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ORIGINAL ARTICLE

Homo heidelbergensis and The Origins of The Middle Stone Age: The Kabwe (Broken Hill) Lithic Assemblage

David L. G. Miedzianogora · Ceri Shipton · Matt Pope

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Abstract The Middle Stone Age (MSA) saw the emergence of novel behaviours in the archaeological record and is generally associated with our own species, *Homo sapiens*. Yet, most archaeological assemblages contain no fossil remains, with those rare assemblages with a fossil association giving a less than clear-cut picture. Here, we describe the lithic assemblage from Kabwe, Zambia, a cave site that was originally discovered in the early twentieth century and is most famous for the Kabwe cranium, an exceptionally well-preserved Middle Pleistocene *Homo* fossil. The nature of the assemblage's excavation means that it is not well-provenanced. To address this issue, we draw on archival data related to the original excavations and discoveries during the 1920s and use the remains of original matrix still adhering to several of the lithic artefacts to separate out the assemblage stratigraphically. This indicates no significant difference in technological strategies across the assemblage. Whilst there is an Early Stone Age component to the assemblage in the form of spheroids, it is generally consistent with MSA technological strategies, including notably Levallois-like and laminar modes of production evident from cores and debitage. We thus interpret the Kabwe assemblage as a transitional ESA/MSA industry. Due to the possible association with *Homo heidelbergensis* sensu lato fossils in the form of both the Kabwe cranium and postcranial remains, this hints that the early MSA could have included other members of our clade rather than just *Homo sapiens*, complicating current models of MSA origins.

Archaeological period: Middle Stone Age, Middle Pleistocene.

Country and region discussed: Zambia, the Zambezi Basin.

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D. L. G. Miedzianogora (✉) · C. Shipton · M. Pope
UCL Institute of Archaeology, University College London, 31-34 Gordon Square, London WC1H 0PY, UK
e-mail: david.miedzianogora.23@ucl.ac.uk

C. Shipton
School of Culture, History and Language, College of Asia and the Pacific, the Australian National University, ACT 2601, Australia

Résumé Le Middle Stone Age (MSA) qui vit l'émergence des comportements nouveaux dans le matériel archéologique, s'associe généralement à notre propre espèce, le *Homo sapiens*. Cependant, la plupart des assemblages archéologiques ne contiennent aucun reste fossile, et les rares assemblages associés à des fossiles donnent une image guère sans équivoque. Ici, nous décrivons la collection lithique de Kabwe, Zambie, un site de caverne qui était à l'origine découvert à l'aube du XXe siècle et fameux pour le crâne de Kabwe, un fossile du *Homo* du Pléistocène moyen, exceptionnellement bien conservé. La nature de l'excavation de l'assemblage signifie que la documentation de son origine est peu fiable. Pour aborder ce problème, nous nous basons sur des données des archives liées aux excavations et aux découvertes originelles pendant les années 1920 et nous utilisons les restes de la matrice originelle qui adhèrent encore à plusieurs des artefacts lithiques pour diviser la collection de manière stratigraphique. Ceci n'indique aucune différence importante dans les stratégies technologiques à travers la collection. Bien qu'il y ait une composante du paléolithique inférieur (ESA) dans l'assemblage sous la forme de sphéroïdes, elle est généralement consistante avec les stratégies technologiques du MSA, qui incluent notamment des modes de production de type Levallois et laminaire mis en évidence par les nucléus et le débitage. Ainsi, nous interprétons l'assemblage de Kabwe comme une industrie transitionnelle de l'ESA/MSA. Due à l'association possible avec les fossiles du *Homo heidelbergensis* sensu lato à la fois sous la forme du crâne de Kabwe et des restes postcraniaux, il y a une indication que le début du MSA aurait pu inclure d'autres membres de notre clade, plutôt que le *Homo sapiens* uniquement. Ceci complique ainsi les modèles actuels de l'origine du MSA.

Keywords Middle Stone Age · *Homo* · Lithics · Kabwe · Zambia · Middle Pleistocene

Introduction

The Middle Stone Age (MSA) began around 315 thousand years ago (kya) and is often associated with the emergence of *Homo sapiens* in the fossil record (Bruner, 2023; Chazan et al., 2020; Eren et al., 2014; Lombard, 2022; McBrearty & Brooks, 2000; Richter et al., 2017; Scerri & Will, 2023; Shea, 2011; Spinapolice, 2020; Wadley, 2015). It is a key transition in hominin evolution as it sees the emergence of novel behaviours associated with "behavioural modernity" (Barham, 2013; Foley & Lahr, 1997, 2003, 2020; McBrearty & Brooks, 2000; Scerri et al., 2019; Willoughby, 2012), a transition that has been hypothesised to be the product of changes in hominin cognition (Foley, 2016; Foley & Lahr, 1997, 2003, 2020). In particular the increased depth of planning needed to successfully manufacture Levallois technology compared with previous Early Stone Age (ESA) technologies (Muller et al., 2017, 2022) and the emergent ability to conceptualise multiple distinct tool types (Barham, 2013). Whilst *Homo heidelbergensis* sensu lato and *Homo naledi* were also present in Africa during this transition (Dirks et al., 2017; Harvati & Reyes-Centeno, 2022), the former is usually associated with ESA technology (Bruner, 2023; Lombard, 2022) whilst the latter has no lithic association.

The archaeological and fossil records associated with the transition to the MSA are complex. ESA-like large cutting tools (LCT) have been found in association with *H. sapiens* fossils dated to 160 kya in Herto, Ethiopia (Clark et al., 2003; McBrearty, 2003; Sahle et al., 2019), despite the transition to the MSA in the region dating to 300 kya (Scerri & Will, 2023). Proposed transitional industries such as the Fauresmith in South Africa, the Sangoan in Zambia, and the Kapthurin early Levallois in Kenya are distinct from previous ESA traditions and include otherwise MSA technology, *e.g.*, prepared cores, blades, hafting, and retouched points, despite predating the full emergence of the MSA in these regions by some hundred thousand years, with research teams variably designating them as either ESA or MSA industries (Blegen et al., 2018; Chazan et al., 2020; Kuman et al., 2020; McBrearty, 1988; Olszewski et al., 2023; Taylor, 2014; Wilkins et al., 2012). This mosaic could imply a more complex transition to the MSA with the continued use of ESA-like technology by *H. sapiens* groups in some parts of Africa and a gradual transition to the full-blown MSA in other parts of the continent, possibly involving other members of the genus *Homo*.

At Kabwe (formerly Broken Hill) in Zambia, this picture is further muddled. The site is famous for the Kabwe skull, an unusually well-preserved Middle Pleistocene fossil; it was originally the holotype of *Homo rhodesiensis* (Woodward, 1921), although most researchers today consider it either *H. heidelbergensis s.l.* or simply an unspecified, Middle Pleistocene member of the genus *Homo* (see Harvati & Reyes-Centeno, 2022; Grün & Stringer, 2023). Here, we follow the former convention. It has been directly dated to ~ 300 kya (Grün et al., 2020), coinciding with the emergence of the MSA on the continent, although this is a minimum age, meaning that the fossil could possibly predate the MSA as well. Further hominin fossils were also recovered from the site, as well as a lithic assemblage with MSA artefacts, which are potentially associated with the *Homo* fossils (1959b;

Barham et al., 2002; Clark et al., 1947). Any association between fossils and artefacts is a rarity in the Middle Pleistocene (Table 1). However, uncertainties relating to the original discoveries in the early twentieth century and the lack of a comprehensive technological study of the lithic assemblage mean that this association remains untested. Here, we present a study of the lithic assemblage from Kabwe to determine its relation to the hominin fossils, the coherence of the assemblage, its technological characteristics, and how it fits within the broader MSA of the region.

Kabwe: History, Research, and Study Material

Kabwe is named after the Zambian town (Fig. 1, 1181 m above sea level, −14.45° latitude, 28.4303° longitude) which grew around the Broken Hill Mine, within which the site was located. This was one of the largest mining operations in Africa from its opening in 1906 until its closure in 1994 (Forrest, 2008). Informal quarrying might date from 1895 (Hrdlička, 1930) and continues today (Orellana & Quinn, 2021).

The presence of Palaeolithic archaeology at Kabwe was recognised soon after the opening of the mine (Mennell & Chubb, 1907; White, 1908), but it was not until the discovery of the Kabwe skull that serious interest in the site emerged. The majority of research since then has focused on the skull and other hominin remains from the site, with a principal focus on the pathology and integrity of the skull and its teeth (Bartsiokas, 1989; Bartsiokas & Day, 1993; Lacy, 2014; Montgomery et al., 1994; Price & Molleson, 1974; Puech et al., 1980; Tappen, 1987), or the morphology of the cranium (Rightmire, 2001, 2004; Balzeau et al., 2017; Godinho & O'Higgins, 2017; 2018; Thackeray et al., 2020; Pagano et al., 2022). A handful of studies have looked at the less well-preserved postcranial remains, all of which have an unclear association with the skull and most of which were recovered ex situ; these are either considered *H. sapiens* (NHMUK PA E688, NHMUK PA E720, NHMUK PA E898) or undiagnostic late *Homo* fossils (NHMUK PA E689, NHMUK PA E690, NHMUK PA E691, NHMUK PA E793), with at least three individuals present (Clark et al., 1968; Stringer, 1986; Trinkaus, 2009, 2012). Another avenue of research has attempted to constrain the dates of the site through faunal analysis (Avery, 2002, 2003, 2018; Klein, 1973) or radiometry (Bada et al., 1974; Grün et al., 2020). These results indicate a Middle Pleistocene–early Late Pleistocene age, with every directly dated fossil from the site (hominin and non-hominin) falling within a period of 301–102 kya (Table 2, Grün et al., 2020), although several of these are U-series dates and thus represent minimum ages (Grün & Stringer, 2023). It has been noted that most of the micromammals are similar to extant species (Avery, 2003, 2018), but comparisons with well-dated sites and molecular estimates of dates of divergence suggest that the age of the rodent fossils is bracketed between 720–300 kya (Grün et al., 2020). Unfortunately, none of the hominin fossils with more *H. sapiens*-like morphologies have been dated, meaning that even a Holocene occupation cannot be ruled out for some. Based on current age estimates, however, Kabwe was occupied by hominins during the late Middle Pleistocene, between 300 and 100 kya, and the lithic assemblage might be expected to have been deposited at the same time.

The kopje (isolated hill) in which the Broken Hill Mine was located housed two caves. One (the "New Cave") was sterile whilst the "Bone Cave" produced the artefacts and palaeontological remains, including the hominin fossils. The exact number of artefacts recovered is unknown, but it is estimated that there were hundreds if not thousands in the Bone Cave (Clark et al., 1947), with the vast majority sent for smelting or left in dumps (Hrdlička, 1930; Leakey, 1934; Woodward, 1922). Only 98 artefacts (lithics and osseous artefacts) are known today, of which 74 are in the Natural History Museum (NHM) in London (Clark et al., 1947). The remaining assemblage is spread across the Iziko and Albany Museum in South Africa, and the Livingstone Museum in Zambia (Barham et al., 2002), with an unknown number in personal collections. These artefacts were recovered ad hoc during mining operations. Consequently, only a few studies have considered them. Early contributions interpreted the lithics and osseous artefacts as contemporaneous with ethnographically modern hunter-gatherer toolkits (Mennell & Chubb, 1907; White, 1908; Mennell, 1922; Hrdlička, 1930, p. 122; Leakey, 1934, pp. 126–127), although they were also lumped with the European Mousterian by some (notably Smith, 1928). Studies since the recognition that Africa had its own distinct Palaeolithic sequence (Goodwin & van Riet Lowe, 1929) have

Table 1 List of African Middle Pleistocene sites with hominin fossils associated with archaeological artefacts

Site	Technocomplex	Lithic industry	Taxon	Country	Key references
Kabwe	?	?	*H. heidelbergensis s.l.*	Zambia	Grün et al. (2020); this paper
Cave of Hearths	ESA	Late Acheulean, early MSA	MP *Homo*	South Africa	Beaumont and Vogel (2006); Wood (2010); Dusseldorp et al. (2013)
Sterkfontein	ESA	Acheulean	*H. erectus s.l.*	South Africa	Reynolds et al. (2007); Dusseldorp et al. (2013)
Ndutu	ESA/MSA	ESA/MSA	MP *Homo*	Tanzania	Mturi (1976); Rightmire (1983); Lombard (2022)
Eyasi	MSA	MSA, potential Sangoan	MP *Homo*	Tanzania	Mehlman (1987)
Omo AHS	MSA	MSA	*H. sapiens*	Ethiopia	Brown and Fuller (2008); Shea (2008)
Omo KHS	MSA	MSA	*H. sapiens*	Ethiopia	Brown and Fuller (2008); Shea (2008)
Melka Kunture Garba III	ESA/MSA	Late Acheulean/MSA	*H. sapiens*	Ethiopia	Shea (2008)
Middle Awash Bodo	ESA	Middle-Late Acheulean	*H. heidelbergensis s.l*	Ethiopia	Asfaw (1983); Conroy et al. (2000); Schick and Clark (2003); Carratero et al. (2009)
Middle Awash Herto Bouri	ESA	Late Acheulean	*H. sapiens*	Ethiopia	Clark et al. (2003); McBrearty (2003); White et al. (2003); Schick and Clark (2003); Sahle et al. (2019)
Ternifine	ESA	Acheulean	*H. erectus s.l*	Algeria	Geraads et al. (1987); Sharon (2011)
Jebel Irhoud	MSA	MSA	*H. sapiens*	Morocco	Richter et al. (2017)
Dar es Soltane 2	MSA	Aterian	*H. sapiens*	Morocco	Nespoulet et al. (2008); Barton et al. (2009)
Oulad Hamida 1	ESA	Acheulean	MP *Homo*	Morocco	Rhodes et al. (2006); Raynal et al. (2010)
Sidi Abderrahman La Grotte des Littorines	ESA	Middle Acheulean	*H. erectus sl*	Morocco	Arambourg and Biberson (1956); Texier et al. (2002); Rhodes et al. (2006); Raynal et al. (2010)
Thomas Quarry 1	ESA	Acheulean	MP *Homo*	Morocco	Texier et al. (2002); Rhodes et al. (2006); Raynal et al. (2010)
Saldanha	ESA	Acheulean	*H. heidelbergensis s.l*	South Africa	Klein et al. (2007)
Pinnacle Point 13B	MSA	Mossel Bay	*H. sapiens*	South Africa	Marean et al. (2004); Jacobs (2010); Marean et al. (2010); Thompson et al. (2010); Lombard (2022)

Table 1 (continued)

Site	Technocomplex	Lithic industry	Taxon	Country	Key references
Klasies River Mouth Shelter 1B	MSA	MSA 2a	*H. sapiens*	South Africa	Singer and Wymer (1982); Wurz (2002); Lombard (2022)
Border Cave	MSA	Howiesonspoort, MSA 1	*H. sapiens*	South Africa	Butzer et al. (1978); Grün and Beaumonth (2001); Grün et al. (1990); Pfeiffer and Zehr (1996); Grün et al. (2003); Lombard (2022)
Florisbad	MSA	Early MSA	MP *Homo*	South Africa	Grün et al. (1996); Kuman et al. (1999); Lombard (2022)
Canteen Kopje	ESA	Fauresmith	*H. sapiens*	South Africa	Smith et al. (2012); Kuman et al. (2020)
Elandsfontein	ESA	Acheulean	*H. heidelbergensis s.l*	South Africa	Lombard (2022)
Blombos Cave	MSA	Pre-Still Bay, Still Bay	*H. sapiens*	South Africa	Lombard (2022)
Sibudu Cave	MSA	Pre-Still Bay	*H. sapiens*	South Africa	Lombard (2022)
Witkrans	MSA	Mossel Bay	*H. sapiens*	South Africa	Dusseldorp et al. (2013)

The dataset is derived from the Role of Culture in Early Expansions of Humans Out of Africa Database (Kandel et al., 2023), with additional key references to contextualise the information.?=uncertain, *MP*=Middle Pleistocene; *MSA*=Middle Stone Age; *ESA*=Early Stone Age; *sl*=sensu lato, *H.*=*Homo*

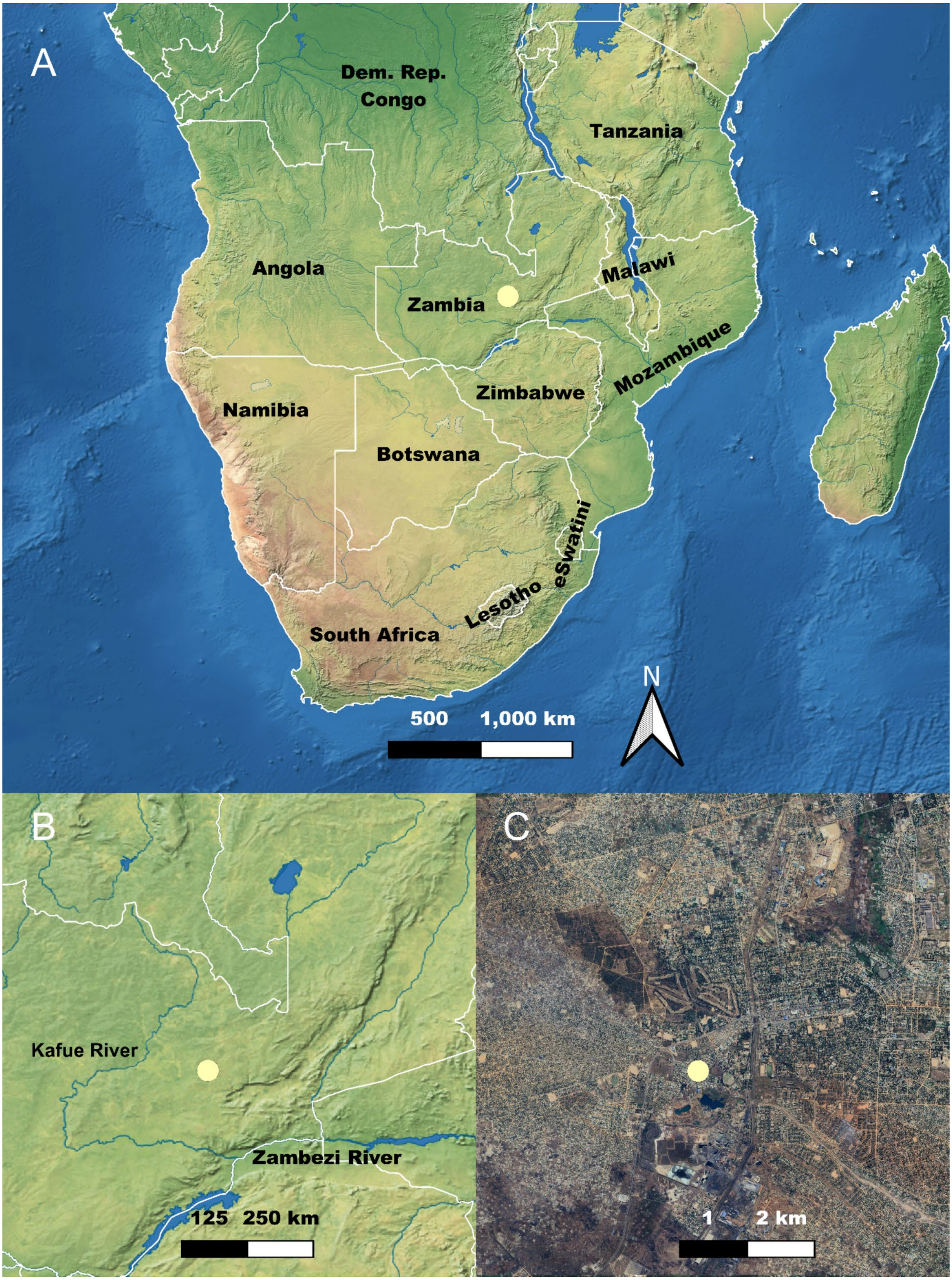
either considered the assemblage late ESA (Barham, 2000; Howell & Clark, 1963), early MSA (Barham et al., 2002; Clark et al., 1947; Clark, 1959b, 1981), or undiagnostic (Clark et al., 1968). Notwithstanding Barham et al. (2002), most of these publications did not directly study the artefacts from Kabwe, with the two most recent analyses of the Bone Cave lithics being almost 60 and 80 years old, respectively (Clark et al., 1947, 1968). Nevertheless, the Kabwe assemblage continues to be used in regional and global studies on the Palaeolithic (*e.g.*, Cabanès et al., 2022; Lombard, 2022; Scerri & Will, 2023), despite the exact relation of Kabwe to stratified ESA and MSA assemblages remaining unknown. An updated study of the lithic material has the potential to improve the data used for models of MSA origins.

Study Material

Funding and logistical constraints meant that we could not access the South African or Zambian collections. However, the NHM collection makes up around 80% of the known artefacts and was sent to the United Kingdom at a time when it was customary to send representative samples of archaeological assemblages to European institutions.

Another assemblage was systematically excavated on the plains outside Kabwe in 1953 by J.D. Clark, 60–75 m from the probable entrance to the Bone Cave (Clark, 1959a). It consists of 315 artefacts assigned to the Sangoan industry (Clark, 1959a). A few of these artefacts were present alongside the Bone Cave assemblage in the NHM and consisted of LCTs, radial cores, flakes, and a spheroid, all on coarse-grained material (Online Resource 1, Fig. 1). Since the relationship between Clark's 1953 assemblage and the Bone Cave assemblage is unknown, these were not studied further.

The Bone Cave assemblage at the NHM also contained nine osseous artefacts. These were originally considered tools (*e.g.*, Pycraft et al., 1928), with three of the artefacts studied through scanning electron microscopy confirmed to resemble tools, but it is uncertain if they were deliberately modified (Barham et al., 2002). The six remaining bone artefacts are still to be studied using modern methods (Online Resource 1, Fig. 2), but the focus here is on the lithic assemblage for comparative contextualisation.


A
Dem. Rep.
Congo
Tanzania
Angola
Malawi
Zambia
Mozambique
Zimbabwe
Namibia
Botswana
eSwatini
Lesotho
South Africa
N
500
1,000 km
B
Kafue River
Zambezi River
125
250 km
C
1
2 km

◂**Fig. 1** Map of Kabwe. **A**: Kabwe in relation to the broader region of Africa. **B**: Kabwe in relation to its central Zambian environment. **C**: The location of Kabwe in its modern, built environment. Basemap is Natural Earth 2 (available at: https://www.naturalearthdata.com/downloads/10m-raster-data/). Made with QGIS 3.34

Methods

Archival Visits

To reconstruct the stratigraphic history of the Bone Cave and understand the potential association between the fossils and artefacts, archival material relating to the early discoveries of the cave was consulted. This included both published and unpublished sources held at the NHM Archives and University College London (UCL) Special Collections. The archival materials at the NHM Archives were early NHM publications relating to Kabwe (DF/PUB/509/152, DF/PUB/509/217, DF/ADM/1004/775, DF/PAL/109/42), as well as notes on private collections from G.E. Smith (DF/PAL/100/198/4, DF/PAL/100/198/3), W.L. Strauss, Jr. (DF/PAL/100/207/20), E.H.L. Schwarz (DF/PAL/100/192/25), and correspondences with the Broken Hill Development Company (DF/PAL/100/184/15). The material at the UCL Special Collections related to the Smith Woodward collections.

3D Modelling

All artefacts were modelled in 3D using cross-polarised photogrammetry. Cross-polarisation can improve digital models made on reflective material (Bartoš et al., 2023; Nicolae et al., 2014). Since it was known that most of the assemblage consisted of crystalline quartz (Peña, 2015), which is a highly reflective material, it was decided to apply cross-polarisation to a turntable-based photogrammetry methodology, based on that of Porter et al. (2016). The room in which the artefacts were modelled was partly lit by natural light, impacting the cross-polarisation. Prior to the visit, the planned cross-polarisation methodology was tested on artefacts from the UCL Institute of Archaeology using a mixture of cross-polarised and naturally polarised light with different degrees of capture detail to ensure the Kabwe models could be produced successfully. Four artefacts were made either entirely or partly from fully translucent rock crystal quartz (NHMUK PA E911, NHMUK PA E1097, NHMUK PA E1103, NHMUKA PA E1108). Two of these could not be successfully modelled due to the translucence (NHMUK PA E911, NHMUK PA E1097), so analysis was undertaken directly at the NHM. The three potential bone tools (NHMUK PA E700, NHMUK PA E702, NHMUK PA E1094, see Barham et al., 2002) were also modelled.

The photogrammetric data was captured with a Panasonic Lumix DMC-G7 camera with a 12–60 mm zoom lens, with zoom levels kept constant for each artefact. Modelling was undertaken in Agisoft Metashape Pro (Online Resource 1 A). All models and their metadata are publicly available under a Creative Commons Attribution Non-Commercial license (Online Resource 2; 3).

Lithic Analyses

Artefact measurements were taken in Artifact3-D (Grosman et al., 2022). Flaked artefacts were positioned according to their debitage axis, cores according to the last major flake scar, and spherical artefacts (*e.g.*, spheroids) following the software's automatic positioning according to the model's centre of mass. Measurements in the software can be taken either on the bounding box or directly on the models; the latter was used since it replicates how most researchers measure artefacts in practice, and it captures better the morphology of artefacts.

Diacritical scar-ordering analysis (Pastoors et al., 2015) was carried out on hierarchical cores from the assemblage. Cores are often the most informative artefact type for an assemblage from a technological point of view, with hierarchical Levallois and blade cores being a hallmark of MSA technology (McBrearty & Brooks, 2000; Tryon et al., 2005). A rich variety of raw material is present at the site, but no data as to the local availability of materials were discovered in the archives or literature consulted. Hence this is not considered further here.

Analyses were carried out in R 4.4.1 (Online Resource 4, R Core Team, 2024). For the diacritical analysis, negative flaking features such as scar ridges and force ripples were highlighted using the built-in cavity function on model ridges in Blender 4.2. For ambiguous and hard-to-read raw material such as quartz (Pargeter et al., 2023; Proffitt & de la Torre,

Table 2 Direct dates from Kabwe. All dates are from Grün et al. (2020)

Material	Details	Age (kya)	Age error (kya)	Method
NHMUK PA E686	Skull, outside holes	301	±37	U-series
NHMUK PA E686	Skull, inside holes	298	±34	U-series
NHMUK PA E686	Skull	256	+66/−52	ESR
NHMUK PA EM793	Femur midshaft	169–162	±9	U-series
NHMUK PA E907	Femur head	158.1	±0.8	U-series
NHMUK PA E719	Pelvis	145	+48/−23	Gamma spectrometry
NHMUK PA E719	Pelvis	117.6	±0.5	U-series
NHMUK PA E691	Tibia	175	±9	U-series
Calcitic layer	Found near skull	175.1	±0.2	U-series
Calcitic layer	Found near skull	137.6	±1.4	U-series
Micromammals	Cluster 1 inside skull	136	±7	U-series
Micromammals	Cluster 2 inside skull	108	±5	U-series
Rodent	ID not given	102.2	±0.4	U/Th

2014), this may highlight diagnostic features better than physical examination of artefacts.

Results

The Stratigraphy of the Bone Cave

The Kabwe skull was originally reported in association with lithics and a fully articulated skeleton (Harris, 1921), but the lack of any stratigraphic resolution for either the artefacts or the fossils precludes any firm conclusions. This eventually led to two conflicting accounts of the discovery of the skull and its association with other hominins and archaeology. F.A. Bather (1928), Keeper of Geology at the British Museum for Natural History (now the Natural History Museum), argued, following Harris' (1921) account, that there was a fully articulated skeleton and a spheroid associated with the skull (which Harris (1921) had originally referred to as a rounded stone similar to a grinding stone), but that miners inadvertently destroyed everything but the skull. A. Hrdlička (1930), curator at the U.S. National Museum (now the Smithsonian), insisted instead that the skull was found in isolation. Both researchers based their accounts on testimony from workers at the mine. Hrdlička's account was mainly based on interviews with the miner who discovered the skull, T. Zwigelaar, which was independently corroborated 28 years later (Clark, 1959b). This version should therefore be favoured, although it must be noted that both accounts were removed in time from the actual finding of the skull and that neither is fully satisfactory.

An alternative possibility was recently proposed by Grün et al. (2020), who argued that the skull might in fact be entirely unrelated to the Bone Cave. This was based on a sketch by F. White, an engineer at the cave, which, together with the original photograph of the findspot as given in the *Illustrated London News* in 1921 (Fig. 2A), was taken to suggest that the skull was unrelated to the cave (Grün et al., 2020). This sketch is unfortunately not in the letter by F. White that the authors referenced as their source, although it was made available with the kind help of the NHM Archives staff and C. Stringer. It is indeed the case that, based on the sketch, the skull could have moved to the place of its discovery from outside the cave through a fissure (Fig. 2B). But in the sketch, the location of the skull is still given as within the cave (Fig. 2B). The photograph accompanying the original article describing the finding of the skull (Harris, 1921) might be more indicative (Fig. 2A). Although only the New Cave (which was sterile) is seen next to the alleged findspot of the skull, the Bone Cave would have been completely quarried away at the time of the photograph, since the skull was found at the bottom of the cave. This is further evident by the fact that the diagram drawing featured in the same newspaper (Fig. 2C) showed the rails of the mining wagons a

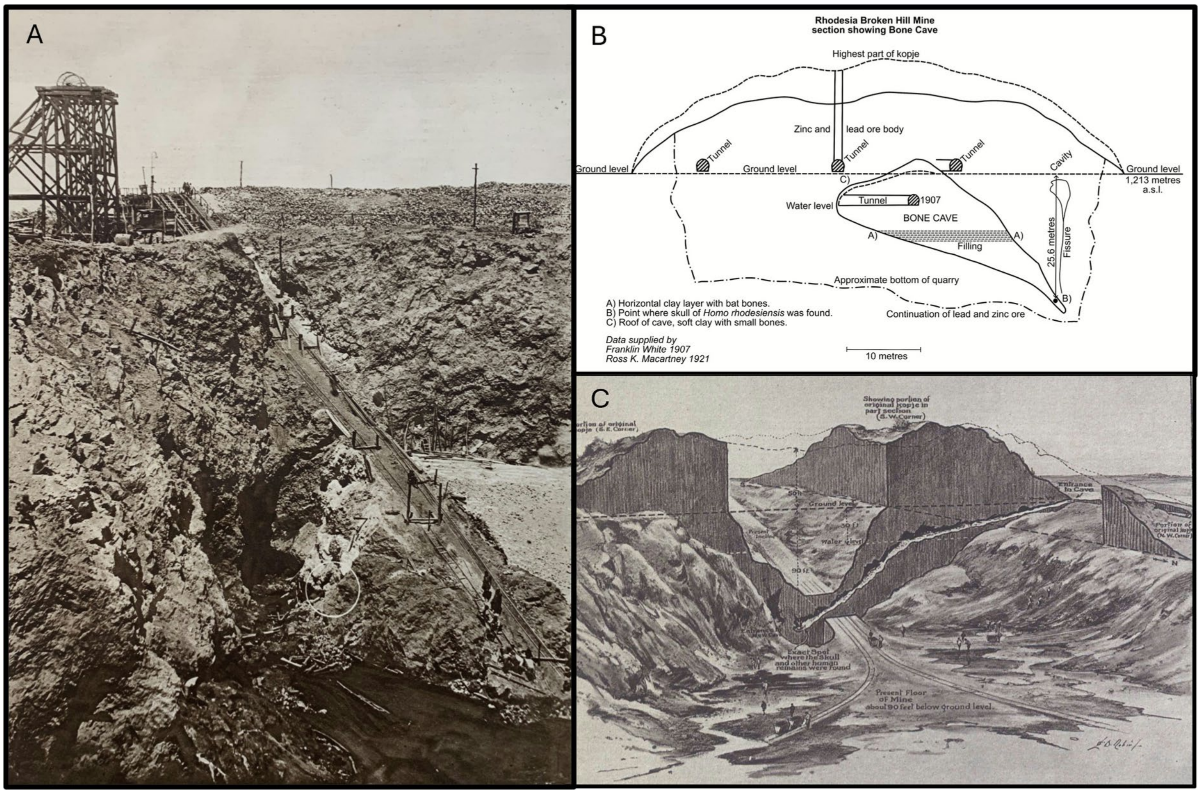


Fig. 2 Original find-spot of the Kabwe skull. A. Photograph of the original findspot of the Kabwe skull, indicated by the white circle. Note that although the New Cave is seen to the left of the spot, the Bone Cave would have been quarried away completely by the time that the photo was taken. Scanned from copy held by the Library and Archive collections of the Natural History Museum, London. B. Sketch of the Bone Cave drawn by Ross K. Macartney in 1921, based on a previous sketch by Franklin White in 1907. Digitised from original drawing. Scan provided by the NHM Archives (DF/PAL/100/226/3, Library and Archives, Natural History Museum, London) and previously published in Grün et al., (2020, Extended Data Fig. 2). Note that feet measurements have been converted to metres. Whilst the illustration clearly indicates that the skull could have moved down to its findspot through a fissure, it is importantly still indicated on the sketch that it was found within the confines of the Bone Cave. Made available with the help of Prof Christopher B Stringer and Victoria Devenport. Original held by the Library and Archive collections of the Natural History Museum, London. C. Profile sketch of Kabwe by W.B. Robinson, originally published in the *Illustrated London News* in 1921. The location of the Kabwe skull is here given at the foot of the Bone Cave. Scanned from copy held by the Library and Archive collections of the Natural History Museum, London. Made with Inkscape 1.3.2

few metres west of the findspot but more or less level with it, deeper than the rest of the cave. Nevertheless, it is indeed a possibility that the findspot was a secondary context, and that the skull could have been deposited outside of the cave and then moved through the fissure to where Zwigelaar and his local assistant (who was never named) found it. The exact relationship between the skull and the lithic assemblage is therefore uncertain.

It is possible to reconstruct the stratigraphy of the Bone Cave to get a better sense of the coherence of the lithic assemblage. This was first done by Clark et al. (1947) drawing on published reports and unpublished notes by F. White, F.P. Mennell, E.C. Chubb, and S.S. Armstrong, all of whom had worked at the Broken Hill Mine, and relating their accounts to the independent investigations of Hrdlička (1930) and Leakey (1934). This led to the conclusion that the steep decline in the innermost part of the cave had been infilled by bone breccia, followed by a superimposed layer of dark, clayey soil, where the artefacts and bones were stratified, with a short break in the form of a dolomite floor, before the final depositional regime which deposited a yellow clay, which they argued contained a thick horizon of bones and artefacts (Clark et al., 1947; Fig. 3). In this scenario, the skull was not found in its original context but had moved down due to subsidence. Utilising mineralogical descriptions of the Bone Cave, it was noted that there was widespread agreement that the lower part of the cave was impregnated with lead whereas the upper part was rich in zinc (Clark et al., 1947). The authors further analysed fossils and artefacts for their ratios of lead/zinc/vanadium, which showed a correlation across the material, although the skull (NHMUK PA E686) contained higher values of zinc than lead (Clark et al., 1947; see Online Resource 1, Table 2). The conclusion of Clark et al. (1947) was that the skull was associated with most of the recovered hominin bones, which all belonged to the same taxon (although not necessarily the same individual). This conclusion was strengthened by the notion of F.P. Mennell that the artefacts found in the same layers as the skull did not differ "in any important respect from those which were found higher up" (Mennell, in Clark et al., 1947, p. 17) in association with the other hominin bones.

These conclusions were largely supported by Bartsiokas (1989). However, the mineralogical profile of the Bone Cave was updated by relating it to what had by then become known about limestone caves in semiarid regions, which all have a similar profile (Bartsiokas, 1989, pp. 285–296). It was also shown that the high zinc levels of the Kabwe skull were due to a thin crust of hemimorphite, which meant that the skull could not have been deposited in its findspot since this mineral would only occur in the upper cave (Bartsiokas, 1989, pp. 262–264). Moreover, reanalysis of the skull using dentine samples indicates that the zinc levels given by K.P. Oakley in Clark et al. (1947) were not reflective of the skull itself (Grün et al., 2020). The micromammals associated with the skull contained similar levels of lead and zinc as the skull itself, suggesting similar depositional environments despite disparate ages, although differences in vanadium levels could be supportive of

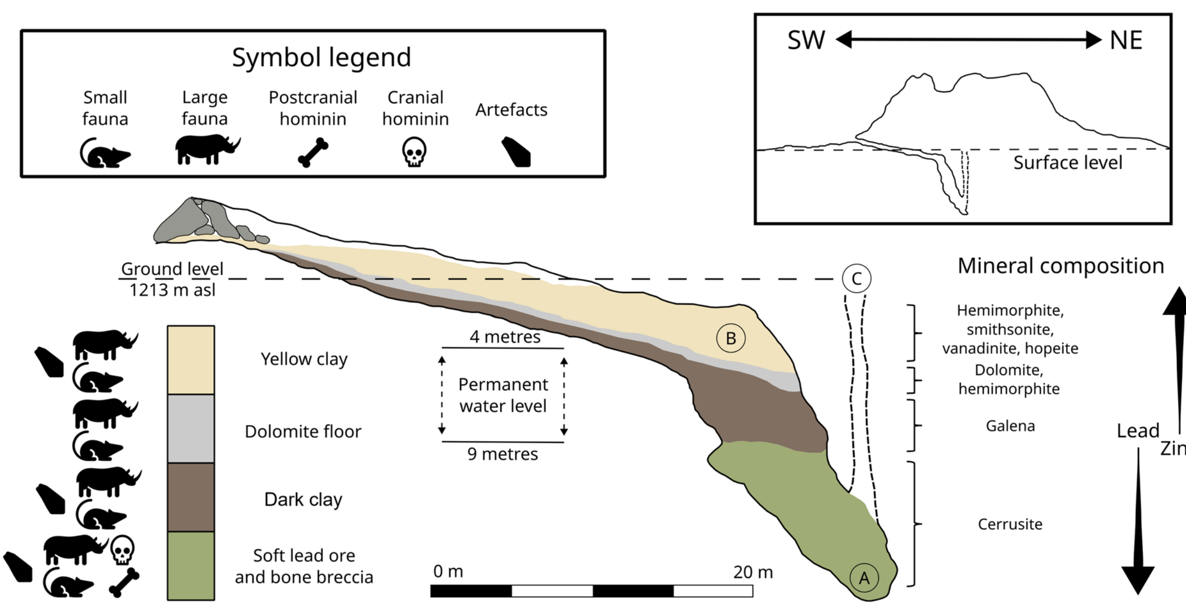


Fig. 3 Interpretative reconstruction of the Bone Cave's stratigraphy. Redrawn from Clark et al. (1947) and corroborated with information from Mennell and Chubb (1907), White (1908), Hrdlička (1930), Leakey (1934), Clark (1959b), Bartsiokas (1989) and Grün et al. (2020). Whilst hominin fossils were originally found in the bone breccia at the foot of the cave, Hrdlička (1930) and Leakey (1934) both recovered hominin remains in waste-dumps outside the cave. Although lacking stratigraphic information, these fossils might indicate that hominin remains could have been spread throughout the layers of the Bone Cave, which is supported by the direct dates from the site as well, spanning 300–100 kya. A indicates the findspot of the skull, B and C where it could originally have been deposited. Made with Inkscape 1.3.2

distinct depositional environments (Online Resource 1, Table 2, see Grün et al., 2020).

Nor was the skull the only bone that had moved postdeposition: the femur midshaft (NHMUK PA EM793) contained a higher concentration of lead than zinc in its bone structure, but in its adhering matrix, this was reversed, indicating that its find context was secondary (Bartsiokas, 1989, pp. 257–262). The skull also had a different depositional environment based on divergent dating for the micromammals in its adhering matrix and the skull itself, and a different uranium-series uptake than the remaining hominin fossils (Grün et al., 2020). This is hardly surprising, as caves can be extremely complex stratigraphically, with extensive postdepositional movement (Goldberg & Macphail, 2009, pp. 169–187; Mentzer, 2017; Karkanas & Goldberg, 2018, pp. 172–189). The above findings thus suggest that the artefacts, too, could have moved. The main question for the coherence of the lithic assemblage is therefore whether it is consistent across the depositional layers or rather indicates distinct depositional events?

Stratigraphic Coherence of the Assemblage

Several of the lithics in the NHM still had some matrix adhering to them, which made it possible to visually correlate them to the potential stratigraphic horizons. Whilst the matrix was clear for some of the artefacts, others were ambiguous, largely owing to the dryness of the clay, making it difficult to tell its exact hue in some cases. Moreover, four stratigraphic layers in total might be an oversimplification based on what was actually present in the cave, and it is entirely possible that several depositional events might be represented in each distinct layer. However, since further excavation is impossible due to the full exhaustion of the kopje, the information that can be gleaned from the original notes and letters combined with the stratigraphic separation based on matrix colour is the closest we can come to determining the stratigraphic position of the artefacts in the assemblage.

Following the visual separation of artefacts based on the colour of their adhering matrix, 21 seem to have originated from the dark clay, whereas 25 had remnants that were correlated with the yellow clay. Of the artefacts that could be correlated with a geological horizon, 70% ($n=32$) are fresh, with a larger proportion of fresh artefacts associated with the yellow clay stratum (80%) than the dark clay (57%). Breakage is also largely similar across the two layers, with 56% ($n=14$) complete artefacts associated with the yellow clay and 67% ($n=14$) from the dark clay.

The proportion of different raw materials is similar across the layers, with vein quartz being the most common in both the dark and yellow clay layers, although the dark clay includes a tiny component of shale and arkose that is not present in the artefacts associated with the yellow clay. For general artefact categories, proportions are also similar, with slightly more edge-modified flakes in the dark clay layer and a single manuport in the yellow clay layer, as well as the presence of four cores in the yellow layer. The main difference in terms of typological artefact types across the layers is the presence of a core maintenance flake, unifacial point, and backed flake in the yellow layer, versus two perforators and a scraper associated with the dark layer (Figs. 4 and 5A). Complete or fragmented laminar blades are present in both layers (Fig. 5B, C). Almost a third of the assemblage ($n=19$) could not be associated with any stratigraphic layer, and this includes the typologically distinct cores (discussed below). This makes any association of technological strategies with distinct layers ambiguous, and at the same time, the most technologically distinct flake type – laminar blades – is present in both the dark and yellow layers, further complicating separation of the assemblage into technologically or typologically distinct periods.

Technomorphological Characteristics of the Kabwe Lithics

A variety of raw materials was used at Kabwe, with a significant preference for vein quartz (Table. 3). The manuports are the only general category that is not dominated by vein quartz, with three artefacts on quartzite and one each on arkose and limonite. 50 flakes were present in the collection, of which 18 were unmodified and 32 had modified edges.

Manuports

Of the manuports, there are three spheroids, or stone balls shaped through pecking (Cabanès et al., 2022), and two hammerstones (Fig. 6). No microdebitage is present in the NHM collections, although it was noted that small chips were found at Kabwe (Clark et al.,

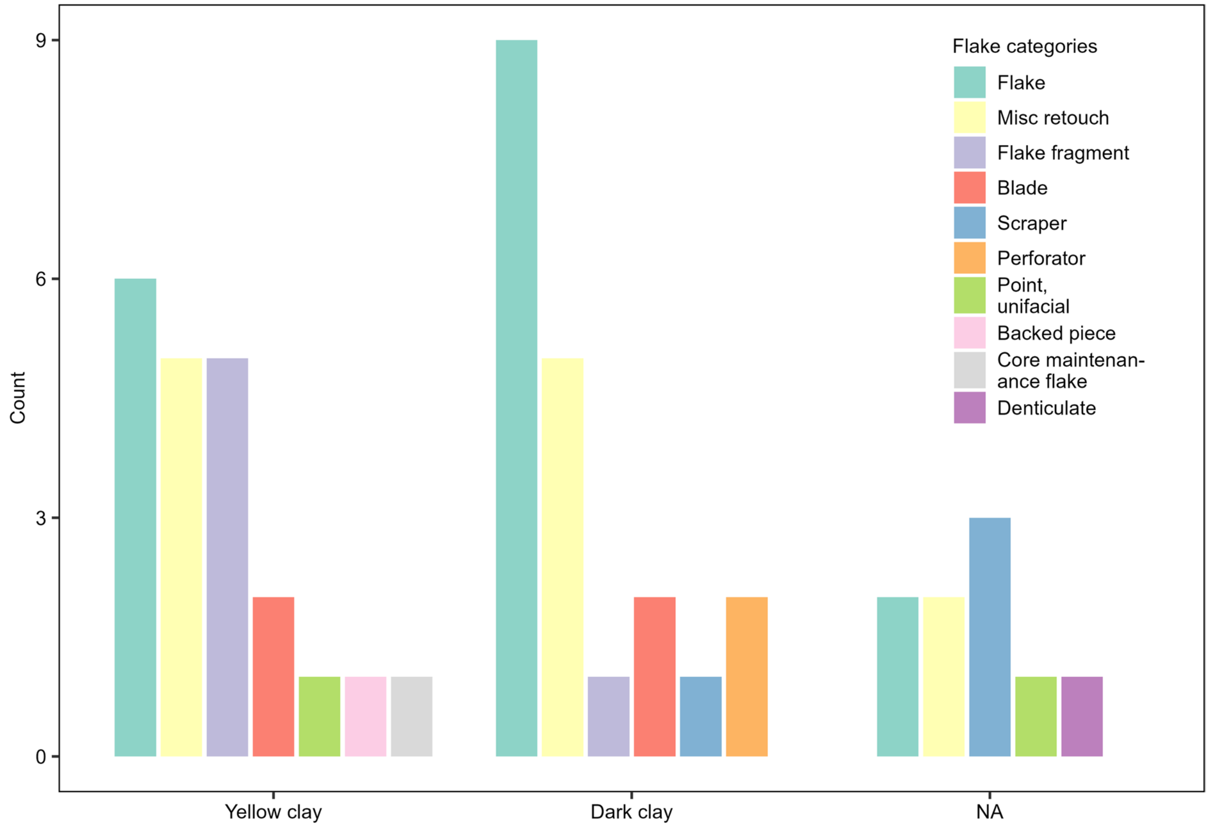


Fig. 4 Counts of flake and tool types from different layers at Kabwe. Note that edge-damaged flakes are counted as normal flakes, and blade fragments are counted as blades. Made with R 4.4.1

1947), so its absence is likely due to collection bias. This, together with the presence of utilised hammerstones, indicates that primary flake production was undertaken at Kabwe.

Reduction Strategies

There are 11 cores in the collection, including one core-on-flake. Six of the cores are discoidal, three are hierarchical, one is bipolar, and one is multiplatform. The hierarchical cores were either radially ($n=2$) or unidirectionally ($n=1$) flaked.

The most common platform types are plain platforms ($n=14$), followed by multifacetting ($n=8$), crushed platforms ($n=8$), simple facetting (unidirectional facetting or few facets, $n=4$), point ($n=2$), cortical ($n=2$), and dihedral ($n=1$) platforms. The most preferential scar pattern is bidirectional ($n=14$), followed by orthogonal ($n=10$), radial ($n=8$), unidirectional ($n=8$), convergent ($n=7$), and irregular scars ($n=2$). Of the multifacetted platforms, half are radial ($n=4$), which can be indicative of Levallois reduction systems, also supported by the thinness of several of the flakes (Online Resource 1, Table 3), with a mean of 0.45 for the unretouched flakes, similar to the thinness seen at for example the MSA site Mumbwa Caves in Zambia (0.47 for unretouched flakes in Unit VII > 250 mm, see Barham, 2000).

There is no significant difference between the dark and yellow clay layers in terms of either platform types (Fisher's Exact Test, $p=0.11$), scar patterns (Fisher's Exact Test, $p=0.32$), or retouching (Fisher's Exact Test, $p=0.14$).

Modified Flakes

Most of the edge-modified flakes were minimally modified ($n=29$), with only 9% ($n=3$) carrying invasive modification, these latter all associated with the dark clay layer. Due to the high brittleness

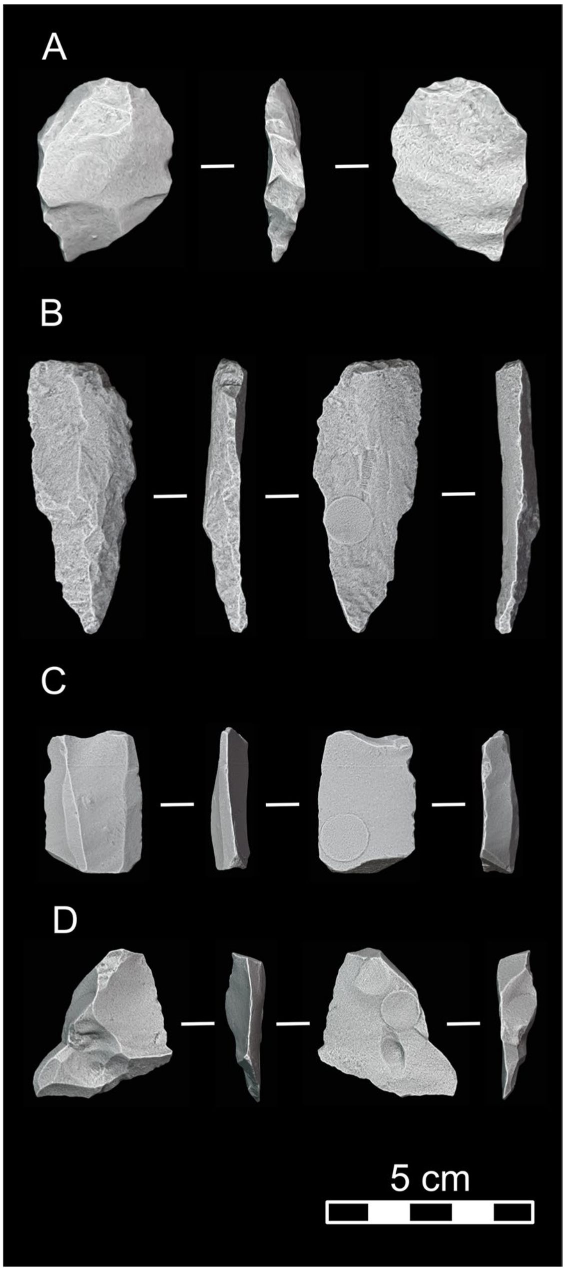


Fig. 5 Example of diagnostic artefacts from Kabwe. **A**: NHMUK PA E538e, a backed flake on chert. **B**: NHMUK PA E1101, blade on vein quartz. **C**: NHMUK PA E1121, laminar blade fragment on shale. **D**: NHMUK PA E1122, flake with potlidding on chert. All models were made from artefacts from the collections of the Natural History Museum, London and are available online under a Creative Commons license (Online Resource 3). Made with Inkscape 1.3.2. Courtesy of the Trustees of the Natural History Museum, London 25/4/2024, 2/5/2024, 10/5/2024

Table 3 Raw materials used at Kabwe. 3A: Count of raw materials used at Kabwe across artefact classes. 3B: Raw material frequencies across the assemblage

3A: Raw material usage at Kabwe across artefact classes

Raw material	Artefact class	Count
Vein quartz	Cores	3
Cherts	Cores	2
Shale	Cores	2
Limonite	Cores	1
Quartzite	Cores	1
Vein quartz	Unmodified flakes	12
Cherts	Unmodified flakes	1
Limonite	Unmodified flakes	1
Rock crystal quartz	Unmodified flakes	1
Vein quartz	Edge-modified flakes	10
Shale	Edge-modified flakes	3
Cherts	Edge-modified flakes	3
Limonite	Edge-modified flakes	2
Quartzite	Edge-modified flakes	1
Rock crystal quartz	Edge-modified flakes	1
Vein quartz	Broken flakes	11
Quartzite	Broken flakes	1
Shale	Broken flakes	1
Rock crystal quartz	Broken flakes	1
Quartzite	Manuports	3
Arkose	Manuports	1
Limonite	Manuports	1

3B: Raw material usage at Kabwe across whole assemblage

Raw material	Count	Percentage of total
Vein quartz	36	57.1%
Cherts	6	9.5%
Shale	6	9.5%
Quartzite	6	9.5%
Limonite	4	6.3%
Rock crystal quartz	3	4.8%
Arkose	1	1.6%
Limonite	1	1.6%

of vein quartz, it is more prone to shatter and breakage than other raw materials (Driscoll et al., 2016; Spry et al., 2021), leading to a higher likelihood of pseudo-tools that are indistinguishable from formal tools, with minor flake removals resembling intentional retouch (McBrearty et al., 1998). As 55% ($n = 16$) of the minimally modified flakes are on

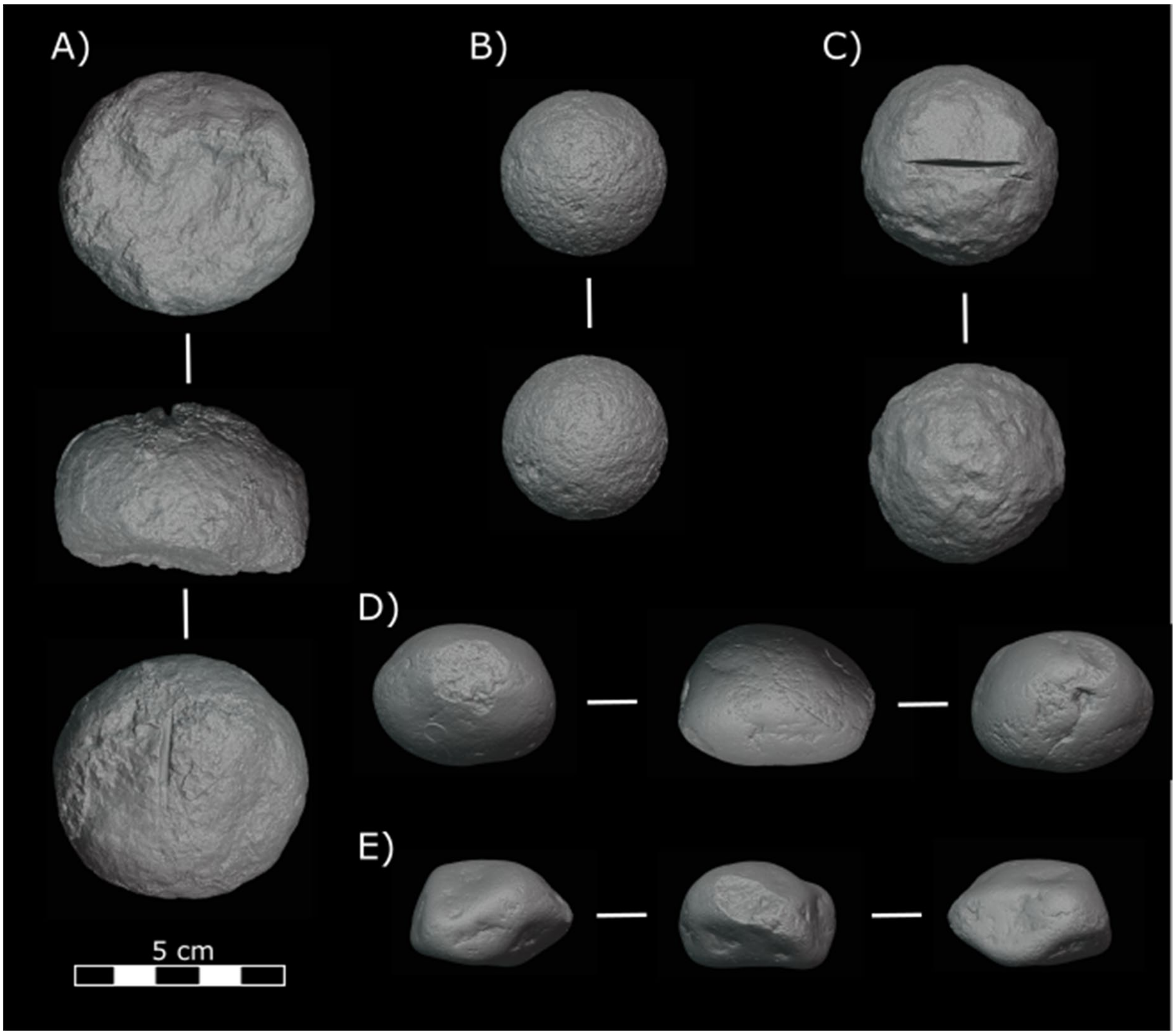


Fig. 6 Manuports from Kabwe. **A**: NHMUK PA E537, spheroid. **B**: NHMUK PA E915, spheroid. **C**: NHMUK PA E699, spheroid. **D**: NHMUK PA E916, hammerstone. **E**: NHMUK PA E1120, hammerstone. All models were made from artefacts from the collections of the Natural History Museum, London and are available online under a Creative Commons license (Online Resource 3). Made with Inkscape 1.3.2. Courtesy of the Trustees of the Natural History Museum, London 2/5/2024, 9/5/2024, 10/5/2024

vein quartz, it is likely that a proportion of them are taphonomic rather than retouched.

The most common edge modification is on the side of the flake ($n=16$), followed by nosed ($n=4$), notched ($n=4$), circular ($n=4$), end-modified ($n=3$), and denticulated ($n=1$) artefacts. Edge modifications are most common on the dorsal surface ($n=23$), followed by bifacial ($n=5$), ventral ($n=2$), and backing ($n=1$), along with a single burination.

Some of the flakes contain evidence of heat damage in the form of pot-lidding, indicating the presence of fire at Kabwe (Fig. 5D, see Purdy & Brooks, 1971; Brown et al., 2009; Key et al., 2021; Abdolahzadeh et al., 2023).

Hierarchical Core Reduction

Three cores are categorised as hierarchical, defined as a systematic difference in either the mode or products of flake removals between faces of the core (Shea, 2013). One of them (NHMUK PA E1108) can be distinguished as a core-on-flake resembling a point core, but its dorsal side has a hard matrix adhering to it which makes it difficult to unambiguously relate the upper and lower face to each other, and its interpretation as hierarchical is thus presumed since it cannot be satisfactorily demonstrated. It is not analysed further here. Diacritical analyses of the two other hierarchical cores are presented below.

NHMUK PA E705: A Bifacial Hierarchical Core

The bifacial hierarchical core (NHMUK PA E705) was made on a nodule of chert and contains significant amounts of cortex on the upper and lower faces (Fig. 7A). The core consists of three stages of reduction on the upper and lower faces aimed at preparing it for the removal of a large, preferential flake (Fig. 8A). First, the lower face of the core was reduced, which led to the removal of most of the cortex and flattened the base. Then, a series of alternate removals around the circumference established a high-angled platform on the lower face and a low-angled convexity on the upper face. The final removal was a big, hard hammer-detached flake (indicated by the size of the negative bulb of percussion) in the opposite direction of the radial removals on the upper face (U8). This flake did not manage to invade into many of the radial removals, likely because of the cortex on the upper face leading to a deviation in the direction of the force towards the distal end of the negative flake scar.

The reduction of this core is akin to what would be expected for Levallois technology, although it is unclear if the platform was facetted and the convexity preparation on the upper surface was only partially effective. Whilst no typologically distinct Levallois flakes are present, four of the flakes in the assemblage (associated with both the yellow and dark clay) had both radial scar patterns and complex facetting present on their platforms, which can be indicative of Levallois-like reduction.

NHMUK PA E908: A Unifacial Hierarchical Core

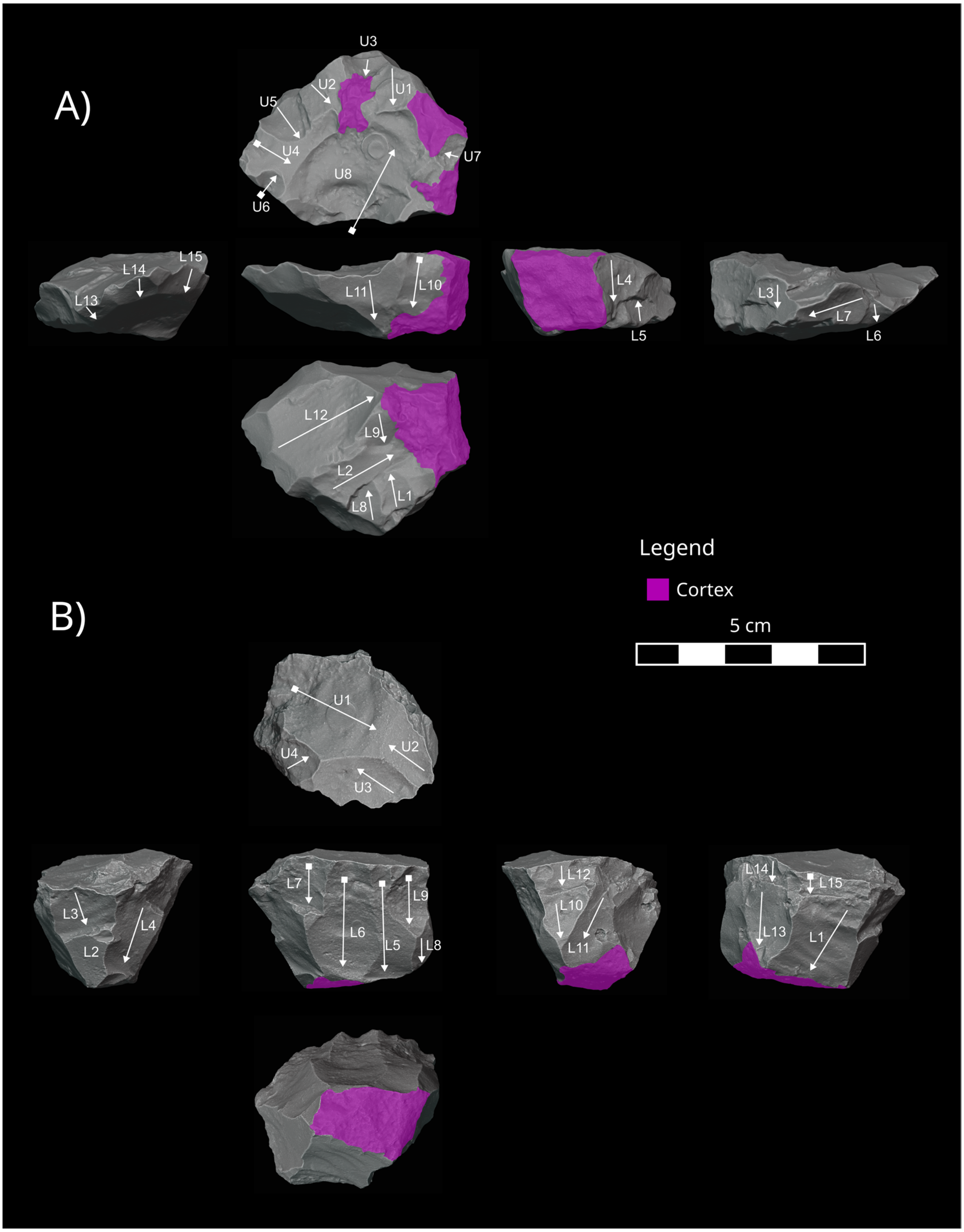
There is also a unifacial hierarchical core (NHMUK PA E908), made on chert and representing a distinct form of hierarchical core reduction compared to NHMUK PA E705 (Fig. 7B). It still contains cortex on the distal end of the lower face. The lower face scars are all unidirectional, whilst the upper face scars converge towards the center of the face, producing a somewhat radial patterning. The reduction can be divided into at least three phases (Fig. 8B).

Three flake scars indicate blade-like reduction (L1–3), with unidirectional flake removals along the circumference of the core with what was likely a flattened, upper surface serving as the platform. L3 terminates in a step, however. Following this failed flake detachment, the upper face was rejuvenated through the removal of several core tablet flakes, seemingly aimed at flattening the upper face for further removals along the lower face. Following the flattening of the upper face, detachments continued along the lower face. The final detachments all terminated in steps, after which the core was abandoned. Several internal faults within the chert were exposed during the final reduction phase, and the remaining cortex on the distal end of the lower face seems to have presented further difficulties during the final removals, with L11 and L13 failing to remove cortex on their side of the core, instead terminating around it.

Whilst this core follows the hierarchy and sequence of pyramidal blade cores, there are no negative blade scars with an elongation ≥ 2, the most complete scar having an elongation of 1.71. Nevertheless, blades are also distinguished by their laminar scar pattern (Bar-Yosef & Kuhn, 1999), and following this definition, four blades (including fragments) are present in the collection (Fig. 5B, C). The core NHMUK PA E908 exhibits prismatic flaking principles, which together with the laminar blades indicate a potential awareness of prismatic systems at Kabwe.

Discussion and Conclusion

Kabwe is an important Middle Pleistocene site due to the possible association between an archaeological assemblage and hominin fossils belonging to *H. heidelbergensis s.l.* (Table 1). The exact relationship between the lithic assemblage and the fossils cannot be determined due to a lack of detailed stratigraphic information about the lithics and the fossils, and it therefore remains a possibility that all the lithics are unrelated to the *H. heidelbergensis s.l.* fossils, that the Sangoan assemblage outside the cave is related to the fossils, or that the assemblage represents


A)
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Cortex
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L1

◂**Fig. 7** Reduction sequence for hierarchical cores at Kabwe. **A**: NHMUK PA E705, a bifacial hierarchical core on chert interpreted as a failed preferential-centripetal Levallois core. **B**: NHMUK PA E908, a unifacial hierarchical core on chert interpreted as a blade-like core. Squares on arrows indicate negative bulbs of percussion. Purple indicates cortex. All models were made from artefacts from the collections of the Natural History Museum, London and are available online under a Creative Commons license (Online Resource 3). Made with Inkscape 1.3.2. Courtesy of the Trustees of the Natural History Museum, London 26/4/2024, 10/5/2024

distinct occupational phases by different hominins. Direct dates from the fossils indicate occupation between 300–100 kya (Table 2, see Grün et al., 2020). Although the presence of undated *H. sapiens* fossils makes it impossible to rule out Holocene occupation, none of the artefacts strongly indicate Later Stone Age technology.

Previous studies have suggested postdepositional movement of fossils in the Bone Cave (Bartsiokas, 1989; Clark et al., 1947; Grün et al., 2020), where all the fossils and artefacts were found, and this remains a possibility for the lithic artefacts as well. It has also previously been noted in passing that the artefacts from across the cave were similar (Mennell, in Clark et al., 1947, p. 17). Here, separating out artefacts from distinct layers for the first time based on adhering matrices confirms only small differences across the layers. It is therefore impossible to identify distinct occupational horizons. The assemblage is best considered a time-averaged unit (Olszewski et al., 2023; Stern, 1994) spanning the 200 ky of the dates for the hominin fossils. The presence of spheroids suggests the Kabwe assemblage could in part belong to the ESA, with perhaps the earlier component at the base of the stratigraphy representing this.

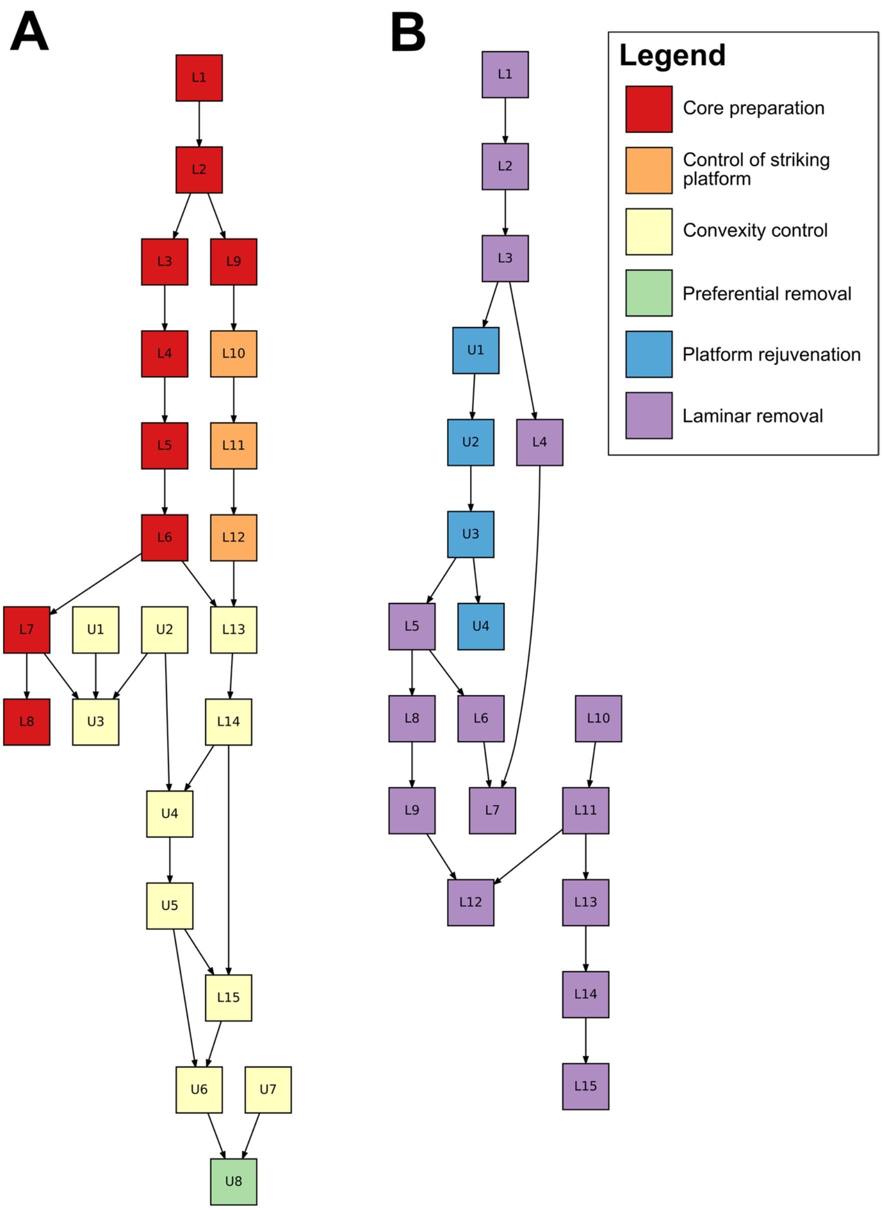
Three key divergences of the MSA from earlier ESA technology are the presence of Levallois and prismatic blade production, as well as backing (Barham, 2000, 2013; Clark, 1969; Kandel & Conard, 2012; McBrearty & Brooks, 2000; Tryon et al., 2005; Wadley, 2015; Wurz, 2024). Laminar blades are present in the Kabwe assemblage across the layers (Fig. 5B, C), and whilst no true blade core is present in the assemblage, the hierarchical core NHMUK PA E908 was reduced along laminar principles (Figs. 7B and 8B). Levallois-like production is indicated by the high degree of multifacetted platforms, radial scar patterns, and the thinness of the flakes (Shipton, 2022), with a diacritical analysis of the hierarchical core NHMUKPA E705 showing Levallois-like reduction strategies undertaken at Kabwe (Figs. 7A and 8A). One artefact has a backed edge (NHMUK PA E538e), although the size of this piece suggests it may have been for prehension rather than hafting. The presence of two potlidded artefacts (NHMUK PA E1122, NHMUK PA E1125, see Fig. 5D) indicates the presence of fire at the site, a trait more common in the MSA than the ESA, although the burning could be natural.

The MSA of the central Zambian region has an emphasis on Levallois technology and specialised, retouched tool types (Barham, 2000). At Kabwe there is a Levallois-like component, although there is a greater emphasis on prismatic blades whilst specialised tool types found at other Zambian MSA sites are lacking. There could therefore be two distinct occupational periods at Kabwe corresponding with the late ESA and early MSA, the former associated with the *H. heidelbergensis s.l.* fossils and the latter with *H. sapiens*. Table 1 shows that across Africa 11 sites have associations between *H. sapiens* and MSA, but only 4 have associations between *H. sapiens* and ESA; conversely 2 sites have associations between *H. heidelbergensis* and ESA, and none other than potentially Kabwe have an association between *H. heidelbergensis* and the MSA.

Nevertheless, the technology at Kabwe is similar across the stratigraphy as far as it can be resolved, so a division of the technology by species is difficult. An alternative possibility is that Kabwe represents an early or transitional MSA industry. The occasional association with *H. sapiens* and ESA technology elsewhere in Africa might be mirrored by *H. heidelbergensis* being associated with early MSA, given Levallois is known to have been used by Neanderthals, another large-brained hominin species. It is also possible that the ESA components at Kabwe represent recycling of artefacts by subsequent hominin groups. To disentangle these potential associations, detailed excavations integrating geoarchaeological methods are necessary. Whilst this is not possible at Kabwe, other African sites have the potential to shed further light on the transition from the ESA to the MSA.

Climate modelling indicates that the Zambezi basin would have been an important refugium during the Late Pleistocene (Blinkhorn et al., 2022), and the same was likely the case during the Middle

Fig. 8 Diacritical ordering of flake removals on hierarchical cores. **A**: NHMUK PA E705. **B**: NHMUK PA E908. Colours indicate distinct phases in core reduction. Made with R 4.4.1. and Inkscape 1.3.2



Pleistocene. At Kabwe, the marine isotope stage (MIS) 6–8 dates of the hominin fossils and the late persistence of several mammal communities (Grün et al., 2020) indicate some occupation during glacial stages. Moreover, the dates for the Kabwe skull indicate that *H. heidelbergensis s.l.* was present in the Zambezi basin region as late as MIS 8, and it is therefore possible that the basin could have been one of the last refugia for the species, persisting into the early MSA. Currently, the MSA is most often associated with *H. sapiens* (Scerri & Will, 2023) and transitional sites from the ESA seen as a gradient in the emergence of our species (Kuman et al., 2020). Whilst the later MSA is likely fully associated with *H. sapiens*, the lithic assemblage at Kabwe highlights the tantalising possibility that a transitional technocomplex could have been associated with other members of our clade, although larger, well-provenanced assemblages are needed to clarify this hypothesis.

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Authors Contribution All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by David Leon Greisen Miedzianogora. The first draft of the manuscript was written by David Leon Greisen Miedzianogora and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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Data Availability TThe datasets generated and analysed during the current study are available via Github at https://github.com/JPGW7/kabwe_lithics_article or upon request from the authors.

Declarations

All authors certify that they have no affiliations with or involvement in any organisation or entity with any financial interest or non-financial interest in the subject matter or materials discussed in this article.

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