bones in good condition, as well as a prolific stone industry' (Singer & Wymer, 1982, p. 14). A small, concentrated accumulation of burnt stone and bone was reported just south of the Witness Baulk (Singer & Wymer, 1982, Fig. 3.22). Along the eastern wall, Layer 16

became thick calcareous clay which covered thin deposits of culturally sterile aeolian sand (Butzer, 1982a, p. 37; Singer & Wymer, 1982, p. 14). Marine shell was abundant, but generally only well preserved in the rubble. Local formation of stalagmites occurred, along with partial cementation (Butzer, 1982a, p. 37).

Layer 15 was excavated in a small area which ran diagonally on either side of the Witness Baulk and included parts of Squares G, H and K in the West Cutting and went up to the boundary of Squares A and B in the Main Cutting (Singer & Wymer, 1982, Fig. 3.21). It appears to have lain exclusively on Layer 16 and been overlain by Layer 14 only (Singer & Wymer, 1982, Figs. 3.2–3.4). Singer and Wymer (1982, Fig. 3.21) suggest mixing of Layer 15 with both Layer 16 and Layer 14 in the Main Cutting, but it is unclear if they mean that post-depositional mixing occurred between these deposits, or that the layers could not be distinguished during excavation, resulting in mixing of material by the excavators. The deposits were described as brown or greyish brown organic silty sand and lenses of ash which accumulated as a steeply dipping mound with a maximum thickness of 1.7 m (Butzer, 1982a, p. 37; Singer & Wymer, 1982, p. 14). On the eastern profile of the Witness Baulk, this mound banked up on a large stalagmite which stands almost vertical (Singer & Wymer, 1982, Fig. 3.2). Stalagmites and localised calcite crusts formed both during and after deposition of Layer 15 (Butzer, 1982a, p. 37; Singer & Wymer, 1982, p. 14). As with most of the MSA layers in Cave 1, Layer 15 merged with clay and soft calcite along the eastern wall (Singer & Wymer, 1982, Fig. 3.21).

Layer 14 was mapped across almost all the excavated area of Cave 1, being absent only in parts of the entrance and Square J of the West Cutting (Singer & Wymer, 1982, Fig. 3.20). It lay variously on Layers 15, 16 and 37 and, in the rear of the cave the beach gravel of Layer 40, while it was overlain by Layers 12 and 13 (Singer & Wymer, 1982, Figs. 3.2–3.5). It was a rubble of 'beach pebbles and boulders, lumps of calcite [tufa or phytokarren/photokarren], broken stalagmites or stalactites, and fragments of the rock wall' with a silty sand matrix, neither of which were stratified (Singer & Wymer, 1982, p. 14, brackets this paper). Butzer (1982a, p. 37) also noted the presence of aeolianite fragments and reworked cemented sediment within the rubble. These deposits were almost 1 m thick in the Main Cutting but became notably thinner in the West Cutting and the rear of the cave. Moving down the Main Cutting and into the Rear Chamber, the deposits appear to have become notably finer (Singer & Wymer, 1982, Fig. 3.20). In the Rear Chamber, the rubble contained a far higher proportion of pebbles than elsewhere, but it appears to have been disturbed and mixed with the underlying Layer 40 beach deposits (Singer & Wymer, 1982, p. 14). Wymer noted mixing with Layer 16 in an area of the Main Cutting, and with Layer 15 and/or 16 in parts of the West Cutting (Singer & Wymer, 1982, Fig. 3.20). Some cementation of the deposits onto the cave wall and onto flowstone occurred in the West Cutting. Lithic artefacts and bones were found at a very high density within Layer 14 (Singer & Wymer, 1982, p. 14).

Layers 22–36 in Cave 1A

Layers 22 to 36 of Cave 1A were grouped into the MSA II by Singer and Wymer (1982, p. 11). These deposits were sampled in a number of cuttings down the slope of this area of the site (Singer & Wymer, 1982, Fig. 3.1A). These layers are not described in as much detail as those within Cave 1 (Singer & Wymer, 1982, p. 21–22).

At the base of this sequence were the deposits of Layers 34 to 36 (Singer & Wymer, 1982, Fig. 3.1). They appear to have lain conformably on each other and to have had broadly similar lithologies, comprising silty sands with lenses of carbonaceous material and (less commonly) shell (Singer & Wymer, 1982, p. 22). However, water saturation made both excavation and description of the sediments difficult. Lithic artefacts were common, while the well-preserved bone varied in abundance. In contrast, shell was either entirely absent or very poorly preserved. Layers 27 to 33 comprised laminated deposits of carbonaceous sediment, ash, and shell which were contained within or alternated with sandy deposits of varying thickness (Singer & Wymer, 1982, pp. 21–22). The density and degree of preservation of bone, shell and lithic artefacts varied through the layers. Layer 26 was a thin rubble horizon of calcite and rock infilled by sand and occupational debris (Singer & Wymer, 1982, p. 21). The debris included many lithics, well-preserved but rare bone and numerous shell fragments. Layers 23 to 25 were sandy deposits with carbonaceous layers and lenses which occurred at varying densities (Singer & Wymer, 1982, p. 21). Lithic artefacts were very common, while both shell and bone were well-preserved but often fragmented. Finally, Layer 22 comprised alternating laminated deposits with two thicker black horizons and some rubble (Singer & Wymer, 1982, p. 21). The collapse of boulders onto the deposits has resulted in localised deformation of the original bedding. Both lithic artefacts and shell were common, but bone other than microfauna was relatively rare.

The SAS in Cave 1

In Cave 1, Deacon and Geleijnse (1988, p. 9) split the SAS Member into several sub-members created as rough equivalents of the layers defined during the original excavations (Fig. 6). These sub-members—defined from the standing sections of the Witness Baulk prior to Deacon's excavations—are the SAS RBS (later removed from the SAS), the SAS Base or Lower (SASB or SASL), SAS Upper (SASU), SAS Wedge (SASW) and SAS Rubble (SASR). The SASL (SASB is no longer used) and SASU constitute a single lithostratigraphic sub-member which has been split so that they correlate roughly with Layers 17 and 16 respectively (Deacon, 2008; Deacon & Geleijnse, 1988; Rightmire & Deacon, 1991). SASW (Layer 15) and SASR (Layer 14) are distinct sub-members (Deacon, 2008; Deacon & Schuurman, 1992; Rightmire & Deacon, 1991).

Deacon did not excavate any of the SAS deposits in Cave 1 until the 1990s, and therefore, no unit names were provided initially. However, following Deacon's partial excavation of the Witness Baulk, and Wurz's ongoing work, units have now been published for much of the SAS. The SASL contains units SBLS (Silty Black

Soils) to SMONE (Shell Midden One), the SASU contains units HHH (Hearth Hearth Hearth) to D1 and the SASW is divided into units H3 to A1. No unit names have been published for the very limited portion of the SASR that has been excavated. As these units have all been published in papers focused on specific types of finds (e.g. human remains or lithics) with limited contextualisation, and not in specialist geoarchaeological papers, there is little published information (and often none) on their properties (e.g. Brenner et al., 2020; Rightmire & Deacon, 2001; Wurz et al., 2018).

Technological analysis conducted on lithic assemblages that were excavated by Deacon (and later Wurz) from the SAS in Cave 1 has resulted in materials from SASL and SASU being grouped into the MSA II lower, and those from SASW being classified as MSA II upper (Brenner & Wurz, 2019; Brenner et al., 2020; Wurz, 2000, 2002). Only a very limited volume of the SASR was excavated, and the lithic sample was too small for analysis (Wurz, 2000). Given Singer and Wymer's (1982) characterisation of Layer 14 as MSA II, it is reasonable to assume that the SASR lithics would likely belong in the MSA II upper, but this cannot be confirmed.

A number of dates are available for the SAS in Cave 1 (Table 2). A tooth from the SASL was dated using ESR, with late uptake results from two dated subsamples of 93.5 ± 10.4 ka and 88.3 ± 7.8 ka (Grün et al., 1990). Subsequent combined *in situ* U-series and ESR dating of the same tooth yielded an age estimate of 101 ± 12 ka (Eggins et al., 2005). The SASU was dated to 89 ka using AAR (Bada & Deems, 1975) and, more recently, U-series dating of flowstone on tufa which fell into the HHH unit has provided a maximum age of 126.0 ± 1.5 for the base of this sub-member (Wurz et al., 2018). The SASW was argued to date to either MIS 5c (106–93 ka) or MIS 5a (84–73 ka) based on oxygen isotope ratios in shells (Shackleton, 1982). Feathers (2002) subsequently obtained a TL-OSL date of 70.9 ± 5.1 ka. Vogel (2001) published three U-series dates from two stalagmites which formed on the base of the SASR near the back of Cave 1 (Squares D and M). The bases of the stalagmites were dated to 100.8 ± 7.5 ka (Square M) and 94.6 ± 3.2 ka (Square D), while the tip of one was dated to 85.2 ± 2.1 ka (Square D). Unfortunately, the relationships between the stalagmites and the Witness Baulk deposits are not fully understood, with implications for assessing how confidently these ages can be associated with the SASR and over- and underlying deposits (Wurz et al., 2018, p. 107). Millard (2008) used statistical analysis of previously published ESR, U-series and luminescence dates from Caves 1 and 1A to estimate an age range for the SAS at KRM of 104–64 ka. Although this estimated range relates to the whole of the SAS, its association to the single ESR sample from the SASL in Cave 1 has recently been highlighted (Grine et al., 2017, p. 60; Wurz et al., 2018, p. 108).

The SAS in Cave 1A

The sequence in Cave 1A was recorded by Deacon and Geleijnse (1988) by conducting small excavations into profiles along the Wymer cuttings. The SAS Member in Cave 1A (including the Cave 1/1A boundary) was correlated with Layers 23 to 36 of the original excavations, while Layer 22 was designated as the Rockfall (RF) Member. The Cave 1A SAS was subsequently split into two divisions because

the deposits correlated with Layer 36 (AA43 SCB2–T50 SM5T) were found to contain MSA II lower assemblages, while those correlated with Layers 23 to 35 (T50 BS4L–L51 YS) yielded lithics assigned to the MSA II upper (Wurz, 2000, 2002). Significantly, the 'RBS correlates' in AA43 were included in the MSA II lower division (Wurz, 2000, 2002). There appears to be neither a change in lithology nor an unconformity associated with this lithic technology-based stratigraphic division.

Wymer did not recognise any stratigraphic relationships between Layers 14–17 in Cave 1 and Layers 36–23 in Cave 1A during the initial excavations (Singer & Wymer, 1982, p. 23). Deacon and Geleijnse (1988) also did not correlate any specific SAS Member deposits in Cave 1A with any in Cave 1. However, several suggestions have been made subsequently. Wurz et al. (2018, p. 106) hypothesise based on similarities in sedimentary properties that a group of SAS lower deposits in AA43 (units B2 to SM1) correlate with at least part of the SASL in the Witness Baulk (Fig. 7), but emphasise that this has to be tested. Layer SM5 has been correlated with SASU in the Witness Baulk (Deacon, 1995, p. 125, 2008, p. 148; Feathers, 2002; Rightmire & Deacon, 1991, p. 136, 2001, p. 538). No information other than the recovery of human fossils from these deposits has been presented in support of this hypothesis. Finally, the top of SASW has been linked to the top of Layer 25 in Cave 1A—effectively correlating the SASR with Layers 24 and 23 (Grine et al., 2017, p. 59).

Relatively limited dating has been conducted for the Cave 1A SAS deposits (Table 2). A sample for TL-OSL dating was collected from unit SM5, Layer 36 (assigned to the SASU in that study) in a profile at the boundary between Caves 1 and 1A and dated to 68.4 ± 6.5 ka (Feathers, 2002). A calcium carbonate crust within deposits equated with Layer 30 was dated using U-series to 77.4 ± 7.0 ka (Vogel, 2001). Grün et al. (1990) obtained late uptake ESR age estimates of 60.5 ± 4.9 ka, 65.8 ± 7.0 ka and 72.8 ± 6.4 ka from a tooth recovered from Layer 27.

The SAS/DC in Cave 1B

The assemblages excavated from Layers 1 to 15 in Cave 1B were all assigned to the MSA I (Singer & Wymer, 1982). However, Deacon and Geleijnse (1988) recognised lithological changes in the sequence which led them to correlate two groups of deposits, which were called the RS (Rubble Sand) and DC (Dark Carbonised) Members, with the LBS and SAS respectively (Fig. 8). Subsequent technological analysis of lithics excavated from square PP38 revealed that the assemblages from the SAS/DC fall within the MSA II, rather than the MSA I (Thackeray, 1989; Wurz, 2000, 2002). As in Cave 1A, the SAS deposits could be further divided into lower and upper groupings based on the presence of MSA II lower assemblages (units DCCP12–DCCP7) and MSA II upper assemblages (units DCCP6–DC surf) (Wurz, 2000, 2002). Based on Deacon's unpublished work, the lower SAS deposits were correlated with Layers 11–6, while the upper ones were equated with Layers 5–1 (Wurz, 2002, Table 2).

The limited sedimentary descriptions provided by Singer and Wymer (1982, p. 24) indicate that both groupings are made up of alternating layers of relatively sandy and relatively carbonaceous sediment. No detailed profile of the Deacon

excavation in Cave 1B has been published, nor has a basic description of the SAS/DC sediments, apart from those excavated at the very top of the sequence by Henderson (1990, 1992). Therefore, it is not currently possible to assess the proposed correlations between Deacon's units and Wymer's layers, or to determine if the change in cultural stratigraphy within the SAS can be linked to a change in lithology.

Discussion

Stratigraphy

Unfortunately, the high-resolution stratigraphic work conducted at KRM by Hilary Deacon has been published in very limited detail as he passed away before he could complete a detailed publication incorporating all his data and interpretations. Therefore, the literature reviewed in this paper represents only a portion of his work at the site, while the excavation and recording conducted at relatively low resolution by John Wymer has been published in far greater detail. Significantly, there are clear spatial differences in the quality and quantity of published data from both sets of excavations, with the sequence in Cave 1B proving to be particularly poorly published. The groupings are discussed individually below, followed by an assessment of the current stratigraphic approach.

Depositional and post-depositional processes in cave and shelter sites can be extremely complex and vary considerably through time and space, with numerous geogenic, biogenic and anthropogenic inputs potentially playing a role in the formation of any specific deposit (Butzer, 1982b; Goldberg & Berna, 2010; Goldberg & Sherwood, 2006). People can be powerful geomorphic agents in these contexts, and this is apparent at KRM, where almost all the clastic deposits contain anthropogenic inputs (Butzer, 1982a, p. 41). The combination of spatial variation in natural processes and human behaviour across the site complex, and the resulting potential for localised patterns of deposition and erosion, complicate the use of lithostratigraphic and allostratigraphic approaches in intra-site stratigraphic correlation.

Most research into the formation of deposits at KRM has been broadly focused, with the goal of elucidating site-scale processes which acted over long periods of time (Butzer, 1982a; Deacon & Geleijnse, 1988). As a result, we have a comprehensive list of potential site formation processes which may have been involved in the formation of various deposits (Table 3). However, there is only a limited understanding of precisely which of these processes were involved in the formation of specific deposits (Table 4). This is problematic given that many of the layers or members are composed of dozens or even hundreds of discernible deposits, some of which are just millimetres thick. Furthermore, deposits in similar contexts often contain microfacies which cannot be identified and/or analysed at the macroscale (e.g. Goldberg & Berna, 2010; Karkanas et al., 2015; Wadley et al., 2020) and this has been demonstrated to be the case for some deposits at KRM (Larbey et al., 2019).

Broad sedimentological characteristics have been determined based on the analysis of bulk sediment samples (Butzer, 1982a; Deacon & Geleijnse, 1988). Butzer's

Table 3 List of site formation processes suggested in the published literature for Klasies River Main site, and possible associated deposits and post-depositional effects (Butzer, 1982a; Deacon, 1995, 2008; Deacon & Geleijnse, 1988; Henderson, 1992; Rightmire & Deacon, 1991; Singer & Wymer, 1982). Cave 2 is omitted because little has been published on the formation of the deposits, and these layers are not relevant for this paper. Any of the members/sub-members or layers at the site were likely formed by a mix of depositional and post-depositional processes due to lateral variation in geogenic processes, spatial patterning of human activity and the presence of numerous distinct deposits within each grouping. Explicit published links between deposits or groups of deposits to these processes are considered in Table 4

Process	Deposit type	Effects on previous deposits	Cave 1	Cave 1A	Cave 1B
Seawater inundation due to high stands or storm surges	Beach sands and shingle	Erosion, winnowing, saturation	x	x	x
Speleothem formation	Flowstones, stalactites, stalagmites, columns, soda straws	Cementation, flowstone formation	x	x	
Downward movement of water and fine sediment through bedrock joints	Clay	Water saturation, burial, dissolution	x	x	
Mass wasting	Colluvium, talus, scree, sheetwash	Erosion and slumping (upslope) and burial (downslope)	x	x	
Mechanical and chemical weathering of the bedrock, spalling, collapse	Rubble, sand grains	Burial, deformation of saturated sediment	x	x	x
Aeolian transport and saltation	Silt and sand, dunes, lag	Winnowing, burial	x	x	x
Occupation of the site by birds and bats	Guano, eggshells, gastric stones, owl pellets, microfaunal bones	Phosphatization and dissolution (when combined with moisture)	x	x	x
Human occupation	Shells, animal bones, manuports, lithic debitage, urine, feces, plant remains, burned fuels	Burial, heat alteration	x	x	x
Human site maintenance[a]	Middens	Excavation and burial	x	x	x
Surface stability	Soil or weathered surface	Chemical weathering, translocation, effects of plant roots, bioturbation	x	x	x

[a]It has been suggested that small features in Cave 1B represent the disposal of food waste, but these have not been categorised as middens (Henderson, 1992)

Table 4 A summary of published site formation interpretations for the basal gravels, and the LBS, RBS and SAS deposits at Klasies River Main site. The SASL and SASU are combined as they are generally described as being a single lithostratigraphic sub-member (e.g. Deacon, 2008). A general description of the sedimentology of the deposits is provided in the text, with only member-specific information provided here and a list of possible processes and associated deposits/post-depositional effects is presented in Table 3

Basal Gravels in Cave 1 and 1A (Layer 40)	
Beach deposits formed around a + 7 m highstand, likely formed by swash and backwash	Butzer, 1982a; Deacon & Geleijnse, 1988
Calcite fragments within the gravels in Cave 1 indicate an earlier phase of speleothem formation and subsequent erosion (presumably) during the highstand	Butzer, 1982a
Post depositional alteration of clasts noted; no process proposed	Butzer, 1982a
Possible hiatus in clastic deposition in Cave 1 after formation of gravels based on flowstone and stalagmite formation on surface	Hendey & Volman, 1986
LBS Member in Cave 1 and 1A (Layers 39–38)	
Alternating sandy geogenic units and anthropogenic deposits interpreted as hearths and shell middens	Deacon & Geleijnse, 1988; Singer & Wymer, 1982
The sand component fines up through the member, with a gradual reduction in the input of beach sand and a steady increase in the contribution of particles derived from local weathering and from erosion of the overlying palaeodune system	Butzer, 1982a; Deacon & Geleijnse, 1988
Micromorphological analysis confirms in-situ hearths and shell lenses in Cave 1 Witness Baulk	Larbey et al., 2019
The absence of coeval speleothems in Cave 1 indicates limited supply of dripwater	Butzer, 1982a
Deposits truncated by erosion	Deacon & Geleijnse, 1988; Singer & Wymer, 1982
RS Member/sub-member in Cave 1B (Layer 15–12)	
Layer 15 gravels included in the RS sandier than Layer 40 gravels in Cave 1; also interpreted as beach deposits	Singer & Wymer, 1982
Sands considered equivalent to LBS, but no explicit formation interpretations made	Deacon & Geleijnse, 1988
Deposits truncated by erosion	Deacon & Geleijnse, 1988
RBS Member in Cave 1 (Layer 37)	
This fine-grained dark sediment is rich in organic carbonaceous material with well-defined beds and laminae; its composition suggests significant anthropogenic input (cf. "mineral soil" in Butzer, 1982b, 80)	Butzer, 1982a; Deacon, 2008; Deacon & Geleijnse, 1988; Singer & Wymer, 1982
Lack of speleothem growth during deposition indicates a limited supply of dripwater in Cave 1 while the RBS was forming	Butzer, 1982a
An unconformable upper surface, and small drip-eroded pools and associated clay filling in this surface suggest a depositional hiatus between the RBS and overlying sediments	Deacon & Geleijnse, 1988; Singer & Wymer, 1982

Table 4 (continued)

Contortion of beds and laminae attributed to plastic deformation due to loading of saturated sediments following burial	Deacon & Geleijnse, 1988
SASL and SASU Sub-members in Cave 1 (Layers 17–16)	
A mix of rubble and various finer facies, often with sharp boundaries	Singer & Wymer, 1982; Deacon, 2008
The rubble is argued to have been formed by either a) the movement of debris down a relatively gentle slope from the cave entrance, or b) localised winnowing of finer material from matrix dominated sediments	Brenner et al., 2020; Brenner & Wurz, 2019; Deacon, 2008; Deacon & Schuurman, 1992; Rightmire & Deacon, 1991, 2001; Singer & Wymer, 1982
The fine facies in the SASL are dark silty sands relatively rich in clay and organic material which have yielded numerous artefacts and faunal remains; they are interpreted as occupational deposits altered by post-depositional water movement, leading to winnowing and the loss of stratigraphic detail	Brenner & Wurz, 2019; Brenner et al., 2020; Singer & Wymer, 1982
The fine facies in the SASU include numerous anthropogenic deposits, including combustion features (evidenced by carbonised material), ash and shell lenses; some relatively coarse aeolian sand lenses were reported	Butzer, 1982a; Deacon, 2008; Singer & Wymer, 1982; Wurz et al., 2018
The modern drainage routes through the site suggest that water movement above and/or below the surface could have affected the rubble and/or finer deposits	Deacon, 2008; Deacon & Geleijnse, 1988; Singer & Wymer, 1982
The formation of stalagmites and calcrete lenses, and the cementation of some deposits indicate that dripwater was plentiful, especially towards the end of this depositional phase	Butzer, 1982a
SASW Sub-member in Cave 1 (Layer 15)	
Initially considered to be wholly or partially composed of primary occupational deposits, seemingly due to high artefact density	Butzer, 1982a; Singer & Wymer, 1982
Later reinterpreted as colluvial talus slope deposits due to steep tip lines dipping away from the cave mouth; reworking of deposits in Cave 1A most likely source of material	Deacon, 2008; Deacon & Geleijnse, 1988; Rightmire & Deacon, 1991
SASR Sub-member in Cave 1 (Layer 14)	
This rubble-rich deposit was interpreted by Karl Butzer as a storm beach gravel formed by the reworking and deposition of clasts and finer sediment by waves and swash funnelled by the cave walls	Butzer, 1982a
More widely argued to be a colluvial deposit formed by artefactual and natural material being eroded from Cave 1A and moving downslope into the cave; supported by the lack of widespread erosion of the uncemented deposits in Cave 1 and the absence of bedding	Deacon, 2008; Deacon & Geleijnse, 1988; Rightmire & Deacon, 1991; Singer & Wymer, 1982

Table 4 (continued)

SAS in Cave 1/1A and 1A (Layers 36–22)	
Alternating sandy geogenic units and anthropogenic deposits	Deacon & Geleijnse, 1988; Singer & Wymer, 1982
Sand notably finer than in the underlying LBS; generally fining up but with some coarser 'peaks'; dominant source was the overlying palaeodune (colluvial deposition)	Deacon & Geleijnse, 1988
Anthropogenic deposits include shell middens, hearths and carbonised plant material	Deacon, 1993; Deacon & Geleijnse, 1988
The rubified sand unit YS1, at the base of the SAS deposits, is considered to represent weathering during a depositional hiatus	Deacon & Geleijnse, 1988
Unit SCB1, overlying YS1, is interpreted as a lag deposit formed by drip erosion although no data are presented to support this claim	Deacon & Geleijnse, 1988
Some cementation of deposits by calcium carbonate from Layer 29 to Layer 33; no specific process suggested, but dripwater has been proposed for similar cementation in Cave 1	Singer & Wymer, 1982
Saturation of Layers 34 to 36 was noted during excavation, potentially contributing to dissolution and obscuring stratification	Singer & Wymer, 1982
DC Member/sub-member in Cave 1B (Layers 11–1)	
Rubified sand unit near the base of the DC deposits interpreted as the product of a depositional hiatus and equated with YS1 in Cave 1A	Deacon & Geleijnse, 1988
Upper deposits are alternating sandy geogenic units and anthropogenic deposits, including hearths and carbonised plant material	Deacon, 1993; Henderson, 1992

samples exclude Cave 1B and the SAS in Cave 1A, while Deacon and Geleijnse only published data for samples from the Cave 1/1A boundary and Cave 1A. The general results for the LBS, RBS and SAS are summarised below, with member/sub-member specific information summarised in Table 4.

The deposits contain a mix of anthropogenic, biogenic and geogenic components in varying proportions (Butzer, 1982a; Deacon & Geleijnse, 1988). Sand sized material dominates most of the deposits but coarser (grit and gravel) and finer (silt and clay) particles are significant components. Anthropogenic inputs include lithic artefacts, bone, shell and manuports, but also fine organic material and sand and grit sized pieces of flaking debris. These are most common in anthropogenic units but are also present at lower concentrations in geogenic deposits. Biogenic inputs (predominantly microfauna and fish bones) are more common in geogenic deposits. Beach/dune sands seaward of the caves and the palaeodunes overlying the hosting cliff were significant sources for the geogenic component of the sand fraction. Roof spall is rare or absent in these parts of the sequence, but local weathering was an

important contributor to the sand and grit fractions. Comparison of samples reveals a general fining up from the base of the LBS to the top of the SAS, but some variation within the SAS, including some significantly coarser sands in some Cave 1 deposits (Butzer, 1982a, Fig. 4.2; Deacon & Geleijnse, 1988, Fig. 10). This corresponds with a gradual decrease in the contribution of beach/dune sand and an increase in colluvial deposition of sands eroded from the palaeodunes as sea levels fell (Deacon & Geleijnse, 1988).

The LBS Member

The LBS Member appears to be the least problematic of the basal lithostratigraphic groupings defined by Deacon and Geleijnse (1988). The lithological description is fairly broad but provides enough detail to exclude the directly overlying RBS and SAS deposits in the Witness Baulk and at the Cave 1/1A boundary (AA43/Z44), and there is a good correlation between the deposits assigned to the LBS Member and Layers 38 and 39 in Cave 1 and 1A. However, there are issues which complicate the use of the LBS as a lithostratigraphic grouping.

Singer and Wymer's (1982) sedimentary descriptions and the authors' own observations indicate that there are deposits throughout the sequence which fit the description (and descriptive name) of the LBS. These include units in the SAS and Upper Members in Cave 1A and, more significantly as they directly overlie the RS/LBS, the DC/SAS deposits in Cave 1B. The occurrence of these facies in other members has implications for the use of the LBS as a lithostratigraphic grouping.

The direct equation of the RS deposits with the LBS obscures variation in sedimentary facies between Cave 1B and Caves 1 and 1A. The name Rubble Sand implies the presence of clast-rich deposits in the lower portion of the Cave 1B sequence, but the limited description of the LBS makes no mention of this facies (or multiple facies). The deposition of different facies in different areas of the site during the same period is both likely and expected, so the apparent presence of different sedimentary properties in the RS/LBS and the LBS does not rule out a temporal correlation, but it does complicate the use of the LBS as it is currently defined. It is unclear if the name RS can be attributed purely to the inclusion of Wymer's basal gravels in Cave 1B into the RS/LBS (they are excluded from the LBS across the rest of the site) or if the name relates to other deposits (Table 4). Determining how the RS deposits formed could help to address these issues.

We argue that the LBS is best viewed as a combined cultural and lithostratigraphic grouping, defined by the presence of both MSA I lithic technology and deposits with a light brown sand geogenic matrix. With this consideration, it is a useful entity for temporal correlation across Caves 1 and 1A, but further work is needed to understand the poorly published deposits in Cave 1B. It may be necessary to consider the RS as a distinct lithostratigraphic member, re-define it as a spatial sub-member of the LBS (e.g. the LBS-RS or LBRS) or to broaden the definition of the LBS to incorporate the RS.

The RBS Member/Sub-member

The RBS/Layer 37 is the most problematic of the defined lithostratigraphic groupings within the basal deposits at KRM. The RBS is present only in the Cave 1 Witness Baulk. In contrast, Layer 37 was reported across much of Cave 1 and Cave 1A during the initial excavations. However, the deposits designated as Layer 37 in Cave 1A appear to be absent in Deacon's excavations at the Cave 1/1A boundary and in Cave 1A itself. There are two possible explanations for this. Firstly, Layer 37 may have a limited distribution in Cave 1A and could be locally absent in this area (Fig. 9a). Secondly, the Layer 37 deposits in Deacon's excavations could be so thin that they have not been distinguished from the LBS and SAS (Fig. 9b). Thirdly, it is possible that Wymer may have erroneously correlated relatively dark sediments in Cave 1A with Layer 37 in Cave 1 based purely on lithological similarities, and that there were no contemporaneous deposits in Cave 1A (Fig. 9c).

There is a significant disconnect between the name Rubble Brown Sand and the type description provided by Deacon and Geleijnse (1988). The inclusion of rubble in the name associates the deposits with a characteristic which appears to be generally absent or limited compared to other members/sub-members. Furthermore, the highly location-specific type description, focused on a single corner of the Witness Baulk, and lack of any published data on the properties of the rest of the deposits assigned to the RBS complicates meaningful lithostratigraphic correlation even within the same baulk. This approach to the RBS differs notably from the broad, generalised descriptions provided for the LBS and the different SAS sub-members.

The published lithological descriptions indicate that the RBS/Layer 37 cannot be grouped with the LBS, but the recovery of MSA I lithics from these deposits during the original excavations rules out temporal correlation with the SAS. Therefore, it is argued here that the RBS should be considered a distinct stratigraphic entity, as suggested by Wurz et al. (2018), rather than a sub-member of the LBS or SAS. As different facies may form at the same time in different areas, it is possible that the RBS is contemporaneous with the uppermost parts of the LBS in other areas of the site rather than representing a distinct event after the deposition of the LBS across the site (Fig. 9d), but there is currently no published evidence with which to evaluate this possibility.

Detailed field recording is required to assess both the validity of the RBS as a lithostratigraphic entity in the Witness Baulk and its relationship with the Layer 37 deposits that were excavated from Cave 1, but understanding the formation of these deposits could also be vital for stratigraphic correlation. Layer 37 in Caves 1 and 1A was repeatedly described as a soil by Singer and Wymer (1982). Pedogenesis (soil formation) seldom plays a role in forming cave deposits (Goldberg & Sherwood, 2006), but the use of the term suggests that Wymer recognised the influence of post-depositional processes on the properties of Layer 37, as Deacon and Geleijnse (1988) did more explicitly for the RBS (Table 4). A high-resolution understanding of the formation of the 'RBS' developed from ongoing micromorphological studies may provide more data with which to assess the potential stratigraphic relationships between the RBS and LBS (Fig. 9) by

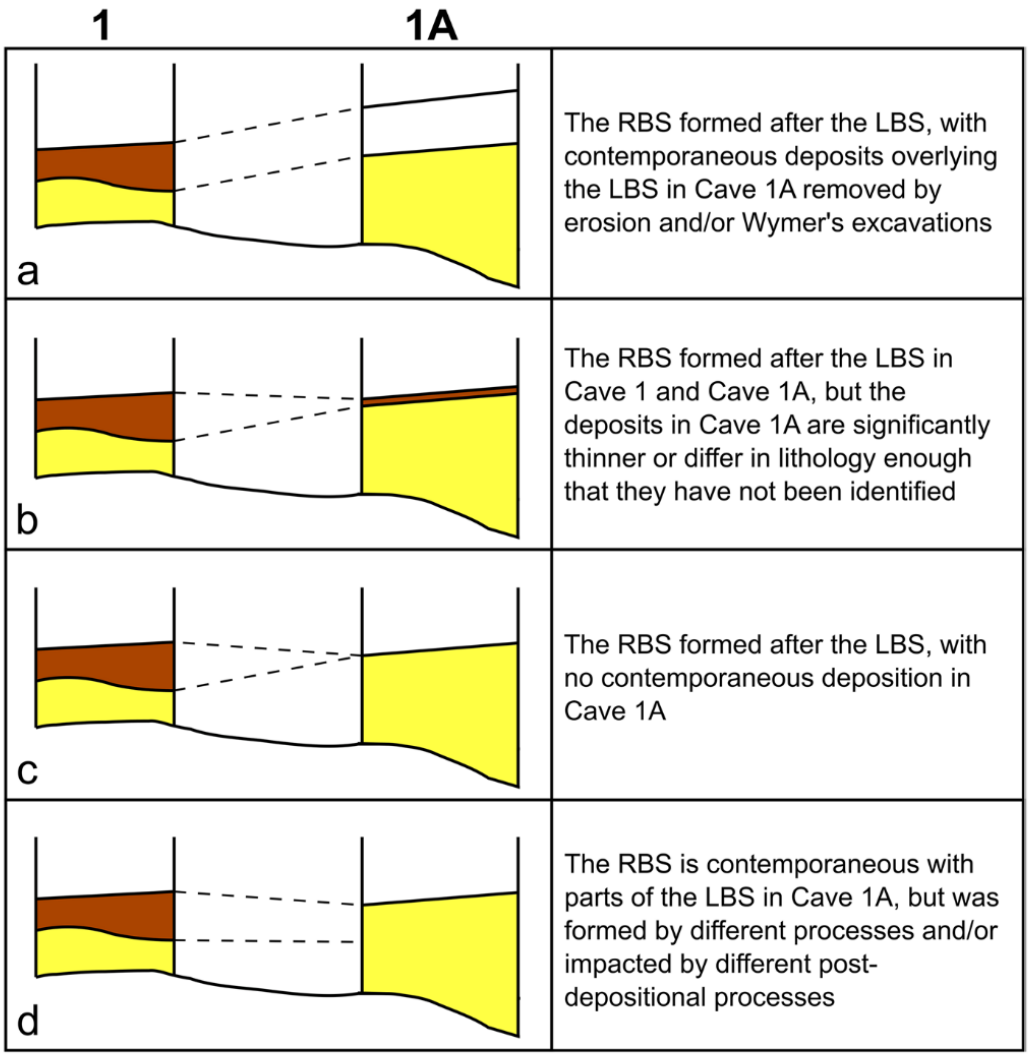

Fig. 9 Four potential stratigraphic relationships between the RBS (and Layer 37) and the LBS Member in Caves 1 and 1A

clarifying whether they differ only due to the influences of post-depositional processes on the RBS, or if they also have distinct depositional histories.

The SAS Member

While more clearly defined than the RBS, the SAS Member is a more problematic stratigraphic entity than the LBS. No lithostratigraphic definition has been published for the SAS in its entirety, likely due to its lithological diversity. The sub-members defined in the Cave 1 Witness Baulk were created primarily to place deposits in groupings roughly equivalent to Wymer's Layers 17 (including 17a and 17b) to 14 (Deacon & Geleijnse, 1988). The SASL (17) and SASU (16) both contain clast-rich and finer facies and are considered to be a single lithostratigraphic sub-member. The

SASW (15) deposits seem to all fall within a single facies of sandy talus slope units, while the SASR (14) comprises a clast-rich facies with a sandy matrix that is very similar to parts of the SASU and SASL.

There is significantly less information available on the extensive SAS deposits in Cave 1A and the DC/SAS in Cave 1B. The descriptive name Shell and Sand suggests the presence of alternating sandy and shell-rich deposits in these locations, but this description is also applicable to deposits in other members, especially within the LBS. This is well demonstrated by the naming of some of the excavated LBS units in AA43/Z44 with the prefix SAS (Fig. 7). The initial naming of the SAS deposits in Cave 1B as the Dark Carbonised appears to represent more variation in sedimentary properties which has not been addressed. The SAS and DC are the only groupings named after seemingly anthropogenic deposits/components (both of which are also reported from other members).

As a unified lithostratigraphic definition is not available (and perhaps not possible) for the diverse deposits assigned to the SAS, it is more accurate and useful to view the SAS as a cultural stratigraphic grouping which includes all deposits containing MSA II lithic material apart from those assigned to the RF Member/Layer 22. The SAS can also be divided into two cultural sub-groupings based on the distribution of the MSA II lower and MSA II upper (Wurz, 2002). In Cave 1, the boundary between these two corresponds with the change from an apparent mix of occupational deposits and either secondary context rubbles or deflated deposits in the SASL and SASU to secondary context accumulations in the SASW and SASR (Table 4), but there do not appear to be any obvious unconformities or changes in depositional processes associated with this cultural boundary in Caves 1A and 1B. The overlying RF deposits (Layer 22) have a similar geogenic matrix to the SAS in Cave 1A but are assigned to a distinct member by Deacon and Geleijnse (1988, p. 9) because of (a) a lower density of anthropogenic deposits (seemingly due to reduced occupation intensity) and (b) the presence of large pieces of host rock and calcite at the top of the RF. As clast-rich 'rubbles' are included in sub-members of the SAS in Cave 1 (in the SASL, SASU and SASR), the exclusion of the RF from the SAS appears to be primarily due to differences in human behaviour but not cultural stratigraphy.

Unlike the LBS deposits which can be tracked easily between Caves 1 and 1A, the SAS deposits have proven more difficult to correlate between the Witness Baulk (Cave 1) and AA43/Z44 (Cave 1/1A) and Cave 1A. This is unsurprising given the site formation interpretations (Table 4). The formation of colluvial slope deposits in the SASW and SASR, and potentially in the SASL and SASU, would require the erosion of deposits in Cave 1A. This sink and source relationship means that contemporaneous deposits may not exist in Cave 1A unless they were in areas not undergoing erosion. No unconformities have been reported within the SAS in Cave 1A (Deacon & Geleijnse, 1988; Singer & Wymer, 1982) which suggests that the source area was subsequently eroded during the Holocene events which removed large quantities of the deposits from Cave 1A and further complicates correlations with the extant SAS deposits.

Water action, including winnowing, proposed for the fine facies in the SASL and the clast-rich facies in the SASL and SASU (Table 4) would also hinder correlation

due to potential loss of stratigraphic detail in the affected deposits (Deacon, 2008). It is possible that the unit SCB1 in AA43 could be contemporaneous with the SASL/SASU based on its hypothesised formation by dripwater (Table 4), but these processes can be highly localised, reducing the usefulness of clast-rich pockets for stratigraphic correlation.

New evidence from field and/or micromorphological studies of the SAS deposits may lead to a better understanding of how specific groups of SAS deposits within different profiles relate to one another (Wurz et al., 2018, p. 106), but it is also possible that we may never be able to clarify these relationships. As with the RS/LBS deposits, new field descriptions of the DC/SAS in Cave 1B may help to clarify whether these deposits should be viewed as a distinct lithostratigraphic member or grouped into the cultural grouping of the SAS.

Evaluating the Current Stratigraphic Approach

The main goal of any stratigraphic approach to an archaeological site—whether lithostratigraphic, culture stratigraphic or based on the use of arbitrary spits—is to divide deposits into distinct three-dimensional excavation units and then place those units (and their contents) into a relative chronology. At KRM, there has also been the added need to identify stratigraphic correlations between different areas of the site which are not joined by extant deposits, and to correlate the new units and members with the older system of numbered layers (e.g. the splitting of the SASL and SASU into different sub-members).

The stratigraphic system in use at KRM has been characterised explicitly as a lithostratigraphic system, distinct from the cultural stratigraphy defined by Singer and Wymer (e.g. Deacon, 2008, p. 144; Deacon & Wurz, 2005, p. 133). The use of members (a term strongly associated with lithostratigraphy) to group units and the descriptive names provided for units and members implicitly support this characterisation. However, as this review demonstrates, the system is not clear-cut. The fine-scale excavation units have been distinguished based on their lithological properties, but the grouping of these units into members and sub-members has been made based on a combination of lithostratigraphic (including the use of both geogenic and anthropogenic deposits) and culture stratigraphic approaches. The repeated re-classification of the RBS due to its lithological similarity to the basal SAS in Cave 1, and its association with MSA I lithics (also found in the LBS), aptly demonstrates the interplay and contradictions between these approaches.

The name (if it is descriptive) and description of a deposit or group of deposits are important as they are used to determine how deposits should be grouped lithostratigraphically, and they have a significant impact on how specialists and non-specialists alike interpret them. For almost all of Deacon's excavation units, the only available information on their lithology is that which can be inferred from their descriptive names and the general descriptions provided by Singer and Wymer (1982) for their lower resolution layers. As discussed previously, the naming and description of the members at KRM is problematic given their characterisation in the literature as purely lithostratigraphic groupings because the properties used to define them

are not unique to those members. Variation in geogenic and anthropogenic facies is expected across a site like KRM, with differing depositional environments and areas suited to different human activities. The removal of deposits through erosion or low-resolution excavation prevents the direct tracking of deposits between different standing profiles, particularly across boundaries where facies changes could be expected within contemporaneous deposits. The apparent similarity of some deposits throughout the sequence (Deacon & Geleijnse, 1988) also impacts the usefulness of a lithostratigraphic approach. It appears that a purely lithostratigraphic system is probably not viable at KRM, which explains why Deacon's system is based on a hybrid lithostratigraphic and culture stratigraphic approach.

Much of Deacon's work aimed at correlating deposits between caves and correlating his units and members to Wymer's layers was based around the goal of understanding the temporal relationships between different accumulations of human remains excavated from the site during the 1967–1968 and 1986–1995 excavations (e.g. Deacon, 2008). The taphonomy of several of these specimens (cut marks, breakage and blackening) and the association of some human remains with shell middens have both been presented as evidence for cannibalism (e.g. Deacon, 2008; Rightmire & Deacon, 1991; Rightmire et al., 2006; White, 1987), although other forms of post-mortem processing or treatment cannot be ruled out (Hellewell & Milner, 2016). Much effort has been expended on trying to link various specimens in the SAS to a hypothesised single event of cannibalism across Caves 1, 1A and 1B in which multiple individuals died and were cannibalised over a period as short as a few weeks (Deacon, 1992, 1995, 2008; Deacon & Schuurman, 1992). Two closely associated human specimens in the LBS Member do appear to represent a single short-term event of the deposition or discard of two individuals earlier in the site's history (Deacon, 2008; Rightmire & Deacon, 1991). However, the occurrence of the hypothesised larger second event is reliant on fine-scale temporal correlations between various units and layers both within and between caves which have been made with limited data. As it has been demonstrated that lithostratigraphic correlations are not viable in many cases, and the use of ostrich eggshell as a biostratigraphic marker is problematic, the validity of these correlations largely falls on the recovery of human remains from the deposits. That the presence of human fossils means deposits must correlate with other human fossil-bearing deposits is a circular argument, and this would also require the use of human fossils as a biostratigraphic marker of sorts, which is not viable at a site with such a long history of human occupation. Therefore, in the absence of new evidence, we argue that the fine-scale correlations in the SAS/DC are largely unsupported.

Despite the shortcomings of the member-based stratigraphic system, it allows the grouping of the basal deposits in Caves 1, 1A and 1B into the same broad cultural phases recognised by Singer and Wymer (1982) and facilitates meaningful correlation between Deacon's units and Wymer's layers in many cases. Without the need to make fine-scale correlations to support the cannibalism hypothesis, the current system does allow broad but acceptable correlation of archaeological assemblages and palaeoenvironmental proxies across the site. The major advantage of the fine-scale excavation and recording approach used during the Deacon excavations (and the ongoing Wurz excavations) is that the units (and associated assemblages) can be

regrouped into different lithostratigraphic, culture stratigraphic, biostratigraphic and chronostratigraphic groupings as new data becomes available or new interpretations are made. Ongoing geoarchaeological research aimed at collecting and publishing detailed information about the deposits at KRM will help to clarify the lithostratigraphy of the site and allow us to redefine the existing groupings and/or create new groupings where necessary, while recognising the limitations of a purely lithostratigraphic stratigraphic system at the site.

Conclusions and Broader Implications

The Current Picture at Klasies and Future Prospects

The human fossils from KRM have contributed to our understanding of the physical origins of our species, while assemblages of lithics, faunal remains and various other artefact types have played a role in the ongoing endeavour to clarify when, where and how modern cognitive abilities developed in *Homo sapiens* populations. Therefore, determining the relationships between finds recovered from various areas of the site and different parts of the sequence has significance not only for understanding KRM, but also for the broader MSA record in the southern Cape and beyond. This task is complicated by the history of work at the site, with excavations conducted at very different scales of stratigraphic and spatial recording. The complexity of the site formation processes (Tables 3 and 4), and our limited knowledge of them, presents another challenge to these efforts.

This review is the first to consider the published information and interpretations of the stratigraphy of KRM in detail and it creates a firm basis for further work which will impact our understanding of several important foci of MSA research at the site, including human physical evolution, palaeoenvironmental proxies and cultural developments (including evidence for cognitive evolution). Hilary Deacon's work has made an immeasurable contribution to our understanding of this rich and complex site (e.g. Deacon, 1989, 1995, 2008; Deacon & Geleijnse, 1988). His approach to excavation was focused on generating detailed contextual information (both stratigraphic and spatial) for archaeological material. Unsurprisingly, the assemblages he excavated (and those subsequently excavated by Wurz) have allowed for more nuanced understandings of human behaviour and palaeoenvironmental conditions than were possible with material from the original excavations (e.g. Brenner & Wurz, 2019; Deacon, 1993; Langejans et al., 2017; Larbey et al., 2019; Nel et al., 2018; Reynard & Wurz., 2020; Van Pletzen-Vos et al., 2019; Wurz, 2002).

Further work is needed to understand the stratigraphy and formation of deposits at Main Site to provide better context to the human fossils and archaeological assemblages. Some deposits have been identified as particular targets for research. The stratigraphy of PP38 in Cave 1B has never been published in anything but the most basic form, hampering efforts to correlate this sequence with that reported for Cave 1B by Singer and Wymer (1982) and the deposits in Caves 1 and 1A. A more detailed understanding of the formation of the SAS deposits in Cave 1 could have

implications for assessing Deacon's hypothesised model for the accumulation of human fossils (e.g. Deacon, 2008). Finally, the deposits grouped into the RBS Member in the Cave 1 Witness Baulk require reinvestigation to evaluate the validity of the member as currently defined.

Detailed field recording will help to address these problems to some extent, but the application of micromorphology and other micro-analytical approaches is vital for understanding site formation. The ongoing multiscale geoarchaeological research programme at KRM (Mentzer et al., 2014) will make a significant contribution to continuing the work Deacon began with the goal of understanding this fascinating and complicated site at the highest resolution possible. Profiles covering different parts of the sequence across the caves and rockshelters have been opened, recorded, photographed and sampled. Detailed and largely unpublished stratigraphic profile drawings produced by the Deacon teams (e.g. Figures 7 and 8) have been used to link the new descriptions and samples to previous work at the site. The new field and laboratory data will contribute to developing high-resolution understandings of the stratigraphy and formation of the deposits within individual profiles. High-resolution 3D recording using photogrammetry and a total station will provide detailed spatial context for understanding patterns and relationships within and between profiles. This will then allow comparisons between different areas of the site and sequence, with the potential for the refinement of the stratigraphic model.

Implications for Middle Stone Age Research

Klasies is an undeniably complicated site compared to most MSA sites in southern Africa, with the varied depositional environments across the complex and the presence of both primary and secondary deposits making it perhaps more akin to the stratigraphic complexity of the karstic sites the Cradle of Humankind (e.g. Edwards et al., 2020; Stratford., 2020; Sutton et al., 2009), while the removal of deposits by erosion and excavation has made stratigraphic work even more difficult. However, this review highlights several issues of significance for research at other MSA cave and rock shelter sites, especially those which have undergone multiple phases of fieldwork. This makes KRM a useful—if somewhat extreme—case study.

The use of high-resolution lithostratigraphic excavation units is typical of recent and on-going fieldwork projects at MSA sites in the region, and lithology is widely used to group or separate units at these sites (e.g. Henshilwood et al., 2001; Marean et al., 2010; Porraz et al., 2013, 2016; Wadley & Jacobs, 2006). The nomenclature used for these units and larger groupings varies from site to site, including both descriptive and non-descriptive naming systems. Although the use of descriptive naming has been effective at some sites (including some of the studies referenced above), this paper highlights the potential pitfalls of using descriptive names in some contexts.

This review also points to the importance of detailed site formation information for understanding whether lithostratigraphic correlations are possible across a site or site complex, especially where deposits have been removed by erosion or excavation. Furthermore, it demonstrates the need to think about why, and at what

resolution, we attempt to correlate deposits across a site or between different excavations, the potential biases these aims may introduce and how practical and achievable they are. Perhaps the most important point that this case study raises is the need to view stratigraphy as a process in which interpretations are revised as new data or approaches become available rather than a largely static system defined for a site during initial fieldwork. Archaeologists should not be discouraged from changing their minds about the stratigraphy of a site, but we must be careful to report these changes adequately, including explanations of the data and reasoning behind them.

Acknowledgements The authors wish to acknowledge the use of photographs taken by Kathryn Croll and profile drawings made by the late Hilary Deacon and colleagues and redrawn digitally by Liezl van Pletzen Vos. We also thank the reviewers and editors for comments which have improved the quality of this paper.

Funding This research was made possible by funding from the DSI-NRF Centre of Excellence in Palaeosciences.

Data Availability Not applicable.

Code Availability Not applicable.

Competing Interests The authors declare no competing interests.

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Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

CHAPTER 4. PUBLISHED PAPER #2

Thesis pages: 93–128

Morrissey, P., Mentzer, S.M. & Wurz, S. Published in 2023

Journal of Human Evolution 183, 103414, 1–34 (page numbers below reflect publication page numbers)

The stratigraphy and formation of Middle Stone Age deposits in Cave 1B, Klasies River Main site, South Africa, with implications for the context, age, and cultural association of the KRM 41815/SAM-AP 6222 human mandible

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Journal of Human Evolution 183 (2023) 103414

Contents lists available at ScienceDirect

Journal of Human Evolution

journal homepage: www.elsevier.com/locate/jhevol

The stratigraphy and formation of Middle Stone Age deposits in Cave 1B, Klasies River Main site, South Africa, with implications for the context, age, and cultural association of the KRM 41815/SAM-AP 6222 human mandible

Peter Morrissey [a, *], Susan M. Mentzer [b], Sarah Wurz [a, c]

[a] School of Geography, Archaeology and Environmental Studies, University of the Witwatersrand, Johannesburg, South Africa
[b] Senckenberg Centre for Human Evolution and Palaeoenvironment, Institute for Archaeological Sciences, Department of Geosciences, Eberhard Karls Universität Tübingen, Tübingen, Germany
[c] SFF Centre for Early Sapiens Behaviour (SapienCE), University of Bergen, Bergen, Norway

ARTICLE INFO

Article history:
Received 9 April 2023
Accepted 12 July 2023
Available online xxx

Keywords:
Klasies River
Archaeological micromorphology
Middle Stone Age
Site formation
Archaeological stratigraphy

ABSTRACT

Cave 1B, in the Klasies River Main site complex (KRM), is best known for the recovery of the KRM 41815/SAM-AP 6222 human mandible. After initial skepticism over the modernity of this specimen, it is accepted that the mix of archaic and modern traits it displays is characteristic of early *Homo sapiens* individuals. Different authors have associated this specimen with the Middle Stone Age (MSA) I and II/Mossel Bay cultural phases, but the published data do not allow an unambiguous attribution. KRM 41815's frequent use in studies of the evolution of the human mandible, and its well-developed chin, makes clarifying its age and context important objectives. The field and micromorphology observations presented here provide greater insight into the stratigraphy and formation of the sequence exposed in the PP38 excavation. There are three major divisions: the basal Light Brown Sand (LBS) Member (not excavated), the Rubble Sand (RS) Member (MSA I), and the Shell and Sand Dark Carbonized (SASDC) Submember (MSA II). Cultural stratigraphy based on lithic artifacts remains the only way to make secure (but broad) temporal correlations with the rest of the site complex. This investigation shows that a range of anthropogenic, geogenic, and biogenic processes contributed to the deposition and post-depositional alteration of the identified microfacies. Short depositional hiatuses are reasonably common, and a significant hiatus was identified between the RS and SASDC. The impact of post-depositional processes on the RS is significant, with anthropogenic deposits poorly preserved. In comparison, the SASDC is dominated by hearths contained within deposits rich in reworked anthropogenic materials known as carbonized partings. Small shell disposal features are also present. The distribution of these anthropogenic features suggests continuity in the management of space throughout the MSA II occupations, from before 110 ka. New stratigraphic correlations indicate that KRM 41815 is unambiguously associated with the MSA I. Therefore, it predates 110 ka, with a lower age limit potentially in Marine Isotope Stage 6.
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1. Introduction

Archaeological assemblages excavated from caves and rock shelters along South Africa's southern and Western Cape coast have contributed significantly to understanding the development of modern human cognition during the Middle Stone Age (MSA) from Marine Isotope Stage (MIS) 6 onwards (McBrearty and Brooks, 2000; Henshilwood and Marean, 2003; Wadley, 2015). These finds have provided insight into innovative behaviors including the earliest known use (and later, the oldest known intensive use) of marine food resources, and early symbolic practices (e.g., Henshilwood et al., 2004, 2009, 2011; Marean et al., 2007; Marean, 2014, 2016; Niespolo et al., 2021; Tribolo et al., 2022; Wurz et al., 2022). However, in contrast to the rich assemblages of artifacts and faunal remains, these sites have yielded few human fossil specimens (Grine, 2016). Relatively large Late Pleistocene human

* Corresponding author.
E-mail address: Peter.Morrissey@students.wits.ac.za (P. Morrissey).

https://doi.org/10.1016/j.jhevol.2023.103414
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fossil assemblages have been recovered only from Die Kelders Cave 1 (DK1) and Klasies River Main site (KRM). The DK1 assemblage comprises 30 specimens which are mostly teeth, along with two finger bones, a single thumb bone, and a mandible fragment (Grine, 2000; Grine et al., 2017a). The published sample from KRM includes more than 50 specimens,[1] which are predominantly cranial and mandibular (including teeth), with a far smaller proportion of postcranial bones (Singer and Wymer, 1982; Rightmire and Deacon, 1991, 2001; Grine et al., 1998, 2017b, 2020; Rightmire et al., 2006).

The specimens from KRM have played an important role in characterizing *Homo sapiens* anatomy during the Late Pleistocene (e.g., Bräuer, 1992; Smith, 1992; Grine, 2016; Bergmann et al., 2021; Grine et al., 2021). They display a mix of relatively archaic and more modern traits, and the size variation among the cranial and mandibular specimens is significant, perhaps reflecting far greater sexual dimorphism than is present in human populations today (e.g., Rightmire and Deacon, 1991; Smith, 1992; Bräuer and Singer, 1996; Lam et al., 1996; Rightmire, 2009; Royer et al., 2009). The morphology of the postcranial bones indicate that the represented individuals were relatively small-bodied, with similar proportions to Holocene hunter gatherers and modern Khoe-San people from the region (Cameron et al., 2021). This is argued to be the result of phenotypic adaptation to conditions in the Cape during these periods (Cameron et al., 2021).

Human fossils have been recovered across much of the site complex and from different parts of the sequence, but there are clear spatial and temporal patterns (Deacon, 2008; Grine et al., 2017b, 2020). Six confirmed specimens have been recovered from the MSA I deposits (Light Brown Sand [LBS] Member and Layer 37/ 'Rubble Brown Sand' ['RBS'[2] Member) in Cave 1 and at the Cave 1/ 1A boundary (Figs. 1 and 2), but more than 20 potential human fossils from Cave 1 were lost at some point between their excavation and Ronald Singer's analysis of the human fossil assemblage, meaning that they could not be confirmed as either human or animal. The MSA II/Mossel Bay deposits (Shell and Sand [SAS] Member) have proven to be far richer, with 40 confirmed specimens discovered in Cave 1 (34 of the 40) and in Cave 1A (the remaining six). A further five specimens come from the Upper Member in Cave 1A: one from the Howiesons Poort (HP), and four from the MSA III or post-HP. Only two specimens were recovered from Cave 1B (Singer and Wymer, 1982): the relatively robust partial mandible published as KRM 41815 (cataloged as SAM-AP 6222 at the Iziko Museums of South Africa in Cape Town), and an associated mandibular condyle, which disappeared at some point after Singer's analysis.

Cave 1 is clearly the richest area of the site complex for human fossils, with the MSA II–bearing SAS Member deposits yielding most of the sample (Deacon, 2008; Grine et al., 2017b, 2020). Abundant faunal remains have been recovered across the complex and throughout the sequence (Singer and Wymer, 1982; Van Pletzen-Vos et al., 2019; Reynard and Wurz, 2020), indicating that this pattern is not a product of variable preservation of bone in different areas. Dating of the sequence indicates that the fossil-bearing deposits span a significant period of time, from prior to MIS 5e up to ~43 ka (see recent reviews in Grine et al., 2017b; Wurz et al., 2018; Morrissey et al., 2022). Recent dating of speleothems associated with a hiatus in the basal SAS Member deposits in Cave 1 suggests that all specimens assigned to the MSA I and the oldest part of the MSA II (the SAS Lower [SASL] Submember or Singer and Wymer's Layer 17b) are older than 110 ka (Wurz et al., 2022).

Although the spatial and stratigraphic distribution of the human fossil specimens is generally well understood, the stratigraphic context of some has been the subject of debate. Hilary Deacon argued that many, if not all, of the human fossils assigned to the upper MSA II deposits in Cave 1 by John Wymer are actually associated with units near the base of the MSA II (Rightmire and Deacon, 1991; Deacon and Schuurman, 1992; Deacon, 2008). As the excavations were conducted at relatively low stratigraphic resolution, including in areas of Cave 1 where it was difficult to distinguish between deposits with similar properties and thus avoid mixing material between layers (Singer and Wymer, 1982), this is possible, but it cannot be proven or disproven with the evidence that is currently available. The cultural attribution of KRM 41815 has been particularly difficult to assess due to the lack of interconnecting deposits between Cave 1B and the rest of the KRM site complex and because there are no published absolute dates for the Cave 1B deposits. The mandible has been variously associated with the MSA I (e.g., Singer and Wymer, 1982; Deacon and Geleijnse, 1988; Grine et al., 2017b, 2021, 2023), MSA II (e.g., Deacon, 2008), and even the HP/MSA III (Binford, 1984; 1986b). A potential association with the HP/MSA III has subsequently been conclusively disproven (Deacon and Geleijnse, 1988; Thackeray, 1989, 1992; Wurz 2002), but the question of whether KRM 41815 dates to the MSA I or the MSA II has not been settled definitively due to a lack of published data (Morrissey et al., 2022).

The cultural attribution of KRM 41815—and thus, its age—is significant for understanding its temporal relationship to other specimens from Klasies. The mandible (Fig. 3) is fairly robust but is small in comparison to some other early *H. sapiens* mandibles and has a form broadly consistent with anatomically modern humans (Singer and Wymer, 1982; Smith, 1992; Lam et al., 1996; Bergmann et al., 2021). The corpus is described as "robust with bulging triangular mental protuberance" by Singer and Wymer (1982:146) who calculated a robusticity index of 48.93% at the right M_1. With the inclusion of the associated KRM 41820 mandibular condyle, the incomplete ramus appears to have been "massive" (Singer and Wymer, 1982:147). The preserved teeth are heavily worn, and there are indications of bone resorption (Singer and Wymer, 1982:146). This individual is estimated to have been the oldest at death of the KRM dental specimens and had suffered extreme hypercementosis (Grine et al., 2023). Of particular significance is the chin which, while somewhat controversial (e.g., Frayer et al., 1993; Wolpoff and Caspari, 1996), is the most strongly developed example of the mandibles at KRM (Singer and Wymer, 1982; Rightmire and Deacon, 1991; Bergmann et al., 2021; Grine et al., 2021). Whether it should be grouped with the MSA I or MSA II specimens has implications for assessing the overall anatomical characteristics of both groups of fossils and the breadth of variation in these populations. Given the paucity of *H. sapiens* fossils during this period (Grine, 2016), this also has significance beyond the site and the Cape coastal region.

The different areas excavated across the KRM site complex (Fig. 1) encompass a variety of depositional environments and human activity zones (Deacon and Geleijnse, 1988; Mentzer et al., 2014; Morrissey et al., 2022; Wurz et al., 2022). The resolution of excavation and recording and the amount of detail provided in descriptions of the stratigraphy of excavations have varied significantly between the coarser-scale excavations conducted in the late 1960s and the finer-scale work from 1984 onwards (Singer and Wymer, 1982; Deacon and Geleijnse, 1988; Wurz et al., 2018,

[1] Some unconfirmed specimens are missing from the museum collection, complicating a precise count.

[2] The 'RBS' in Cave 1 is a poorly understood stratigraphic entity in terms of its distribution and formation, and its relationship to both the LBS Member in Cave 1A and Wymer's Layer 37 in Caves 1 and 1A (Morrissey et al., 2022). The term is used throughout this paper for consistency with the existing literature, and because a re-evaluation of the 'RBS' is still in progress. Here it is used to refer explicitly to the deposits placed in this entity by Hilary Deacon (e.g., Deacon and Geleijnse, 1988: fig. 7; Rightmire and Deacon, 2001: fig. 2).

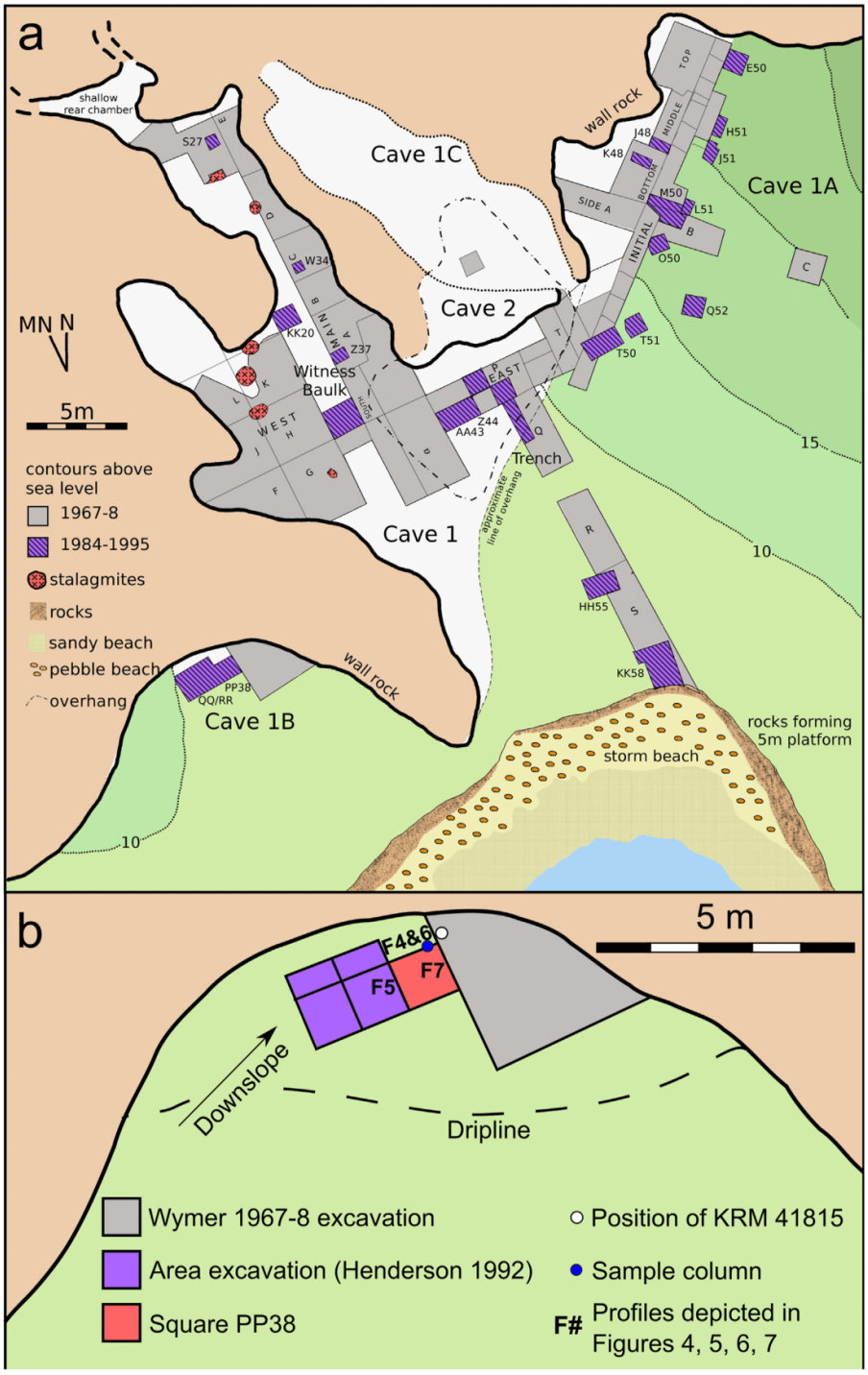

Figure 1. a) Map of the Klasies River Main site complex and b) Map of Cave 1B (after Deacon et al., 1986, Henderson, 1992; Wurz et al., 2018). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article).

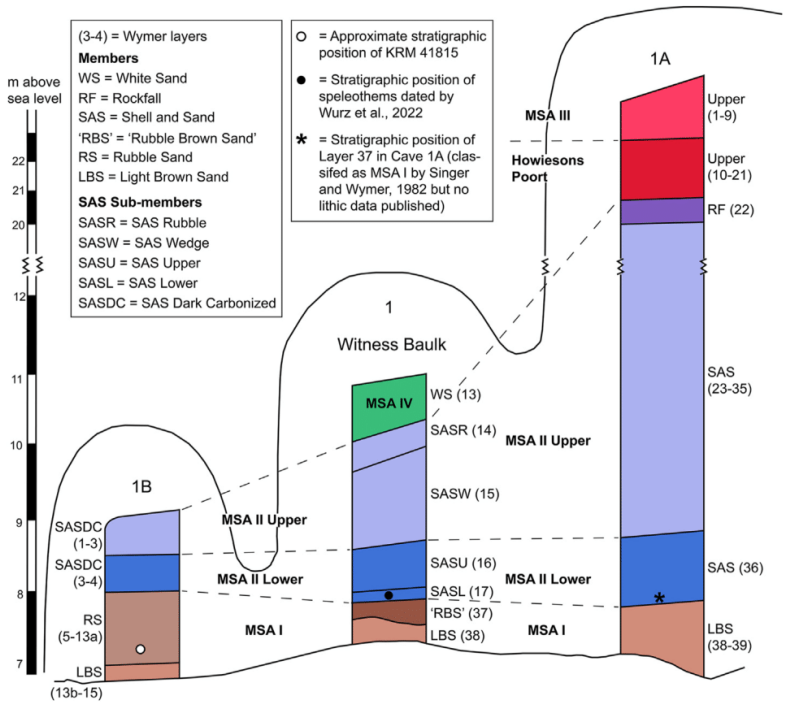

Figure 2. Simplified stratigraphy of the Middle Stone Age (MSA) deposits in Caves 1, 1A, and 1B at Klasies River Main site, showing the cultural stratigraphy, Wymer's excavation layers, and Deacon's lithostratigraphic members/submembers (after Deacon and Geleijnse [1988] and Wurz et al., [2022]). The depiction of the Cave 1B sequence, including the correlations between the two stratigraphic systems, reflects the results of this study. See Morrissey et al., 2022 for discussion of the presence or absence of MSA I–bearing deposits between the LBS and SAS in Cave 1A. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article).

Figure 3. Lateral view of the KRM 41815/SAM-AP 6222 mandible (from the Deacon archive).

2022). It is therefore unsurprising that making stratigraphic correlations between both different parts of the site complex and different generations of excavation has proven to be a challenging task (Morrissey et al., 2022).

Very little information has been published on the stratigraphy of both the Wymer and Deacon excavations in Cave 1B, which complicates any assessment of the stratigraphic position of Layer 10 and KRM 41815 relative to Deacon's excavation units (Morrissey et al., 2022). In particular, Cave 1B lacks stratigraphic description and reconstruction of site formation processes, which hampers interpretations of human behavior that could be made from both the excavated assemblages and anthropogenic features and deposits.

Archaeological micromorphology and complementary microscale analyses have proven to be highly effective for identifying geogenic, biogenic, and anthropogenic depositional and post-depositional processes at MSA sites in the region (e.g., Goldberg, 2000; Miller et al., 2013, 2016; Karkanas et al., 2015; Haaland et al., 2021). As sedimentary stratigraphy is the product of site formation processes, microscale analyses can also provide important information for stratigraphic interpretation, especially in cases where the type or intensity of post-depositional processes have varied across a site or complex (e.g., Goldberg, 2000; Karkanas and Goldberg, 2010). Only relatively limited microscale research has been published on the KRM site complex to date, but these studies have provided important insights into site formation processes in Caves 1, 1A, and 2, including the human behaviors represented by anthropogenic features in these areas of the complex (Larbey et al., 2019; Wurz et al., 2022).

Here, we present the most detailed description of the stratigraphy of Cave 1B to date, and the first micromorphological data for this part of the site complex. These new data, along with previously published observations, are used to 1) better understand the formation of deposits in Cave 1B, 2) broadly correlate the deposits in Cave 1B with the rest of the KRM site complex, and 3) clarify the stratigraphic relationships between Layer 10 and Deacon's excavation units in order to confirm the cultural association of KRM 41815.

1.1. Past research on the Cave 1B deposits

Cave 1B is a relatively small, shallow shelter on the western side of the KRM site complex (Fig. 1). It is roughly 10 m wide at the outer edge of the excavated area, and the overhang covers only a few meters from the back wall outwards. The morphology of the hosting quartzite outcrop provides protection from coast-parallel easterlies and westerlies, but the shelter is very exposed to onshore winds from the south. As a result, the precipitation of salt onto various surfaces within the shelter due to sea spray is commonly observed. The formation of barrier dunes between the complex and the sea during parts of the Late Quaternary—as proposed by Deacon (1995)—could have provided greater protection from onshore winds than at present. The combination of these factors means that Cave 1B, while the most exposed area of the site complex, does enjoy some protection from rain, wind, and wind-blown sand. However, the degree of exposure would have varied over time, and across the extent of the shelter.

The deposits within the shelter have been truncated by erosion, most notably towards the seaward edge of the shelter, and there is increasing disturbance of deposits moving away from the shelter wall (Singer and Wymer, 1982). The current scree surface slopes steeply down from the southeast to the edge of the original excavation. Here, it is roughly 9 m above mean sea level (amsl). The lowest exposed bedrock within the shelter is at around 7 m amsl on the southern edge of Wymer's excavation (Henderson, 1992: fig. 3), just a little higher than the ~6-m quartzite wave-cut bench south of the site.

Cave 1B is physically separated from Cave 1 by the host rock (Fig. 1), and there are no recorded continuous deposits (either extant or excavated) between these two areas. It is possible that there were continuous deposits around the spur of rock joining them, perhaps related to activities taking place in the variably exposed cave, shelter, and open area between them based on the type of activity and changing weather conditions. However, this area is more susceptible to continuous processes of erosion and disturbance (like slope wash and trampling) and would have been more heavily impacted by coastal erosion during sea level high-stands. Therefore, the chances of any distinguishable interlinking deposits surviving to the present day are very low, particularly for anthropogenic deposits.

The Wymer excavations John Wymer excavated in Cave 1B in the years 1967–1968, digging several square meters of the shelter down to bedrock in a series of 15 layers (Fig. 1; Table 1). The sedimentary properties of the layers were described in very limited detail (Singer and Wymer 1982:24–25), and none were considered in Butzer's (1982) sedimentological study. No lithological correlations were made with the rest of the site except for the basal gravels (Layer 15), which were correlated with similar deposits in Cave 1 and 1A (Layer 40).

The layer descriptions followed guidelines for recording soil properties for engineering assessments, which do not distinguish between soils and sediments (Jennings and Brink 1961). As a result, the word 'soil' in the descriptions (Table 1) appears to largely be used synonymously with sediment, and, with the possible exception of Layer 13 and the disturbed deposits to the south of Wymer's excavation, there is no clear indication of any pedogenesis in Cave 1B from the published descriptions. Singer and Wymer's (1982) use of the term 'carbonaceous' denotes dark sediments rich in (mostly charred) organic matter, including both charcoal and finer material. It is unclear precisely how rich in this material the sediment had to be in order to be described in this manner. It is also unclear if the term 'occupational soil' was intended to be largely synonymous, or if this reflects a lower density of charred organic matter within the layer.

Singer and Wymer (1982) grouped their layers into cultural phases using the typological compositions of the lithic assemblages excavated from each layer. They assigned the entire Cave 1B sequence to the MSA I, correlating these deposits with the basal layers in Caves 1 and 1A. This was supported by the oxygen isotope values for marine shells from Layer 12, which were similar to those from Layer 38 in Cave 1 and suggested a Last Interglacial age (~120 ka) for the lower part of the Cave 1B sequence (Shackleton, 1982). The sequence was argued to represent fairly continuous occupation

Table 1
John Wymer's descriptions of the layers he excavated in Cave 1B (quoted from Singer and Wymer, 1982:24–25). The layers are numbered from the surface downward.[a]

Layer	Description
1	Sandy soil with some ash and small rock fragments. Artifacts were numerous, but only a small part of this layer remained, and they were mixed inadvertently with the underlying layer.
2	Buff [yellowish brown] sand, which contained small rock chips and rubble. The layer was silty in patches. Bones and artifacts were numerous.
3	This was a black carbonaceous soil with ash laminations and a spread of small, angular rock fragments at the base. Shells were decomposed to white flecks, but bone was in fair condition. Artifacts were numerous.
4	Same as the layer above without the rock fragments at the base.
5	Buff [yellowish brown] sand and small rock fragments, which thinned toward the shelter wall. The base was marked by a thin layer of carbonaceous soil. Artifacts were numerous, but only a few fragmentary bones and shells were present.
6	A gravelly to silty occupational soil with smears of ash hearths. Artifacts and bones were numerous, but the latter were in poor condition and were very fragmentary. Shells were scarce.
7	Buff [yellowish brown] sand and silty soil with many small, angular rock fragments. The numerous artifacts and many bones were in better condition than those in the layer above. Shells were scarce.
8	The surface of a thin (1–2 cm) but continuous hearth spread. There were several artifacts and bones, the latter in good condition. No shell was found.
9	Buff [yellowish brown] sand and silty soil with small, angular rock fragments. Several bone fragments were found in good condition, also shell fragments. Artifacts were numerous.
10	A dark gray clayey soil, which had many small, angular rock fragments at its base and one large block of soft calcite. It was flecked with charcoal but had no clear hearth spreads. Several bone fragments in good condition were recovered, including a near-complete human mandible (no. 41 815). Artifacts were numerous.
11	A firm buff [yellowish brown] sandy silt, which contained many small, angular rock fragments. A few bone fragments and several shells in good condition, as well as numerous artifacts, were found.
12	A thin, soft silty layer with a spread of loose, mainly burnt shell. Several bones in good condition and numerous artifacts were found.
13a	Brown sand that appeared to be a weathered horizon of the underlying layer. A few bone fragments, shells, and artifacts were recovered.
13b	Yellow sand and silt. Many bone fragments in a good, semimineralized condition, a few shells in poor condition, and numerous artifacts were found.
14	A thin (2–4 cm) spread of carbonaceous soil with small fragments of shell. On the south side lay two large fallen blocks of the rock wall or overhang: one is featured in the drawn section. Several bones were found in good mineralized condition. Artifacts were numerous.
15	Clean, angular, sandy beach gravel. Artifacts were numerous in the upper part, and there were a few bone fragments but no shells.

[a] All square parentheses and content therein are added by the authors.

of the shelter during the MSA I, following regression from the peak of the Last Interglacial sea-level highstand, with the weathering of Layer 13 viewed as representing the only evidence for a depositional hiatus during this period (Singer and Wymer, 1982:25).

Lewis Binford (1984) challenged some of the interpretations made by the original excavators and their collaborators. He argued that the species composition of the faunal assemblages published by Klein (1976) from Cave 1B suggested that these layers were contemporaneous with the HP or MSA III layers in Cave 1A or had an age falling between these deposits. Singer and Wymer (1986) defended their original position, pointing to differences in lithic typology between the HP and MSA III and the assemblages from Cave 1B, and stressing that the Cave 1B deposits and the MSA I layers in Caves 1 and 1A formed on similar gravels at the base of these respective recesses. Binford (1986a) responded by highlighting some apparent similarities in typological and raw material characteristics between the Cave 1B assemblages and the HP and MSA III and by arguing that deposits of varying ages could have formed on the same beach gravels. The faunal data were subjected to two distinct sets of multivariate analyses. Neither found a correlation between Cave 1B and the MSA I fauna from the rest of the site, instead suggesting greater similarity with the MSA II for one study (Thackeray, 1986) and the HP, MSA III, and MSA IV for the other (Binford, 1986b).

The Deacon excavations Deacon dug a 1-m^2 sampling square (PP38) into the western profile of the Wymer excavation but did not reach bedrock (Fig. 1). A larger surface excavation was carried out to the west of PP38, which sampled some of the upper units over an area of 3 m^2 (Henderson, 1990, 1992). Both excavations were conducted at significantly higher stratigraphic resolution than Wymer's, with distinct deposits excavated as individual excavation units so far as practical.

Based on broad lithological similarities between the Cave 1B deposits and those in Cave 1 and 1A, the sequence was split into two members, interpreted as being equivalent to the LBS and SAS Members in Caves 1 and 1A (Deacon and Geleijnse 1988:11). Only the basal deposits above the gravel were assigned to the LBS, with the bulk of the sequence placed in the SAS Member (Deacon and Geleijnse, 1988: figs. 5 and 6). The SAS was later revealed to have been split into two submembers, the Rubble Sand (RS) and Dark Carbonized (DC; Henderson, 1992: fig. 3). It was argued that Wymer's Layer 13 (and hypothesized hiatus) could correlate with a similar event proposed for unit YS1 in AA43/Z44 at the Cave1/1A boundary (Deacon and Geleijnse, 1988). However, deposits overlying Layer 13 were also correlated with deposits underlying YS1 (Deacon and Geleijnse, 1988:11), suggesting that these proposed hiatuses represent different events (see Morrissey et al., 2022:21).

As with Butzer's work during the initial excavations, no sedimentological data were published for Cave 1B by Deacon and Geleijnse (1988). An unpublished report (Deacon et al., 1986) includes the grain-size properties of two bulk sediment samples from Cave 1B, but it is unclear if further samples were analyzed, and why the results presented in the report were never published. The unit names given with the samples do not match any of the excavated units in PP38 or the larger surface excavation, preventing the use of the data to characterize any of these deposits.

The area of excavation adjacent to PP38 sampled the uppermost portion of the DC, revealing a sequence of alternating sandy units and more stratigraphically complex groups of units containing deposits interpreted as being largely anthropogenic in origin (Henderson 1992). As with similar deposits across the site complex (e.g., Deacon, 1993, 1995), the latter units were called carbonized partings (CPs), except for one which was designated as a partly carbonized parting (PCP), the only published occurrence of the use of this term at Klasies.

It was noted that the stratigraphy was poorly preserved near the shelter wall, grading into a homogenous gravelly sediment perhaps due to disturbance by water movement (Henderson, 1990:37). Little information was provided on the sandy units as the anthropogenic deposits were the focus of the study. The anthropogenic units include concentrations of ash, shell, bone, and carbonized (or partly carbonized) organic matter (Henderson, 1992). Concentrations of shells were interpreted as "small shell disposal features" (Henderson, 1992:25), representing discard of food waste in specific locations but on a smaller scale than the middens preserved in other parts of the complex. The clustering of ash features, especially prevalent in the lowermost excavated anthropogenic unit, was interpreted as the result of repeated fires being made in a single part of the shelter. These features are argued to represent organization of space within the shelter by the people occupying the shelter during this period.

Other than these interpretations, almost no information on site-formation processes in Cave 1B is available (Morrissey et al., 2022: tables 3 and 4). Furthermore, none of the units in the area excavation were correlated to any of Wymer's layers (Henderson, 1992).

A single relative date for Cave 1B was obtained by Goede and Hitchman (1987). Their electron spin resonance dating of marine shell fragments suggested a temporal correlation between Layer 10 (and KRM 41815) and Layer 37 in Cave 1. However, this result must be treated with caution as it appeared that rates of uranium enrichment varied across KRM and through the sequence (Goede and Hitchman, 1987:171–172).

A techno–typological analysis of lithic artifact samples from Deacon's excavations across KRM concluded that the Cave 1B sequence included a lower MSA I phase and an overlying MSA II phase (Thackeray, 1989:52). This pattern was confirmed through further detailed techno–typological research by Sarah Wurz (2002), who recognized two cultural subgroupings within the MSA II, the MSA II lower, and MSA II upper (or Mossel Bay lower and upper). Wurz (2002) was the first to publish correlations between the excavation units in PP38 and Wymer's layers (see also note in Grine et al., 2017b:57). These correlations were made based on Deacon's interpretations of unpublished data and only correlated cultural groupings (and their associated excavation units) with groups of Wymer's layers, rather than correlating specific units with layers (Table 2).

The placement of Layer 10 within the MSA II corresponds with Deacon's repeated assessment that KRM 41815 is roughly contemporaneous with a hypothesized event involving the cannibalization and discard of the remains of multiple individuals in Cave 1 early in the MSA II cultural phase (Deacon and Schuurman, 1992; Deacon, 1995, 1998, 2008). The apparent contradiction between Layer 10 being correlated with MSA II deposits while sharing a similar relative date with the MSA I–bearing Layer 37 was never addressed. The association of a significant portion of the PP38 sequence with the MSA I (Wurz 2002) was also never dealt with, despite Singer and Wymer's (1982) figure 3.14 showing that the specimen was recovered relatively low down within their excavation. Grine et al. (2017b:57) subsequently suggested that the PP38 units Deacon correlated with Layers 10 and 11 should be correlated temporally with the 'RBS' Member/Layer 37 (thus attributing the mandible to the MSA I) but did not provide any supporting evidence or discussion. This paper will provide more stratigraphic resolution and allow the development of a firm hypothesis for the age of the mandible.

Table 2
Summary of the published stratigraphy of both phases of excavation in Cave 1B (data from Singer and Wymer, 1982; Deacon and Geleijnse, 1988; Henderson, 1992; Wurz, 2002).

Wymer excavations		Deacon excavations		
Excavation units	Cultural stratigraphy	Excavation units	Lithostratigraphic members/submembers	Cultural stratigraphy
Layer 1	MSA I	DC surface to DCCP6	Dark Carbonized/Shell and Sand	MSA II upper
Layer 2				
Layer 3				
Layer 4				
Layer 5				
Layer 6		DCCP7 to DCCP12		MSA II lower
Layer 7				
Layer 8				
Layer 9				
Layer 10				
Layer 11				
Layer 12		RSYS1 to RSBCH	Rubble Sand/Light Brown Sand	MSA I
Layer 13a and b				
Layer 14				
Layer 15				

Abbreviations: DC, Dark Carbonized; MSA, Middle Stone Age.

2. Materials and methods

2.1. Field description of stratigraphic units

The excavation units defined by the Deacon team were identified in the three profiles (northern, western, and southern) of square PP38 based on their stratigraphic drawings and labels they had placed on the profiles (Figs. 4–6). The units were then described based on macroscopic observation in the field in 2020. Variables recorded include the texture and color of the matrix, the nature of any clasts (including artifacts) within the unit, whether contacts between units are sharp or diffuse, and the presence of finer stratification within a unit. Due to the fine and complex stratification of many of the deposits referred to as CPs, the Deacon team grouped some excavation units into a single CP in multiple cases. For consistency, these groupings were used in the field descriptions.

2.2. Microanalysis of thin sections

Three micromorphology blocks (KRM-13-10, KRM-13-11, and KRM-13-12) were collected in 2013 in a column near the eastern edge of the northern profile of PP38 in 2013 (Figs. 4 and 6). The column includes the upper portion of the MSA I–bearing RS and most of the MSA II lower deposits in the DC. The blocks were carved and plastered with gypsum bandage to allow the removal and transport of intact sediments.

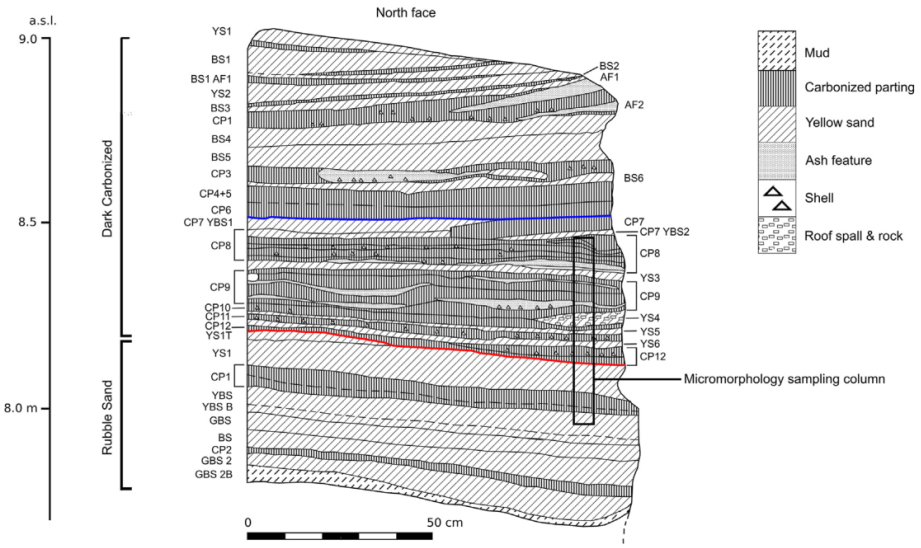

Figure 4. A partial stratigraphic drawing showing the excavation units for the northern profile of square PP38 (profile redrawn by L. van Pletzen Vos from the original field drawings by the Deacon team). The rest of the profile is shown in Figure 6. The red line indicates the boundary between the Middle Stone Age (MSA) I and MSA II lower, and the blue line shows the transition from the MSA II lower to the MSA II upper (following Wurz, 2002). Due to the complex and finely stratified nature of the deposits in the Dark Carbonized, the individual excavation units Deacon grouped into the Carbonized Partings are not labelled. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article).

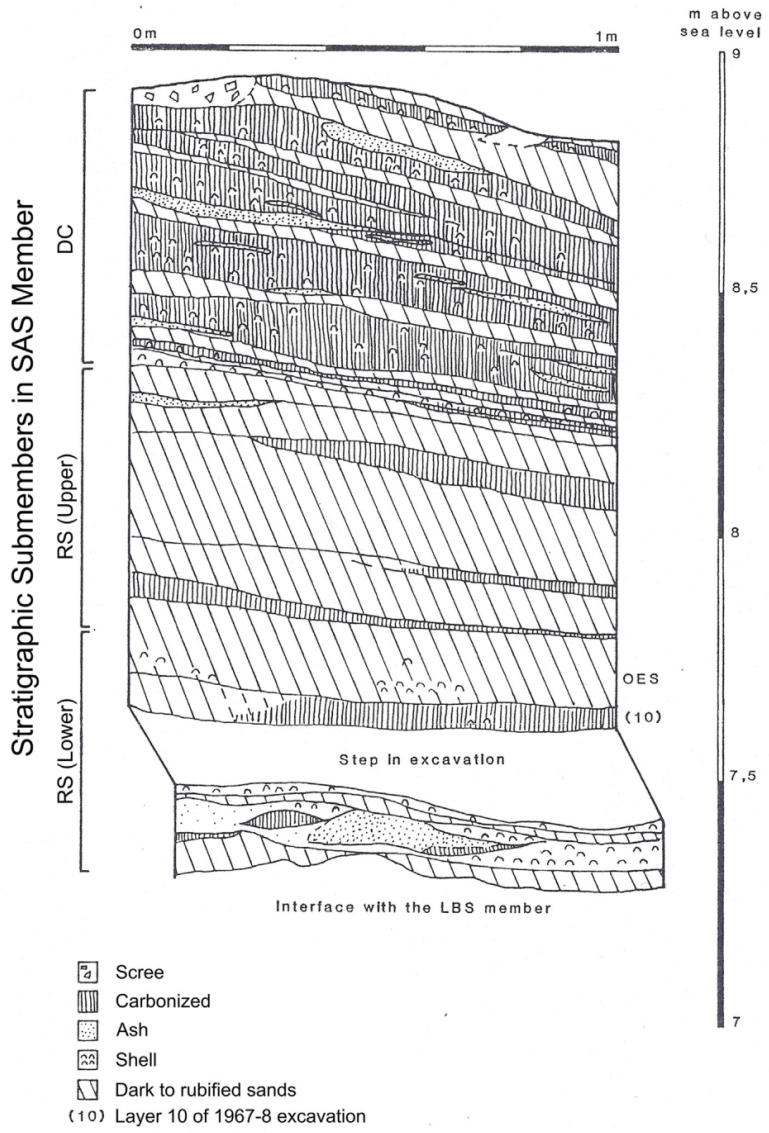

Figure 5. A previously unpublished drawing of the western profile of PP38 (Deacon archive), including the step and the contact with the unexcavated LBS. In contrast to Figure 4, this drawing shows the full extent of the excavation, but shows less stratigraphic detail and lacks unit labels. Note the suggested correlation for Layer 10 directly above the step.

Block KRM-13-12 includes the top of unit RSYBS, the vertical extent of RSCP1 and RSCP1T, and the base of RSYS1. KRM-13-11 samples the upper portion of RSYS1, the vertical extent of DCCP12, DCYS6, and DCCP11. KRM-13-10 includes part of DCYS4 at its base, along with the vertical extent of DCCP9 and DCYS3, and the majority of DCCP8.

After transport to University of Tübingen, the blocks were dried, indurated with a mix of resin and styrene and then were processed into seven thin sections. Micromorphological analysis of the thin sections was carried out using a petrographic microscope at a variety of magnifications under both plane-polarized and cross-polarized light. Description of the sediments followed standard terminology (Stoops, 2021). The sections were also analyzed using a Bruker M4 Tornado micro-X-ray-fluorescence (μXRF) analyzer to produce elemental maps of each section to supplement the micromorphology (Mentzer, 2017). As detailed in Wurz et al. (2022) for the analysis of thin sections from the rest of the KRM complex, the following parameters were used: dual detectors, 60-micron pixel spacing, ~25-micron spot size, 50-kV rhodium tube voltage, and a 600-microamp current. The micromorphology observations and the distribution of key elements in the elemental maps were used together to identify and describe microstratigraphic units (MSUs). Elemental overlay maps for each thin section are provided in the figures of this paper to help the readers see important

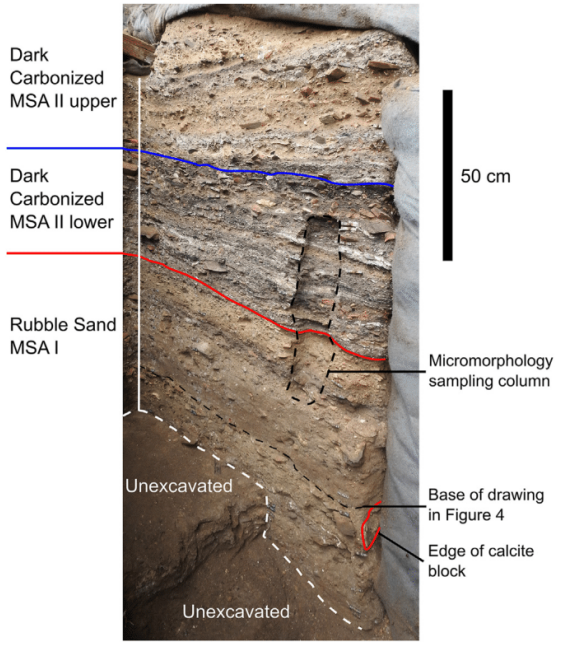

Figure 6. Photograph of the northern profile of square PP38, which includes the deposits not shown in Figure 4. As the photograph was taken in 2020, the sampling column from 2013 has been eroded slightly. Note the step in the excavation and that bedrock has not been reached anywhere in the square. The calcite block (Fig. 8) visible in the western profile of the original excavation is present in Singer and Wymer's (1982) figure 3.14 and plate 26 (see further discussion in text), and in photographs taken during the Deacon excavations (see Fig. 7). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article).

sedimentary components such as shell and bone. The microfacies approach (Courty, 2001) was used to classify the numerous MSUs identified in the samples into categories of deposit with similar formation histories.

3. Results

3.1. The macrostratigraphy of square PP38

Deacon's excavation in PP38 did not reach bedrock, and the basal beach gravel described by Singer and Wymer (1982) is not exposed. The unexcavated deposits were assigned to the LBS Member by Deacon (Fig. 5). The exposed profiles include roughly 1.8 m of deposits. The only detailed profile drawings with labelled excavation units (e.g., Fig. 4) were drawn prior to the completion of the excavation, excluding multiple excavation units and up to 30 cm of deposit (at the deepest point) from the drawings (Figs. 5 and 6). There is a step at the base of the excavation, with only a ~20-cm-wide strip excavated along the eastern edge of the square (Figs. 5 and 6). The units excavated there are thus only exposed in the northern and southern profiles. They are the only units in PP38 not included in Wurz's (2002) lithic analysis, perhaps due to limited sample sizes. As they underlie units assigned to the MSA I, it is reasonable to assume an association with this technocomplex.

Descriptions of the PP38 excavation units are presented in Table 3. Throughout the text, the unit abbreviations include RS or DC as prefixes to indicate which group of deposits each unit falls within. Full unit names are provided with the descriptions in Table 3. Due to the finely stratified nature of many deposits in the DC, a single description is provided for each of the CP unit groups.

The exposed deposits throughout the sequence generally dip down towards the back of the shelter (north) when viewed in the western profile. Dip angles along the east–west axis (observed in the northern and southern profiles) are shallower and more variable in direction, but the majority dip down towards the east. The deposits are often thicker in the southern profile than in the northern, especially in the RS.

The RS is dominated by deposits of varying shades of light brown, gray, and yellowish silty sand. Clay is present, but there is a notable reduction from RSBS upward. Likewise, there is a significant increase in the density of quartzite fragments from RSYBSB (a few units above RSBS) upward, and microfauna remains are first visible from the same point in the sequence. Materials introduced by anthropogenic processes—including lithic artifacts, charcoal, bone fragments, shell, and (what appears to be) rubified quartzite—are present in almost all units. Deposits seemingly formed through significant anthropogenic inputs are limited to occasional lenses rich in carbonized material in the sand units and in units RSCP2, RSCP1, and RSCP1T. The contacts between units are typically relatively diffuse throughout the RS, with many units grading into the overlying unit. The DC is initially dominated by ash lenses, shell-rich layers, and dark charred organic-rich deposits grouped into CP unit groups, which are interbedded with relatively thin sandy units. Most of the CPs also contain thin laminae or lenses of sand. From DCBS5 upwards, the sandy units become thicker, and the CPs thin notably (Fig. 4). The deposits in the CPs are often very finely bedded but typically thicken towards the south of PP38. Lateral changes in sedimentary properties across the extent of a CP are common, with shell density increasing markedly to the south in most units which contain shell. The sandy units are a variety of shades of brown, gray, and yellow. Most contain at least some material of anthropogenic origin, and thin black lenses are present in some of these units. Quartzite fragments are common in the sandy units except for DCYS6. The density of these clasts increases from DCBS6 upwards, and microfauna remains are observed from the same point in the sequence. Contacts between deposits are typically sharper than in the RS, especially within CPs and between CPs and sandy units. However, some relatively diffuse contacts were observed, especially between sandy units.

Correlating the PP38 excavation units (Table 3) with Wymer's layers (Table 1) is not straightforward due to the difference in stratigraphic resolution and the observed spatial variation in unit sedimentary properties. However, a relatively large piece of calcite recorded in Wymer's excavation profile (Singer and Wymer 1982: fig 3.14 and plate 26) is still present just to the north of PP38. It is only partially visible behind the protective sandbag wall erected by the Deacon team along Wymer's profile on either side of PP38 (Fig. 6), but drawings (Henderson 1992: fig. 3) and previously unpublished photographs from the PP38 excavation (Figs. 7 and 8) show it is the same as the one recorded by Wymer. This provides a vital anchor point for correlating between the two stratigraphic systems.

The calcite block is shown to lie mainly within Layer 9 of the original excavation (Singer and Wymer, 1982: fig. 3.14) but is listed as being in Layer 10 in the layer descriptions (Table 1). This suggests that the base of the rock is within Layer 10. The top of the block corresponds roughly with the base of unit RSGBS2B in PP38, and its lowermost point is near the top of unit RSBCH. The recorded properties of RSBCH (Table 3) are broadly consistent with the description of Layer 10 (Table 1), further supporting this correlation. KRM 41815 was assigned to Layer 10, its stratigraphic position was indicated as being just level with the base of calcite block, and it was found next to the block (Singer and Wymer, 1982:146).

Table 3
Basic descriptions of the excavation units visible in the profiles of square PP38 in Cave 1B. A single description is provided for each of the carbonized parting unit groups in the Dark Carbonized deposits due to the fineness and complexity of the stratification of most of these deposits. The full name of each unit (as inferred from the abbreviated names by the authors) is given in parentheses after its description.

Unit	Description
Rubble Sand	
BR	Not excavated completely—up to 5 cm in maximum excavated thickness. Slightly reddish light brown silty fine sand with some grit and clay. Clasts are rare and include shell and small lithics. (Brownish red)
BSH2	~Four- to 5-cm-thick light brown silty fine sand with grit and clay. Clasts slightly more common than in BR and include rare bone and lithics. Some dispersed charcoal flecks. (Brown shelly 2)[a]
BYS1	Up to 6-cm-thick yellowish light brown silty fine/medium sand with some grit. Clasts more common and include quartzite fragments, very small pebbles, shell, and bone. Some quartzite appears to be rubified. Shell preservation variable. (Brownish yellow sand)
BSH1	Not distinguishable in profile between BYS1 and BCH. (Brown shelly 1)
BCH	First unit above the small, stepped excavation. Up to 10-cm-thick light brown silty fine sand with some clay. Clast density higher than units in stepped excavation. Lithics, bone, small pebbles, and well-preserved shell all observed. Charcoal flecks common and regularly distributed. Some very thin dark lenses with limited lateral extent visible. (Brown charred)
Y/SH	Up to 8-cm-thick yellowish light brown silty fine sand with some clay. Clasts relatively rare, but often concentrated in patches. Variably preserved shell found both dispersed through the sand and in short 'lines' of several shells. Lithics and quartzite fragments also observed. Small charcoal fragments dispersed throughout. (Yellow shelly)
DRU	Up to 6-cm-thick light brown silty fine sand with clay and grit. High density of quartzite fragments, but variable across the unit, with some areas almost clast-free. Most pieces are under 5 cm in length, but many are larger—up to 14 cm. Fragments show preferred dip towards the east and south, matching the general dip of the deposits. Grit often found in concentrated pockets between larger clasts. Shell, bone, and lithics are all rare. (Dark rubble unit)
YRU	Up to 4 cm thick. Almost identical to DRU except that the matrix is yellower in color. Includes a single thin dark lens in the southern profile. (Yellow rubble unit)
GBS2B	Lowermost unit included in the Deacon profile drawing of the nothern profile. ~2.5- to 5-cm-thick slightly grayish brown silt with clay. Clasts are very rare and widely dispersed and are almost exclusively quartzite fragments (some of which appear to be rubified). (Grayish brown sand 2 base)
GBS2	~Three- to 10.5-cm-thick slightly grayish brown silty fine sand with some clay. Clast properties the same as in GBS2B. (Grayish brown sand 2)
CP2	~Two- to 3-cm-thick dark grayish brown silty fine sand with charcoal flecks and relatively large pieces. Only present in the northern and western profiles. (Carbonized parting 2)
BS	~Four- to 10-cm-thick light brown silty very fine sand. Clasts relatively uncommon and widely dispersed. Mainly quartzite fragments, but some shell in varying condition in southern and western profiles. (Brown sand)
GBS	~Four- to 10.5-cm-thick grayish light brown silty fine sand. Clasts similar to BS. (Grayish brown sand)
YBSB and YBS	~4.5- to 13-cm-thick yellowish light brown silty fine/medium sand with some grit. Relatively high clast density, with some concentrated patches. The clasts include bone, lithics, and quartzite fragments. Some of the bones are recognizable as microfauna. Rare charcoal flecks dispersed through the units. (Yellowish brown sand base and Yellowish brown sand)
CP1	~One- to 6-cm-thick dark silty sediment with some sand and grit that is rich in carbonized material. Some charcoal pieces visible. Clasts are relatively rare and include decayed shell and small quartzite fragments (with many apparently rubified). In the western profile, a lens of yellowish-brown gritty sand is present across much of CP1, splitting it almost in two. In the southern profile, the unit is limited to the eastern edge of the profile. Here, the dark sediment contains little visible sand and, unlike in the other profiles, there are distinct ash lenses or pockets overlying the dark sediment. (Carbonized parting 1)
CP1T	~Three- to 4.5-cm-thick very dark brown silty fine sand with significant grit and many charcoal flecks. Thin black lenses are common. Clasts include lithics, quartzite (with some apparently rubified), and very rare shell. This unit is only present in the northern profile. (Carbonized parting 1 top)
YS1	~Five- to 14.5-cm-thick yellowish silty fine/medium sand with a significant grit component. Small quartzite fragments (mostly between 3 and 5 cm in length) are extremely common throughout. Microfauna bones visible across the unit. Other clasts are fairly limited and include larger quartzite fragments, lithics, shell fragments, bone fragments, and charcoal (exclusively in the western profile). Several lenses of black sediment and/or ash are present in YS1 or between YS1 and YS1T in the western and southern profiles. (Yellow sand 1)
YS1T	~0.5- to 1.6-cm-thick unit very similar to the underlying YS1. The major differences are that the matrix in YS1T is somewhat darker in color and slightly finer in texture, and that lithics, bone, shell, and charcoal are all notably more common. Uppermost unit associated with the MSA I. (Yellow sand 1 top)
Dark Carbonized	
CP12	~0.5- to 4.5-cm-thick spatially variable package of deposits with both vertical and lateral contacts between distinct deposits. Deposits include sediment rich in charred organic material, brown sand, and gray sand with dark patches, dispersed shell, and ashy laminae. The shell is typically fairly degraded and often forms layers which can be tracked within the matrix even when the shell is relatively dispersed. Charcoal is common throughout the deposits. Other clasts very rare. Lowermost units associated with the MSA II lower. (Carbonized parting 12)
YS6	Up to 3-cm-thick grayish light brown silty medium sand with some faint darker lenses. Clasts are rare and mostly quartzite fragments <1cm in length. Absent in the southern profile and somewhat discontinuous in the northern and western profiles. (Yellow sand 6)
CP11	Up to 1.5-cm maximum thickness. On the eastern end of the northern profile, it comprises black sediment rich in charred material with no shell. Across much of the northern and western profile, it is a very thin lamination of broken shell with some black sediment and charcoal. However, there are also patches of more concentrated shell. Indistinguishable from CP12 in southern profile due to the absence of YS6 in this profile. (Carbonized parting 11)
YS5	Up to 5-cm-thick brown silty medium sand. Quartzite fragments are common, while lithics, bone, and shell are less so. Shell and charcoal are typically dispersed, but there are some concentrations of shell. Often difficult to identify in the northern profile (and less commonly in the western profile) between CP11 and CP10. (Yellow sand 5)
CP10	~One- to 4-cm-thick unit comprising dark sediment rich in charred organics and several distinct ash lenses. Small quartzite clasts common, including some which appear to be rubified. Shell present but rare. (Carbonized parting 10)
YS4	Wedge-shaped deposit present on the eastern edge of the northern profile and across the eastern half of the southern profile. Up to 6-cm-thick on profile edges. Dark gray silty fine sand matrix with significant grit component. Clast density very high, mostly quartzite fragments under 4 cm in length, many of which appear rubified. Some lithics present, along with very rare bone fragments and dispersed charcoal. (Yellow sand 4)
CP9	~Nine- to 12-cm-thick package of alternating laminated to bedded deposits of black charred organic-rich sediment, ash, gray sand, and shell. Clast density is fairly high, with quartzite fragments, small pebbles, lithics, and very rare bone all present. Some quartzite appears rubified. Shell is relatively rare and dispersed in places, but there are also distinct layers of dense compressed shell. Charcoal visible throughout. Typically, more finely laminated in the northern profile than in the western and southern ones. Relatively difficult to distinguish from the underlying CP10 except where YS4 is present. (Carbonized parting 9)
YS3	~1.5- to 3-cm-thick brown medium sand with some grit. Quartzite fragments common, particularly smaller pieces (<1 cm). Lithics present by not common. Shell and charcoal dispersed throughout, but the density of shell increases notably in the southern profile. (Yellow sand 3)
CP8	Up to 15-cm-thick package of deposits including laminated to finely bedded ash, black carbon-rich sediment, and gray sand with dispersed carbon. Paler sand lenses are also present but have limited lateral extent. Quartzite fragments (some seemingly rubified), lithics and bone present throughout. Shell is mostly poorly preserved. The deposits are notably more coarsely bedded, less clearly defined, and richer in shell moving towards the southern profile.

Table 3 (*continued*)

Unit	Description
	Capped by a deposit of brown sand with relatively faint black lenses. Dispersed shell and charcoal flecks present throughout, along with some lithics and bone. Lithic artifacts and quartzite fragments occur at a higher density than the rest of CP8. (Carbonized parting 8)
CP7	Up to 5.5-cm-thick package of relatively thickly bedded deposits including black sediment rich in charred material, dark gray sand, and ash packets of varying lateral extent and thickness (up to 6 cm thick). Charcoal is common but varies in density. Shell is rare and mostly absent from northern profile. Clasts relatively common and include quartzite fragments and lithics. The base of CP7 is a deposit of dark silty sand, which is extremely clast-rich on the western edge of the square but has a far lower clast density across the rest of the square. Uppermost units associated with the MSA II lower. (Carbonized parting 7)
CP6 to CP4	Up to 13-cm-thick package of laminated to relatively thickly bedded deposits. Deposits include ash, black charred organic-rich sediment, yellowish light brown sand, brown sand, and dark gray sand. Bedding thickness increases for most deposits moving towards the south. Shell is virtually absent in the northern profile but is found in multiple distinct laminae across the western and southern profiles. Charcoal flecks common throughout. Quartzite fragments and lithics present at low density throughout. Lowermost units associated with the MSA II upper. (Carbonized partings 6 to 4)
BS6	~0.5- to 3-cm-thick yellowish light brown sand with very rare charcoal and dispersed shell. Quartzite fragments common, as are microfauna remains. Some bone fragments and lithics observed. Matrix grayer in the western profile. Not present in southern profile. (Brown sand 6)
CP3	Up to 9-cm-thick package of deposits ranging in thickness from laminae to relatively thick beds. Deposits include yellowish light brown sand, black sediment rich in charred material, and shell-rich layers. Thicker deposits often include lenses of other material. Shell density increases notably moving towards the south. Quartzite fragments, bone, and charcoal are all reasonably common, but dispersed through the deposits. Largely indistinguishable from CP4 in the southern profile due to the absence of BS6. (Carbonized parting 3)
BS5	~2- to 7.5-cm-thick light brown medium sand with some rare faint darker laminae. Most clasts are small (<0.5 cm) quartzite fragments, but larger quartzite pieces and lithics are also common. Shell is present but very rare and some microfauna remains observed. Charcoal flecks common, but largely found in a few concentrated patches. Not preserved in southern profile. (Brown sand 5)
BS4	~2.5- to 6.5-cm-thick alternating laminae of light brown sand, yellowish brown sand, and black lenses. Quartzite fragments are typically small, but there are a few concentrations of larger pieces. Lithics, bone and some charcoal observed throughout, along with microfauna remains. Not preserved in southern profile. (Brown sand 4)
CP1	Up to 8-cm-thick package of laminated to thinly bedded deposits of ash, shell, gray sand, and black carbon-rich sediment. Charcoal and lithics are common throughout. Most clearly stratified on the western edge of the northern profile. Moving across and into the western profile, the package is dominated by beds and laminae of black sediment and shell. Moving across the western profile, the shell density gradually increases, but black laminae remain. Not preserved in southern profile. (Carbonized parting 1)
BS3	Up to 2.5-cm-thick light brown sand. Clasts are relatively rare and include isolated quartzite fragments and a single piece of bone. Charcoal flecks throughout. Only preserved in the northern profile. (Brown sand 3)
BS2	~0.5- to 2-cm-thick brown medium sand. Clasts relatively common and include lithics, quartzite fragments and rare shell. Charcoal flecks throughout and more common than in BS3. Only preserved in the northern profile. (Brown sand 2)
YS2	~2.5- to 5-cm-thick yellowish brown medium sand. Quartzite fragments are common, as are microfauna remains. Only preserved in the northern profile. (Yellow sand 2)
BS1	Up to 8-cm-thick light brown to brown fine/medium sand, with a ~1-cm-thick layer of black sediment and ash at its base. Clasts are common and include lithics, microfauna remains and quartzite fragments (some of which appear rubified). Charcoal flecks throughout. Only preserved in the northern profile. (Brown sand 1)
YS1	Heavily eroded yellowish light brown sand with quartzite fragments. Original thickness unclear. Only preserved in the northern profile. (Yellow sand 1)

[a] No shell was observed in RSBSH2, but this unit has a very limited exposure in the profiles of the stepped portion of the excavation. It is likely that this deposit was richer in shell towards the center of the excavation (and perhaps further east into Wymer's excavation) but contained little shell on its edges.

Therefore, it must relate to RSBCH. This matches the suggested correlation in the previously unpublished Figure 5. This correlation places the specimen unambiguously within the MSA I deposits.

Based on the descriptions of the layers and units and visual comparison of the Wymer and PP38 profiles, correlations can be made or suggested for much of the sequence (Table 4). A few of the more significant correlations, and those with either less clear boundaries or less secure correlations, are presented in more detail here:

1. RSCP2 is the only unit with properties similar to Layer 8 that falls within roughly the right part of the sequence. However, as it is somewhat higher up the profile than Layer 8 is depicted in the original profile drawing, there is an element of doubt in this correlation.
2. The uppermost MSA I deposits—units RSYS1 and RSYS1T—correspond well with both the description and depth of Wymer's Layer 5. However, it is possible that the underlying RSCP1T could have been the base of Layer 5, rather than part of Layer 6.
3. The DC below the marked increase in thickness of sandy units (from the base of DCBS5) is correlated with Layers 4 and 3. The gravel-rich base of Layer 3 corresponds best with the gravel unit at the base of DCCP7. DCYS4 also matches the description of Layer 3's base, but this would make Layer 4 thinner than it is depicted by Wymer. With either boundary, the transition from the MSA II lower to the MSA II upper (the contact between DCCP7 and DCCP6) falls within Layer 3.
4. Due to erosion and the slope of the shelter surface, it is not entirely clear where the top of Wymer's profile would have been relative to the sloping tops of PP38's northern and southern profiles.

It can be assumed that the unexcavated deposits in PP38 must broadly correlate with the rest of Wymer's sequence. As these deposits cannot be observed without removing the supporting sandbag walls along Wymer's profile—which could result in significant collapse and loss of deposit, even with carefully planned mitigation—there are no data with which to confirm this assumption.

3.2. Microstratigraphy

More than 70 MSUs were identified within the seven micromorphology slides analyzed (Figs. 9–11). These MSUs are assigned to one of 12 microfacies (MF) types, which are described in Table 5. Representative photomicrographs for each of the MFs are provided in Figs. 12–14. The microstratigraphy of the samples is detailed below, following the excavation units (or unit groups where more appropriate) utilized by the Deacon team.

Unit RSYBS (Fig. 9) is the lowest excavation unit represented in the thin sections and falls within the MSA I–bearing RS. The sampled portion comprises three MSUs of ashy sand with quartzite clasts, bone, shell, and charcoal (MF 1.2.1). The size and density of the coarse inclusions and the amount of ash in the matrix all vary between the MSUs. The quartzite and bone fragments are

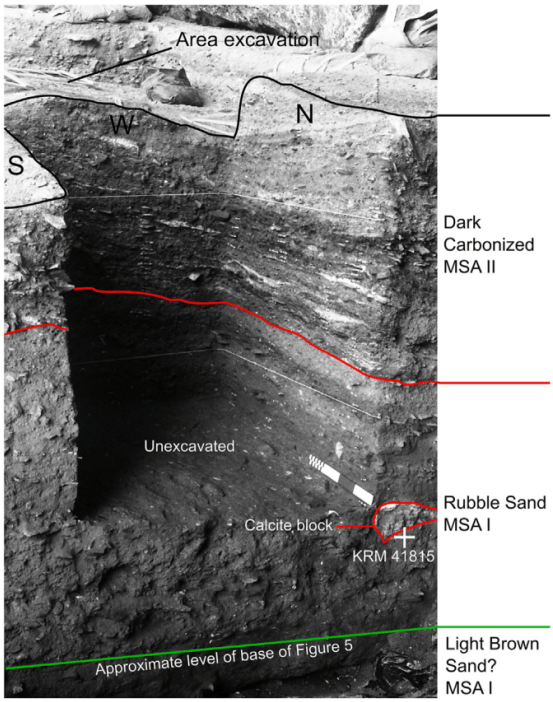

Figure 7. Photograph of square PP38 taken during the Deacon excavations from the eastern side of Cave 1B (from the Deacon archive). The scale bar is 40-cm long, and the base of the excavated portion corresponds roughly with the drawing in Figure 4. Note the calcite block which is depicted in a site photograph and profile drawings from the original excavation and still visible in the section (Figs. 6 and 8). The white cross shows the approximate stratigraphic position of KRM 41815 as depicted in Singer and Wymer's (1982) figure 3.14. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article).

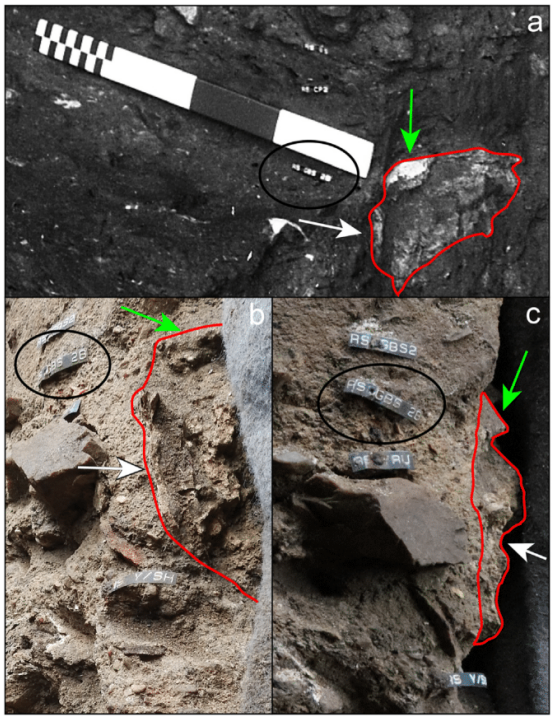

Figure 8. Multiple views of the calcite block (outlined in red) in Wymer's western profile, adjacent to PP38. a) View from the southeast during the excavation of PP38 (scalebar is 40 cm), b) View from the east in 2020, and c) View from the south in 2020. The arrows indicate parts of the block visible in all three views. The green arrow (upper) and white arrow (lower) each point to the same part of the block in each view. Note Deacon's label for unit RSGBS2B (circled in black). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article).

significantly larger in the lowermost MSU. The arrangement of several relatively large clasts in a rough line at the base of the third MSU is suggestive of a possible surface. Some small coprolites were observed towards the base of the unit.

Unit RSCP1 (Fig. 9) is composed mainly of ash with some sand, small quartzite fragments, shell, and charcoal (MF 3.2). Finer charred organic material is present throughout but is most highly concentrated in a thin deposit, which also contains numerous very small charcoal pieces (MF 4.1). There is also a small zone of significantly sandier and less ashy sediment, with a relatively high density of small quartzite fragments (MF 1.2.1).

Table 4
Revised correlations between the different stratigraphic systems utilized in Cave 1B, moving down from the surface. Layers 13b, 14, and 15 are believed to fall within the unexcavated portion of the sequence in what Deacon and Geleijnse (1988) considered to be the LBS Member.

Layer	PP38 excavation unit or unit group	Lithostratigraphic members/submembers	Cultural stratigraphy
1	DCCP1 upward[a]	Dark Carbonized	MSA II upper
2	DCBS5 and DCBS4		
3	DCCP7 to DCCP3[a]		MSA II lower
4	DCCP12 to DCCP8[a]		
5	RSYS1 and RSYS1T[a]	Rubble Sand	MSA I
6	RSCP1 and RSCP1T[a]		
7	RSBS to RSYBS		
8	RSCP2[b]		
9	RSY/SH to RSGBS2		
10	RSBCH		
11	RSBYS1		
12	RSBSH2		
13a	RSBR		

MSA, Middle Stone Age.
[a] Uncertain boundaries; see text for more detail.
[b] Less certain correlation; see text for more detail.

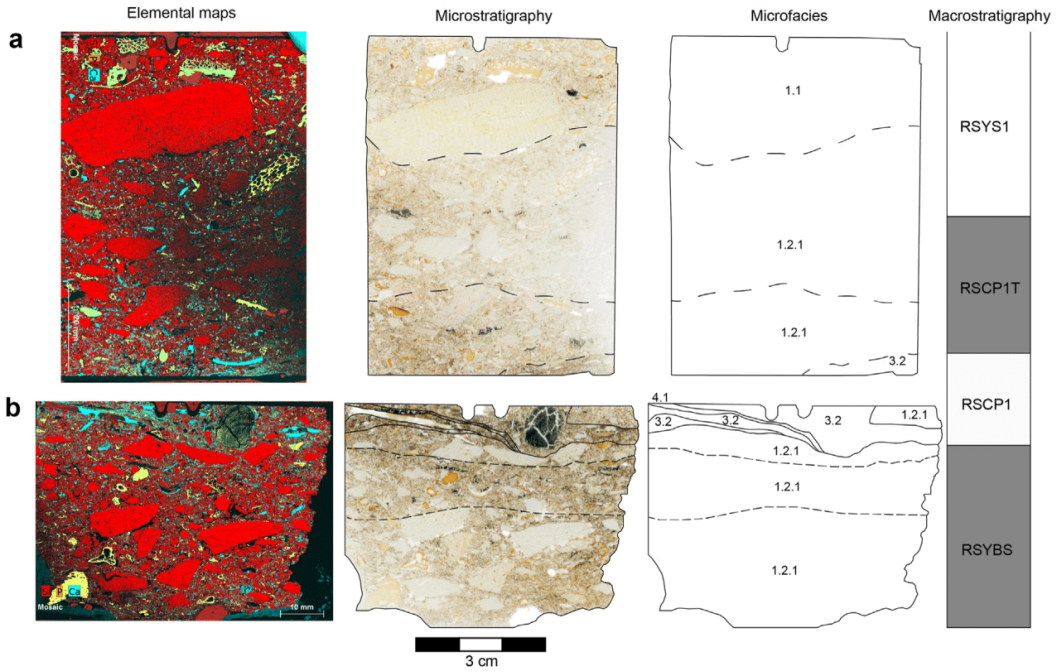

Figure 9. The micro-X-ray-fluorescence elemental maps, microstratigraphy, microfacies attributions, and excavation unit correlations (macrostratigraphy) for slides A (top row) and B (bottom row) from KRM-13-12. On the elemental maps blue denotes calcium (mostly ash or shell) and red represents silicon in the form of quartz and quartzite. Yellow shades show the presence of both calcium and phosphorus, e.g., in bone, phosphatized ash, and apatite nodules. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article).

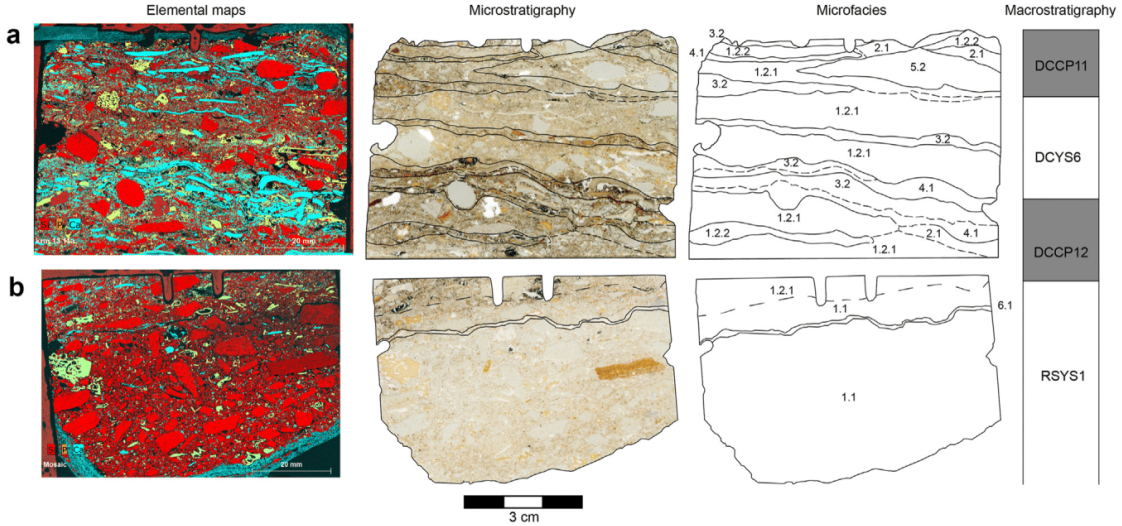

Figure 10. The micro-X-ray-fluorescence elemental maps, microstratigraphy, microfacies attributions, and excavation unit correlations (macrostratigraphy) for slides A (top row) and B (bottom row) from KRM-13-11. On the elemental maps blue denotes calcium (mostly ash or shell) and red represents silicon in the form of quartz and quartzite. Yellow shades show the presence of both calcium and phosphorus, e.g., in bone, phosphatized ash, and apatite nodules. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article).

The unit RSCP1T includes one MSU and part of another (Fig. 9). Both are ashy sands with a significant quartzite component (MF 1.2.1), but the lower deposit is notably ashier and contains more charcoal. Shell fragments are common but seldom more than a few mm in length. Bone is also common, ranging from sand-sized to ~9 mm. There is a significant increase in the size of the quartzite fragments moving up through the unit. The transition to RSYS1 is diffuse, and thus, the depiction in Figure 9 is an approximation.

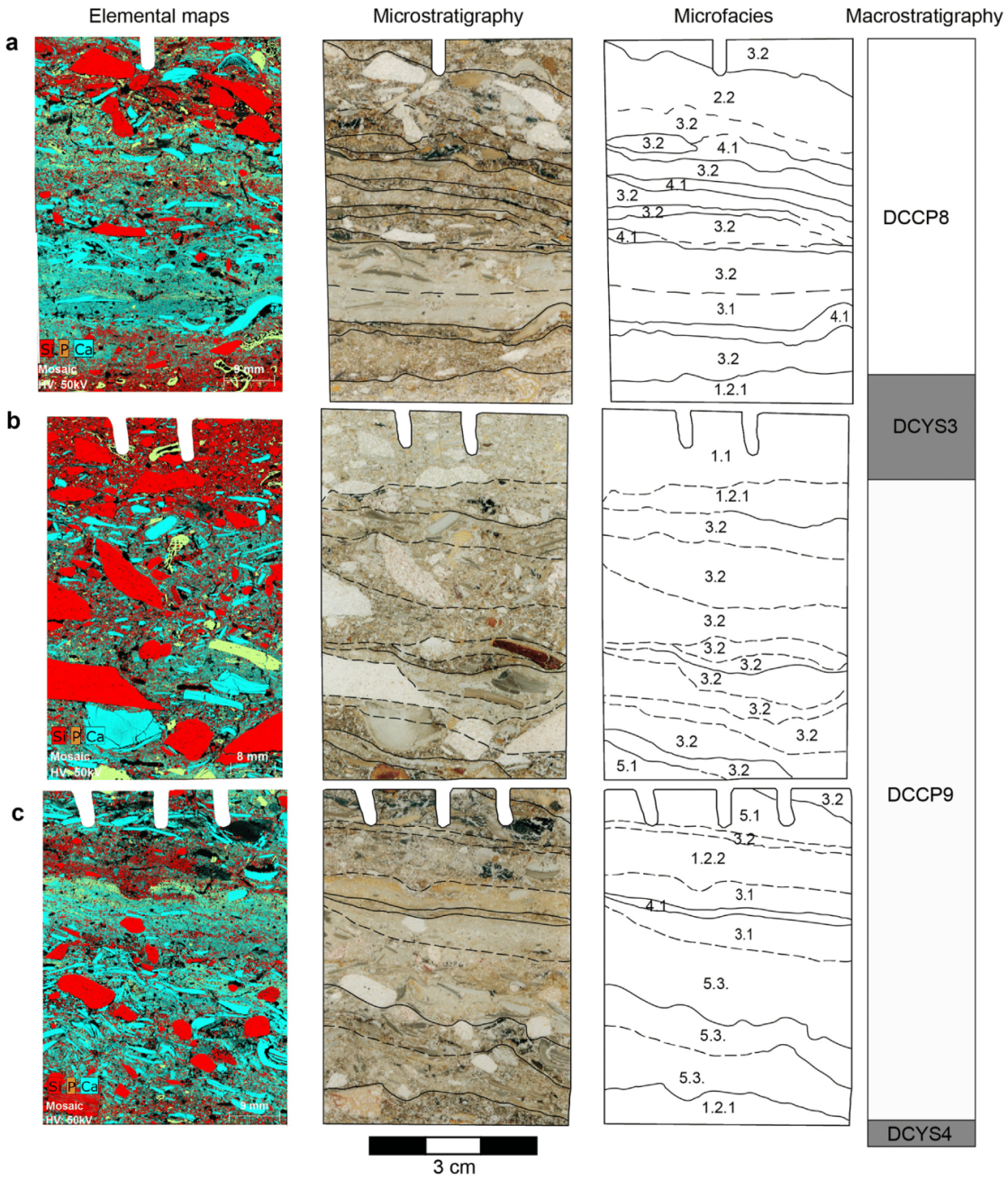

Figure 11. The micro-X-ray-fluorescence elemental maps, microstratigraphy, microfacies attributions, and excavation unit correlations (macrostratigraphy) for slides A (top row), B (middle row), and C (bottom row) from KRM-13-10. On the elemental maps blue denotes calcium (mostly ash or shell) and red represents silicon in the form of quartz and quartzite. Yellow shades show the presence of both calcium and phosphorus, e.g., in bone, phosphatized ash, and apatite nodules. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article).

The slightly ashy sand deposit (MF 1.2.1) at the base of RSYS1 is overlain by several sandy MSUs (Figs. 9 and 10). These deposits, assigned to MF 1.1, have a very high concentration of angular quartzite fragments, which range in size from coarse sand to several cm in length. Shell fragments, including sand-sized pieces, are relatively limited and are seldom larger than a few mm (note

Table 5
The microfacies identified in the samples from square PP38, Cave 1B. A general description is provided for each microfacies, along with a list of the excavation units/unit groups in which they were recorded, and the number of microstratigraphic units assigned to the microfacies. See Figures. 12–14 for photomicrographs of each microfacies. All observed phosphatization of ash is by apatite.

No.	Microfacies	Description	Context
1	Shelly sand		
1.1	Shelly sand with quartzite	Matrix of predominantly sand-sized subangular to rounded grains of quartz and marine shell. Quartz significantly more common than shell. Angular fragments of quartzite ranging from coarse sand to several cm in length are very common. Rare larger quartzite clasts. Bones and bone fragments common, up to ~1 cm in length. Many appear to be microfauna. Larger elongated shell fragments far less common than bone. In situ breakage of bone and shell common but with very limited vertical displacement of pieces. Small secondary apatite nodules are present dispersed through the matrix and in a thin layer in one case (see text for further description).	RSYS1 (three MSUs) DCYS3 (one MSU)
1.2	Ashy shelly sand with coarser inclusions		
1.2.1	—with quartzite	Shelly sand as defined earlier but with a greater concentration of shell. Ash fills the interstitial space to varying degrees. Angular quartzite fragments with size ranging from coarse sand to pebble-sized are common. Both the size and density of quartzite vary within and between MSUs. Elongated shell fragments up to ~4 cm in length, but mostly under 1 cm, are present in many of these deposits but are never very common. Bone, including microfauna, is more common than shell, but has a similar size range. Charcoal fragments under 1 cm were observed in some deposits, whereas fine charred organic material was more common but still a relatively minor component. Some in situ breakage of shell but very limited vertical displacement of fragments. Minor phosphatization of ash common.	RSYBS (three MSUs) RSCP1 (one MSU) RSCP1T (two MSUs) RSYS1 (one MSU) DCCP12 (three MSUs) DCYS6 (two MSUs) DCCP11 (one MSU) DCYS4 (one MSU) DCCP9 (one MSU) DCYS3 (one MSU)
1.2.2	—without quartzite	Sand and ash matrix as in MF 1.2.1. Larger elongated shell fragments (<1 cm) and some more equant pieces are relatively common, and bone ranging in size from coarse sand to granule/pebble is present but less common. Charcoal up to ~5 mm observed in some MSUs. Some finer charred organic material distributed through the ash. Pockets of minor ash phosphatization. No visible in situ fragmentation of shell.	DCCP12 (one MSU) DCCP11 (two MSUs) DCCP9 (one MSU)
2	Quartzite gravel		
2.1	Fine sandy gravel with ash	Angular quartzite clasts all <1 cm in length in a matrix of shelly sand, with some ash filling the interstitial spaces. Small bone fragments and charred fine organic matter are present in some units, but relatively rare. The quartzite fragments all show a general preferred orientation which matches that of the respective MSU in both direction and degree of dip.	DCCP12 (one MSU) DCCP11 (two MSUs)
2.2	Fine ashy gravel with coarse inclusions	Angular quartzite clasts all <2 cm in length in a matrix of ash and shelly sand. Matrix-supported in some pockets. Some of the clasts resemble lithics in cross-section. One rounded clast also present. Relatively small shell and bone fragments present throughout the MSU. Some in situ breakage of bone and shell visible but with very limited vertical displacement of pieces. The quartzite fragments have a general preferred orientation which corresponds with the direction and degree of dip of the MSU itself. Minor phosphatization of ash throughout.	DCCP8 (one MSU)
3	Ash		
3.1	Microlaminated ash and sand	Ash with virtually no coarse inclusions, interbedded with microlaminae of shelly sand (often just a single sand grain in thickness) and extremely thin bands of phosphatized ash. Some variable recrystallisation and cementation of ash in this MF and all others with a significant ash component. Small channels are present at low frequency in some of the deposits.	DCCP9 (two MSUs) DCCP8 (one MSU)
3.2	Ash with sand and coarser inclusions	Ash-dominated deposits containing varying quantities of shelly sand. The presence, density, and size ranges of coarser inclusions vary widely between the MSUs assigned to this MF. Quartzite ranges from angular coarse sand to granule-sized fragments and clasts several cm in length. Many, but not all, of the latter are either rounded pebbles or have cross-sections suggestive of being lithics. Bone fragments are relatively common in many MSUs, but are generally quite small, seldom exceeding 4 mm in length. Shell fragments are typically elongated, and few are more than 1 cm in length. Charcoal pieces under 1 cm are present in some deposits, and fine charred material is found within the ash matrix of some MSUs. The dip and orientation of the coarser inclusions typically corresponds roughly with that of the MSU they are in. In situ breakage of shell is common where shell is present, but vertical displacement of the fragments is relatively limited. Phosphatization of ash is very common but varies in intensity. It is often patchy, but sometimes there are extremely thin lenses of phosphatized	RSCP1 (three MSUs) RSCP1 (one MSU) DCCP12 (two MSUs) DCYS6 (one MSU) DCCP11 (one MSU) DCCP9 (11 MSUs) DCCP8 (9 MSUs)

(*continued on next page*)

Table 5 (*continued*)

No.	Microfacies	Description	Context
		ash within ash that is either not phosphatized or less phosphatized. Small channels are present at low frequency in some of the deposits.	
4	Organic material		
4.1	Charred organic material	Fine charred organic material and charcoal with ash and some shelly sand filling spaces between charred material and other inclusions. Larger elongated shell fragments (up to ~9 mm) are common, while sand to granule-sized bone is also present, but less common. Minor phosphatization of ash and charcoal in some MSUs of this microfacies. In situ fragmentation of shell is variable.	RSCP1 (one MSU) DCCP12 (two MSUs) DCCP11 (one MSU) DCCP9 (one MSU) DCCP8 (four MSUs)
5	Shell		
5.1	Shell with charred organic material	Shell fragments <2 cm in length (mostly elongated) with a matrix of ash and some shelly sand. Charcoal fragments up to ~9 mm are common, along with some finer charred organic material within the ash. In situ breakage of shell common, but with limited vertical displacement of fragments. Minor phosphatization of ash throughout. The shell fragments typically dip at a similar angle, and in the same direction, as the MSU itself.	DCCP9 (one MSU)
5.2	Shell with rounded quartzite	Shell fragments <2 cm in length (mostly elongated) with a matrix of ash and shelly sand. Some angular quartzite from coarse sand to granule-sized, and several relatively large (up to ~1 cm) rounded quartzite pebbles. Minor localized phosphatization of ash. Very little in situ fragmentation of shell visible. Dip of shell fragments largely corresponds to upper and lower surfaces of MSU.	DCCP11 (one MSU)
5.3	Ashy shell	A very high density of shell fragments up to ~1 cm long in an ash matrix. Both charcoal and finer charred organic material present but vary in concentration between different MSUs. Some shelly sand and sand-sized angular quartzite throughout, but there are clear concentrations in some areas. Larger quartzite pieces are mostly rounded. Some shell fragments appear to represent whole shells broken in situ with relatively limited vertical displacement. Small bone fragments present but not common. The shell and larger quartzite dip relatively steeply, matching the overall orientation of the deposits. Phosphatization of ash throughout but variable in degree.	DCCP9 (3 MSUs)
6	Calcite		
6.1	Micritic calcite	Thin, laterally continuous lamina of mostly micritic calcite, with some small areas of more microsparitic calcite. No visible clastic sediment within the calcite and internal stratification absent. Heavily affected by dissolution.	RSYS1 (one MSU)

Abbreviations: MF, microfacies; MSU, microstratigraphic unit.

the lack of calcium in these units in the elemental maps in Figs. 9a and 10b). In contrast, bone—including microfauna—is far more common and some pieces are more than 1 cm in length. Small secondary apatite nodules are present through the deposits. The sandy MSUs are interrupted only by a very thin layer (up to ~2-mm-thick) of micritic calcite (MF 6.1) with localized domains of more microsparitic calcite (Fig. 10). This deposit has been partially dissolved but can be tracked across the slide as a distinct accommodated planar void (Fig. 15). It is overlain by another MSU assigned to MF 1.1 which is notably less rich in quartzite and has generally smaller bone fragments than the deposits below. Clasts throughout RSYS1 show a general, but not particularly strong, tendency towards horizontality. In the upper MSU, however, there is an apparent line of quartzite fragments and bone within the sand just above the calcite. Above this, at the very top of the unit, small secondary apatite nodules form another rough line within the sandy matrix (Fig. 15).

DCCP12 is a group of units at the base of the DC deposits, which are the lowermost MSA II units in Cave 1B. It comprises two distinct portions, each containing multiple MSUs (Fig. 10). The lower portion includes five deposits of ashy sand with varying concentrations of quartzite, which are assigned to MFs 1.2.1, 1.2.2, and 2.1. Bone and shell fragments under ~5 mm are present at relatively low concentrations throughout, while charcoal is only present in the basal MSUs. Small secondary apatite nodules are scattered through a few of the deposits. The upper portion contains four alternating deposits dominated by charred organic material (MF 4.1) and ash (MF 3.2). Quartzite is fairly limited in quantity, but both bone and shell are present in high concentrations, especially in the ash-dominated deposits. The bone fragments are all under 1 cm, but some pieces of shell are several cm in length. In situ breakage of shell and bone is very common across the lateral extent of these deposits. Visible vertical displacement is limited, and many fragments appear to fit with surrounding fragments (Fig. 16). The general dip of the shell and bone matches that of the deposits themselves. Pockets of slightly phosphatized ash are common within both the lower and upper portions of DCCP12. In this case, and for all examples in the sampled deposits, the phosphatization was in the form of apatite replacing calcite.

DCYS6 (Fig. 10) is made up of a very thin deposit of sandy ash with bone and charred organic material (MF 3.2) sandwiched between two deposits of slightly ashy sand (MF 1.2.1). The lower is notably richer in bone and quartzite, whereas the upper contains more shell.

The DCCP11-unit group has a thin, discontinuous ash-dominated deposit (MF 3.2) at its base (Fig. 10). Most of the rest of the unit is comprised of ashy sand with varying concentrations of quartzite and shell. This includes an MSU with some quartzite assigned to MF 1.2.1, two with virtually no quartzite (MF 1.2.2), and two with highly concentrated quartzite (MF 2.1). A wedge-shaped deposit rich in shell and rounded quartzite pebbles (MF 5.2) makes up a significant portion of the unit. Some in situ breakage of shell was observed, with limited displacement of fragments. A lens of sediment rich in charred organic material (MF 4.1) also wedges out within the predominantly sandy unit. An extremely thin layer of sandy ash (MF 3.2) with small coprolites is the uppermost MSU

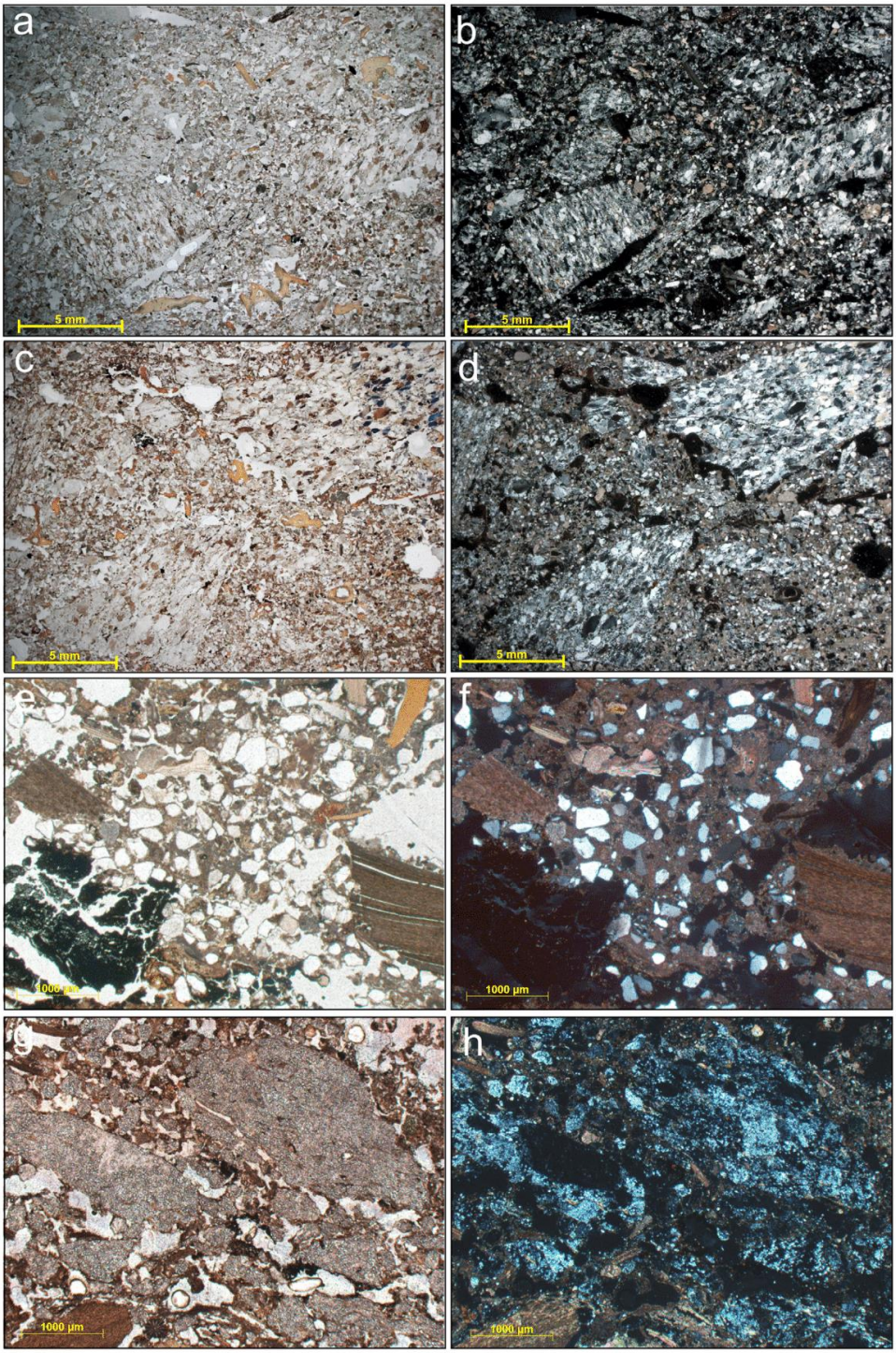

Figure 12. a) Sand-sized quartz, quartzite, and shell with angular quartzite gravel and bone fragments (microfacies [MF] 1.1), plane-polarized light (PPL). b) Same as a, cross-polarized light (XPL). c) Shelly sand with ash, charred material, angular quartzite gravel, and bone fragments (MF 1.2.1), PPL. d) Same as c, XPL. e) Shelly sand with ash, charred material, and shell and bone fragments (MF 1.2.2), PPL. f) Same as e, XPL. g) Quartzite gravel with shelly sand, ash, and charred organic material (MF 2.1), PPL. h) Same as g, XPL. Note that the colors (especially for quartzite) differ from normal because the pictured area of this slide was ground relatively thin.

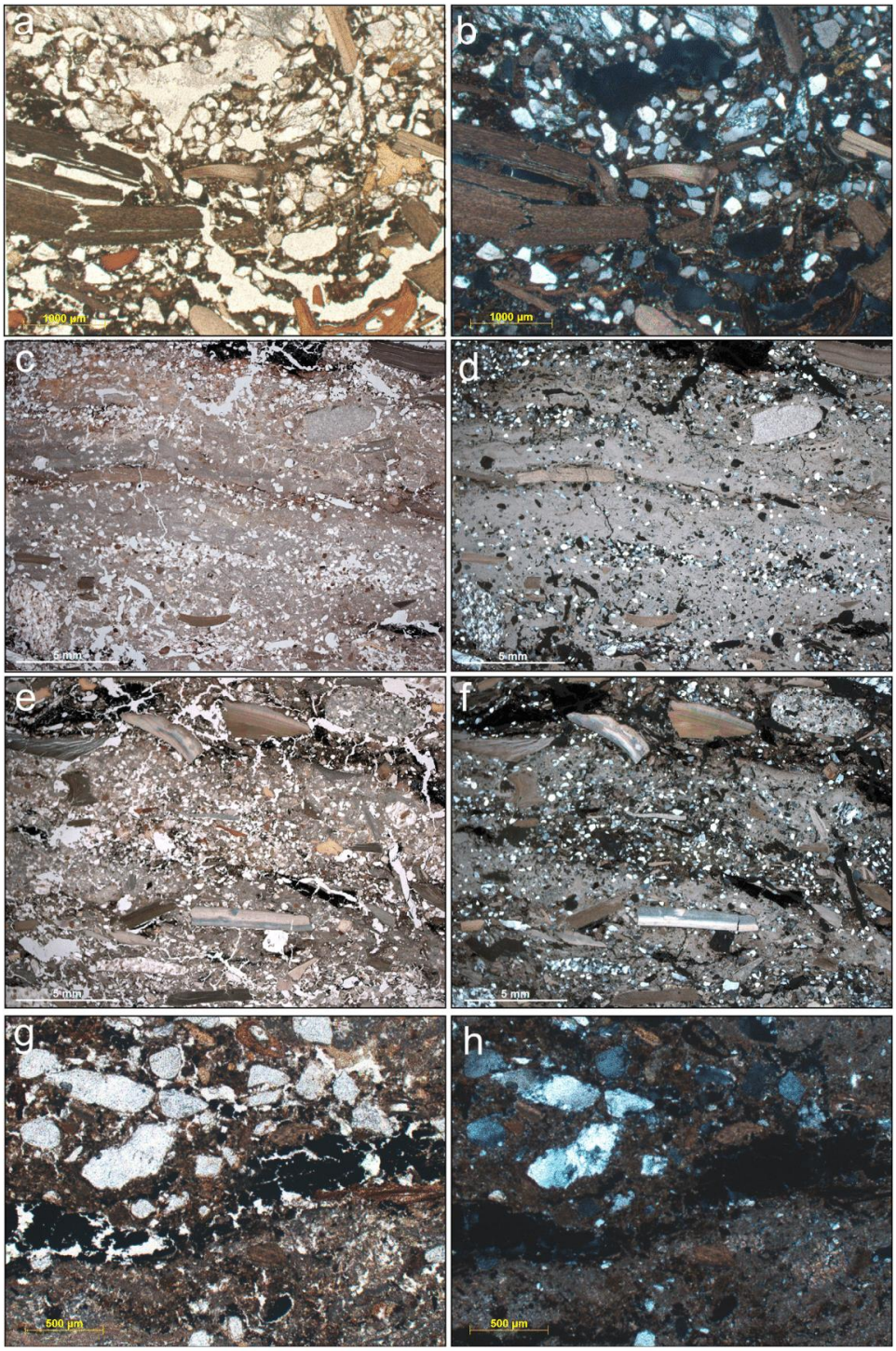

Figure 13. a) Quartzite gravel in an ash matrix, with shell, sand, and bone and shell inclusions (microfacies [MF] 2.2), plane-polarized light (PPL). Note contact with underlying ash-dominated deposit. b) Same as a, cross-polarized light (XPL). c) Microlaminated ash with phosphatized bands and very thin sand laminae (MF 3.1), PPL. Note the scarcity of larger inclusions. d) Same as c, XPL. e) Multiple ash-dominated deposits with shelly sand and larger inclusions (MF 3.2), PPL. Note the variation in the type and proportion of inclusions, and the presence of lenses of charred material (MF 4.1) f) Same as e, XPL. g) A thin lens of charred organic material (MF 4.1) between two ash-rich deposits, PPL. h) Same as g, XPL.

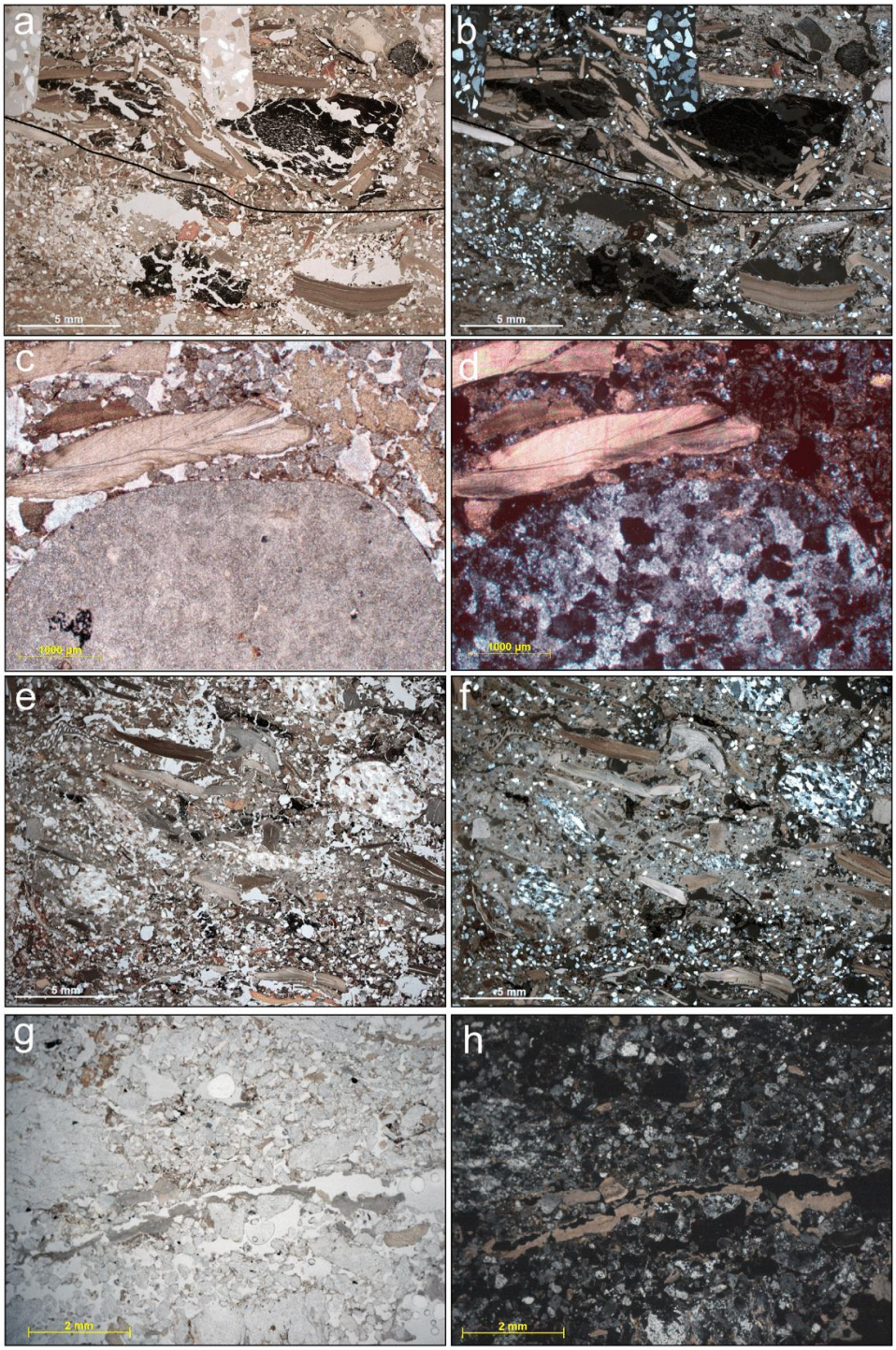

Figure 14. a) Above the line: shell and charred organic material, including charcoal, in a matrix of ash and shelly sand (microfacies [MF] 5.1), plane-polarized light (PPL). The deposit below the line is assigned to MF 1.2.2 The cuts into the deposit are a product of thin-section production, and the grains are unrelated to the original deposits. b) Same as a, cross-polarized light (XPL). c) Shell with relatively large, rounded quartzite in a matrix of shelly sand and some ash (MF 5.2), PPL. Note the crushed bone (upper right of the image). d) Same as c, XPL. e) Shell fragments in an ash matrix with charred material, bone fragments and shelly sand as inclusions (MF 5.3), PPL. The density of shell varies within and between MSUs of this type. Note the contact with the underlying MF 1.2.1 deposit. f) Same as e, XPL. g) Thin lamina of micritic calcite, with some more microsparitic zones (MF 6.1), PPL. Note the void within the calcite. h) Same as g, XPL.

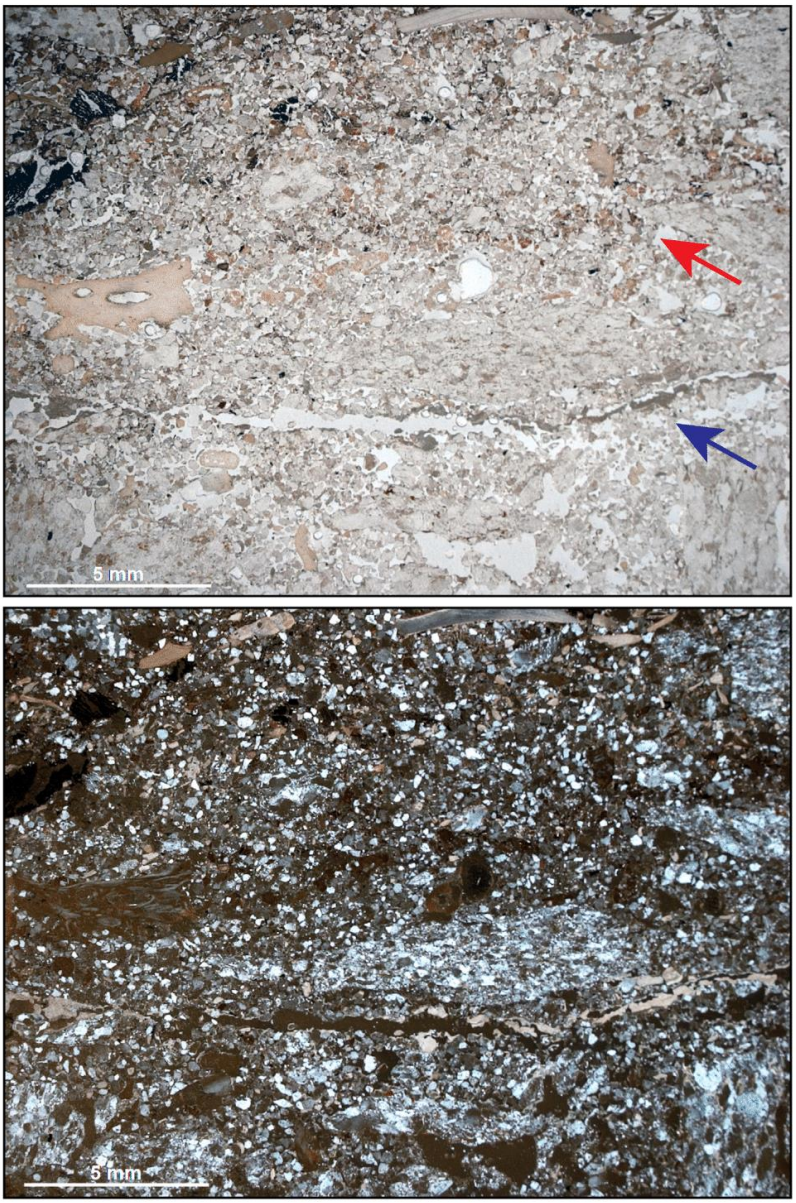

Figure 15. The upper portion of RSYS1 in plane-polarized light (top) and cross-polarized light (bottom). The calcite crust (microfacies 6.1.) is indicated with the blue arrow. Note the void due to dissolution. The red arrow indicates the line of apatite nodules. Most of the view is composed of microfacies 1.1 sediment. The appearance of anthropogenic materials (ash, charcoal, shell) above the apatite nodules marks the transition to DCCP12. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article).

from DCCP11 represented in the samples. The ash is relatively highly phosphatized at the very top of the sample.

DCYS5 and DCCP10 both appear to have fallen between samples KRM-13-11 and KRM-13-10 and thus are not represented in the thin sections. This is not unexpected, as they are both extremely thin at this point in the northern profile.

DCYS4 is also very thin across the sampling column location and is represented by a single thin MSU (Fig. 11). This deposit of ashy sand (MF 1.2.1) contains a single relatively large quartzite clast and limited bone and shell fragments but is fairly rich in charred organic material, both as small charcoal fragments and finer material within the ash. Some small coprolites are spread through the unit. A portion of the contact with the overlying MSU is a lens rich in relatively highly phosphatized ash, concentrated apatite nodules, and containing a partially phosphatized shell fragment (rare for Cave 1B; Fig. 17). This lens lies directly on the quartzite clast but appears to have been deformed next to the clast, wrapping along the side of the clast, before flattening out somewhat moving away

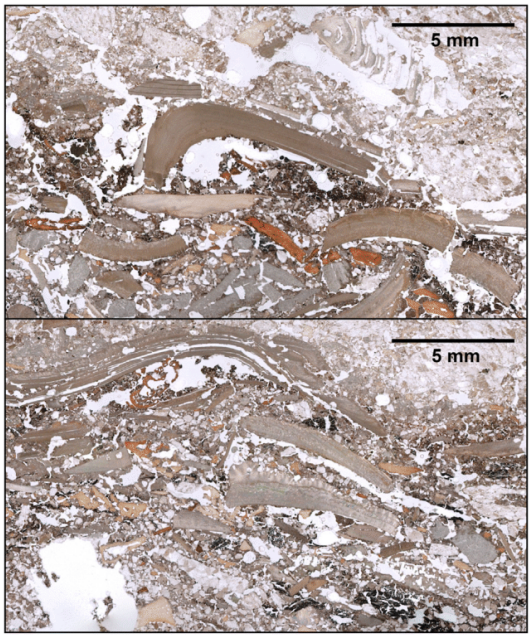

Figure 16. Two views of the upper portion of DCCP12 (plane-polarized light). Note the general horizontality and limited displacement of bone and shell fragments.

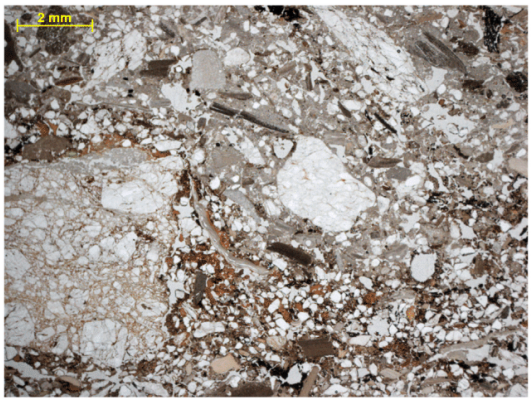

Figure 17. The contact between DCYS4 (microfacies 1.2.1) and the overlying microfacies 5.3 within DCCP9, showing the deformed lens of apatite above and next to the quartzite clast (plane-polarized light). Note the nearly vertical partially phosphatized shell fragment, and the conformity of the base of the overlying ash to this surface.

from the clast. The base of the overlying ashy MSU is conformable to this surface.

The unit group DCCP9 is a relatively thick package of mostly ash-dominated deposits (Fig. 11). Its base is made up of three relatively steeply dipping MSUs assigned to MF 5.3, which are rich in large shell fragments and rounded quartzite pebbles within an ash matrix. Sand and some smaller angular quartzite fragments are present but occur at their highest concentration just above the bulk of the shell. Charred organic material is concentrated in the middle of the three MSUs, with little in the other two. Minor ash phosphatization is common. There is some in situ fragmentation of shell, most notably at the upper surfaces of the two lower MSUs. These

Figure 18. The contact between laminated ash (microfacies 3.1) and ashy sand (microfacies 1.2.2) within DCCP9 (plane-polarized light). Note the truncation of the ash by a channel-like feature (red arrow) and the bands of yellowish phosphatized ash (black arrows). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article).

deposits are overlain by two laminated MSUs of ash, phosphatized ash, and sand lenses (MF 3.1) separated by a thin layer rich in charred organic material (MF 4.1). The laminated ash contains virtually no inclusions larger than sand. The upper contact of the laminated ash is an unconformity, with the overlying deposit filling a hollow in the surface (Fig. 18). This deposit is mostly ashy sand (MF 1.2.2) but varies laterally with some ash-dominated domains, which contain most of the shell and charcoal in this MSU. It is capped by a very thin layer of sandy ash (MF 3.2), which is overlain in turn by a shell-rich deposit with an ashy matrix, significant charcoal content, and a single relatively large bone (MF 5.1). Shell fragmentation is particularly common in this MSU, but the displacement is limited, and most fragments can be associated with other fragments from the same shell. This deposit is followed by a sequence of 10 MSUs, which are all assigned to MF 3.2 but vary in the concentration of different inclusions. The first seven contain some sand and a few large pieces of bone, shell, and quartzite. Charred organic material (both fine and some charcoal) is concentrated in a few of the MSUs. The next two MSUs are richer in sand and smaller quartzite fragments, with notably smaller bone and shell fragments than below. Charred organic material is limited. The uppermost of the MF 3.2 MSUs is rich in shell, with some bone and small quartzite fragments. Some shell has been fragmented in situ, with very little displacement of fragments. Minor phosphatization of ash is common through these 10 MSUs, sometimes present in the form of extremely thin lenses. The final MSU within DCCP9 is a deposit of ashy sand with charcoal, shell, and quartzite (MF 1.2.1).

Unit DCYS3 comprises two sandy MSUs (Fig. 11). The lower contains a high concentration of angular quartzite, bone (including microfauna), and some shell. Sand-sized shell fragments are rare (note the lack of calcium in this deposit in the elemental map in Fig. 11b). It is assigned to MF 1.1, whereas the upper MSU is ashy enough to fall within the characteristics of MF 1.2.1. Shell and quartzite are both less common in this deposit than in the lower one.

DCCP8 is the uppermost unit group represented in the samples (Fig. 11). As with DCCP9, it is primarily made up of ash-dominated deposits. The basal deposit is ash with some sand and relatively fine quartzite (MF 3.2), which grades laterally into a sandier sediment with larger quartzite pieces and bone (MF 1.2.1). Most of the rest of the unit is characterized by an alternating sequence of deposits rich in charred organic material (MF 4.1) and ash-

dominated layers (MF 3.1 and 3.2). The first organic-rich MSU contains relatively dense shell, which has been relatively heavily fragmented in situ, with very little displacement. This deposit is overlain by an MSU of laminated ash, phosphatized ash, and sand (the only example of MF 3.1 in this unit), followed by an ash deposit rich in shell with some sand and quartzite. Some of the shell in the upper of these MSUs may have been pressed into the ash, and there are indications of in situ breakage with limited displacement. The second carbon-rich MSU contains few coarse inclusions and is followed by a succession of three ash-dominated deposits. The lowermost is rich in shell, and contains some sand and quartzite, including pieces that appear to be lithics. The second is richer in charred material but contains less shell, sand, and quartzite, whereas the third is sandier but has few coarser inclusions. The third charred organic MSU and the overlying ash-dominated deposit are both relatively rich in shell and sand, with rarer inclusions of very small bone and quartzite fragments. The ash in the ash-dominated deposit is more notably phosphatized than in any of the preceding MSUs in DCCP8. The fourth and final of the MSUs assigned to MF 4.1 is relatively rich in ash and contains shell and bone, along with larger charcoal pieces than in the preceding deposits. The ash in both this deposit and the two overlying ash-dominated MSUs is also relatively highly phosphatized. The uppermost ash contains shell, quartzite, charcoal, small pieces of bone, and a single rounded piece of calcarenite. This succession of alternating charred organic and ashy deposits is capped by a relatively steeply dipping deposit dominated by quartzite fragments and sand, with ash filling much of the interstitial space (MF 2.2). Shell and bone fragments are both reasonably common, and some charcoal is visible. The final MSU in the sampled sequence is ash with sand, shell, bone, and very small quartzite fragments (MF 3.2). Some in situ fragmentation of shell is visible, and a round piece of shell appears to have been pressed down into the ash near the base of the deposit.

Table 6
The interpretation of the microfacies identified in the sampled deposits in PP38, Cave 1B. Note that phosphatization of ash is by apatite.

No.	Microfacies	Interpretation	Geo.	Bio.	Anth.
1	Shelly sand				
1.1	Shelly sand with quartzite	Deposition through aeolian and/or colluvial processes (sand) and breakdown of the host rock (angular quartzite clasts), with the latter mostly driven by salt weathering. Bone (much of it microfauna) and shell introduced by marine birds, raptors, and small mammal carnivores. Secondary apatite nodules formed by biogenic apatite. Possible incomplete decalcification due to acidic phosphates.	x	x	
1.2	Ashy shelly sand with coarser inclusions				
1.2.1	—with quartzite	Predominantly geogenic deposits containing material reworked from combustion features, trampling probably a significant process. Some biogenic input in the form of bone, shell, and alteration of ash by secondary apatite.	x	x	x
1.2.2	—without quartzite	Very similar to 1.2.1, but lack of quartzite suggests either slower host rock breakdown or more rapid accumulation of deposit.	x	x	x
2	Quartzite gravel				
2.1	Fine sandy gravel with ash	Similar to MF 1.2.1 but thinness and significantly greater quartzite content indicate winnowing after deposition, most likely by localized low energy surface water flows.	x		x
2.2	Fine ashy gravel with coarse inclusions	Similar to MF 1.2.1 but with a greater concentration of reworked anthropogenic components. Some evidence for trampling but perhaps prior to final deposition. Alteration by biogenic secondary apatite.	x	x	x
3	Ash				
3.1	Microlaminated ash and sand	Intact hearths, with laminae of sand and phosphatized ash suggesting multiple burning events in the same location. The alteration of ash by secondary calcite and apatite, and minor bioturbation by soil mesofauna are the only obvious post-depositional processes.	x	x	x
3.2	Ash with sand and coarser inclusions	Combustion features that have been reworked to varying degrees. Some still clearly identifiable as hearths with inclusions of food debris or lithics. Trampling and alteration by secondary calcite and apatite common. Some minor bioturbation by soil mesofauna.	x	x	x
4	Organic material				
4.1	Charred organic material	Incomplete combustion of organic material at the base of hearths. Bone and shell either fuel/discard or chance inclusions from pre-existing surface. Minor alteration of ash and charcoal by apatite.	x	x	x
5	Shell				
5.1	Shell with charred organic material	Incomplete combustion of organic material on top of shell. Deposit trampled and altered by secondary apatite.	x	x	x
5.2	Shell with rounded quartzite	Reworking and mixing of ash, sand, and shell-rich deposits which could have been small middens. Some trampling likely involved in this process. Some ash altered by biogenic secondary apatite.	x	x	x
5.3	Ashy shell	The product of the mixing of originally more distinct shell and ash deposits, or the reworking of a combined ash and shell midden. The size of the shell fragments, and evidence for in situ fragmentation, suggest trampling likely played a role in this mixing. Sand (comprising both shelly sand and angular quartzite coarse sand) mixed into the deposits was likely originally present in distinct geogenic lenses. The secondary apatite that altered some ash was biogenic in origin.	x	x	x
6	Calcite				
6.1	Micritic calcite	Precipitation of calcite from calcium enriched water on the surface to form a crust during a hiatus in clastic deposition. Partial dissolution by relatively acidic water.	x		

Abbreviations: Geo., geogenic; Bio., biogenic; Anth., anthropogenic; MF, microfacies.

4. Discussion

4.1. Microfacies interpretation

The interpretations of the processes responsible for forming each of the MFs are discussed here and summarized in Table 6.

Shelly sand There are three MFs dominated by shelly sand in the sampled sequence: 1.1, 1.2.1, and 1.2.2 (Table 5). The sand component at KRM has been attributed to two primary sources: beach or dune sand transported and deposited by aeolian processes, and colluvial deposition of sand weathered from the Geelhoutboom palaeodune overlying the quartzite host rock (Deacon and Geleijnse, 1988). As both sources comprise sand-sized quartz and shell fragments, it is likely that the shelly sand in any specific MSU is from one or both of these sources.

Angular quartzite fragments ranging from coarse sand to pebble-sized are also a significant component of many of the MFs. Some pieces appear to be lithic debitage, but the majority are fragments of host rock. Given the climatic and geological context of the site, salt weathering would have played more of a role in the production of angular quartzite sand and gravel than frost-spalling (Miller et al., 2013, 2016), but insolation likely made some contribution to shelter breakdown (Butzer, 1982; Deacon and Geleijnse, 1988).

MF 1.1 is dominated by these geogenic components, but there are also inclusions of biogenic origin. The bone (much of it microfauna) and shell fragments were most likely deposited by birds and small mammals that utilized the shelter and the cliff above, whereas the small secondary apatite nodules are the product of the breakdown of phosphate-rich bird guano and subsequent reprecipitation of apatite within the groundmass (Karkanas, 2017). The relatively low proportion of sand-sized shell fragments in comparison to other deposits containing shelly sand suggests that some decalcification took place (e.g., Goldberg, 2000). The decomposition of guano can significantly lower pH levels, leading to the potential dissolution of calcite—with significant impacts on the preservation of ash, shell, and bone (e.g., Schiegl et al., 1996; Weiner et al., 2002). In this case, the presence of some shell and bone shows that this decalcification was not total.

MFs 1.2.1 and 1.2.2 are both dominated by shelly sand but also contain significant quantities of anthropogenic materials. The incorporation of wood ash, charred organic material, bone, and shell suggest the reworking of combustion features into largely geogenic deposits. Trampling is likely to have played a significant role in reworking the anthropogenic components (e.g., Goldberg et al., 2009; Miller et al., 2013; Rentzel et al., 2017). Raking or sweeping out of hearths could also have contributed to redistributing these materials, but no direct evidence for this behavior (e.g., Miller et al., 2010; Mallol et al., 2013a) was observed. Some bone, particularly microfauna, and shell is likely biogenic in origin, as is the apatite which has altered the ash in places. The presence and absence of quartzite is the major difference between these two MFs, reflecting a difference in host rock breakdown and/or in the rate at which a deposit was accumulated.

Quartzite gravel The composition of the thin, sloping MF 2.1 deposits suggests a broadly similar depositional process to MFs 1.2.1 and 1.2.2—primarily geogenic with some reworked anthropogenic material with trampling likely being a significant factor. In all cases, they have lateral and/or vertical contacts with MSUs assigned to MFs 1.2.1 or 1.2.2. The dominance of coarse sand to granule-sized quartzite over shelly sand and the relatively limited extent of these MSUs suggest that they could be lag deposits produced by the winnowing of finer material, perhaps by very localized low-energy surface water movement.

The single sloped deposit assigned to MF 2.2 contains significant quantities of both geogenic (shelly sand and angular quartzite) and anthropogenic components (ash, bone, shell, charred organic matter, and lithic artifacts). It is broadly similar to MF 1.2.1 but contains far more ash and more concentrated quartzite. The morphology of the deposit conforms to the surface of the seemingly truncated deposit beneath it, with the clasts showing the same general dip (Fig. 11). This deposit is interpreted as the product of the mixing of the geogenic components with lithic artifacts and material reworked from combustion features. The shell fragment size and angularity point to trampling as a possible process (Rentzel et al., 2017). The secondary apatite that altered patches of the ash is biogenic in origin (Karkanas, 2017).

Ash The ash in MF 3.1 is the product of complete combustion of wood (Canti and Briochier, 2017). The almost complete lack of coarse inclusions, and the common association with underlying deposits rich in charred organic material (MF 4.1) indicate that these MSUs are intact hearths (Mentzer, 2014; Mallol et al., 2017). The extremely thin sand laminae and slightly thicker bands of phosphatized ash suggest that each deposit is the result of repeated burning events at the same location. The sporadic recrystallization and cementation of ash by secondary calcite in this MF and other ash-rich deposits is a common phenomenon driven by water percolation through deposits (Karkanas et al., 2007; Karkanas, 2021). It is also possible that some secondary calcite was introduced by calcium-enriched water—as is the case across the rest of the complex (Deacon and Geleijnse, 1988; Wurz et al., 2022). The few small channels in the ash point to limited bioturbation by burrowing soil mesofauna (Stoops, 2021).

The dominance of ash, regular inclusion of charred organic material, and common association with deposits of MF 4.1 all indicate that MSUs assigned to MF 3.2 can be considered combustion features. However, the other inclusions suggest varying degrees of modification or reworking of these features but notably less than MFs 1.2.1 and 1.2.2 (Mallol et al., 2017). Apart from shelly sand and some quartzite (especially the coarse sand to granule sized pieces), the inclusions are anthropogenic in origin. Some could have been deliberately discarded into hearths both during and after burning events, but many were probably mixed into the ash after having been initially deposited in distinct layers. The shell fragments in some deposits are very small, and quite angular, and many of the larger fragments have experienced some in situ breakage (although typically with very limited vertical displacement of pieces). This, along with the mixing of sand and coarser material into the ash suggests that trampling played at least some role in the modification of these combustion features. As with MF 3.1, the ash has been altered by both secondary calcite and secondary apatite, although the latter tends to be relatively patchy, with lenses and lamina of phosphatized ash much less common and restricted to relatively intact hearths. The limited impact of burrowing soil mesofauna is evident from the rare small channels in some deposits.

The phosphatization of ash deposits in cave and rock shelter settings has been attributed to the decomposition of bird and bat guano (e.g., Karkanas et al., 2000; Karkanas, 2017). Cave 1B is relatively exposed, so bats are unlikely to have contributed guano, but marine birds have been observed roosting on ledges directly above the shelter. Their fish-dominated diet means their droppings are particularly rich in phosphorus, and the leaching and reprecipitation of the apatite produced by the alteration of the guano has even been known to phosphatize limestone (Glenn et al., 1994:758).

The bands of phosphatized ash within some combustion features (e.g., Fig. 18) are indicative of the exposure of these features

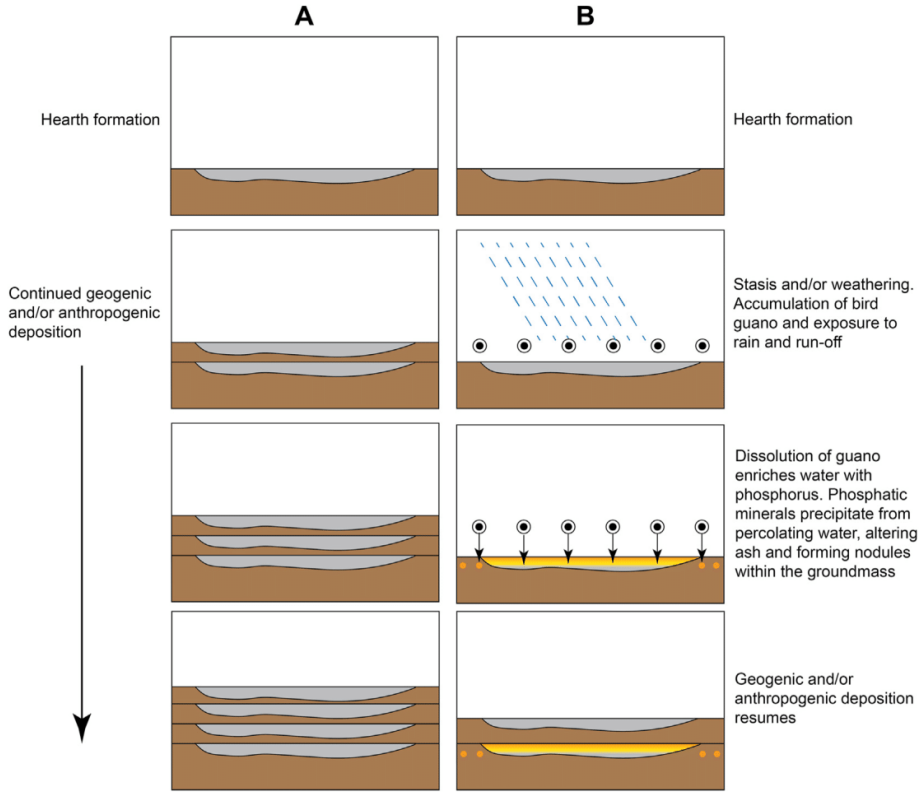

Figure 19. A comparison between A) hearths buried by continued deposition soon after their initial formation and B) hearths exposed on the surface for extended periods due to erosion or lack of deposition, leading to the alteration of the ash by biogenic secondary apatite. The secondary apatite can also precipitate into non-ash groundmass, forming nodules, but this is less common in the sampled sequence. Examples of both phosphatized and non-phosphatized hearths are preserved in the sampled sequence.

on the surface for a period of time due to erosion or a depositional hiatus (Fig. 19). The localized phosphatization points to a period of surface stability during which the ash was altered. The absence of phosphatized surfaces in some combustion features indicates that these were buried relatively quickly by natural or cultural deposits. The presence of ash, shell, and bone in the sampled combustion features and the relatively limited phosphatization of the ash suggest that this process was not a significant diagenetic process for these deposits. This stands in stark contrast to Cave 2, where some ash layers have been fully replaced by apatite, and all carbonates have been dissolved in one area of the cave (Wurz et al., 2022). The limited effects of phosphates on the sampled sequence may be due to either a comparatively low presence of guano or through calcite-rich water buffering the pH.

Most of the combustion features that can be interpreted as in situ hearths are stacked hearths (Figs. 18 and 20a), the product of multiple burning events in the same location (Mentzer, 2014). In some stacked sequences, the ash deposits are separated by charred layers of varying thickness (Mentzer, 2014: fig. 8e), but in others, charred layers are absent (Mentzer, 2014: fig. 8h), and different ash deposits are distinguished by phosphatized surfaces or extremely thin sand lenses. Single hearths (Fig. 20b) are notably less common. Charred organic material MF 4.1 is always overlain by ash deposits assigned to either MF 3.1 or 3.2. This association and the dominance of charcoal and fine charred organic material indicate that this MF is the product of incomplete combustion at the base of hearths (Mallol et al., 2017). The presence of shell and bone suggests that these materials were either deliberately placed in the fire as fuel or as discard or that they were already present on the surface when the fire was made and were thus incorporated into the base of the hearth (Mallol et al., 2013b). There is a minor biogenic input through the limited phosphatization of both ash and charcoal.

Shell The single deposit assigned to MF 5.1 shares similarities with that of MF 4.1 but contains significantly more shell. This deposit is interpreted as the base of a hearth, where the fire was made on top of a few shells, which were then covered by the charred organic material and ash that accumulated at the base of the hearth (Mallol et al., 2013b). The shell has fragmented in situ, although with little vertical displacement of fragments, suggesting that the deposit has been trampled (Villagran, 2019). Bird guano is the source of the secondary apatite which altered the ash in patches.

There are some similarities between the single MSU assigned to MF 5.2 and the three grouped into MF 5.3, but the former is far sandier and less ashy, and does not have the marked dip of the latter. MF 5.2 appears to be the product of the reworking and mixing of a midden-like deposit with sand and ash. The size and angularity of the shell suggests a mechanical process like trampling played at least some part in the formation of the deposit (Rentzel et al., 2017). MF 5.3 could potentially be the product of the mixing of shell midden layers with previously distinct ash and charred organic layers (either dumped material or reworked hearths) and geogenic lenses of sand and angular quartzite. Alternatively, it could represent the mixing of geogenic material into combined ash and shell midden layers. The shell in MF 5.3 is less fragmented than

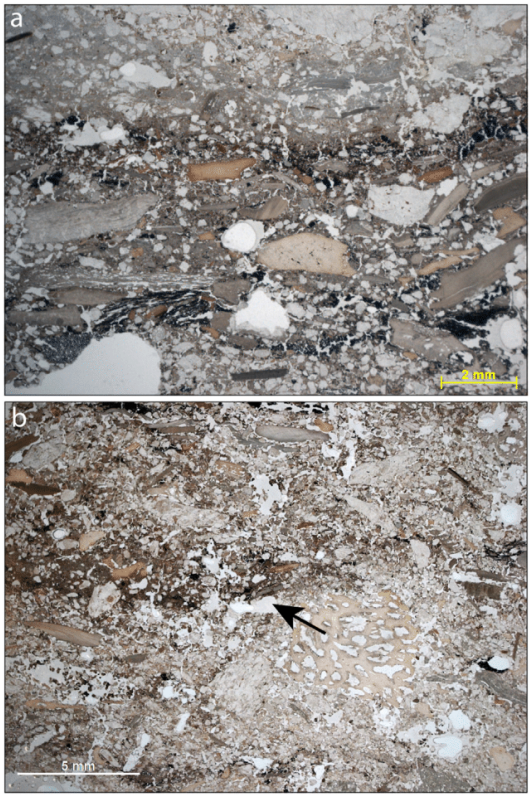

Figure 20. Stacked and single combustion features (both in plane-polarized light). a) Two hearths stacked directly one above the other in DCCP12. Note the thicker and more pronounced layers of carbonized organic material than those observed in the stacked hearths in Figure 18 (DCCP9). b) A single combustion feature at the base of DCCP11 within sediments of microfacies 1.2.1 The feature is probably the edge of a hearth but has been impacted by trampling.

in MF 5.2, but the visible in situ breakage and the mixing of material suggests some impact by trampling (Villagran, 2019). The secondary apatite which altered some of the ash in both MFs is biogenic in origin.

Calcite The extremely thin layer of mostly micritic calcite (MF 6.1) near the top of RSYS1 was formed through the precipitation of calcite from calcium-enriched water. Its clearly defined upper and lower boundaries and conformity to the underlying sediment suggest it was a thin crust, which formed on a stable surface, but its lateral extent beyond the slide is unknown as it is not visible to the naked eye in the profile. Speleothem and other forms of geogenic calcite are fairly common in other areas of KRM due to the dissolution of the calcite cement in the Geelhoutboom aeolianite by rainwater and the percolation of the resulting calcium-enriched water down through the quartzite host rock and into the various recesses that make up the complex (Butzer, 1982; Deacon and Geleijnse, 1988). The absence of clastic inclusions suggests that there was no clastic deposition in this location while the crust formed. The distinct accommodated planar void in areas where the calcite is no longer present (Fig. 15) indicates that the partial dissolution of the crust took place after the deposition of at least some overlying sediment. Therefore, it likely involved the movement of relatively acidic water through the deposit, perhaps as a result of guano breakdown.

4.2. Site formation in Cave 1B

The formation of each of the units/unit groups analyzed using micromorphology and μXRF is discussed in the following sections to explore general patterns in site-formation processes, including human behaviors, through time. Where appropriate, the micromorphology data are used to help interpret the macroscopic properties of deposits in the RS and DC, which were not included in the samples. The context of KRM 41815 is also considered.

The Middle Stone Age I in the RS deposits Due to the lack of microscale data, the formation of only a few of the most significant units in the unsampled portion of the RS is discussed here (see Fig. 21 and Table 3). The lowermost excavated unit in PP38, RSBR, is correlated with Layer 13a, which has previously been suggested to be the product of weathering during a hiatus (Singer and Wymer, 1982; Deacon and Geleijnse, 1988) and perhaps even a soil (Singer and Wymer, 1982:25). Surface stability in open-air archaeological contexts is typically associated with the pedogenic alteration of sediments resulting in the formation of soil horizons (Holliday et al., 2017). However, these horizons are very uncommon in caves and rockshelters, but a variety of diagenetic processes can weather deposits to different degrees during periods of surface exposure (Goldberg and Sherwood, 2006; Mallol and Mentzer, 2017; Mallol and Goldberg, 2017). The current exposure of RSBR is very limited, and the underlying deposit is not visible, but its macroscopic properties suggest greater diagenesis than in the sampled deposits. It does appear to represent a period of surface stability, but it cannot be considered a soil. The unit RSBCH (correlated with Layer 10) contains a relatively large proportion of anthropogenic materials, including dark lenses, which could be intact portions of charred deposits, in a relatively fine matrix (silty sand with some clay). This suggests that it could be the remains of a poorly preserved CP-like set of deposits. The clast-rich but artifact-poor RSDRU and RSYRU could reflect a period of relatively slow deposition or the winnowing of the deposit by water. The particularly clay-rich unit RSGBS2B could represent a period of surface exposure and weathering when the breakdown of material due to diagenetic processes increased the proportion of clay relative to other units (Farrand, 2001:555). The macroscopic properties of RSCP2 suggest it could be similar to RSCP1 (see below) but that the combustion features have been more heavily impacted by reworking and diagenesis.

The deposits in unit RSYBS, the lowest unit sampled for micromorphology (Fig. 4), are all primarily the product of geogenic deposition of shelly sand and quartzite (Fig. 9), but the inclusion of varying proportions of reworked ash and charcoal show that humans occupied Cave 1B during these periods and made fires within the shelter. The overlying RSCP1 is made up of several relatively poorly preserved in situ combustion features that have undergone mechanical reworking and minor chemical alteration. The properties of the MF 1.2.1 deposits in RSCP1T and the base of RSYS1 indicate a return to largely geogenic deposition with significant input of material from reworked combustion features. The rest of RSYS1 is overwhelmingly geogenic in character, with some biogenic inputs.

Macroscopically, there are some isolated artifacts and carbon-rich lenses (Table 3), but it appears that human occupation of Cave 1B was very limited at this time or took place in an entirely different area of the shelter with limited lateral reworking of anthropogenic material. The high density of autogenic quartzite (both sand- and gravel-sized) in the unit suggests a reduction in allogenic sedimentation, or more rapid breakdown of the host rock. However, the notable reduction in sand-sized shell fragments could be the result of partial dissolution of calcite in these deposits (e.g.,

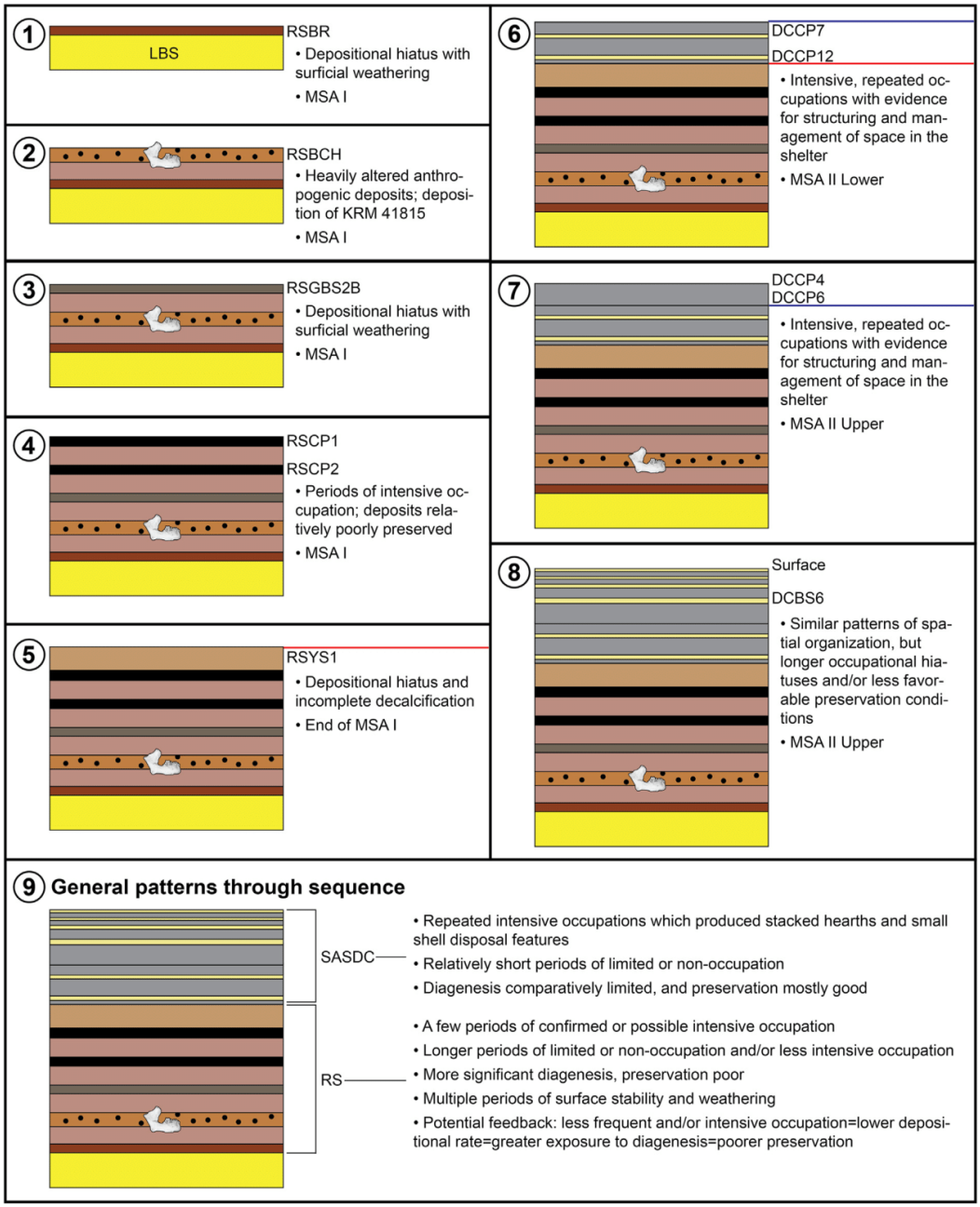

Figure 21. A simplified view (not to scale) of the proposed sequence of events in Cave 1B following the deposition of the Light Brown Sand (Panel 1), up to the deposition of the youngest preserved deposits (Panel 8). Only the most significant and/or informative deposits in the Rubble Sand Member are mentioned explicitly, but note the accumulation of other deposits between them. Panel 9 is a summary of the general patterns of anthropogenic site formation and diagenesis.

Goldberg, 2000), which would likely have removed any ash the deposits may have contained.

There were several short depositional hiatuses toward the end of RSYS1's formation. The thin calcite crust, overlying thin layer of quartzite and bone, and the incipient crust composed of secondary apatite nodules (Fig. 15) all indicate periods of surface stability in which clastic deposition ceased or slowed significantly for unknown periods of time. The resumption of deposition above the nodule layer corresponds with the transition to the MSA II–bearing DC deposits. These periods of surface stability could also be a factor

in the dissolution of shell fragments in the shelly sand and in the partial dissolution of the calcite crust. A time-gap between the deposits associated with the MSA I and II has previously been proposed across the site complex based on different unconformities or disconformities (Singer and Wymer, 1982; Deacon and Geleijnse, 1988).

The Middle Stone Age II in the DC deposits The micromorphology supports the macroscopic observation that the transition to the DC coincides with a marked increase in the preservation of anthropogenic deposits and features (Fig. 21). However, the preservation of any particular deposit can vary widely through the sampled sequence.

The basal unit group, DCCP12 (Fig. 4), is made up of two distinct phases (Fig. 10). The lower comprises deposits of MFs 1.2.1, 1.2.2, and 2.1, which are predominantly geogenic in nature but contain a relatively high proportion of reworked ash, charred organic material, and shell. This is likely due to lateral reworking of combustion features by trampling and indicates a resumption of more frequent and/or longer duration human occupation after the limited evidence for occupation in RSYS1. The upper portion of this unit group comprises alternating deposits of MFs 4.1 and 3.2, which are the remains of two hearths that appear to have undergone some reworking but are largely in situ. The ash-rich layers are very thin, and the lower of the two contains a relatively high density of shell and bone fragments. This suggests that there was either deliberate discard of shell and bone into the hearth or that distinct shell and ash layers have become mixed. The thinness of the ash could reflect reworking of some ash, compression due to trampling and the weight of overlying sediment, or even that the hearths each represent a single fire event and not multiple refirings (Karkanas 2021). The clear in situ fragmentation of roughly horizontal shell and bone (Fig. 16) is strongly indicative of trampling (Balbo et al., 2010; Villagran et al., 2011; Villagran, 2019), and this is interpreted as a trampled surface.

DCYS6 is strongly geogenic in character, mostly comprising shelly sand and quartzite. However, the presence of ash and charred organic material, the size of some of the shells in the unit, and a very thin ash lens all point to at least some human occupation which included making fires.

The DCCP11 unit group is characterized by a generally geogenic, but ash-rich, sediment with several distinct deposits of more concentrated anthropogenic material which thin out and end within the slide (Fig. 10). The ash at its base, which includes sand and bone fragments, could represent the edge of a hearth that has been reworked by trampling. The thin layer rich in carbonized material (MF 4.1) has no distinct ash layer over it, suggesting this material was removed by geogenic or anthropogenic processes. The most significant deposit is a wedge of ashy shell-dominated sediment (MF 5.1). This appears to represent the edge of a small, locally reworked shell disposal feature. As trampling is more likely at the edge of such a deposit, this could well be responsible for the shell fragmentation and the mixing of ash and sand into this feature, but it is also possible that some ash was deliberately discarded with the shell. The presence of two thin winnowed deposits (MF 2.1) above this feature suggest some localized water movement at the surface after its formation.

DCYS5 is absent from the thin sections, but comparing its field description to those of sampled deposits (Table 3) suggests that it is predominantly geogenic but with a significant component of ash and charred organic material from reworked combustion features, broadly comparable to MF 1.2.1. DCCP10 is also not represented in the thin sections, but a similar composition suggests it is probably similar to DCCP11 in containing layers of ash- and organic-rich sands similar to particularly silty MF 1.2.1 deposits and ashy deposits broadly similar to MF 3.2 (and perhaps 3.1).

Only a very small portion of DCYS4 appears in the thin sections (Fig. 11). This deposit is sandy but very rich in charred organic material and ash. As with many deposits of this type, it is very likely the product of the reworking of material from combustion features into otherwise largely geogenic sediment. The deformed apatite-rich lens at the top of this unit, seemingly an incipient crust, indicates a period of surface stability, followed by deformation of the sediment due to trampling.

DCCP9 is the thickest of the CP unit groups represented in the thin sections. The first few deposits are sloping layers of shell-rich ash with rounded quartzite pebbles (MF 5.3). It is possible that they are the product of the mixing of originally more distinct shell and ash deposits, or the reworking of a combined ash and shell midden. The size of the shell fragments, and evidence for in situ fragmentation, suggest trampling likely played a role in this mixing (Villagran, 2019). These deposits are overlain by two well-preserved hearths (MF 3.1), which include extremely thin layers of phosphatized ash, and lenses of sand, indicating that each of the hearths likely formed through multiple burning events. Apart from some alteration by secondary calcite and apatite, and very limited bioturbation by soil mesofauna, these deposits have seen little modification or disturbance. It is possible that at least some of the sand in the less preserved hearths in the sequence was originally in the form of similar lenses prior to mixing into the surrounding ash by trampling. The upper surface of this group of hearths represents a disconformity, which is locally unconformable. The ash at the surface is relatively highly phosphatized, in a band notably thicker than the laminae below, indicating a longer period of surface exposure, while depressions suggest localized erosion of ash. This unconformity/disconformity is overlain by a very ashy sand (MF 1.2.1) with some ash-dominated patches, which is capped by a thin ash lens. It seems to be the product of the reworking and mixing of anthropogenic and geogenic deposits. The overlying shelly and carbon-rich deposit (MF 5.1) appears to be the base of a hearth where the substrate included shells. The in situ fragmentation of the shells and their roughly horizontal orientation indicates trampling (Villagran, 2019), and this appears to represent a trampled surface. The preservation of relatively large charcoal fragments could indicate that burning took place following the trampling. The ash deposits above include some relatively large pieces of possibly burnt bone and shell and fairly big pieces of quartzite, some of which could be lithics. Alternating MSUs of more and less charred organic-rich ash suggest that these deposits may represent several hearths stacked on one another which were subsequently modified through the mixing of sand into the ash and resulting loss of stratigraphic detail. The overlying ash deposits contain significantly more quartzite and are obviously more geogenic in character than those below. Some pockets are similar to MF 1.2.1, suggesting far more significant reworking and mixing than in the hearths below. The in situ fragmentation of some shell near the top of this sequence could be the product of trampling. The uppermost deposit is a sandy deposit (MF 1.2.1) with some ash, charred material and shell that is predominantly geogenic, and transitional to the unit mentioned earlier.

DCYS3 is initially very strongly geogenic in nature, with some biogenic inputs, and has a similar density of autogenic quartzite to RSYS1 (MF 1.1). However, there is an increasing anthropogenic signature towards the top of this thin unit as ash and charred organic material fill some of the interstitial space between the sand and gravel (MF 1.2.1). This points to a period with no or extremely limited human occupation, followed by human occupation and reworking of combustion features. As with RSYS1, however, the

limited proportion of sand-sized shell in the lower part of DCYS3 could be due to post-depositional dissolution of calcite, which would also impact any ash that may have been in this deposit.

The basal MSU in the overlying DCCP8 unit group shows a lateral transition from potentially in situ, but locally reworked, ash to a sandier deposit with reworked ash and charred organic materials. This is very likely the edge of a combustion feature, where trampling and other human activities have dispersed and mixed these materials (e.g., Miller et al., 2013). This is followed by a very well-preserved hearth (MF 4.1, 3.1, and 3.2), which appears to have been formed by multiple fires based on the presence of distinct extremely thin lenses of sand and of phosphatized ash. The shell at the base of this hearth was trampled prior to the burning and represents a trampled surface, while some of the shell at the top of the hearth may have been pressed downward into the ash by trampling. Overlying this hearth is a succession of distinguishable, but less well-preserved hearths, with alternating charred material-rich (MF 4.1) and ash deposits (MF 3.2). The ash in the uppermost few hearths is relatively highly phosphatized, and there appears to have been an erosional event that truncated the top hearth. This suggests a hiatus with the ash being exposed on the surface for some time. The deposit lying on this sloping truncated surface is a mix of geogenic and anthropogenic materials, which includes a high proportion of relatively large quartzite (some of which are lithics; MF 2.2). It is possible that this represents localized colluvial deposition of mixed material, filling the cut below. The uppermost MSU in DCCP8 that is represented in the thin sections is an ash-dominated but mixed deposit, suggesting reworking of a combustion feature. Shell fragmentation and the apparent pressing of a shell into the sediment are indicative of trampling.

None of the deposits above DCCP8 have been sampled, but it is possible to make some broad interpretations based on the micromorphology and the macroscopic properties of the sampled and unsampled portions of the DC. The deposits appear fairly similar up to the top of DCCP4, but from the base of DCBS6 there is a shift towards thinner CP unit groups separated by thicker sandy units, which appear to contain a lower concentration of fine organic material and ash than most of the sandy units below. This could be due to longer occupational hiatuses, greater exposure of the shelter leading to less preservation of fine anthropogenic materials, more rapid deposition of sand, or a combination of these factors. The sandy unit excavated by Henderson (1990) in the squares to the west of PP38 contained a fairly high density of lithic artifacts and bone but no distinguishable combustion features or shell concentrations. This suggests that the sandy units through the sequence cannot automatically be assumed to represent hiatuses, but many could reflect limited preservation of anthropogenic features, rather than nonoccupation.

The CP and PCP units in the area excavation contained numerous anthropogenic features, including stacked hearths and small shell disposal features (Henderson 1990, 1992). The spatial organization of these features had a significant impact on the sedimentary properties of the deposits, concentrating ash, charred organic material, and shell in particular areas of the excavation. This is particularly evident in DCPCP, where numerous combustion features were concentrated in one area, and the surrounding sediment gradually lightens from black to brown, presumably due to a decrease in the quantity of charred organic material in the sediment further away from the combustion features. The concentration of combustion features and the presence of the small shell disposal features have both been interpreted as evidence for the organization of space within the shelter by the occupants, while the burnt shell is attributed to the cooking of shellfish (Henderson, 1992).

The sedimentary properties reported by Henderson (1990, 1992) suggest broadly similar formation processes for the uppermost CPs in the preserved sequence to those inferred for the CPs lower down in the DC. The spatial variation within the CPs is similar to those described in PP38 (Table 3), although the lateral variation in DCPCP appears to have been more extreme than was observed for any of the CPs in PP38.

Formation and preservation of anthropogenic features The "carbonaceous soil" reported in various layers of the original excavation by Singer and Wymer (1982:24–25) appears to be broadly comparable to the CPs defined by the Deacon team. The formation of the "carbonaceous soil" was never explicitly addressed by Singer and Wymer (1982). The bulk of the sediment in the CPs at KRM—dark silty sands around the distinct combustion features—has been argued to be the product of the burning of the inedible portions of plants, including geophytes, during food processing and cooking (Deacon, 1993, 1995). Direct evidence for the consumption of cooked geophytes at Klasies has been recovered from MSA I and HP deposits, suggesting a long history of this behavior at the site (Larbey et al., 2019).

Our micro-scale observations of the CP units indicate that lateral reworking of combustion features has resulted in the formation of deposits characterized by variably preserved combustion features (including hearths), and less common small shell disposal features, surrounded by sandier deposits rich in reworked ash, carbonized material, and other anthropogenic inclusions. This is most clearly visible in the thin sections in DCCP11 (Fig. 10) and at the base of DCCP8 (Fig. 11). These deposits represent repeated relatively intensive occupations of the shelter.

Trampling played an important role in reworking material around hearths to form the CPs. Evidence of trampling as a site formation process has been identified at almost every MSA cave or shelter site studied with micromorphology in South Africa, although its importance varies (Goldberg, 2000; Goldberg et al., 2009; Karkanas and Goldberg, 2010; Miller et al., 2013; Karkanas et al., 2015; Wadley et al., 2020; Haaland et al., 2021; Wurz et al., 2022). In contrast, the identification of trampled surfaces (e.g., Figs. 16 and 17) is far less common in the region, with previous published examples from only Sibudu Cave (Goldberg et al., 2009) and Diepkloof Rock Shelter (Miller et al., 2013). Most of the trampled surfaces in Cave 1B are characterized by in situ fragmentation of horizontally oriented shell, with some indication of compaction (Fig. 16). Similar trampling has been identified in Cave 1 (Wurz et al., 2022: fig. 5). These surfaces are most comparable to well-studied occurrences of trampling in shelly deposits at coastal sites in South America, which have broadly similar substrates to KRM (Balbo et al., 2010; Villagran et al., 2011; Villagran, 2019).

Anthropogenic deposits are uncommon in the RS (Fig. 6). Only two CPs were identified by the Deacon team, and smaller deposits of ash or charred material are rare (Table 3). The CPs in the RS are almost exclusively composed of dark silty sands rich in charred organic materials, with few or no macroscopically distinguishable ash deposits. Darker deposits lower down in the sequence could be poorly preserved occupational deposits (Singer and Wymer, 1982), with RSBR the most convincing example. Small shell disposal features are absent in the RS samples, and the limited presence of visible shell in the unsampled deposits (Table 3) also stand in contrast to the properties of the DC.

Shell midden deposits and distinct combustion features have been recorded in MSA I deposits in Cave 1 and 1A (Singer and Wymer 1982; Deacon and Geleijnse, 1988; Wurz et al., 2022). This raises the question of whether the pattern observed in the RS is a result of behavioral differences between these areas (e.g., Cave 1B being used for different activities, less frequently, or less intensively) or the product of diagenetic processes.

The association of parts of the MSA I with one or both MIS 5e sea-level highstands suggests that Cave 1B could have been more exposed to onshore winds at this time. In comparison, sea-level regression after the peak of MIS 5e (~120 ka) could have resulted in the formation of barrier dunes during the MSA II, which would have provided some protection for the site, as argued by Deacon (1995). Greater exposure to wind during the MSA I could have contributed to the destruction or alteration of deposits by eroding ash and fine burnt material from exposed combustion features and by blowing more rain into the shelter than would otherwise enter this area. Additionally, closer proximity of the shoreline to the site could increase the impacts of sea spray and the potential for the erosion of the outer areas of the shelter by storm waves. These factors could also have decreased the attractiveness of Cave 1B for occupation during the MSA I.

It is also possible that the unsampled RS deposits were more heavily impacted by the dissolution of guano—and resulting increase in the acidity of pore water—than the sampled units. This process can result in varying degrees of alteration or destruction of ash, shell, and bone depending on local conditions (e.g., Schiegl et al., 1996; Goldberg 2000; Weiner et al., 2002). There is evidence to suggest that these diagenetic processes have destroyed significant midden deposits and combustion features in areas of Cave 2 (Wurz et al., 2022). Surface stability during the observed hiatuses in the RS sequence would have increased the likelihood and impact of this process.

Anthropogenic depositional rates are higher than geogenic rates, but also more sporadic, so more intensive and/or frequent anthropogenic depositional events result in shorter exposure times for most deposits. As the observed diagenesis in Cave 1B all occurred at or near the surface, there would have been feedback between anthropogenic depositional rates (and thus, the nature of human occupation) and the likelihood of anthropogenic deposits being preserved well, or at all (Fig. 21). Therefore, it is very likely that the pattern observed in the RS is due to both greater diagenesis than observed in the DC, and comparatively limited and/or less intensive human occupation during the MSA I.

In stark contrast to the RS, anthropogenic features are numerous and well preserved in the DC deposits, making up a significant proportion of its thickness. Hearths are very common within the CPs, and most are stacked.

The presence of phosphatized surfaces and sand and quartzite lenses of varying thicknesses within stacked sequences or between groups of hearths within a single CP suggest that some CPs may have formed over the course of several distinct occupations with relatively short hiatuses between them (perhaps seasonal or even monthly visits). Stacked hearths representing multiple firings in a short period of time have previously been reported from the MSA I occupations in Cave 1 and the HP deposits in Cave 1A (Larbey et al., 2019).

The shell-rich MFs 5.2 and 5.3 share some similarities in composition and structure with reworked midden deposits across the rest of the site complex (Wurz et al., 2022). As these deposits in Cave 1B have extremely limited spatial extent and low thickness relative to their degree of compression when compared to the MSA I and II middens in Cave 1 and 1A, it is more appropriate to continue to describe them as shell disposal features, as suggested by Henderson (1992), rather than middens. However, the micromorphology suggests they are functionally the same thing—a specific place to discard shell (and perhaps also ash). The major difference is the size and thickness of the original feature and thus the intensity and/or frequency of their use for this function. Unfortunately, it is difficult to assess whether this is due to relatively limited consumption of shellfish in Cave 1B in comparison to the rest of KRM, the existence of an unidentified (or even destroyed) midden elsewhere in or near the shelter, or other behavioral and/or preservation factors.

The presence of stacked hearths and shell disposal features are both indicative of the organization of domestic space within the shelter during human occupations of Cave 1B. The behaviors involved in organizing and managing space in Stone Age contexts are among the multiple proxies used by archaeologists to understand the evolution of modern human cultural practices and cognitive abilities (Clark et al., 2022). Various expressions of such behaviors have been documented throughout the MSA and Middle Paleolithic (e.g., Deacon, 1995; Roebroeks and Villa, 2011; Wadley et al., 2011, 2020), with a general intensification of the organization and management of occupation sites and changes in the use of domestic spaces (Clark et al., 2022).

The stacked hearths and shell disposal features identified by Henderson (1992) in the upper portions of the MSA II indicate organization of space in the shelter late in this cultural phase, but our results show that this behavior took place in Cave 1B throughout the MSA II, almost certainly from before ~110 ka (based on the new dating of basal SAS deposits by Wurz et al., 2022).

Implications for the context of KRM 41815 The KRM 41815 mandible and the associated KRM 41820 condylar fragment were found next to the calcite block in Wymer's western profile (Singer and Wymer 1982:146). Their close proximity to the northern profile of PP38 (Fig. 1) means that the properties of RSBCH (Table 3) are likely very similar (or even identical) to the context from which they were recovered. As the conditions in Cave 1B are not conducive to the formation of speleothem, the calcite block almost certainly formed outside of the shelter. It is very likely a large piece of the tufa/phytokarren, which formed on the host rock above the complex.

The properties of RSBCH are suggestive of very poorly preserved occupation deposits, which may once have been similar to the CPs in the overlying deposits. The micromorphology of the CPs in the upper RS and in the DC points to both physical reworking and chemical diagenesis as factors influencing the preservation of anthropogenic deposits.

It is tempting to attribute the breakage of KRM 41815 to the impact of the block falling into the site, and the resulting deformation of deposits, but this event could predate the deposition of the specimen. Trampling and the accumulation of overlying deposits could also be responsible for the damage. Wind and water movement may also have contributed to physical reworking of finer materials within RSBCH.

The mandible has been described as “well-mineralized” (Singer and Wymer, 1982:146). Calcite appears to be the most likely mineral in this case, but no further information is available to confirm this. Observations from the sampled deposits suggest it is very likely that RSBCH has been impacted by the precipitation of secondary minerals (including calcite and apatite) and the dissolution of primary calcite.

Although KRM 41815 was not recovered from a well-preserved group of deposits, it was likely in either primary or near-primary (very limited movement from point of deposition) context. However, the impact of post-depositional processes has implications for correlating this deposit (and over- and underlying deposits) with units elsewhere in the site complex (which is already a difficult task for well-preserved anthropogenic units). Sampling and microanalysis of RSBCH and adjacent deposits would provide stronger evidence on which to evaluate the specific context and assess the accuracy of our inferences.

4.3. Stratigraphy

Deacon's excavation units in PP38 are far more constrained than Wymer's layers, typically representing single macroscopically distinguishable deposits, except where deposits are so thin or localized that it was not practical to excavate them separately (e.g., some dark charred layers underneath ash deposits). However, these excavation units were found to contain multiple MSUs (Figs. 9–11). DCCP11, which was excavated as a single unit, contains nine MSUs, and DCCP9, which comprises six grouped excavation units, was found to be made up of 20 MSUs. This information is important for interpreting material excavated from PP38 because, despite the high-resolution excavation approach, the assemblages recovered from the units cannot be considered the product of a single event, although the events forming some units may have taken place within a relatively short period of time.

Given the difference in resolution of excavation and recording and the limited descriptions provided by Wymer, it would never be possible to correlate the Wymer and Deacon stratigraphy with total precision, even without the lateral variation observed at multiple scales in many deposits in Cave 1B. However, the new correlations suggest that the transition between the RS and DC in PP38, and thus the MSA I and MSA II lower cultural phases, corresponds to the contact between Wymer's Layers 5 and 4, while the shift from the MSA II lower to the MSA II upper falls within Layer 3 (Table 4). This contrasts with Hilary Deacon's correlations between Wymer's layers and the PP38 units (published in Wurz, 2002), which placed these cultural changes at the boundaries between Layers 12 and 11 (MSA I to MSA II lower), and Layers 6 and 5 (MSA II lower to MSA II upper) respectively (Table 2). However, the labeling in the previously unpublished Figure 5 (from the Deacon archive) is in agreement with our correlation of Layer 10 with RSBCH. As no details of the data or reasoning used by Deacon are published (and none have been found among available unpublished materials), it is impossible to discuss why they differ so greatly from the revised correlations or the earlier assessment in the previously unpublished Figure 5 without resorting to conjecture. The implications of these new data for stratigraphic correlation with the rest of the complex and the age of the KRM 41815 mandible are discussed in the following sections.

Correlation with the rest of the complex Lithostratigraphic systems such as the one in use at KRM (Fig. 2) are based on the grouping or division of deposits based on their visual properties—including the color and composition of sediments. As a result, post-depositional alteration of deposits by chemical and physical processes (which likely varied spatially across the complex) is a significant complicating factor for making lithostratigraphic correlations. This is of particular concern for understanding how the mostly unsampled RS deposits relate to the MSA I deposits in Caves 1 and 1A.

Due to the rare use of the names RS and DC for the deposits in Cave 1B, the very limited and conflicting published information available on this part of the complex and the fact that the RS deposits are associated with MSA I lithics, it is easy to conflate the RS with the LBS (e.g., Morrissey et al., 2022). Given the culture-stratigraphic nature of the SAS Member (Morrissey et al., 2022), and the presence of MSA I lithic technology throughout the RS deposits (Wurz, 2002), it is clear that the RS cannot be included in the SAS as a submember as suggested by Deacon and Geleijnse (1988), Deacon and Schuurman (1992), and Henderson (1992) prior to the exclusive association of the SAS with the MSA II.

The RS is broadly similar to the LBS across KRM in that the nonanthropogenic deposits are predominantly yellowish brown or light brown sands (Deacon and Geleijnse, 1988:8). However, there are also notable differences based on published descriptions (Deacon and Geleijnse, 1988) and field observations of the LBS, and the RS and LBS in PP38 were considered to be distinct entities (Fig. 5). The lower RS deposits contain more silt and clay, and there are no published examples from the LBS of deposits such as the extremely clast-rich deposits at the top of the RS. Likewise, none of the deposits are similar enough to the 'RBS' to suggest a lithostratigraphic correlation with this entity as defined by Deacon and Geleijnse (1988:9). The fact that Deacon and Geleijnse (1988:11) recognized a change in sedimentary properties from the LBS to the RS does not mean this automatically correlates with the transition from the LBS to the 'RBS' in Cave 1, especially because the difference in properties could be due to post-depositional processes rather than a change in depositional processes.

Based on a review of past studies, Morrissey et al. (2022) raised the question of whether the RS should be included in the LBS as a submember, considered a member in its own right, or even placed into a more broadly (re)defined LBS. Due to our new observations of the differences in lithology, we argue that the RS deposits should not be grouped in with the LBS, the 'RBS', or the SAS and should instead be classified as the RS Member, a distinct stratigraphic entity associated with the MSA I (Fig. 2). Due to the differing contexts of Caves 1, 1A, and 1B, and the lack of dating, the RS Member's correlation with the LBS and 'RBS' members is uncertain.

The alternating deposits of sand and dense anthropogenic units preserved in the DC are broadly similar to the SAS Member in Cave 1A (Deacon and Geleijnse, 1988). However, they differ from the four SAS submembers in the Cave 1 Witness Baulk (Fig. 2), being sandier and more clearly stratified than the SASL and SASU, and in primary or near-primary context unlike the talus deposits in the SASW and SASR (Deacon and Geleijnse, 1988; Wurz et al., 2018).

The significant lithological diversity of the deposits assigned to the SAS means that it is more useful to consider it a cultural grouping of the MSA II–bearing deposits below the RF Member (Fig. 2) rather than a lithostratigraphic member similar to the more uniform LBS (Morrissey et al., 2022). Therefore, the best option appears to be to follow Henderson (1992:17) and retain the DC deposits within the SAS as a submember. Following the established naming convention but also retaining the full abbreviation to avoid confusion, the submember is designated as the SASDC (Fig. 2).

The SASDC presents a challenge from a lithostratigraphic perspective. The deposits are clearly distinguishable from the underlying RS Member due to the presence of dense accumulations of anthropogenic materials and features. However, there are notable similarities in the properties of the predominantly geogenic units in the upper RS and the SASDC. Distinguishing this boundary could be significantly more difficult in currently unexcavated areas of Cave 1B. Given the nature of the CPs, the properties of the RS and SASDC would only be consistent across the shelter if the same behaviors were happening (or not happening) across the extent of the site throughout the periods of occupation, which is unlikely. This is an inherent problem with the use of anthropogenic deposits as defining characteristics of lithostratigraphic groupings. Spatial variation in preservation could also have a significant impact, such as that observed in Cave 2 (Wurz et al., 2022). It is possible that the SASDC has been heavily impacted by dissolution and phosphatization elsewhere in the shelter or that the MSA I occupations are better preserved in other areas. If the distinct pattern in PP38 were not present in other excavations, the use of lithic techno–typological analysis to determine cultural stratigraphy would become even more important.

Implications for the age of KRM 41815 Being able to confidently associate KRM 41815 with the MSA I is an important step given that it has variously been assigned to the MSA I and the MSA II in different publications for several decades (e.g., Deacon and Geleijnse, 1988; Deacon, 2008; Grine et al., 2017b, 2021, 2023).

Whenever the mandible has been assigned to the MSA I previously, it has been considered contemporaneous with Layer 37/the 'RBS' Member. This is due in large part to the relative dating conducted by Goede and Hitchman (1987), which suggested a similar age for Layer 10 and Layer 37. They noted significant potential for variation in uranium enrichment, which could skew the ages of samples, but did not attempt to make corrections for this variation. Given the potential for differences in depositional and post-depositional processes between Cave 1 and Cave 1B, this correlation is particularly likely to have been affected by this problem.

As Layer 10 is relatively deep within the RS and the only evidence for a direct correlation with the 'RBS' is not ironclad, the possibility that it could correlate with part of the LBS in Caves 1 and 1A rather than the 'RBS' must be considered. It must also be noted that because depositional rates in different areas of the site are not well understood, and truncation of the LBS has been reported in parts of the site (Deacon and Geleijnse, 1988), depth cannot be assumed to be a reliable indicator of relative age. The fact that the LBS, 'RBS', and RS are all MSA I–bearing (Wurz 2002) further complicates correlation.

KRM 41815 (and the missing KRM 41820) is very broadly contemporaneous with six confirmed human fossil specimens which have also been associated with the MSA I (Grine et al., 2017b). KRM 24396 (SAM-AP 6297) was excavated from Layer 38 in Cave 1 but was not analyzed by Singer and Wymer (1982). It was subsequently identified as a cranial vault fragment, perhaps parietal or supraoccipital (Grine et al., 2017b). It is the only confirmed human specimen from 27 cranial vault pieces from Layer 38, which could not be located by Ronald Singer when he analyzed the human fossil assemblage (Singer and Wymer, 1982: table 8.1; Grine et al., 2017b). Hilary Deacon subsequently recovered two maxillary fragments from shell midden deposits in the LBS Member at the Cave 1/1A boundary (Rightmire and Deacon, 1991). Measurements of these fragments revealed a greater similarity to Holocene-comparative specimens than to a sample of archaic or early modern *H. sapiens* specimens (Bräuer et al., 1992). The size difference between the two maxillae has also been interpreted as evidence for sexual dimorphism (Rightmire and Deacon, 1991). The excavation of Layer 37 in Cave 1 yielded three cranial vault fragments: KRM 26909 (SAM-AP 6105), KRM 26910, and KRM 27070 (SAM-AP 6106) (Singer and Wymer, 1982). The first specimen is most likely a parietal fragment, the second was never analyzed, and the third is also considered to be a parietal (Singer and Wymer, 1982; Grine et al., 2017b).

The MSA I has been dated using several different absolute and relative dating techniques, but the results require careful interpretation. Samples from speleothem associated with the base and top of the LBS in Cave 1, but not directly associated with archaeological deposit at the time of sampling, were dated using uranium thorium (U–Th) but yielded contradictory ages, with the results suggesting that the LBS is older than 110 ka in one case (Deacon et al., 1988) but younger than ~109 ka in the other (Vogel, 2001). These dates were reported with extremely limited contextual information (none in the case of Deacon et al., 1988), making it practically impossible to independently assess how they relate to the LBS deposits or to each other (see also Wurz et al., 2022). Vogel (2001) did not discuss the discrepancy or even mention the previous publication of a U–Th date. This is particularly problematic, given that the two results are in direct opposition.

A sediment sample collected from roughly halfway up the LBS Member deposits at the Cave 1/1A boundary yielded a result ranging widely from ~119 ka to ~94 ka based on a combination of thermoluminescence and optically stimulated luminescence dating (Feathers 2002). Feathers (2002:178) noted significant challenges for estimating radioactive dose rates, which are vital for interpreting luminescence results to produce age estimates. He also suggested that the true age of the sample was more likely to fall within the older end of the range produced (Feathers, 2002:191).

Aspartic acid racemization (AAR) dating of bone from Layers 37 and 38 in Cave 1 produced ages of 90 ka and 110 ka, respectively (Bada and Deems, 1975). These ages were estimated using a calibration developed by AAR-dating a bone from ^{14}C-dated Terminal Pleistocene deposits at Nelson Bay Cave, roughly ~90 km west of KRM. It was assumed that the similar climate would mean that bone at both sites would have been exposed to similar temperatures and would thus have experienced the same rate of racemization since their deposition. This is problematic, given that there was significant climatic variation between the start of the Late Pleistocene and the deposition of the bone used in the calibration at ~17 ka (Thackeray, 1992; Blome et al., 2012; Loftus et al., 2017; Reynard, 2021). Since the publication of these results, a number of challenges have been identified with the use of AAR dating of bone in archaeological contexts, particularly for older studies conducted with less sophisticated equipment or relying on ^{14}C calibrations produced prior to the introduction of accelerator mass spectrometry (Thackeray, 1992; Miller et al., 1999; Moini et al., 2013). There is even evidence to suggest that the species of animal is a factor in the rate of racemization of the bone (Moini et al., 2013). Concerns over the uncritical use of these dates at KRM were first raised by Anne Thackeray (1992:403), but there has been little other engagement with these issues.

The results of oxygen isotope analysis of shell from the LBS in Cave 1, the Cave 1/1A boundary, and the RS in Cave 1B were used to provide a relative age estimate based on the comparison of these values to the isotopic characteristics of dated marine cores (Shackleton, 1982; Deacon et al., 1988). They were argued to best match MIS 5e, suggesting an age range of between 130 ka and 115 ka for the shells. No data were provided for where within Wymer's layers 38 (Cave 1) and 12 (Cave 1B), the dated shell was collected, and only a single shell was dated per layer (Shackleton, 1982). Deacon et al. (1988) provided no data and no detail on the number of shells they dated or from where within the LBS they were recovered, but this information was eventually published by Thackeray (2018).

Recent results from U–Th dating of well-contextualized speleothems indicate that the basal MSA II–bearing deposits in the SAS in Cave 1 accumulated before 110 ka (Wurz et al., 2022). The speleothems were carefully sampled to date the oldest part of each and thus, provide the age at which speleothem formation began following the deposition of the basal unit in the SASL submember. This means that both the 'RBS' and LBS must predate 110 ka, and perhaps significantly so, given that the maximum age of the SASL is unknown. This is supported by a recent faunal study, which found that the environmental signal derived from the MSA I faunal assemblages points to conditions more akin to the MIS 6 glacial (188 ka to 130 ka) than the interglacial conditions associated with MIS 5e (Reynard and Wurz, 2020).

On the balance of evidence and considering the issues raised with the published absolute dates for the MSA I, KRM 41815 must predate 110 ka, and its age likely falls within early MIS 5e or MIS 6. KRM 41815 has the most developed chin of the mandibles recovered from KRM (Rightmire and Deacon, 1991). As the other specimens are from the MSA II, with ages perhaps as young as ~85 ka for some (Vogel, 2001), the unambiguous association of this specimen with the MSA I adds greater support to Grine et al.'s (2021:4) observation that "there seems to be a counterintuitive temporal trend for chin development" in the KRM assemblage. A clearer age for KRM 41815 would provide greater context to this pattern. Dating of well-contextualized U–Th samples is needed to clarify the age of the MSA I in the 'RBS' and LBS Members in Cave 1 and to

allow extrapolation of these dates to other areas of the complex, which lack in situ speleothem, including the RS Member. The lack of evidence for bioturbation suggests that luminescence dating could be an option for obtaining direct dates for the Cave 1B sequence, with due regard for potential challenges in estimating dose rates (see Feathers, 2002).

5. Conclusions

The multiscale data presented here provide greater insight into the stratigraphy and formation of the deposits in Cave 1B than previously published information allows. A range of anthropogenic, geogenic, and biogenic site-formation processes were identified in the PP38 sequence, with implications for understanding human behavior in Cave 1B and for making stratigraphic correlations with the rest of the Klasies complex. The stacked hearths in the well-preserved CPs within the SASDC show repeated use of the site over short periods of time, with clear spatial organization of activities. The small shell disposal features also reflect management of space. It appears that roughly the same degree of spatial organization and management was repeated during different periods of occupation for the duration of the MSA II/Mossel Bay cultural phase. Anthropogenic deposits are poorly preserved in the RS Member, due at least in part to the precipitation of secondary apatite. Multiple depositional hiatuses and resulting periods of surface stability and weathering likely contributed to this pattern. However, occupational frequency and/or intensity may also have been lower during the MSA I. Micromorphology sampling of more of the RS sequence would help to understand variation in site formation during the MSA I, would provide better context to KRM 41815, and could aid in identifying the impacts of post-depositional processes on the stratigraphy of the RS.

Several significant conclusions have been reached regarding the stratigraphy of PP38 and its relationships to the rest of the main site complex. The MSA I–bearing RS deposits correlate with Wymer's Layers 13a to 5, while the DC deposits, associated with the MSA II, are equivalent to Layers 4 to 1. The RS deposits should be considered a distinct lithological member and not a submember of the SAS or LBS Members. However, it is appropriate to retain the DC deposits as a submember of the SAS Member, designated as the SASDC. The cultural stratigraphic phases determined through lithic technotypologies remain the only means of making secure (but broad) temporal correlations between Cave 1B and the rest of the complex.

Finally, the revised stratigraphic correlations show that the KRM 41815/SAM-AP 6222 human mandible recovered from Wymer's Layer 10 is clearly associated with the MSA I cultural phase, and not the MSA II. However, it is not possible to definitively correlate Layer 10 with either the LBS or the 'RBS' in Cave 1, preventing a more secure determination of whether the mandible dates to an earlier or later phase of the MSA I. While this specimen definitely predates the ~110 ka speleothem within the SASL submember, the lower limit for its age is unclear, with the MSA I potentially extending back into MIS 6. Given that the mandible is among the most morphologically modern specimens recovered from Klasies, with a relatively strongly developed chin, being able to confidently associate it with the oldest cultural phase at the complex and a potential age of MIS 6/early MIS 5 is significant.

Acknowledgments

The authors wish to acknowledge the use of photographs and a profile drawing produced by the late Hilary Deacon and his excavation teams. Another of their profile drawings was redrawn digitally by Liezl van Pletzen-Vos. The support of GENUS (DSI-NRF Centre of Excellence in Palaeosciences, UID 86073 to P. Morrissey, and Grant 86073 to S. Wurz) toward this research is hereby acknowledged. The authors also wish to acknowledge the Palaeontological Scientific Trust (PAST) for a fieldwork grant and the Baden-Württemberg Ministerium für Wissenschaft, Forschung und Kunst for funding a research fellowship to P. Morrissey to facilitate the micromorphological analysis. Funding for the processing of the micromorphology samples was provided by a Baden-Württemberg Stiftung Elitepostdoc grant to S. Mentzer. Opinions expressed and conclusions arrived at are those of the authors and are not necessarily to be attributed to any of these funders. We thank three anonymous reviewers, Associate Editor Chris Campisano, and Co-Editor-in-Chief Andrea Taylor for comments which led to the improvement of this manuscript.

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CHAPTER 5. SUBMITTED PAPER #3

Thesis pages: 129–209

Morrissey, P., Wurz, S, Ligouis, B, & Mentzer, S.M. Submitted to **Geoarchaeology** (page numbers below are thesis page numbers)

Burning, cleaning, dumping and dissolution: insights into the role of human behaviour and diagenesis in the formation and stratigraphy of pre-110 000-year-old MSA l deposits in Cave 1, Klasies River Main site, South Africa

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Burning, cleaning, dumping and dissolution: insights into the role of human behaviour and diagenesis in the formation and stratigraphy of pre-110 000-year-old MSA I deposits in Cave 1, Klasies River Main site, South Africa

Peter Morrissey [a,*], Sarah Wurz [a,b], Bertrand Ligouis [c,d], Susan M. Mentzer [c]

[a] School of Geography, Archaeology and Environmental Studies, University of the Witwatersrand, Johannesburg, South Africa

[b] SFF Centre for Early Sapiens Behaviour (SapienCE), University of Bergen, Bergen, Norway

[c] Senckenberg Centre for Human Evolution and Palaeoenvironment, Institute for Archaeological Sciences, Department of Geosciences, Eberhard Karls Universität Tübingen, Tübingen, Germany

[d] Laboratory for Applied Organic Petrology (LAOP), Tübingen, Germany

*Corresponding author: Peter.Morrissey@students.wits.ac.za

Abstract

Understanding the formation and stratigraphy of sequences in southern African Middle Stone Age (MSA) sites is vital for contextualising evidence for the evolution of modern human behaviours and cognition. Deposits at these sites often have complex formation histories, typically involving a range of anthropogenic, geogenic and biogenic depositional and post-depositional processes, and micro-laminated deposits are common. Consequently, archaeological micromorphology and related micro-analyses are now routinely a major component of MSA geoarchaeological research in

the region. In the past few decades, microscale studies of the formation of anthropogenic features and deposits at MSA sites have begun to provide important behavioural information, including evidence for varying occupational intensities and the structuring and maintenance of living spaces. Here, a microscale geoarchaeological approach is applied to deposits dating to the MSA I lithic cultural phase (>110 ka) in the Cave 1 Witness Baulk. The results show that humans played a considerable role in site formation and that subsequent diagenesis affected the guano, charcoal, ash, and shell, with particular impact on the carbonates which were variably dissolved, altered, or recrystallised. This latter process helped to preserve ash through reduced dissolution potential. Spatial and temporal patterns in these factors influence the macroscopic properties of the deposits in any particular area, with significant implications for the correlation of extant deposits across areas excavated at low resolution during the 1960s. Different, variably preserved, anthropogenic features and deposits were found to make up a significant proportion of the deposits. Inferred behaviours range from repeated long-term low intensity use of individual stacked hearths through to the formation of dumped deposits (including shell middens) due to repeated hearth maintenance and patterned discard of food waste during more intensive occupations. Differences in occupational intensity and frequency both within and between the two recognised MSA I members could indicate adaptation to changing conditions as temperatures and sea levels fluctuated between late Marine Isotope Stage 6 and the end of Marine Isotope Stage 5e, but changes in geogenic depositional rates over the same period could skew our perception of occupational frequency. The current limited and low-resolution dating evidence prevents correlation with any specific event/s which might have affected behaviour and/or depositional rates.

Keywords

Klasies River; Middle Stone Age; Archaeological micromorphology; Site formation processes; Diagenesis; Combustion features

1. INTRODUCTION

Klasies River Main site (KRM), on South Africa's southern Cape coast (Figure 1), is well known for its Late Pleistocene deposits, which have yielded important *Homo sapiens* fossils, large informative Middle Stone Age (MSA) archaeological assemblages, and significant palaeoenvironmental datasets (Singer & Wymer, 1982; Deacon & Geleijnse, 1988; Deacon, 1989; Grine et al., 2017; Wurz, 2023). Evidence from KRM has played an important role in the characterisation and contextualisation of MSA human behaviour during a significant period for understanding cognitive evolution (Deacon, 1995; McBrearty & Brooks, 2000; Wadley, 2015; Scerri & Will, 2023). The site complex, comprising five closely associated caves and rockshelters, has seen extensive fieldwork in three phases: 1967-1968 (Singer & Wymer, 1982), 1984-1995 (Deacon, 1995), and 2013-present (Wurz et al., 2018, 2022). Scales of excavation, recording and interpretation have varied, with implications for understanding stratigraphy across the site complex (Morrissey et al., 2022).

All three phases of investigation have included geoarchaeological research. Both the initial study and Deacon's work were based on macroscopic field descriptions and bulk sample analysis, with the former particularly focused on reconstructing environmental conditions (Butzer, 1982) and the latter placing greater emphasis on the impacts of site formation processes on human fossils and archaeological assemblages (Deacon & Geleijnse, 1988; Deacon, 2008). The second phase also resulted in behavioural interpretations of some anthropogenic features (Henderson, 1992; Deacon, 1993, 1995). The on-going Wurz research programme coincided with a rapid increase in the application of archaeological micromorphology and related micro-analyses at MSA sites in southern Africa (e.g., Miller et al., 2013, 2016; Karkanas et al., 2015, 2021; Haaland et al., 2017, 2021). Micromorphology, and integrated organic petrology, micro-x-ray-fluorescence (μXRF), and micro-Fourier transform infrared spectroscopy (μFTIR) analysis, have been applied to different areas of the KRM complex (Larbey et al., 2019; Wurz et al., 2022; Morrissey et al., 2023). The results provide detailed information on the formation histories of the sampled deposits, including insight into diagenesis and evidence for a range of human behaviours.

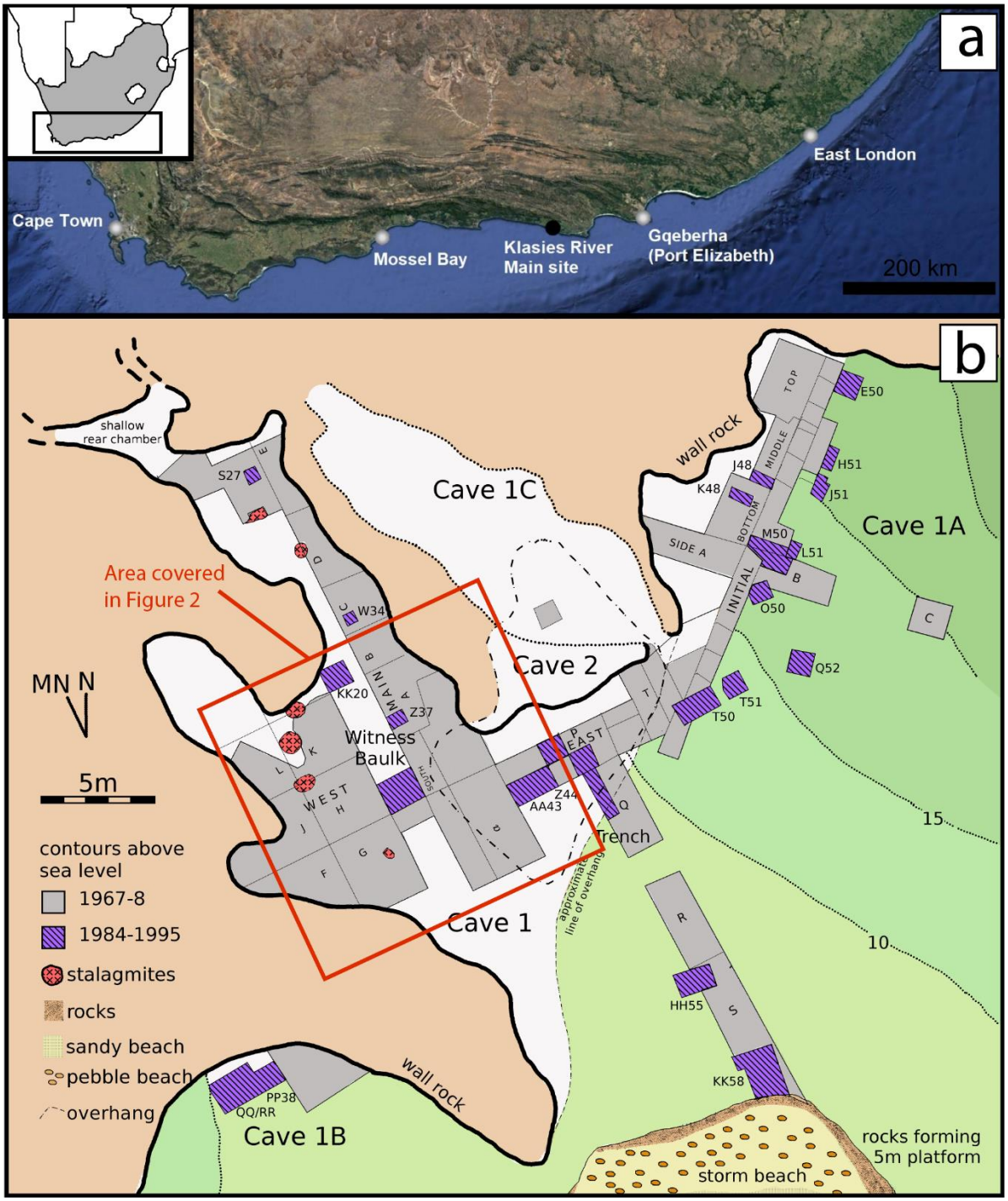

Figure 1. a) The location of Klasies River Main site along South Africa's southern Cape coast. b) A map of the Klasies River Main site complex (after Wurz et al., 2018). See Figure 2 for a more detailed view of Cave 1, including the locations of samples used in this study.

This study focuses on deposits associated with the MSA I (Figure 3), the oldest lithic cultural phase (Singer & Wymer, 1982; Wurz, 2002). They are currently exposed in Caves 1, 1/1A, and 1B and contain lithic technology characterised by the production of elongated, relatively thin curved blades and points. The technology was geared towards thinning platforms at the dorsal surface through step flaking and rubbing,

resulting in significantly different platform to length ratios of points and blades in this industry compared to the overlying MSA II or Mossel Bay technocomplex (Wurz et al., 2003). Associated human remains include skull fragments from Cave 1, two maxillary fragments from Cave 1/1A and the mandible KRM 41815 from Cave 1B (Grine et al., 2017). Anthropogenic features are poorly preserved in Cave 1B (Morrissey et al., 2023), but preservation is far better in Cave 1 (Deacon & Geleijnse, 1988; Larbey et al., 2019; Wurz et al., 2022).

Published microscale observations for Cave 1 (Larbey et al., 2019; Wurz et al., 2022) come from samples collected from the southern end of the Witness Baulk and the Cave 1/1A boundary (Figure 2). These studies focused on human behaviours involved in forming a few anthropogenic features and subsequent impacts of post-depositional processes. The limited microscale information on geogenic deposits in Cave 1 means that there is a significant bias towards using macroscale data to interpret their formation histories. However, these descriptions and interpretations are generalised (Singer & Wymer, 1982; Butzer, 1982; Deacon & Geleijnse, 1988), and do not address spatial variation in sedimentary properties observed in the field.

Here, we interpret the formation of MSA I deposits deeper into Cave 1, exposed on the western and eastern faces of the Witness Baulk (Figure 2). Our goals are to provide greater insight into geogenic deposition in the centre of Cave 1, to broaden the understanding of anthropogenic site formation processes during the MSA I, and to determine the nature, extent, and impacts of diagenesis on the studied deposits.

2. SITE CONTEXT

Cave 1 extends roughly 25 m into the quartzite cliff. It is ~10 m wide at its mouth and ~6 m above mean sea level at its lowest point. There is no distinct boundary with Cave 1A, an overhang immediately to the east, but Cave 1B, to the southwest, is physically separated by the bedrock.

The quartzite cliff is overlain by aeolianites which have undergone varying degrees of weathering and pedogenesis and are the primary source of secondary calcite (Butzer, 1982; Deacon & Geleijnse, 1988). Calcium-enriched groundwater reaches Cave 1 via

joints and cracks in the otherwise impervious quartzite. The water forms speleothems inside the cave, and within the joints and cracks. This creates the potential for the movement of drip locations if routes fill with precipitated calcite or are re-opened by relatively acidic groundwater (Butzer, 1982).

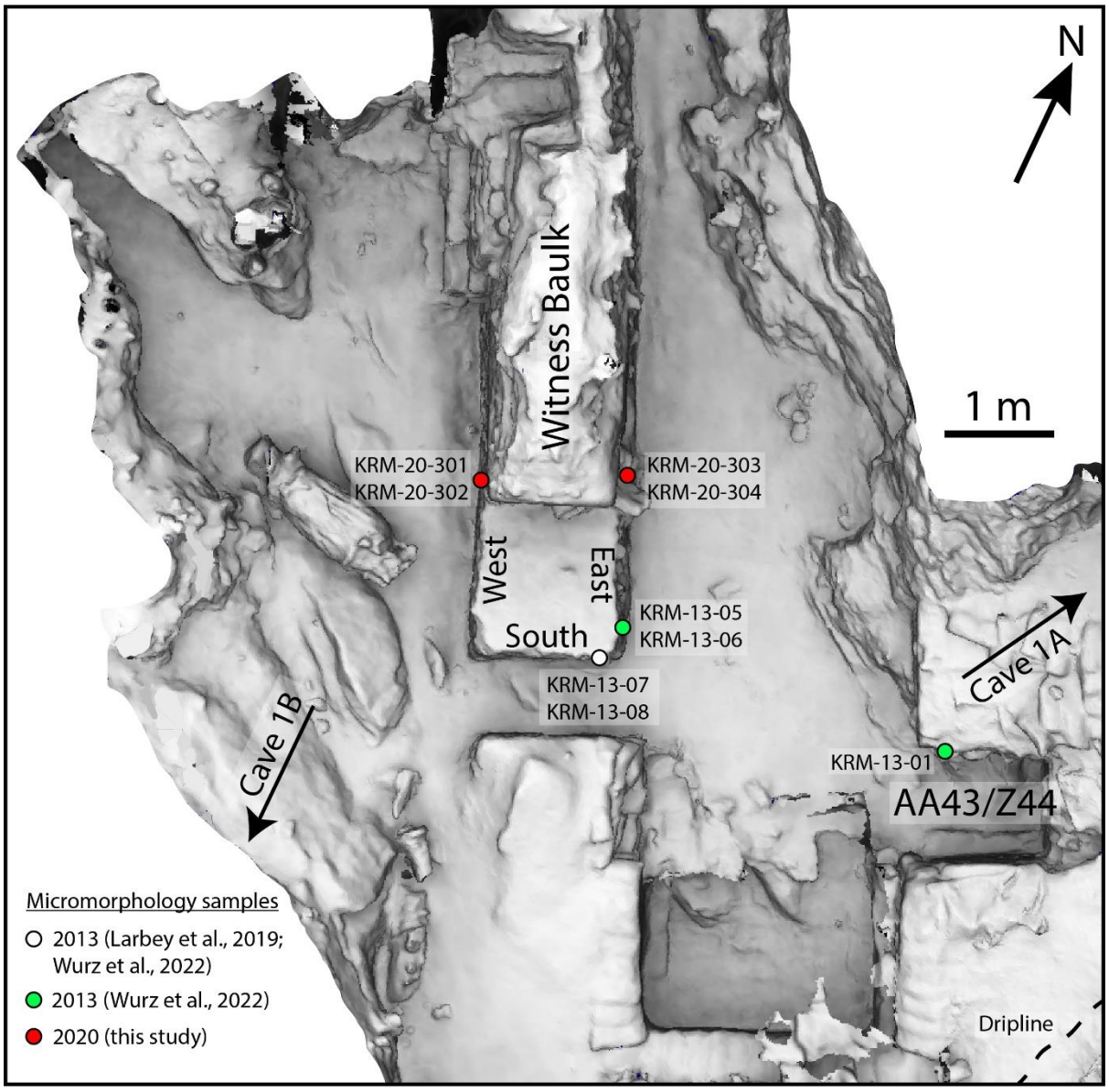

Figure 2. Cave 1 at Klasies River Main site with the locations of micromorphology samples collected from the MSA I deposits in the Witness Baulk and the AA43/Z44 excavation at the Cave 1/1A boundary (Imagery from 3D scanning by the Zamani Project). See Figure 1 for contextualisation of this view within the site complex. Unlike Cave 1A, Cave 1B is separated from Cave 1 by the bedrock. Note that only KRM-13-07 was analysed by Larbey et al. (2019). Most of the cave was excavated to bedrock (Singer & Wymer, 1982), with subsequent higher-resolution excavations in AA43/Z44 and (on-going) the Witness Baulk (Wurz et al., 2018).

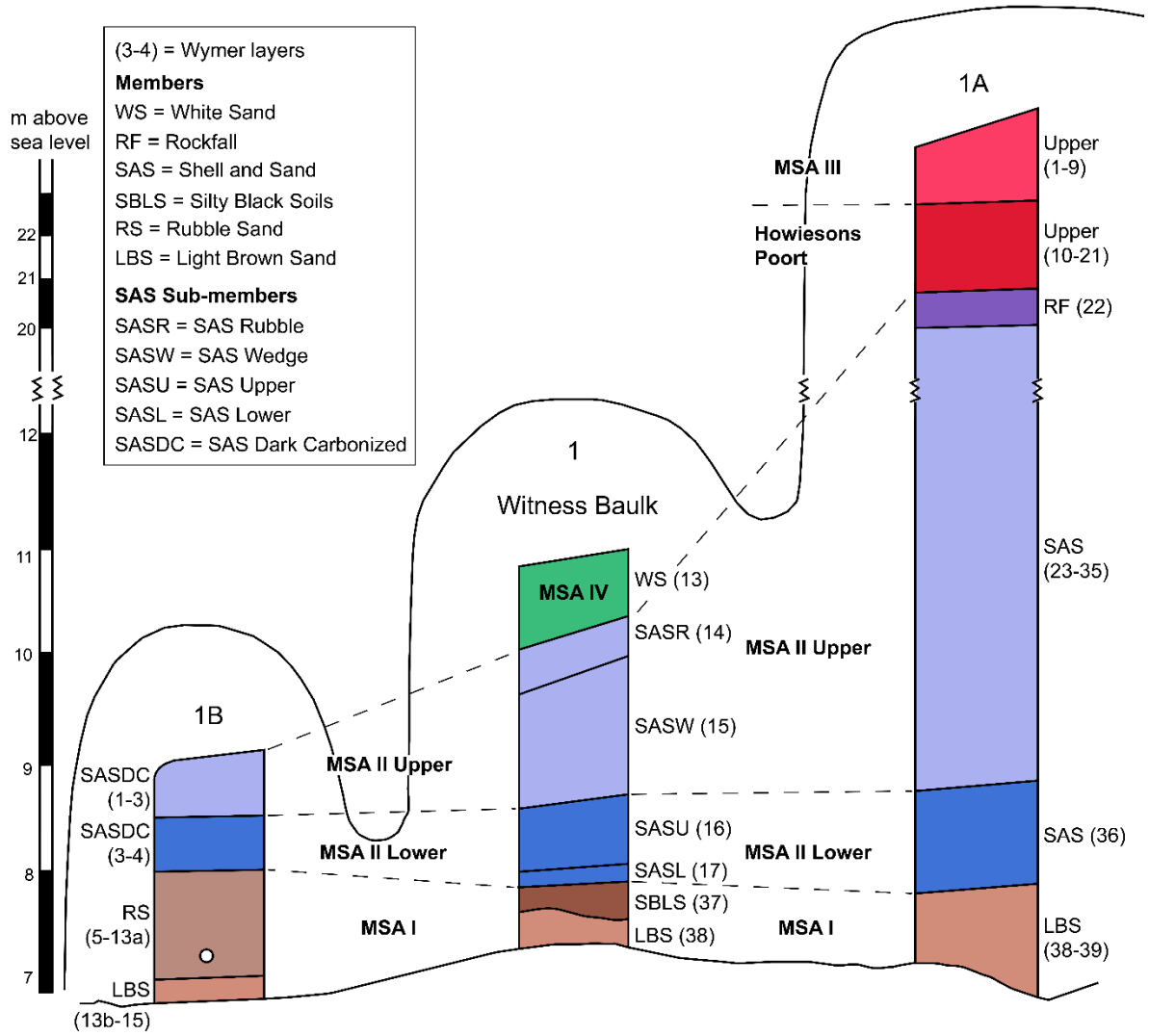

Figure 3. The generalised lithostratigraphy and cultural stratigraphy of Caves 1, 1A, and 1B at Klasies River Main site (after Morrissey et al., 2023). Cave 2 is not shown but is above Cave 1 and contains deposits assigned to the Rockfall and Upper Members.

In Cave 1, the MSA I is associated with two published lithostratigraphic members. The Light Brown Sand (LBS) Member (Layer 38) lies on either bedrock or basal gravel and is characterised by light yellowish-brown sands with distinct ash and/or shell layers (Singer & Wymer, 1982; Deacon & Geleijnse, 1988). It is overlain (sometimes unconformably) by darker sediments which were excavated as Layer 37 by Singer and Wymer (1982) and placed into the Rubble Brown Sand (RBS) Member by Deacon and Geleijnse (1988). The RBS is more diverse and complex than its basic and very localised description suggests (Morrissey et al., 2022), and is currently being re-evaluated. The excavated portion of these deposits is now named the Silty Black Soils (SBLS) (Wurz et al., 2022).

The MSA I has been associated with MIS 5e and 5d (130 ka – 105 ka) based on both absolute and relative dating (see reviews in Grine et al., 2017; Morrissey et al., 2022). However, a range of contextual and/or methodological concerns have been raised over some dates (Thackeray, 1992; Morrissey et al., 2023). Recent well-contextualised uranium-thorium dates indicate that all the MSA I deposits in Cave 1 pre-date 110 ka, with the lower age limit of the MSA I potentially falling within MIS 6 (188 ka – 130 ka) (Reynard & Wurz, 2020; Wurz et al., 2022; Morrissey et al., 2023). At Cave 5, ~2 km from KRM, the MSA I has a single luminescence date of 137.4 ± 13.6 ka (Feathers, 2002). Future dating may help to constrain the lower age limit.

3. MATERIALS AND METHODOLOGY

Four micromorphology blocks were collected from the Witness Baulk in 2020. Two each were taken in columns along the western and eastern profiles (Figure 2) sampling the MSA I-bearing deposits to the north of the on-going excavation. At the western location, KRM-20-302 (hereafter referred to as 302) includes the full vertical extent of the LBS and part of the SBLS, while the overlying KRM-20-301 (301) contains most of the remainder of the SBLS (Figure 4a). At the eastern location, KRM-20-304 (304) samples the LBS, and the overlying KRM-20-303 (303) includes the upper portion of the LBS and much of the SBLS (Figure 4b).

The blocks were prepared and processed (see Wurz et al., 2022, p. 7) at the University of Tübingen for the purposes of micromorphology and organic petrology. Eight thin sections were produced – two from each sample, with the upper designated ‘A’ and the lower ‘B’. They were ground relatively thick, ~50 µm rather than 30 µm, due to the ease with which softer materials could be inadvertently ground out while grinding harder materials. Additionally, one chip used in the production of a thin section underwent a dry fine polishing (without lubricants).

The thin sections were analysed with a petrographic microscope using plane- and cross-polarised light (PPL and XPL), and the descriptive terminology of Stoops (2021). A Bruker M4 Tornado µXRF analyser allowed the production of elemental maps (Mentzer, 2017). Analytical parameters matched those in previous KRM studies (Wurz et al., 2022, p. 7). Distinct microstratigraphic units (MSUs) were identified and

described based on the micromorphology observations and elemental maps. The microfacies approach (Courty, 2001) was used to group and interpret MSUs with similar properties.

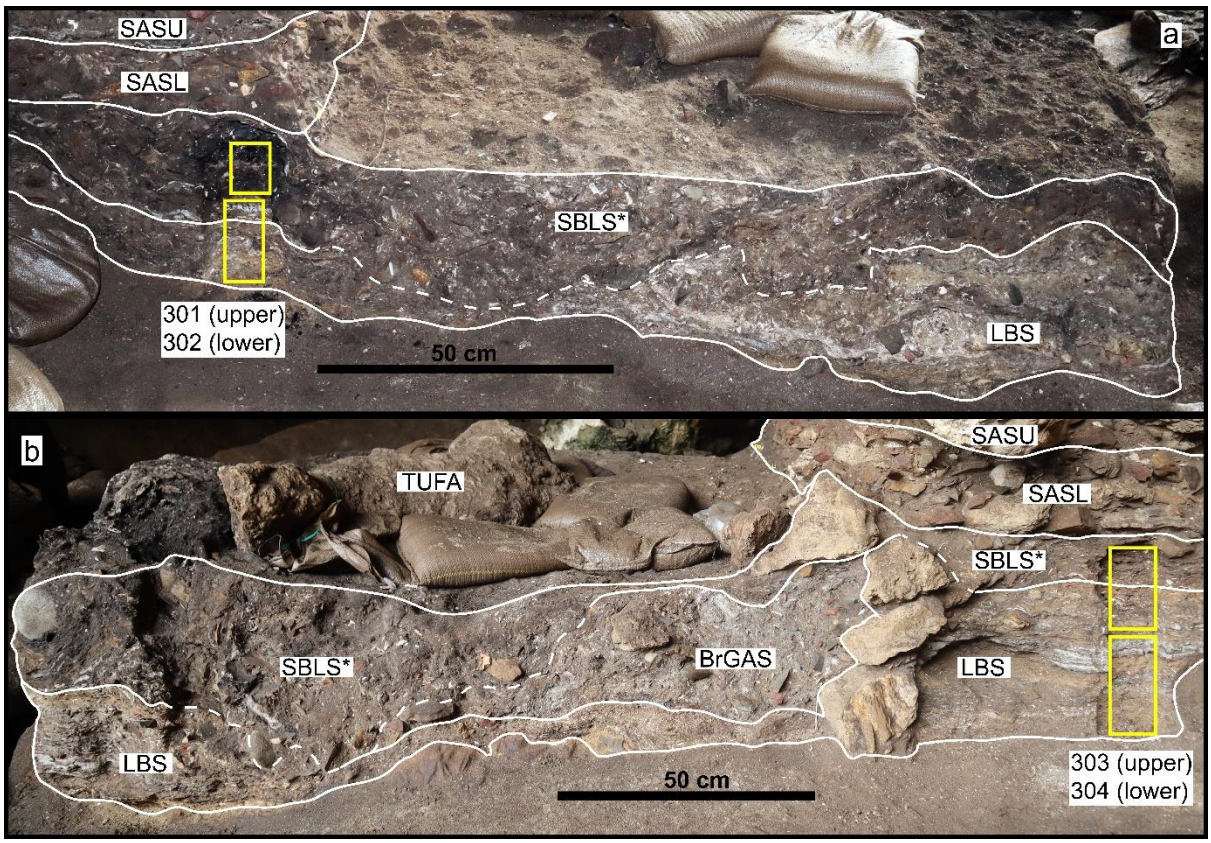

Figure 4. The western (a) and eastern (b) profiles of the Witness Baulk with major stratigraphic groupings and the locations from which samples were collected for this study (photographs by K. Croll). Note the large piece of tufa/speleothem lying within the excavation, and the 'rock column' between the LBS and BrGAS (b). *The deposits grouped as the SBLS include some which could be excavated as distinct units in the future.

Larger bone and shell fragments in the thin sections were analysed using μFTIR (Berna 2017). Absorbance spectra were collected using an Agilent Technologies Cary 610 FTIR microscope with a germanium attenuated total reflectance objective. A digital reference library was used to classify the spectra, allowing the determination of whether a bone was heated, and to what temperature range (Larbey et al. 2019; Wurz et al. 2022). The presence or absence of the Phosphate High Temperature peak marked heating above or below ~600-700°C (Thompson et al., 2013; Stepka et al., 2022).

Spectra were also collected from shells to determine whether they were composed of calcite or aragonite. Where spatial relationships between shell and burned materials

and/or the petrographic properties of the fragments (Villagran, 2014) indicate that shell was likely heated or burnt, the presence of aragonite in some or all of the fragments suggests temperatures below 400°C. If all fragments within a deposit meeting the same criteria are calcite, then they were likely heated to above 400°C, especially if multiple taxa are represented (Wurz et al. 2022), although various factors may influence the temperature at which the transformation occurs (Aldeias et al., 2019; Toffolo, 2021). This approach was previously applied to combustion features at KRM (Larbey et al. 2019).

The polished chip of 304 was analysed using reflected light microscopy at a magnification of 500x. The analysis was performed following Taylor et al. (1998) under oil immersion with a Leica DMRX/MPV-SP microscope photometer in reflected white-light (RLo) and incident ultra-violet light (RUVLo), and in plane polarised (RPPLo) and cross polarised light (RXPLo). Description and classification of the organic micro-components (macerals) is based on the nomenclature of macerals in brown coal and coal (Taylor et al., 1998; Sýkorová et al., 2005).

Determination of reflectance of plant tissues is an established means of measuring the maturation degree of organic matter in peats, brown coals, coals and sedimentary rocks (Borrego et al., 2006). Its application in archaeology typically focuses on reconstructing the burning and preservation conditions of wood, charcoal, and char derived from bone and fats (Ligouis, 2017). Reflectance analyses of charcoal, bone and fat-derived char paired with archaeological micromorphology have been previously applied at KRM in the study of combustion features by Larbey et al. (2019), and elsewhere in South Africa (Goldberg et al., 2009; Clark & Ligouis, 2010). Random reflectance in oil (mean % Rr) of the organic particles from three discrete MSUs was measured according to standard procedure (Taylor et al., 1998). Only one measurement was made on tissue.

4. RESULTS AND INTERPRETATION

4.1. Macrostratigraphy

The western and eastern profiles of the Cave 1 Witness Baulk are described below, more broadly for the entire profile, and in greater detail at two locations north of the excavation which were subsequently sampled for micro-analysis (Figure 4).

4.1.1. Western profile

The LBS Member is thickest on the southern end, where it is initially dominated by sandy sediment with thin lenses of anthropogenic material, followed by a succession of thicker shell-rich, ash, and charred deposits (Figure 4a). Moving north, the member is truncated, with several hollows in its surface. This upper surface is difficult to follow, with the exact location of the contact with overlying deposits often unclear. Most of the original vertical extent of the LBS has been lost in several places. The overlying deposits have been provisionally assigned to the SBLS. All are darker than the underlying LBS, but there are variations in: colour, the presence or absence of internal stratification, and the density and organization of clasts. The contact with the overlying SASL Sub-member (specifically the Brown Occupational Soils or BOS) is characterised by increased clast density and size.

At the sample location (301 and 302), a basal pale orangish-brown gritty sand with larger angular quartzite inclusions is overlain by faintly bedded darker silty sand deposits which are fairly rich in shell and ash but do include interbedded sand. They are capped by a yellowish-brown sandy unit with an associated very thin ash layer. The transition to the SBLS is marked by a ~25 cm wide, ~3 cm thick, undulating ash feature with a faint dark lamina at its base. The ash is truncated at its upper surface in several locations. The SBLS here is particularly dark and clast rich, with a moist fine silty sand matrix. Some stratification was observed, but this is indistinct, except for a laterally constrained (~10 cm wide) slightly undulating ashy deposit. The clasts include shell, bone, rubified quartzite, lithics, and charcoal. Overall, they appear chaotic in arrangement, but there are localised areas with preferred orientations.

4.1.2. Eastern profile

The LBS Member is again characterised by basal sandy deposits, followed by layers rich in ash, charred material, and shell (Figure 4b). These deposits are more finely bedded than in the western profile and are interbedded with sandy deposits of varying thickness. A series of three rocks (quartzite and speleothem/tufa) form an almost vertical ‘rock column’ in the profile just north of the ongoing excavation. They are separated by sediment but do directly touch in places. There is a notable truncation of the LBS deposits from near the southern end of the profile up to the ‘rock column’. The Brownish Grey Ashy Sand (BrGAS) unit, which is part of the LBS, lies on this surface, and is banked up against the southern face of the ‘rock column’. To the north of the ‘rock column’, the LBS was not truncated in this way and is up to 32 cm thick. BrGAS is comparatively clast-rich, including many lithic artefacts, and contains patches of cemented ash. The clasts in some areas are chaotically arranged, but in others they conform to the underlying morphology. The SBLS overlies the LBS (including BrGAS). The steeply dipping contact between BrGAS and the SBLS to the south (Figure 4b) is suggestive of the lateral truncation of the BrGAS. As in the western profile, the SBLS here has variable sedimentary properties across its extent. Its upper contact with BOS (SASL Sub-member) is marked by a significant increase in clast density and size.

At the sample location (303 and 304), the basal deposit is yellowish-brown sand with some grit, which fines upward (both coarse and fine fraction) and has some thin, faint, and discontinuous darker laminae. It is overlain by a layer of very dense shell and ash. This is followed by silty brown sand, then a dark silty layer with ash and dispersed shell. The overlying deposit is yellowish-brown sand with some silt which contains very thin grey and pale orange laminae. Above this is a ~6-cm thick succession of charred laminae and thicker ash deposits. This packet of deposits has a curved base and the exposed portion was more than 50 cm wide. Its southern boundary is between the lower two rocks in the ‘rock column’, and it appears to have been compressed by the deposition of the second rock. The remainder of the LBS consists of alternating beds and laminae of yellowish-brown sand, ash, and darker finer sediment, some of which is relatively rich in shell. Some ashy deposits are truncated laterally or show signs of distortion. Microfauna bones are clearly visible in the profile, unlike the lower portion of the LBS. The transition to the SBLS is marked by darker and finer sands with some

laminae of different shades, including what looks like charred material. Microfauna bones remain common, but macroscopically distinguishable ash deposits are absent. Clasts are comparatively rare, and mostly small, in contrast to much of the SBLS. There are a few locations where the LBS appears to have been eroded, with darker SBLS sediments infilling the spaces.

4.2. Microstratigraphy

The two samples (302 and 301) from the western location contain a total of 29 distinct MSUs (Figures 5-6), while those from the eastern location (304 and 303) comprise 46 (Figures 7-8). The MSUs are grouped into 12 MF types, which are described in Table 1. Representative photomicrographs of each MF type are provided in Figures 9-12. Foraminifera (Figure 13a) are common in many MSUs (Table 1). The microstratigraphy is described in the online Supporting Information.

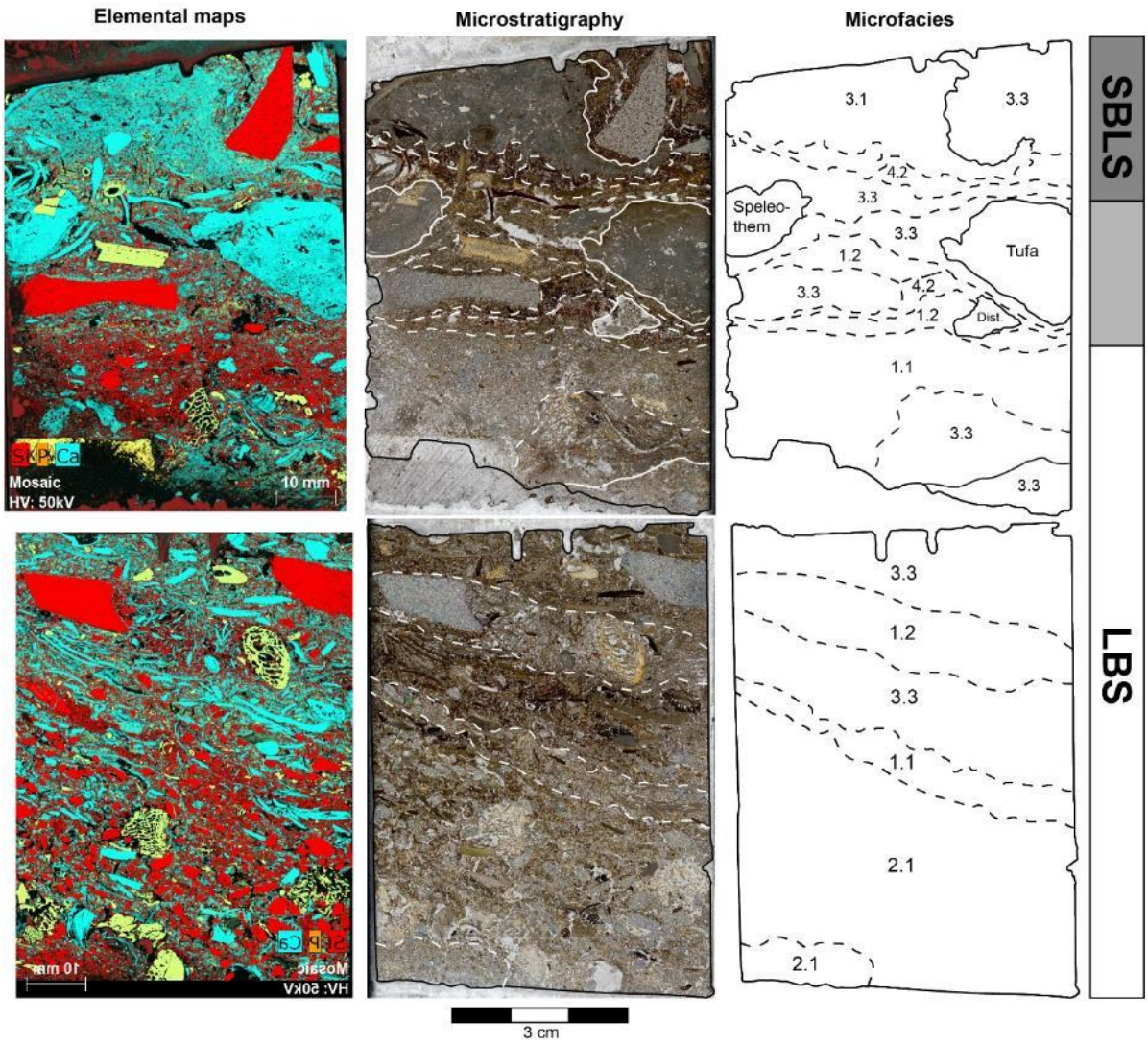

Figure 5. The µXRF elemental maps, microstratigraphy, microfacies attributions, and macrostratigraphy for slides A (top row) and B (bottom row) from KRM-20-302, lower half of the western sample column. On the elemental maps blue denotes calcium (mostly ash or shell) and red represents silicon in the form of quartz and quartzite. Yellow shades show the presence of both calcium and phosphorus, e.g., in bone, phosphatised ash, and apatite nodules. The paler grey portion of the stratigraphic column denotes MSUs which cannot be confidently attributed to either the LBS or SBLS.

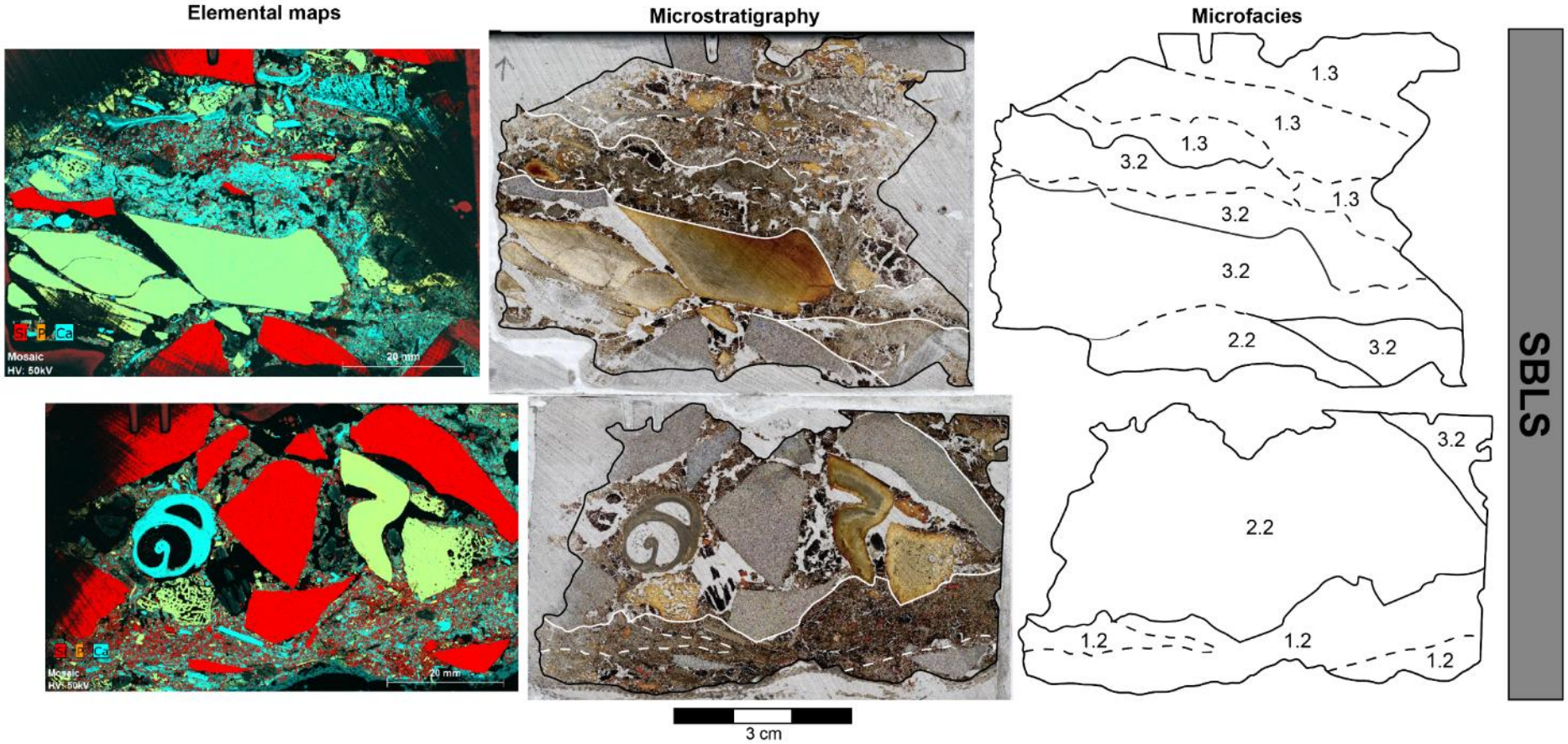

Figure 6. The μXRF elemental maps, microstratigraphy, microfacies attributions, and macrostratigraphy for slides A (top row) and B (bottom row) from KRM-20-301, upper half of the western sample column. On the elemental maps blue denotes calcium (mostly ash or shell) and red represents silicon in the form of quartz and quartzite. Yellow shades show the presence of both calcium and phosphorus, e.g., in bone, phosphatised ash, and apatite nodules.

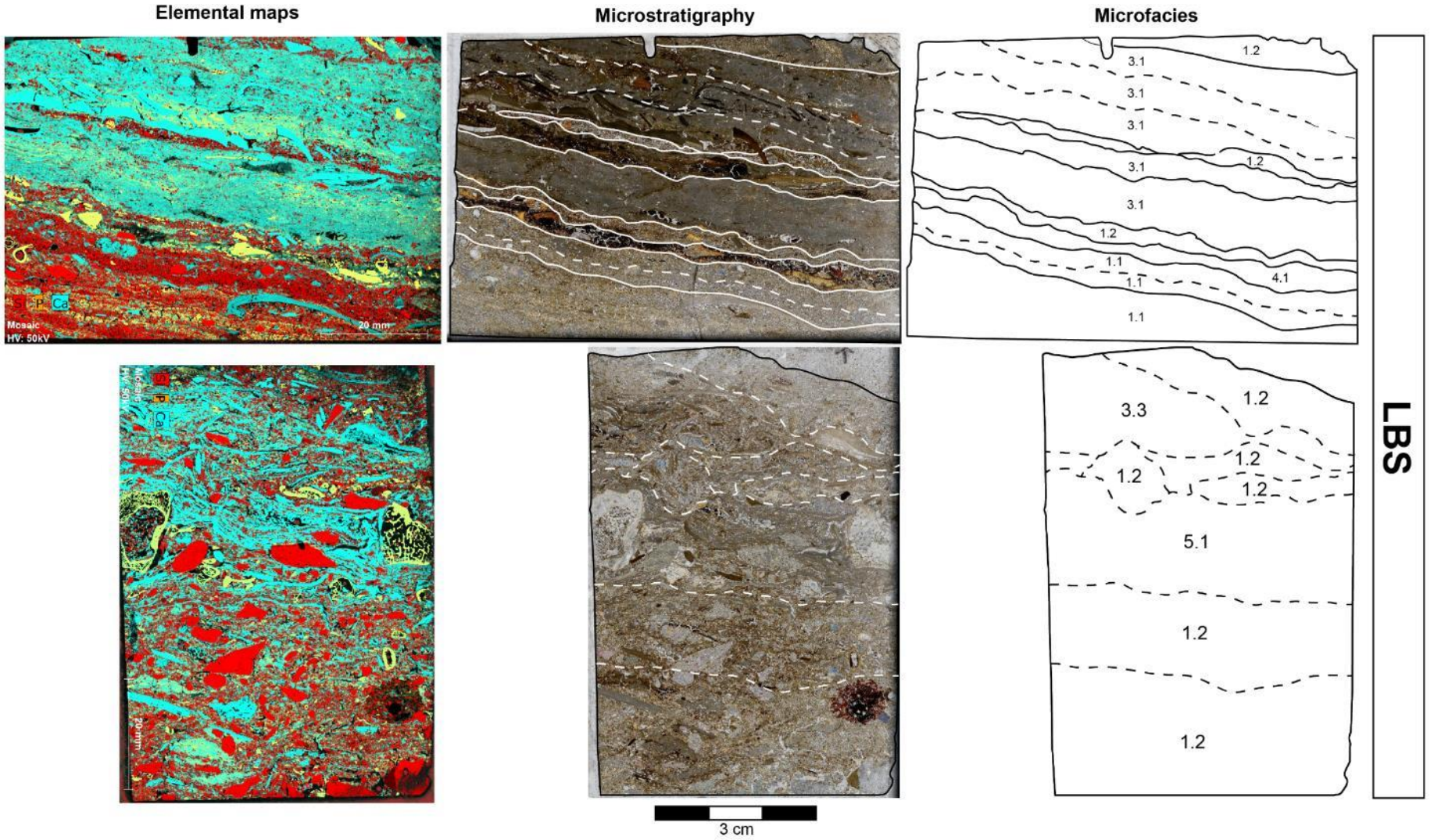

Figure 7. The μXRF elemental maps, microstratigraphy, microfacies attributions, and macrostratigraphy for slides A (top row) and B (bottom row) from KRM-20-304, lower half of the eastern sample column. On the elemental maps blue denotes calcium (mostly ash or shell) and red represents silicon in the form of quartz and quartzite. Yellow shades show the presence of both calcium and phosphorus, e.g., in bone, phosphatised ash, and apatite nodules.

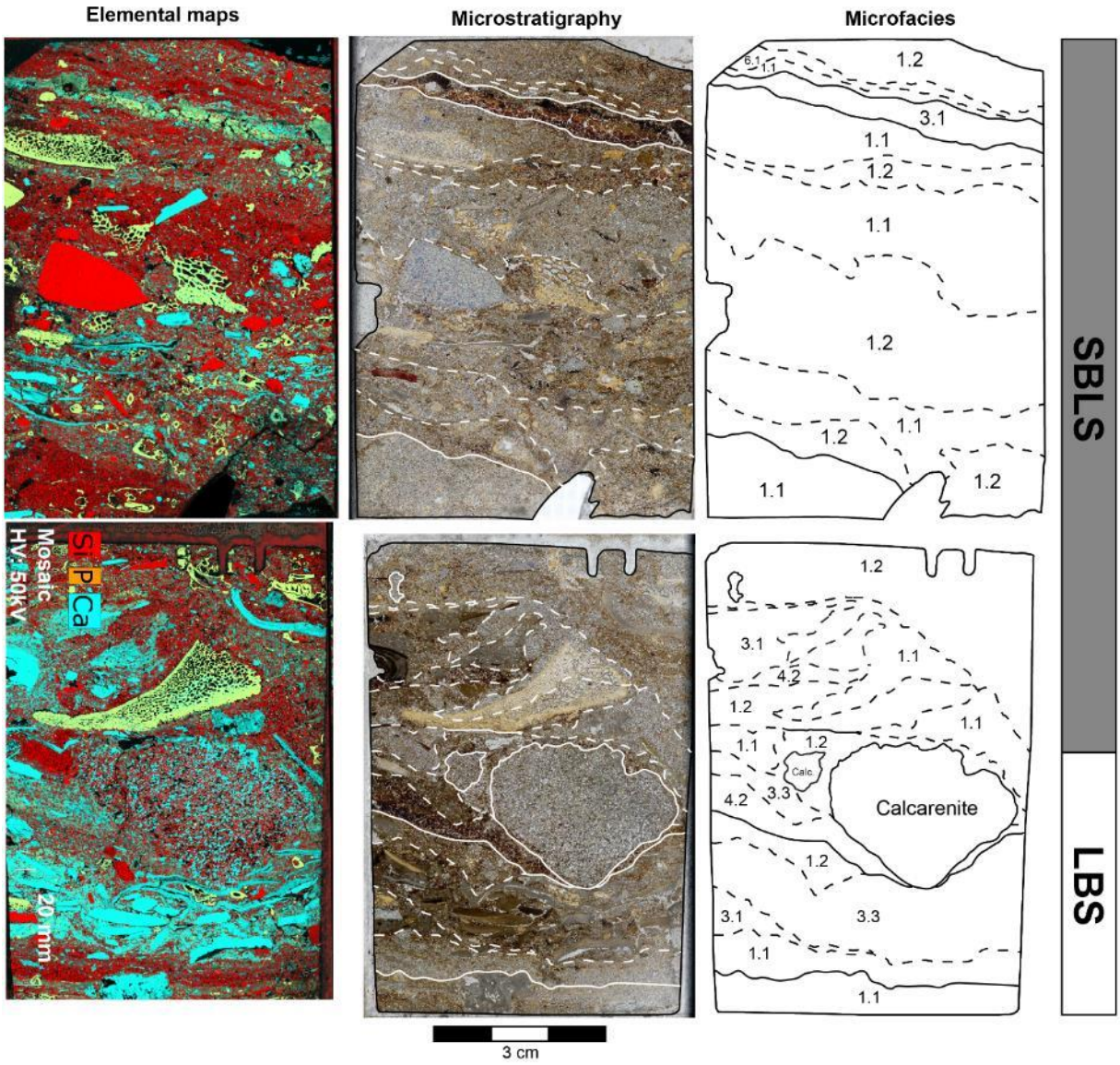

Figure 8. The µXRF elemental maps, microstratigraphy, microfacies attributions, and macrostratigraphy for slides A (top row) and B (bottom row) from KRM-20-303, upper half of the eastern sample column. On the elemental maps blue denotes calcium (mostly ash or shell) and red represents silicon in the form of quartz and quartzite. Yellow shades show the presence of both calcium and phosphorus, e.g., in bone, phosphatised ash, and apatite nodules.

Table 1. The microfacies identified in the samples from the western and eastern sample locations. A general description is provided for each microfacies, along with the slides in which they were recorded. The distribution of microfacies is presented in Figures 5 to 8, and representative photomicrographs are provided in Figures 7 to 12.

No.	Microfacies	Description	Slides
1	*Shelly sand*		
1.1	Shelly sand	Quartz sand (sub-angular to sub-rounded) and some sand-sized shell with limited fine matrix. Where matrix is present, it is predominantly calcite (seemingly wood ash) which is almost entirely altered to apatite, but there are also some patches where siliceous silt and clay fill interstitial spaces. The sand is interbedded with ash (or ash-rich) lenses in a few cases, and ashy patches are present in some MSUs. Many of the lenses are phosphatised. Rounded ash aggregates and aggregates of calcareous mud are also observed in some deposits. Tufa fragments are present but very rare. Shell fragments, some angular and others more rounded, are present at low frequency; few are larger than 5 mm. Bone is less common than shell in most MSUs, and ranges from sand-sized to several centimeters. However, some deposits are rich in bone (including microfauna). Some in situ fragmentation of shell and bone is observed. Quartzite fragments ranging from coarse sand to 1 cm are present in all MSUs but are never a significant proportion of the sediment. Foraminifera are found in all MSUs. They are only present within pockets of fine matrix, or (in a few cases) as distinct lenses comprised of only foraminifera.	302A&B, 303A&B, 304A
1.2	Ashy shelly sand	Shelly quartz sand in an ashy matrix. The quartz is sub-angular to sub-rounded, while the shell (which makes up a smaller proportion than the quartz) is more rounded. The	301B, 302A&B, 303A&B, 304A&B

No.	Microfacies	Description	Slides
		matrix is primarily wood ash (mostly recrystallized), with less common secondary calcite. The matrix typically contains fine comminuted organic material and some siliceous silt and clay (usually far less than the organics), making it appear relatively dark, but the proportion and distribution of these materials within the matrix varies widely. The degree to which matrix fills the interstitial space between the sand grains and larger inclusions varies both within and between MSUs. Phosphatisation of the matrix is minor and patchy relative to MF 1.1 but is widespread. Many MSUs contain patches or lenses of comparatively pure ash (few inclusions), which are often more strongly phosphatised than the matrix. Small bone fragments (coarse sand-sized to ~2 mm) are common in most MSUs. Similarly sized apatite nodules and guano fragments are present in some MSUs but very rare. Coarser inclusions occur at different densities and include shell fragments, larger bone fragments (up to ~3 cm), microfauna bones, and quartzite (with some potential artifacts). The quartzite fragments are typically angular and range from coarse sand-sized to ~2 cm. Charcoal is absent from most deposits but is relatively common when present. In situ breakage of bone and shell is absent in most MSUs, and typically rare in the deposits where it is observed. Foraminifera are present in all deposits but vary in number and distribution through the sediment.	
1.3	Loose coarse heterogenous sand	A loose, chaotic combination of shelly sand, angular bone and shell fragments, and charcoal fragments. The various fragments range from coarse sand to ~1 cm. There is notable variation over short distances in the proportions of these materials, with some	301A

No.	Microfacies	Description	Slides
		domains dominated by one material and others far more mixed. Secondary calcite coats many of the grains, and there are some sand-sized aggregates of recrystallized wood ash and finely comminuted organic material. Some areas have a denser matrix of recrystallized and cemented wood ash, secondary calcite, and fine organic material. There is also a ~7 mm long rounded aggregate of the same material. The calcareous matrix has undergone very limited phosphatisation by secondary apatite, and some shell has been slightly dissolved. Limited quantities of charcoal and soft calcareous matrix were removed inadvertently during thin section production, making the apparent porosity slightly higher than the actual porosity. The charcoal contains some secondary calcite and (in a few cases) apatite, and some bone fragments have been slightly calcified. Larger clasts (>1 cm), including shell, bone and lithics, are typically oriented more horizontally and/or correspond to the general dip of the deposit they are in. Several larger bones analyzed with µFTIR were not heated above 300°C, but the smaller fragments have a range of colours, suggesting potential differential heating. Most of the bone and shell fragmentation appears to have occurred prior to deposition as fragments can seldom be associated with others nearby. In situ fragmentation of charcoal is more common. Foraminifera are extremely rare and only ever observed in the areas with a dense calcareous matrix.	

No.	Microfacies	Description	Slides
2	*Gravel*		
2.1	Fine quartzite gravel	Sub-rounded to angular mostly elongated quartzite ranging from very coarse sand-sized up to ~6 mm, and shell fragments of largely similar size and shape, in a matrix of shelly sand and fine calcite. In-situ fragmentation of shell is very rare. There is localised variation in the proportion of shell and fine calcite. The fine calcite includes wood ash (mostly recrystallized) and secondary calcite. There is some phosphatisation of the calcite, and rare dissolution of shell. Very small apatite nodules and localized very thin crusts are present but uncommon. Bone up to ~1 cm largely comprises a few whole pieces, but there are smaller scattered fragments (mostly fairly angular), and in-situ fragmentation of some larger pieces. Limited calcification of bone was noted. Both fine charred organic material and small pieces of charcoal are scattered throughout at low density. There are also several small concentrations of charred material. Foraminifera are present, but not very common.	302B
2.2	Coarse heterogenous gravel	A mix of different types of relatively large clasts (from ~6 mm to more than 3 cm) including angular quartzite (some of which are possible or obvious lithic artifacts), whole shell, bone, and charcoal. The clasts display a range of orientations, from almost horizontal to near vertical. Only one large piece of bone was burnt. The matrix is recrystallized wood ash rich in finely comminuted organic material with shelly quartz sand, and angular bone and shell fragments ranging from sand-sized to a few millimeters. The deposit is clast-supported in parts, but matrix-supported overall. The	301A&B

No.	Microfacies	Description	Slides
		matrix has a sub-angular blocky microstructure in some areas. The removal of some softer material like charcoal and ash during thin section production has artificially increased the porosity, but this MF is still relatively porous compared to most others. No in situ breakage of bone or shell is visible, and potential in situ breakage of charcoal is limited to the upper portion of the deposit. There is minor patchy phosphatisation of the ashy matrix, and the charcoal fragments contain some secondary calcite and (to a lesser extent) apatite. The more porous bone has been slightly calcified. Some foraminifera are present in the matrix.	
3	*Ash*		
3.1	Ash	Wood ash with anthropogenic inclusions and rare sand-sized quartz. Where present, sand often forms thin lines within the ash (sometimes just one grain thick). Otherwise, it is distributed at extremely low density throughout the ash. Recrystallisation of the ash is fairly common but not complete, with some thin bands of greater recrystallization. Phosphatisation is observed in all MSUs but varies in intensity and distribution. Phosphatised patches are most common, but there are also sub-millimeter lenses in most deposits. In a few of the thinnest MSUs, calcite has been almost completely replaced by apatite. Channels are present in most units, at varying density. Foraminifera were not observed.	302A, 303A&B, 304A

No.	Microfacies	Description	Slides
3.2	Ash with coarse inclusions	Wood ash with anthropogenic inclusions and more shelly sand than MF 3.1. Recrystallisation of the ash is patchy, with some distinct bands of recrystallized ash, most notably near the top of MSUs. Some secondary calcite is present, particularly in bone fragments. Fine charred material is distributed through the ash to a greater degree than in MF 3.1. Coarser inclusions are more common and diverse than in MF 3.1. They include shell, bone, charcoal, and lithics, with notable variation in the proportions and sizes of these clasts. Larger inclusions (>5 mm) are typically relatively horizontal or conform to the underlying morphology, but there are some zones in which smaller inclusions have a more chaotic fabric. Thin lenses of charcoal (often articulated) are common in some MSUs. These typically undulate and are sometimes associated with planar voids. There is some in situ fragmentation of bone and shell, but much of the fragmentation seems to have occurred ex situ as few fragments appear to fit with nearby fragments. Phosphatisation is variable in extent, both within and between deposits. Many phosphatised lenses appear to be pseudomorphic to thin charred lenses, with some unaltered charred material remaining. A few small coprolites are observed, along with equally rare rounded aggregates of phosphatised ash. Channels up to ~3 mm wide are relatively common. A few are filled or partially filled with loose sand and reworked anthropogenic materials. Planar voids are common in some MSUs and are typically accommodated or partially accommodated. Foraminifera were not observed.	301A&B

No.	Microfacies	Description	Slides
3.3	Sandy ash	Wood ash matrix with a significant proportion of shelly sand. Recrystallisation of ash is very common, and there is some secondary calcite. Fine charred organic material is distributed throughout the matrix, with particularly high concentrations making the calcareous material appear 'dirty'. Phosphatisation is variable in distribution and intensity. There is some variation in the proportion of sand both within and between MSUs. Shell fragments (predominantly angular) are present in all deposits but vary considerably in size (up to several centimeters) and frequency. Bone (mostly fragmentary), quartzite (including lithics), and charcoal are found in some MSUs. Foraminifera were observed, but are very uncommon and only present in a few deposits.	302A&B, 303B, 304B
4.	*Organic material*		
4.1	Charred	A dense concentration of charcoal and fine charred organic material, with ash filling much of the interstitial space. There is some minor phosphatisation of ash and charcoal. Bone fragments ranging in size from very coarse sand to ~9 mm are numerous. The µFTIR spectra indicate that some bone fragments are unburnt, some were burnt below 700°C, and some were burnt at more than 700°C. Foraminifera were not observed. Organic petrology (see online Supporting Information) reveals the presence of fat-derived char, supports the observation that charcoal has been altered, and demonstrates that charcoal formation occurred at 280°C.	304A

No.	Microfacies	Description	Slides
4.2	Fine charred	Concentrated fine charred organic material in an ashy matrix with occasional small pieces of charcoal. Shell fragments and quartz sand are present, with the former ranging from sand-sized to ~9 mm. Bone is uncommon and mostly comprises angular fragments under 2 mm. Rare unburnt organic material was observed, but not in all MSUs. There is localised phosphatisation of ash. A few foraminifera were observed in one deposit but are otherwise absent from this MF type.	302A, 303B
5	*Shell*		
5.1	Dense shell	Very densely packed shell in a matrix of shelly sand and fine calcite (recrystallized ash with some secondary calcite). The shell is typically horizontal, with localised more steeply dipping occurrences due to the presence of harder inclusions and sandy lenses. Fine charred organic material is present within the ash, but at low densities, while charcoal is uncommon. Larger inclusions include quartzite clasts (both rounded and angular) up to ~1.2 cm and bone up to ~1.5 cm. The angular quartzite fragments appear to be lithic debitage. There is some in situ fragmentation of shell and bone, with limited movement of fragments. Both dissolution and compression of shell are commonly observed, while delamination is less common. Phosphatisation was observed in a few shells. Minor secondary calcification of bone was noted. Foraminifera were observed in both the calcareous matrix and sandier domains.	304B

No.	Microfacies	Description	Slides
6	*Fine siliceous sediment*		
6.1	Siliceous silt and clay	Siliceous and relatively iron-rich silt and clay with some quartz sand. Sand is scattered throughout, but there are some concentrations. Other inclusions of sand-size or larger are very rare. There is no phosphate, and calcite is absent except in the form of numerous foraminifera.	303A

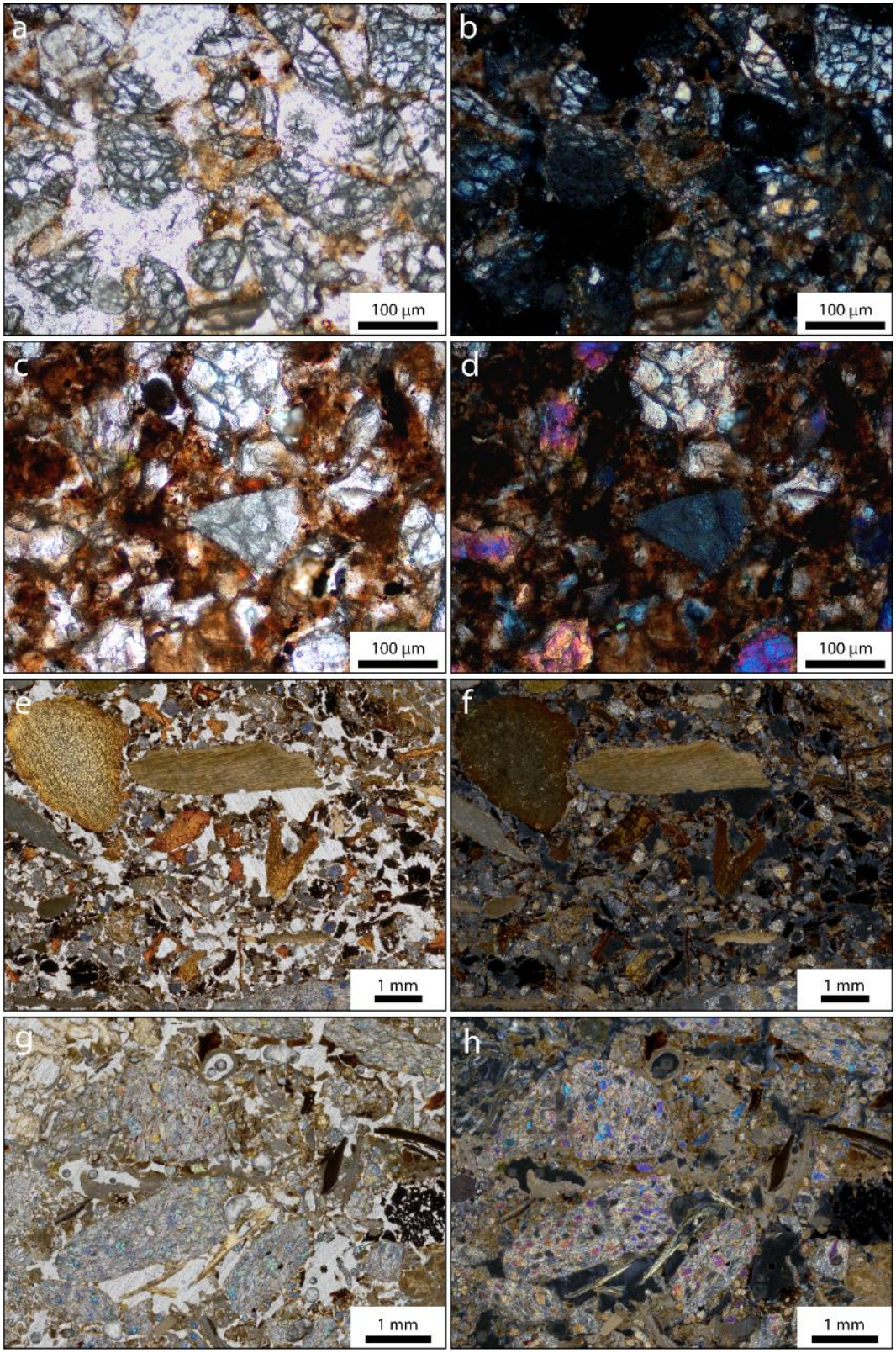

Figure 9. Note: due to the relative thickness of the slides, some of the components in this and subsequent figures do not look exactly as they would in a thin section of standard thickness. a) shelly sand with limited phosphatic matrix (MF 1.1), PPL. Note the clear dominance of quartz grains over shell. b) same view, XPL. c) shelly sand with ashy slightly phosphatised matrix (MF 1.2), PPL. d) same view, XPL. e) loose heterogenous mix of sand, charcoal, and bone (MF 1.3), PPL. f) same view, XPL. g) fine quartzite gravel and sand in a calcareous (mainly ash) matrix (MF 2.1), PPL. h) same view, XPL.

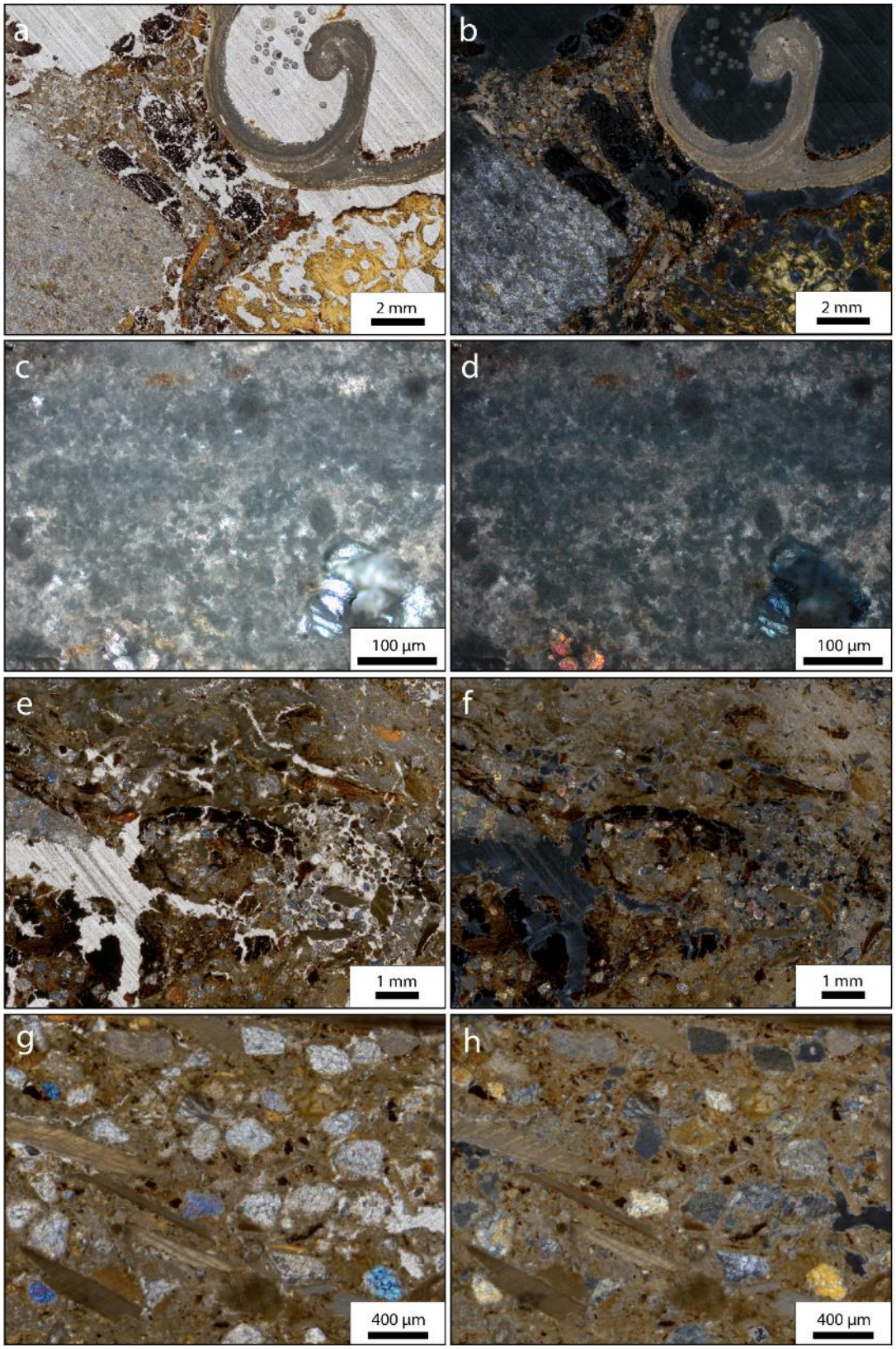

Figure 10. a) heterogenous clasts with blocky matrix of wood ash and various small inclusions (MF 2.2), PPL. b) same view, XPL. c) partly recrystallised wood ash (MF 3.1), PPL. Note the darker ash rhombs and lighter recrystallised ash. d) same view, XPL. e) wood ash with sand and anthropogenic inclusions (MF 3.2), PPL. Note the filled chamber and undulating charred lenses. f) same view, XPL. g) sandy ash with coarse inclusions (MF 3.3), PPL. h) same view, XPL.

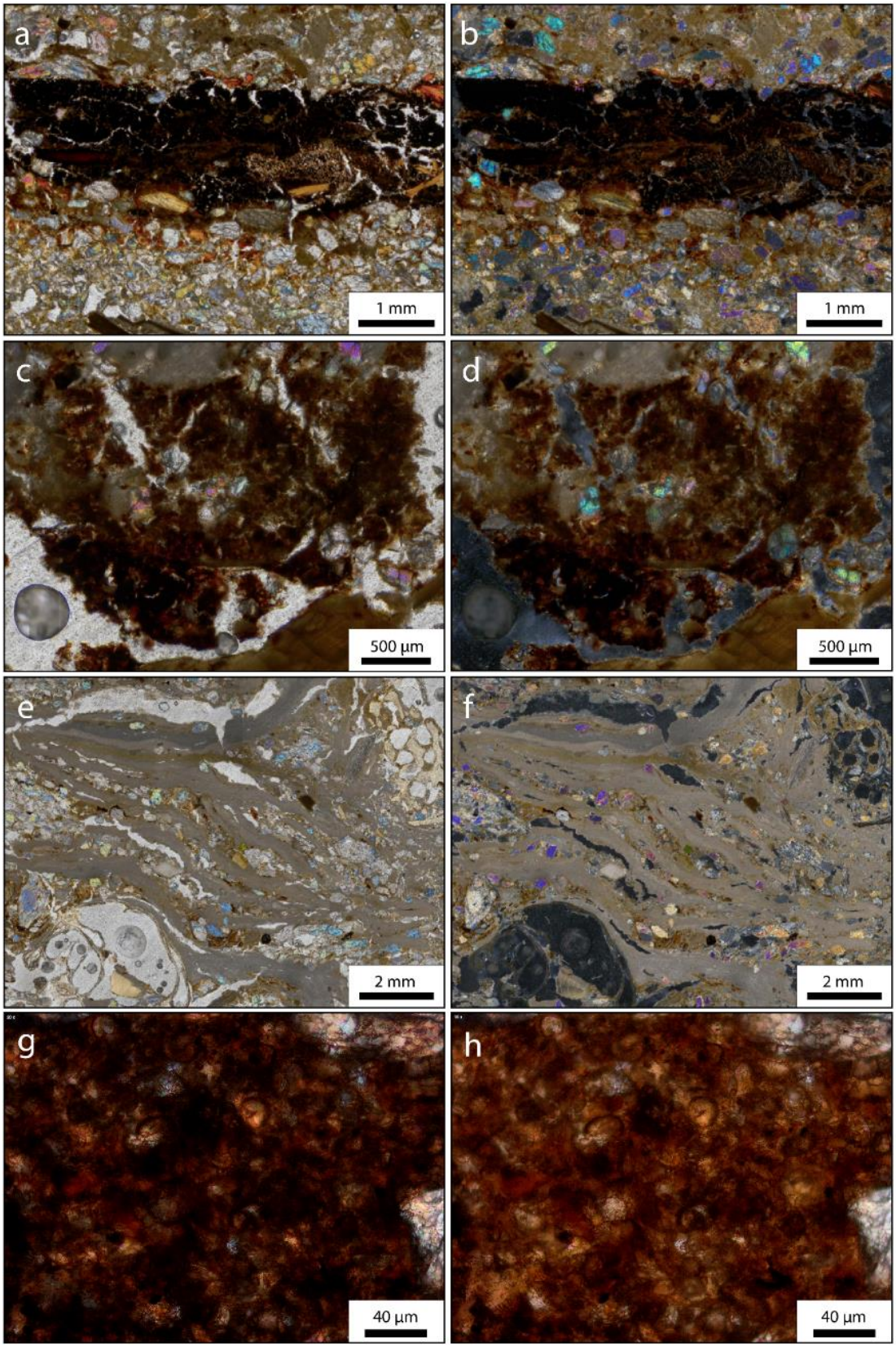

Figure 11. a) charred organic material in an ashy matrix with both burnt and unburnt bone (MF 4.1) sandwiched between two sandy deposits, PPL. b) same view, XPL. c) fine charred organic material in an ashy matrix (MF 4.2), PPL. d) same view, XPL. e) densely packed shell in matrix of ash and secondary calcite (MF 5.1), PPL. f) same view, XPL. g) iron-rich siliceous silt and clay with foraminifera and rare sand grains (MF 6.1), PPL. h) same view, XPL. See Figure 12 for a more general view of the MF 6.1 deposit.

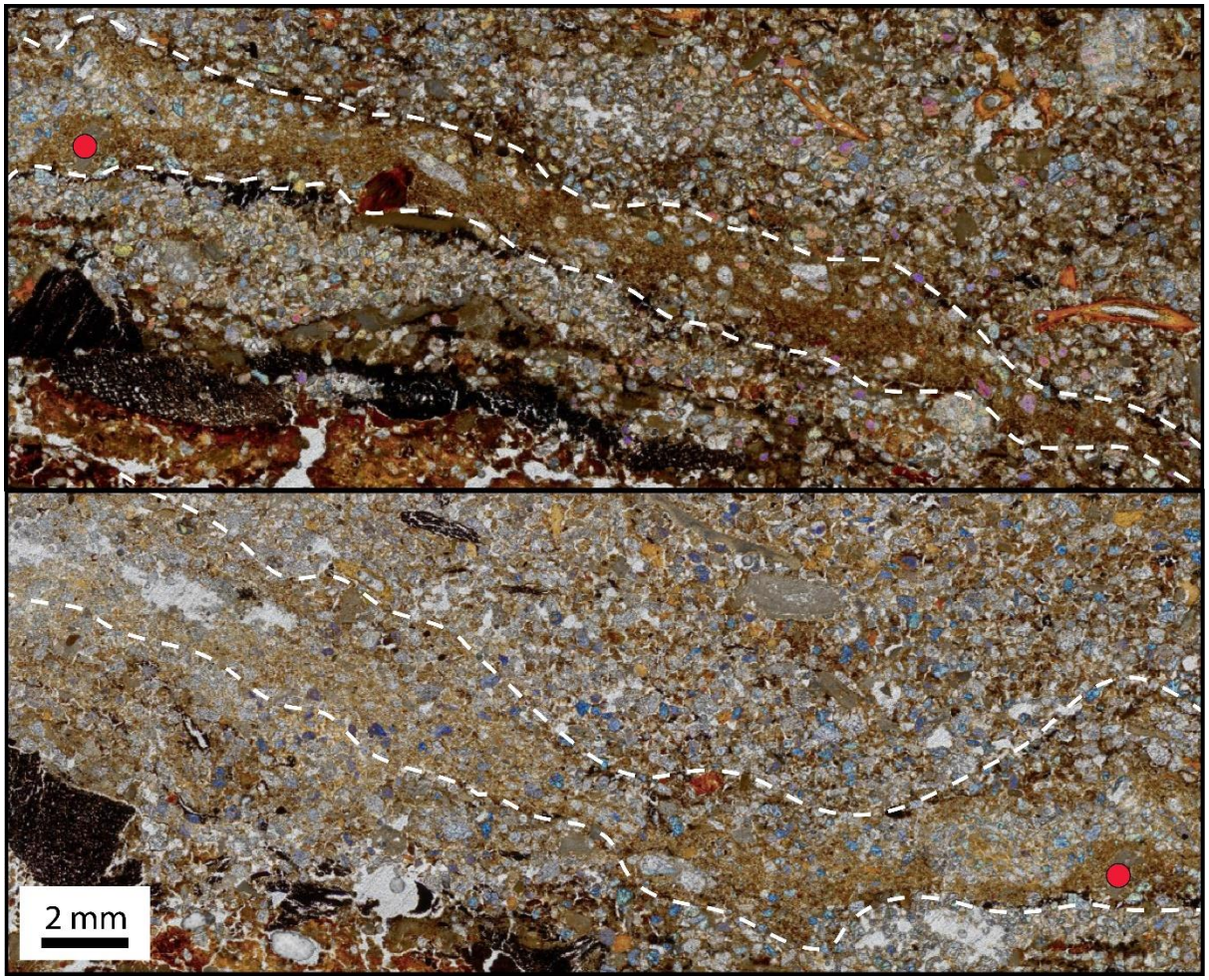

Figure 12. Two overlapping views across the iron-rich silt and clay of MF 6.1 and the over- and underlying sands in KRM-20-303A (both PPL). The red dots show the same location in both images. Note the significant change in the ratio of the finer sediment (silt and clay) to the sand moving from the right (upper image) to the left (lower image) of the slide.

4.3. Microfacies interpretation

The formation of each of the MF types is discussed here, with a summary presented in Table 2.

4.3.1. Shelly sand

Shelly sand is present in many of the MF types and is the dominant component in three MFs: 1.1, 1.2, and 1.3 (Table 1). It was introduced into the site by either aeolian or colluvial processes from two possible sources: beach and/or dune deposits seaward of the site complex, and the aeolianites above KRM (Deacon and Geleijnse, 1988). Sand- to pebble-sized angular fragments of quartzite occur in most MFs, most notably

in the sandy MFs. Some are lithic debitage, but many derive from bedrock breakdown due to salt weathering and insolation (Butzer 1982; Deacon & Geleijnse, 1988; Morrissey et al., 2023).

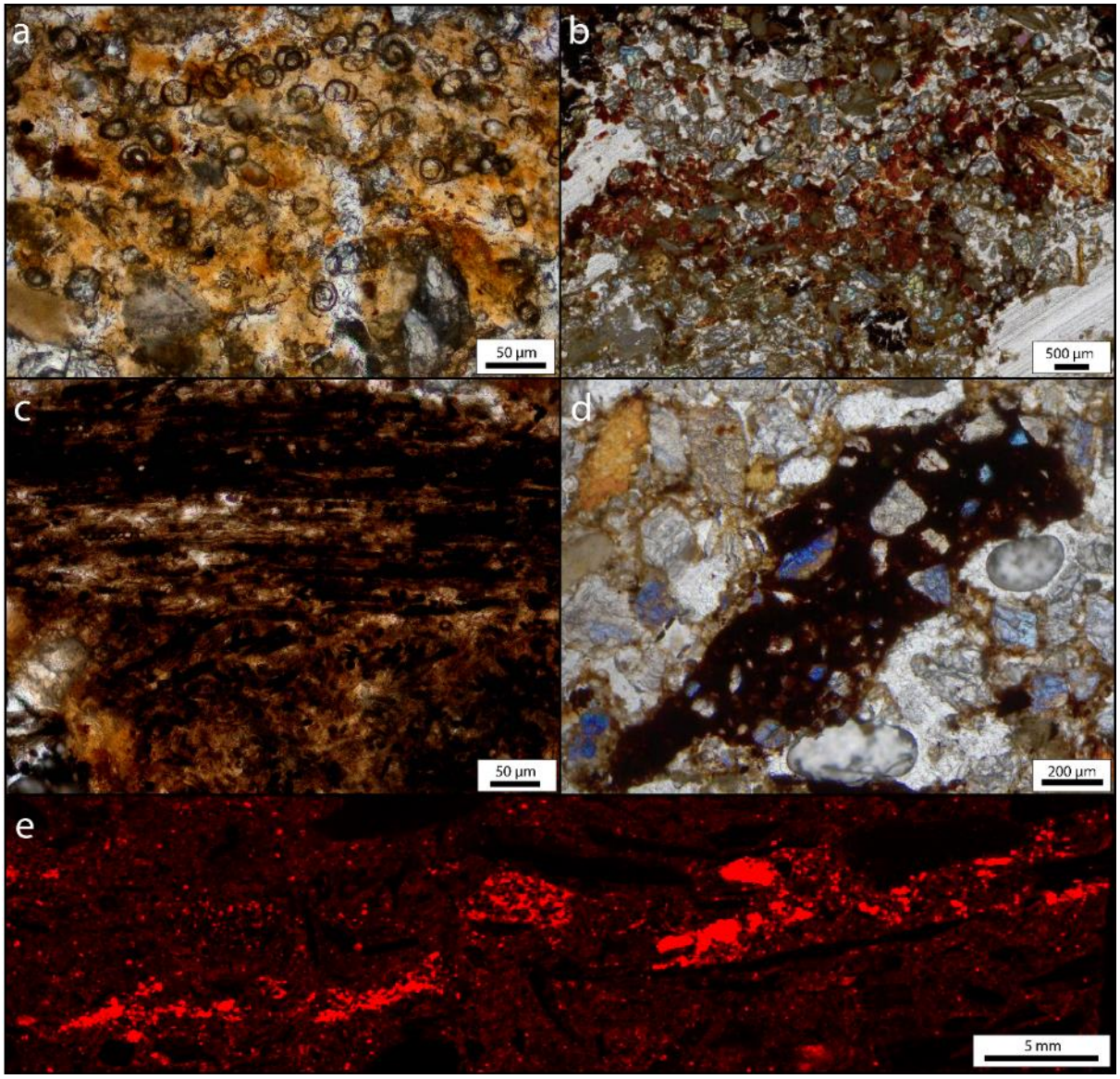

Figure 13. a) Unidentified foraminifera in a phosphatised ashy matrix, PPL. b) Deformed apatite crust in ashy sand of MF 1.2 (302A), PPL. c) Unburnt organic material in MF 4.2, PPL. d) Sub-angular iron-rich aggregate with fine quartz sand inclusions, PPL. e) µXRF map of iron distribution showing the discontinuous lens of iron-rich aggregates in 303A. This scan was made on the chip.

The sandy MFs are divided based on the proportion of anthropogenic materials (including ash, charred organic material, and bone and shell fragments) within the sand. Here, they are discussed in a progression from least to most altered by post-depositional processes.

Table 2. Summarised interpretations of the microfacies identified in the western and eastern sample columns in the Cave 1 Witness Baulk. See discussion in the text for greater detail. Geo = Geogenic; Bio. = Biogenic; Anth. = Anthropogenic

No.	Microfacies	Interpretation	Geo.	Bio.	Anth.
1	*Shelly sand*				
1.1	Shelly sand	Allogenic deposition of shelly sand (aeolian and/or colluvial) was the dominant depositional process, with autogenic deposition of weathered quartzite contributing to a lesser degree. Ash and other anthropogenic materials were reworked into the geogenic sand – mainly due to hearth maintenance and trampling. Biogenic secondary apatite (from the breakdown of guano) caused incomplete dissolution of calcite, and the phosphatisation of surviving ash. The microfauna and some shells are also biogenic.	x	x	x
1.2	Ashy shelly sand	This MF has a similar formation history to MF 1.1, but with little to no dissolution of calcite, and (potentially) greater initial input of anthropogenic components.	x	x	x
1.3	Loose coarse heterogenous sand	These deposits are the product of the dumping of anthropogenic material from hearths and (largely) geogenic components from adjacent and underlying deposits. These materials were swept out during hearth maintenance and may have been trampled prior to sweeping. There is a minor biogenic input of secondary apatite.	x	x	x
2	*Gravel*				
2.1	Fine quartzite gravel	This MF is similar in formation to MF 1.2 but is distinguished by reduced allogenic sedimentation and/or more rapid bedrock breakdown and also by potentially greater dissolution of calcite and/or less anthropogenic input.	x	x	x

No.	Microfacies	Interpretation	Geo.	Bio.	Anth.
2.2	Coarse heterogenous gravel	This deposit was formed by the dumping of a range of different types of relatively large anthropogenic clasts along with swept finer material during hearth maintenance. There is a minor biogenic input of secondary apatite.	x	x	x
3	*Ash*				
3.1	Ash	These deposits are intact, relatively well-preserved hearths. The shelly sand and secondary calcite observed in many MSUs are geogenic in origin. The recrystallisation of ash was driven by water percolation. The secondary apatite which altered some ash is biogenic. Lenses of sand, or recrystallized or phosphatised ash indicate that most deposits were formed in multiple firings. Very minor bioturbation by soil mesofauna took place after deposition.	x	x	x
3.2	Ash with coarse inclusions	This MF represents in situ but relatively poorly preserved hearths. Stratigraphic integrity has been reduced by trampling and bioturbation, but these impacts are comparatively minor. Most deposits appear to be the product of multiple fires. There is some biogenic input in the form of secondary apatite.	x	x	x
3.3	Sandy ash	These deposits are the product of the reworking of combustion features by trampling and site maintenance activities, resulting in the mixing of anthropogenic and geogenic sediment. Some MSUs are similar to MF 1.2, but with far greater input and/or preservation of anthropogenic components. In other cases, there is only localized reworking. Secondary apatite is the only biogenic input.	x	x	x

No.	Microfacies	Interpretation	Geo.	Bio.	Anth.
4	*Organic material*				
4.1	Charred	This MF was formed by the incomplete combustion of wood. Associated bone fragments were burnt both deliberately and incidentally. There is a geogenic input in the form of the recrystallisation of the ash matrix, while the secondary apatite which altered some ash is biogenic.	x	x	x
4.2	Fine charred	These deposits represent the incomplete combustion of both non-woody plant material and wood. It is unclear if this material was burnt deliberately for site maintenance, or incidentally. The inclusion of sand into some MSUs is likely due to trampling or other disturbance. The secondary apatite is biogenic in origin.	x	x	x
5	*Shell*				
5.1	Dense shell	This deposit was formed by the discard of shell and, to a lesser extent, other anthropogenic materials into a midden. Stratigraphic integrity was reduced by compression and some trampling. Guano breakdown resulted in shell dissolution, while the resulting biogenic secondary apatite altered some ash and shell. Secondary calcification was due to calcium-enriched dripwater.	x	x	x
6.	*Fine siliceous sediment*				
6.1	Siliceous silt and clay	This deposit appears to have been formed by dripwater enriched in iron and transporting siliceous silt and clay weathered from the bedrock or overlying deposits. There may have been localised mixing with the overlying sands, but this is not	x	x	

No.	Microfacies	Interpretation	Geo.	Bio.	Anth.
		certain. Biogenic inputs are limited to numerous foraminifera. This is the only MF type with no observed anthropogenic input.			

The composition and structure of MF 1.3 (Table 1) are consistent with reported properties of experimental and archaeological deposits formed by dumping material removed from hearths and adjacent or underlying sediment during hearth maintenance (e.g., Schiegl et al. 2003; Miller et al., 2010, 2013; Marcazzan et al., 2022). The aggregates of recrystallised ashy sand could be rip-up clasts produced during sweeping (Miller et al., 2010). The high proportion of bone fragments broken ex situ supports the interpretation that the material was swept, but some breakage likely occurred due to trampling prior to hearth maintenance. The almost complete lack of trampling after dumping is an important factor in the preservation of these deposits (Miller et al., 2013; Rentzel et al., 2017). The occurrence of multiple dumping events is also supported by the orientation of larger clasts, which suggest they were discarded onto surfaces between dumping events.

The ashy shelly sand of MF 1.2 was initially like MF 1.3 in having been swept or raked from in and around hearths (Miller et al., 2010, 2013). However, this material was subsequently reworked and mixed with otherwise geogenic sands through trampling and other physical disturbance (Miller et al., 2013; Rentzel et al., 2017). There is a comparatively high proportion of ashy matrix (both phosphatised and not) in the sand, although this does vary. The re-precipitation of secondary apatite as a result of the breakdown of guano causes the phosphatisation of ash (Karkanas et al., 2000). This process can lower pH levels in the sediment, resulting in the dissolution of calcite, including wood ash (Schiegl et al., 1996; Karkanas, 2017). The differing proportions of ash in some deposits may reflect variation in anthropogenic input, but it is likely that some ash has been dissolved, and that the phosphatisation of ash aided preservation to some extent (Karkanas et al., 2000). Both birds and bats could have contributed guano.

MF 1.1 deposits are more geogenic in character and are poor in ashy matrix relative to MF 1.2. The comparatively limited sand-sized shell, the partial dissolution of most large shell fragments and ash aggregates, and the general scarcity of non-phosphatised ash all indicate varying degrees of incomplete decalcification (Goldberg, 2000). A lower frequency of small bone fragments suggests that many of these deposits initially contained less reworked ash than the MF 1.2 deposits. The presence

of ash-rich lenses (mostly phosphatised) may be a result of periods of better preservation of the matrix, or of more intensive periods of human activity at the site.

4.3.2. Gravel

MF 2.1 is broadly similar to MF 1.2 and was likely formed by the same general processes (reworking of anthropogenic material into geogenic sediment). However, abundant autogenic quartzite suggests either far more rapid breakdown of the bedrock, reduced input of allogenic sand, or a combination of these (Morrissey et al., 2023). The relatively limited matrix could reflect greater dissolution of non-phosphatised ash or less availability of anthropogenic material.

The chaotic fabric of MF 2.2 (Figure 6) and the mix of large anthropogenic components are consistent with dumping (Miller et al., 2010). The properties of the limited matrix (Table 1) suggest sweeping of combustion materials and associated shelly sand. The deposit is matrix-supported, suggesting that the matrix and clasts were deposited in one event, rather than the finer sediment filtering into the deposit after the initial dumping. MF 2.2 appears to be the product of site maintenance activities carried out around a hearth with a focus on removing larger clasts as well as sweeping away ash and other materials from the hearth and its periphery.

4.3.3. Ash

The ash in these three MF types is consistent with the complete combustion of wood (Canti & Brochier, 2017). MF 3.1 is characteristic of in situ (generally) undisturbed hearths (Mentzer, 2014; Mallol et al., 2017). The incomplete recrystallisation of ash is the result of the movement of water through the ash (Karkanas et al., 2007; Karkanas, 2021), with secondary calcite potentially introduced by dripwater (Deacon & Geleijnse, 1988). The phosphatisation of ash is by secondary apatite leached from guano (Karkanas et al., 2000; Karkanas, 2017). The distinct laminae of phosphatised or recrystallised ash reflect periods of surface exposure (Morrissey et al., 2023, Figure 19). Small channels indicate limited bioturbation by burrowing mesofauna (Stoops, 2021).

The presence of numerous charred laminae within the ash of MF 3.2, and the relatively limited input of geogenic clastic material, indicate that these MSUs are in situ hearths (Mentzer, 2014; Mallol et al., 2017). In situ fragmentation of bone and shell and the undulating charred laminae suggest trampling (Rentzel et al., 2017). Although generally relatively minor, this has impacted the integrity of distinct layers, and potentially introduced additional sand into the ash. Bioturbation by mesofauna also occurred and a combination of the burrowing and infilling of chambers resulted in some loss of stratigraphic integrity, but this is relatively minor in comparison to some recorded cases of similar bioturbation (Mentzer, 2011, 2014).

The proportion of shelly sand in MF 3.3 indicates greater geogenic input than in MFs 3.1 and 3.2. As with MF 1.2, MF 3.3 is interpreted as anthropogenic deposits reworked through processes like trampling and site maintenance (Miller et al., 2013; Mallol et al., 2017; Rentzel et al., 2017). The greater proportion of anthropogenic materials in MF 3.3 than observed in MF 1.2 might indicate greater availability of these materials due to more intensive occupation, or the sampled locations being closer to the source of these materials. Alternatively, this could reflect more localised reworking, with trampling and other processes resulting in breakage of shell and bone, the mixing of distinct anthropogenic deposits, and the introduction of geogenic sand, but with relatively limited lateral redistribution of ash and other anthropogenic components.

4.3.4. Organic material

The single MSU assigned to MF 4.1 can be interpreted as the base of a hearth, where the wood was not fully burnt to ash (Mallol et al., 2017). Some burnt bone fragments are likely to have been discarded into the fire. The mix of fragments with different degrees of heating in the upper portion of the deposit (some exceeding 700°C) indicates that temperatures were not uniform within the hearth. This is supported by charcoal reflectance values, which show charcoal formation at 280°C (Figure S3). Bone fragments at the base of the deposit may have been present on the surface prior to the formation of the hearth (Mallol et al. 2013), and none of the analysed fragments show evidence for heating above 300°C, suggesting limited penetration of heat into the substrate.

The fine charred organic material which dominates MF 4.2, and the association with ash-dominated deposits (MFs 3.1 and 3.3) suggests a hearth base. Two of the four MSUs assigned to this MF have been deformed and compressed, and sand is present in all four. Unburnt organic material (Figure 13c) and some charcoal fragments suggest that the fine charred organic material is the remains of incompletely burnt non-woody plant matter rather than charcoal which has broken down through physical and/or chemical processes. However, these deposits were not analysed using organic petrology. Deacon (1993) argues that fine charred organic material at KRM may have been waste from edible plants, but other material such as grass bedding could also have been burnt at the site. It is unclear whether this is deliberate burning as site maintenance (e.g., Wadley et al. 2011, 2020) or if wood fires were made on discarded organic matter.

4.3.5. Shell

The densely packed roughly horizontal shell in MF 5.1 is consistent with a midden (Aldeias & Bicho, 2016; Villagran et al., 2011; Villagran, 2019). The occurrence of some in situ fragmentation of shell and bone suggests some trampling, but much of the compression is more likely by overburden. This results in a loss of stratigraphic detail, and some of the sand and ash may have been distinct deposits interbedded with the shell (Wurz et al. 2022, Figure 10b). Secondary calcification was due to the percolation of calcium-enriched dripwater (Wurz et al., 2022).

4.3.6. Fine siliceous sediment

Although siliceous silt and clay is present in low quantities in many deposits, MF 6.1 is the only MF type which is dominated by this sediment. Similar discontinuous stringers of geogenic fine sediment seem to represent periods of surface stability at Die Kelders (Goldberg, 2000, p. 54). In this case, it appears most likely that dripwater enriched in ferrous minerals from iron-rich veins in the quartzite transported siliceous silt and clay weathered from the landscape surface or the bedrock itself down into the cave. The precipitated iron is in the form of goethite, a common secondary mineral in caves formed in a wide range of lithologies (Hill & Forti, 1997). This deposit could represent surficial ponding, as suggested by Deacon and Geleijnse (1988) for the

upper surface of the SBLS, but the underlying deposits are far sandier here (Figure 12) than the sediments they described, so this appears unlikely. The increasingly sandy nature of the deposit moving across its sampled extent might reflect increasing distance from the drip location or could be the product of localised post-depositional mixing with the overlying sands.

4.4. Anthropogenic features

The sampled deposits contain variably preserved anthropogenic features which include hearths (Figures 14a-e and 15), middens (Figure 7), dumps (Figures 6 and 16), and palimpsests deformed and mixed by trampling (Figure 14c). The distribution of different deposits is presented in Figure 17. Two features indicative of different behaviours are described and discussed below.

Much of slide 304A is a stacked hearth feature (Figure 15). There is no ash layer above the basal charred MSU, and the overlying sand (MF 1.2) contains reworked ash and small bone fragments. The charred layer appears intact, and its fabric (Figure 15a) is inconsistent with experimental swept hearths (Miller et al., 2010). The ash must have been removed by a natural process gentle enough to cause limited disturbance to the base. Although wind may have removed some ash, it is likely that much of it was dissolved. Another charcoal-rich deposit higher up is also similarly overlain unconformably by ashy sand (Figure 15c). The tissue structures of charcoal fragments in the two charcoal-rich deposits are identical (online Supporting Information), and their reflectance values (Figures S3 and S5) are very similar, suggesting the same wood and burning conditions for both. There is a final unconformity at the top of the stack where ash has been reworked, including in the form of angular aggregates.

Internal lamination in the ash packets (Figure 15b) indicates that, consistent with experimental work (Karkanas, 2021), these deposits were formed by repeated fires. The number of firings between erosional events suggests a high frequency of use, while the lack of evidence for trampling and hearth maintenance indicate comparatively short occupations and/or small groups of occupants (Karkanas et al., 2015; Haaland et al., 2021). The period of exposure required for erosion/dissolution to take place in different cave contexts is unclear, but this can occur rapidly in open-air

settings (Shahack-Gross et al., 2004; Mallol et al., 2007). The loss of ash makes it difficult to assess how many occupational periods occurred, but this feature may have formed across more than four occupations. Although the time ranges for both occupation and abandonment are uncertain, people clearly returned and used the same space for the same purpose across multiple occupations, including after absences in which the hearth was partly buried by a thin layer of sand.

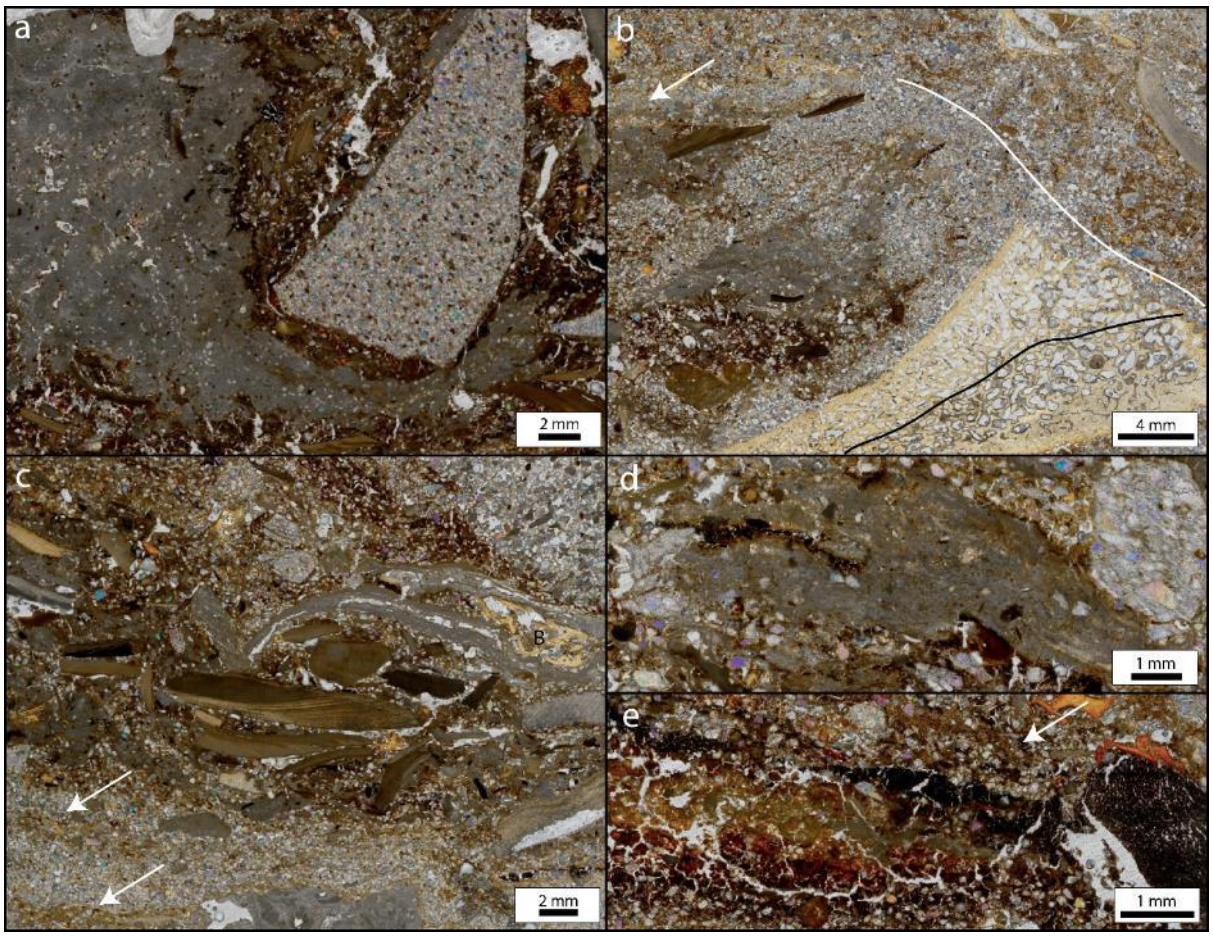

Figure 14. a) Truncated hearth at the base of the SBLS in the western profile, PPL. b) Truncated hearth in the upper LBS, eastern profile, PPL. The white line marks an erosional contact with the infilling SBLS. Note the relatively low proportion of calcareous matrix in the SBLS, both in the infill and above the hearth. The black line indicates the extent of secondary calcification (below the line) and subsequent decalcification (above the line) in an unburnt bone. The white arrow shows the location of a sub-millimetre lens of foraminifera in the MF 1.1 sands above the hearth. c) Compressed (by trampling) anthropogenic or anthropogenic-component-rich deposits in the LBS, eastern profile, PPL. Note the loss of stratigraphic resolution and the crushed unburnt bone fragment (B). Some shell fragments are composed of calcite and others of aragonite. The white arrows indicate thin lenses of (mostly) phosphatised ash within the otherwise largely decalcified MF 1.1 sands below. d) Remains of a combustion feature in the basal gritty sand, eastern profile, PPL. e) A heavily phosphatised hearth in the upper SBLS, eastern profile, PPL. Note the dissolution of the ash associated with the upper charred layer. The white arrow marks part of the deposit of iron-rich silt and clay (MF 6.1) near the contact with the SASL Sub-member.

The sequence of events in sample 301 is illustrated in Figure 16. The lowermost deposits (MF 1.2) are notably richer in anthropogenic matrix and sand-sized pieces of charcoal and bone than is normal for this MF (Figure 16a), indicating relatively high input of hearth materials. The overlying dumped deposits (MFs 1.3 and 2.2) indicate multiple hearth cleaning events in a period short enough that distinct geogenic deposits did not form between them. The evidence throughout 301 for hearth maintenance activities, the mixed use of space (hearths between dumped deposits), and the light trampling of the hearths and of the upper dumped deposits (Figure 16d) are all suggestive of a period of intensive occupation in which anthropogenic materials accumulated rapidly at this location (Miller et al., 2013; Karkanas et al., 2015).

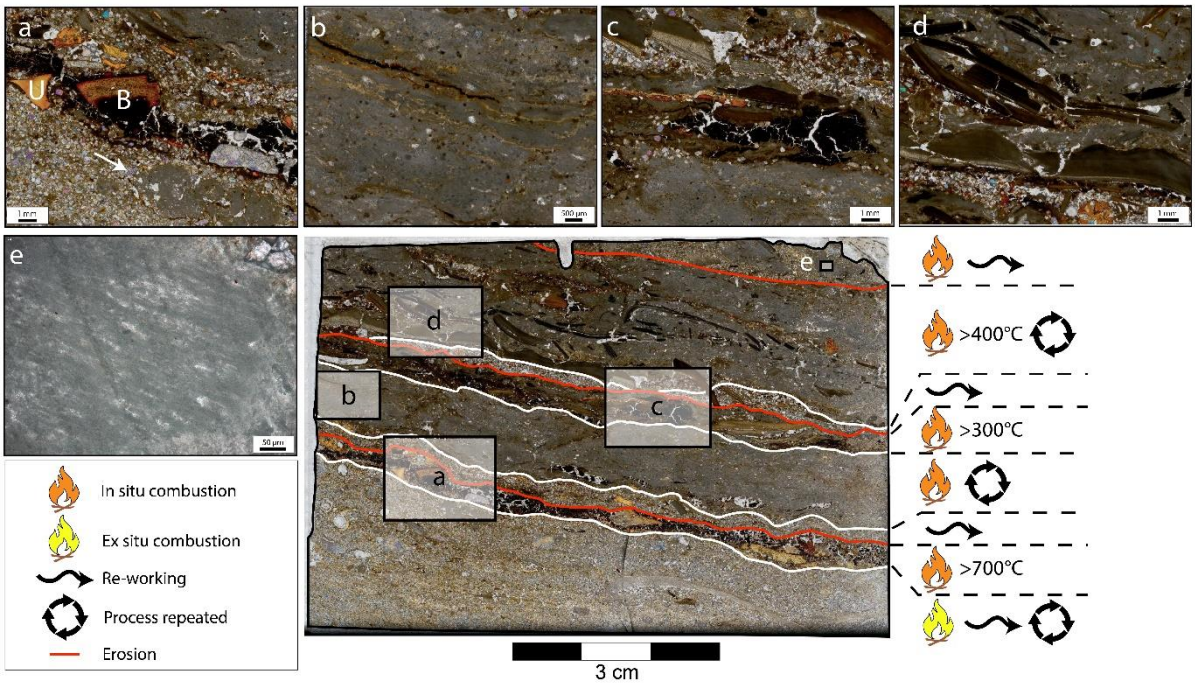

Figure 15. A summary of the anthropogenic processes involved in forming the deposits in slide 304A, LBS, eastern profile. All insets are in PPL. a) The largely intact basal charred layer underlain by MF 1.1 and overlain by MF 1.2. Note the close association of burnt (B) and unburnt (U) bone fragments. No bone in the MF 1.2 deposit was found to be burnt. The white arrow shows a rounded ash aggregate beneath the hearth. b) Alternating laminae of ash, recrystallized ash, phosphatised ash and (less commonly) charred material. Sand grains are distributed throughout at very low density, but sometimes form discontinuous lines of one or two grains thickness. c) Discontinuous charred material with burnt bone and both calcite and aragonite shell fragments (the latter are not pictured) in ash of MF 3.1. Note the unconformable contact with the overlying sand. d) Burnt shell of multiple taxa which were all found to be composed of calcite, indicating a minimum temperature of 400°C. e) Articulated wood ash or calcified charcoal in ash which has undergone limited reworking at the top of the hearth stack.

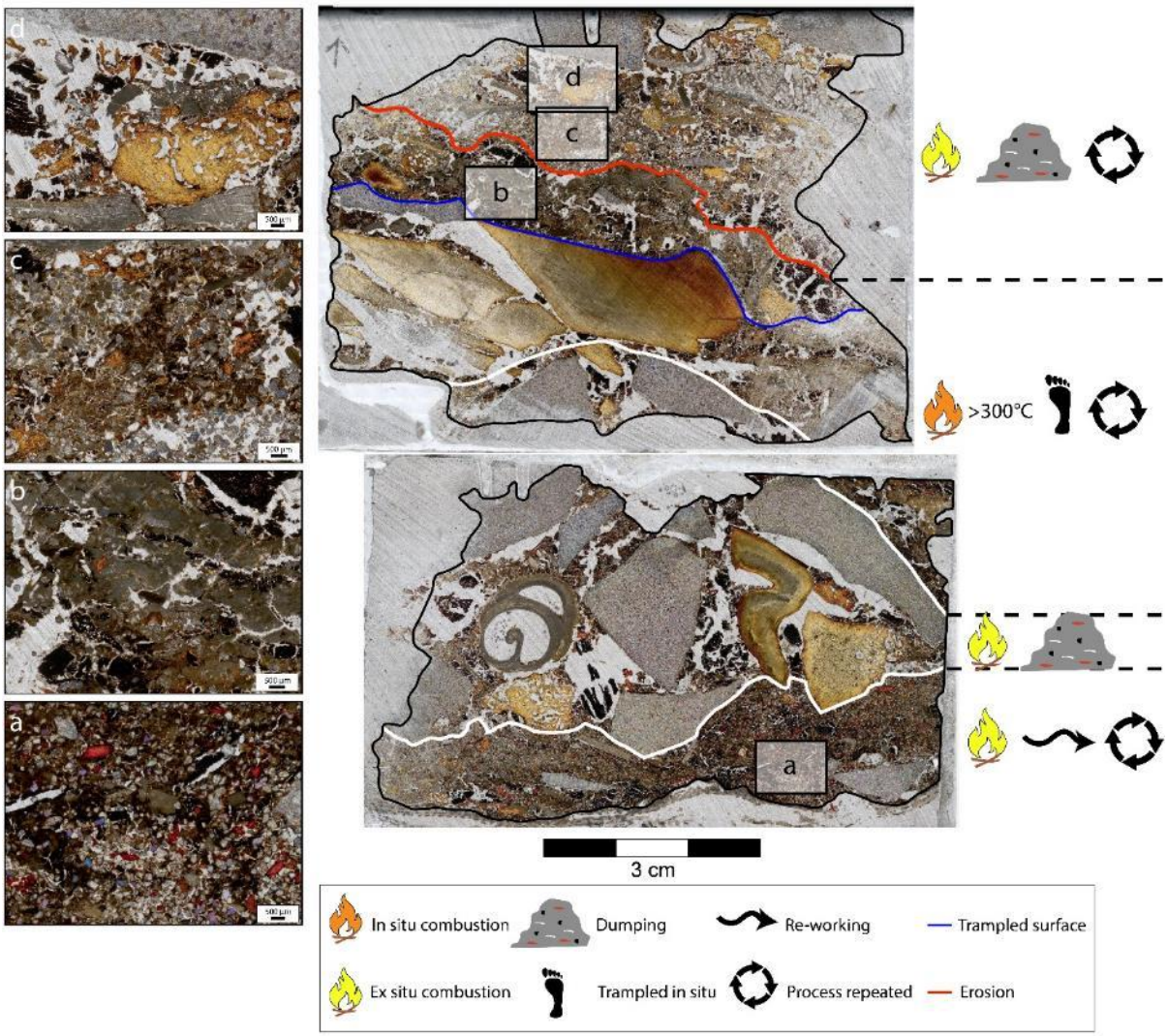

Figure 16. A summary of the anthropogenic processes involved in forming the deposits in slides 301A (above) and 301B (below), SBLS, western profile. All insets are in PPL and are arranged in stratigraphic order on the left side of the figure. a) Ashy sand (MF 1.2) which is particularly rich in ashy and charred matrix, micro-charcoal, and small (apparently) burnt bone fragments. b) Lightly trampled ash of MF 3.2. Note the undulating thin charred lenses and the variable recrystallisation and phosphatisation. c) An area of the MF 1.3 deposits which is particularly rich in ashy and charred organic matrix. d) A portion of the MF 1.3 deposits which is dominated by sand-sized and larger bone and shell fragments, with some charcoal but little matrix. The broken shell and crushed bone (unburnt in this case) are rare examples of in situ breakage of clasts.

4.5. Diagenesis and hiatuses

Intact and reworked crusts are present in several parts of the sequence (Figures 13 and 17). Thin localised and/or reworked apatite crusts occur in the basal gravel at the western location. Thicker and less disturbed, sometimes discontinuous, apatite crusts are present in the deposits at the transition between the LBS and SBLS in the west and at the contact between the LBS and SBLS in the east. A roughly linear zone rich

in numerous small sub-angular goethite aggregates with sand inclusions (Figure 13d-e) in the eastern SBLS is the reworked remnants of another crust. It likely formed in a similar manner to MF 6.1, but the dripwater contained limited siliceous silt and clay and was more heavily enriched with iron. All crusts indicate periods of surface stability (Hill & Forti, 1997; Karkanas, 2017; Haaland et al., 2021; Morrissey et al., 2023), followed by differing degrees of disturbance of these surfaces.

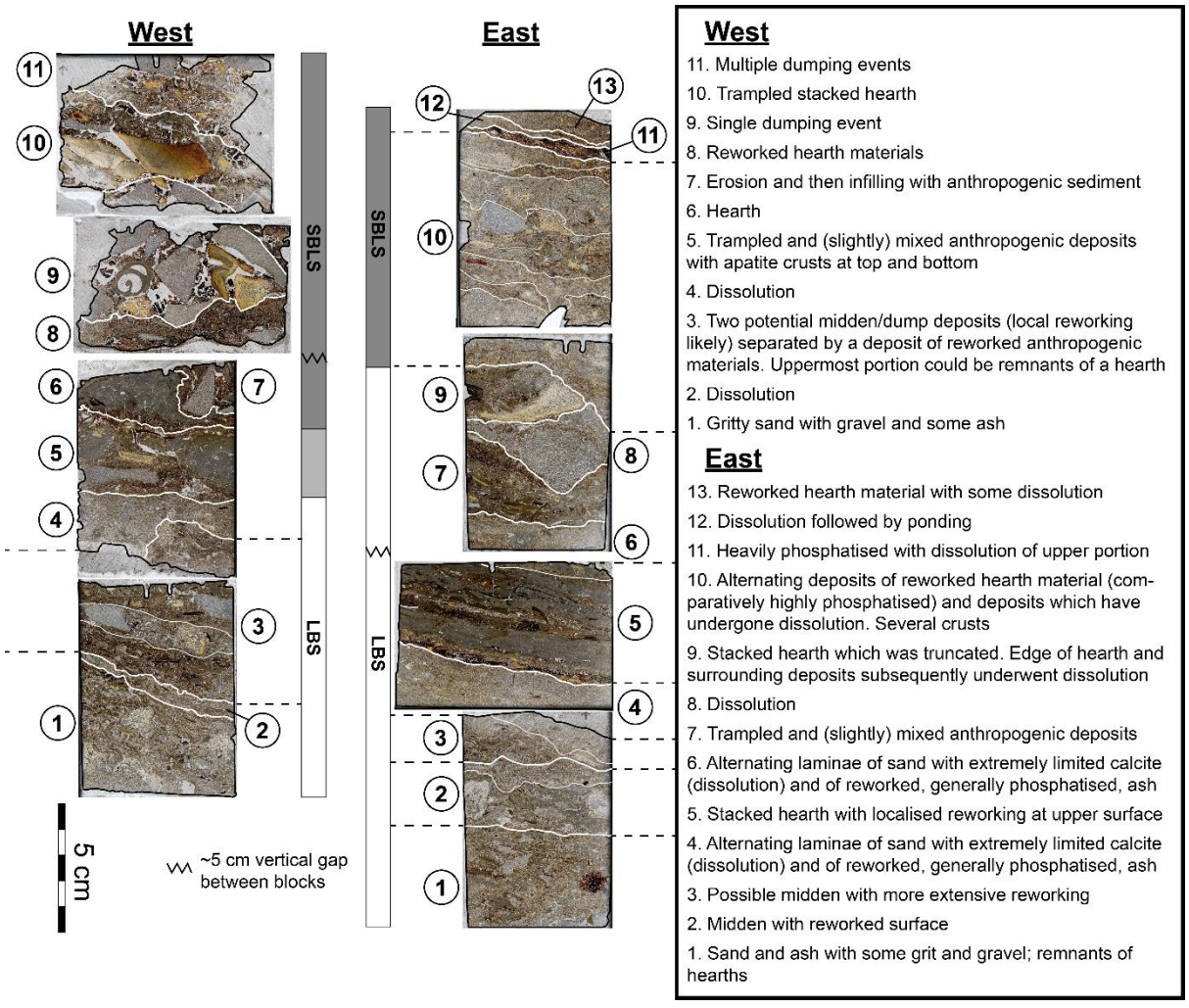

Figure 17. Interpretive microstratigraphy of the western (samples 302 and 301) and eastern (samples 304 and 303) profiles. Note that microstratigraphic units have often been grouped due to representing the same general set of processes or due to cycles of multiple repeated events/processes.

The recrystallisation, cementation, and phosphatisation of ash all improve preservation (despite destruction of some original ash morphologies) through reducing the potential for dissolution and physical disturbance (Mentzer, 2014; Mallol et al., 2017). Repeated firings are also beneficial for ash preservation (Karkanas, 2021).

Organic petrology observations of charcoal-rich deposits in 304A reveal the degradation and diagenesis of both charcoal and fat-derived char, and variation in the intensity of these processes between MSUs (online Supporting Information). Similar processes were recorded by Larbey et al. (2019) in the LBS in the southern end of the Witness Baulk. Unlike in past work, there is evidence from both micromorphology (Figure 15e) and organic petrology (Figure S6) for the replacement of wood or charcoal by calcite, but this phenomenon is poorly understood. Although these observations are limited to a single slide, they may explain the rarity and variable preservation of hearth bases in the sampled deposits.

The calcification of bone through precipitation of secondary calcite occurred in some cases, and a few of these bones have undergone subsequent incomplete dissolution of the secondary calcite (Figure 14b). The dissolution of shell (to varying degrees) is common (see the elemental maps in Figures 5-8). Delamination is visible, and this can be confidently attributed to heating in some cases but in others could be a result of the precipitation of salts (Wurz et al., 2022). Bone and shell have been impacted by trampling in many deposits, but particularly in the reworked sandy MF types. Trampling has also contributed to a loss of stratigraphic detail due to compression and mixing (Figure 14c).

The microcontextual evidence shows that both physical and chemical processes have impacted the preservation of shell and bone, but detailed taphonomic studies of excavated assemblages (e.g., Reynard, 2022) will provide greater insight into these impacts and any spatial or temporal patterns in occupational intensity. The dissolution of ash and shell observed in many deposits is the most significant destructive diagenetic process and requires greater consideration here.

The alternation of various ash-rich MSUs and the sand of MF 1.1 suggests that the dissolution of calcite at the sampled locations occurred at, or very near, the surface. The length of time a deposit is exposed is controlled by depositional rates, with slower deposition or a depositional hiatus (with or without erosion) both resulting in longer exposure and greater diagenetic potential. The regularity and nature of anthropogenic deposition can have a marked impact on deposit exposure in cave and rockshelter contexts, as it is generally more rapid (but less continuous) than geogenic deposition

(Morrissey et al., 2023). Exposure time is not the only potential factor at play. A lower proportion of ash within a deposit reduces the pH buffering effect of calcite, making dissolution of any ash and shell that is present more likely (Berna et al., 2004; Sherwood et al., 2004; Miller et al., 2013). A deposit containing less ash would be impacted more heavily by the same period of surface exposure than an ashier deposit. The occurrence and intensity of diagenetic processes may also vary over space and time within a site (Schiegl et al., 1996; Goldberg, 2000; Wurz et al., 2022), further complicating the matter.

There is a clear spatial pattern in the diagenesis of the LBS, with fewer partially decalcified deposits in the western profile than the eastern profile (Figures 5-8 and 17). This is even stronger in the SBLS, with no decalcified deposits in the west, and MF 1.1 making up roughly half of the member in the east. The sands in the western SBLS are particularly high in ashy and fine organic matrix, with a higher density of small charcoal and bone fragments than most other MF 1.2 deposits. In contrast, MF 1.2 MSUs in the east contain less matrix than those in the LBS, with greater ash phosphatisation. The MF 1.1 deposits in the eastern SBLS also appear more completely decalcified than those in the LBS. A poorly preserved hearth is the only anthropogenic feature in the eastern SBLS (Figures 14e and 17).

The general pattern of greater dissolution in the east is probably due to cave morphology. The roof is relatively low on the western side of the Witness Baulk but rises steeply on the eastern side (Singer & Wymer, 1982, Figure 3.3). Small ledges and crannies are common, and this area is, and would have been, attractive as a bird roosting area due to the greater availability of suitable surfaces with more physical distance from non-avian predators. A pattern in the distribution of guano should be present unless there have been changes to the ceiling due to rock fall, speleothem development, or other factors. Periods with higher concentration of guano in this location probably also reduced the likelihood of it being used as an activity area.

The greater difference between the two sampled locations in the SBLS could have been influenced by the decreasing distance between the accumulating deposits and the lower roof in the west, but other factors seem to be more important. Anthropogenic deposition appears to have been markedly higher in the western SBLS (Figure 16),

with a resulting increase in preservation potential due to shorter exposure times and greater pH buffering. The sudden increase in microfauna and fish remains in the eastern profile seems to reflect less human occupation of the cave and the congregation of birds in this area. In other areas of the site complex, in particular Cave 2, localised absence of bone appears to reflect particularly intense diagenesis. However, minerals like leucophosphite also form under conditions conducive to bone dissolution (Karkanas et al., 2000) and, although leucophosphite is present in Cave 2 (Wurz et al., 2022), it was not observed in any of these thin sections. This suggests that the increase in the density of microfauna remains is not due to a significant change in the intensity of diagenesis. Alongside the distinguishable microfauna, the MF 1.1 and 1.2 deposits contain more relatively large bone fragments than their counterparts in the LBS, suggesting a reduction in trampling. A reworked iron-rich crust (Figure 13d-e), a heavily phosphatised hearth (Figure 14e), and the silt and clay deposit assigned to MF 6.1 all support the idea of greater surface exposure, including hiatuses, of the SBLS in the east.

The SBLS deposits on either side of the Witness Baulk appear to represent highly contradictory situations. In the west, well preserved anthropogenic features/deposits with little indication of significant occupational and/or depositional hiatuses; in the east, poorly preserved and far less common anthropogenic features, and clear evidence for a comparatively low rate of anthropogenic deposition, periods of abandonment, and depositional hiatuses (Figure 17). The proposed explanation is that there were periods of intensive activity in the cave, but also periods of abandonment or far lower intensity occupation. Spatial patterns in both human activities and biogenically driven diagenesis then resulted in greater susceptibility to dissolution and phosphatisation in the east and lower potential for these processes in the west. A broadly similar pattern of preservation being controlled by both human choice of where to carry out different activities and geomorphic controls on biological activity (bioturbation in this case) has been inferred at Üçağızlı II Cave in Turkey (Baykara et al., 2015).

This extreme variation in properties highlights the significance of anthropogenic deposition in Cave 1, as spatial and temporal patterns impact the likelihood of distinguishable anthropogenic features and deposits being preserved and studied. Anthropogenic deposits are common in the SBLS in the southern end of the Witness

Baulk (Figure 4) and are relatively well preserved, with some hearths surviving significant plastic deformation while remaining otherwise intact (Wurz et al., 2022). As in the western location, the high density of anthropogenic deposits and a lower roof likely played a role in this preservation.

5. DISCUSSION

5.1. Stratigraphic implications

Stratigraphic correlation within and between different recesses at KRM is complicated due to both variation and similarities in sedimentary properties, and comparatively limited recording during the initial excavations (Morrissey et al., 2022). The new insights into site formation from this study have several significant implications for the stratigraphy of Cave 1 and beyond.

The properties of the SBLS deposits differ significantly between the two sampling locations (Figure 4). If these sets of deposits were encountered on either side of one of Wymer's excavation trenches, without the means to directly track stratigraphic relationships between them, they might easily be considered distinct lithostratigraphic members. Therefore, the specific set of site formation processes which occurred at a particular location, including a range of potential human behaviours, has a considerable impact on whether deposits would be correctly correlated (or not correlated) across the site complex.

Plastic deformation of deposits at the western and eastern sample locations is limited in comparison to most of the current excavation area, especially in the east (Figure 4). The limited extent of this contorted bedding across Cave 1 is highlighted by Singer and Wymer (1982, Figure 3.24). This suggests that the deformation is due to the collapse of the large tufa/speleothem column (and perhaps other previously excavated pieces) into the deposits, with subsequent uneven loading as overlying deposits accumulated. Although they have been presented as a defining characteristic of the SBLS (e.g., Deacon & Geleijnse, 1988), these contortions, and occasional relatively clast-rich zones which led to the deposits being called the RBS, are not truly representative of this member (Morrissey et al., 2022, pp. 19–20). However, they do

represent important localised depositional and/or post-depositional events which are vital for understanding the deposits in these locations.

Attempts to correlate the MSA I deposits across the site complex have met with mixed success (Morrissey et al., 2022). General similarities in sedimentary properties and stratigraphic position mean that the correlation of the LBS deposits in Cave 1 and Cave 1A has been uncontroversial. In contrast, suggested correlations of the SBLS with deposits in Cave 1A (units SCB2 to SCB1) and Cave 1B (Wymer's Layer 10) (Deacon & Geleijnse, 1988; Grine et al., 2017) have subsequently been shown to be inaccurate (Morrissey et al., 2022, 2023).

As the SBLS appears to be the product of particularly intensive occupation and a specific set of post-depositional conditions, contemporaneous deposits in these areas would very likely have differing properties. Therefore, it is possible, but not guaranteed, that some of the upper LBS deposits in Cave 1A could correlate with the SBLS (Morrissey et al., 2022, Figure 9d). The formation of the RS Member in Cave 1B likely spans part of the same period as the LBS in Cave 1, and all or part of the period in which the SBLS was deposited (Morrissey et al., 2023). Any temporal patterning in the composition of MSA I faunal and lithic assemblages excavated at high resolution during the Deacon and Wurz excavations could help with making finer stratigraphic correlations across the site complex independent of lithology (Discamps et al., 2023).

5.2. Behavioural significance

The MSA and Middle Palaeolithic are characterised by increasing structuring and maintenance of sites which, along with many other lines of evidence, provides insight into the evolution of modern human behaviours during this period (e.g., McBrearty & Brooks, 2000; Conard, 2015; Clark et al., 2022; Scerri & Will, 2023). Intensity and frequency of occupation, and the activities for which a space is used all impact the expenditure of effort and time on structuring and maintenance (Miller et al., 2013; Haaland et al., 2021; Clark et al., 2022). However, it can be difficult to quantify both sides of this equation at a site, especially when faced with imprecise dates and spatial and/or temporal variation in the preservation of evidence.

The MSA I shell middens at KRM are among the few known occurrences pre-dating 100 ka in South Africa (Jacobs, 2010; Karkanas & Goldberg, 2010; Niespolo et al., 2021; Tribolo et al., 2022; Wurz et al., 2022). These features are significant because they show occupational intensity and exploitation of marine resources that are both high enough to result in the formation of distinct shell-dominated dumps (e.g., Deacon, 1995; Marean, 2014; Niespolo et al., 2021; Wurz et al., 2022). Dumps other than shell middens have received comparatively limited attention in the MSA due to the strong interest in coastal adaptations, but still indicate structuring and maintenance of space (Goldberg et al., 2009; Miller et al., 2013).

The intensity of occupation in Cave 1 in the LBS and SBLS appears to have been higher than has been inferred for the MSA I-bearing RS Member in Cave 1B (Morrissey et al., 2023). However, this is somewhat deceptive. Cave 1 is far more sheltered than Cave 1B because it is more closed, but also because the mouth of the cave is east-facing. In contrast, Cave 1B is particularly exposed to the winter westerlies which were the most geomorphologically effective winds along the southern Cape coast throughout the Middle and Late Pleistocene (Roberts et al., 2014). Unlike the studied Cave 1 deposits, geogenic units are fairly common in the RS, and anthropogenic deposits are rare and generally poorly preserved (Morrissey et al., 2023). It is almost certain that the rate of geogenic deposition was far higher in Cave 1B. Within the enclosed space of Cave 1, the limited geogenic sediment would have been easily mixed with anthropogenic sediment by trampling and site maintenance activities even without very regular or intensive occupation. The anthropogenic signal in Cave 1B would be comparatively diluted due to the more rapid geogenic deposition, even without the difference in the preservation potential of ash and any possible variation in how the two spaces were utilised.

The anthropogenic features/deposits in the sampled LBS do not seem to indicate a stable level of occupational intensity throughout the formation of the member. The properties of the SBLS have long been suggested to represent significant anthropogenic input, with Singer and Wymer (1982, p. 16) referring to these deposits as an “occupational soil” (see Morrissey et al., 2022, p. 34 for discussion of their use of “soil” in this case). Given the excellent preservation of some features in the LBS in Cave 1 (Larbey et al., 2019; Wurz et al., 2022; this study), and the nature of the

deposits in the SBLS at the western sample location (Figure 16), the significant increase in anthropogenic sedimentary components in the SBLS must reflect a change in occupational intensity and/or reduced geogenic deposition rather than widely differing preservation potentials. A period of sea-level regression and the resulting hypothesised formation of a barrier dune between KRM and the sea (Deacon & Geleijnse, 1988; Deacon, 1995) would have led to reduced aeolian deposition across the site complex (and a corresponding increase in the contribution of colluvial silt and sand from deposits around and overlying KRM). This possibility is supported by evidence for a notable reduction in allogenic deposition in Cave 1B associated with the end of the MSA I (Morrissey et al., 2023).

Changes in occupational intensity over time, with differing degrees and types of site structuring and maintenance and other anthropogenic disturbances, have been noted at several South African MSA sites studied at the microscale (Goldberg et al., 2009; Wadley et al., 2011; Miller et al., 2013; Karkanas et al., 2015; Haaland et al., 2021). At Blombos Cave and Pinnacle Point 5-6, these changes in site use correspond to the transition from MIS 5 to the colder MIS 4 and likely reflect a range of adaptations to changing resource availability (some driven by lower sea levels) and physical conditions (Karkanas et al., 2015; Haaland et al., 2021).

The MSA I deposits formed during a period spanning late MIS 6 to early MIS 5d (Wurz et al., 2022; Morrissey et al., 2023). This period is associated with multiple significant changes in sea level in relatively quick succession (Cawthra et al., 2018: Cooper & Green, 2021). Terminal MIS 6/early MIS 5e is associated with a rapid rise to above current levels from more than 90 m below present (at times greatly exceeding 12 m per 1000 years [Grant et al., 2012]), while there is a notable decrease from ~120 ka. There is some evidence for the occurrence of two highstands separated by a relative lowstand during MIS 5e, but this is not universally accepted (Cooper & Green, 2021). Changes in local resource availability, the attractiveness of KRM for occupation, and aeolian depositional rates (which are influenced by shoreline position and geomorphology) would have occurred during these events, but it is not currently possible to confidently link the boundary between the LBS and SBLS to any particular event.

The ongoing excavation and analysis of MSA I lithic and faunal assemblages and anthropogenic features in the Witness Baulk will provide more detailed, and better contextualised, evidence with which to further assess changes in occupational intensity (e.g., Haaland et al., 2021). These data, along with any further dating of the MSA I deposits, could also provide clarity on what role (if any) sea levels and other environmental or geomorphic factors played in driving behaviours which led to changing occupational intensities within and between members and/or causing changes in the rate of geogenic deposition in Cave 1.

6. CONCLUSIONS

The application of a microscale geoarchaeological approach to deposits north of the Witness Baulk excavation has provided insight into events which likely took place in periods of hours or days and revealed the cumulative effects of thousands of years of depositional and diagenetic patterns. The results have improved our understanding of the MSA I deposits in this part of Cave 1 and, along with previous work on the southern end of the baulk, provide vital context to the interpretation of excavated assemblages and features.

The significant roles of both natural processes and human behaviour in forming deposits, and clear evidence for spatial patterns in both, highlight the importance of clarifying site formation processes when attempting to understand stratigraphic relationships over even comparatively short distances. As the lithostratigraphic members and sub-members have often been presented as monolithic, and human behaviour typically interpreted in large time slices spanning entire lithic cultural phases, this also has important implications for how excavated assemblages are viewed.

Given that the MSA I pre-dates 110 ka, evidence for the structuring and maintenance of space within Cave 1 throughout this period is significant. The behavioural insights gained from individual anthropogenic features/deposits is highly informative about specific events or sequences of related events, but the patterns of both intra- and inter-member variation in occupational intensity and/or frequency provide a broader view of changes in the use of the site over time, although potential variation in geogenic

depositional rates is a complicating factor. Integration with data from excavated assemblages and a better understanding of the ages of the LBS and SBLS will provide a fuller picture of these changes, and the context with which to better understand human adaptation to varying local and regional conditions during a period of significant global change.

ACKNOWLEDGMENTS

Kathryn Croll assisted with micromorphology sampling and took field photographs. Thin sections were prepared by Panos Kritikakis. The support of GENUS (DSI-NRF Centre of Excellence in Palaeosciences, UID 86073 to Peter Morrissey, and Grant 86073 to Sarah Wurz) toward this research is hereby acknowledged. The authors also acknowledge the Palaeontological Scientific Trust (PAST) for a fieldwork grant and the Baden-Württemberg Ministerium für Wissenschaft, Forschung und Kunst for funding a research fellowship to Peter Morrissey to facilitate microscale analysis. Opinions expressed and conclusions arrived at are those of the authors and are not necessarily to be attributed to any of these funders.

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SUPPORTING INFORMATION

Supplementary Information for: *Burning, cleaning, dumping and dissolution: insights into the role of human behaviour and diagenesis in the formation and stratigraphy of pre-110 000-year-old MSA I deposits in Cave 1, Klasies River Main site, South Africa*

This document contains further information on (1) the microstratigraphy, and (2) the results of the organic petrology analyses that were conducted on the upper part of block KRM-20-304.

1. MICROSTRATIGRAPHY

General microfacies descriptions are provided in Table 1 in the paper. Microstratigraphic units are largely described here based on deviation from the general descriptions and/or details not included in the general descriptions. The microstratigraphic units are visible in Figures 6 – 8 in the paper.

1.1. Western profile

All the deposits in 302B dip to the south at angles ranging from 10° to 20°, which is due to a slope in the underlying bedrock at the sample location. All contacts are somewhat diffuse, with the deposits grading into each other over a few millimetres. The lower half of the slide is dominated by two MSUs of fine quartzite gravel (MF 2.1), which are distinguished from each other primarily by the lower containing less

calcareous material and more phosphate within the matrix. However, the upper deposit includes some very small apatite nodules and very localised apatite crusts. A near vertical clast with a thin apatite coating on one of its edges suggests the reworking of a crust. The overlying deposit is shelly sand (MF 1.1) which contains a few ashy lenses roughly halfway up the deposit and features a small ash pocket underneath a quartzite clast. There is a concentration of shell which appears to be from a single shell which has undergone dissolution, delamination, and in situ fragmentation. The following deposit is sandy ash (MF 3.3) which is rich in shell fragments of varying size, including a *Turbo sarmaticus* operculum. A few pieces of shell have undergone significant dissolution, and there are both calcite and aragonite fragments. While there is a general preferred orientation of fragments (matching the slope of the deposit), there are concentrations of smaller fragments which differ from the trend. This deposit is overlain by an MSU of ashy shelly sand (MF 1.2) with relatively chaotic inclusions and some domains with limited ashy matrix (similar to MF 1.1). The large bone fragment in this deposit was heated below 600°C. The final deposit in 302B is sandy ash (MF 3.3) with a high proportion of sand relative to most deposits assigned to this MF type. As with the lower MF 3.3 deposit, there is a general trend in orientation, but this trend is weaker and more of the smaller inclusions have varied dip angles and directions. Dissolution and delamination of shell were both observed, and there are both heated and unheated fragments.

There is no significant gap between slides 302B and 302A, but the loss of material at the base of 302A during thin section production has created an artificial gap across much of this slide. The sandy ash in 302B continues but is preserved in only the northern corner. The only notable feature is a small pocket of concentrated sand and bone fragments. The sandy ash (MF 3.3) has some domains of relatively pure ash (similar to MF 3.1), and of shelly sand with limited inclusions (similar to MF 1.1). Overall, this deposit contains numerous preserved small, charred plant structures and articulated fine charcoal, but is also rich in small, angular bone fragments. The larger bone fragments have undergone minor calcification. Shell in the upper portion of the MSU is relatively heavily dissolved. This deposit is truncated both laterally and vertically, with the same MSU both next to and above it. The shelly sand (MF 1.1) in this MSU is notably porous compared to most other sandy deposits, with both relatively large packing voids and some channels observed. There are a few pockets with ashy

matrix or secondary calcite, but much of the ash has been phosphatised. Large shell fragments, rounded ash aggregates, and tufa are relatively common, but all have undergone some dissolution. The upper contact of this deposit is fairly diffuse, with a gradual increase in the proportion of ashy matrix. The overlying ashy sand (MF 1.2) contains an apatite crust which ranges from 0.4 to 1.5 mm in thickness. Although there are a few local discontinuities, it can be tracked across the width of the slide. However, it has been deformed, and there is some localized reworking at its upper surface (Figure 13b). The layer of fine charred organic material and ash (MF 4.2) above it is similarly deformed but contains some well-preserved pieces of unburnt organic material (Figure 13c). Several small channels and a larger (1.2 cm wide) partially filled channel or chamber cut through both deformed deposits. A lithic artifact and a piece of tufa (both more than 2 cm) in the two overlying ashy sand (MF 3.3) deposits directly overlie the two areas of deformation. The upper of these two deposits also includes the lower portion of a ~1.5 cm piece of speleothem which contains three associated bone fragments. The speleothem has undergone some dissolution, most notably at its base. Its upper half falls within another MSU of sandy ash (MF 3.3) which is weakly phosphatised throughout. Part of its upper surface is marked by one or two discontinuous crusts of ash heavily altered to apatite. Isolated apatite nodules and zones with a similar degree of alteration are present across the rest of the surface. This MSU also includes a shell-rich area with no matrix and very little sand, where the relatively well-preserved shell has been broken in situ. The contact with the fine charred organic-dominated (MF 4.2) deposit above is somewhat diffuse where crusts are absent. This MSU also contains some areas of highly phosphatised ash, including a ~1.6 cm wide apatite crust. There is some delamination of shell. The overlying deposit is ash with very rare coarse inclusions and little sand (MF 3.1). There are many small channels within the partially recrystallized ash, and a few very small pieces of partially calcified charcoal. Phosphatisation is relatively limited. Some of the shell has been delaminated, and all analysed fragments are composed of calcite. The ash is truncated laterally, and the infilling material is sandy ash (MF 3.3) which is particularly rich in fine organic material. Most inclusions dip almost vertically, including a lithic which has pure ash cemented along one of its (now) vertical surfaces.

There is a ~5 cm gap between the top of 302A and the base of 301B.

The bottom third of 301B comprises three MSUs of ashy sand (MF 1.2) which are notably richer in ash, charcoal, and fine organic material (the latter dispersed within the ash) than other deposits assigned to this MF type. Small angular bone fragments, many of which appear burnt or stained, are also particularly common. The contact with the overlying heterogenous gravel (MF 2.2) deposit is fairly sharp. This MSU fills much of the rest of 301B and continues up into the bottom 1.5 cm of 301A. Only one of the larger bone fragments is burnt, and the complete *Burnupena limbosa* shell is unheated. The deposit has a steep (~40°) and sharp contact with a deposit of ash with coarse inclusions (MF 3.2). The ash in this MSU is relatively heavily phosphatised and is rich in charcoal and small angular bone fragments. Despite the steep contact with the MF 2.2 deposit, charred lenses and some inclusions still have a roughly horizontal orientation. This MSU also continues into the base of 301A. Both deposits are overlain by another MSU assigned to MF 3.2 which is notable for several large pieces of unburnt bone which fractured in situ, and a lithic artifact directly overlying the broken pieces. The thin, undulating charred layer at the base of the MSU contains a rounded aggregate of cemented and phosphatised organic-rich ash. The overlying deposit drapes over the bone and lithic. It is ash with patchy phosphatisation (MF 3.2) which is rich in charcoal, including small, dispersed pieces, distinct lenses, and large chunks. Channels are common. Another MSU of MF 3.2, containing less phosphate and dispersed charcoal, but more bone, follows. The bone has been slightly calcified, and several pieces were burnt below 600°C. There are numerous undulating charred lenses, with some altered to apatite and only minor traces of charred material remaining. Channels and planar voids are common. This deposit is truncated laterally and across at least some of its upper surface. The laterally adjacent MSU is assigned to MF 1.3 but is particularly rich in charcoal and less sandy than the overlying deposits. The remaining three MSUs are all assigned to MF 1.3 but vary somewhat in their composition. The MSU directly overlying the ash deposit is relatively sandy and has areas with little or no bone. The next deposit is less sandy and richer in bone and charcoal. Its upper surface slopes toward the north. The uppermost MSU contains several relatively large clasts, two of which – a lithic and a *T. sarmaticus* operculum – lie on the surface of the previous deposit. The operculum lies on top of a domain in the underlying MSU where the sand grains are densely packed. This is the only such occurrence in any of the MF 1.3 deposits. The area between the large clasts in the uppermost deposit contains particularly loose bone- and charcoal-rich sand.

The porosity of all MF 1.3 and 2.2 deposits in slides 301A and B has been increased to an extent by the accidental removal of some soft material (charcoal and ash) during thin section preparation. MF 3.2 has also been affected, but to a lesser degree. However, comparison to the chips and visual analysis of the slides suggests that the porosity of these three MFs prior to thin sectioning was still higher than the other deposits sampled in this study.

1.2. Eastern profile

The lower half of 304B comprises two MSUs of ashy sand (MF 1.2) which are relatively rich in quartzite clasts and organic-rich ashy matrix. The quartzite is predominantly angular and ranges from coarse sand-sized to ~1.3 cm. The lower MSU contains several ash pockets with distinguishable internal laminae of fine charred organic material and apatite (Figure 14d), and phosphatised patches. Another notable feature is a ~1 cm wide moderately to strongly impregnated iron- and manganese-oxide orthic nodule. Dissolution and delamination of shell occur in both deposits, and some shell has been heated. There is an increase in large shell pieces in the upper of the two MSUs as it grades into the overlying shell-rich MSU assigned to MF 5.1. The compressed shell in this deposit is typically horizontal, with localised more steeply dipping shell due to the presence of harder inclusions and sandy lenses. The largest bone in the deposit is filled with loose ashy shelly sand (see elemental map of 304B in Figure 7), suggesting it was broken or cut prior to being discarded. The large bone fragments are not burnt. Both calcite and aragonite shell fragments are present. The upper contact of this deposit is unconformable, with a small (~1 cm wide) erosional hollow. The three overlying deposits are all ashy sand (MF 1.2) but differ somewhat in their properties. In the southern half of the slide, there is an MSU which is particularly rich in bone fragments, including some clear in situ breakage. Unusually for this MF, almost all the ashy matrix has been phosphatised. There is also a ~2 mm wide fragment of ochre. The erosional hollow is filled with a deposit rich in near-horizontal to horizontal shell fragments, while the sediment on either side has a similar composition but the shell has a markedly more horizontal orientation. These MSUs grade upwards into a particularly shell-rich and sandy deposit of MF 3.3. The shell fragments range from a few millimetres to more than 2 cm, and are often horizontal, but in some areas are chaotic. Both delamination and dissolution occur. Most charcoal

fragments are heavily phosphatised, but the ash itself has undergone very limited alteration. There are several pieces of partially calcified organic material, one of which appears to be unburnt. The sloping upper contact of this deposit is diffuse, grading into ashy shelly sand (MF 1.2). This MSU is typical of this MF type but has several zones of near horizontal inclusions at its base, and the matrix is relatively rich in apatite. As with the underlying deposit, some charcoal is particularly heavily phosphatised. Some shell has undergone significant dissolution.

There is a gap of roughly 2 cm between the uppermost MSUs in 304B and the base of 304A. All the deposits in 304A have the same ~10° dip towards the south. The lower portion of the slide comprises three distinct deposits of shelly sand (MF 1.1). In the basal MSU, the sand is interbedded with apatite laminae. The presence of unaltered ash and some fine organic material indicates that the laminae were originally wood ash with some sand and fairly small (<5 mm) coarser inclusions, similar to MF 3.3. The top of this MSU is marked by a similar laminate which is relatively unaffected by phosphatisation. It is associated with an almost whole (in section) mussel shell and several probable fish bones. Some shell has undergone minor dissolution, and there are both calcite and aragonite pieces in this MSU. The overlying sand has virtually no calcareous inclusions, but the MSU above it contains both rounded to sub-angular aggregates of (mostly) recrystallized ash, and sub-millimetre lenses of organic-rich ash. The aggregates have been partially dissolved. There is a sharp contact with the overlying charcoal dominated MF 4.1 deposit. This thin layer, less than 6 mm thick, is overlain unconformably by a particularly bone-rich deposit of ashy sand (MF 1.2) of similar thickness. Sub-millimetre ashy lenses are common in this MSU, and there are several larger concentrations of ash. Analysed bone fragments were not burnt, and there are both calcite and aragonite shell fragments. The following two MSUs are both ash (MF 3.1), with the upper rich in charcoal and shell. The very rare coarser inclusions in the lower deposit are shell fragments composed of calcite and mostly unburnt bone. The more numerous inclusions in the upper MSU include a mix of calcite and aragonite shell fragments, and bone fragments which are almost all burnt below 600°C. The deposit overlying these two ash-dominated MFs is another laminate of ashy sand (MF 1.2) which lacks the bone in the earlier MF 1.2 deposit, but contains a mix of calcite and aragonite shell fragments. A 5 cm wide shell, fragmented in situ and clearly heated, lies across more than half the surface of this deposit. The following three

MSUs are ash-dominated and are assigned to MF 3.1. The first is shell-rich and relatively heavily phosphatised, the second is also rich in shell, and the third contains very few inclusions. The shell in these three MSUs is almost all calcite (with all fragments in the lowermost composed of calcite), but the rarer bone fragments are unburnt. All the MF 3.1. deposits in this slide contain at least one example of small charcoal fragments which have been partially or completely replaced with secondary calcite (Figure 15e). The uppermost MSU in 304A is ashy sand (MF 1.2) with several relatively large (up to ~1 cm) angular ash aggregates, one of which contains two pieces of completely calcified charcoal.

The gap between the top of 304A and the base of 303B is around 5 cm. The basal MSU in 303B is shelly sand (MF 1.1) interbedded with laminae of sandy ash similar to MF 3.3. The ash is relatively heavily phosphatised, particularly in the uppermost laminate, which is extremely rich in foraminifera, to the extent that there are lenses composed entirely of them. A ~1.5 cm piece of tufa is the most notable inclusion. The overlying deposit is also assigned to MF 1.1. It contains a few discontinuous ash lenses, some of which are very rich in foraminifera. Sand-sized apatite nodules are relatively common in a few areas. This deposit grades into two ash rich MSUs. The first is a thin wedge of ash with some coarse inclusions (MF 3.1), which is overlain by a very shell-rich sandy ash (MF 3.3) with some sandier lenses. The remainder of the ash deposit appears to have been reworked into the latter MSU. The MF 3.3 MSU has been deformed at its upper surface, and seemingly compressed to some extent. In contrast to lower down, the shell in the upper portion of the MSU has been broken in situ and has undergone dissolution. Some bone has also been fragmented in situ. None of the bone is burnt. The shells include some composed of calcite and some of aragonite. There is a discontinuous band of phosphatised ash at the surface of the deposit to the south. This MSU is overlain by deposits of ashy sand (MF 1.2) and fine charred organic material (MF 4.2), the latter of which has also been deformed and compressed. A thin deposit of sandy ash (MF 3.3) wedges out above this. The overlying ashy sand (MF 1.2) MSU includes two rounded pieces of calcarenite, the larger of which (~3.4 cm) directly overlies the zone of deformation of the underlying sediment. Deposits of shelly sand (MF 1.1) lie next to and above this unit, to the south and north respectively. Both contain very little sand-sized shell. Larger shell fragments in both, and an ash aggregate in one, have been partially dissolved. Overlying all three

of these deposits is another ashy sand (MF 1.2) MSU. This is overlain in the south by deposits of fine charred organic material (MF 4.2) and ash with some coarse inclusions (MF 3.1), and across the rest of its extent it is overlain by/adjacent to sand which is relatively poor in sand-sized shell (MF 1.1). The contact with the latter MSU also includes a frontier of calcification and/or decalcification within a large unburnt bone fragment (Figure 14b). The MSU assigned to MF 3.1 contains multiple sub-millimetre lenses of phosphatised ash and of recrystallized ash. There is also a thicker band of altered ash across much of its upper surface, parts of which have been disturbed. All analysed shell fragments are composed of calcite. This MSU and the underlying charred organic layer both have a lateral contact with the shelly sand, which partially extends into the ash. The ash is not split in this way in the chip, suggesting that this complex contact is due to the thin section cross-sectioning this deposit very near its edge relative to the viewer. The uppermost MSU is ashy sand (MF 1.2) with some localised non-ashy zones (MF 1.1). The base of the deposit is horizontal in the south, where it is marked by a discontinuous apatite crust (seemingly altered ash), and then dips at ~45° northwards from halfway across the slide. There is initially some continuity of internal lamination across this change in deposit morphology, but higher up in the MSU larger inclusions are more horizontal. This deposit is the first to exhibit several marked changes in the properties of MF 1.2 deposits throughout the rest of the sampled eastern profile. Microfauna and fish bones are far more common, in this case including a ~1 cm long rodent mandible with teeth. There are also changes in the density, distribution, and composition of the matrix. Unfilled packing voids are far more common, with matrix more often concentrated in lenses or pockets than previously. There is less matrix overall, and it is less calcareous, with greater phosphatisation observed.

There is a gap of ~1.5 cm between 303B and 303A. A series of alternating ashy shelly sand (MF 1.2) and shelly sand (MF 1.1) deposits make up most of 303A. These deposits contain a large quantity of microfauna and fish bone, but larger bone fragments are present too, particularly in the upper MSUs in this sequence. Only one of the larger bones was found to have been burnt (below 600°C). Shell is common in the lower deposits. It is mostly angular but broken ex situ, with only a few related fragments found in association. Some pieces have been impacted by dissolution. Both calcite and aragonite shell fragments are present. The second MF 1.2 deposit in the

sequence has a roughly linear (but slightly dipping zone) which contains numerous small, sub-angular iron-rich aggregates. These range from fine sand- to very coarse sand-sized, and the larger aggregates contain quartz grains (Figure 13d-e). This zone and adjacent areas are also relatively rich in bone fragments. The uppermost MF 1.2 deposit is very rich in foraminifera and contains several pieces of a reworked phosphatic crust, which may be heavily altered ash. Overlying this series of alternating deposits is a MSU dominated by a deposit of wood ash with limited inclusions (MF 3.1) which has been almost completely altered to apatite (Figure 14e). Despite this heavy phosphatisation, there are several domains with unaltered ash. This base of this MSU is similar to MF 4.2, while parts of the uppermost portion could be assigned to MF 4.1. These zones are also rich in apatite. This MSU is followed by a thin deposit of shelly sand (MF 1.1), which is in turn overlain by siliceous silt and clay (MF 6.1). This deposit contains sandy pockets throughout but becomes far sandier and less silty on the southern end of the slide (Figure 12). The final MSU is ashy sand (MF 1.2) with domains low enough in ashy matrix to be considered similar to MF 1.1.

2. ORGANIC PETROLOGY

Three MSUs were targeted, which macroscopically on the surface of the chip appeared to be black to dark brown in colour. These MSUs were designated C1, C2, C3 for the purposes of the analysis, and correspond to microfacies types 4.1 and 3.1 (Fig. S1).

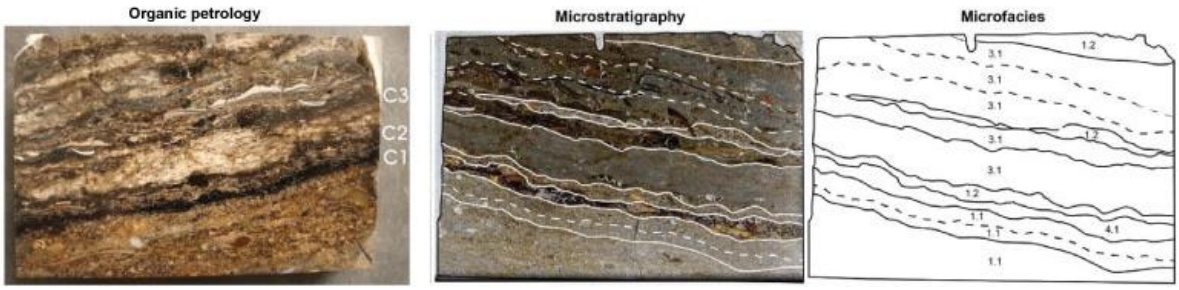


Fig. S1. The locations of the three MSUs that were analysed under reflected and fluorescent light. Note that the MSUs visible on the surface of the chip (left) are a mirror image to the MSUs that were analysed in the thin section (right). The three MSUs are designated C1, C2, and C3 and these correspond to microfacies types 4.1 and 3.1.

2.1. Results from layers C1, C2 and C3

Due to the very high resolution of the reflected light analyses (typically conducted under magnification of 500x), the thicker analysed MSUs can be subdivided and observations described below are organized based on the internal stratigraphy.

The sediment at the base or just under C1 consists of a sandy and ashy unit containing few zooclasts (lamellibranch and gastropod shells), dark grey micro-fragments of burnt bones and frequent micro-fragments of bone fat-derived char of very variable size (5 to 100 µm). The char particles appear fine heterogeneous and porous. A thin char coating was observed on one burnt bone fragment. Overall, the burnt bone fragments show a brownish fluorescence of low intensity.

C1 itself is continuous across the full width of the polished block. C1 is composed of numerous fusinite fragments (wood-derived charcoal, mostly 20 to 25 µm in size) and few fragments of burnt bones. Several charcoal tissues are partly degraded resulting in the agglomeration of numerous cell walls fragments and the destruction of the wood structure (disappearance of cell cavities). The upper part of C1 is characterized by the presence of greyish phosphates that often fill the cell cavities of the tissue fragments (10 to 25 µm in size). This domain is followed by a unit composed of burnt bone fragments whose size reaches up to 40 µm associated with larger tissue fragments (50 to 70 µm) of the same origin as the tissues encountered in the middle part of the layer. Some tissues show several very small perforations due to fungal attack prior to burning. Towards the top, the number and the size of the tissues (up to 30 µm) decrease rapidly and the amount of ash increases. Within the ash above the layer, there are well-preserved pieces of charcoal, and char is also present as homogeneous masses with a humic gel-like appearance.

The reflectance of the tissues in C1 ranges from 0.67 to 0.94 %Rr (see reflectance histogram). These tissues can be classified as low reflecting fusinite (mean value of 0.80 %Rr). In reflected white light the tissues are light grey. A few of the tissues could have been affected by humification and fungal attack (perforated cell walls) prior to burning.

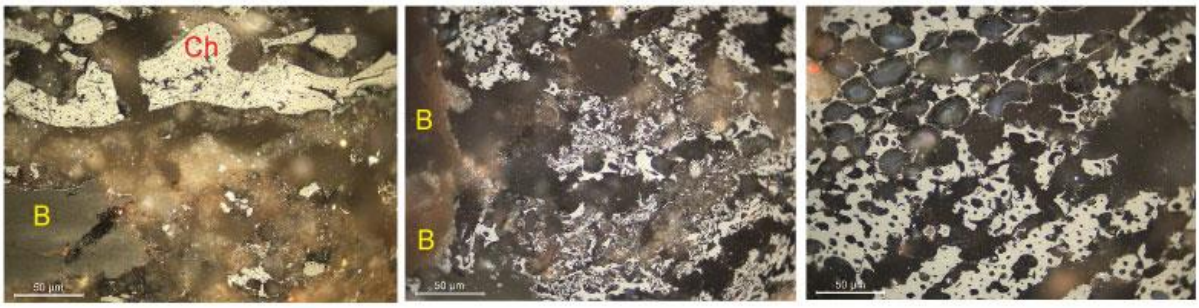
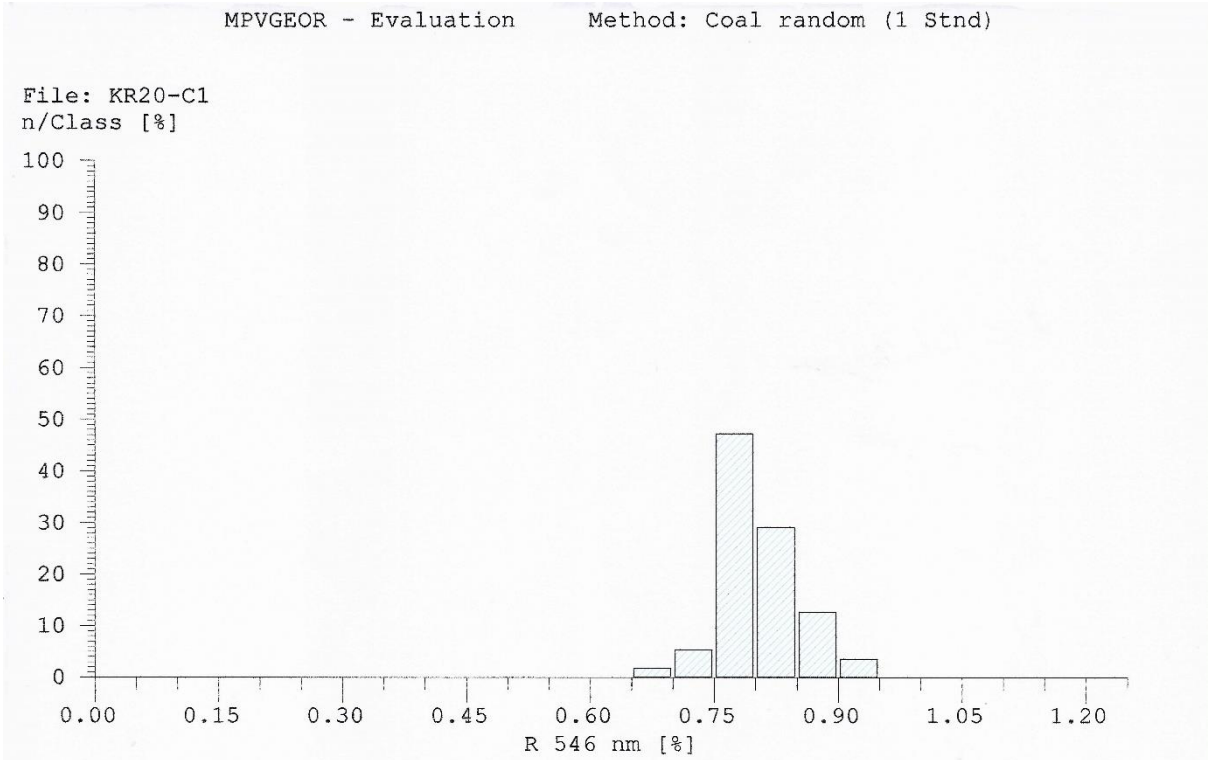


Fig. S2. Reflected light images from C1. Left: the base of the layer contains fragment of burnt bone (B) as well as porous char (Ch). Middle: burnt bone (B) is also present along with poorly-preserved charcoal. Right: some of the charcoal associated with the ash at the top of the layer and just above it is well preserved.

The low standard deviation indicates homogeneous and reliable results of the reflectance measurements, which is supported by the homogeneity of tissue structures in the whole layer (same plant origin possible). Using the formula of Jones and Lim (2000), a mean reflectance value of 0.80 %Rr suggests a charcoal formation temperature of 280°C.

Layer C2 contains only rare and dispersed fragments of charcoal tissues. These fragments are poorly preserved and show either a disintegrated appearance or are partly permineralized by calcium phosphate. The sizes of the tissue fragments range from few microns to about 20 µm. Because of the significant diagenesis undergone by this layer, the analysis of the reflectance of the micro-charcoal tissues (which were affected by permineralization processes) could not be carried out.



File: KR20-C1
Reflectivity[%]

Lambda :	546 nm
Minimum :	0.675
Maximum :	0.941
Mean_Value :	0.804
Standard-Dev. :	0.047
Variance :	0.002
Rel.Var.-Coeff. :	0.56%
Total N :	110

File: KR20-C1
Reflectivity[%] at 546 nm

No.:	values										mean
1	0.830	0.839	0.876	0.699	0.817	0.865	0.878	0.939	0.793	0.806	0.83
11	0.772	0.765	0.798	0.791	0.787	0.782	0.769	0.811	0.819	0.765	0.79
21	0.747	0.785	0.796	0.761	0.778	0.793	0.824	0.765	0.821	0.876	0.79
31	0.848	0.780	0.734	0.760	0.789	0.841	0.769	0.793	0.726	0.675	0.77
41	0.787	0.800	0.808	0.787	0.856	0.819	0.793	0.782	0.761	0.765	0.80
51	0.839	0.878	0.826	0.859	0.791	0.837	0.819	0.817	0.841	0.769	0.83
61	0.771	0.889	0.902	0.835	0.830	0.876	0.817	0.771	0.802	0.787	0.83
71	0.941	0.856	0.784	0.795	0.811	0.776	0.765	0.804	0.754	0.741	0.80
81	0.776	0.769	0.782	0.761	0.765	0.876	0.785	0.778	0.935	0.776	0.80
91	0.856	0.776	0.806	0.832	0.743	0.846	0.785	0.869	0.846	0.817	0.82
101	0.728	0.761	0.856	0.809	0.796	0.752	0.776	0.761	0.760	0.822	0.78

Fig. S3. Histogram of reflectance measurements in C1

Layer C3 is discontinuous across the full width of the polished block and is characterized by a very irregular thickness (50 to 400 µm). In the thin section, it was not identified as a discrete MSU, but instead is present at the base of a layer that is

classified as microfacies type 3.1. The charcoal-rich C3 is locally interrupted by components that are typical of microfacies type 3.1 (e.g. shell fragments, ash domains). The base of C3 is composed of whitish-brown to brown-orange ash containing tiny char fragments (10 to 20 µm in size) and fragments of burnt bones (up to 60 µm in size). Locally the fragments (100 to 200 µm in size) of wood-derived tissues are piled up and poorly cemented. It seems that they are all of the same type (i.e. one type of tissue structure) and identical to the wood-derived tissues of layer C1. C3 is often interrupted by relics of strongly fragmented burnt woody tissues, partially degraded and intimately associated with ashes with numerous idiomorphic calcitic crystals (i.e. ash rhombs or geometric forms). C3 is covered by an ash unit rich in shell fragments and burnt bones as well as char fragments. This corresponds to the majority of the unit that in thin section was classified as microfacies type 3.1.

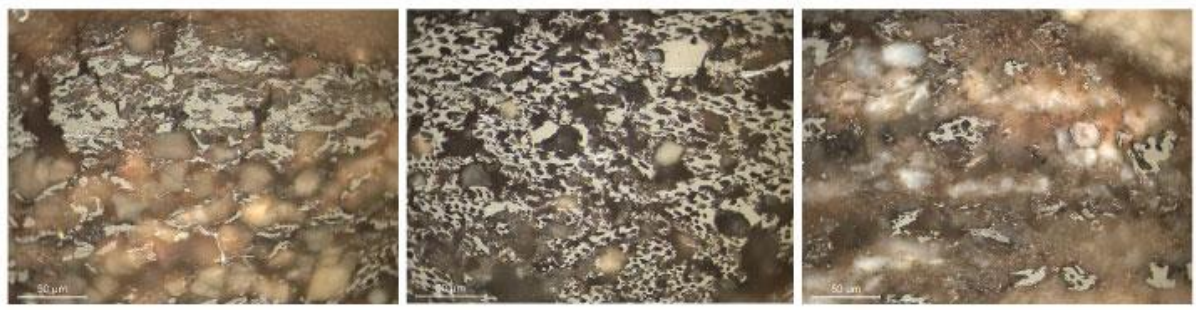


Fig. S4. Reflected light images from C3. Left: corroded and partially mineralized charcoal in association with particles of wood ashes with geometric forms. Middle: charcoal crushed in situ. Right: relicts of woody plant tissue in ash.

The reflectance of the tissues in C3 ranges from 0.72 to 0.92 %Rr (see reflectance histogram). These tissues can be classified as low reflecting fusinite (mean value of 0.82 %Rr). In reflected white light the tissues are light grey. Because of the poor state of preservation of the fusinite tissues, it was not possible to measure more than 22 tissues. However, the low standard deviation indicates homogeneous and reliable results of the reflectance measurements which is supported by the homogeneity of tissue structures (same plant origin possible). Using the formula of Jones and Lim (2000), a mean reflectance value of 0.82 %Rr suggest a charcoal formation temperature of 280 °C.

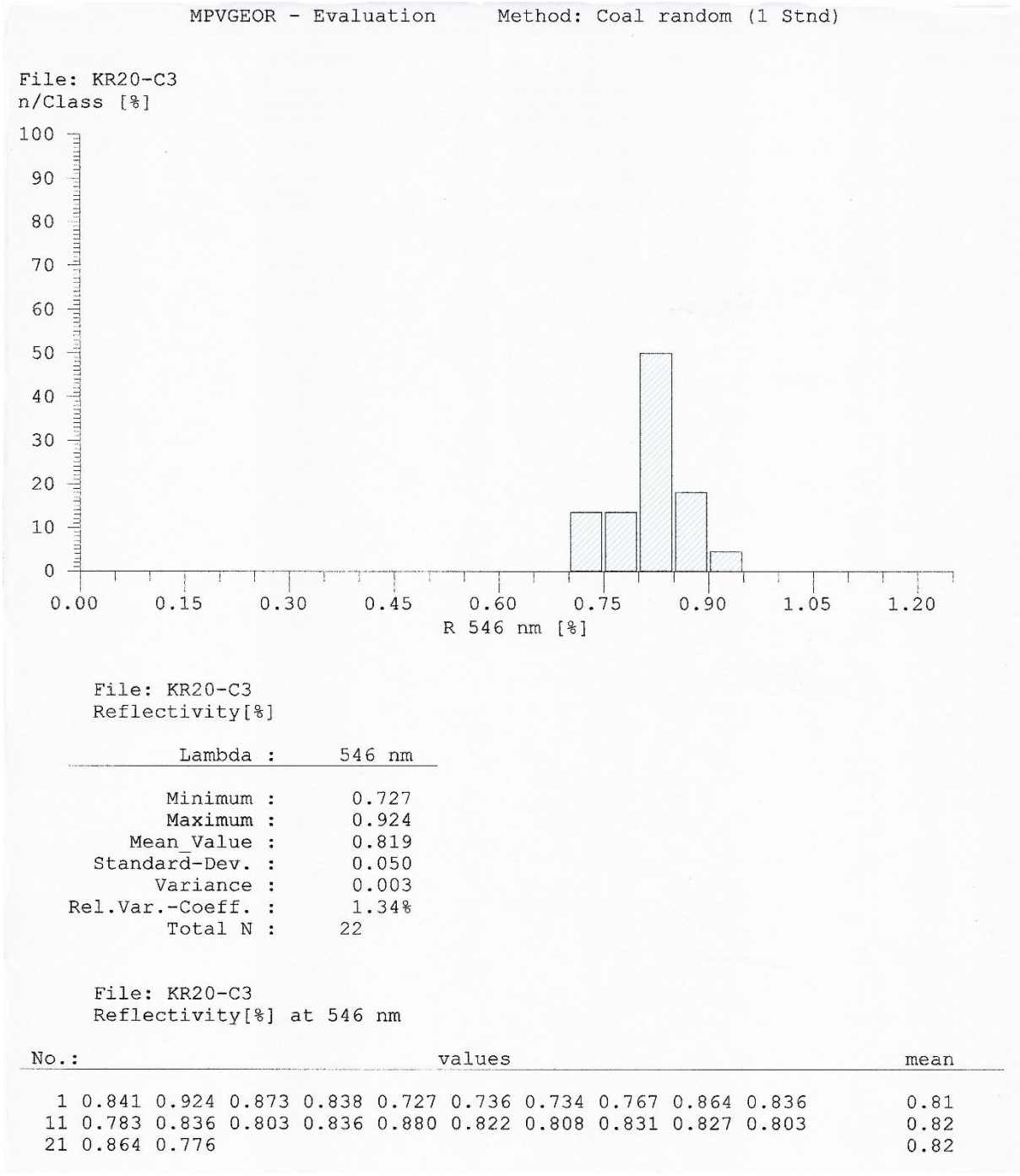


Fig. S5. Histogram of reflectance measurements in C3

2.2. Observation of calcified charcoal

Figure 15e of the main text illustrates a fragment of wood or charcoal that appears to have been completely replaced by calcite. This material is present in an ash layer at the top of sample KRM-20-304. Similar materials could also be seen in the polished chip (Fig. S6) that support the hypothesis that some of the charcoal in the ash layers at the site may have been replaced by calcite, with the mineral preserving the

morphology of tissues that were originally composed of cellulose and lignin in the wood. The process of replacement of charcoal by calcite is not understood.

Fig. S6. Calcite with an internal morphology consistent with woody tissue. The appearance contrasts with that of more typical charcoal fragments present in the top right corner of the image.

2.3. Summary

Opportunities to conduct organic petrology observations and measurements are limited in this study due to the low abundance of so-called hearth bases (microfacies type 4.1). In fact, only one MSU was attributed to this type, although charcoal fragments were locally abundant elsewhere in the samples. In the analysed layers, there was strong similarity in the type of charcoal between C1 and C3. C3 contained more degraded charcoal due to post-depositional alteration, resulting in fewer measurements from this layer, while the degree of degradation in layer C2 was so high that measurements were not possible. Diagenesis impacting charcoal and char, including possible calcification of charcoal, could be one reason why hearth bases are so rare in these sample. These results also support the observation that there are

significant changes in post-depositional processes between MSUs that are separated only by millimeters or centimeters. Despite the impacts of diagenesis, the reflectance measurements from layers C1 and C3 show a good correlation of results which may suggest similar combustion conditions, but also the use of a wood-derived fuel probably from the same source.

REFERENCES

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CHAPTER 6. DISCUSSION AND CONCLUSION

In this chapter, the results presented in the preceding three chapters are discussed in order to address the three stated research questions and to consider what gaps still exist in understanding the formation and stratigraphy of the studied deposits.

The research questions were:

1. What are the stratigraphic relationships between the basal deposits (layers assigned to the LBS, RBS and SAS Members/Sub-members) at KRM both within and between Caves 1, 1A and 1B?

2. What geogenic, biogenic, and anthropogenic processes were involved in the formation and post-depositional alteration of the deposits in Cave 1B?

3. What geogenic, biogenic, and anthropogenic processes were involved in the formation and post-depositional alteration of the basal deposits in the Witness Baulk of Cave 1?

The associated aims were:

1. To clarify the stratigraphy of the basal deposits (LBS, RBS and SAS Members/Sub-members) at KRM across Caves 1, 1A and 1B using published information and/or new observations of lithostratigraphy, allostratigraphy, cultural stratigraphy, chronostratigraphy, and biostratigraphy.

2. To determine – using data from micro- and macroscale analyses – what depositional and post-depositional processes were involved in the formation of the deposits in Cave 1B.

3. To determine – using data from micro- and macroscale analyses – what depositional and post-depositional processes were involved in the formation of the layers assigned to the LBS, RBS and SAS in the Cave 1 Witness Baulk.

Chapters 3 to 5 (Morrissey et al., 2022, 2023, submitted) include their own discussion sections in which the results of each are discussed to varying degrees. However, there are topics which require synthesis and/or greater discussion to bring the information from the manuscripts and previous published works together in a more cohesive manner.

Formation processes will be considered first, followed by a discussion of the challenges of stratigraphic correlation at KRM. This will be followed by a synthesis of what stratigraphic relationships appear to be supported by the different lines of available evidence. Then, evidence for the intensity and frequency of human occupation of the site complex will be considered. Finally, limitations and research opportunities will be discussed, followed by the overall conclusions of the thesis.

Unfortunately, the SAS deposits in the Cave 1 Witness Baulk were not sampled for micromorphological analysis because the exposed deposits are largely clast-supported or very rich in clasts and could not be sampled without posing a significant risk to the integrity of the baulk itself. Where relevant and appropriate, the published literature on deposits which were not reported on will be used to assess their formation and stratigraphy. In a few cases, basic field observations and photographs of deposits will also be presented when hypotheses for their formation or stratigraphic correlations are discussed or put forward.

6.1. The formation of the basal deposits

Here, the formation processes are split into geogenic, anthropogenic, and biogenic sub-sections to match the divisions listed in the research questions. These processes are discussed in order to address Aims 2 and 3 (and the corresponding research questions), but some of the information is also relevant for understanding site formation in Cave 1A, with due consideration for spatial variation in these processes across the site complex. As stratigraphy is the product of site formation processes, these results also have some bearing on addressing Aim 1, which will be discussed in Sections 6.2 and 6.3.

6.1.1. Geogenic processes

The breakdown of the quartzite bedrock introduced (largely sub-angular to angular) clastic material ranging from sand- to boulder-sized to many deposits. However, the size and frequency of these inclusions varies widely. The proportion of autogenic sediment appears to have been controlled by several factors, including the rate of allogenic sedimentation (both aeolian and colluvial), dissolution of calcite, winnowing of deposits by wind or water, and the rate of bedrock breakdown.

The rate of bedrock breakdown can be linked to the prevalence of salt weathering and insolation weathering (Deacon & Geleijnse, 1988). Some change in the rates of insolation weathering could be expected through the climatic changes associated with the glacial-interglacial cycles, but this process is likely too limited at KRM to result in identifiable patterns which can be linked to specific climatic events (Butzer, 1982a). The rate of salt weathering cannot necessarily be tied to sea level change and the proximity of the shoreline to the site as salt weathering of sandstone and quartzite has been reported at coastal, near coastal, and inland sites in South Africa (Goldberg et al., 2009; Miller et al., 2013, 2016). As Cave 1B is very exposed in comparison to the rest of the KRM site complex, it would be particularly susceptible, even during periods of relatively low sea level.

The majority of geogenic sand entered the site complex through aeolian[2] or colluvial processes, from beach and dune deposits (for the former) and the overlying palaeodunes (for the latter) (Deacon & Geleijnse, 1988). It should be noted, however, that the morphology of the complex and its immediate surrounds make it very likely that some of this sediment entered the site due to aeolian reworking of colluvial deposits (or aeolian processes aiding in colluvial transport) and colluvial reworking of aeolian deposits. This, combined with the similarity in the sediment sources, means that definitively identifying sandy deposits as purely aeolian or purely colluvial is

[2] Other than thin lenses (millimetre-scale), which are present across KRM, the only definite (seemingly) purely aeolian deposits within the site complex are in Cave 1 and fall within the White Sand (WS) Member (Layer 13), which is associated with the MSA IV (Butzer, 1982a; Singer & Wymer, 1982; Deacon & Geleijnse, 1988). These deposits, which significantly post-date those studied in this thesis, display typical aeolian bedding (very fine in this case) with ripples, and contain well-sorted fine sand (Butzer, 1982a, pp. 37–38). They are, however, interbedded with finer colluvial deposits and "stone lines" of quartzite bedrock (Deacon & Geleijnse, 1988, p. 10), and are also associated with calcareous marls (Butzer, 1982a, p. 38). All other MSA deposits at KRM which include (or may include) aeolian sediment also contain colluvial and anthropogenic material.

extremely difficult, if not impossible. A change to the palaeodunes as the primary source was noted within the SAS deposits in the Cave 1A sequence by Deacon and Geleijnse (1988) based on the analysis of large bulk samples. This change was not observed moving from the RS to the SASDC in Cave 1B, but it is unlikely to be distinguishable without statistical analyses of particle size distributions from bulk samples.

As the shelly sand has two potential sources, there are numerous factors which could control its availability. The weathering and erosion of aeolianites would be controlled by prevailing weather and geomorphic conditions, to what degree the aeolianite is protected by overlying deposits or soils or stabilised by vegetation, if any pedogenesis of the aeolianite has taken place, and how strongly it is cemented – which can vary widely even within a single deposit (e.g., McLaren & Gardner, 2004). Factors like vegetation cover and the geomorphology of the landscape above the site could also influence how easily sand weathered from the aeolianite could travel via colluvial processes down to the site. The availability of sand from the beach and/or dune source would be impacted by a variety of factors (Pye, 1983; Bateman et al., 2011), including changes in shoreline position due to sea level fluctuations, the presence or absence of barrier dunes (and to what degree they were stabilized by vegetation), and whether the beach deposits were rocky, sandy, or mixed.

Unfortunately, all these variables make it extremely difficult to link the density of the autogenic quartzite to global sea level curves or climatic phases without significantly tighter chronological control. It is also possible that some of these variables could change or remain stable independent of the impacts of stable or changing climatic conditions.

Finer geogenic sediment is comparatively uncommon in the studied deposits relative to sand-sized and coarser material. Siliceous (generally iron-rich) silt and clay was introduced into Cave 1 by dripwater during the MSA I, becoming more common towards the end of the formation of the SBLS (Morrissey et al., submitted). The wetter conditions in Cave 1 during the MSA II (Butzer, 1982a) may mean that the siliceous silt and clay is more common in the SAS deposits there. Secondary calcite is relatively uncommon in the MSA I in Cave 1, both in the form of flowstone and within the matrix

of deposits (Butzer, 1982a; Wurz et al., 2022; Morrissey et al., submitted). However, this process becomes far more significant during the wetter MSA II (Butzer, 1982a; Deacon & Geleijnse, 1988; Wurz et al., 2022). Secondary calcite is also uncommon in both the RS and SASDC in Cave 1B, but there is a thin calcite crust in the uppermost RS deposits (Morrissey et al., 2023, Figure 15).

Tufa and speleothem fragments of widely varying sizes (from a few centimetres to more than a metre in length) have been incorporated into the deposits after either falling directly from the roof of the respective recess or moving downslope after falling from another area or from the hosting cliff (Wurz et al., 2018, 2022). It is also entirely possible that people moved some of these clasts around within the site complex. While many of the carbonates are geogenic, it is worth noting that much of the tufa is actually phytokarren (or photokarren), which forms due to biological activity which causes the localised dissolution, and then re-precipitation, of calcite (Viles, 1984; Vanara & Maire, 2006; Wurz et al., 2022).

Blocks of the quartzite bedrock are also present in some deposits. Some show signs of heating, such as colour changes (reddening) and cracking (Bentsen & Wurz, 2017, 2019; Wurz et al., 2018), and could have been placed at specific locations by people. However, many other pieces probably ended up there naturally due to spalling by salt weathering and/or insolation and then varying distances of colluvial transport within (and perhaps even between) the particular recesses. Many (likely the vast majority) of the rounded quartzite cobbles and pebbles found in various deposits would have been introduced into the site complex by humans as (unused) raw material for lithic production.

There is a clear increase in clast density (relative to the MSA I) in the lower SAS deposits in Cave 1, including at its eastern edge (Figures 6.1 and 6.2). This includes big tufa/speleothem columns and blocks and comparatively large quartzite blocks, and suggests a period (perhaps including one or more significant events) in which the collapse of these materials was far more common than during the MSA I. A similar period of significant collapse occurred during the formation of the RF Member overlying the SAS in Cave 1A (Deacon & Geleijnse, 1988).

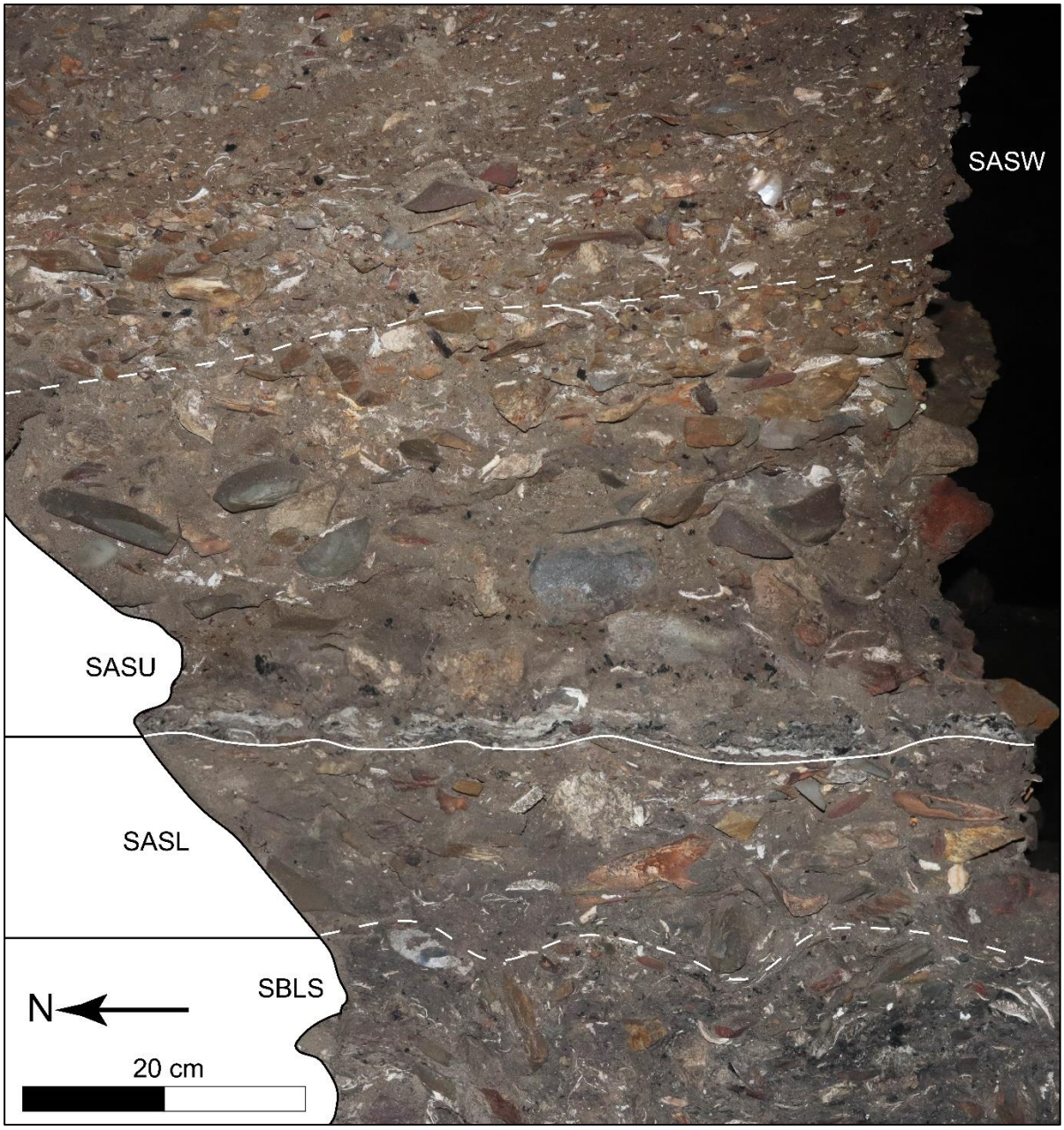

Figure 6.1. A portion of the sequence on the western side of the Cave 1 Witness Baulk, from the SBLS to the SASW, with only part of the upper and lower member/sub-member shown (photograph by Kathryn Croll). The white areas are covered by sandbags stabilising the baulk. Apart from the upper ~5 mm, the SASL here is the equivalent of the BOS (Brown Occupational Soil) excavation unit because the Shell Midden One (SMONE) unit pinches out to the west of the baulk (Wurz et al., 2018). Note the ash-rich deposits at the base of the SASU, which were excavated as unit HHH (Hearth-Hearth-Hearth).

Winnowing of deposits by waterflow has been proposed as a significant process in the formation of some clast-rich (including clast supported) deposits in the SASL and SASU Sub-members in Cave 1 (Deacon & Geleijnse, 1988; Deacon, 2008; Brenner

et al., 2022). This would have effectively created palimpsests of (roughly) in situ material. It has not been explicitly stated if this flow would have occurred above or below the surface (or both), but the lack of notable void space suggests it could not have occurred below the surface. However, some of these deposits have also been interpreted as ”tumble”, which formed due to material moving down a gentle slope from Cave 1/1A (Singer & Wymer, 1982, p. 26; Brenner et al., 2022, p. 222).

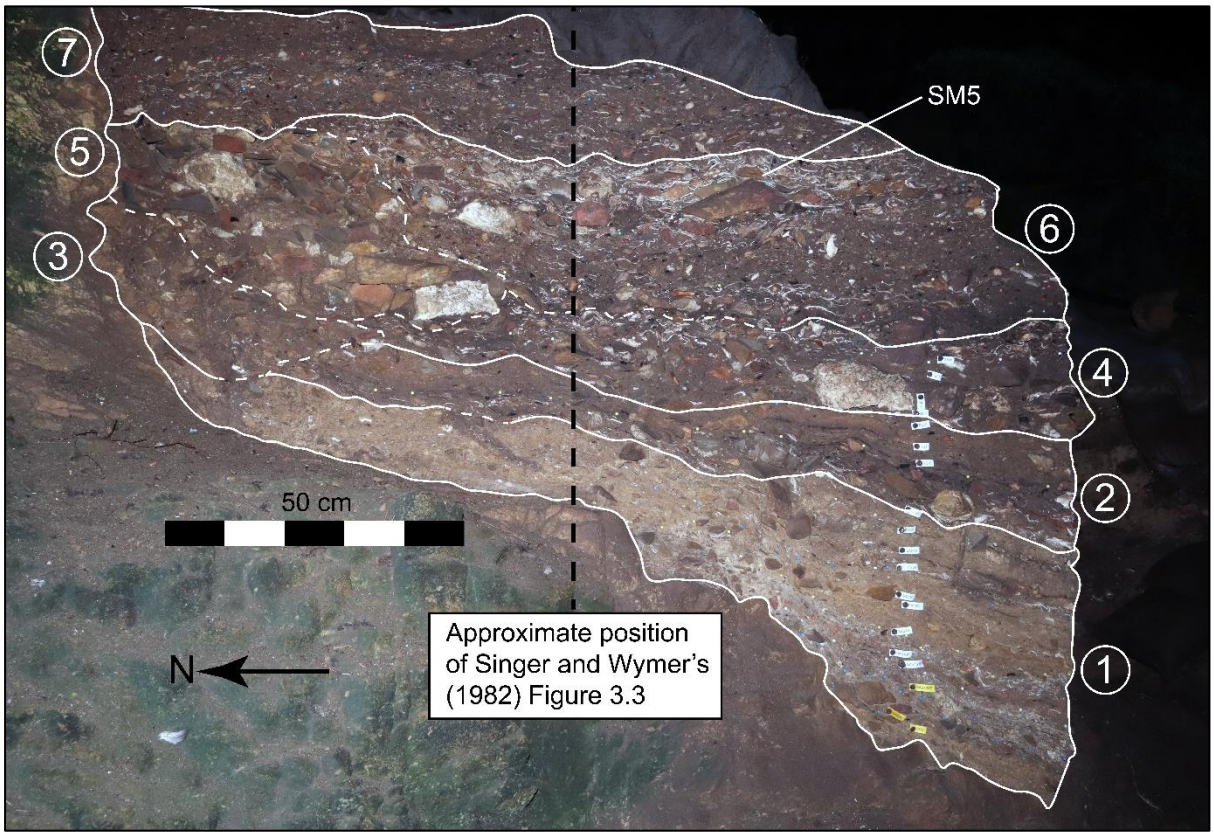

Figure 6.2. The sequence of deposits at the eastern edge of Wymer's Cave 1 excavation, north of Deacon's square AA43, which is to the right of the profile (photograph by Kathryn Croll). Unless specified otherwise, named excavation units were defined during the excavation of AA43. Interpretations of stratigraphic relationships are discussed in the text. 1) the LBS Member deposits, which become less stratified in the northern half of the profile. 2) Units SCB2, YS1B, YS1, and SCB1, which Deacon correlated with the SBLS (then called the RBS) due to similar lithologies, but which have subsequently been found to contain MSA II lithics. 3) Massive, clast-rich deposits which correlate with 2 and perhaps also 4. 4) Units BS2, SM2, BS1, and SM1, which Deacon considered the base of the MSA II deposits, and which Wurz et al. (2018) tentatively correlate with the SASL in the Witness Baulk. 5) Clast-supported rubble (potentially both initially comparatively clast-rich and then subsequently winnowed) including tufa/speleothem, quartzite blocks, lithics, and possible manuports. 6) Deposits either banked against the rubble of 5, or (far less likely) contemporaneous with the rubble. SM5 is a significant laterally continuous deposit which Deacon correlated with the top of the SASU. 7) Deposits definitely post-dating the formation of the rubble.

There are also preserved anthropogenic deposits in the SASU (Figure 6.1; Deacon, 2008), suggesting that any winnowing by water would have had to have been

constrained to particular drainage routes or to have occurred periodically and only at the surface. Very little has been published in the way of data or detailed explanation for the two interpretations, and more work is needed to understand particular deposits. It is likely that some combination of colluvial deposition and winnowing (by water and perhaps also wind) may have formed some of the deposits. The SASL and SASU are not monolithic sub-members, and they appear to have a more complex formation history than has often been suggested (e.g., Deacon, 2008).

Similar clast-rich deposits make up much of the sequence of SAS deposits at the eastern edge of Cave 1 north of AA43 (Figure 6.2). The rubble there, which is most concentrated against the cave/shelter wall, is spatially consistent with water flowing down into Cave 1 along a route which would pass through the areas of concentrated rubble in the Witness Baulk. This appears to correlate with the general distribution of coarse facies in the SASL across Cave 1 more broadly (Singer & Wymer, 1982, p.16). However, some of the anthropogenic material in the comparatively clast-poor deposits in AA43 itself appears to be in secondary context rather than locally reworked into a palimpsest (Wurz et al., 2018, p. 106). Many of these deposits, and others between AA43 and the rubble, are likely to post-date the deposition and winnowing of the rubble deposits they lie against.

There is some evidence (see Morrissey et al., 2023, Table 5: MF 2.1) for the highly localised winnowing of a few deposits by surface water in the SASDC (DCCP12 and DCCP11) in Cave 1B. More significant impacts appear to have occurred earlier on, in the underlying RS Member, including the formation of the clast rich RSDRU and RSYRU deposits.

The SASW and SASR Sub-members in Cave 1 have been interpreted as the product of sediment (including anthropogenic material) being eroded from Cave 1A and transported down a talus slope into Cave 1 (Deacon & Geleijnse, 1988; Rightmire & Deacon, 1991; Deacon, 2008). Consistent with previous descriptions (Butzer, 1982a; Singer & Wymer, 1982; Deacon & Geleijnse, 1988), the SASW is relatively sandy and contains shell, charcoal, bone and lithics, both distributed through the deposits and

more concentrated in distinct 'tip-lines'[3], while the SASR has a darker and finer matrix, with clasts both more numerous and notably larger on average (Figure 6.3). Both sets of deposits dip between 16° and 20° from horizontal down towards the north and west (in the site grid) both in terms of their overall morphologies (other than the shallower base of the SASW) and their internal stratification (the latter absent in the SASR). Although it appears that the published interpretation of these deposits as colluvial and deriving from Cave 1A is accurate, there has been no real discussion of the implications of the change in sedimentary properties other than Butzer's (1982a) widely dismissed hypothesis that the SASR was a marine deposit.

The change from the SASU to the SASW (Figure 6.1) appears more gradual than generally presented in published descriptions (e.g., Singer & Wymer, 1982; Deacon & Geleijnse, 1988). Most of the SASU deposits are fairly horizontal and have been found to contain some intact hearths (Deacon, 2008; Wurz et al., 2018). In contrast, the clasts in the uppermost units in the SASU, D1 and D2, have an average dip intermediate between the SASU and SASW. These deposits also contain fewer (and generally smaller) clasts than the rest of the SASU. However, the distinctive 'tip-lines' found in the SASW are absent. This probably reflects more rapid accumulation in Cave 1A (and the area between the recesses) than in Cave 1 towards the end of the formation of the SASU, leading to the incremental development of a talus slope while Cave 1 was still occupied. After occupation effectively ceased and more sediment accumulated outside the cave, the talus slope grew steeper, resulting in the distinctive properties of the SASW.

The SASW appears to represent cycles of reasonably regular erosion in Cave 1A and deposition in Cave 1. The alternation of 'tip-lines', which are comparatively rich in anthropogenic materials, and sandier sediment with a lower proportion of these components (Figure 6.3) could represent periods of occupation (or more intensive occupation) and non-occupation (or less intensive occupation). Alternatively, fluctuations in geogenic deposition, with a stable erosional rate, could result in

[3] This term was first used to describe these deposits at KRM by Rightmire and Deacon (1991, p. 135). They are dipping 'lines' of sediment within the SASW which have the same matrix as the rest of the sediment, and the same dip angles and direction, but are notably richer in anthropogenic materials. They are occasionally discontinuous, likely due to very localised absences of anthropogenic material and the similarity in matrix to the rest of the deposits.

alternating deposits with greater or lesser proportions of anthropogenic material. Some combination of these two factors is also possible.

Figure 6.3. A view of the western profile of the Cave 1 Witness Baulk, including most of the SASW, the full vertical extent of the SASR (which thickens considerably to the north), and part of the overlying WS Member which is associated with the MSA IV (photograph by Kathryn Croll). The white areas are covered by sandbags which stabilise the baulk.

The properties of the SASR (Figure 6.3) are suggestive of more rapid deposition than the SASW. The lack of bedding could be due to slumping of deposits in Cave 1A, with subsequent movement down the talus slope into Cave 1 over a significantly shorter period of time than the episodic deposition of the SASW. The very high proportion of boulder-sized clasts would likely have contributed to the potential instability of source deposits in Cave 1A, making them more susceptible to slumping following triggers like particularly intense rainfall, rockfalls, and earthquakes. Such a rapid movement could also explain some of the mixing observed between the SASR and underlying deposits in many areas of the cave (Singer & Wymer, 1982, Figure 3.20). Slumping of SAS deposits has been noted in Cave 1A (Deacon & Geleijnse, 1988). This may have

occurred in multiple events, but at least some slumping is attributed to Holocene erosion of deposits and thus would be unrelated to the SASR's formation (Deacon & Geleijnse, 1988; Deacon, 1995).

6.1.2. Anthropogenic processes

It has long been recognised that humans played a major role in site formation at KRM, with very few deposits containing no anthropogenic input (Butzer, 1982a; Deacon & Geleijnse, 1988). Along with introducing a great deal of the silt- and clay-sized sediment, humans also contributed sand- to boulder-sized material.

From my own experience of excavating BOS and the SBLS in the Witness Baulk, it is difficult to overstate how common lithic artefacts are in some deposits. Even in particularly clast-rich deposits, they still make up a high proportion of the coarse clastic component. While the deposits in the SASU have a maximum lithic density per excavation unit of ~6 artefacts per litre of sediment (calculated from data in Wurz et al., 2018, Tables 1 & 2), these values rise to a maximum of ~62 per litre in the SASL and ~291 per litre in the SBLS (Brenner et al., 2022, Table 5). Although lithic density is controlled by both human behaviour (occupational intensity, and spatial and temporal patterning in activities) and natural processes (natural depositional rate and post-depositional winnowing by wind and/or water and dissolution), it is obvious that lithics can make an important volumetric contribution to the composition of deposits at KRM, and influence the texture of these deposits, especially when small debitage is common.

Bone, shell, and plant matter introduced by humans are also significant sedimentary components (Butzer, 1982a; Deacon & Geleijnse, 1988; Deacon, 1993, 1995). Fine organic material and wood ash make up a significant proportion of the matrix of the deposits analysed in this thesis, including many predominantly geogenic sandy deposits. As discussed by Morrissey et al. (submitted), the amount of ash present in any deposit would have had some influence on how easily ash and other calcite could be dissolved. This is of particular relevance in the MSA I given the limited supply of calcium-enriched dripwater relative to the MSA II.

Although stacked hearths and shell middens have received attention at KRM as indicators of the structuring and maintenance of living spaces (Henderson, 1990, 1992; Deacon, 1993, 1995), the maintenance of hearths has not been discussed. Likewise, trampling has not been considered a significant site formation process until recently (Reynard, 2022; Wurz et al., 2022). However, hearth cleaning (sweeping and/or raking out) and trampling have both been demonstrated to be important processes in constricted MSA occupation spaces (e.g., Goldberg et al., 2009; Miller et al., 2013). Therefore, it is unsurprising that they played a significant role in forming the LBS, SBLS, RS, and SASDC deposits.

Experimental research has demonstrated that different substrates produce different microfabric and microstructures when trampled (e.g., Miller et al., 2010; Banerjea et al., 2015a, b). Published examples from MSA sites in South Africa are variable. At Diepkloof, the combination of dry conditions and abundant organic material has resulted in a characteristic microgranular structure (Miller et al., 2013), while the trampled surfaces at Sibhudu are associated with grass bedding layers (Goldberg et al., 2009). It is unsurprising that trampled surfaces in the wetter, sandier, and shell-rich deposits at KRM do not look like the surfaces at these sites. Instead, trampled surfaces in both Cave 1 and Cave 1B are identified due to the deformation of crusts (e.g., Morrissey et al., 2023, Figure 17) or the occurrence of concentrations of minimally displaced horizontally oriented shell fragments (e.g., Morrissey et al., 2023, Figure 16). The most similar published trampled substrates to KRM, which informed the identification of the trampled shelly surfaces, are shelly and sandy deposits at South American coastal sites (Balbo et al., 2010; Villagran et al., 2011; Villagran, 2019).

Middening took place throughout the MSA sequence at KRM both in the same location as hearths and in dedicated dumping areas (Wurz et al., 2022). These middens are characterised by a high density of shell, but typically contain some combustion materials and other food debris. The dump identified in the SBLS at my western sampling location differs in containing very limited shell and being dominated by lithics, bone, and materials associated with hearth cleaning (including material from the periphery). Wurz et al. (2022, Figure 10d) report a broadly similar deposit in the Howiesons Poort deposits in Cave 1A. It is very likely that some of the reworked ash

and other anthropogenic materials found in sandy deposits across the site complex was dumped in discrete dumping areas prior to being reworked again by trampling and other processes, but it would be very difficult (if not impossible) to prove this definitively for any particular deposit.

6.1.3. Biogenic processes

Birds contributed clastic material to the deposits in the form of shell fragments, microfauna, fish bones, and guano (Deacon & Geleijnse, 1988). Mammalian predators likely played at least some role, given sightings of the droppings of Cape clawless otter (personal observation) and genet (Henderson, 1992) within the site complex in recent years and the recovery of an articulated leopard skeleton from the WS deposits in Cave 1 (Singer & Wymer, 1982). Increasing quantities of macroscopically visible microfauna (mainly rodents and other micromammals) may indicate decreased human occupation resulting in more faunal occupation of the particular area and better preservation of the microfauna due to reduced trampling. They may also indicate lower depositional rates (Deacon & Geleijnse, 1988) which is controlled by both human and natural sedimentation. Increases like this occur in the upper portion of the RS and (in places) in the upper LBS and SBLS in Cave 1. In the former case, this correlates with an increase in the proportion of quartzite spall; in the latter, it does not.

As discussed by Morrissey et al. (2023, submitted), the breakdown of guano resulted in both phosphatisation of ash and (to a far lesser extent) shell, and the dissolution of calcite in the studied deposits. While the former contributed to preserving anthropogenic features and deposits, the latter is perhaps the most significant destructive process in the studied deposits. Dissolution in various parts of the sequences at KRM may also have been unrelated to guano. Changes in dripwater amount and composition, and the exposure of deposits to rain (which is naturally somewhat acidic) or overland flows of rainwater could all have resulted in dissolution of ash (Drever, 1997; Mentzer, 2014; Canti & Brochier, 2017).

Dissolution is notably more common in the RS than the SASDC in Cave 1B and occurs frequently in the LBS and SBLS in the Witness Baulk. It is unclear if the SASL and SASU deposits have been impacted by dissolution, but the evidence for greater

precipitation of secondary calcite from dripwater (Butzer, 1982a; Wurz et al., 2018, 2022) suggests that dissolution could have been less common and less destructive.

Bioturbation of ash deposits by soil mesofauna has been observed in both Cave 1 and 1B, but this was very minor. As noted by Morrissey et al. (submitted), there are some disturbances at the contact between the LBS and SBLS on the eastern side of the Witness Baulk which are up to ~5 cm wide and ~8 cm deep (but generally shallower). These could be small burrows or small localised erosional features infilled with younger sediment (or a mix of the two features). A few similar, but deeper-penetrating, features at the upper surface of the LBS on the eastern edge of Cave 1 are more likely to be burrows (Figure 6.2, contact between 1 and 2), but this is not certain. Molehills (which could be produced by moles or mole-rats) occur in the general vicinity of the site complex, but I have never observed any within the caves or shelters. These appear to be the most likely candidates for making these potential burrows.

Bioturbation by both soil mesofauna and larger organisms often results in the loss of stratigraphic detail through the mixing and homogenisation of different deposits (Wood & Johnson, 1978; Farrand, 2001; Mentzer, 2014, 2023). The generally finely stratified nature of the deposits at KRM, and many other MSA sites in southern Africa, suggests that many have escaped significant bioturbation (Mentzer, 2023). It is possible that some more homogenous massive deposits at the site complex could be the product of more intense bioturbation than that observed in the microscopically studied deposits, with or without the involvement of other turbatory processes, but this is not guaranteed as such deposits can be formed by other processes (e.g., see Goldberg et al., 2009, p. 112).

6.1.4. Discussion of the division of processes

The division of site formation processes into the tripartite classification of geogenic, biogenic, and anthropogenic is valid as each of these distinct sets of processes have different causes and outcomes. However, even with this strict division, it was impossible to discuss one of the three types of processes without the other two types entering the discussion at some point (often quite frequently), even if they were not explicitly mentioned in all cases. This situation is not unique to KRM. Influential reviews of site formation processes in caves and rockshelters typically highlight the co-

occurrence of, and interplay between, these three categories in sites' depositional histories, even in cases when the authors are more focused on understanding environmental conditions through natural deposition than on developing a more holistic understanding of site formation (e.g., Butzer, 1982b; Farrand, 2001; Goldberg & Sherwood, 2006; Mallol & Goldberg, 2017).

It is notable that, of the 12 microfacies types identified by Morrissey et al. (submitted, Table 2), none could be considered purely a product of one of the sets of processes, and only one was not influenced by all three. The situation is very similar for the microfacies in Cave 1B (Morrissey et al., 2023, Table 6). There is clearly considerable interplay between different site formation processes at KRM, which means that understanding the formation of any particular deposit requires the consideration of the potential roles of geogenic, biogenic and anthropogenic processes.

A good example from the work conducted for this thesis is the influence of different processes on the preservation of a hearth. After the initial burning event, the hearth could be completely or partially physically destroyed through site maintenance or trampling (anthropogenic), by wind or surface waterflow (geogenic), or bioturbation (biogenic). It could also be partially or completely destroyed due to dissolution as a result of relatively acidic dripwater, rain, or surface waterflow (geogenic), or due to the acidity caused by the breakdown of guano (biogenic and geogenic). The preservation of the hearth could also be made more likely by rapid burial with geogenic or anthropogenic (and perhaps even biogenic) sediment, or through the recrystallisation (geogenic) or phosphatisation (biogenic and geogenic) of the ash.

This interplay between different types of process can extend well beyond unrelated processes combining to produce a particular deposit. In many cases, there are also causal relationships between processes. Evidence for bioturbation by soil mesofauna is only observed in ash deposits. These creatures would have been attracted by organic material like charcoal, wood, and fat-derived char, but organic material is also observed other deposits at the site, and most of the organics which were originally present have been partly or completely consumed or degraded. This suggests that the lack of evidence for this minor bioturbation in other MF types may be due to their generally sandier and more porous fabric being less likely to preserve these biogenic

voids in an identifiable form than the dense ashy matrix is. It is obvious that at KRM, as at many other sites in a variety of contexts, human activity encouraged biological activity. Conversely, lower frequency and/or intensity of human occupation resulted in greater use of the site complex by birds and mammals, leading to the introduction of more microfauna remains, shell fragments, and guano (with the latter tying into the complex web of processes described in the previous paragraph).

The complexity of site formation at KRM has been demonstrated through the application of microcontextual analyses, both in this thesis and in previous work (Larbey et al., 2019; Wurz et al., 2022), to an extent that past macroscale analysis has not been able. This thesis further highlights the utility of a microscale geoarchaeological approach (especially when supported by, and integrated with, macroscale observations) to the often complex deposits in MSA cave and rockshelter sites in South Africa which first became apparent at Die Kelders (Goldberg, 2000), and has been consistently proven at other sites in the country ever since (e.g., Goldberg et al., 2009; Karkanas & Goldberg, 2010; Miller et al., 2013, 2016; Karkanas et al., 2015; Haaland et al., 2021a).

6.2. Stratigraphy at Klasies River Main site: theoretical and practical considerations

As discussed in Morrissey et al. (2022), despite the stratigraphic system in use at KRM sometimes being presented as a lithostratigraphic system, it is in fact based on a combination of multiple different types of stratigraphic evidence, including lithostratigraphy, allostratigraphy, biostratigraphy, chronostratigraphy, and cultural stratigraphy. Site formation processes impact all these types of stratigraphic evidence at KRM to varying degrees. This is most obvious for lithostratigraphy and allostratigraphy, with the properties of deposits (in the former case), and weathering (including dissolution) and erosion (in the latter case) both being controlled directly by site formation processes.

While biostratigraphy is fundamentally controlled by what species are present within the general vicinity of the site complex, preservation of different types of fossils and microfossils plays an important role in whether biostratigraphic units can be identified. For example, calcareous microfossils like foraminifera and ostracods are preserved in

the MSA I and II deposits in Cave 1 due to relatively high pH resulting from the presence of large quantities of ash, shell, and secondary calcite (Faul, 2021; Morrissey et al., submitted). However, pollen and phytoliths are very unlikely to preserve in these conditions as they are susceptible to dissolution under alkaline conditions (Grill et al., 2007; Cabanes et al., 2011).

The most significant chronostratigraphic impact is in the distribution of speleothems suitable for uranium-thorium dating, which appears to be the most precise dating technique for the MSA deposits at KRM (Wurz et al., 2022). In situ speleothems are absent from Cave 1B, where the only secondary calcite deposit is an extremely thin partly dissolved crust (Morrissey et al., 2023). The situation in Cave 1A is better, with at least one dateable in situ calcite crust (Vogel, 2001). Speleothems are far more common in Cave 1, but temporal changes in moisture availability and calcite precipitation (Butzer, 1982a) mean that only some members and sub-members can be dated in this manner (Vogel, 2001; Wurz et al., 2022).

The respective morphologies and orientations of the occupied recesses at KRM mean that they represent distinct depositional and diagenetic environments. The clear evidence for spatial and temporal patterns in natural and anthropogenic site formation processes within individual recesses, and significant interplay between different processes in the formation of individual deposits only complicates this further. Therefore, there is considerable potential for significant facies changes over even quite short distances, and the loss of deposits due to erosion or excavation can easily result in the destruction of evidence for lateral relationships.

6.2.1. Lithostratigraphy

Lithostratigraphy is frequently used as the primary means of grouping excavated deposits at MSA sites (e.g., Deacon, 1979; Opperman, 1996; Mackay, 2010; Marean et al., 2010; Oestmo & Marean, 2015). However, its use at KRM has been complicated by both spatial variation in site formation processes across the many depositional (and diagenetic) environments within the site complex and by the occurrence of similar geogenic matrix in deposits of vastly different ages (see Morrissey et al., 2022 for greater discussion and examples).

Unsurprisingly, given how common they are at KRM, Deacon's stratigraphic system makes significant use of anthropogenic deposits in characterising and distinguishing members and sub-members (Deacon & Geleijnse, 1988; Deacon, 1995). Perhaps the most notable example is the naming of the Shell and Sand Member (at times called the Sands-Ash-Shell Member; Grün et al., 1990; Henderson, 1992; Feathers, 2002) due to the alternation of anthropogenic and geogenic units throughout the Cave 1A and Cave 1B sequences. The overlying RF Member, also associated with the MSA II, is distinguished from the SAS (at least in part) because of a significantly lower density of anthropogenic deposits.

Anthropogenic deposits make up a significant proportion of the sequences at KRM, and changes in the density and nature of these deposits could distinguish different periods of occupation in a specific location (e.g., the changes between the RS and SASDC in Cave 1B and the differences between the LBS and SBLS in the Witness Baulk). However, lateral changes in human behaviour and/or the preservation potential of these deposits can lead to contemporaneous deposits with the same (or similar) geogenic matrix being placed into different members due to changes in the density and integrity of anthropogenic deposits. This is a significant complicating factor for lithostratigraphic correlation at KRM, where possible lithostratigraphic boundaries between deposits in different recesses (or different areas of the same recess) could be lost due to erosion or the removal of deposits during earlier excavations.

Anthropogenic deposits are very common at some MSA cave and rockshelter sites in South Africa and, when micromorphological analysis has been conducted, anthropogenic materials are generally found (at differing but sometimes high concentrations) in deposits otherwise dominated by geogenic materials (Opperman, 1996; Goldberg, 2000; Goldberg et al., 2009; Miller et al., 2013, 2016; Karkanas et al., 2015; Haaland et al., 2021a). Micro-stratification of deposits, including anthropogenic or anthropogenic-material-rich deposits, is also particularly common at cave and rockshelter sites in southern Africa (Mentzer, 2023). People clearly had a significant impact on the lithology of deposits at these sites, including in deposits not typically viewed as anthropogenic. The advantage of micromorphology in this setting is that the origins of the matrix can be investigated more thoroughly than macroscale and bulk sample analyses allow, providing greater ability to recognise how humans have

influenced stratigraphy and how subsequent diagenesis may have further complicated matters.

The new observations of the SBLS provide important insight into how widely the properties of contemporaneous deposits at KRM may vary due to the interplay of different site formation processes (across roughly 1.5 m in this case), including where people chose to carry out various activities (Morrissey et al., submitted). Given this pattern, it is unsurprising that it has proven difficult to track Wymer's Layer 37 across Cave 1 into Cave 1A despite the great interest in doing so (Morrissey et al., 2022), especially since there is a greater variation in depositional environments (and a greater chance of localised erosion) across that space than across the width of the Witness Baulk. In addition to the problem of lateral variation in facies across contemporaneous deposits, there is also the potential for adjacent deposits of differing ages to have similar lithologies. This would be especially problematic (from the perspective of making correlations across space) in the case of excavation through an area with a lateral erosional contact.

6.2.2. Allostratigraphy

The considerable potential for lateral variation in facies at KRM means that linking hiatuses and erosional events across the site complex could be incredibly valuable for making stratigraphic correlations. However, it is also entirely possible for these events to occur independently in different areas, as evidenced by the localised nature of the macroscopically visible truncation of the LBS in Cave 1 (Morrissey et al., submitted, Figure 3) and the many highly localised erosional events identified at the microscale by Morrissey et al. (2023, submitted). Furthermore, the formation of the SASW and SASR in Cave 1 involved simultaneous erosion in Cave 1A and deposition in Cave 1 (Deacon & Geleijnse, 1988; Deacon, 2008), meaning that if the associated unconformities were identified in Cave 1A, there would not be contemporaneous ones in Cave 1.

If a single event were to somehow occur simultaneously across the site complex, it is very likely that the local impacts would vary widely. The following is a purely hypothetical example but is based on general observations of conditions within the site complex and demonstrates this point. A period of no (or very limited) anthropogenic

and allogenic geogenic deposition could result in the formation of speleothem or flowstone in the comparatively moist Cave 1. Meanwhile, the same hiatus would probably lead to weathering and dissolution in Caves 1A and 1B. As there is a relative lack of tufa on the western cliff face, there may be less input of alkaline water into Cave 1B than into Cave 1A. Therefore, the weathering and dissolution would probably be more pronounced in Cave 1B, further complicating correlation.

The most significant use of allostratigraphy to correlate deposits at KRM to date does involve the inference of a site-complex-wide event occurring at the same time in different depositional environments. Deposits in Cave 1, Cave 1/1A, and Cave 1B were correlated based on inferred hiatuses and the position of the deposits above the LBS Member at each location (Deacon & Geleijnse, 1988). Although there are indications that hiatuses occurred at these locations, the associated lithic assemblages and overlying deposits in each case indicate that these are three distinct events, likely separated by millennia (Wurz, 2002; Morrissey et al., 2022, 2023).

Allostratigraphy has proven to be a very useful approach for correlating deposits in open-air contexts, where periods of significant erosion or surface stability can reasonably be expected to occur across landscapes (e.g., Bettis et al., 2008; Stanistreet et al., 2018; Morrissey et al., 2020; Gallotti et al., 2021). However, the rapid change between distinct micro-environments at a site complex like KRM is a very different scenario. There is some possibility that allostratigraphic correlations may be possible over short distances between standing sections when combined with other lines of evidence, but the approach appears unlikely to achieve much success over greater distances without supporting dates, particularly between Cave 1B and the rest of KRM.

6.2.3. Biostratigraphy

Biostratigraphy is typically used in archaeological and palaeoanthropological research to date deposits within a particular site or locality relative to dated sites with the same taxa or similar taxonomic proportions within their floral and/or faunal assemblages, or to divide the sequence within a site into biostratigraphic units (e.g., McKee, 1995; Preece et al., 2006; Braun et al., 2013; Urban & Bigga, 2015; Rofes et al., 2021). Biostratigraphy has been used more recently at KRM to suggest an external temporal

correlation. The comparatively high proportion of grazing species in the large mammal assemblages excavated from the LBS in Cave 1/1A has led Reynard and Wurz (2020) to conclude that there were open grasslands in the vicinity of the site complex. This, in turn, suggests relatively low sea levels during this period, more akin to the glacial MIS 6 than the interglacial MIS 5e with which the LBS has generally been associated.

The only application of biostratigraphy to KRM for the purposes of understanding intra-site-complex relationships was the use of ostrich eggshell to correlate deposits which seemingly all formed during a period in which environmental conditions were suitable for ostrich to occur somewhere near the site (Rightmire & Deacon, 1991; Deacon & Schuurman, 1992; Deacon, 2008). However, as discussed by Morrissey et al. (2022), this is not a valid biostratigraphic marker as both MSA I and II deposits have yielded some ostrich eggshell.

As mentioned previously, there is good preservation potential for calcareous microfossils but a low likelihood of pollen and phytolith preservation. Foraminifera are present and in a good state of preservation in many deposits in both the LBS and SBLS in the Witness Baulk, and are sometimes very common (Morrissey et al., submitted, Table 1). These have not been identified to higher taxonomic resolution, and it is possible that multiple taxa may be present. Similarly well-preserved foraminifera have also been identified by Susan Mentzer in micromorphology samples taken in and around AA43 from the LBS and SAS deposits (S. Mentzer, pers. comm., 2023).

Nine benthic foraminifera taxa, and one planktic, were identified from bulk samples of the BOS and SMONE units in the SASL (Faul, 2021). However, foraminifera are relatively uncommon in the SASL, with the microfossil assemblages instead dominated by ostracods (Faul, 2021). In contrast to the MSA I deposits and the SAS in AA43, where foraminifera are well preserved and sometimes found in distinct lenses, the tests are relatively poorly preserved in the SASL, which Faul (2021) interpreted as being due to their transport into the cave. It is unclear whether the preservation state of the foraminifera could also be explained by their reworking within Cave 1 during the winnowing of the SASL by waterflow proposed by Deacon (2008).

It seems that there could be potential for the use of microfossils to distinguish MSA I and MSA II deposits in the Witness Baulk and AA43, which is relevant in areas of the cave where the contact between the SBLS and BOS is somewhat ambiguous. However, there is currently a disconnect in that taxa have been identified and compared in terms of abundance in the SASL but not in the other deposits, while how the microfossils are distributed within deposits is only understood in the deposits examined using micromorphology. Ultimately, any use of these microfossils as biostratigraphic indicators requires a better understanding of a) what taxa are present in the MSA I and II deposits in both areas, b) where the various microfossil taxa lived and how they entered the cave (if they were transported in), and c) how widespread the preservation of these microfossils is within each member/sub-member across Cave 1 and Cave 1/1A.

6.2.4. Assessing stratigraphic possibilities

I feel that it is reasonable to conclude that it will never be possible to correlate many of the individual deposits in any of the recesses with contemporaneous deposits in other areas of the site barring the development of an extremely accurate and precise dating technique which could be used on individual micro-stratified deposits. The Wymer excavations likely removed some evidence which *might* have been more apparent during a higher resolution excavation (e.g., a potential lateral contact between the SBLS and SCB2-SCB1 at the edge of the Cave 1 excavation), but there is still no guarantee that this would have been identified. Furthermore, the erosion of deposits during the Holocene (which made the discovery of the site possible) definitely removed inter-linking deposits which might have helped to correlate between the sequences in different recesses.

Even without the erosion and the excavation, and even if KRM were currently being excavated for the first time, with the same high-resolution approach to understanding provenience and context, many deposits simply could not be correlated. Especially with the micro-stratified nature of the deposits at KRM, there is no guarantee that deposition took place in different recesses at exactly the same time, and differing depositional rates could mean that a deposit less than a centimetre in thickness could have formed across the same period of time as multiple deposits with a combined thickness of 10 cm. This is especially relevant given the rapidity of anthropogenic

deposition compared to geogenic. Additionally, extant deposits in one recess may have been contemporaneous with deposits which were partly or completely eroded in another.

A far more important point is the question of why deposits need to be correlated, and at what resolution. As discussed by Morrissey et al. (2022), fine-scale stratigraphic correlations across the KRM site complex were largely made as a means to support the argument that the death and cannibalism of multiple people occurred within a very short period of time (Deacon, 1992, 1995, 2008). This required linking deposits in Cave 1, Cave 1/1A, and Cave 1B which would have had to have been forming contemporaneously and had human remains deposited within them in the span of a few weeks.

The (very limited) evidence for this correlation was not considered strong enough given the extreme precision of stratigraphic correlation across distinct depositional environments this would have entailed (Morrissey et al., 2022). It is now clear that the specimen from Cave 1B is older than the hypothesised event (Morrissey et al., 2023) and, while there is some evidence for a general temporal correlation between the specimen from Cave 1/1A and some specimens in Cave 1, a finer-scale correlation is not supported.

The micro-stratified deposits at KRM, and many MSA sites in South Africa, allow for significant insights into human behaviours (and spatial and temporal patterning in these behaviours) that would be impossible or far more difficult at sites with lower preservation potential. Ironically, however, this relative lack of natural disturbance and homogenisation has also contributed to the difficulties of stratigraphic correlation at KRM. The same changes in sedimentary properties over short distances that make it difficult to link many deposits between Cave 1 and Cave 1A allow for a more detailed understanding of variation in different site formation processes. The negative side of this trade-off is particularly evident at KRM, where activities took place across such distinct environments, and would not be as apparent and problematic within a single cave or rockshelter.

The coarser correlations made based on cultural stratigraphy and the lithostratigraphy of the members and sub-members will be considered in the next section. These correlations, while covering broad periods of time, do allow for secure grouping of features and excavated material from different recesses. This should not preclude the high-resolution analysis and interpretation of assemblages from different excavation areas by the Deacon and Wurz teams, as such studies provide greater insight into human behaviour and palaeoenvironmental conditions than grouping results and interpretations by member or lithic cultural phase (e.g., Brenner et al., 2022; Wurz et al., 2022).

6.3. The stratigraphy of the basal deposits

This section is focused on addressing Aim 1 of the thesis following the discussion of the realities of stratigraphic correlation at KRM in the previous section.

Cultural stratigraphy remains the primary means by which most deposits are correlated (in broad groupings) across the KRM site complex (Figure 6.4; Table 6.1). Lithostratigraphy also plays an important role, but this is often in the form of distinguishing different groups of deposits in the same area of the site complex into different members or sub-members (Morrissey et al., 2022). There is no evidence that suggests any need to challenge the culture-stratigraphic associations of Deacon's excavation units published by Wurz (2002), meaning that the fundamental basis of the stratigraphic system remains sound.

The MSA I includes the basal gravels and the LBS Member across the site complex, the RS Member in Cave 1B, and the SBLS Member in Cave 1 (Figure 6.4). As discussed by Morrissey et al. (2023), the lithology of the RS Member in Cave 1B is distinct enough from the LBS and SBLS that a correlation cannot be made with either on lithostratigraphic grounds. The observations from Cave 1 presented by Morrissey et al. (submitted) support this view.

The MSA II lower is present in the lower half of the SASDC Sub-member in Cave 1B, the SASL and SASU Sub-members in Cave 1 (and perhaps Cave 1/1A), and a small portion of the considerable thickness of the SAS Member in Cave 1A (Figure 6.4). There are grounds for correlations between several sets of MSA II lower deposits in

the Witness Baulk and AA43 (Table 6.2). These are based on a combination of lithostratigraphic and allostratigraphic evidence over a comparatively short distance and seem plausible as still relatively broad correlations. In one case, there is the potential to link the SASU Sub-member across into deposits in Cave 1A proper, but only very limited evidence has been published for this.

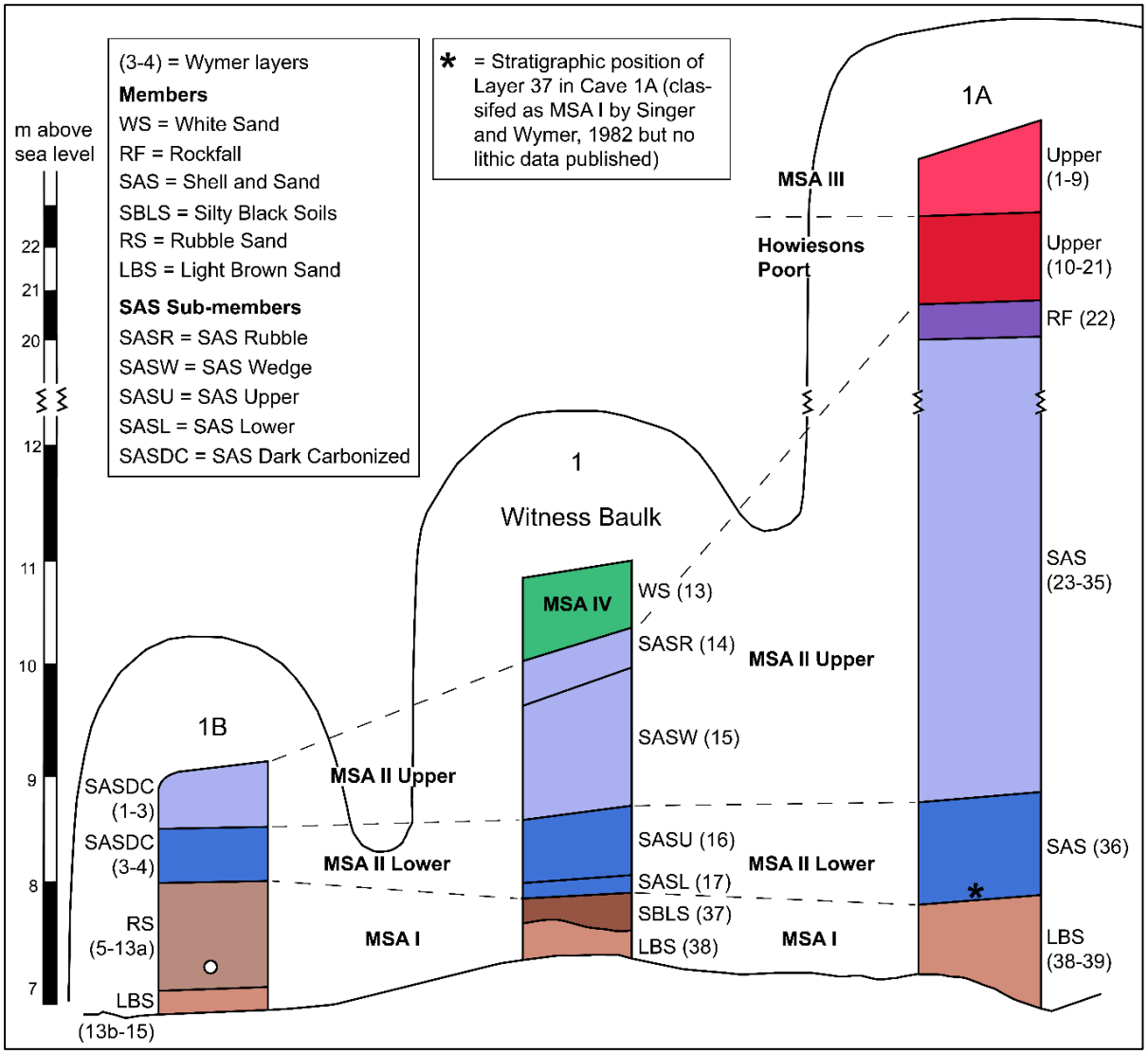

Figure 6.4. Generalised cultural stratigraphy and lithostratigraphy of the Klasies River Main site complex (modified from Morrissey et al., 2023). Cave 2, not included in this schematic, lies above Cave 1 and contains RF and Upper Member deposits.

Table 6.1. The general stratigraphy of the MSA I and II deposits at Klasies River Main site (adapted from Wurz, 2002, Table 2). The deposits are grouped by lithic cultural phase and then member, sub-member, or other grouping. Deposit ranges are presented from oldest to youngest. Where the relevant grouping has not been excavated by Deacon or Wurz (or no unit names have been published) Wymer's layer numbers are included. *The deposits north of AA43 overlying SM1 and underlying SM5 (Figure 6.2) would presumably fall within the MSA II lower (as would SM5 at this location) and potentially correlate with the SASU.

	Cave 1B (PP38)	**Cave 1 Witness Baulk**	**Cave 1/1A (AA43 and Z44)**	**Cave 1A**
MSA II upper	SASDC (DCCP6–DC surf)	SASR (Layer 14) SASW (H3–J4)		SAS (T50 BS4L–L51 YS)
MSA II lower	SASDC (DCCP12–DCCP7)	SASU (HHH base–D1) SASL (BOS–SMONE)	SASL (SCB2–SM1*)	SASU (T50 SM5LB–SM5T)
MSA I	RS (RSBR–RSYS1) LBS (Layers 15 – 13b)	SBLS (formerly RBS) LBS (Layer 38) Basal gravel (Layer 40)	LBS (SBS–SCB3S)	LBS (Layers 39-38) Basal gravel (Layer 40)

Table 6.2. More specific stratigraphic correlations between deposits in Cave 1 and Cave 1/1A, generally based on lithostratigraphy and/or allostratigraphy. Where a range of deposits is given, they are from oldest to youngest. WB = Witness Baulk

Deposit/s in Cave 1/1A	**Deposit/s in Cave 1 WB**	**Reasoning and confidence**
SCB2–SCB1 (AA43, Cave 1/1A)	BOS (SASL)	There are different types of evidence for slow deposition and hiatuses during and following the formation of the lowermost MSA II deposits in AA43 (Deacon & Geleijnse, 1988; Wurz et al., 2018; Morrissey et al., 2022) and the Witness Baulk (Wurz et al., 2022; Morrissey et al., submitted). Given the relatively close proximity of these deposits and a similar event of speleothem/tufa collapse in their lower portion, it seems very likely that they are contemporaneous. While this correlation would benefit from confirmation through other lines of evidence or more lithostratigraphic or allostratigraphic data, it seems secure.
BS2–SM1 (AA43, Cave 1/1A)	SMONE (SASL)	This correlation was proposed by Wurz et al. (2018). There are similarities in lithology which support this idea and, as BS2–SM1 directly overlies SCB2–SCB1 and SMONE lies directly on BOS, the probable correlation between the lower sets of deposits makes this correlation appear very likely.
SM5 (north of AA43, Cave 1/1A to T50, Cave 1A)	SASU	No evidence or discussion presented by Deacon (1995, 2008), who proposed this. As the uppermost MSA II lower deposit in T50, SM5 cannot be associated with the SASL. This correlation is plausible but needs further investigation.

The MSA II upper spans the upper half of the SASDC Sub-member in Cave 1B, the SASW and SASR Sub-members in Cave 1, and most of the SAS Member in Cave 1A. The broad similarity in lithology throughout the SASDC deposits also prevents specific correlations with the SAS in Caves 1 and 1A beyond the MSA II lower/upper division. As the SASW and SASR are in secondary context and were formed by sediment which eroded from Cave 1A, it would be impossible to find specific correlations to MSA II upper deposits in Cave 1A.

6.4. Human occupation

This section relates to Aims 2 and 3, with a particular focus on inferring possible changes in human occupational intensity and frequency in Caves 1 and 1B during the MSA I and II.

Following the initial excavation of the KRM site complex, Singer and Wymer (1982, p. 107) argued that occupation of the site complex was fairly continuous throughout the MSA sequence. This was due to an apparent lack of truncated or weathered deposits or large accumulations of archeologically sterile colluvial sediment other than those which clearly post-date the post-Howiesons Poort deposits. Occupation was also described as “permanent or semipermanent” (Singer & Wymer, 1982, p. 27), but it is unclear if this includes the entire site complex and sequence or only the MSA II, Howiesons Poort, and MSA III deposits in Cave 1A. The term “semipermanent” is never explicitly explained, but discussion elsewhere in the monograph (Singer & Wymer, 1982, p. 107) suggests that this may have referred to seasonal occupations. Layer 13a in Cave 1B, interpreted as a weathered deposit (Singer & Wymer, 1982, pp. 24-25), appears to have been considered anomalous in this respect. The alternating anthropogenic and geogenic deposits in the LBS in Cave 1 and in the SAS in Cave 1A were suggested to represent changing occupational intensities, potentially of a seasonal nature (Singer & Wymer, 1982, p. 107). It is not clear what impact the grouping of numerous distinct deposits into single layers may have had on the interpretation of the presence or absence of sterile deposits.

The higher resolution approach adopted by Deacon led to a different interpretation. The composition of >2 mm sedimentary components in “occupation” and “non-

occupation" units in Cave 1/1A and Cave 1A differed notably, with anthropogenic materials more common in the former and biogenic components more frequent in the latter (Deacon & Geleijnse, 1988). Occupation of the site complex was viewed as being episodic in nature. The thick sandy deposits in the LBS in the trench at the base of Cave 1A suggest comparatively infrequent occupation during the earlier part of this period, with changes in deposit thickness showing more frequent occupation (Deacon & Geleijnse, 1988). The presence of carnivore toothmarks on bones which do not display cutmarks or other anthropogenic signatures throughout the MSA sequence also suggests regular abandonment of the site complex for periods long enough for carnivores to occupy the space (Reynard, 2022). Furthermore, there is now clear evidence for depositional hiatuses of varying lengths both within and between members from dating of speleothem (Wurz et al., 2022), macroscopic observations of weathered horizons (Deacon & Geleijnse, 1988; Morrissey et al., 2023; this chapter), microscale observations of decalcification and the formation of different types of crust (Morrissey et al., 2023, submitted), and the presence of pools formed by dripwater (Deacon & Geleijnse, 1988; Morrissey et al., submitted).

New observations from the LBS in Cave 1 (Wurz et al., 2022; Morrissey et al., submitted) show that there was occupation intensive enough for the structuring and maintenance of space to occur, including the discard and accumulation of waste in middens. Significantly, extremely thin lenses of reworked ash were identified in some otherwise sandy deposits, pointing to occupations not visible in the field (e.g., Morrissey et al., submitted, Figure 12c). There does seem to be variation in the frequency and intensity of occupations preserved in these deposits, along with clear indications of hiatuses (Morrissey et al., submitted). The overall frequency of occupation appears higher than that inferred for the LBS by Deacon and Geleijnse (1988) in Cave 1/1A. However, the accumulation of geogenic sediment would likely have been far slower within Cave 1 itself, and preservation potential (especially of less intensive occupations) would be lower in Cave 1/1A, particularly in the trench.

The SBLS appears to represent more intensive occupation of Cave 1 but there are clear indications of occupational hiatuses, along with potential changes in intensity (Morrissey et al., submitted). It is also very likely that geogenic deposition was slower during the formation of the SBLS than it was for the LBS, which complicates an

assessment of how much occupational intensity actually differed (Morrissey et al., submitted). The other MSA I member studied here, the RS in Cave 1B, is also difficult to interpret in this regard due to potential differences in both diagenesis and geogenic depositional rates, but there may have been comparatively low occupational intensity and/or frequency relative to the LBS in Caves 1 and 1A (Morrissey et al., submitted).

The lower half of the SASDC, associated with the MSA II lower, appears to have been deposited during a period of fairly intensive occupation (see Morrissey et al., 2023, Figures 6, 10 and 11), but seemingly less intensive than the occupations which led to the formation of the SBLS based on the limited evidence for hearth maintenance. The few, mostly very thin, sandy deposits within this sequence suggest that these occupations also occurred frequently. In contrast, the MSA II upper phase in the upper SASDC appears to have seen far less frequent and generally less intensive occupation during those periods, with greater variation between different occupations. It is possible that periods of more rapid deposition of geogenic sand and/or lower preservation potential may have accentuated this pattern to some extent, but the general occupational differences between the upper and lower SASDC appear to be real.

Regardless of what factors (including environmental, demographic, or cultural changes) caused the variable occupation intensities and frequencies observed within lithic cultural phases, and what role changing geogenic depositional rates played in potentially overstating variation, the simple presence of these differences demonstrates the need to consider behavioural and palaeoenvironmental evidence at the scale of the excavation unit rather than only grouping this evidence by cultural phases distinguished using techno-typological changes or continuities in lithic assemblages. Recent studies of lithic artefacts and shellfish conducted at this scale (Brenner & Wurz, 2019; Brenner et al., 2022; Wurz et al., 2022) have provided a more nuanced insight into changing human behaviours and palaeoenvironments than similar studies which grouped material by cultural phase (e.g., Wurz, 2002; Langejans et al., 2017).

6.5. Limitations and recommendations

The limitations listed here are directly related to the availability and interpretation of geoarchaeological data. In contrast, the recommendations also include ways in which faunal and lithic assemblages could contribute to better understanding the formation and/or stratigraphy of the MSA I and II deposits in the KRM site complex.

The greatest limitation for understanding the formation of the deposits in Cave 1 is the lack of micromorphology samples from the SAS deposits in the Witness Baulk. Due to the high clast density of most deposits, including many clast-supported zones or entire deposits, collecting block samples would require large amounts of sediment. Due to the baulk being comparatively tall and narrow, removing enough sediment for a viable block could destabilise the baulk, leading to a collapse. This would pose a significant threat to the safety of anyone working in the cave, and the loss of an enormous quantity of important archaeological evidence. Targeted sampling of comparatively clast-poor areas of the SASU would give an idea of how these portions of the deposits formed but would still have the potential to destabilise the baulk given how limited these deposits are and how much weight they support. The quantity of sediment which would be required to sample these deposits (perhaps requiring a block as large as 50 cm x 50 cm) would also pose a significant logistical challenge, and the sacrifice of a large quantity of artefacts and potentially even human fossils.

In terms of understanding the formation and stratigraphy MSA I and II across the entire KRM site complex, the two biggest limitations are now the lack of work on the deposits in Cave 1A (excluding the Cave 1/1A boundary area) and the limited and sometimes contradictory dating of the MSA I deposits. Field description and sampling in Cave 1A (which was not included in the aims of this study) could help to improve our understanding of this part of the site complex. Hopefully, new dates for the MSA I deposits will become available, potentially aiding correlation across KRM and allowing the association of the three MSA I members and/or specific excavation units with broader environmental and behavioural patterns along the southern Cape coast and beyond.

The lower excavation areas of Cave 1A (including deposits assigned to Layer 40 and the LBS) are not currently accessible due to backfilling with either loose sediment or

sandbags. These excavations are fairly close to AA43 (closer than they are to the exposed standing Cave 1A profiles), and a number of correlations have been made between Deacon's trench and AA43 (Deacon & Geleijnse, 1988, Figure 8). Therefore, any work on these deposits would largely be focused on understanding lateral variation in site formation processes (including human behaviour and the preservation of anthropogenic features/deposits.

Some of the basal SAS deposits were also recorded in the filled trench and the majority were considered continuous across to AA43 by the excavators (Deacon & Geleijnse, 1988, Figure 8). Only the uppermost deposits assigned to the MSA II lower – the various units making up SM5 in square T50 – are relatively easily accessible. Given the lateral extent of SM5 (~10 m), the fact that it is the only individual deposit which appears to link Cave 1 and Cave 1A across the arbitrary boundary between them, and the behavioural significance of such a large feature, field and microscale analysis of this feature wherever it is accessible is an important objective for future geoarchaeological research.

The majority of the SAS deposits are associated with the MSA II upper and are exposed moving up through the Cave 1A excavations. As noted in Sub-section 6.2.4, it is unlikely that it will be possible to make specific correlations with either Cave 1 or Cave 1B. However, given the number of anthropogenic features in this long sequence (Deacon & Geleijnse, 1988), they could be a significant source of behavioural information.

The interpretation of microfacies related to trampling, hearth cleaning, and dumping of hearth (and associated) materials is currently heavily influenced by the results of experimental work conducted on a very different substrate (Miller et al., 2010). Carrying out experiments on a substrate more representative of conditions at KRM, and which seek to test particular interpretations and/or recreate specific observed microfacies, could help to refine the understanding of these deposits (and associated behaviours) and either confirm the current interpretations or allow more nuanced insights.

The identification of potential microfossil biostratigraphic units within Cave 1 and AA43 offers another possible line of evidence with which to refine our understanding of the stratigraphy of this important area of the site complex. However, this requires dedicated sampling and analysis by a specialist capable of identifying these microfossils in order to build a clearer picture of which taxa are present in which deposits, and to determine if there is lateral variation in microfossil assemblages within the Witness Baulk, and if this variation in species/genera is large enough to provide a proxy for palaeoenvironmental differences.

This point has been raised by Morrissey et al. (2023, submitted), but taphonomic analysis of faunal assemblages (including shell) excavated at high resolution during the Deacon and Wurz excavations has the potential to provide a great deal of information on both human behaviour and natural site formation processes (including the role of carnivores in accumulating faunal remains). Significantly, these results can provide some insight into the intensity of human occupations (Reynard, 2014, 2022) which complement the information gained from the analysis of anthropogenic features and deposits (e.g., Haaland et al., 2021a). Along with published information for some deposits (Reynard, 2022), assemblages from various parts of the site are being studied at present (or will be in future). This includes in the on-going Witness Baulk excavation. An integration of the interpretations of this study, other geoarchaeological work (Wurz et al., 2022), and the taphonomic studies should provide a clearer view of occupational intensity and frequency during different periods of occupation across the KRM site complex (e.g., Haaland et al., 2021a).

Detailed technological analysis of lithic assemblages excavated at high resolution from the SASL (MSA II lower) in the Witness Baulk has shown temporal changes between different excavation units in the sub-member (Brenner & Wurz, 2019). If similar changes were identified in the MSA II lower deposits in Caves 1A and 1B, this could provide the means to make higher resolution correlations across the site and confirm the hypothesised correlations between the Witness Baulk and AA43 (Table 6.2). If any temporal changes were identified in MSA I assemblages, these could be particularly helpful for identifying any deposits which may be contemporaneous with the SBLS. However, this possibility comes with a significant caveat. Different areas of the site are unlikely to have been used for exactly the same activities or at the same time, which

could result in differing lithic assemblage composition. Likewise, natural site formation processes could alter lithic assemblages. This is especially relevant given the evidence for the winnowing of some deposits by water, and the likelihood that at least some deposits were deflated by wind during periods when the shoreline was relatively close to the site complex.

6.6. Conclusion

This study aimed to address the following three research questions relating to the MSA I and II deposits at KRM:

1. What are the stratigraphic relationships between the basal deposits (layers assigned to the LBS, RBS, and SAS Members/Sub-members), both within and between Caves 1, 1A and 1B?

2. What geogenic, biogenic, and anthropogenic processes were involved in the formation and post-depositional alteration of the deposits in Cave 1B?

3. What geogenic, biogenic, and anthropogenic processes were involved in the formation and post-depositional alteration of the basal deposits in the Witness Baulk of Cave 1?

A critical review of the published descriptions and interpretations of the stratigraphy of the site complex (Morrissey et al., 2022) is followed by the application of microcontextual analyses – with supporting macroscopic observations – to deposits in Cave 1B (Morrissey et al., 2023) and the Cave 1 Witness Baulk (Morrissey et al., submitted). Finally, in this chapter, previously published information is integrated with my results to cover aspects of the project not addressed by the manuscripts.

The general stratigraphy of the site complex has been refined as a result of this work, including through the re-assessment of the evidence and reasoning used in previous correlations. This is most obvious in the case of Cave 1B, where the two stratigraphic approaches utilised at KRM have been reconciled as much as their differing resolutions permit, allowing a re-evaluation of their relationships to deposits elsewhere in the site complex. This thesis demonstrates that it will never be possible to know the

specific relationships between many of the deposits at KRM, but that multiscale analysis and the use of multiple types of stratigraphic evidence does allow the refinement of our understanding of some relationships. Therefore, while Research Question 1 has been answered to some extent, it is also impossible to answer it entirely, which is a useful discovery.

The research conducted for this thesis has also allowed for a more nuanced understanding of the formation of the studied deposits than previous macroscale work (generally published in limited detail) had provided. Along with other recent microscale analysis, the results reveal aspects of site formation which were not obvious at the macroscale. A range of processes played a role in forming deposits in Cave 1 and 1B, and the formation of any particular deposit could involve any number of combinations and relative intensities of different processes. The interplay between geogenic, biogenic, and anthropogenic processes should always be considered.

Although humans have long been recognised as important depositional agents at KRM, it is now clear that they also played a major role in reworking sediment through daily actions within occupation areas, which included (but certainly were not limited to) trampling and site maintenance activities. Chemical diagenetic processes played a significant role in both preserving and dissolving ash, with implications for the preservation of hearths and other anthropogenic features and deposits. However, the intensity and frequency of anthropogenic deposition (which appear to have varied over time and space within the site complex) also influenced how susceptible deposits were to diagenesis.

Geoarchaeological research at KRM has evolved from the initial (comparatively) low resolution work of the 1960s, through higher resolution macroscopic research in the 1980s and 1990s, to the application of a microcontextual approach in recent years. There is considerable potential for future multiscale geoarchaeological research at KRM, especially as excavations continue and potentially complementary data from other specialisations accumulate. This thesis contributes to the growing understanding of this remarkable site complex and will hopefully encourage further investigation, just as the work of Karl Butzer, Hilary Deacon and colleagues, and Susan Mentzer and colleagues laid a platform for this study.

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APPENDIX A

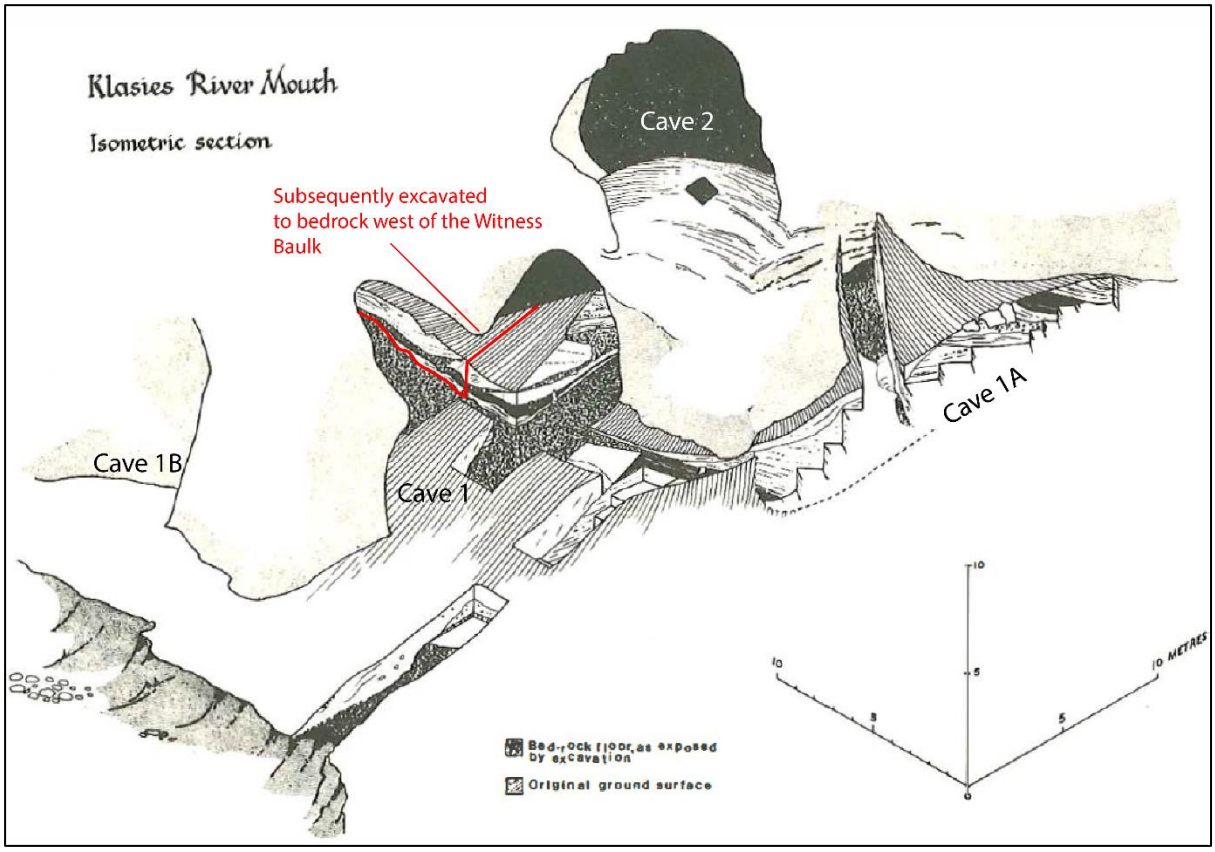

Figure A1. An annotated isometric section of the KRM site complex drawn during the 1967-1968 excavations showing the excavated areas and relationships between the different recesses (after Singer & Wymer, 1982, Figure 3.1A). Note that Cave 1 appears as a partial cut-away, with some of the quartzite roof not drawn in favour of showing more of the interior of the cave. This section was drawn prior to the excavation of the western cutting. Much of Cave 1 was excavated to bedrock, in stark contrast to Cave 1A.

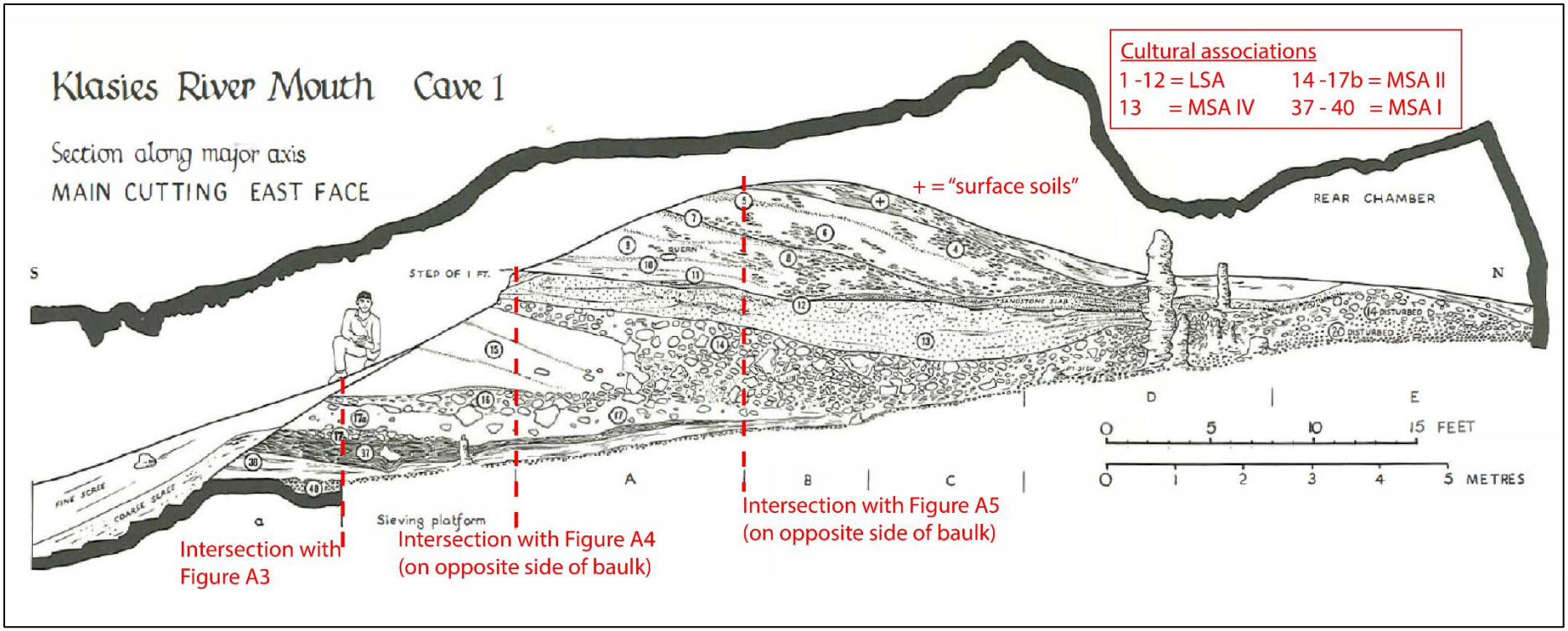

Figure A2. Annotated section drawing of the Cave 1 Witness Baulk prior to the excavation of the western cutting during the 1967-1968 excavations (after Singer & Wymer, 1982, Figure 3.2). The significant variation in roof height is also shown. A ~1 m wide portion of the area south of the intersection with Figure A3 was excavated, leaving a passage between the Witness Baulk and extant scree deposits. Note that the profile presented in Figure A3 extends across the width of Cave 1, including deposits on either side of the baulk, while those in Figures A4 and A5 only span the west cutting, on the other side of the Witness Baulk (relative to this view).

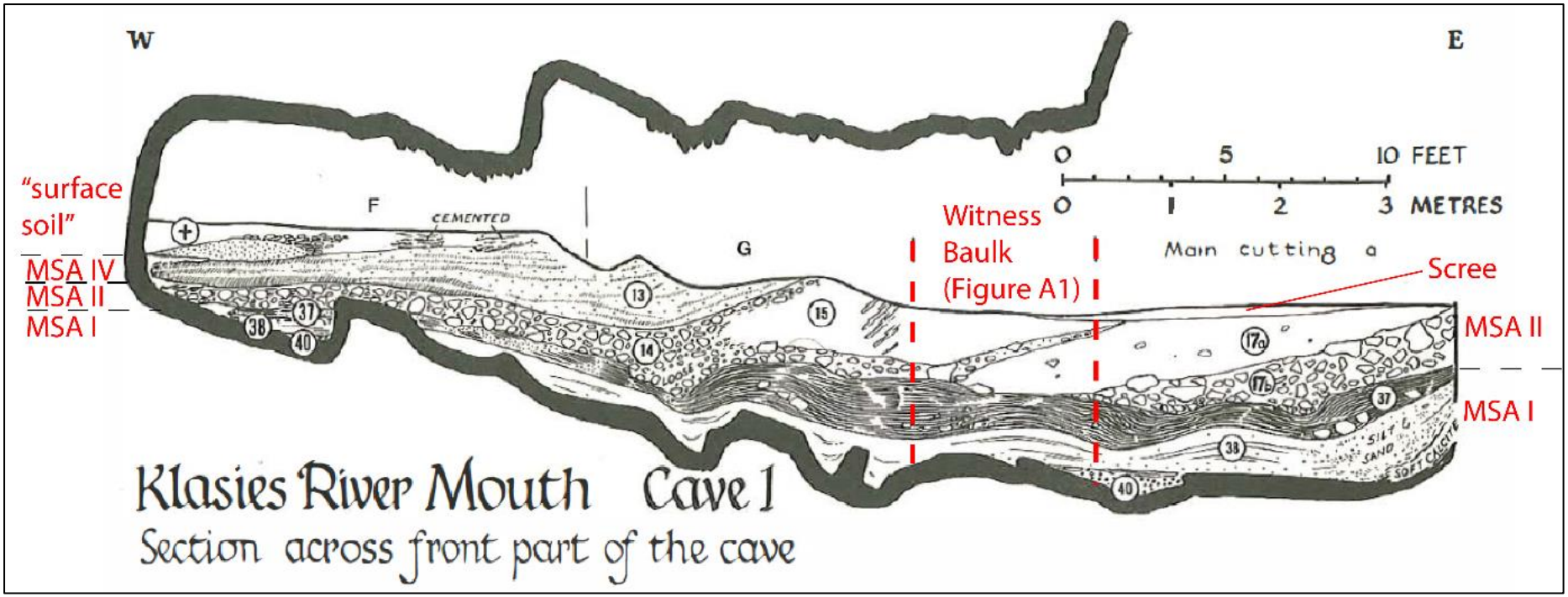

Figure A3. Annotated section drawing spanning the width of Cave 1, to the south of the Witness Baulk (after Singer & Wymer, 1982, Figure 3.3). Note the variation in the elevation of both the floor and the roof of the cave.

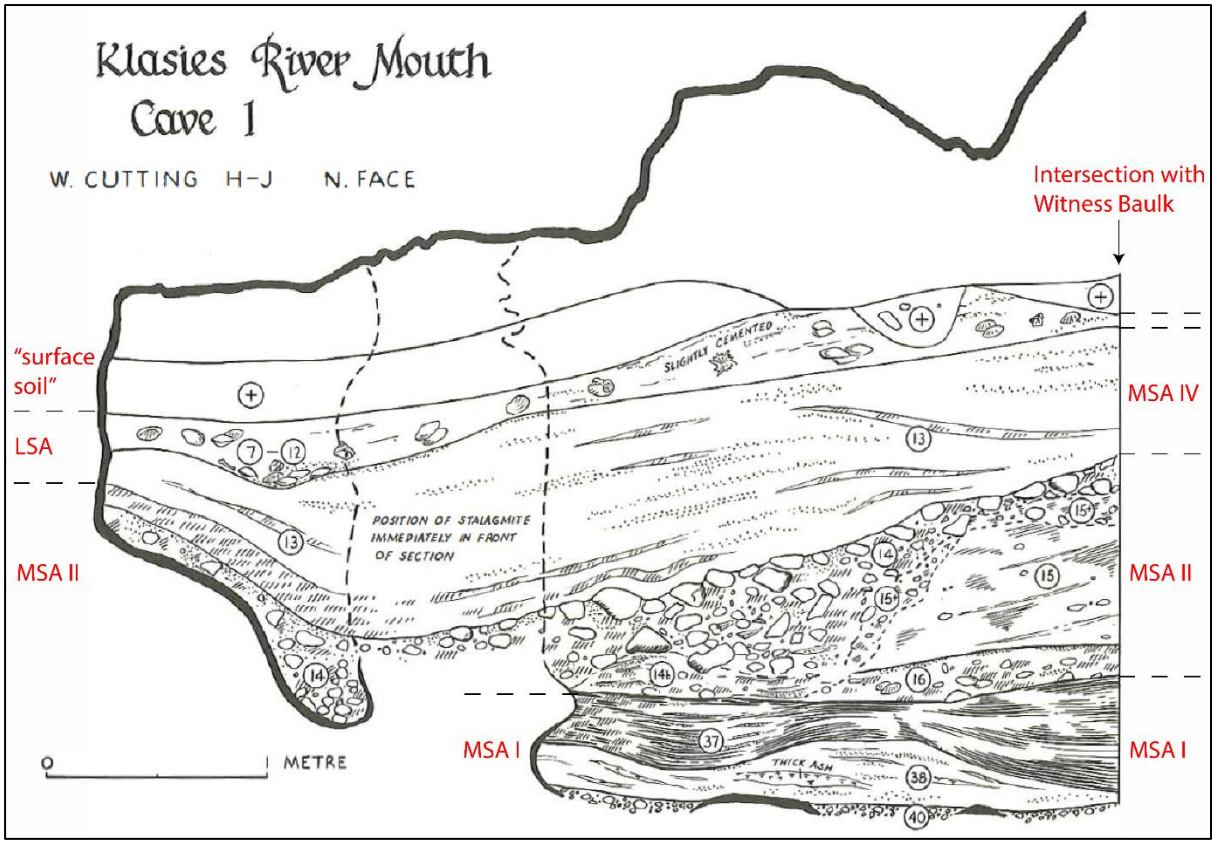

Figure A4. An annotated section drawing of a profile in the west cutting of Cave 1 during the 1967-1968 excavations (after Singer & Wymer, 1982, Figure 3.4). There is a clear difference in cave and deposit morphology over the ~2.5 m between this profile and the more southerly profile in Figure A3.

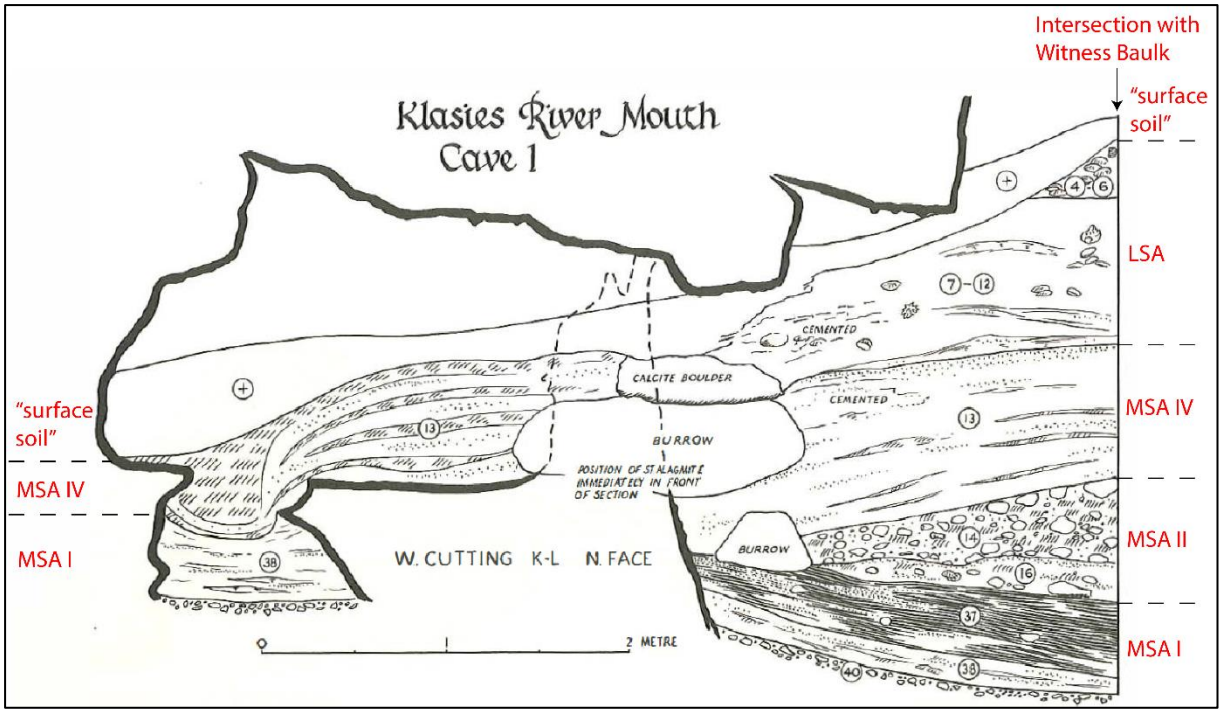

Figure A5. An annotated drawing of the northernmost recorded profile in the west cutting during the 1967-1968 excavations of Cave 1 (after Singer & Wymer, 1982, Figure 3.5). It is roughly 3.5 m north of the section in Figure A4, and about 6 m north of that in Figure A3, with differences in cave and deposit morphology between all three.