Archaeological and Anthropological Sciences
https://doi.org/10.1007/s12520-018-0749-9

ORIGINAL PAPER

Revisiting Mwulu's Cave: new insights into the Middle Stone Age in the southern African savanna biome

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Received: 20 September 2018 / Accepted: 31 October 2018

Abstract
In this paper, we present a revised stratigraphy and results of preliminary analyses of the archaeological material from Mwulu's Cave. This arises from two excavation campaigns conducted in 2017, 71 years after the site was initially investigated by P.V. Tobias. This cave, located in Limpopo Province (South Africa), preserves one of the few known Middle Stone Age sequences in the northeastern part of the country. Here, we revisit the stratigraphic sequence of the site and provide new analyses of sediments, palynomorphs, phytoliths, ochre and lithics. The renewed excavations and reappraisal of the archaeological material from Mwulu's Cave form part of a larger research project exploring Middle Stone Age variability in the northeastern part of South Africa, with a specific focus on the so-called Pietersburg industries.

Keywords Stratigraphy · Sedimentology · Pollen · Phytoliths · Ochre · Lithics · Pietersburg industry

Introduction

Mwulu's cave: a new project

The literature for the Middle Stone Age (MSA) archaeology of southern Africa is far from being clear. The MSA, a term somewhat ambiguously defined in the late 1920s (Goodwin and Van Riet Lowe 1929), has had supporters and detractors since its conception. Nonetheless, it has been retained as a useful framework by most researchers. The MSA in southern Africa has included, from its initial definition until now, a variety of industries and regional expressions, which include amongst many others: the Still Bay, Proto-Still Bay, Pietersburg, Bambatan, Howiesons Poort, Hagenstad, Mazelspoort, Magosian, Pre-Still Bay, Post-Howiesons Poort, and the Sibudan. Some of these industries, such as the Still Bay, were vehemently rejected in the second half of the twentieth century (Sampson 1972, 1974), but now have strong defenders (Wadley 2008; Henshilwood 2012; Conard and Porraz 2015). This contrasts with others, notably the Howiesons Poort, which had a complex stratigraphic position and was considered to represent industries mixed with other assemblages (Magosian) and is now again in an ambiguous chrono-stratigraphical position and thus the focus of new academic debate (e.g. Jacobs and Roberts 2015; Tribolo et al. 2009, 2013), although no one would dispute its idiosyncrasy anymore. Finally, some initially weakly defined variations, such as the Pietersburg, went through a 'golden age' before falling into oblivion. Nonetheless, this term has recently been resumed (Lombard et al. 2012; Porraz et al. 2015, 2018). This paper contributes directly to the latter: the lithic material retrieved from Mwulu's Cave was indeed fully attributed to this

Electronic supplementary material The online version of this article (https://doi.org/10.1007/s12520-018-0749-9) contains supplementary material, which is available to authorized users.

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Published online: 23 November 2018

industry (Tobias 1949). Different sites in Limpopo Province were also attributed to the Pietersburg by Mason (1957): Cave of Hearths, Olieboomspoort, Rufus Cave, Kalkbank, Rooirand, Border Cave, Bushman Rock Shelter and Koedoesrand. Mason (1957) paid special attention to this industry and published some of the first statistical comparisons on southern African stone tools. Therefore, the Pietersburg was arguably, for some time, one of the most accurately described industries in Africa.

When Mwulu's Cave was excavated by Tobias in 1947, this site was only the second sequence found in a cave 'with a sealed deposit' attributed to the Pietersburg, following Border Cave (Cooke et al. 1945). It seems ironic that Tobias mentions several problems relating to the definition of the Pietersburg at the beginning of his paper on Mwulu's Cave: 'Was it of long duration or short? Was it a single cultural manifestation, or did it show a range of variation within itself? The answers were necessary in order to view the Pietersburg in proper perspective' (Tobias 1949: p. 2). Tobias thought that the recent—at that time—excavation of Border Cave by Malan, Cooke and Wells (1945), a newly excavated sealed deposit, would solve all questions surrounding the Pietersburg. In a similar manner, Mwulu's Cave was viewed as a good candidate to solve those issues. Seventy-one years later, however, we still have analogous questions. In the two publications of Tobias (1949, 1954), a stratigraphy and a general description of the archaeological materials were provided, and a hypothesis on the accumulation of sediment in the cave was proposed (Tobias 1954).

In 2017, a new project at Mwulu's Cave was initiated with the following objectives: to provide a revised stratigraphy, as well as a chronological and palaeoenvironmental framework, and to re-study, technologically, the archaeological material from Tobias's and the new collections. The ultimate goal was to include all of these data in a renewed discussion on the MSA lithic variability in the northeastern part of southern Africa. In trying to understand the reasons behind this variability, one can propose hypotheses on these alleged periods of change or stasis. The latter will require further work, since we are still in a descriptive phase.

Exploring the variability of the MSA in that region was deemed an important task to accomplish for several reasons.

First, although at some stage during the twentieth century the Pietersburg could have been regarded as one of the better known industries of the MSA (Sampson 1972: p.63), many questions remain today regarding its idiosyncrasy and chronostratigraphical context. Such questions include notably the following: does the Pietersburg truly correspond to a distinct technological entity, which are its main techno-typological characteristics, and how long did it last?

Second, as summarised by Wadley (2015), it seems that the oldest MSA sites in southern Africa are located in the interior part of the region. Investigations about the Pietersburg could therefore contribute to shed some light on the beginning of the MSA in southern Africa.

Third, it is certainly pertinent to attempt to propose a different picture from a somewhat simplistic view according to which the Still Bay and Howiesons Poort techno-complexes would be, respectively, preceded and followed by the monotonous pre-Still Bay and post-Howiesons Poort phases (Will et al. 2014). Interestingly, neither at Mwulu's Cave nor at Cave of Hearths or Bushman Rock Shelter (two other sites located in Limpopo Province, South Africa) have these techno-complexes been identified.

Fourth, inquiry into MSA variability in this area allows us to link it with other African regions where the MSA is still poorly described, such as in Zimbabwe, Botswana and Mozambique. Notably, most of the hypotheses put forward in the last decade on the MSA have originated mainly from coastal sites, such as the cape floral hypothesis (Marean 2010, 2014).

A final issue, recently mentioned by Porraz et al. (2018), is that if the Pietersburg corresponds indeed to a local variation, then true techno-cultural regionalization would exist since the early stages of the MSA, as proposed by Clark (1959).

Mwulu's cave: discovery of the site and Tobias's excavation (1947)

'Serendipity': this is how P.V. Tobias described in his memoirs his discovery of Mwulu's Cave (Tobias 2005). Brian Maguire had decided to show a group of students from the University of the Witwatersrand a yellowwood tree at the entrance of a cave in a remote location on his family farm in Limpopo. Amongst this group of students was a young P.V. Tobias, who, just after they had climbed to the site, found some stone tools scattered on the surface of this small cave. Soon after, in 1947, Tobias decided to excavate the cave they had found with B. Maguire, a rather disappointing excavation for the trainee palaeoanthropologist, given the lack of bone preservation.

The name of the site ('Mwulu's Cave') was given by Constantine Duncan Maguire, the former owner of the farm where the cave stands, in memory of a hermit called 'Mwulu', who lived in the cave in the nineteenth century (pers. comm. Judy Maguire, 2016). Indeed, during his excavations, Tobias found some large pottery sherds that he assumed belonged to Mwulu, the hermit.

Tobias did not leave any information about the precise location of the site, other than that is was located near the famous Makapan Valley in the Makapansberg Mountains. In van Riet Lowe's archives housed at the Origins Centre, University of the Witwatersrand, there were some coordinates, which correspond to the boundary between the *Spanje 36KS* and *Portugal 55 KS* farms.

Mwulu's Cave is located in the eastern escarpment of the Makapansberg Mountains in the district of Mokopane

(Limpopo Province), very near the Makapan Valley (around 5 km away from Cave of Hearths; Fig. 1). The cave is situated directly in a mountain pass, informally called the 'Monkey Nek' by the Maguire family. It is north facing and accessing it requires climbing an ca. 15 m high quartzite cliff (Fig. 2).

Tobias excavated half of the cave deposits. Even though he did not specify which half it was in his 1949 paper, it is likely that it was on the left-hand side as one enters the cavity (Fig. 3). This is quite evident nowadays as this is where the bedrock is visible. For his excavation, he established a grid, following Malan's excavation method. Unfortunately, the exact location of his squares is unknown as he did not provide any spatial information, in either the archaeological material (currently stored in the basement of the Origins Centre at the University of the Witwatersrand, Johannesburg), or in his two papers on Mwulu's Cave (Tobias 1949, 1954). The only information available to us today is the name of the squares, not their location (see Table S1 and Supplementary material).

In his first paper on the site, Tobias described the surface layer ('surface rubble') overlying five more layers, namely (from top to bottom): 'Ash and Sand III', 'Red Sand', 'Ash and Sand II', 'Red Sand' and 'Ash and Sand I' (Fig. 4a). According to his description, the red sand layers were virtually sterile, whereas the ashy and sandy layers were rich in archaeological lithic material. Nonetheless, bone remains are not preserved at all, most likely because the cave formed in quartzite. Besides the few pottery sherds found in the surface layer and attributed to the hermit's occupation of the cave, the entirety of the archaeological assemblage is composed of lithic artefacts.

Even if Tobias had adequately described the stratigraphy illustrated in his 1949 paper (Fig. 4a), the labelling of the archaeological material at the Origins Centre reveals that he excavated by spits, measured in inches and followed irregular divisions. Moreover, he grouped these spits in three 'Beds (I, II and III)', I being the lowest. A synthesis of the relationships between the different spits and various stratigraphic beds is provided in the Supplementary Material and in Table S1. Those divisions highlight two issues concerning the relationship between the stratigraphy on the one hand and Tobias's excavation methods on the other. Firstly, the fact that all spits are strictly continuous means that it is more than likely that some of them are lumping the three ashy and sandy beds with the inter-stratified two red sands layers. In other words, if the red sands were actually sterile, as Tobias pointed out in his 1949 paper, one would expect that some spits would contain no material. This is not the case, thus suggesting that some mixing occurred, because of the excavation methods rather than stratigraphic processes. Secondly, his labelling of the lithic material shows that Beds III and II share some spits, notably spits 12-24 and 12-25. With no further notes or explanations, we cannot know if this corresponds to the bottom part of 'Ash and Sand III', the 'Upper Red Sand' or the top part of 'Ash and Sand II'.

Regarding Tobias's excavation methodology, it is clear that he did not collect the chips and it is likely that he selected the material stored at the Origins Centre. As an argument to support this statement, our two campaigns yielded 1700 lithic pieces over 2 cm and around 15,000 chips in an area of 170×40 cm (0.68 m^2), whereas Tobias's excavation targeted a much larger area (around 25 square yards or 20.9 m^2) of the cave but yielded 'only' 3000 pieces. Furthermore, the preliminary analysis of the old collection has revealed that quartz blanks seem particularly underrepresented in his collection.

Mwulu's cave: geological, geomorphological and ecological setting of the site

Geological setting

Mwulu's Cave is hosted within the middle beds of the Late Archaean, Early Proterozoic (2642–2584 Ma) quartzites of the Black Reef Formation (BRF), which are considered the basal lithostratigraphic unit of the Transvaal Supergroup exposed around the margins of the Transvaal basin (Eriksson et al. 1995; Els et al. 1995). In the area of Mwulu's Cave, the BRF unconformably overlies Archaean basement rocks and the Godwan Formation and conformably overlies the Wolkberg Formation (Button 1973; Eriksson et al. 1995). The BRF is conformably overlain by, and in some areas grades into, the dolomites of the Malmani Subgroup (Button 1973, 1986; Eriksson et al. 1993, 1995). Locally, the BRF quartzites are described as a sequence of trough and planar cross-bedded quartzites and sandstones with interbedded conglomeritic units (Button 1973; Henry et al. 1990; Eriksson et al. 1993, 1995). Quartzites are generally medium to coarse-grained and light coloured (Maguire 2009). Genetically, the BRF sediments formed under fluvial conditions, with the lower, upwards-fining sequences, interpreted as either subtidal, marginal marine-fluvial sand sheet settings (Button 1973; Key 1983, 1986; Eriksson et al. 2001). The upper, coarsening-upwards sedimentary sequences are interpreted as forming in a braided delta, possibly lacustrine environment (Henry et al. 1990; Eriksson et al. 2001).

Geomorphology

The south-west tilted, heavily fractured BRF forms the NNW-SSE orientated Highlands Mountains of the Makapansberg eastern escarpment overlooking pre-Wolkberg Archaean formations of the Springbok Flats to the east (1524 average masl.). The overlying dolomites have been weathered back from the escarpment edge, resulting in extensive exposures of resistant quartzite as the highest topographical feature (up to 2040 msl) (Maguire 2009). The western slopes of the escarpment are heavily faulted but less abrupt, tilting with the bedding of the BRF and overlying dolomites and carrying water away from the escarpment (Maguire 2009). The scarp

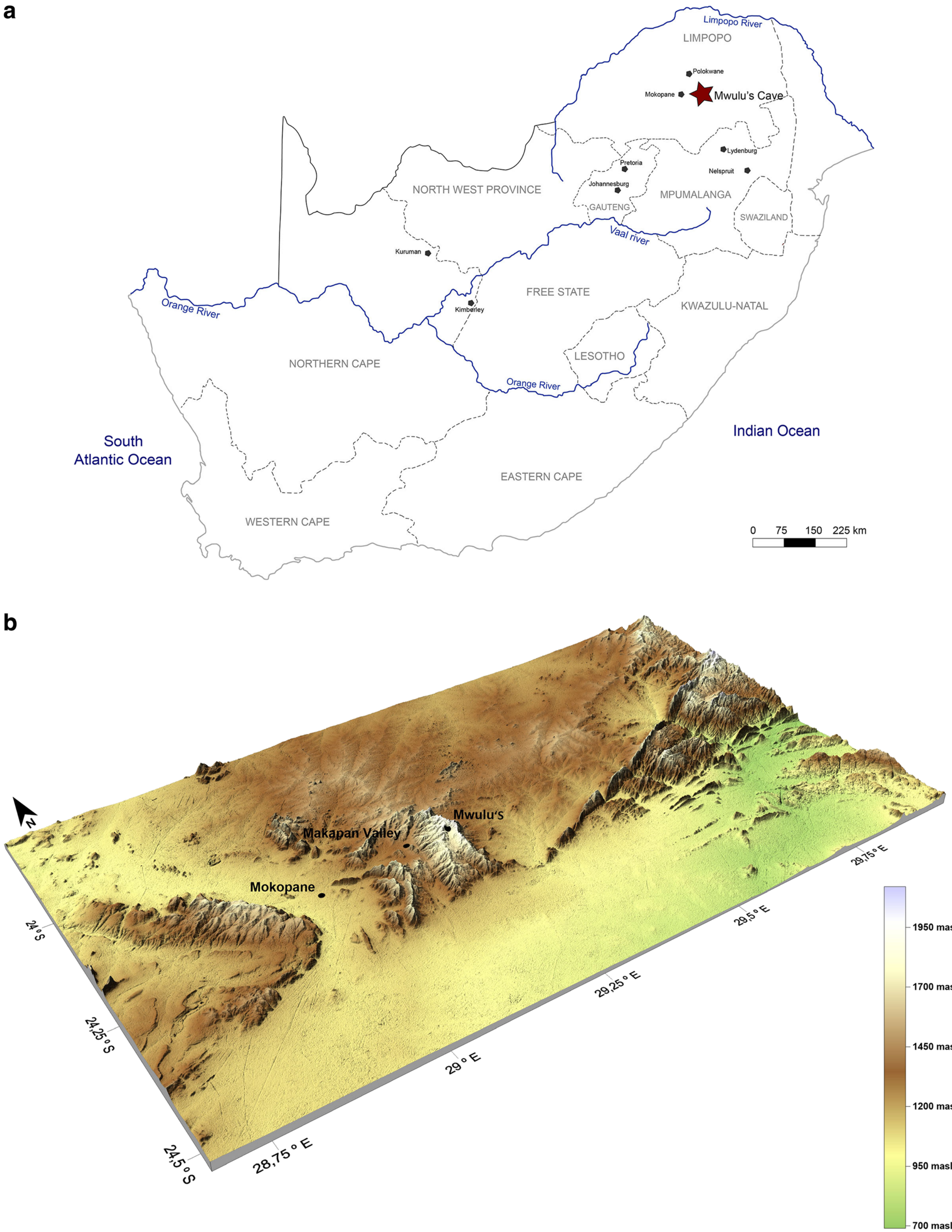


Fig. 1 **a** Location of Mwulu's Cave (Limpopo, South Africa). **b** Digital model of terrain with Geographical coordinates and Makapan Valley, Mwulu's Cave and Mokopane indicated. The digital model of the terrain was retrieved from https://lpdaac.usgs.gov/ maintained by the NASA EOSDIS Land Processes Distributed Active Archive Center (LP DAAC)

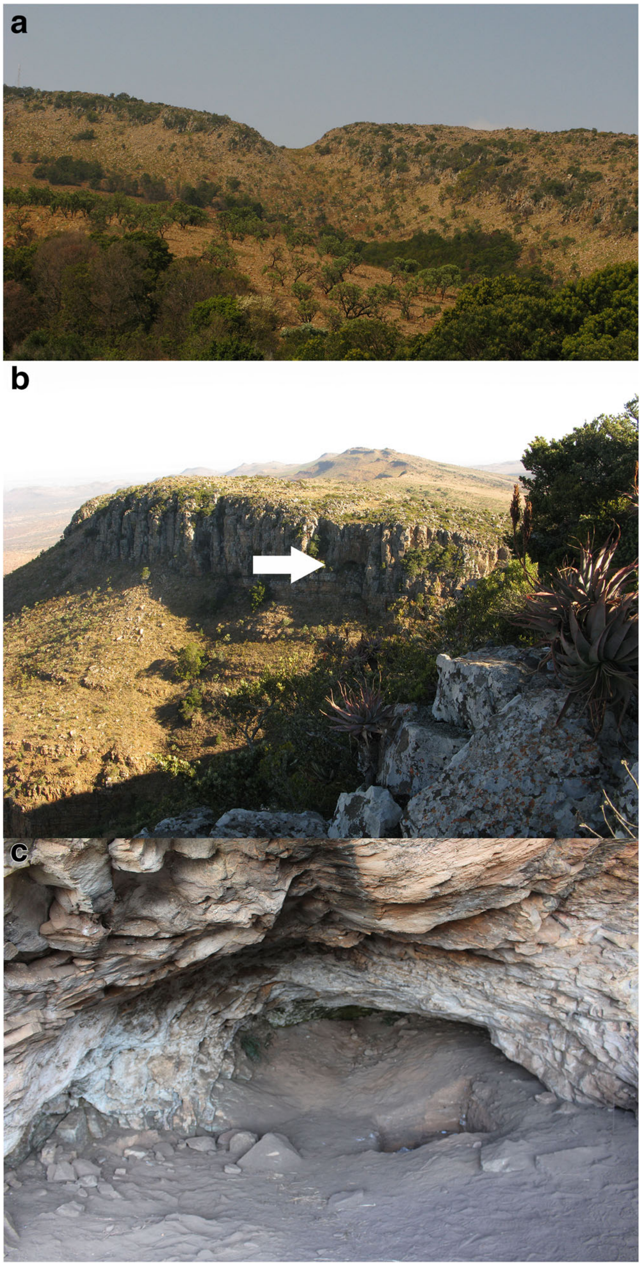


Fig. 2 **a** Mountain pass, informally called the 'Monkey Nek', which leads to Mwulu's Cave. **b** Mwulu's Cave in the Makapansberg Mountain range. **c** Interior of the cave in September 2017

near the opening to Mwulu's Cave presents a range of vertically variable quartzitic facies including medium to coarse-grained sediments with cross-bedded, upwards-fining and massive structures. The cave formed in a coarse-grained (−1.0 to 0.5 Phi) massive quartzite, which is exposed in the walls, roof and floor.

In the area of Mwulu's Cave, significant NE to SW fracturing has formed steep fault-controlled valleys and cliffs dissecting the scarp (Maguire 2009). It is along a similarly orientated vertical fracture system that the cave formed in the exposed cliff face.

Mwulu's Cave is located 30 m below the overhanging quartzite ledge, ca. 15 m above the base of the cliff and 5 m below a compound fracture that branches into two diverging joints above the roof of the cave. It is most likely that the cave formed through the localised collapse of the quartzite as a result of the development of this fracture complex. Two smaller cavities have formed as a result of the same process several meters to the left and right of Mwulu's Cave. The lateral extent of Mwulu's Cave is constrained by the limits of the fracture complex and is about 8 m wide at its opening. Abundant vertical joints in the cave's roof and walls facilitate cave breakdown and fluid penetration all the way to the back of the visible cave. Longitudinally, the cave extends into the cliff at least 14 m in a SW direction and the roof and walls taper towards the back of the cave (Fig. 3) to a width of 4 m and height of 50 cm respectively above the deposit surface. Although not explored past this point, the cave appears to extend further several meters and is almost completely filled with collapsed blocks and sediments. Exposures of the floor of the cave are limited to excavations by Tobias's (1949) and this project, both of which suggest that the floor is irregular in morphology with occasional boulder-sized blocks and abundant medium (10 cm) tablets and angular chunks of dipping quartzite detached from the floor but decaying in situ. Abundant small to medium (5–10 cm) tablets and angular chunks are found on surface of the deposit especially near the northern wall. Small tablets are seen exfoliating from the walls and roof of the cave. As Tobias (1954) notes, the walls and roof (especially in the northern part of the cave) are covered in a thin coating of speleothem, which has also locally calcified sediments and formed thin, punctuated flowstone on surficial sediments and on the undersides of clasts to a depth of 10 cm (Fig. 4). Tobias (1954) attributes this speleothem growth to the last phase in the depositional sequence of Mwulu's Cave.

Although there is no evidence of flowing water within the cave, moss, grasses and small woody plants grow all the way to the back and sediments are generally moist to the base of the deposits. Tobias notes that during his visit 'abundant water was dripping from the walls in the recesses of the cave' (1949: 3).

Outside the cave, a platform extending about 4 m has formed on very large collapsed quartzite blocks. Shallow soils trapped by these blocks create a generally flat platform surface, which is well vegetated. This has probably been significantly supplemented by Tobias's sieve pile. The platform ends abruptly in a 15-m cliff above a steep but stable scree-slope composed of quartzite boulders. Access to the cave is achieved by climbing up the edge of this platform and is likely to have limited entry to animals with climbing proclivities. Abundant small mammal spoor are present in the cave, as are their bones, suggesting regular small mammal occupation (especially the rock hyrax *Procavia capensis*) and visitation by small carnivores and owls.

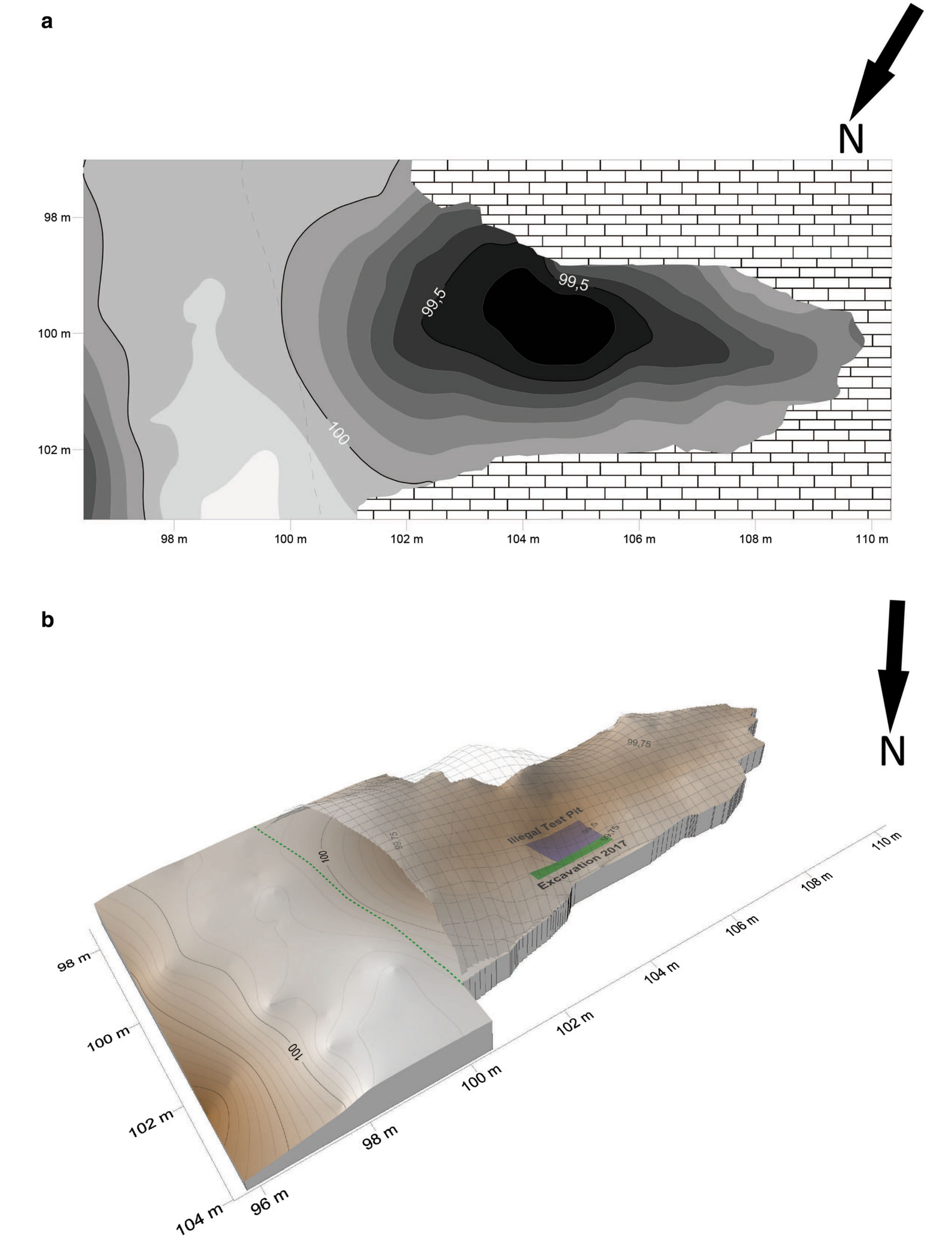


Fig. 3 Topography of Mwulu's Cave. **a** Zenithal view. **b** 3D with excavation areas. In purple: illegal test pit found in 2016. In green: area excavated in 2017. Topography: F. Colino

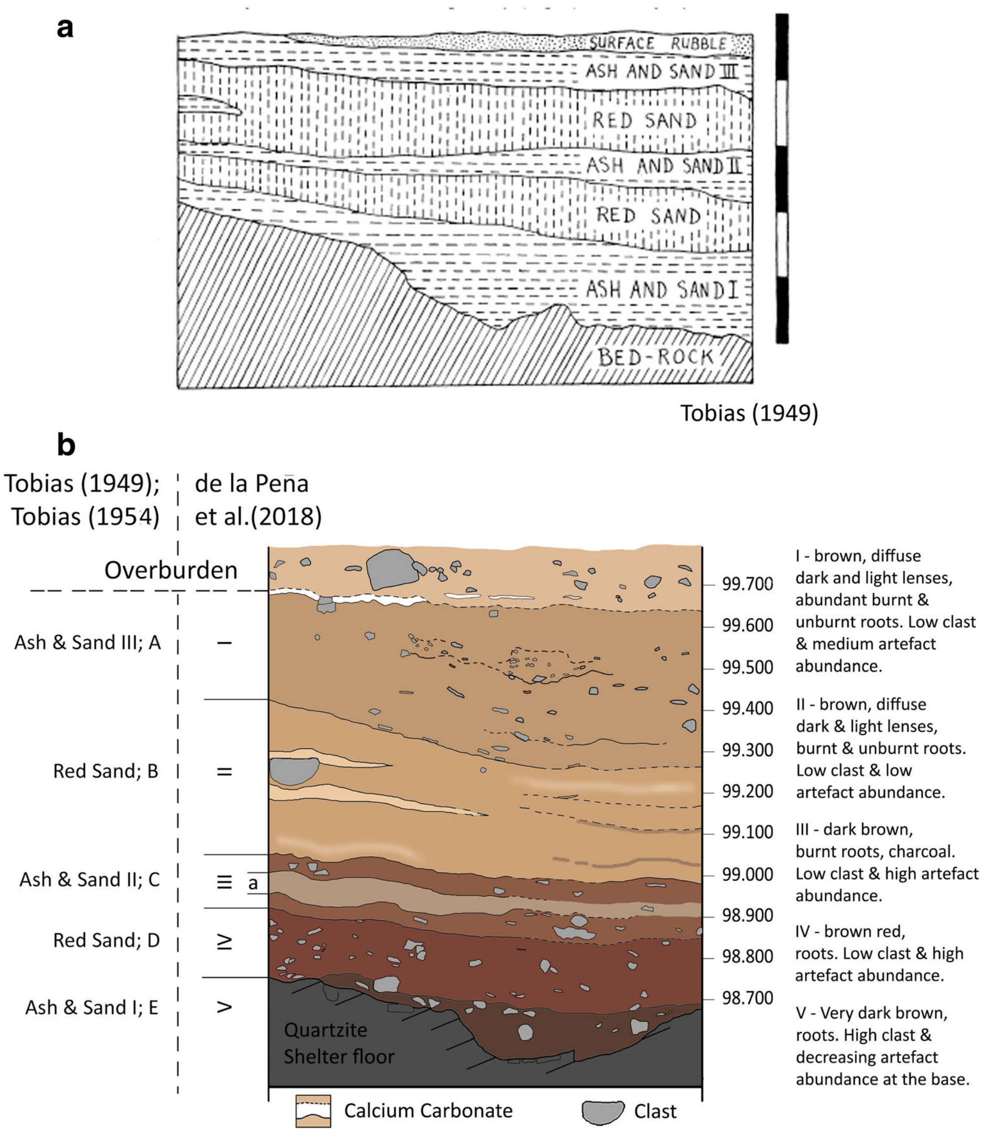


Fig. 4 **a** Tobias's stratigraphy (Tobias, 1949). **b**. Mwulu's Cave West profile stratigraphic sequence with total station-derived depths on the right vertical axis. The left vertical axis presents Tobias's stratigraphic divisions and nomenclature (1949, 1954) and the Units identified in the field and excavated in 2017 (I–V)

Climate and vegetation background

Located in the northern Highveld of South Africa, the Limpopo Province has been characterised by summer rainfall conditions throughout the Pleistocene, unaffected by the persistent fluctuations in the position of the winter rainfall zone in the southern half of the country during the Quaternary (cf. Thackeray and Fitchett 2016; Fitchett et al. 2017). The summer climate is dominated by convective storms in the late afternoons, while the dominant high pressure over the interior results in atmospheric stability throughout the winter months (Tyson and Preston-Whyte 2005). The study region receives a mean annual precipitation of ~ 520 mm/year, of which a substantial 90% falls between the months of October and March (Repinski et al. 1999). Mean annual temperature for the region is in the range of 18–19 °C, with a range from mean minimum temperatures of 2.4 °C in winter to mean maximum temperatures of 27 °C in summer (Repinski et al. 1999; Stevenson et al. 1999). Due to the clear skies and high diurnal temperature variation, frost occurs occasionally during the winter months (Rayner et al. 1993).

Mwulu's Cave is located in the Savanna biome of South Africa. The vegetation of the region has been mapped at 1:250,000 scale by Mucina and Rutherford (2006), and we use this assessment for identifying and describing vegetation units within our study area. Two savanna vegetation units dominate in the area, the Polokwane Plateau Bushveld in the high-lying plains west of the site and Mamabolo Mountain Bushveld on the hills and small mountains of the area (after Rutherford et al. 2006). Patches of the Strydpoort Summit Sourveld vegetation unit belonging to the Mesic Highveld Grassland bioregion of the Grassland biome are also present along rocky summits and mountain slopes (Rutherford et al. 2006). The hills and low mountains are very rocky, covered by small trees and shrubs with several succulents. On the high-lying plains, the vegetation is characterised by a short open tree layer with a well-developed grass layer with occasional trees at higher altitudes (Rutherford et al. 2006). C_4 grasses dominate the graminoid component, mainly belonging to three Poaceae subfamilies, which are, in decreasing abundance, the Panicoideae, Chloridoideae and Aristidoideae.

New excavation: results and analyses

New excavation protocol, sampling and analytical methods

When we accessed the cave for the first time in September 2016, there was a test pit partially covered by a deteriorated large plastic sheet, which did not seem to correspond to Tobias's excavation. The size of this test pit was approximately 1.70 cm long by 85 cm wide and 1.5 m deep (Fig. 3b, see square in purple). In the first excavation campaign (in June 2017), the first task was to clean this putative illegal test pit to access the exposed profiles and compare them with Tobias's stratigraphic description. Once the four profiles were cleaned, it became clear that this half of this putative illegal excavation only damaged the backfill of Tobias's excavations. Although, it must have cut unexcavated deposit at least ~ 15 cm to the west. On the west profile, the stratigraphy seemed to correspond to Tobias's description. We decided to excavate a 40-cm area into this profile in two squares: W1 and W2 (Figs. 3 and 4). We established these two squares in order to have a general location for all the chips and small archaeological remains measuring under 2 cm. These two squares occupy a total surface of 1.70 m × 40 cm. Tobias's excavations exposed deposits to a depth of 144 cm (57 in) at Mwulu's Cave. Our excavations reached a comparable depth of 127 cm from the current deposit surface to the cave floor. During the second campaign, we continued these excavations until we reached the floor of the shelter. We plotted all archaeological finds measuring over 2 cm with a Nikon Nivo 5C Total Station. As some of the layers lacked discernible internal stratigraphy, we subdivided them into successive plans during excavation, following the natural stratigraphy. All sediments were dry-sieved and labelled by square.

Fabric information was recorded for all natural or artefactual pieces larger than 5 cm with an elongation ratio of at least 1.7:1 (*L*/*W*) (following Bertran and Texier 1995) and with a flat underside surface. Orientation was divided into cardinal points (N, NE, E, SE and S), and dip was measured with a Brunton geological compass recording the direction of dip using the same cardinal points. The data yielded three possible fabric variables, orientation, dip and dip direction (if different from orientation).

Several photogrammetry models were produced using Agisoft software, notably one recording the whole site and another one documenting the new profile unveiled by the new excavation.

The topography of the cave surface and ceiling of the cave were documented with Surfer software (v. 12.0.626) (Fig. 3). In both processes, the interpolation of points was accomplished using the Kriging method.

We took 29 bulk samples for sedimentology, pollen and phytolith analyses (specific methodology is presented in the Supplementary material).

Four micromorphology blocks were extracted at the contacts between Units I and II, II and III and III and IV. Analysis of the blocks is ongoing.

Established methods and criteria for the physical analysis of archaeological ochre were used to categorise the assemblage (e.g. Watts 1998; Hodgskiss 2012). Pieces were classified by geological form, grain size, hardness, colour and specularity (mica-inclusions), and the presence of use-traces and post-depositional markings was recorded.

For the chronology, 12 samples were taken for optically stimulated luminescence analysis. These samples were separated into two sets of six samples each, and sent to two different laboratories. The preliminary results were completely contradictory and alternative methodologies are being applied in order to understand these discrepancies and in order to obtain an accurate optically stimulated luminescence chronology of the site. These results are not presented here as these analyses are ongoing. In addition, three burnt lithic samples were collected during excavation for thermo-luminescence dating.

The lithic technology analysis followed the methodology elaborated upon by de la Peña (2015), which follows the *chaîne opératoire* approach combined with simple controlling statistical tests. The spatial analyses of the lithic distribution were performed with QGIS (v. 2.18.11), ARCGIS (v. 10.1) and PAST.

Results

Deposits

The present day surface topography of Mwulu's Cave (Fig. 3), inside the dripline, may not accurately reflect its original state. Tobias's excavation was orientated longitudinally, extended in one yard squares (presumably in a trench configuration) and 'confined to one half of the cave floor, leaving the other intact to provide a witness section' (Tobias 1949: p. 4). Through the excavation process, some areas may have been trampled flat, sediments may have been displaced to the sides of the cave, and the trench itself may have suffered post-backfill subsidence. When this project started, laterally, the deposit has a shallow concave profile, with a central depression orientated longitudinally and extending from just inside the drip line to the back of the cave. Close to the walls, and out of reach of animals, the surface was flat. Surficial water runoff from the drip line into the central area of the cave was evident.

Stratigraphy and sediments

The excavation of Mwulu's Cave identified five stratigraphic units, named I to V from the surface to cave floor (Fig. 4b). These units were defined in the field prior to and during excavation through close inspection of vertical and lateral sedimentary characteristics including colour, content, texture, structure and clast fabric. Within defined units, very little to no internal stratigraphy was observed. It must be noted that units I to V are not identified as distinct facies and the nature of the boundaries identified in the field and the stratigraphic division of the sequence is discussed later. Units I to V compare closely to those identified by Tobias (1949; 1954; Fig. 4a, b) although unit boundaries were more diffuse than illustrated in Tobias (1954). Sedimentological analyses were conducted to test the accuracy of the identified units with respect to Tobias's (1954) hypothesis that his 'layers A to E' and 'strata 1 to 5' (our I to V) represented distinct phases of fluctuating aeolian sedimentation in the shelter.

Throughout the Mwulu's sequence, sediments are sandy, unconsolidated and without structure. Textures vary laterally and vertically locally but can be considered sandy to loamy sand (granulometry is discussed below). Sediment colour varies from pale grey to very dark brown and reflects varying abundances of organic matter and moisture. Inorganic carbon varies between 0.4 and 1.2% content with the highest content found in Unit III. Only one clearly conformable structurally defined contact was found which separated Unit I from II; otherwise, deposit contacts are diffuse and structural intra-unit stratification is not discernible. Infrequent laterally punctuated horizontal dark lenses with diffuse upper and lower contacts do appear in the deposit and represent concentrations of burnt plant matter.

Sedimentologically, no significant distinction can be made between the field-identified units (and by association Tobias's 'strata'), and analyses of bulk samples presented here provides useful insights into the nature of accumulation of the Mwulu's sediments. The matrix of the Mwulu's deposits ranges from coarse sands to medium silts with a dominance of sand-sized particles and relatively minor silt faction that contributes to the 'loam' classification of the sediment texture. Figure 5 shows particle size distribution curves for sediment samples representing the different stratigraphic units identified through the Mwulu's sequence from deposit surface to cave floor (units I to V respectively). For comparative purposes, a sample from the decaying wall of the cave is presented, as is the identified particle size range for the Kalahari sands (Schlegel et al. 1989). Through the Mwulu's sequence a consistent and proportionally similar contribution of two granulometrically distinct sediments (represented by the bimodality of the particle size distribution curves in Fig. 5) is demonstrated in the sand component (Fig. 6).

Autogenic contributions to the matrix are simple to spot within the bimodal particle size distribution curves, contributing particles of between −1 and 1.0 Φ, and are generally consistent with a very coarse faction contributing up to 5% of the sands (Fig. 6), and coarse faction contributing 15 and 23%, suggesting an even rate of cave breakdown over the depositional sequence. The medium and fine (2 to 3.5 Φ) sand component represented in the finer distribution peak matches closely with the size range expected of an aeolian provenance. The most likely source of aeolian grains being the Kalahari sands (proposed as a significant contributor to the cave's sediment by Tobias (1954) (see comparative particle size range in Fig. 10; from Schlegel et al. 1989), a significant aeolian contributor to the southern African landscape after 2.4 million years ago (Partridge 1993). Given the dramatic elevation of Mwulu's Cave above the southern and eastern Springbok Flats (1524 average msl), it is to be expected that the generally finer (3.5 Φ) faction of the Kalahari sands were deposited in the cave. Ongoing microscopic analyses of the sediments,

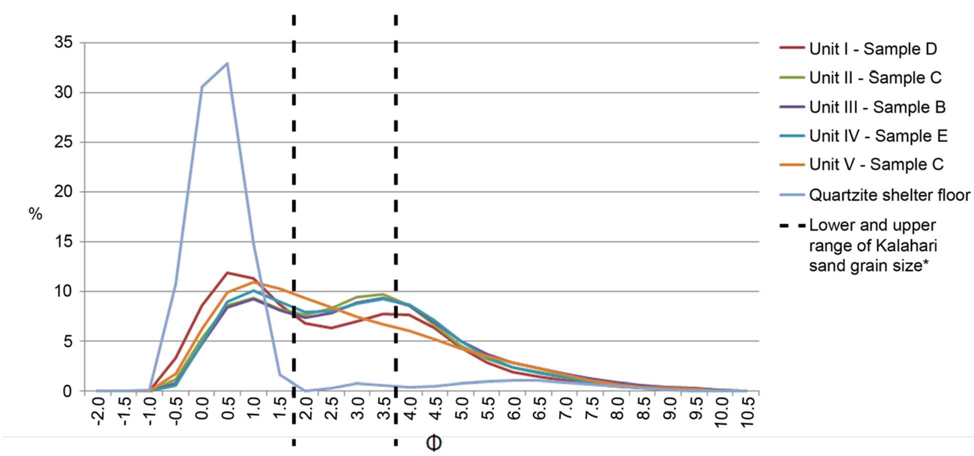
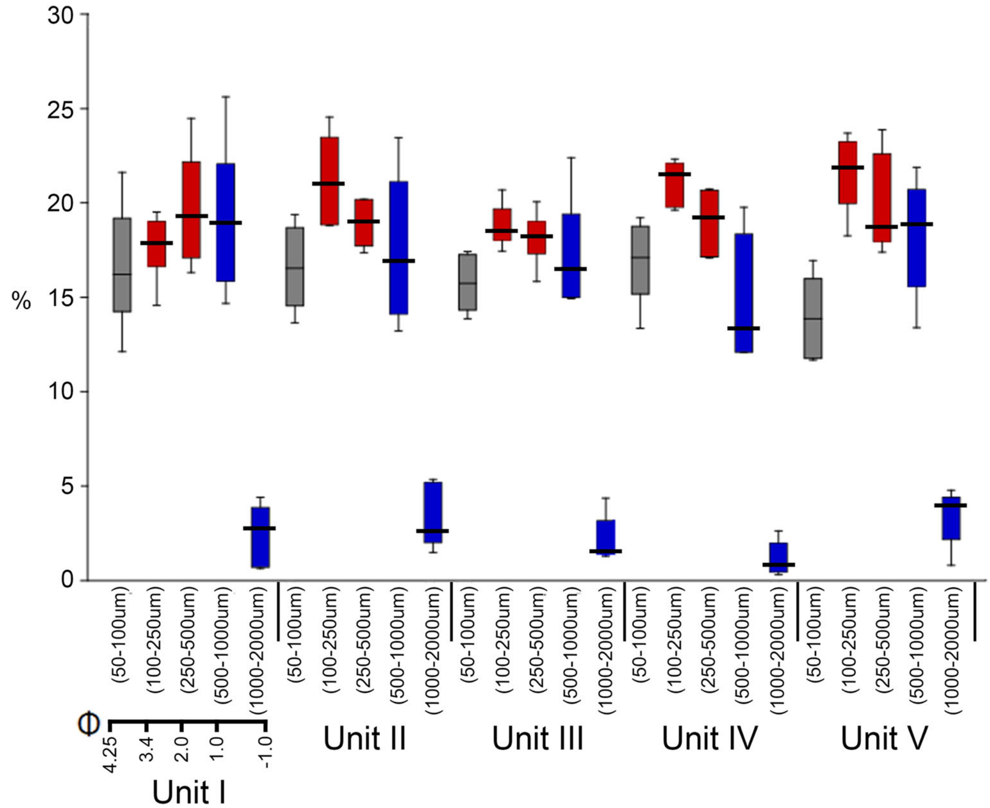


Fig. 5 Particle size distribution curves in Phi Units (Φ) of representative samples for each identified stratigraphic unit in Mwulu's Cave. Data are distilled from quantitative granulometry yielded from a Mastersizer 3000

Fig. 6 Variation in proportional contribution of different sand to coarse silt factions (in Φ and μm) through the Mwulu's Cave sediment sequence. Granulometric data yielded from Mastersizer 3000 analyses of all sediment samples. Blue data represents the autogenic contribution of very coarse and coarse sands and red data represents the contribution of medium to fine sands



including micromorphology and SEM, will help confirm the provenance of the finer sand particles. The allogenic sands (2 to 3.5 Φ) consistently contribute 35–40% of the total sands but do not vary through the sequence to a degree that would suggest distinct episodic fluctuations in aeolian deposition (contrary to Tobias 1954).

Natural clasts derive from the autogenic decay of the cave, and generally, clast abundance is low through the sequence, except at the base where abundant unsorted tabular natural clasts are found in varying states of decay associated with the shelter floor. Minor additional local lithologies are represented as clasts in the deposits in the form of shales, mudstone, siltstones, sandstones, quartz crystals and iron oxide nodules in various forms. Once deposited, the tabular coarse-grained quartzite clasts decay in situ, rounding rapidly and contributing angular coarse sand particles to the matrix. In numerous instances, discrete, unconsolidated light grey patches of coarse sand were identified during excavation and represent completely decayed autogenic clasts that have remained undisturbed.

Biotic and chemical contributions to the Mwulu's Cave sediment suite include abundant burnt and unburnt plant material, represented as very small to medium (< 1 cm diameter) roots distributed in fluctuating quantities throughout the deposits. The distributions of these components can be seen in the distribution of moisture and organic carbon content through the sequence (Fig. 7). There is a close association between areas of high artefact abundance and moisture and organic carbon content. All three lower units (III to V) show higher organic carbon contents than units I and II. For example, Unit III is dark brown, wet to the touch and comparatively rich in organic carbon, with roots often directly associated with artefacts and clasts. Unit IV, although demonstrating a drop in moisture from unit III, shows a relatively high organic carbon content, and both moisture and organic carbon increase significantly in to unit V, where natural clast abundance is high. The consistency of poorly consolidated sandy sediments through the sequence suggests water (and by association plant growth) has accumulated in areas of increased artefact and clast abundance.

Larger biotic contributions include modern bones and fur of visiting animals and their prey, although the rare occurrence of bones is limited to the uppermost unit—the low pH of the host quartzitic sediments destroyed older faunal material. Animal faecal matter and dust from visiting animals, in addition to ash and decomposed charcoal, probably contribute to the majority of the silt faction (from 4 to 7 Φ). Biogenic structures are present in the eastern wall and have significantly disturbed the deposits. These biogenic structures have various sizes and, therefore, could be attributed to different agents (Backwell et al. 2012).

Post-depositional modifications will be studied in detail through the ongoing micromorphological analysis, but here there is an opportunity to propose hypotheses based on the

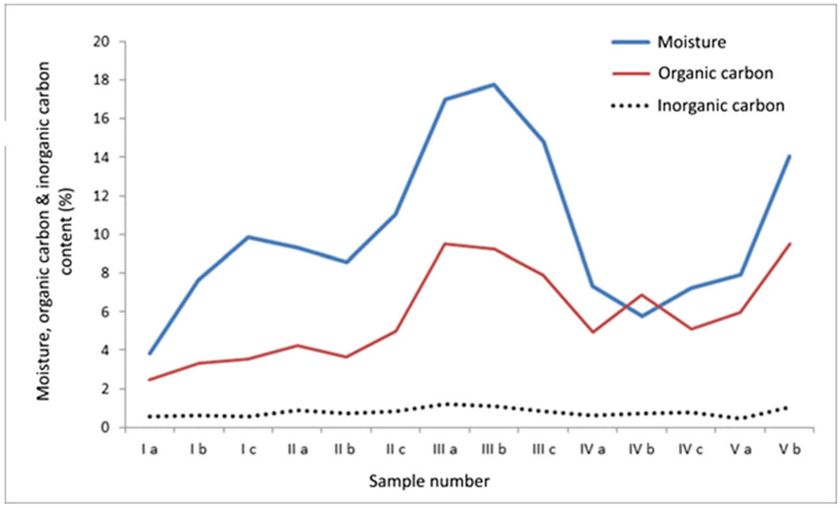


Fig. 7 Histogram of proportional moisture, organic carbon and carbonate content vertically through the Mwulu's Cave sediment sequence from loss of ignition (LoI) analyses. Data represented includes only vertically associated samples and excludes laterally associated samples

sedimentology and organisation of the artefacts and clasts excavated from the units. In the central part of the chamber, numerous borrows, anthropogenic cuts and fill structures are seen, which is why excavations focused on the more intact western wall where no such features could be seen. Figure 8 presents a rose diagram and stereonet projection of orientations and dips of elongated and flat-bottomed clasts and artefacts excavated ($n = 131$). Although a large enough sample was not present for a statistical comparison between units, the data, and observations during excavation, indicate generally flat depositional surfaces and an absence of directional processes (isotropic orientations). Vertical biogenic processes (i.e. trampling, burrowing, root disturbance indicated by strongly dipping pieces) affecting the larger components of the deposits is also minimal. It can be suggested that although bioturbation may have affected finer factions of the sediments and probably blurred unit boundaries and destroyed ancient anthropogenic features, artefacts and clasts probably remain in close proximity to their original organisation and distribution in the deposits.

Pollen analyses

A very low pollen concentration was observed for the majority of samples (Table 1). For two samples, IIIa and IIe, higher pollen concentrations were recorded, but significantly lower than the 300 grain threshold required for statistical analyses. No pollen grains were observed in the analysis of the slides from samples Id, Ie, If, IIIc, IVc and Va. The variability in the number of pollen grains preserved per sample could be explained by differences in production, dispersal, deposition or preservation; each of these factors is significant in potentially representing stratigraphic distinctions and is likely driven by variations in regional climate. It is difficult, however, to determine the proximal cause for the variation in abundance or to assign a causal factor, without a greater and more representative pollen distribution.

For the samples containing fossil pollen, the most common pollen that was identified throughout each of the layers included cosmopolitan families, notably Cyperaceae, Poaceae and Asteraceae (Table 1). Two samples contained smaller

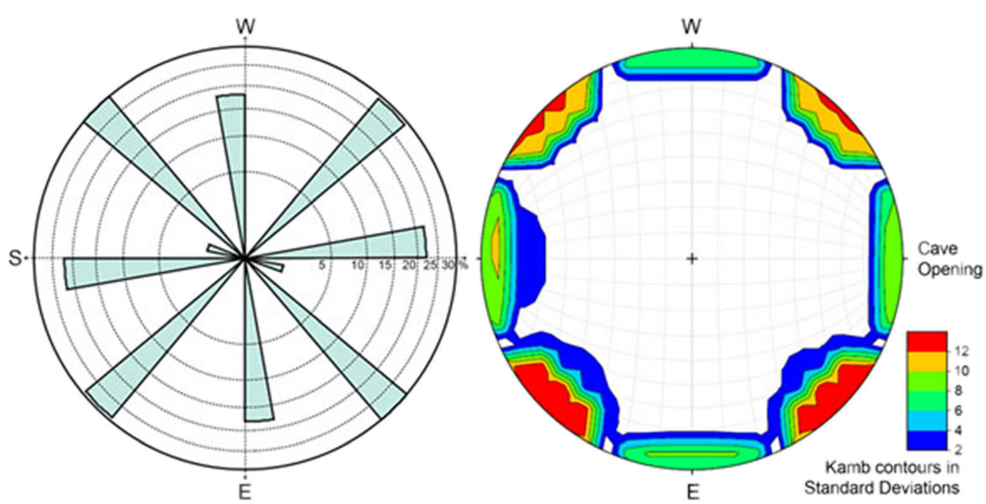


Fig. 8 Rose diagram and stereonet projection of elongated (> 1.6 length: 1 width) and flat clasts ($n = 131$) excavated through the Mwulu's Cave sediment sequence during the 2017 campaign. The rose diagram was generated using Rose.net freeware and the stereonet projection was generated using Stereonet 10.1 freeware based on Allmendinger et al. (2013)

Table 1 Raw pollen counts from Mwulu's Cave

Sample no.	Asteraceae	Poaceae	Cyperacea	Combretac	Proteaceae	Malvaceae	Apiaceae	Liliaceae	Cheno-Am	*Crassula*	Pinus	Grewia	Spores	Microchacoal	Algal material
Ia	1	4											Y	Y	Y
Ib		1											Y	Y	Y
Ic									1				Y	Y	Y
Id	No pollen												Y	Y	Y
Ie	No pollen												Y	Y	Y
If	No pollen												Y	Y	Y
IIa		1											Y	Y	Y
IIb			1	1									Y	Y	Y
IIc		1	1										Y	Y	Y
IId	1		1										Y	Y	Y
IIe	6	68	33	5			4				1	10	Y	Y	Y
IIf	9	16	12	2						8	1	2	Y	Y	Y
IIIa	7	7	28	1		1		1			1	2	Y	Y	Y
IIIb			2		1						1		Y	Y	Y
IIIc		No pollen											Y	Y	Y
IIId		2											Y	Y	Y
IIIe	1	1											Y	Y	Y
IIIf		1											Y	Y	Y
IVa	10	4		1		1			1				Y	Y	Y
IVb													Y	Y	Y
IVc		No pollen											Y	Y	Y
IVd	1	1							1				Y	Y	Y
IVe	1												Y	Y	Y
IVf		14	2								1		Y	Y	Y
Va		No pollen											Y	Y	Y
Vb	1	1											Y	Y	Y
Vc			1										Y	Y	Y
Vd		1											Y	Y	Y
Ve											2		Y	Y	Y

proportions of fossil pollen from the Combretaceae, Malvaceae, Liliaceae and Cheno-Am group families and of *Crassula*, *Grewia* and *Pinus* species (Table 1). Spores and algal materials were found on slides from all of the samples, including those for which no pollen grains were found, indicating high humidity suggestive of the persistent infiltration of water into the cave throughout the time period represented by the sample material. Microcharcoal grains were also found in all samples. Due to the light weight of these particles, they could be sourced from a large catchment area. Moreover, the timing of the deposition of these charcoal grains cannot be ascertained from the pollen assemblage.

Notably, each of the higher-concentration samples contained *Pinus* pollen grains, indicative of contamination from the contemporary environment, as this species was introduced to South Africa ~ 300 years ago. *Pinu*s pollen was also identified in samples Ve, IVf and IIb, indicating contamination from modern pollen in samples throughout the sequence. The variation in the total number of preserved pollen grains, and the differential degrees of degradation of individual grains, would however prohibit a conclusion that all pollen grains from the excavated material are modern contaminants.

Phytoliths

Here, we present the preliminary results of the phytolith study from the entire deposit at Mwulu's Cave. The ongoing study will include the study of modern surface soil samples from the cave surface and from the vegetation surrounding the cave. A more in-depth taphonomic analysis of the assemblage will also be provided in the future.

There is an increase in phytolith concentration from the lowermost layers (V to III) to the uppermost ones (II and I) (Fig. 9). Sample IIe showed the highest phytolith concentration amongst samples (4.2 million phytoliths /g of sediment). Together with phytoliths, diatoms and sponge spicules were also identified in most of the samples analysed, being an indication of moist soil conditions in the cave. The abundance of these bio-siliceous microfossils increases accordingly with that of phytoliths, and it could be indicative of differential preservation conditions at the site.

A total of 64 phytolith morphotypes were identified in the 29 archaeological sediment samples. These were later grouped by plant types and plant parts into ten general categories: grasses—Poaceae, sedges-Cyperaceae, leaves and wood/bark of dicotyledonous plants, spheroids, epidermal appendages, elongates with and without decorated sides, blocky morphologies and irregular and indeterminate morphologies.

The phytolith assemblage from Unit V was characterised by a low abundance of grass phytoliths, and the dominance of spheroid phytoliths, blocky and thin parallelepipeds, and irregular morphologies which have all been traditionally associated with wood/bark (Albert 2000; Albert and Weiner 2001; Collura and Neumann 2017; Esteban et al. 2017a, b; Murungi 2017; Tsartsidou et al. 2007). These morphotypes are amongst the most resistant phytoliths and tend to dominate phytolith assemblages affected by post-depositional processes (Cabanes et al. 2011; Cabanes and Shahack-Gross 2015); therefore, the phytolith results from unit V will not be interpreted until more in-depth taphonomic studies are conducted.

Conversely, the phytolith assemblage from the uppermost levels (Fig. 10) was dominated by the presence of grass phytoliths, mainly grass silica short cells (GSSCs) from the lobate and rondel types. The grass phytolith assemblage showed considerable differences amongst samples from units I and II. The former showed the highest presence of GSSC rondels, typically associated with C_3 grasses from the Pooideae, Ehrhartoideae and Danthonioideae subfamilies, and the lowest of lobates, which are generally common Panicoideae in South African records (e.g., Cordova 2013; Cordova and Scott 2010; Esteban et al. 2017a, b; Murungi 2017; Rossouw 2009). Conversely, C_4 graminoids (C_4 grasses and sedges) dominated the phytolith assemblage in unit II.

Samples from unit II was characterised by the dominance of GSSCs lobates, followed by high frequencies of rondels and saddles, sedge phytoliths (papillae/hat shape

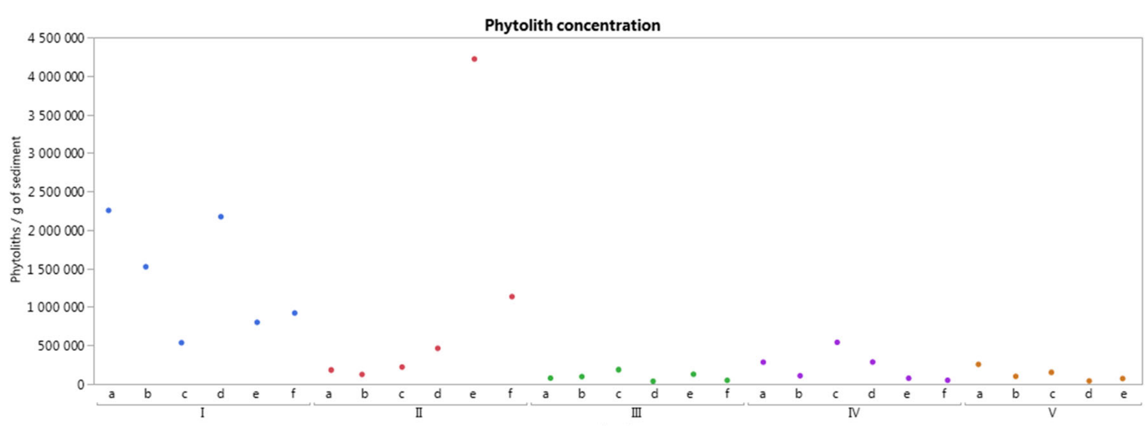


Fig. 9 Phytolith concentration (phytoliths per gram of sediment) at the different levels studies from Mwulu's

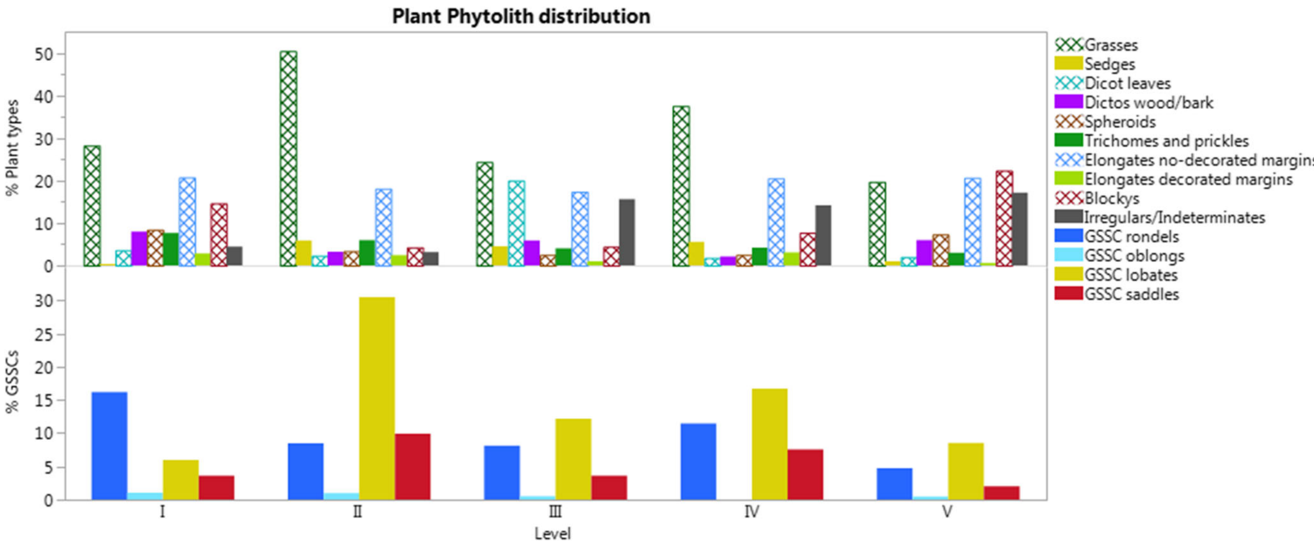


Fig. 10 Histogram showing the phytolith morphological distribution, by plant types and plant parts and Grass Silica Short Cell, in samples from Mwulu's Cave amongst the different stratigraphic units

and achene morphotypes), blocky parallelepipeds and elongates without decorated sides are also well represented in the phytolith assemblages. Conversely, the phytolith assemblage of unit I was characterised by the dominance of elongates without decorated sides, GSSC rondels and blocky morphologies (polyhedral and parallelepiped), followed in abundance by GSSC lobates, prickles, spheroids and irregular morphologies. Samples from this level showed the lowest frequencies of sedge phytoliths (papillae/hat shaped and achene morphotypes).

Ochre

The 2017 Mwulu's Cave excavations uncovered a total of 356.3 g of ochre. Of that, 189 g is attributed to pieces < 10 mm in maximum length. All pieces ≥ 10 mm were analysed, totalling 137 pieces with a weight of 167.3 g.

Five geological forms constitute the assemblage—shale, ferruginous mudstone, ferruginous siltstone, ferruginous sandstones and iron oxide. The analysed pieces comprise mostly shales (56.2%), followed by mudstones (21.2%) and siltstones (11.7%), with only four iron oxide (or 'haematite') pieces in the assemblage. Just over half of the assemblage (56.2%) is soft (Mohs 2 and below), and 40.1% have 'medium' hardness values (Mohs 3 and 4). Most of the pieces have a small grain size, with 64.2% of the pieces with either clayey or mixed clayey-silty grain sizes. Few of the pieces (21.2%) are mica-rich which gives them a specular, sparkly quality. Colour was grouped into seven categories (see Hodgskiss 2012)—purple-red, bright red, weak red, orange, yellow, yellow-brown and grey. Slightly less than half the assemblage (44.5%) has red hues, with unusually high quantities of yellow hues and oranges (54.7%) compared to other MSA sites.

The percentage of utilised pieces is lower than average for MSA sites (roughly 10–15%) with only three pieces showing signs of utilisation (2.2% of the assemblage) (Fig. 11a–c). All the utilised pieces are bright red, which is consistent with the general MSA preference to use bright red ochre (Henshilwood et al. 2001, 2014; Watts 2002; Hodgskiss 2012; Dayet et al. 2013). Two are specular iron oxide pieces and one is a mudstone. All have medium-hard hardness values (Mohs 4 and 5) and are fine grained. They appear to have been rubbed against soft materials (like skin or hide) resulting in the formation of microstriations, smoothing and polish. No striations that would have formed if they were ground against a hard rock surface are apparent.

The bulk of the assemblage derives from units I and II (30.7% and 42.3% of the assemblage respectively). The three utilised pieces are from units I, II and IV, with the utilised iron oxide pieces appearing in the younger layers (I and II). The piece appearing in the older unit (unit IV, Fig. 11b) is the only piece from the 2017 excavations that has clear grinding striations. No mica-rich, specular pieces (utilised or unutilised) are found in the older layers (units IV and V). There is no significant variation in the types of ochre collected through time.

Previous ochre studies

Amongst his finds, Tobias focused particularly on different fragments of specularite and proposed that the use of this material in the MSA people would have been for artistic purposes: 'Well-rubbed pieces of specularite suggest the artistic practices of the Pietersburg folk' (Tobias 1949: p. 10). Watts (1998) analysed the ochre excavated by Tobias. Like him, we found 13 pieces of ochre (termed 'pigment' by Watts) with a total weight of just under 500 g (our weight = 497.1 g, Watts' = 477.6 g). These 13 pieces together weigh almost

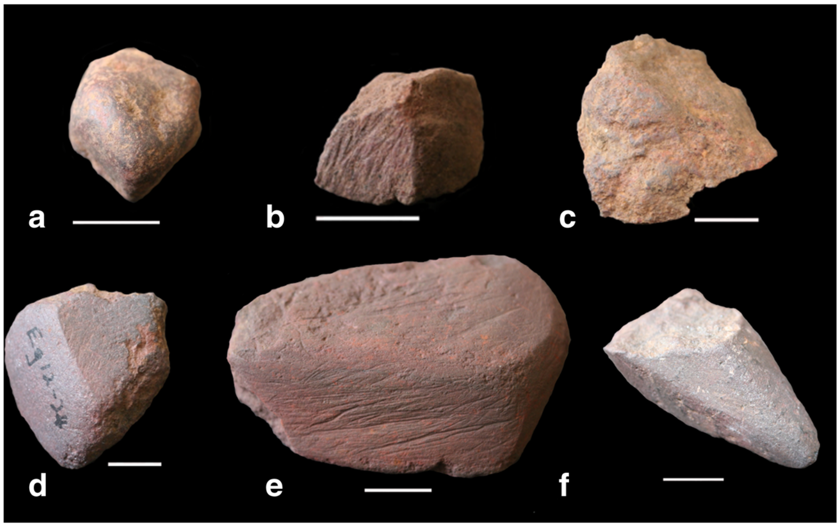


Fig. 11 A selection of utilised ochre pieces from Mwulu's Cave (2017 and Tobias's excavations). **a** A hard, specular iron oxide nodule (MWO_049 from Layer 1, square W1, 2017 excavations) that has smoothing, rounded edges and microstriations, indicating it was rubbed against a soft material. **b** A hard, iron oxide nodule (MWO_095 from Layer II, square W2, 2017 excavations) displaying microstriations and smoothing on the surface, indicating that the piece was rubbed against a soft material. **c** Medium hardness mudstone piece (MWO_052 from Layer 4, square W1, 2017 excavations) with grinding striations on two surfaces. **d** A hard, specular iron oxide nodule (MWO_141 from spit 12–24, square Eg, Tobias excavations) that has two adjacent ground surfaces. **e** A large, medium hardness, shale nodule (MWO_147 from spit 12–24, square Eg, Tobias excavations) with grinding use-wear on most surfaces of the piece, forming flat, faceted surfaces. **f** A hard, specular iron oxide nodule (MWO_148 from spit 12–25, square Dd, Tobias excavations). The ground and rubbed surfaces of this piece form a crayon-shaped, faceted tip

three times more than the entire 2017 ochre assemblage. These pieces are mostly heavy iron oxides—haematite and specularite—and they are generally larger pieces than the 2017 assemblage, with 12 of the 13 pieces over 30 mm in length. It is likely that only the bigger and 'more impressive' pieces would have been kept, with a large portion of the small pieces being thrown away by excavators or unidentified. We agree with Watts's analysis of the utilised assemblage apart from one piece. We identified six pieces with use-traces while Watts identified seven; the differing one piece we could not confidently identify as utilised. Four of the utilised ochre pieces are from the 12–24 in spit, and two have unknown stratigraphic provenance. The utilised pieces are mostly ground, some with clearly faceted surfaces and crayon-shaped tips (Fig. 11d–f). Some of these ground pieces have polish and microstriations on the ground surfaces, possible evidence that they were rubbed on a soft material after they were ground.

Spatial analyses of the lithic artefact distribution

The 2017 excavations sampled the full stratigraphy from the surface until bedrock. As can be seen in the plotting of the lithic artefacts (Fig. 12a), the distribution-density of the lithic artefacts does not correspond with the five units described during our excavation. Indeed, as illustrated in Fig. 12a, it seems that instead of the five clusters (that would be expected following the five stratigraphical units defined in the field), there are only three clusters regarding the lithics: a first one consistent with unit I, a second one with unit II and a third one with units III-IV-V lumped together (Fig. 12b, c). The lithic distribution of lithics every 10 cm in depth (Fig. 12d) also indicates three distinct clusters.

In order to test this further, we performed different spatial analyses to see if the lithic material from the five stratigraphical units cluster or not spatially. Firstly, we used the Moran's I, which is a measure of spatial autocorrelation. This analysis determines whether the distribution is positively correlated (that is, there are preferential clusters, values close to 1), negatively (without any association since they are uniformly distributed, values close to − 1) or is random (values close to 0). We performed this test for all the lithics, plotted in the five units together. The first task performed was building up a grid f (Table 2) for determining the randomness of events; in this case, the lithic distribution. From this grid, we ran a Spatial Autocorrelation Analysis, and the results clearly show that there is a cluster distribution being the Z-score 12.18 and the I Moran value 0.64 (positive autocorrelation) (Table 3). Clustering was also demonstrated following the average nearest neighbour analysis, being the Z-score − 15.93 call to Table 4; thus, it is highly unlikely that the distribution responds to a random pattern. Finally, a hotspot analysis was carried out; for this, the Kernel density estimate was used (Getis and Ord 1992) (Fig. 12c). This analysis is the

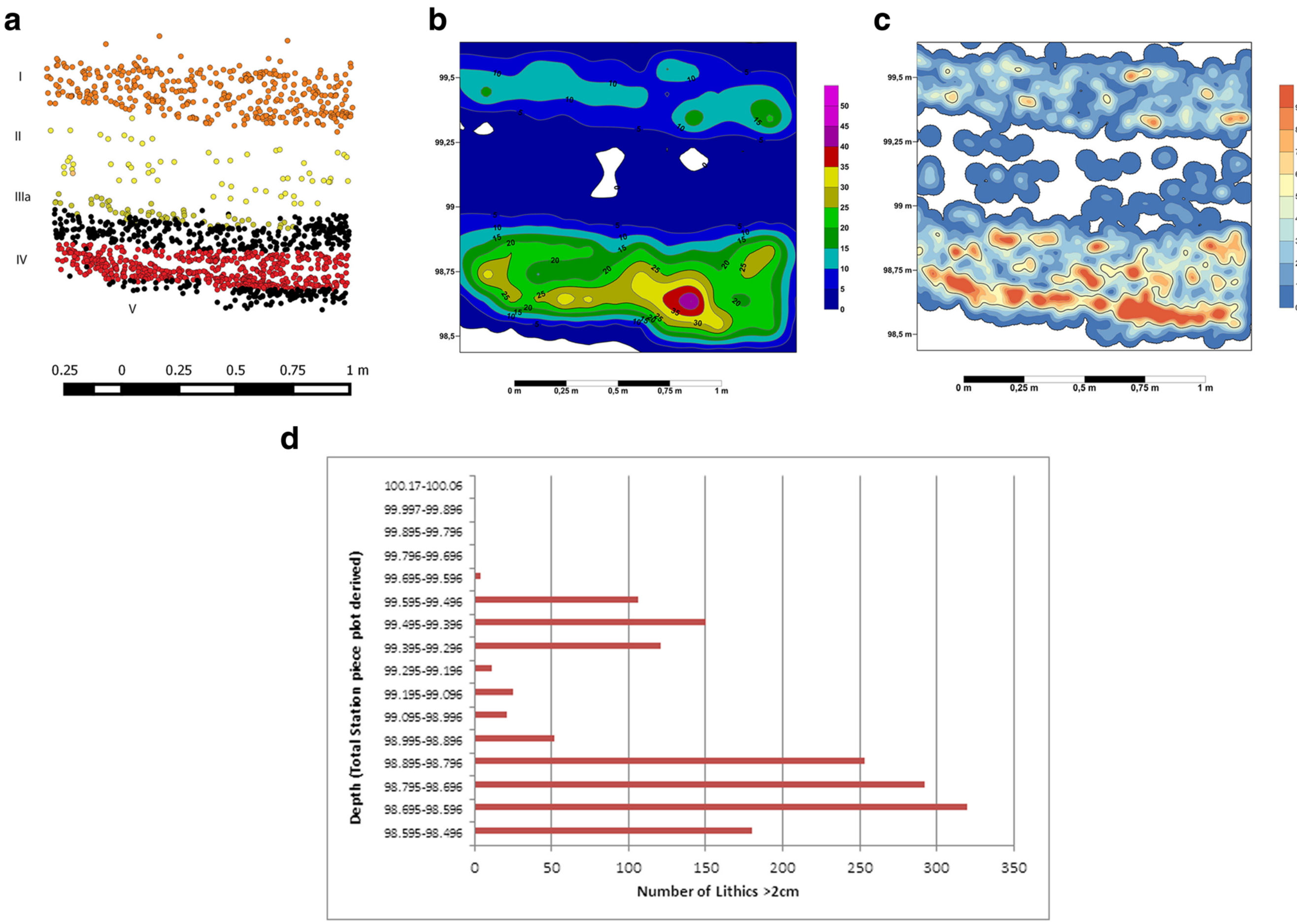


Fig. 12 **a** Vertical distribution of lithics in West profile distinguished by layer. **b** Map of density of lithic material using kriging extrapolation. **c** Hotspot analysis. **d** Lithic distribution every 10 cm depth, where three clusters are quite evident

representation of the distribution of Z-scores over space. Clearly, areas of varying intensity are drawn, which indicates, at least, three lithic clusters, with a potential extra one between IV and V.

2017 Lithic collection

The 2017 excavations yielded 1747 lithic pieces over 2 cm in length and over 15,000 chips (pieces under 2 cm) (Table 5). Interestingly, there is an inverse correlation between the volume of sediments excavated and the abundance of artefacts over 2 cm (Fig. 13). The most remarkable example of this inverse proportion is observed in units II and IV, the former being the one with the most litres excavated but the smallest amount of artefacts recovered, while unit IV follows the opposite trend (most artefacts and second least sediment).

Table 2 Number of cells, pieces and study area for the grid

Cells (10 × 10 cm)	Pieces	Study area
182	1534*	1.51 m^2

Another significant result is that there is not a single sterile layer, thus contradicting Tobias's conclusion that two of the layers were completely devoid of archaeological material.

The raw materials knapped at Mwulu's Cave include quartzite, quartz and chert (Table 5). While in previous analyses (i.e. Watts 1998; Sampson 1972), hornfels is also mentioned, no hornfel blanks were identified in the new collection. The dominant raw material in all layers is quartzite, likely originating from the cave's surroundings. Quartzite tools could have been made from raw material directly collected from the same outcrop where the cave is located, a potential reason for the occupation of this site. The second raw material for units I, III and V is chert, whereas in units II and IV, quartz is more abundant. The quartz sample of unit II is remarkable as this layer has very few pieces.

Most of the pieces are well preserved, even though a small amount in each layer present traces of water patina or alteration. There does not seem to be a correlation between weathered pieces and spatial distribution. The category 'other' for raw materials in Table 5 refers to pieces with a high degree of weathering, which made the identification of the raw material type difficult.

Table 3 Statistical results for the I Moran index

Spacial autocorrelation							
I Moran index	Expected Index	Variance	z-score	*p* value	Conceptualization	Distance method	Distance threshold
0.649604	− 0.005525	0.002889	12.187662	0.000000	Fixed distance = 0.10001 m	Euclidean	0.10001 m

Regarding the main technological categories in all the layers, there is a clear dominance of flakes and flake fragments, and a similar proportion of flakes and blades, blade/bladelets throughout the sequence (Table 6 and Fig. 14).

Although this is preliminary appreciation, it seems that the blade production is integrated within the same reduction sequence as the flakes. The preliminary technological analysis shows that most of the blanks present centripetal scar removals. Therefore, most of the production seems related to a *Levallois*-like type of reduction that will be described more in-depth in future technological works.

Regarding the retouched pieces, their percentage amongst the > 2 cm material is extremely low (Table 7). Unit IV has provided the most retouched material. The retouched pieces can be grouped into three main clusters: side-scrapers, notches and denticulates (Table 7; Fig. 15). While unfortunately no bifacial piece was found during the new excavations (in contrast to Tobias's excavation, Fig. 16), it is worth noting the recovery of a unifacial point in unit I and of denticulated points in units III, IV and V, which, when these two categories are lumped together, constitute the third typological group.

Besides these three groups, we should highlight the presence of triangular blanks, which also seem integrated within the *Levallois*-like production of flakes and blades already mentioned, although this too requires future technological analyses to be confirmed. It is also worth noting that 60% of the triangular blanks occurred in unit IV.

Following the spatial analysis presented in the previous section, if we group the techno-typological characteristics that we just highlighted in the three clusters of density of lithics (I, II, III-IV-V), we see some interesting results. Firstly, the triangular blanks ($n = 75$) as well as the denticulated points ($n = 3$) appear mainly in the lower unit (III-IV-V) (Table 7), whereas unifacial points with simple retouch seem related to the upper unit I ($n = 3$). Secondly, regarding the raw material distribution, it is interesting to note that units I and III-IV-V (lumped together) have a very similar percentage of rock types represented, whereas unit II differs with a higher percentage of quartz and rocks from the category 'other', which might be related to post-depositional processes (Fig. 17).

Nonetheless, with this preliminary study, it is still not clear whether the *Levallois* technology is consistent across these three units. Moreover, we have to clarify how flakes, blades and triangular blanks are related in these three units. Such techno-functional questions will be the focus of a future publication specifically dedicated to the lithic technology from Mwulu's Cave.

Tobias's lithic collection

Tobias attributed all the archaeological material from his excavation to the Pietersburg industry (Fig. 17). He also proposed an evolutionary interpretation of the archaeological material stating that: 'From the earlier to the later levels of occupation there is evidence of a progressively more careful selection of materials'. This statement concerns the raw material representation and the retouched material. Tobias highlighted in his paper the most remarkable retouched pieces from his excavation. He paid special attention to some pieces from 'the middle level' (which we assume is 'Ash and Sand II'), where he found bifacial and unifacial pieces (Fig. 4; this layer would tentatively correspond to our unit III). In the upper layer ('Ash and Sand III'), he also uncovered unifacial and bifacial pieces; he mentioned that these layers had more retouched pieces than the lower ones.

Sampson (1972) listed quartzite, quartz, chert and lydianite (hornfels) as raw materials. He allocated the 'trimmed points' to Beds II and III. He also indicated the presence of adjacent platform cores and discoid cores in Bed I, whereas in unit III four *Levallois* cores were documented. As explained above and see Supplementary Material and Table S1, he considered that Bed II was dubious because of the possibility of admixture during Tobias's excavation. Nonetheless, following his figure with the stratigraphical reconstruction and correspondence with the Origins Centre material, it seems that all of Tobias's Beds actually comprised mixed material because of

Table 4 Nearest neighbour result

Nearest neighbour					
Nearest neighbour ratio	Observed mean distance (m)	Expected mean distance (m)	z-score	*p* value	Distance method
0.787386	0.012683	0.016107	− 15.930720	0.000000	Euclidean

Table 5 Raw material representation for lithic pieces per unit

Pieces > 2 cm						Chips
	Quartzite	Quartz	Chert	Other	Total per layer	
I	217	47	58	4	326	2504
II	66	27	8	11	112	767
III	353	57	95	20	525	3707
IV	444	102	85	12	643	6524
V	107	15	19	0	141	2172
Total per raw material	1187	248	265	47	1747	

excavation inexperience, rather than stratigraphic problems. Moreover, as already pointed out, Beds III and II share some spits, notably spits 12–24 and 12–25 (Supplementary Material and Table S1).

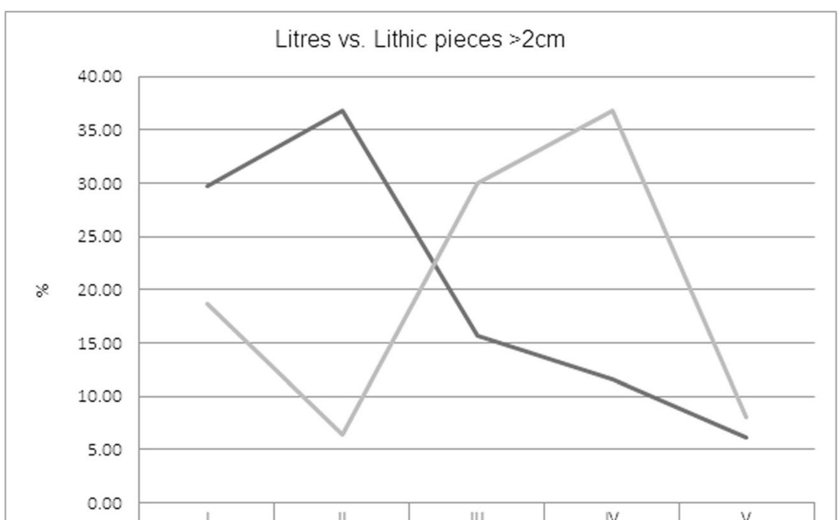
Even if spatially we do not know where Tobias's squares were situated, we conducted a preliminary evaluation of the material stored in the Origins Centre, technologically classifying the material from the two squares with a presumably larger excavation depth (Table S2). Some of the lower- and uppermost spits (included in Beds I and III respectively) could be related to units I and III-IV-V of our cluster lithic analysis. From the preliminary technological analysis of his 'bed' division, it seems that he selected the material, as can be seen in Fig. 17 where the central spits have a remarkably low proportion of quartz, which does not match with the raw material distribution in our three clusters (cf. Figs. 17 and 18).

Discussion

Our renewed excavations at Mwulu's Cave have allowed us to propose a new stratigraphy of the archaeological deposits, based on sedimentology and the spatial analysis of lithic artefact densities. Furthermore, data on the vegetation surrounding the site, based on the pollen and phytoliths preserved in those deposits, are now available. Such data will be temporally constrained by luminescence ages at a later stage in order to provide a more accurate understanding of the palaeoenvironmental conditions existing during periods of human occupation of the site. Finally, the cultural archaeological remains have confirmed the management of ochre pieces throughout the sequence and the presence of a techno-typological lithic sequence comprising unifacial pieces and triangular blanks.

Sedimentology and new stratigraphy

The sedimentology generally fits the deposit accumulation model for a small cave gradually filled with a combination of aeolian and autogenic sands with biological contributions of finer sediments through ash, faecal matter and dust, and anthropogenic contributions of lithics of varying sizes (bones are not preserved in the low pH quartzitic autogenic sediments). Fluid interaction is limited to diffuse vertical drip



	I	II	III	IV	V
Litres	29.74	36.83	15.71	11.61	6.12
Pieces	18.66	6.41	30.05	36.81	8.07

Fig. 13 Comparison between volume of sediments (data presented here in litre percentages) and lithic material density (pieces over 2 cm) per stratigraphic unit

Table 6 Main technological categories per layer

	I	II	III	IV	V
Flakes + flake fragments	271	67	420	504	116
Blade + blade fragments	35	11	56	84	18
Cores	4	1	11	12	4
Retouched	7	3	8	27	2
Chunks	6	30	30	16	1
Total	326	112	525	643	141

water away from the entrance and limited runoff into the cave from rain and mist (Maguire 2009). Morphologically, a shallow gradient is seen sloping into the cave from the dripline and in this area, low-energy water runoff has played a part in the redistribution of sediments and biological material away from the cave mouth into the cave, aiding in the catchment of smaller anthropogenic material. Where previous excavation walls were exposed by new excavations, a combination of collapse and low-energy surface runoff eroded the remnant walls—especially noticeable in the northern wall of the excavation, closest to the shelter entrance. The limited size, morphology, location (away from any source of high-energy fluvial or colluvial processes) and lithology of the cave restricts any significant processes of erosion removing deposits. Although depositional hiatuses and minor erosions are undoubtedly present and represent potentially significant periods of 'missing time' in the Mwulu's sequence, catchment of archaeological material is good and post-depositional movement of larger interred lithics is limited.

The close association between artefact and clast abundance, moisture and organic matter (and by association sediment colour) and their noticeable fluctuations through the deposit in contrast to an absence of clear changes in unit sedimentological characteristics suggests that Tobias's (1949, 1954) stratigraphic definitions are sedimentologically unsupported. Structurally, a distinction can be made between units I and II but it is proposed here that moisture, organic carbon and colour (light and dark) are post-depositional accumulations favouring artefact-rich layers through the sequence in a generally well-draining consistently sandy-loam matrix. In numerous instances through the sequence, modern and old roots were found directly associated with artefacts and clasts. Moisture accumulation in artefact dense layers encourages organic matter accumulation and silt capture with silt quantities enriched in upper unit III samples compared to units I and II). Tangible differentiation of units can be made by artefact abundance, which does distinctly fluctuate through the sequence without evidence of significant vertical or lateral disturbance.

It is posited here that Tobias's stratigraphic sequence, although identifying the same basic units, incorrectly attributed those units to sedimentological and therefore depositional differences. It is likely that although some depositional surfaces remain intact and represent hiatuses on which artefacts and clasts accumulated (e.g. between units I and II), the stratigraphic sequence of Mwulu's Cave can be simplified into three major units represented by occupation of the shelter.

We can therefore propose that the Mwulu's sequence be divided up into three archaeological strata following the lithic spatial analysis. An uppermost layer represented by unit I (Tobias's A), a middle layer represented by unit II (Tobias's B) and lower layer represented by units III, IV and V (Tobias's C, D and E).

Palaeoenvironments at Mwulu's Cave

The pollen results from this investigation refute previous suggestions that there is no fossiliferous material preserved in Mwulu's Cave (Tobias 1954). This is important, should these records be found to be scientifically valid, as this would

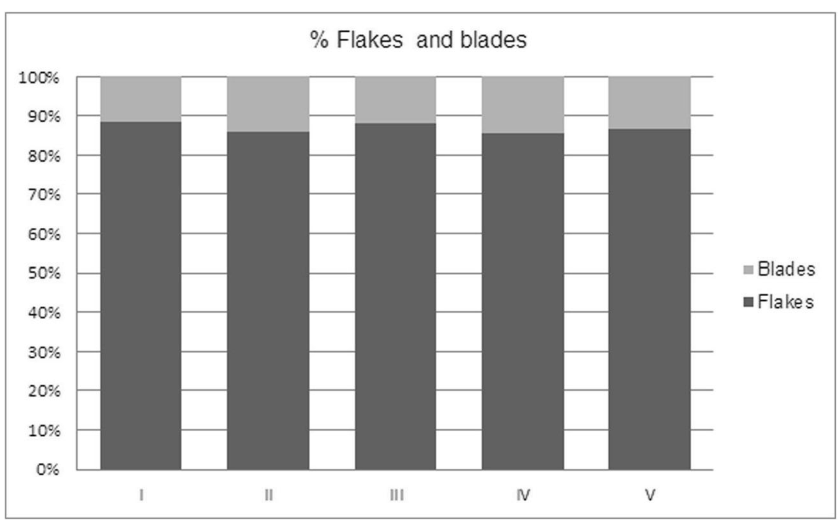


Fig. 14 Percentage of flakes and blades

Table 7 Retouched pieces per layer

	I	II	III	IV	V	Total
Retouched flake		1	1			2
Retouched blade	1			1	1	3
End-scraper	1					1
Side-scraper			3	3		6
Indeterminate retouched piece	3	1		9	1	14
Denticulate		2	1	2		5
Unifacial point (simple retouch continuous)	3			1		4
Unifacial point (denticulated retouch)			1	1	1	3
Notch				4	1	5
Total	8	4	6	21	4	43

facilitate a more detailed environmental reconstruction than was afforded by the sedimentary properties alone (Tobias 1949). However, the age and origin of the pollen identified from these samples must be critically interrogated, particularly as cave environments prohibit the *in situ* deposition of pollen, and consequently, such records are indicative of the broader regional environment at best (Carrión and Scott 1999). This is of course true for any pollen record, due to the inherent mechanism of wind transport as a method of cross pollination, facilitating transport distances of at least a 100-km radius (Andrews and Bamford 2008). However, where pollinating plants are found *in situ*, the regional and local influence can be at least broadly inferred through what is termed the 'witches hat' hypothesis, which considers the proportion of local grains in any given sample, while the 'Neves effect'

Fig. 15 Retouched pieces retrieved during the 2017 excavation. **a**, **b**. Unifacial points. **c**, **f**, **i.** Triangular blanks. **d**, **e**. Denticulated point. **g**, **h**. Denticulates. **j**. Side-scraper

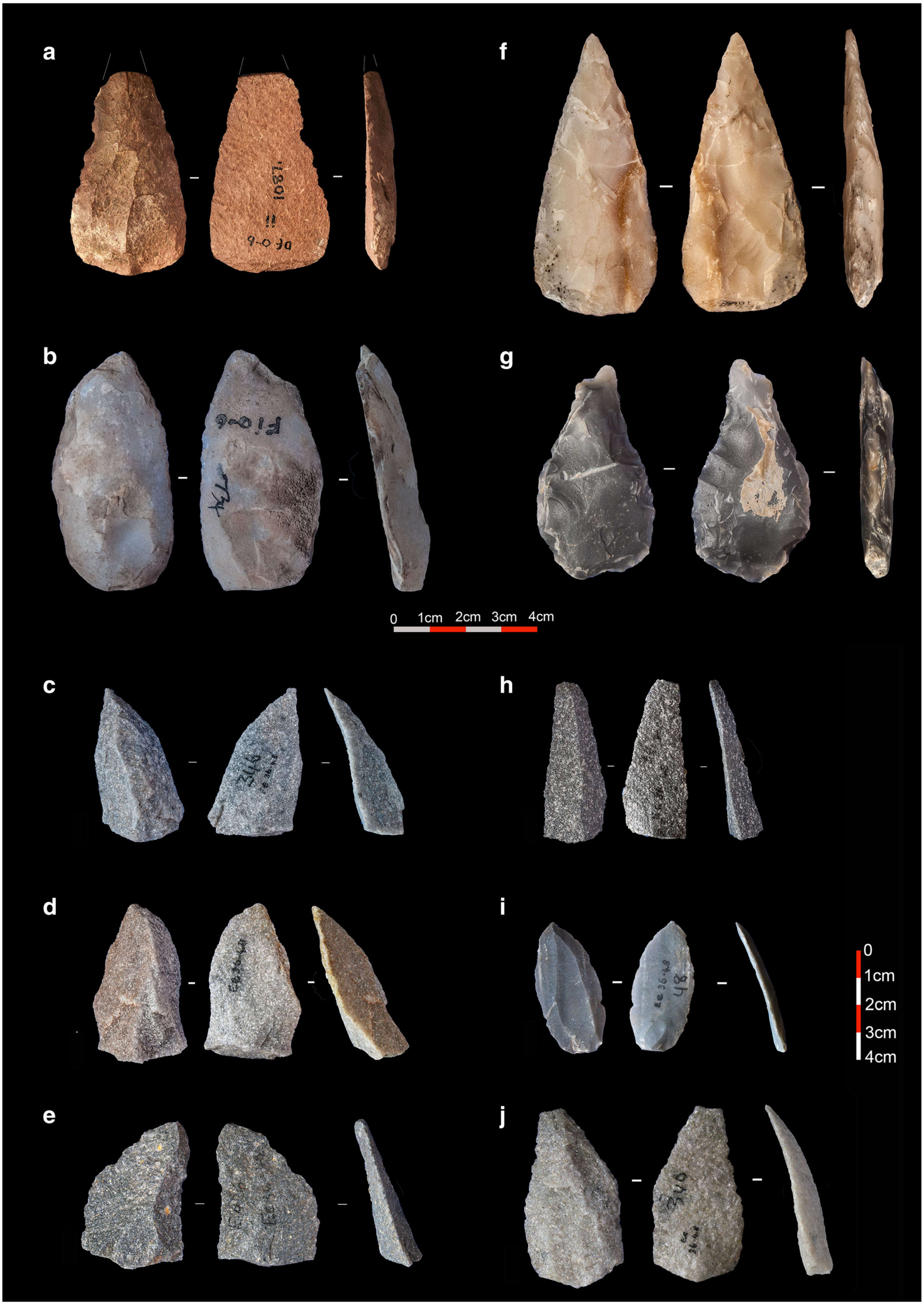


Fig. 16 **a**,**b**,**f**,**g**. Bifacial and unifacial pieces from Tobias's collection. **c**,**d**,**e**,**h**,**i**,**j**. Triangular blanks from 'Bed I' from Tobias's collection

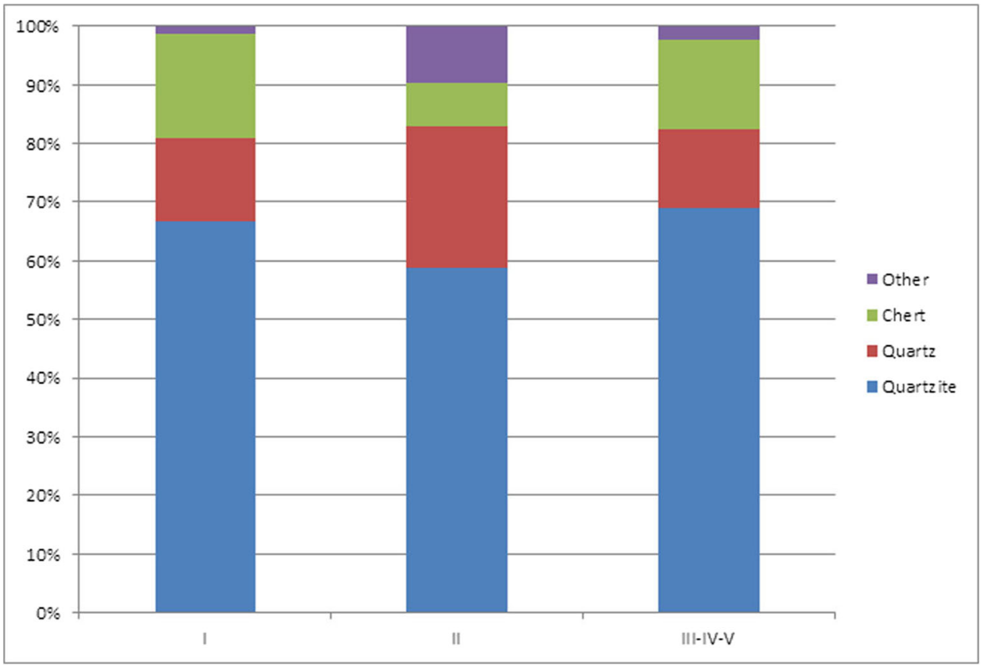


Fig. 17 Raw materials following the three lithic clusters proposed by the spatial analysis

incorporates the role of the size, and thus weight, of different pollen grains which in turn influences the proportional representation of lighter pollen grains within a profile (Prentice 1985; Traverse 2007). For cave environments, further complications arise from the angle of the cave opening relative to the angle of dominant and secondary wind directions. In the case of open excavations, the potential for contemporary pollen contamination exists (Carrión and Scott 1999), and we therefore interpret the pollen diagram for its palaeoenvironmental significance. Large proportions of grass pollen can be indicative of contamination during excavation and sampling. A clearer indicator is, however, in the form of exotic species. *Pinus* pollen was identified through the profile and is generally taken as indicative of modern contamination as the species was introduced in South Africa ~ 300 years ago (Turner and Plater 2004; Van Wilgen and Richardson 2012). However, samples IIe and IIIa contained high pollen concentrations, and this is not seen in other layers where *Pinus* is also present. This suggests that modern contamination does not explain the higher pollen counts in these two samples, but rather it might indicate a higher plant cover during these occupation layers.

The relatively low number of pollen grains preserved and the cosmopolitan nature of their species distributions limit the capacity for definitive reconstructions of the palaeoenvironment

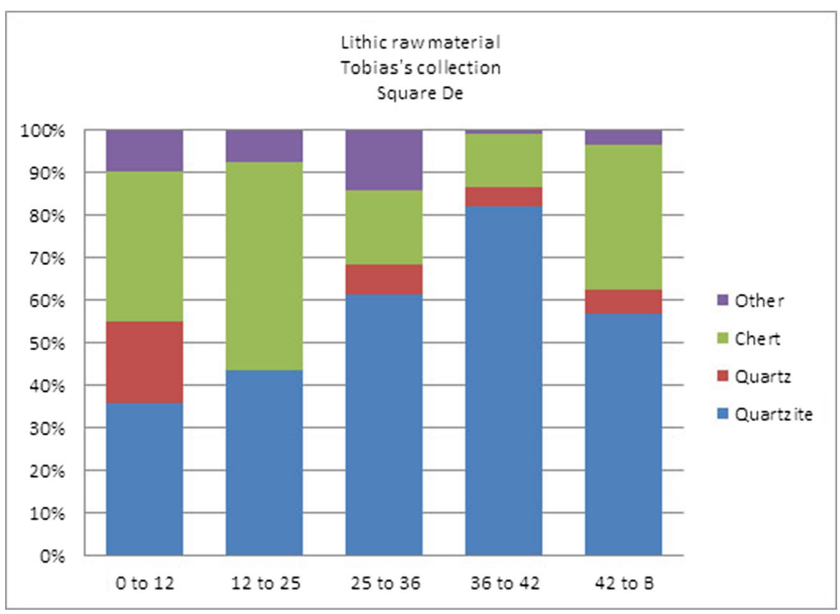


Fig. 18 Lithic raw material distribution of Tobias's spits in square De

or palaeoclimate. However, broad inferences can be tentatively made on the basis of the broad assemblage of the pollen, and the variations in preservation. The ratio of Poaceae, Cyperaceae and Asteraceae fossil pollen grains is often used to interpret the amount and seasonality of maximum regional moisture availability, and in turn the precipitation (Fitchett and Bamford 2017).

With regard to the phytolith analysis, the abundance of phytoliths decreases accordingly with that of other biosiliceous microfossils (i.e. diatoms and sponge spicules), which could be indicative of differential preservation conditions at the site.

Asteraceae, Poaceae, Cyperaceae and Combretaceae families dominate the pollen diagram at Mwulu's Cave. In unit III, Cyperaceae pollen grains represent the greatest percentage composition of sample IIIa, and equal proportions of Poaceae and Asteraceae grains have been identified. This would suggest greater regional moisture availability, and a heightened occurrence of winter rainfall (Fitchett and Bamford 2017). For the remaining samples of unit III, insufficient pollen grains have been identified to facilitate environmental inferences.

During the occupation of unit II, the two samples with the greatest fossil pollen concentration, IIe and IIf, grains from the Poaceae family represented the greatest percentage contribution of each sample. This was followed by Cyperaceae, with low percentage composition from the Asteraceae family for both samples. The phytolith assemblage of unit II in general and of sample IIe in particular was characterised by the dominance of grass phytoliths, mainly GSSCs lobates, which are characteristic of the C_4 Panicoideae subfamily. Sedge phytoliths (papillae/hat shape and achene morphotypes), blocky parallelepipeds and elongates without decorated sides were also well represented in the phytolith assemblage. The pollen and phytolith records tentatively indicate a change in the environmental conditions towards an increase in warmer and drier conditions and the expansion of open environments where grasses would dominate the landscapes probably typified by edaphic grasslands. Summer rainfall conditions would be expected during the occupation of unit II. The higher presence of sedges in samples from unit II might also indicate that local wet conditions were also present in the surrounding areas of the site.

Based on the phytolith record, the vegetation during the occupation of unit I experienced an important change expressed at Mwulu's Cave in the form of decreasing grasses, which, when present, were mostly of the C_3 type. This, coupled with a shift in the ratio of Poaceae:Asteraceae pollen grains, tentatively suggests a return to colder conditions and possibly a higher occurrence of winter rainfall.

The presence of algal material (including diatoms and sponge spicules) and spores throughout the record may be of palaeoenvironmental significance, as this does likely reveal *in situ* deposition (Balme 1995). Tobias (1949: p. 4) reflects that the 'deposit was damp throughout, particularly towards the back of the cave. The water which had gained access by seepage had leeched out almost all bony remains…' The spores and algal material throughout the record indicate that damp conditions and moisture availability characterised the cave throughout the period represented by this profile.

The future availability of ages for Mwulu's Cave will provide the opportunity to chronologically contextualise and refine this preliminary palaeoenvironmental reconstruction.

Cultural remains

Archaeologically, Mwulu's Cave has been fully attributed to the Pietersburg industry and compared to three major archaeological sequences in the northeastern part of South Africa, namely Cave of Hearths (Mason, 1988), Border Cave (Tobias 1949; Beaumont 1978) and Bushman Rock Shelter (Mason 1957; Porraz et al. 2015, 2018).

Investigating the variability of this presumed industry can help in tackling some of the issues that we pointed out in the introduction, such as the idiosyncrasy of the early MSA in the northeastern area of South Africa, the potential link with other northern cultural areas, as well as the hypothesis of regionalization and development of the MSA in southern Africa.

The Pietersburg was first mentioned by E.G. Paterson to describe lithic artefacts collected at a mission station near the town of Pietersburg (today Polokwane) in the late 1920s (Sampson 1974). Later, Goodwin and van Riet Lowe (1929) used this term to refer to different lithic surface scatters, which could be found as far as Victoria West in the Northern Cape. In 1940, van Riet Lowe suggested that it should be elevated to the category of 'industry', probably because of the relevance, in his views, of the Makapan Valley sites (Sampson 1972). Tobias (1949, 1954) assigned the complete lithic assemblage from Mwulu's Cave to the same industry. Finally, Mason (1957) also identified the Pietersburg in the nearby site of Cave of Hearths, and, based on his analysis of the lithics from the site, subdivided it into a Lower (Bed 4), a Middle (Bed 5) and an Upper (Bed 6–9) phase. Sampson (1974) later grouped different southern African industries under the term 'Pietersburg complex', namely the Pietersburg industry described by Goodwin, Tobias and Mason (with Cave of Hearths in the Makapan Valley as the reference site), the 'Orangian industry' and the 'Mossel Bay industry'. Following Sampson's description, the Pietersburg's earlier phase is characterised by utilised flakes, discoid or 'adjacent cores' (sic), large flakes and blades and some frontal scrapers or backed knives. The later phase, still following Sampson, has a lower percentage of large blades and higher percentage of convergent flakes, sometimes converted into frontal scrapers (Sampson 1974: p.159).

The term 'Pietersburg' has recently been used again (see for example Lombard et al. 2012; Porraz et al. 2015, 2018). Porraz et al. (2015, 2018) recognise two techno-typological phases at Bushman Rock Shelter (Phase 21 and Phase 28). The most recent one is characterised by unifacial and bifacial pieces (Porraz et al. 2015), whereas the second one's hallmark is the occurrence of abundant end-scrapers (Porraz et al. 2018). Both of these phases include a strong *Levallois* component.

One of the main questions surrounding the so-called Pietersburg relates indeed to its definition. As is often the case with the MSA, we are dealing here with quite an elusive concept, and there are several reasons for this. The first reason is a change of status, from a local variation to an industry, and, more recently, to a technocomplex. Since the 1960s, very few sites in this part of southern Africa where it was first defined have been excavated. Moreover, the initial definition of the Pietersburg was solely based on typological grounds and, as a result, clear and distinct technological features are lacking. Recent studies are proposing new technological descriptions but those are either still preliminary (Porraz et al. 2015, 2018; Backwell et al. 2018) or facing taphonomic issues (Wadley et al. 2016; de la Peña and Witelson 2018); further work is thus required.

Secondly, the coherence of the Pietersburg industry through time poses a problem, from a technological point of view, since its original definition was somewhat vague. As mentioned above, Mason defined three phases using the Cave of Hearths' sequence, while later on, Sampson recognised only two phases. Whether the Pietersburg includes two or three phases, it remains unclear which features are truly idiosyncratic of this industry.

Thirdly, its exact position within the MSA chronology is problematic. Most Pietersburg sites were radiocarbon-dated and have ages that fall beyond the range of the method (> 40 ka BP). The only existing ages using more modern dating techniques (namely ESR) are for Border Cave, where the Pietersburg phase has been dated to MIS5 (130–80 ka) (Grün and Beaumont 2001; Grün et al. 2003). The attribution of the base of the sequence to the Pietersburg was initially proposed by Cooke et al. (1945), followed 30 years later by Beaumont (1978), but this attribution rests mostly on chronological grounds rather than thorough lithic analyses.

A further issue surrounding the Pietersburg is its relationship with other MIS 5 industrial entities, for instance the so-called MSA I and II from Klasies River Mouth. Indeed, tackling its definition and relationship with other MIS 5 industries leads us to another relevant debate, namely the question of whether there is a regionalization in terms of technological traditions going as far back as the MIS 6/5 in southern Africa (as first proposed by Clark 1959). Nonetheless, as mentioned before, it would be more pertinent to compare Mwulu's Cave's assemblage with Zimbabwean, Mozambican and Botswanan MSA assemblages, which are geographically much closer (see for example recent work in Mozambique by Bicho et al. 2018).

Finally, most of the sites attributed to the so-called Pietersburg at the beginning of the twentieth century were open-air sites, and their relationship with cave and rock shelter sites excavated later requires further clarification.

Mason correlates Mwulu's Cave stratigraphy with layers 6 and 7 of Cave of Hearths (Mason 1988). Sampson also studied and compared the lithic material from Cave of Hearths with the one from Mwulu's Cave (Sampson 1972). He concludes that, because of Tobias's excavation method problems, the collection from Mwulu's Cave Bed II should be considered as dubious in any comparative analysis, since there is a high probability of admixture (Supplementary Material). Sampson also points out that the broad techno-typological differences that he describes at Mwulu's Cave seem to correspond with the differences observed between Cave of Hearths Bed 5 and Beds 6–8. Cave of Hearths' Bed 5 was mainly characterised by convergent flakes, whereas the main hallmarks in Beds 6–8 are 'trimmed pieces' (a term which refers to unifacial and bifacial pieces). In our new excavation, unifacial pieces have been documented in unit I, whereas units IV and V are particularly rich in triangular blanks. Unfortunately, no dates are available for Cave of Hearths, which prevents us from drawing chronological comparisons between the two sites.

Regarding Border Cave, a comparison with Mwulu's Cave is provided by Beaumont in his Master's thesis (Beaumont 1978). Border Cave, as explained by Tobias, was the first sealed cave sequence excavated to be associated with the so-called Pietersburg (Cooke et al. 1945; Tobias 1949, p.1). In the old collection, recovered during Beaumont's excavation, bifacial and unifacial pieces, as well as triangular elements, are described in the basal members. The new excavations started in 2015 (Backwell et al. 2018) have yielded a noticeable amount of triangular blanks in members 4WA and 5BS, but no bifacial or unifacial pieces so far. Ages between 227 and 77 kya have been proposed for members 5WA, 5BS, 4WA and 4BS, all attributed to the Pietersburg/MSA1 (Grün and Beaumont 2001; Grün et al. 2003). Once again, it is worth noting that the main typological categories found at Mwulu's Cave are also mentioned for Border Cave: unifacial and bifacial pieces and mainly triangular blanks, being recovered in the upper layers.

The recent publications on Bushman Rock Shelter (Porraz et al. 2015, 2018) highlight three main technological horizons regarding the lithics. The upper part of the sequence includes several layers containing bifacial and unifacial pieces (phase '21'), while the middle part is characterised by end-scrapers (phase '28'), and the base by a proliferation of triangular blanks. Recent luminescence dating presented by Porraz et al. (2018) provides ages for the upper two phases of, respectively, 73 ± 6 ka (quartz) and 91 ± 10 ka (feldspar), and 75 ± 6 ka (quartz) and 97 ± 10 ka (feldspar), thus positioning this industry within MIS5.

Other sites in Limpopo recently attributed or tentatively related to the Pietersburg include Wonderkrater (Backwell et al. 2014) and Steenbokfontein (Wadley et al., 2016). Wonderkrater has yielded three small MSA lithic assemblages with age estimates of 30 ka, > 45 ka and 138.01 ± 7.7 ka BP. At Steenbokfontein (Wadley et al. 2016), two main knapping methods, namely prismatic blade production and centripetal flake production, were documented. In Layer 1, there seems to be different typometric size objectives for flakes and blades, whereas in Layer 2, a normal distribution for flakes and blades was detected, which probably indicates a continuous reduction process. The high proportion of cortex and the small number of scars on flake dorsal faces might be pointing towards the use of the site as a workshop, perhaps for testing rock slabs. Steenbokfontein cannot readily be compared to other MSA sites in Limpopo. This is not only due to the small sample of lithics analysed but mainly because post-depositional processes significantly damaged the lithics (de la Peña and Witelson 2018).

Another sequence that should be compared with the one from Mwulu's Cave is in Rose Cottage Cave in the Free State, particularly the basal layers excavated by Malan (Wadley and Harper 1989). Malan attributed the whole sequence to the Magosian, but the analysis conducted by Wadley and Harper demonstrated that there were pre- and post-Howiesons Poort industries. Of particular interest is the pre-Howiesons Poort material. The so-called Lower Magosian described by Malan contained 'many "advanced" *Levallois* flakes and blades, and abundant points and sidescrapers'. Wadley and Harper's study shows that some of the most abundant typological categories of the lower layers were 'points' as well as unifacial and partially bifacial pieces.

At Florisbad, another site located in the Free State, Kuman et al. (1999) described a highly retouched form of MSA at 157 ka BP and a minimally retouched, expedient MSA assemblage from a series of occupation horizons at 121 ka BP. They mention small cores and small cores-on-flakes occurring throughout the sequence, predominantly on hornfels. Bifaces are absent from the assemblages recovered during the 1980s excavation.

At Wonderwerk, in the Northern Cape Province, Beaumont and Vogel (2006) report on MSA artefacts dating to between 220 and 73 ka BP and including prepared cores, blades, *Levallois* flakes and unifacial and bifacial points comparable with Middle–Late Pietersburg assemblages like those from Cave of Hearths, Beds 5–8. In-depth analyses of this industry have, however, not yet been published.

Bifacial MSA technology has also been highlighted in the pre-Still Bay layers of Sibudu Cave in KwaZulu-Natal (Wadley 2012; Rots et al. 2017). Nonetheless, detailed technological analyses of these lower layers are still pending; a technological and functional analysis of the serrated points has been recently published, but those are regarded as a regional expression (Rots et al. 2017).

Thus, following these broad typological descriptions, we can assume that, from a lithic point of view, there is in the northeastern part of South Africa a typological succession from triangular blanks/*Levallois*-like industries to bifacial/unifacial pieces/*Levallois*-like industries, as confirmed by the preliminary lithic data from Mwulu's Cave. We can also assume that this succession started (at least) in MIS5, following the dates from Bushman Rock Shelter and Border Cave. The challenge is now to test whether this typological distinction has a technological counterpart. In other words, is this typological change also accompanied by a technological one and, mainly, what does it imply in terms of human behaviours? Accordingly, the question is to know whether this lithic typological sequence is a regional expression and how it relates to older lithic expressions, such as the so-called Fauresmith, as well as to more recent ones, such as the Still Bay or the Rhodesian Still Bay. In other words, what is its diachronic development?

If the chronological program that we have designed to compare TL and OSL dating confirms an MIS5 chronology, Mwulu's Cave would also be confirmed as a sequence with a rather old MSA ochre assemblage, as suggested by Tobias (1949, 1954, 2005). Nonetheless, the 2017 ochre assemblage differs from many of the other well-studied MSA ochre assemblages, such as those from Blombos Cave, Diepkloof Rock Shelter and Sibudu Cave. Grinding of ochre pieces is not directly evident in the 2017 Mwulu's Cave assemblage, while this is the most common method of ochre processing at many MSA sites. There is also no apparent preference to collect red varieties such as is common at many MSA sites, but 100% of the utilised pieces are bright red. The differences between the two ochre assemblages (Tobias's collection and 2017 collection) at Mwulu's Cave are extreme, but excavation methods could account for some of this. Most of the pieces in the 2017 assemblage are small, and if excavation and sorting techniques had not been strict, most of the ochre assemblage would have been lost. The small piece size and the preference for soft, clayey-silty ochre suggest that crushing might have been the favoured way to produce powder. The few hard pieces (often specular iron oxides; rare in the assemblage) would have been difficult to crush, and these were used mostly for grinding and rubbing activities for powder production and possible direct transferal of ochre powder onto a soft surface.

Some examples of MIS5 ochre use are Pinnacle Point Cave 13B and Klasier River Mouth. Over 500 pieces of ochre were found at Pinnacle Point Cave 13B from MSA layers dated to ~ 115–92 ka BP (Marean et al. 2007; Watts 2010). The utilised pieces comprise 12.7% of the assemblage, most of which are red and have been ground (Watts 2010). The MSA ochre collection from Klasies River Mouth consists of 314 pieces dated to 110–60 ka BP (Singer and Wymer 1982). Most pieces are red. Utilised pieces were mostly ground and a few have scored incisions (McBrearty and Brooks 2000; d'Errico et al. 2012). By ~ 100 ka, ochre collection and use was habitual in South Africa (e.g. Watts 2002). Nonetheless, the collection of ochre in Africa predates these lines of evidence. Ochre pieces are found at GnJh-15, Kenya (285 kya) (McBrearty 2001) and in the 250,000-year-old Lupemban Industry at Twin Rivers, Zambia (Barham 2002). At Sai Island, North Africa, ochre was collected and used by 200 kya in the Sangoan (van Peer et al. 2004) and ochre was collected at Kathu Pan, South Africa, in the Fauresmith industry (Wilkins and Chazan 2012).

Conclusion

Renewed multi-disciplinary work at Mwulu's Cave is part of a general ongoing trend within the scientific community to investigate the chronological, technological and cultural characteristics of the MSA from the interior of southern Africa. In our case, we are particularly concerned with the so-called Pietersburg industry, to which the lithic material excavated from the site by P.V. Tobias was assigned. Our reappraisal of the stratigraphy allows us to propose a model for the site formation somewhat different from earlier work (Tobias 1949). The sedimentological study combined with spatial analyses of lithic artefacts highlight a more complex picture than a direct correspondence between visible sedimentary units (those identified by Tobias, which are consistent with ours) and a succession of human occupational events interrupted by abandonment phases. Rather, while three phases of site use consistent with lithic concentrations have been identified (contra five sedimentary units), most of the sediment accumulation can be explained by the action of non-anthropogenic biotic (e.g. roots, rootlets and small animals visiting the cave) and abiotic (i.e. natural erosion of the cave, autogenic decay of clasts, water percolation and aeolian inputs) depositional and post-depositional processes.

Although the geological location of the cave, formed within a quartzitic formation, has prevented bone preservation, remains in the form of pollens and phytoliths are present. Notwithstanding a possible role played in some instances by modern contamination and varying degrees of preservation across the sequence, they provide, for the first time, some information regarding the palaeoenvironmental setting of the site. Specifically, the botanical remains indicate climatic fluctuations through time in the form of changing precipitation patterns.

The results presented here serve as groundwork for future detailed analyses of both the botanical and cultural remains as they provide a more secure stratigraphic framework. Preliminary analysis of the lithic artefacts from the site identifies techno-typological similarities with material from other sites in the northeastern part of South Africa, including Cave of Hearths, Bushman Rock Shelter and Border Cave, thus tentatively attributing the sequence from Mwulu's Cave to MIS 5/6. Luminescence dating is underway and should help in refining the chronological attribution of the sequence.

Acknowledgments The authors would like to thank Judy Maguire, Gary Trower, Lucinda Backwell, Deon Richter and Moloko Madibana, who helped to locate the site, as well as Chris Thornhill, who helped during the two excavation campaigns. J.M. Maíllo, María del Carmen Arriaza Dorado and Lyn Wadley kindly read and gave advice for an early draft of this manuscript. We thank the Shamane Magashula community for kindly giving us permission to excavate in Mwulu's Cave. The support of the DST/NRF Centre of Excellence in Palaeosciences (CoE in Palaeosciences) towards this research is hereby acknowledged. Opinions expressed and conclusions arrived at are those of the authors and are not necessarily to be attributed to the CoE in Palaeosciences. We are grateful to The Palaeontological Scientific Trust (PAST), Johannesburg, South Africa and CoE in Palaeosciences for providing three research grants for Mwulu's Cave project.

References

Albert RM (2000) Study of ash layers through phytolith analyses from the middle Palaeolithic levels of Kebara and Tabun caves. PhD Dissertation, Universitat de Barcelona. https://doi.org/10.1006/jasc.2002.0854

Albert RM, Weiner S (2001) Study of phytoliths in prehistoric ash layers from Kebara and Tabun Caves using a quantitative approach. In: Meunier JD, Colin F (eds) Phytoliths: applications in earth sciences and human history, Lisse, pp 251–266

Allmendinger RW, Cardozo NC, Fisher D (2013) Structural geology algorithms: vectors and tensors. Cambridge, England. Cambridge University Press

Andrews P, Bamford M (2008) Past and present vegetation ecology of Laetoli, Tanzania. J Hum Evol 54:78–98

Backwell LR, Parkinson AH, Roberts EM, d'Errico F, Huchet JB (2012) Criteria for identifying bone modification by termites in the fossil record. Palaeogeogr Palaeoclimatol Palaeoecol 337:72–87

Backwell LR, McCarthy TS, Wadley L, Henderson Z, Steininger CM, Barré M, Lamothe M, Chase BM, Woodborne S, Susino GJ, Bamford MK (2014) Multiproxy record of late Quaternary climate change and middle stone age human occupation at Wonderkrater, South Africa. Quat Sci Rev 99:42–59

Backwell LR, d'Errico F, Banks WE, de la Peña P, Sievers C, Stratford D, Lennox SJ, Wojcieszak M, Bordy E, Bradfield J, Wadley L (2018) New excavations at Border cave, KwaZulu-Natal, South Africa. J Field Archaeol. https://doi.org/10.1080/00934690.2018.1504544

Balme BE (1995) Fossil in situ spores and pollen grains: an annotated catalogue. Rev Palaeobot Palynol 87:81–323

Barham LS (2002) Systematic pigment use in the middle Pleistocene of south-Central Africa. Curr Anthropol 43(1):181–190

Beaumont PB (1978) "Border Cave." M.A. thesis, University of Cape Town

Beaumont PB, Vogel JC (2006) On a timescale for the past million years of human history in Central South Africa. S Afr J Sci 102:217–228

Bertran P, Texier JP (1995) Fabric analysis: application to Palaeolithic sites. J Archaeol Sci 22:521–535

Bicho N, Cascalheira J, Haws J, Gonçalves C (2018) Middle Stone Age technologies in Mozambique: a preliminary study of the Niassa and Massingir regions. J Afr Archaeol 16(1):60–82

Button A (1973) The depositional history of the Welkberg Proto-Basin, Transvaal. S Afr J Geol 76(1):15–25

Button A (1986) The Transvaal sub-basin of the Transvaal sequence. Mineral deposits of southern Africa, Geological Society of South Africa, Johannesburg 1:811–817

Cabanes D, Shahack-Gross R (2015) Understanding fossil phytolith preservation: the role of partial dissolution in paleoecology and archaeology. PLoS One 10:e0125532. https://doi.org/10.1371/journal.pone.0125532

Cabanes D, Weiner S, Shahack-Gross R (2011) Stability of phytoliths in the archaeological record: a dissolution study of modern and fossil phytoliths. J Archaeol Sci 38:2480–2490. https://doi.org/10.1016/j.jas.2011.05.020

Carrión JS, Scott L (1999) The challenge of pollen analysis in palaeoenvironmental studies of hominid beds: the record from Sterkfontein caves. J Hum Evol 36:401–408

Clark JD (1959) The prehistory of southern Africa. Harmondsworth, England

Collura LV, Neumann K (2017) Wood and bark phytoliths of west African woody plants. Quat Int 434:142–159. https://doi.org/10.1016/j.quaint.2015.12.070

Conard NJ, Porraz G (2015) Revising models for the cultural stratigraphic sequence of the Middle Stone Age. S Afr Archaeol Bull 70(201): 127–130

Cooke HBS, Malan BD, Wells LH (1945) 3. Fossil man in the Lebombo Mountains, South Africa: the 'Border Cave', Ingwavuma District, Zululand. Man 45:6–13

Cordova CE (2013) C3 Poaceae and Restionaceae phytoliths as potential proxies for reconstructing winter rainfall in South Africa. Quat Int 287:121–140. https://doi.org/10.1016/j.quaint.2012.04.022

Cordova CE, Scott L (2010) The potential of Poaceae, Cyperaceae and Restionaceae phytoliths to reflect past environmental conditions in South Africa. In: Runge J (ed) African Palaeoenvironments and geomorphic landscape evolution. Taylor & Francis, pp 107–134

d'Errico F, García Moreno R, Rifkin RF (2012) Technological, elemental and colorimetric analysis of an engraved ochre fragment from the middle stone age levels of Klasies River cave 1, South Africa. J Archaeol Sci 39:942–952

Dayet L, Texier P-J, Daniel F, Porraz G (2013) Ochre resources from the middle stone age sequence of Diepkloof rock shelter, Western Cape, South Africa. J Archaeol Sci 40:3492–3505

de la Peña P (2015) Refining our understanding of Howiesons Poort lithic technology: the evidence from Grey rocky layer in Sibudu cave (KwaZulu-Natal, South Africa). PLoS One 10(12):e0143451

de la Peña, P, Witelson, D (2018) Trampling vs. retouch in a lithic assemblage: a case study from a middle stone age site, steenbokfontein 9KR (Limpopo, South Africa). J Field Archaeol 43(7):522–537. https://doi.org/10.1080/00934690.2018.1524219

Els BG, van den Berg WA, Mayer JJ (1995) The Black Reef Formation in the western Transvaal: sedimentological and economic aspects, and significance for basin evolution. Mineral Deposita 30:112–123

Eriksson PG, Schweitzer JK, Bosch PJA, Schereiber UM, Van Deventer JL, Hatton CJ (1993) The Transvaal sequence: an overview. J Afr Earth Sci (and the Middle East) 16(1–2):25–51

Eriksson PG, Hattingh PJ, Altermann W (1995) An overview of the geology of the Transvaal sequence and Bushverld complex, South Africa. Mineral Deposita 30:98–111

Eriksson PG, Altermann W, Catuneanu O, Van der Merwe R, Bumby AJ (2001) Major influences on the evolution of the 2.67–2.1 Ga Transvaal basin, Kaapvaal craton. Sediment Geol 141:205–231

Esteban I, De Vynck JC, Singels E, Vlok JHJ, Marean CW, Cowling RM, Fisher EC, Cabanes D, Albert RM (2017a) Modern soil phytolith assemblages used as proxies for Paleoscape reconstruction on the south coast of South Africa. Quat Int 434:160–179. https://doi.org/10.1016/j.quaint.2016.01.037

Esteban I, Vlok J, Kotina EL, Bamford MK, Cowling RM, Cabanes D, Albert RM (2017b) Phytoliths in plants from the south coast of the greater cape floristic region (South Africa). Rev Palaeobot Palynol 245. https://doi.org/10.1016/j.revpalbo.2017.05.001

Fitchett JM, Bamford MK (2017) The validity of the Asteraceae: Poaceae fossil pollen ratio in discrimination of the southern African summer- and winter-rainfall zones. Quat Sci Rev 160:85–95

Fitchett JM, Grab SW, Bamford MK, Mackay AW (2017) Late quaternary research in southern Africa. Transactions of the Royal Society of South Africa 72(3):280–293

Getis A, Ord JK (1992) The analysis of spatial association by use of distance statistics. Geogr Anal 24(3):189–206

Goodwin, AJH, van Riet Lowe CP (1929). The Stone Age Cultures of South Africa. Annals of the South African Museum, Cape Town, pp 27

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

Grün R, Beaumont PB, Tobias PV, Eggins S (2003) On the age of border cave 5 human mandible. J Hum Evol 45:155–167

Henry G, Master S (2008) Black reef project. Council for Scientific and Industrial Research (CSIR) and University of the Witwatersrand, Johannesburg

Henry G, Clendenin CW, Charlesworth EG (1990) Depositional facies of the black reef quartzite formation in the eastern Transvaal. Extended Abstracts, 23rd Earth Science Congress (Geocongress' 90) of the Geological Society of South Africa, Cape Town 90:234–237

Henshilwood CS (2012) Late Pleistocene techno-traditions in southern Africa: a review of the still bay and Howiesons Poort, c. 75–59 ka. J World Prehist 25(3–4):205–237

Henshilwood CS, Sealy J, Yates R, Cruz-Uribe K, Goldberg R, Grine FE, Klein RG, Poggenpoel C, van Niekerk K, Watts I (2001) Blombos cave, southern cape, South Africa: preliminary report on 1992-1999 excavations of the Middle Stone Age levels. J Archaeol Sci 28:421–448

Henshilwood CS, van Niekerk KL, Wurz S, Delagnes A, Armitage SJ, Rifkin R, Douze K, Keene P, Haaland M, Reynard J, Discamps E, Mienies S (2014) Klipdrift shelter, southern cape, South Africa: preliminary report on the Howiesons Poort layers. J Archaeol Sci 45:284–303

Hodgskiss T (2012) An investigation into the properties of the ochre from Sibudu, KwaZulu-Natal, South Africa. South Afr Humanit 24:99–120

Jacobs Z, Roberts RG (2015) An improved single grain OSL chronology for the sedimentary deposits from Diepkloof Rockshelter, Western cape, South Africa. J Archaeol Sci 63:175–192

Katz O, Cabanes D, Weiner S, Maeir AM, Boaretto E, Shahack-Gross R (2010) Rapid phytolith extraction for analysis of phytolith concentrations and assemblages during an excavation: an application at Tell es-Safi/Gath, Israel. J Archaeol Sci 37:1557–1563. https://doi.org/10.1016/j.jas.2010.01.016

Key RM (1983) The geology of the area around Gaborone and Lobatse, Kweneng, Kgatleng, southern and south east districts. District Memoir Geol Surv Botswana 5:229

Key RM (1986) Sedimentation along the eastern margin of the Bushveld Basin, SE Botswana. Geocongress '86 (Johannesburg, South Africa), Abstracts:527–530

Kuman K, Inbar M, Clarke RJ (1999) Palaeoenvironments and cultural sequence of the Florisbad middle stone age hominid site, South Africa. J Archaeol Sci 26(12):1409–1425

Lombard M, Wadley L, Deacon J, Wurz S, Parsons I, Mohapi M, Swart J, Mitchell P (2012) South African and Lesotho Stone Age sequence updated. S Afr Archaeol Bull 67(195):123–144

Maguire J (2009) An overview of the physical setting of Makapan. In McNabb, J. & Sinclair, A. (eds). The cave of hearths: Makapan middle Pleistocene research project: field research by Anthony Sinclair and Patrick Quinney, 1996–2001. 29–48. Oxford: Archaeopress. University of Southampton Series in Archaeology No 1

Marean CW (2010) Pinnacle point cave 13B (Western Cape Province, South Africa) in context: the cape floral kingdom, shellfish, and modern human origins. J Hum Evol 59(3–4):425–443

Marean CW (2014) The origins and significance of coastal resource use in Africa and Western Eurasia. J Hum Evol 77:17–40

Marean CW, Bar-Matthews M, Bernatchez J, Fisher E, Goldberg P, Herries AIR, Jacobs Z, Jerardino A, Karkanas P, Minichillo T, Nilssen PJ, Thompson E, Watts I, Williams HM (2007) Early human use of marine resources and pigment in South Africa during the middle Pleistocene. Nat 449:905–908

Mason RJ (1957) The Transvaal Middle Stone Age and statistical analysis. S Afr Archaeol Bull 12(48):119–137

Mason RJ (1988) Cave of Hearths. Makapansgat. Transvaal. Occasional paper N.21. Archaeological Research Unit

McBrearty S (2001) The middle Pleistocene of East Africa. In: Barham L, McBrearty S, Brooks AS (eds) 2000. The revolution that wasn't: a new interpretation of the origin of modern human behavior. J Hum Evol 39: 453–563. Robson-Brown (eds), Human roots: Africa and Asia in the Middle Pleistocene. Bristol: Western Academic & Specialist Press, pp 81–98

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

Mucina L, Rutherford MC (2006) The vegetation of South Africa, Lesotho and Swaziland. South African National Biodiversity Institute

Murungi ML (2017) Phytoliths at Sibudu (South Africa): implications for vegetation, climate and human occupation during the MSA. Unpublished PhD thesis, University of the Witwatersrand

Novello A, Bamford MK, Van Wijk Y, Wurz S (2018) Phytoliths in modern plants and soils from Klasies River, cape region (South Africa). Quat Int 464:440–459. https://doi.org/10.1016/j.quaint.2017.10.009

Partridge TC (1993) The evidence for Cainozoic aridification in southern Africa. Quat Int 17:105–110

Porraz G, Val A, Dayet L, de la Peña P, Douze K, Miller CE, Murungi ML, Tribolo C, Schmid VC, Sievers C (2015) Bushman Rock Shelter (Limpopo, South Africa): a perspective from the edge of the Highveld. South African Archaeol Bull 70:166–179

Porraz G, Val A, Tribolo C, Mercier N, de la Peña P, Haaland M, Igreja M, Miller CE, Schmid V (2018) The MIS5 Pietersburg at '28' Bushman Rock Shelter, Limpopo Province, South Africa. PloS One

Prentice IC (1985) Pollen representation, source area, and basin size: toward a unified theory of pollen analysis. Quat Res 23(1):76–86

Rayner RJ, Moon BP, Masters JC (1993) The Makapansgat australopithecine environment. J Hum Evol 24(3):219–231

Repinski P, Holmgren K, Lauritzen SE, Lee-Thorp JA (1999) A late Holocene climate record from a stalagmite, cold air cave, Northern Province, South Africa. Palaeogeogr Palaeoclimatol Palaeoecol 150: 269–277

Rossouw L (2009) The application of fossil grass-phytolith analysis in the reconstruction of late Cenozoic environments in the South African interior. University of the Free State, South Africa

Rots V, Lentfer C, Schmid VC, Porraz G, Conard NJ (2017) Pressure flaking to serrate bifacial points for the hunt during the MIS5 at Sibudu cave (South Africa). PLoS One 12(4):e0175151

Rutherford MC, Mucina L, Lötter MC, Bredenkamp GJ, Smit JHL, Scott-Shaw CR, Hoare DB, Goodman PS, Bezuidenhout H, Scott L, Ellis F, Powrie LW, Siebert F, Mostert TH, Henning BJ, Venter CE, Camp KGT, Siebert SJ, Matthews WS, Burrows JE, Dobson L, van Rooyen N, Schmidt E, Winter PJD, du Preez PJ, Robert A, Ward S, Williamson A, Hurter PJH (2006) Savanna Biome. In: Mucina L, Rutherford M (eds) The Vegetation of South Africa, Lesotho and Swaziland. South African National Biodiversity Institute, pp 429–529

Sampson CG (1972) The Stone Age industries of the Orange River Scheme and South Africa (No. 6). National Museum Bloemfontein

Sampson CG (1974) The Stone Age archaeology of southern Africa. Studies in Archaeology, Academic Press

Santisteban Juan I, Mediavilla R, Lopez-Pamo E, Dabrio CJ, Ruiz Zapata MB, Gil García MJ, Castano S, Martínez-Alfaro PE (2004) Loss on ignition: a qualitative or quantitative method for organic matter and carbonate mineral content in sediments? J Paleolimnol 32(3):287–299

Schlegel GCJ, Harmse HVM, Brunke O (1989) Granulometric and mineralogical characteristics of the Kalahari sands of southern Africa. S Afr J Geol 92(3):207–222

Schwertmann U, Cornell RM (1998) Iron oxides in the laboratory: preparation and characterization. VCH, Cambridge

Singer R, Wymer J (1982) The middle stone age at Klasies River mouth in South Africa. Chicago University Press, Chicago

Stevenson C, Lee-Thorp JA, Holmgren K (1999) A 3000-year isotopic record from a stalagmite in cold air cave, Makapansgat Valley, Northern Province. S Afr J Sci 95:46–48

Thackeray JF, Fitchett JM (2016) Rainfall seasonality captured in micromammalian fauna in Late Quaternary contexts, South Africa. Palaeontol Afr 51:1–9

Tobias PV (1949) The excavation of Mwulu's cave, Potgietersrust district. S Afr Archaeol Bull 4(13):2–13

Tobias PV (1954) Climatic fluctuations in the middle stone age of South Africa, as revealed in Mwulu's cave. Trans Roy Soc S Afr 34(2):325–334

Tobias PV (2005) Into the past: a memoir. Picador Africa, Johannesburg

Traverse A (2007) Paleopalynology. Springer, Dordrecht

Tribolo C, Mercier N, Valladas H, Joron JL, Guibert P, Lefrais Y, Selo M, Texier PJ, Rigaud JPH, Porraz G, Poggepoel C, Parkington J, Texier JP, Lenoble A (2009) Thermoluminescence dating of a Stillbay-Howiesons Poort sequence at Diepkloof rock shelter (Western cape, South Africa). J Archaeol Sci 36:730–739

Tribolo C, Mercier N, Douville E, Joron JL, Reyss JL, Rufer D, Cantin N, Lefrais Y, Miller CE, Porraz G, Parkington J (2013) OSL and TL dating of the Middle Stone Age sequence at Diepkloof Rock Shelter (south Africa): a clarification. J Archaeol Sci 40(9):3401–3411

Tsartsidou G, Lev-Yadun S, Albert RM, Miller-Rosen A, Efstratiou N, Weiner S (2007) The phytolith archaeological record: strengths and weaknesses evaluated based on a quantitative modern reference collection from Greece. J Archaeol Sci 34:1262–1275. https://doi.org/10.1016/j.jas.2006.10.017

Turner S, Plater A (2004) Palynological evidence for the origin and development of late Holocene wetland sediments: Mdlanzi swamp, KwaZulu-Natal, South Africa. S Afr J Sci 100:220–229

Tyson PD, Preston-Whyte RA (2005) The weather and climate of southern Africa. Oxford University Press, Cape Town, pp 144–146

Van Peer P, Rots V, Vroomans JM (2004) A story of colourful diggers and grinders: the Sangoan and Lupemban at site 8-B-11, Sai island, northern Sudan. Before Farming 3:Article 1

Van Wilgen BW, Richardson DM (2012) Three centuries of managing introduced conifers in South Africa: benefits, impacts, changing perceptions and conflict resolution. J Environ Manag 106:56–68

Wadley L (2008) The Howieson's poort industry of Sibudu cave. Goodwin Series 1:122–132

Wadley L (2012) Two'moments in time during middle stone age occupations of Sibudu, South Africa. South Afr Humanit 24(1):79–97

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

Wadley L, Harper P (1989) Rose cottage cave revisited: Malan's Middle Stone Age collection. S Afr Archaeol Bull 44:23–32

Wadley L, Murungi ML, Witelson D, Bolhar R, Bamford M, Sievers C, Val A, de la Peña P (2016) Steenbokfontein 9KR: a Middle Stone Age spring site in Limpopo, South Africa. S Afr Archaeol Bull 71(204):130–145

Watts I (1998) The origin of symbolic culture: the middle stone age of southern Africa and Khoisan ethnography. Ph.D. Thesis, University College, London

Watts I (2001) Ochre in the middle stone age of southern Africa: ritualized display or a hide preservative? S Afr Archaeol Bull 57:1–14

Watts I (2002) Ochre in the middle stone age of southern Africa: ritualized display or hide preservative? S Afr Archaeol Bull 57:64–74

Watts I (2010) The pigments from pinnacle point cave 13B, Western cape, South Africa. J Hum Evol 59:392–411

Wilkins J, Chazan M (2012) Blade production ~500 thousand years ago at Kathu Pan 1, South Africa: support for a multiple origins hypothesis for early middle Pleistocene blade technologies. J Archaeol Sci 37:269–283

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