Technological Complexity as an Indicator of Behavioural Modernity
A Case Study on Middle Palaeolithic Birch Tar Production and South African Microlithic Technology

Dissertation

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I DEDICATE THIS DISSERTATION TO MY PARENTS

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II. SUMMARY

Behavioural modernity is a concept that describes the range of behaviours found in modern humans today. As far as archaeology is concerned with this set of behaviours it is sometimes paraphrased as the question when humans became ‘like us’ and ultimately also how. The term itself is a remnant of the first concise conceptualization which rested on the dichotomy between behaviours displayed by anatomically modern humans and Neanderthals. The physical manifestations of the behaviours that were perceived to be modern were summarized in a list of traits. These traits encompass a technological, a symbolic and an organizational dimension, the latter of which can be further subdivided into human interactions with the environment and spatial organization of sites. Over the past four decades the debate has moved past a simple list-based presence/absence approach, in order to identify modern behaviour in the archaeological record. However, the items on the list still matter because they represent the physical remnants of past behaviours and are therefore connect the archaeological record with the concept of behavioural modernity. A theoretical justification has to be made for each item on the list, in order to see if the physical evidence can be used as an indicator for modern behaviour in the past.

This thesis focusses on two technological aspects of behavioural modernity – microlithic technology in the South African Middle Stone Age and Later Stone Age (MSA and LSA) and Middle Palaeolithic birch tar production. Microlithic technology and birch tar are commonly connected with composite tools, which is thought to be a marker of behavioural modernity based on their complexity. Additionally, it was thought that birch tar only forms under oxygen-restricted conditions. Hence, the production process itself was thought to be complex as well. Furthermore, the intersection between stone artefact technology and symbolism is examined by a study on the standardization of microliths.

Drawing on lithic artefacts from the Late Pleistocene LSA layers of Umbeli Belli as well as bladelets from six Sibudan layers and backed pieces from four Howiesons Poort layers from Sibhudu (both South Africa), questions about the emergence of the LSA, and artefacts standardization in the MSA are examined. These studies target the presumed link between microlithic technology and behavioural modernity as well as the emergence of the LSA which is sometimes

equalled with the regional emergence of behavioural modernity. Moving past *H. sapiens*, a series of predominantly experimental studies on Middle Palaeolithic birch tar production are used to explore technological complexity in Neanderthals.

Using technological complexity as a marker for behavioural modernity is not without issues. Firstly, complexity is not easily measured in general, but particularly not in the archaeological record. Secondly, even if we agreed upon a 'correct' measurement complexity is always relative and the resulting value meaningless if not compared to at least one other value. Therefore, measuring complexity calls for a reference point for comparison and this is reference point is chosen notoriously arbitrary. Thirdly, linking technological complexity and behavioural modernity requires a theoretical basis that seeks to identify the underlying cognitive processes necessary to create the observed outcome in the archaeological record. Here, the theoretical justification for a behaviour to be indicative of modernity intersects with potential explanations for its presence. The data presented in the thesis are explored under these paradigms, in order to review their suitability as proxy markers for behavioural modernity.

In conclusion, this thesis presents novel data on three different cultural traits that are thought to indicate behavioural modernity. It also provides an evaluation if these traits can be regarded as behaviourally modern and why or why not. Both microlithic technology and birch tar production are suitable markers of a concept of behavioural modernity that includes technological aspects alongside symbolic ones. Microliths because of their use in composite tools and birch tar because of the complexity of its production. While the standardization of lithic artefacts reflects planning and regularity in their production, they are not suitable markers for symbolic behaviour.

In the past decades, some researchers have called for the abandonment of behavioural modernity as a concept. And while it needs to be developed and transformed a complete abandonment seems unnecessary. A concept of behavioural modernity that encompasses as many aspects as possible can be tied to recent research in the fields of cumulative culture or Extended Evolutionary Synthesis. Furthermore, advancements in our ability to model some aspects of past societies that are critical to explain complexity provide interesting avenues for future scientific inquiry in when and how past hominins became like us.

II. ZUSAMMENFASSUNG

Verhaltensmodernität als Konzept beschreibt die Spanne von Verhaltensweisen heutiger Menschen. In der Archäologie ist dieses Set von Verhalten mit der Frage verbunden, wann und wie sie entstanden sind. Der Begriff selbst reflektiert die erste konzise Konzeptualisierung von Verhaltensmodernität, die auch der Dichotomie von Verhalten anatomisch moderner Menschen und Neanderthalern beruhte. Die physischen Manifestationen von Verhalten, das als modern angesehen wurde, wurde in einer Liste zusammengefasst. Die dort aufgeführten Charakteristika umfassen eine technologische, eine symbolisch und eine organisatorische Dimension, wobei letzte in Mensch-Umwelt-Interaktion und die räumliche Organisation von Fundstellen weiter unterteilt werden kann. Die Debatte bewegte sich über die letzten vier Jahrzehnte weg von einem Ansatz, der die simple An- bzw. Abwesenheit bestimmter Merkmale von der Liste in der archäologischen Überlieferung als Evidenz für Verhaltensmodernität ansah. Die Merkmale der Liste sind jedoch immer noch von Bedeutung, da sie den archäologischen Befund mit dem Konzept der Verhaltensmodernität verbinden. Jedes Merkmal benötigt eine theoretische Rechtfertigung, um als physische Evidenz für modernes Verhalten in der Vergangenheit zu gelten.

Diese Dissertation fokussiert auf zwei technologische Aspekte von Verhaltensmodernität – mikrolithische Technologie im südafrikanischen Middle Stone Age und Later Stone Age (MSA und LSA) sowie mittelpaläolithische Birkenpechherstellung. Mikrolithische Technologie und Birkenpech werden gemeinhin mit Kompositgeräten in Verbindung gebracht, welche auf Basis ihrer Komplexität als Marker für Verhaltensmodernität angesehen werden. Zusätzlich wurde angenommen, dass Birkenpech nur unter Sauerstoffabschluss entstehen kann, weswegen der Produktionsprozess selbst als komplex angesehen wird. Weiterhin wird die Überschneidung zwischen Steintechnologie und Symbolismus anhand der Standardisierung von Mikrolithen beleuchtet.

Auf Basis von Steinartefakten der spätpleistozänen LSA-Schichten von Umbeli Belli, der Lamellen aus sechs Sibudan-Schichten und rückengestumpften Stücken aus vier Howiesons Poort-Schichten von Sibhudu (beide Südafrika), werden Fragen zum Ursprung des LSA und der Standardisierung von

Steinartefakten im MSA erörtert. Dabei wird die postulierte Verbindung zwischen mikrolithischer Technologie und Verhaltensmodernität ebenso untersucht wie die Verbindung zwischen dem Aufkommen des LSA, welches manchmal mit dem regionalen Erscheinen von Verhaltensmodernität korreliert wird. Eine Serie von hauptsächlich experimentalarchäologischen Studien zu mittelpaläolithischer Birkenpechherstellung des Neanderthalers erkundet technologische Komplexität außerhalb des *H. sapiens*.

Die Nutzung technologischer Komplexität als Marker für Verhaltensmodernität ist jedoch nicht unproblematisch. Zunächst ist Komplexität generell nicht leicht zu messen und im Besonderen nicht in archäologischen Kontexten. Weiterhin, selbst unter der Voraussetzung ein „korrektes“ Maß für Komplexität anzuwenden, ist der errechnete Wert ohne Kontextualisierung bedeutungslos. Daher muss Komplexität immer mindestens einen weiteren Referenzpunkt haben und dieser ist oft willkürlich gewählt. Zuletzt benötig es eine theoretische Basis, um technologische Komplexität mit Verhaltensmodernität zu verknüpfen. Diese theoretische Verknüpfung muss darauf abzielen, diejenigen kognitiven Mechanismen zu identifizieren, die der Beobachtung in der archäologischen Überlieferung zugrunde liegen. Die theoretische Rechtfertigung, ein Verhalten als modern zu klassifizieren, überschneidet sich dabei mit der Erklärung für das Verhalten selbst. Die in dieser Dissertation vorgestellten Daten werden unter den drei erwähnten Paradigmen untersucht und ihre Eignung als Proxymarker für Verhaltensmodernität untersucht.

Die Dissertation präsentiert neue Daten zu drei verschiedenen Charakteristika, die als Indikatoren für Verhaltensmodernität angesehen werden und evaluiert, ob diese Charakteristika als solche angesehen werden können und warum beziehungsweise warum nicht. Sowohl mikrolithische Technologie als auch Birkenpechherstellung sind als Marker für ein Konzept von Verhaltensmodernität geeignet, das eine technologische Dimension einschließt. Für Mikrolithen ist dies auf Basis ihrer Nutzung in Kompositgeräten der Fall, für Birkenpech aufgrund der Komplexität seiner Herstellung. Während die Standardisierung von Steinartefakten sehr wohl Planung und Regularität in der Produktion anzeigt, ist sie als Marker für symbolisches Verhalten nicht geeignet.

In den letzten Jahrzehnten haben manche Forscher für eine Aufgabe des Konzepts der Verhaltensmoderne plädiert. Während eine Überarbeitung und Weiterentwicklung des Konzepts weiterhin notwendig ist, scheint eine komplette Aufgabe indes unnötig. Ein Konzept von Verhaltensmodernität, das so viele Aspekte wie möglich einschließt kann mit jüngeren Fortschritten auf den Gebieten der kumulativen Kultur oder der Extended Evolutionary Synthesis verbunden werden. Weiterhin eröffnen Fortschritte in unseren Möglichkeiten jene Aspekte vergangener Gesellschaften zu modellieren, die für die Erklärung des Entstehens von Komplexität von Bedeutung sind, spannende neue Möglichkeiten bei der Beantwortung der Frage wann und wie der Mensch so wurde wie wir.

III. LIST OF PUBLICATIONS

i) Accepted publications

(1) P. Schmidt, **M. A. Blessing**, M. Rageot, R. Iovita, J. Pfleging, K. G. Nickel, L.Righetti, C. Tennie, Birch tar production does not prove Neanderthal behavioral complexity. *Proceedings of the National Academy of Sciences 116/36* (2019) 17707–17711 (*APPENDIX i.a*).

(2) G. Bader, P. M. Bushozi, M. Will, V Schmid, A. Val, **M. A. Blessing**, P. Schmidt, N. J. Conard, Investigating the 1930s Kohl-Larsen collection from the Lake Eyasi Basin, Tanzania. *Mitteilungen der Gesellschaft für Urgeschichte 29* (2020) 93–103 (*APPENDIX i.b*).

(3) P. Schmidt, M. Rageot, **M. A. Blessing**, C. Tennie, The Zandmotor data do not resolve the question whether Middle Paleolithic birch tar making was complex or not. *Proceedings of the National Academy of Sciences 117/9* (2020) 4456-4457 (*APPENDIX i.c*).

(4) **M. A. Blessing**, P. Schmidt, On the efficiency of Paleolithic birch tar making. *Journal of Archaeological Science: Reports 38* (2021) 103096 (*APPENDIX i.d*)

(5) P. Schmidt, **M. A. Blessing**, T. Koch, K. G. Nickel, On the performance of birch tar made with different techniques. *Heritage Sciences 9, 140* (2021) 1–9 (*APPENDIX i.e*).

(6) **M.A. Blessing**, N.J. Conard, G.D. Bader, Investigating the MIS2 microlithic assemblage of Umbeli Belli rock shelter and its place within the chrono-cultural sequence of the LSA along the east coast of southern Africa. *African Archaeological Review* https://doi.org/10.1007/s10437-022-09497-3 (*APPENDIX i.f*)

(7) **M.A. Blessing**, N. J. Conard, M. Will, Lithic standardization and behavioral complexity in the Middle Stone Age – a case study from Sibhudu, South Africa. *Lithic Technology* doi: 10.1080/01977261.2022.2158591 (*APPENDIX i.g*)

ii) Submitted manuscripts

(8) P. Schmidt, T. Koch, A. Charrié-Duhaut, F.A. Karakostis, K. Harvati, V. Dresely, **M.A. Blessing** (revised), Königsaue birch tar documents cumulative culture in Neanderthals. *Submitted to Science Advances* (*APPENDIX ii.a*)

iii) Manuscript ready for submission

(9) **M.A. Blessing**, N.J. Conard, G.D. Bader, Investigating chrono-cultural developments between the end of the final MSA and the beginning of the Robberg. A supra-regional perspective from Umbeli Belli, KwaZulu-Natal, South Africa (*APPENDIX iii.a*)

IV. PERSONAL CONTRIBUTION

Description of the extent and significance of the personal contribution according to § 6,2 of the PromO of the University of Tübingen. Numbers follow the order as listed in III. LIST OF PUBLICATIONS

(1) I was supporting co-author responsible for the experimental design and helped writing the manuscript.

(2) I was supporting co-author for responsible for analyzing and reporting on the Later Stone Age lithic assemblage of Njarasa Cave and helped writing the manuscript together with the other co-authors.

(3) I was supporting co-author for this letter and provided archaeological background information.

(4) I was first and corresponding author. Together with Patrick Schmidt I conceived of the study design and conducted all experiments. I was lead author in writing the paper. The co-author (P. Schmidt) helped in writing the paper and designing the figures.

(5) I was one of the main experimenters in this study (alongside P. Schmidt and T. Koch). I provided archaeological background information for the paper, did the sample preparation in the laboratory (alongside P. Schmidt and T.Koch) and helped writing the manuscript together with the other co-authors.

(6) I am first and corresponding author on this paper. I was responsible for lithic analysis, sorting the sediments, data processing and lead author in writing the paper. The co-authors (G. Bader and N. Conard) helped in the writing of the article and gave editorial input.

(7) I am first and corresponding author on this article. I was responsible for the lithic analysis and lead author in writing the paper. The co-authors (M. Will and N. Conard) and I developed the study design together. The co-author helped with data processing, writing the article and provision of figures.

(8) I am senior author on this article and provided archaeological background information. Furthermore, I organized the access to the tar pieces, which are housed in the Landesmuseum für Vorgeschichte in Halle (Germany). I was one of the main experimenters (alongside P. Schmidt and T. Koch) and assisted in the sample preparation for the Infrared-Spectroscopy

(alongside P. Schmidt and T. Koch). I also assisted in the graphic documentation of the Königsaue pieces as well as the sampling (alongside P. Schmidt) and helped writing the paper together with the other co-authors.

(9) I am first and corresponding author for this article. I was responsible for sorting the sediments, lithic analysis, data processing, documentation of artefacts and lead author in writing the paper. The co-authors helped in providing figures (G. Bader), helped writing the article and gave editorial input (G. Bader and N. Conard).

Chapter 1 – Introduction

1.1 Archaeology and the question of human uniqueness

The question about the emergence of behavioural modernity is often illustrated by the phrase "humans like us" (Conard, 2008, 2010; Wadley, 2013). While it is clear that the question of what defines us as humans is a highly philosophical one and so far, there is no straightforward and all-around satisfying answer, it essentially boils down to this: what makes us human? There are probably as many answers to this question as there are people who have raised it. Even though they are related, the appropriate question for archaeology to ask is, in my opinion, what *made* us human instead of what makes us human.

I want to use a piece of artwork to explain why it is so hard to answer this question, especially based on archaeological data. In an exhibition of the South Tyrol Museum of Archaeology ("Ötzimuseum") a piece of modern art was on display that, in my opinion, captures both the nature of archaeological work and the difficulty in answering the question about humanness in a very impressive manner. It was a statue of a human, similar to a mannequin, that was hollow inside and had hundreds of little holes in its shell. Inside was a light that peaked through these holes. However, only a fraction of the holes was lit at the same time. How many and which ones depended entirely on the observer's position relative to the statue. For me, this object was a powerful demonstration that even under the most favourable preservation conditions and with the whole array of modern technology used to examine every physical aspect of an individual's life history, it would never be possible for the whole human to be illuminated. While this is edging into the esoteric, it serves as a useful demonstration of why it is difficult for archaeology to answer the question about what makes us human because of the fragmentary nature of the materials remains we have at our disposal.

Collecting the physical manifestations of our ancestors' culture is how our discipline came into being (e.g. Lyman et al., 1997; Trigger, 2006). Hence, it was only logical that one of the first paradigms of archaeology was culture history (Hansen, 2001 for a concise review of the beginnings of European prehistoric research; Lyman et al., 1997 for an extensive review of Americanist archaeological history; Schlanger, 2005; Shepherd, 2003 for an examination of the (South) African research history of archaeology). Archaeology as the study of the physical remnants of past people is therefore ideally suited for exploring the question of what made us human and for a long time the answer seemed simple: Culture. Culture, however, is not restricted to the physical domain for instance, one of the most influential definitions of culture in archaeology as "[…] the extra-somatic means of adaptation […]" (Binford, 1962, 218; White, 1959) included social factors into this definition even though this aspect was to be somewhat neglected in the years to follow. In creating a dichotomy between humans and the animal kingdom culture became equivalent to what sets us apart from animals (e.g. Holloway, 1969), which we know today is by no means restricted to humans. Culture is a well-known phenomenon of the animal kingdom and the body of literature finding new evidence for animal culture is ever growing (see Whiten, 2021 for a recent review). At present *cumulative culture* seems to set us apart from animals as culture-dependent traits have yet to be observed among animals (e.g. Boyd & Richerson, 2005; Nakahashi, 2013; Reindl et al., 2017; Richerson & Boyd, 2008; Tennie et al., 2009; Tomasello et al., 1993).

Over the past decades and related to the expansion of the human family tree, archaeologists and palaeoanthropologists explored the question of what made us human from both a cultural and a physiological angle. It was only recently, that the date for the emergence of anatomically modern humans was pushed back to 315 ka (Hublin et al., 2017; Richter et al., 2017). Genetic evidence for the emergence of *H. sapiens* supports this (Schlebusch et al., 2017), even though the divergence between Neanderthals and *H. sapiens* must have happened earlier and the molecular clock dates this to around 750 and 550 ka (Rogers et al., 2017). Empirically, we might be able to track down the oldest fossil of anatomically modern humans, but evolution is a continuous process and so, from an epistemic point of view, we can never be sure to have discovered the oldest fossil. "Origins fade in continuity" (Foley et al., 2016, 1). The anatomical and genetic side of modern human origins, despite disagreements in details maybe, is comparably well examined and also readily accessible through physical evidence, however scarce it is for the time between 315 and 40 ka. Hence, physiologically, we have a pretty good idea of what makes us human and when 'humans like us' (Conard, 2008, 2010) evolved. As I tried to illustrate by the description of the art object in the Ötzimuseum, this is only a part of the answer to what made us human because “humans like us” also refers to the behavioural realm of human existence, commonly phrased under terms like behavioural complexity, cultural complexity, complex cognition and behavioural modernity (Deacon, 2001; Henshilwood & Marean, 2003; Klein, 1995; Marean, 2015; McBrearty, 2007; McBrearty & Brooks, 2000; Mellars, 1989a, 1991, 2005; Nowell, 2010; Wadley, 2001, 2003, 2013; Wadley et al., 2009; Zilhão, 2007). Even though ‘behavioural modernity’ can be misunderstood as only restricted to anatomically modern humans (see for example Wadley, 2001; 2003 and her arguments for using the term complex cognition therein; Wadley, 2013), I will use the term behavioural modernity throughout this thesis, as in my opinion, the debate has moved forward to a point where the concept of modern behaviour has been decoupled from anatomically modern humans (see also Nowell, 2010). While modernity technically still refers to notions that the behaviours described to define it can be found in ‘us’, we are (or should be) at a point in the debate, where these behaviours are not *a priori* expected to be found in anatomically modern humans exclusively.

1.2 A brief history of the concept of behavioural modernity

If we view behavioural modernity as the question of what defines a human being, the question is age-old. Antique philosophers like Aristotle, Zenon and Seneca have written about these questions. This was also forefront in the thinking of the Enlightenment philosophers, most prominently Kant (1798), and advocates of philosophical anthropology after him (e.g. Gehlen, 1940; Habermas, 1973; Scheler, 1928). Apart from philosophy (I would like to note that not only Western philosophy engaged with this question, but regrettably my knowledge about non-Western philosophy is not deep enough to be cited here), religions and indigenous peoples all over the globe have creation myths and beliefs, which assign humans a place and, in some instances, also a purpose in the world. From a biological point of view 'humanness' was explored from the mid-19th century onwards in the wake of Darwin's concept of evolution (Darwin, 1859, 1871; Haeckel, 1868; Huxley, 1863), and the discovery of Neanderthals fossils that almost coincided with the publication of On The Origin Of Species (Darwin, 1859). During the establishment of archaeology as an academic discipline predominantly, but not exclusively, French scholars engaged with this question (De Mortillet, 1883; de Perthes, 1847; Lartet, 1861; Lubbock, 1865).

Until the 1980s it was debated whether or not modern humans originated in Africa, but their African origin has since been proven beyond reasonable doubt (Bräuer, 1984; Lahr & Foley, 1998; Tattersall, 2009; White et al., 2003). Until the discovery of the human fossils of Jebel Irhoud (Morocco) pushed the evolution of anatomically modern humans to around 315,000 years ago (Hublin et al., 2017; Richter et al., 2017), modern humans were thought to have evolved between 150,000 and 200,000 years ago south of the Sahara Desert (Conard, 2007; Lahr & Foley, 1998; McBrearty & Brooks, 2000; McDougall et al., 2005; White et al., 2003). While the younger dates neatly coincided with early signs of behavioural modernity at Pinnacle Point (South Africa) (Marean et al., 2007), and seemingly closed the gap between the first anatomically modern humans and the first material manifestations of modern behaviour (see e.g. Noble & Davidson, 1996), the findings of Jebel Irhoud once again widen this gap.

Roughly around the same time as the African origin of *H. sapiens* had been confirmed, archaeology sought a more theoretically informed attempt to define ‘modern behaviour’ and the past four decades have seen a growing body of literature related to modern behaviour (Ambrose, 2010; Ames et al., 2013; Conard, 2006, 2008, 2010; Deacon, 2001; Dibble, 1989; Garofoli, 2016; Henshilwood & Marean, 2003; Klein, 1995; Marean, 2015; McBrearty & Brooks, 2000; Mellars, 1989a, 1991, 2005; Nowell, 2010; Wadley, 2001, 2003, 2010a, 2013; Wadley et al., 2009; Wadley et al., 2011; Zilhão, 2003, 2007). In its formation the term has been created in the dichotomy of Neanderthals on the one side and *H. sapiens* on the other (Mellars, 1989a, 1989b, 1991, 1996). The presumed primitiveness of Neanderthals, in and of itself, the result of a “merciless” palaeoanthropological misclassification (Madison, 2021), created the threshold above which modernity was defined. In Eurasia, the discovery of *H. floresiensis* (Brown et al., 2004) and Denisovans (Brown et al., 2016; Krause et al., 2010) have complicated this picture because instead of two species, there are now four that have potentially overlapped chronologically and perhaps spatially. The discovery of *H. naledi* in South Africa (Berger et al., 2015) might constitute a similar complication for the archaeological record in sub-Saharan Africa because it introduces some uncertainty to the previously presumed sole authorship of the Middle Stone Age record by *H. sapiens.* These recent discoveries should have changed the course of the debate about behavioural modernity, but so far, their impact is marginal.

In its initial creation, the concept of behavioural modernity entailed a list of behaviours and their material manifestations in the archaeological record by means of which behavioural modernity could be identified (Mellars, 1973, 1989a, 1989b, 1991; Mellars & Stringer, 1989). In the following decades the list of modern behavioural traits had been expanded over time. It can be subdivided into four overarching sections of archaeological evidence.

1) Artefact technology including;
    - blade production (Ambrose & Lorenz 1990; Deacon & Wurz 1996; Deacon 2001; Foley & Lahr 1997; Mellars 1989a, 1989b)
    - osseous tool manufacture and use (Deacon 1989, 2001; Gibson 1996; Klein 1995, 2001; Knight et al. 1995; Mellars 1989a, 1989b, 1991, 1996)

- microlithic technology and artefact standardization (Ambrose 2002; Clarkson et al. 2018; Elston & Kuhn 2002; Klein 1995; Kuhn & Elston 2002; Mellars 1989a, 1989b)
- artefact diversity (Ambrose & Lorenz 1990; Ambrose 1998; Deacon 2001; Klein 1995; Knight et al. 1995; Mellars 1989a, 1989b, 1996)
- adhesive manufacture and composite weaponry (Ambrose 2002; Clarkson et al. 2018; Groom et al. 2015; Kozowyk et al. 2017; Kuhn & Elston 2002; Lombard & Wadley 2016; Mazza et al. 2006; Niekus et al. 2019; Pargeter & Faith 2020; Porraz et al. 2016; Rots et al. 2015; Rots et al. 2011; Schmidt et al. 2019; Van Peer et al. 2008; Way et al. 2022; Wurz & Lombard 2007)

2) Environmental interactions including;
   - effective large mammal exploitation (Binford 1984; Binford 1985; Klein 2001; Marean 1998; Marean & Assefa 1999; Mellars 1989a; Thackeray 1992),
   - effective exploitation of small game (Hoffecker & Hoffecker 2017; Wadley 2010b, 2013)
   - the population of harsh environments like the Arctic or deserts (Ambrose & Lorenz 1990; Ambrose 1998; Deacon 1989; Klein 1995; Mellars 1989a)
   - the use of aquatic resources (Klein 1995, 2001; Marean et al. 2007; Thackeray 1992; Will et al. 2019; Will et al. 2013)
3) Spatial organization on sites (Ambrose 1998; Deacon 1989, 2001; Deacon & Deacon 1999; Klein 1995, 2001; Mellars 1989a; Soressi 2016; Wadley 2001, 2003)
4) Symbolism as in art or more generally the symbolic use of colours, or the act of burying the dead (Chase & Dibble 1987; Conard 2006, 2008, 2010; d'Errico et al. 2003; d'Errico et al. 2005; Deacon 2001; Henshilwood et al. 2004; Henshilwood et al. 2009; Heyes et al. 2016; Knight et al. 1995; Mellars 1989a, 1989b; Wadley 2001, 2003, 2013)

Of course, this subdivision does not mean that these lines of evidence do not intersect, which will be discussed below (see CHAPTER 3.2). The use of a list of single artefact types or how a site is organized has been criticized on the grounds of a lack of theory connecting these traits to the concept of behavioural modernity. (e.g. Henshilwood & Marean, 2003; Nowell, 2010; Wadley, 2001; Wadley, 2003, 2013; Zilhão, 2003). Hence, the past twenty years have seen an increasing reflection on the concept of behavioural modernity, why traits in the list should be indicative of it and how we could explain the emergence of behavioural modernity. Chase (2003) identified four lines of thinking that are still present in today's debate, even though the weight of them has changed. The first line of thinking refers to the origins of the concept of behavioural modernity and takes the term very literally, in the way that modern behavioural traits can only be referred to as such and appear concurrently to the evolution of *H. sapiens.* The crux in this model is that only behaviours that are identified as modern and appear with the first appearance of anatomical modernity would be counted as modern behaviour. Traits that postdate the emergence of anatomically modern humans or are found in other species as well would not count as evidence for behavioural modernity (e.g. Bickerton, 2007; Mellars, 2005; Monnier & McNulty, 2010). The second line of thinking assumes that the evolution of behavioural modernity postdates the evolution of anatomical modernity. Through circumstances like population bottlenecks, migrations, and external factors acting as selective pressure, the set of behavioural traits that constitute behavioural modernity appeared at once and spread from the original population in which it appeared (Klein, 1995, 2001, 2019; but see Shea, 2011b). A third line of thinking approaches behavioural modernity from a more theoretical point of view. Rather than using the archaeological record to define it, this approach seeks to identify what constitutes as modern behaviour and how it would manifest in the archaeological record. Artefacts and features that are thought to represent behavioural modernity are then used to trace its evolution. This is mostly in relation to symbolic behaviour (Conard, 2008, 2010; d'Errico et al., 2003; Henshilwood & Marean, 2003; McBrearty & Brooks, 2000; Noble & Davidson, 1996; Wadley, 2001, 2003). The fourth approach is strictly bound to the above-mentioned list however, this has more or less fallen from favour as its origins are directly related to the dichotomy between Neanderthals and modern humans and as such dictate what constitutes as modern behaviour on the basis of evidence that we can expect to find in Europe (Henshilwood & Marean, 2003; McBrearty, 2007; McBrearty & Brooks, 2000; Nowell, 2010). The use of any "'modernity' kitchen list” (Soffer, 2009 ,45) is seen problematic because not all traits are universally applicable.

Based on these lines of thinking several models for the origin of behavioural modernity have been derived, most of them tied to specific researchers or groups. Conard proposes a “Mosaic Polycentric Modernity (MPM)”, in which the evolution of modern behaviour is decentralized and heterogenic, emphasizing historical contingency (Conard, 2005; Conard, 2008, 2010; Hovers & Belfer-Cohen, 2006; Lewis-Williams, 2002). While this model does not specifically exclude non-modern humans from developing modern behavioural traits, it has symbolic and artistic expressions at its core. Species or societies that do not produce such physical manifestations will therefore not be recognized as fully modern. The mosaic nature of Conard’s model is also the core of an origin model proposed by Zilhão and d’Errico, but their model specifically includes anatomically archaic humans, even though they also recognized at some point that behavioural modernity became only fully consolidated after 40 ka (d'Errico et al., 2003; d'Errico & Stringer, 2011; d'Errico et al., 2009; Zilhão, 2001a, 2007). Specifically tied to the African archaeological record and therefore opposing to the mosaic models are the following models. Parkington’s model of the origin of behavioural modernity maintains, that the increasing uptake of marine resources in coastal South Africa led to increased brain size and hence increased cognitive capacity (Parkington, 2001, 2003, 2010; Parkington et al., 2004; but see Wilkins et al., 2021). McBrearty and Brooks (2000) argue that the origins of behavioural modernity lie in a gradual accumulation of modern traits, all of them first appearing in Africa. This differentiates it from Parkington’s model as they refrain from pinpointing it to a single African region. Similar to Parkington’s model though, they maintain that the accumulation of behaviourally modern traits happens over considerable time spans. This is in opposition to a revolutionary model as proposed by Klein, in which behavioural modernity appears suddenly around 50-40 ka in Africa and spreads originating from a single population (Klein, 1995, 2000, 2008, 2009, 2019; Klein & Edgar, 2002). Jacobs and colleagues’ ‘Synthetic Model’ tries to combine the gradual and the sudden appearance of behavioural modernity by stating that there are two distinct phases in the MSA (Henshilwood, 2012; Jacobs & Roberts, 2008; Jacobs & Roberts, 2009; Jacobs et al., 2008a) during which behavioural modernity manifests in the archaeological record (Still Bay [SB] and Howiesons Poort [HP]). These are predated and followed by periods of less sophisticated material culture.

Obviously, all models are tied to the archaeological record in one way or another, which in and of itself is not a bad thing, even necessary (e.g. Conard, 2010). They all share an acceptance of items from the ‘shopping list’ of behavioural modernity or reject them as being a physical manifestation of modern behaviour. It is still up to individual researchers or research groups which evidence is accepted as modern behaviour and which is not (see also Wadley, 2013). The debate has recently seen a consensus towards symbolic behaviour as being the centre of behavioural modernity (Conard, 2008, 2010; Henshilwood et al., 2004; Henshilwood et al., 2009). Nonetheless, complex technology is still frequently, although not exclusively, cited as a feature of behavioural modernity, but especially in Neanderthals (Groom et al., 2015; Kozowyk et al., 2017; Lombard & Wadley, 2016; Niekus et al., 2019; Schenck & Groom, 2018; Schmidt et al., 2019; Stolarczyk & Schmidt, 2018).

This thesis will therefore attempt to examine the relationship between technological complexity and behavioural modernity on the basis of lithic technology from the MSA and the LSA in South Africa with an emphasis on microliths as well as birch tar production of Neanderthals.

CHAPTER 2 – METHODS AND OBJECTIVES

This dissertation combines articles on two different topics, which are both related to the concept of behavioural modernity – Neanderthal birch tar production and lithic technology in the MSA and LSA of South Africa, with an explicit focus on microliths. Both have been proposed as proxy markers for behavioural modernity (see chapter 1.1) and the principal objective of this thesis is to evaluate these two technological aspects with regards to the concept of behavioural modernity. Comparing two separate time frames, regions and species pays tribute to the realization that there needs to be an approach that decouples anatomical modernity and behavioural modernity (e.g. Ames et al., 2013; Nowell, 2010).

While the discussion revolving around behavioural modernity has moved beyond simple presence/absence descriptions of items on a list of artefact classes and archaeological features (Henshilwood & Marean, 2003; McBrearty & Brooks, 2000; Mellars, 1989a, 1989b; Nowell, 2010), we still have to rely on these items because they tie the archaeological record to the overarching concept of behavioural modernity. The lack of theoretical justification of most of these items to be indicative of modern behaviour has been pointed out repeatedly (Henshilwood & Marean, 2003; Shea, 2011b; Wadley, 2001, 2013). Hence, the theoretical justification for the assumption that Middle Palaeolithic birch tar and microlithic technology are significant proxy markers for behavioural modernity will be explicitly discussed under various aspects (CHAPTER 3).

The monocentric origin of LSA and European Upper Palaeolithic technology has been proposed two decades ago (Klein 1995) and developed as new data and new findings had been reported (Klein & Edgar, 2002; Klein, 2000, 2001, 2006, 2019). The results from the articles on the LSA lithic technology from Umbeli Belli and Njarasa Cave (*APPENDIX i.b, ii.a and iii.a*; CHAPTER 3.1) will form the baseline to discuss the implications of cultural change within the species of *H. sapiens.* This discussion includes the implications the findings from the Umbeli Belli LSA sequence have for models which assume a single and abrupt transition form the MSA to the LSA. It also reflects on how the practice of structuring the archaeological record by cultural taxa influences our interpretations.

Another aspect of microlithic technology which has been proposed as proxy measure for behavioural modernity is their standardization (e.g. Mellars 1989a; 1991; 1996; Henshilwood & Marean 2003). Standardization is also a feature on the list where symbolism and technology intersect (Chase, 1991; Chazan, 1995; Mellars, 1989a, 1989b; 1996; Wurz, 1999). Based on the technological analysis of bladelets from the Sibudan and backed pieces from the HP of Sibhudu, the significance of artefact standardization for the concept of behavioural modernity is examined. The study employs coefficients of variation as a measure of standardization. The discussion includes a review on previous work on the link between artefact standardization and symbolism. Furthermore, it also incorporates a theoretical reflection on the coefficient of variation as a means to measure standardization (CHAPTER 3.2).

Birch tar and the assumed complexity of its use and production have been proposed as a behaviourally modern trait in Neanderthals since it was first identified in a Middle Palaeolithic context (Koller et al., 2001; Mazza et al., 2006; Niekus et al., 2019). It was simply assumed that birch tar only forms in oxygen-restricted environments and the production without any kind of fire-resistant vessels had to be complex (see Kozowyk et al., 2017). Based on experimental work, this paradigm was ultimately questioned (**Schmidt et al., 2019**; **Schmidt et al., 2020;** *APPENDIX i.a and i.c*) bringing the discussion back to square one. The following efforts to clarify the complexity of birch tar production included inquiries about the tensile strength of birch tar produced with different methods and an evaluation of the efficiency of different aceramic production methods, all based on months of experimental work (**Blessing & Schmidt, 2021**; **Schmidt et al., 2021**; *APPENDIX i.d and i.e*). Using the reference collection that built up during the multiple experiments, it was finally possible to infer the most likely way of production used by the Neanderthals who made the birch tar pieces from Königsaue in Germany (Grünberg et al., 1999; Koller et al., 2001) using a combination of Infrared-Spectroscopy and Gaschromatography-Massspectrometry (**Schmidt et al., submitted;** *APPENDIX ii.c*). The results of this series of articles shall be put into a theoretical reflection of the complexity of birch tar production and use and its significance for behavioural modernity in a species other than *H. sapiens* (CHAPTER 3.3 and CHAPTER 3.4).

Technological complexity as a proxy measure for behavioural modernity has been inferred from both birch tar and microliths as they are seen as indirect evidence for composite weaponry (e.g. Ambrose, 2001, 2002, 2010; Wurz & Lombard, 2007; Lombard & Wadley, 2016). Therefore, the present study discusses different measures of technological complexity from within and outside of archaeological research (CHAPTER 3.4). It aims to connect these measures of complexity within the greater theoretical framework around behavioural modernity. In order to achieve this, the theoretical justification for birch tar, microlithic technology and artefact standardization as indicators for behavioural modernity is critically examined.

The thesis aims to evaluate the significance of technologically complex traits in archaeology for the development of behavioural modernity across two different species. With respect to more recently discovered and described hominin species that temporally and perhaps spatially overlap with Neanderthals and *H. sapiens*, the thesis outlines potential future avenues for the contribution archaeology can make to the concept and evolution of behavioural modernity (CHAPTER 4).

Chapter 3 – Discussion

3.1 The beginning of the Later Stone Age and its significance for the origin of behavioural modernity

This section contextualizes the transition from the Middle to the Later Stone Age within the framework of behavioural modernity. It is based on two papers on the sequence of Umbeli Belli (Kwa-Zulu-Natal, South Africa) that follow the final MSA (Bader et al., 2022b; Bader et al., 2018) as well as a paper on the legacy collection from Njarasa Cave, Tanzania.

- Bader, G., Bushozi, P.M., Will, M., Schmid, V., Val, A., **Blessing, M.A.**, Schmidt, P., Conard, N.J., Investigating the 1930s Kohl-Larsen collection from the Lake Eyasi Basin, Tanzania. *Mitteilungen der Gesellschaft für Urgeschichte 29* (2020) 93–103 (*Appendix i.a*).
- **Blessing, M.A.**, Conard, N.J., Bader, G. submitted (revised), Investigating the MIS2 microlithic assemblage of Umbeli Belli rock shelter and its place within the chrono-cultural sequence of the LSA along the east coast of southern Africa. *Submitted to African Archaeological Review* (*Appendix ii.a*)
- **Blessing, M.A.**, Conard, N.J., Bader, G., Investigating chrono-cultural developments between the end of the final MSA and the beginning of the Robberg. A supra-regional perspective from Umbeli Belli, KwaZulu-Natal, South Africa). *Manuscript ready for submission* (*Appendix iii.a*)

The work of **Bader et al. (2020)** marks a new beginning of research at Njarasa Cave near the shores of Lake Eyasi and in direct vicinity to Mumba Cave (e.g. Bretzke et al., 2006; Diez-Martín et al., 2009; Marks & Conard, 2008; Müller-Beck & Kohl-Larsen, 1978). By analysing the lithic assemblage and the faunal remains housed in the collection of the Department of Older Prehistory and Quaternary Ecology at the University of Tübingen, it proved the scientific potential of both legacy collections in general (see also e.g. Frieman & Janz, 2018; MacFarland & Vokes, 2016), and the potential of re-excavating Njarasa Cave to better contextualise the collection. As such the project set the stage for a new excavation campaign that will be undertaken in August 2022 directed by N. Conard, P. Bushozi and G. Bader and aims for the re-dating of the layers excavated by the Kohl-Larsen team. The initial lithic analysis brought no immediate evidence that Njarasa Cave contained a transitional assemblage between the MSA and LSA. The collection did however demonstrate that the excavations of the Kohl-Larsen expedition, while obviously not up to today's excavation standard, were sufficient for conducting lithic analyses with satisfactory relative chronological resolution to contextualize data which is almost one hundred years old. It therefore follows other examples from East Africa where a reinvestigation of legacy collections has highlighted great research potential which has otherwise been overlooked (Ranhorn & Tryon 2018; Tryon et al. 2019). This might be of future importance as the transition between the final MSA and the Later Stone Age Robberg techno-complex (hereafter referred to as the Robberg) in South Africa is characterized by a scarcity of relevant sites. Studying legacy collections has the potential to increase the count of assemblages covering this period of the Stone Age.

Umbeli Belli (KwaZulu-Natal, South Africa) is one of the sites where the stratigraphy covers the entirety of the sequence from the final MSA into the Robberg. The site is located above the Mbampanyoni River near the town of Scottburg. It was first excavated by Cable in 1979, who stopped the excavation when he thought he had reached bedrock (Bader et al., 2016; Bader et al., 2018; Cable, 1984). The excavation was then continued by a team from the University of Tübingen directed by Conard and Bader from 2016 to 2020. The excavation followed the natural geological horizons (GH), which were subdivided into *Abträge* (see Bader et al., 2018). Due to the absence of organic materials radiometric ages were obtained by Optically Stimulated Luminescence (OSL). In total, Umbeli Belli yielded 18 geological horizons with the uppermost layer named GH 1 and the final layer before bedrock named GH 15. Following Cable's designation of layers, GH 2 is subdivided into 2BE and 2AL and GH 11 into 11a and 11b. The geological horizons analysed in the course of this dissertation are GH 3 (**Blessing et al. submitted a**), GH 4, GH 5 and GH 6 (**Blessing et al. submitted b**). The papers contain detailed techno-typological analyses on the Robberg techno-complex and the layers that cover the time period between the final MSA and the Robberg at Umbeli Belli. They contextualize these comparably small assemblages on a regional and supra-regional scale.

GH 3 could undoubtedly be assigned to the Robberg techno-complex at Umbeli Belli. This layer, as all the other layers excavated by the University of Tübingen, was excavated in the *Abtrag* system. GH 3 is subdivided into 28 *Abträge* providing a fine-grained chronological resolution within the layer which proved invaluable during analysis. We found both gradual and abrupt changes in lithic technology with GH 3 suggesting changes within the Robberg technocomplex at Umbeli Belli, all of them occurring between *Abtrag* 19 and 17. The first observation was an increase in site activity reflected by the find density per *Abtrag*. This was accompanied by an equally sudden shift in raw material frequency. While the nature of the changes in raw material frequency is sudden each time it occurs, the underlying pattern is an increase of quartz at the expense of quartzite, which is only dominant in the lower layers. This development is paralleled with bipolar knapping becoming more common throughout the sequence, however gradually as opposed to abruptly. Interestingly, while the total numbers of bladelets are much higher in the top part of GH 3 (particularly in *Abtrag* 9 to 1), their relative frequency is stable. This observation together with a general scarcity in tools and the OSL date from GH 3 – 17.8 ± 1.5 ka (see also Bader et al. 2018) – places the assemblage into the Robberg techno-complex.

Comparable assemblages in the region come from the sites Shongweni and Umhlatuzana (Davies, 1975; Kaplan, 1989, 1990; McCall & Thomas, 2009). The low number of finds recovered from Shongweni excluded it from a more detailed comparison. Umhlatuzana, however, contained a rich assemblage attributed to the Robberg (Kaplan, 1990). While the stratigraphic integrity at Umhlatuzana was repeatedly questioned (Kaplan, 1990; McCall & Thomas, 2009), it was recently shown to be an intact and reliable (Sifogeorgaki et al., 2020). Kaplan's excavation method, in which he did not follow the natural inclination of the sediments most likely caused admixtures in the lithic assemblage. From an analytical point of view, these admixtures are only a concern at the transition between distinct chrono-cultural units meaning that a large part of the Robberg sequence can be considered intact. The major difference between the assemblages from Umhlatuzana and Umbeli Belli is the greater abundance of tools in the former (Kaplan, 1990), which is a special case for the Robberg as a scarcity in formal tools is one of the key characteristics of this time period (Deacon, 1984). The classification of those layers as Robberg therefore rests on the chronology, the abundance of quartz and frequent bladelet production. Based on the typology of the tools and the radiocarbon dates, Kaplan proposed an early and a later phase of the Robberg (Kaplan, 1989, 1990). This might hold implications for the assemblage of Umbeli Belli because of the observed differences between the lower and the upper part of GH 3. The lower abundance of quartz in the older Robberg layers of Umhlatuzana is certainly an intriguing parallel between the two sites (Kaplan, 1990). Unfortunately, since the subdivision of the Robberg at Umhlatuzana is almost entirely based on tools, which for the most part lack in the assemblage of Umbeli Belli, we do not know if these changes in GH 3 correspond with two different phases of the Robberg. A technological analysis for the Umhlatuzana assemblage needs to be conducted to clarify this circumstance.

The general trends and observations made at Umbeli Belli are also reflected in assemblages from other parts of South Africa. Sehonghong, in the highlands of Lesotho is a key site for the Robberg (Carter, 1977; Mitchell, 1988), despite chronometric dates which suggest that GH 3 of Umbeli Belli predates the Robberg at Sehonghong (Carter & Vogel, 1974; Mitchell, 1988, 1995; Pargeter et al., 2017). Sehonghong is a bit of an outlier regarding the Robberg, as bipolar reduction is not very common and bladelets are mostly produced from handheld cores. However, Low and Pargeter (2020) found that bipolar percussion might be more common than previously thought, because handheld cores seem to have been placed on an anvil for further reduction once they become too small to be continued as handheld cores. We did not find evidence for this continuous reduction of bladelet cores at Umbeli Belli, but the frequent production of bladelets is a connection between the two sites as is the common manufacture of tools on hornfels (Mitchell 1995). The nearby site of Rose Cottage Cave also has opalines as the preferred raw material but unfortunately, nothing has been published on the percussion techniques from the site (Wadley 1996). While the frequency of retouched tools is low in Rose Cottage Cave as well, the site yielded a few backed pieces (Wadley, 1996), which are not observed in Umbeli Belli and most other Robberg sites in South Africa. The analysis of the GH 3 assemblage of Umbeli Belli and the comparison on a regional and supra-regional scale highlighted once again the variability within the Robberg techno-complex (see Low & Pargeter, 2020), but also showed that some traits like the production of microliths are shared on a sub-continental scale. GH 3 in Umbeli Belli and the clear techno-typological signal that places the assemblage into the Robberg techno-complex can be seen as a baseline for the analysis of the GH 4, 5 and 6, which connect the final MSA of GH 7 (Bader et al., 2018) to the fully developed LSA Robberg in GH 3 (**Blessing et al. submitted a**).

In Klein's model, the origin of modern behaviour the beginning of the Later Stone Age marks the transition to behaviourally fully modern people (Klein, 1995, 2000, 2001, 2008). He thinks of the transition from the MSA to the LSA as a relatively disruptive process, in which behaviourally modern traits like increased production and use of microliths, abundance of osseous tools and symbolic behaviour emerged once and spread from this population all over Africa replacing other technological systems swiftly (Klein, 2019). Based on the sequence of Umbeli Belli, we explored the nature and tempo of the MSA/LSA transition and compared it to other sites on the southern African subcontinent. Umbeli Belli is one of very few sites in South Africa that contains stratigraphic units placed between the final MSA and the Robberg. In Umbeli Belli these are GH 4, 5 and 6. **Blessing et al. (submitted b)** provide a techno-typological analysis for these layers and connect them with findings from the final MSA of Umbeli Belli (Bader et al., 2022b; Bader et al., 2018) and the Robberg **(Blessing et al. submitted a)**. We found that GH 4, 5 and 6 reflect a continuous activity on the site, even though the intensity is not as high as compared to the final MSA or the Robberg at the site. We observed a shift in raw material frequency from a dominance of hornfels in GH 6 towards a dominance of quartzite in GH 4. This connects very well with observations made in the underlying final MSA and the superimposed Robberg (Bader et al. 2018; **Blessing et al. submitted a**). This shift in raw material preference is rather gradual with no major difference at layer boundaries, which is an observation that is mirrored in the tool frequency and typology. GH 6, even though representing the thinnest layer, has the most tools overall (n=10). Two of them are bifacials, one of them is a unifacial point. GH 5 yielded five tools, only one of them being a (broken) bifacial. GH 4, despite being the thickest stratigraphic unit, only yielded three tools. The assemblages of GH 6 to GH 4 demonstrate a gradual depletion in tool abundance, which had been deemed a general feature of LSA assemblages in southern Africa (Deacon, 1984), specifically the abandonment of the production of bifacial and unifacial tools, which characterize the final MSA (Bader et al., 2022b; Bader et al., 2018). We observed MSA core technology to be retained throughout the sequence of GH 4, 5 and 6. A central feature of Umbeli Belli's Robberg layer – the handheld production of bladelets on hornfels – emerges in GH 4 already. This is contradictory to earlier classifications of the Early Later Stone Age (ELSA) or MSA/LSA transitional assemblages which list the retention of MSA tool types, but abandonment of MSA core reduction patterns as characteristic features (Clark, 1997). Furthermore, the presence of bipolar cores, indicates that bipolar bladelet production, which is characteristic for the Robberg (e.g. Deacon, 1984; Mitchell, 1995; Porraz et al., 2016; Wadley, 1996), is not a trait that appears suddenly, but rather develops gradually. Its increase therefore reflects an amplification of an already existing behaviour rather than a novel (re-)invention. Altogether, the sequence from the final MSA into the Robberg at Umbeli Belli spans around 12,000 years and as such, we have to reject previous assumptions that the MSA/LSA transition in the coastal regions of South Africa is an abrupt occurrence (McBrearty & Brooks, 2000). The changes we observe are gradual and the archaeological record and stratigraphy indicate continuity rather than abrupt changes.

A comparison of these results to other sites in southern Africa is only reasonable on a broader level. Unlike the Robberg, for which sites are abundant enough to detect regional patterns (Low & Pargeter, 2020), the scarcity of sites containing a stratigraphic sequence like Umbeli Belli is a major obstacle for the identification of such patterns between the final MSA and the Robberg. Differences between assemblages could always simply reflect different uses of sites or raw materials rather than representing a distinct cultural difference. In comparing the results from Umbeli Belli to other assemblages from the same period on a macro-scale can reveal similarities that could reflect the processes behind the transition. All across the southern African subcontinent shifts in lithic technology can be observed which post-date the final MSA but pre-date the Robberg techno-complex. These are always a mix of final MSA and Robberg signals, at least where the latter exists (but see McCall & Thomas, 2009). What seems to be a common parallel is that the layers characterized as ELSA or MSA/LSA transition exhibit the beginning of certain trends, which are completed in the Robberg layers, if they are present. The only clear case in which we can discern a regional variety is Apollo 11 (Karas, Namibia). This instance also highlights a more general problem of defining the ELSA: Its strong dependence of pre-existing cultural taxonomic units and their characteristics.

This problem is best reflected by the Late Pleistocene Later Stone Age (LPLSA) at Apollo 11 (Ossendorf, 2013, 2017). While the LPLSA assemblage of Apollo 11 falls within the temporal range of ELSA assemblages in South Africa and Lesotho (24.2 ka BP and 20.4 ka BP [Ossendorf, 2017]), it exhibits a somewhat different technological pattern. An increase of bipolar reduction has been reported, but no concurrent increase in bladelet production (Ossendorf, 2017). Both of these characteristics are indicative of the Robberg in South Africa and Lesotho, even though bladelets never account for the majority of blanks (Deacon, 1995; Lombard et al., 2012; Mitchell, 1995; Wadley, 1996). This shows how much the definition of the ELSA relies on the characteristics of the following Robberg techno-complex and how the term itself restricts us geographically, despite the continent-wide use of the terms Middle Stone Age and Later Stone Age.

The problems of cultural taxonomy have been highlighted for other periods and regions as well (Conard et al., 2012; Shea, 2014; Wilkins, 2020). A brief overview on the history of the periodization of the African Stone Age highlights the difficulty in characterising the appearance of the Later Stone Age and what it might mean. The trifecta of the African Stone Age – Early, Middle and Later Stone Age – was first stated in 1929 (Goodwin & Van Riet Lowe, 1929) and mirrors the European classification of the Palaeolithic (Schlanger, 2005; Shepherd, 2003). Twenty-six years later, at the Panafrican Congress in 1955, it was already apparent that some assemblages could not be fitted in this threefold system (Clark, 1959; Malan, 1949). Intermediate stages in between the ESA and MSA as well as the MSA and LSA were proposed, the latter called Magosian. At the time, the Magosian included what we call today the Howiesons Poort (Clark et al., 1966; Hole, 1959; Malan, 1949; Wayland & Burkitt, 1932). From today's perspective the term Magosian subsumed distinct chrono-cultural entities like the Howiesons Poort, late MSA and final MSA (Bader et al., 2022b; Bader et al., 2018; Villa et al., 2005). In the original tripartite, the LSA only consisted of the so-called Smithfield and Wilton as techno-complexes (Goodwin & Van Riet Lowe, 1929), which was further developed by Deacon (1976) and then revised in the 1980s (Deacon, 1982, 1984). At that time the LSA was subdivided into Robberg, Albany and Wilton and it became standard that the Robberg would succeed the final MSA (Deacon & Deacon, 1999). This was despite the fact that the term Early Later Stone Age had already been introduced much earlier, however weakly defined (Beaumont & Vogel, 1972). Instead of improving our understanding of the transition from the MSA to the LSA, the continuous addition and abandonment of cultural taxonomic terms has become an obstacle rather than a means of structuring for this specific time frame. This is most evident in the debate about the origins of the LSA at the site of Border Cave (d'Errico et al., 2012; Mitchell, 2012; Villa et al., 2012). The lithic technology there exhibits all the characteristics of a 'true' LSA but predates similar occurrences by at least 12,000 years (Villa et al., 2012), and there is no reasonable basis to question the site's chronology. This has led researchers to assume Border Cave to be the point of origin for the LSA and that the new technological 'package' spread from there into the rest of southern Africa (Bousman & Brink, 2018; Villa et al., 2012). A recent review on the archaeological evidence from the region surrounding Border Cave and a prolonged coexistence of MSA and LSA technological traditions cast serious doubt on the hypothesis that Border Cave marks the origin of the LSA (Bader et al., 2022a; Scerri et al., 2021; Tryon, 2019). In fact, the very characterization of the ELSA as being a combination of trait from both the MSA and the LSA (Clark, 1997; Porraz et al., 2016) can be taken as evidence for a long phase of coexistence of the two units. Rather than representing new technological traditions, the LSA is not more different from the MSA than the Howiesons Poort is from the Still Bay. As such, in retaining these overarching terms, the notion that these periods might reflect two different cultural entities is enforced, even though this is obviously not the case (see also Tryon, 2019).

This has implications for Klein's model on the origin of behavioural modernity (see chapter 1). In its original concise formulation (Klein, 1995), the model was created in the dichotomy between Neanderthals and anatomically modern humans and all its implications at that time. Therefore, it would be a strawman argument to criticize it on this basis and dismiss all the adjustments that have been made over the past decades (Klein, 2000, 2001, 2008, 2009, 2019; Klein & Edgar, 2002). The central point of the model however, that behavioural modernity emerged abruptly and as a package, has never been abandoned. The model now assumes a mixture of previously unconnected population caused by climatic disruption that led to a novel genetic combination, which in turn led to enhanced cognitive abilities in this reshuffled population (Klein, 2019; but see Scerri et al., 2018). In the latest version of Klein's model, emphasis is placed on ostrich eggshell beads from East and South African contexts. Enkapune ya Moto, Magubike, Mumba Cave and the associated dates (Ambrose, 1998; Gliganic et al., 2012; Miller & Willoughby, 2014). This model also assumes Border Cave in South Africa to be the earliest expression of the LSA in South Africa (Bousman & Brink, 2018; d'Errico et al., 2012; Villa et al., 2012). This hypothesis has recently been conclusively rejected (Bader et al., 2022a). The result from Umbeli Belli seem to support this as well the findings of Bader et al. (2022a) (**Blessing et al. 2022 submitted b**). Further evidence for a long coexistence comes from West Africa as well (Scerri et al., 2021). The assemblage at Umbeli Belli in particular, but also characterizations of the ELSA at other southern African sites show that what we define as LSA replaces the technological traditions of the MSA very gradually, to a point where even the division between the MSA and LSA becomes questionable. Undeniably, there is a serious increase in outside storage of symbolic information in the course of the colonization of Eurasia by *H. sapiens* (see also Conard, 2005; Conard, 2008, 2010). Furthermore, linking this to a sudden increase in the cognitive capacity for such behaviour is problematic (see CHAPTER 3.4).

3.2 Artefact standardization and behavioural modernity

The following paper addresses artefact standardization during the MSA. A brief report of our findings is followed by a discussion about the potential of artefact standardization within in the larger framework of behavioural modernity.

- **Blessing, M.A.** and Will, M. (submitted), Lithic standardization and behavioral complexity in the Middle Stone Age – a case study from Sibhudu, South Africa. *Submitted to Lithic Technology* (*Appendix ii.b*)

Blessing and Will (submitted) report on a study of bladelets from the Sibudan layers BSp, SPCA, POX, WOG1, BYA2i and LBYA excavated between 2011 and 2014 under the direction of N. Conard (Conard et al., 2012; Will et al., 2014). Sibhudu is located about 40 km north of Durban in KwaZulu-Natal, South Africa, with a rich stratigraphy of the Middle Stone Age currently dating to >100-38 ka (Jacobs et al., 2008b; Wadley & Jacobs, 2006; Tribolo pers. comm.). Overall, the sequence comprises more than 50 MSA layers, all of them being predominantly anthropogenic in nature. Organic preservation is exceptional and post-depositional disturbances are minimal. In approaching standardization and variability as opposite ends of the same spectrum, we combined the data from the Sibudan bladelet assemblage with additional data on laminar blanks from the Howiesons Poort as well as data from the tool and core assemblages relevant to the question of standardization and variability in the MSA.

Due to the enormous amounts of finds in general, but particularly stone artefacts, the analytical approach for lithic studies at Sibhudu involves a cut-off size of 3 cm. **Blessing and Will (submitted)** focused on the recovery and analysis of bladelets and bladelet fragments smaller than 3 cm. As such this appraoch represents the first study of this kind. The first question was how many, if any, bladelets at all were missed due to the necessary cut-off size. Out of the fraction <3 cm of the six layers we sampled, we found a total of 1179 bladelets. This is especially important as only 60 bladelets had been recovered from the >3 cm fraction of the Sibudan layers (Will et al., 2014) because it highlights the potential of this approach. Building on that, we collected qualitative and quantitative data from all bladelets recovered in order to explore standardization and variability in the Sibudan assemblage. We added data on the segments and laminar blanks from the Howiesons Poort layers from the Conard excavations at Sibhudu (Will &

Conard, 2020). We distinguished standardization of size, standardization of form and standardization of production.

The total number of bladelets recovered somewhat reflects the total amount of debitage recovered from each layer. The relative frequency of bladelets, however, was highest in those layers that had among the fewest total artefacts (BYA2i and LBYA). In terms of raw material, the study found that dolerite was the preferred raw material overall, which matches the observations from the >3 cm assemblage. However, there are significant differences in choice of raw material for bladelet production between the layers. While in the upper two layers (BSp and SPCA) hornfels and dolerite almost exclusively account for the bladelets, there is a clear dominance of dolerite in POX and WOG1 (76 % and 54.5 %, respectively). BYA2i and LBYA also exhibited clear preferences in raw material choice with quartz accounting for 44.4% of the bladelets and other raw materials ranging between 17.8% and 8.9%. The bladelet assemblage of LBYA is dominated by sandstone (65.8%). In terms of metric standardization where we compared the coefficients of variation of length, width and thickness, we found all metric measures to exhibit some standardization except for weight. Standardization of length did not show any trend throughout the sequence, while width was more standardized in the lower layers as compared to the upper three. In absence of 2D or 3D morphometric data, we employed width/thickness-ratios and observed parallelism as measures of shape standardization. We found that the shape of bladelets changes from the bottom to the top of the sequence, but that this change is in no association with relative variability as the coefficient of variations lies consistently between 37% and 43%. The production of bladelets appeared to be very standardized, which is also partly reflected in the core assemblage. The bladelets were produced in a mostly unidirectional manner without core preparation. They exhibit a striking point very close to the platform edge. The cores from the lower Sibudan layers indicate a larger bipolar component compared to the upper three. This, however, is not reflected in the bladelet assemblage at all. We suspect this to be the result of export and use patterns for unretouched bladelets, especially for quartz (e.g. Binneman, 1997; Binneman & Mitchell, 1997). Since bladelets are rarely used for retouch in the Sibudan, we used the Tool Group Index (TGI; see Kandel et al., 2016) to assess the variability in the entire category of retouched pieces, instead of using the overall tool assemblage of the Sibudan. The upper three layers, BSp, SPCA and POX, feature a higher variability in tools than do the lower three layers (see also Will & Conard, 2018).

We continued to explore the standardization of laminar blanks and segments from the Howiesons Poort layers of Sibhudu. We observed a clear diachronic trend from bottom to top of the Howiesons Poort sequence, which means a decrease in bladelet and segment production. This is accompanied by an increased focus on dolerite for both artefact classes, while the overall frequency of dolerite decreases. However, the coefficient of variation indicates no changes in the degree of standardization across the layers despite the decrease in numbers of bladelets and segments. As with the Sibudan bladelets, the standardization of laminar blanks in the Howiesons Poort is highest in length and width. Thickness displays the lowest degrees of standardization except when specifically comparing the segments, where all measures are comparably equal, with a tendency of length being the least standardized. Parallel to the decrease in numbers of bladelets, we observed an increasing variability in cores from which the bladelets were produced. The Relative TGI for the Howiesons Poort layers highlights an increase in tool variability from bottom to top of the sequence; a diachronic trend that continues in the Sibudan layers.

We proceeded to compare the standardization between the two techno-complexes and found the Howiesons Poort to display a slightly higher degree of standardization indicated by lower coefficients of variation. However, the differences are rather marginal, especially when considering that backed pieces haven been deliberately shaped into tools, while the bladelets likely represent blanks from multiple stages of the production chain. In all assemblages we found the standardization to be strongly influenced by raw material choice (see also Chase, 1991; Chase & Dibble, 1987; Dibble, 1989), which led us to explore the question about standardization and its implications on a broader level.

The standardization of lithic artefacts has been one of the central points in the original creation of the concept of behavioural modernity. The hypothesis has been that artefacts become more standardized in the Upper Palaeolithic compared to the Middle Palaeolithic (Mellars, 1989a, 1989b, 1991, 1996). An increased standardization or refinement of artefacts as a means of describing cultural evolution was first used in the 19th and the early 20th century (Commont, 1908; De Mortillet, 1883). Mellars combined this way of thinking with two other existing concepts in order to explain the difference in artefact standardization between the Middle and the Upper Palaeolithic – the mental template and the imposition of arbitrary form (Mellars, 1989a, 1989b, 1991). The concept of a mental template stipulates that when creating an artefact "the idea of the proper form of an object exists in the mind of the maker" (Deetz 1967, 34). The imposition of arbitrary form was one of the key features in defining human culture (Holloway, 1969). It describes the idea that a 'true' cultural item has "[…] no necessary relationship between the form of the final product and the original material" (Holloway, 1969, 401). The making of stone artefacts was seen as a perfect example of this and by combining it with a mental template, Mellars made a case for increased cognitive abilities in modern humans as opposed to Neanderthals. A similar idea had also been proposed for the transition from the Lower to the Middle Palaeolithic (Ronen, 1982). Over the following decades the hypothesis of an increased standardization in the Upper Palaeolithic was put to the test (Chazan et al., 1995; Dibble, 1989, 1995; Marks et al., 2001; Monnier, 2006; Monnier & McNulty, 2010). The concept of standardization also made an impact on research in South Africa, where it was first linked to symbolic behaviour as seen in the backed artefacts from the HP at Klasies River (Wurz, 1999), which has recently been expanded to the entire southern African subcontinent (Way et al., 2022).

Testing Mellars' hypothesis has brought to light that, in fact, there is no increase in standardization from the Middle to the Upper Palaeolithic (Chazan, 1995; Marks et al., 2001; Monnier, 2006; Monnier & McNulty, 2010). Further, it has sparked a discussion about using standardization properly including, which measures to employ and what it can potentially mean (Chase, 1991; Marks et al., 2001). The coefficient of variation is ideally suited to explore the degree of standardization and is therefore widely used (Eerkens & Bettinger, 2001; García-Medrano et al., 2022; Heckel, 2018; Marks et al., 2001; Monnier, 2006; Roux, 2003; Wurz, 1999). Nonetheless, there are important considerations to make for the interpretation since the coefficient of variation is a dimensionless measure and requires further contextualization. First and foremost, by employing the coefficient of variation as a measure of standardization, it is implied that standardization and variation are two extreme ends of the same scale. This urges the question, if this scale is continuous or if there is a sharp break between an assemblage that is standardized and one that is variable. A view to research outside of archaeology helps to clarify this issue. In the 19^{th} century it was observed that there is a limit to the human perception of difference called the Weber fraction (Eerkens & Bettinger, 2001; Norwich, 1987; Weber, 1834). A Weber fraction describes the amount of variation below which humans will perceive a set of objects as identical and it exists for a variety of sensory experiences such as weight (e.g. Coren et al., 2004; Ross, 1997; Weber, 1834), length (e.g. Coren et al., 2004; Teghtsoonian, 1971; Verrillo, 1981) and other visual aspects (Bruce et al., 2003; Howard & Rogers, 1995; Mather, 1997). This value lies between 2 % and 6 % in humans and non-human primates (e.g. Laursen & Rasmussen, 1975). **Blessing and Will (submitted)** used the absolutely minimum given for a Weber fraction which is about 1.7 % as lower threshold of standardization. Lower values are only expected from machine production even though such values have also been reported for handcrafted pottery (Eerkens & Bettinger, 2001; Roux, 2003). The upper threshold for standardization is 57.7 % (Eerkens & Bettinger, 2001). This value marks the amount of variation that is expected from random production in a number space where values are distributed uniformly between 0 and X. While objects with metric measures of zero can’t exist, 57.7 % has been chosen for the sake of comparability. Theoretically, a contextualized upper threshold can be calculated when minimum and maximum values of the assemblage in question are given (Eerkens & Bettinger, 2001), but since this is not always the case the use of the 57.7 % threshold ensures comparability across assemblages. Coefficient of variation values that plot above 57.7 % imply exceeding variability, which could theoretically be interpreted as historical variability. However, since assemblages are sorted using modern classification systems, a deviation >57.7 % could also mean an artificial inflation caused by a flawed classification or improper employment of the metric measure (Eerkens & Bettinger, 2001). We can see this in the remarkably high values of weight reported in **Will and Blessing (submitted)**. Weight is not part of the classification neither in bladelets nor in segments and as such the amount of variability observed in weight is not to be mistaken for a conscious deviation from a standard by the makers or any other sort of historical variability. Rather this reflects the characteristics of the classification system. If we were to include weight into the classification of artefacts, we would most likely see the coefficient of variation for weight also fall below the threshold of 57.7%. The very fact that there is a value marking random production implies that there is a sharp break between standardization and variation.

This has a major implication regarding the production of (stone) artefacts. A standardization of artefacts within one class along the measures that are used to define the class is to be expected, given that objects in this artefact class were not randomly produced. In turn, this has implications for the use of standardization in stone artefacts and their marker as symbolic behaviour and as such for standardized artefacts as a proxy measure for behavioural complexity. With respect to the South African archaeological record, segments came into focus as a highly standardized tool class first (Deacon, 1989) and their association with symbolism came later (McBrearty, 2007; Way et al., 2022; Wurz, 1999). The argument is largely based on viewing segments as a stylistic expression as Wiessner (1983, 1984, 1985, 1997) used it in an ethnographic context. This unifies the intent to communicate with the physical manifestation of this intent via standardized artefacts or conformity to a standard. Archaeologically, we can recognize style as a geographically and chronologically limited phenomenon (Wynn, 1996). What archaeology cannot recognize is the intent to communicate and this is why we have to critically examine our ability to identify symbolism in stone artefacts, rather than taking the mere occurrence of style as an indicator for it (see also Chase, 1991). Contrary to icons and indexes, where the relationship between them and their referent is natural, the relationship between a symbol and its referent is arbitrary (Chase, 1991). This means, that there has to be a social convention for a sign (symbol) and what it refers to. This is essentially how languages work. While it is comparably easy to recognize style in the archaeological record, inferring symbolism from is far more complicated, particularly when long as stone tools are the objects in question. Sackett (1982, 1986) distinguishes between active and passive style as well as adjunct and isochrestic style. Active style refers to an artefact that is intended to convey social information by its maker, while passive style occurs without such an intention. Adjunct style describes the addition of something to an artefact that exceeds its function or technology. Decorated Magdalenian projectile points are an excellent example of this phenomenon as they highlight the function of an artefact in both a subsistence and a social context (e.g. Langley, 2014, 2018). The last characteristic of style – isochrestic style – acknowledges the existence of multiple methods of production for similarly shaped artefacts as well as the importance behind the choice to use one of these varying production methods (see also Chase, 1991; Sackett, 1982, 1986). This focus on choice means that isochrestic style should not be mistaken for passive style (see Wiessner, 1985). For archaeologists two important things can be derived from this reflection on style. Firstly, style is an index of a group of people. With regards to the Howiesons Poort segments, this means that the presence of segments within a certain time frame points towards the Howiesons Poort techno-complex which may or may not reflect a deliberate choice to convey a social message. It can also reflect a shared tradition of how to produce artefacts (Chase, 1991) or, in other words a conformist bias in cultural transmission (e.g. Henrich, 2017; Henrich & McElreath, 2003; Muthukrishna et al., 2016). For the standardization in the archaeological record, this means that there is no necessary relationship between the standardization and symbolism. Only if constraints by technology, raw materials, or function can be excluded to account for the standardization, is it possible to infer symbolism (Chase, 1991). At present, this is not the case for the Howiesons Poort segments.

Blessing and Will (submitted) found a relationship between standardization and raw material choice in both the bladelets from the Sibudan and the Howiesons Poort segments at Sibhudu. This confirms previous notions that raw material choice can account for standardization (Chase, 1991; Chase & Dibble, 1987; Dibble, 1989; Moloney, 1996). The elaboration on style and symbolism also shows that it is entirely possible for a mental template to exist in the mind of the makers of an artefact without the intention of this mental template to be a social marker. Based on these theoretical considerations, we reject the hypothesis that segments are a marker of social identity in the Howiesons Poort. They can still be seen as a marker of connectivity in and among populations (Way et al., 2022), if they are the result of an isochrestic choice that is socially transmitted among different groups. It is unlikely, that segments worked as a marker of social identity because (a) parts of them are always obscured by hafting them and (b) their technological constraints, which are likely also part of the cultural unit that is transmitted (Eerkens & Lipo, 2005), fully account for their standardization. Further to this, the standardization is higher in those parts that are functionally relevant – thickness and width (see also Marks et al., 2001). A technological choice paired with the very act of defining the characteristics for bladelets is also the reason why bladelets exhibit a certain degree of standardization. Therefore, the value of backed pieces as a marker of behavioural modernity is purely the underlying technology of hafting and use in composite weaponry (Lombard & Wadley, 2016; Wadley et al., 2009; Wurz & Lombard, 2007). As shown earlier this does not mean that there is no evidence for symbolic behaviour during the Howiesons Poort (see d'Errico et al. 2005; Henshilwood et al. 2004; Henshilwood et al. 2009; Texier et al. 2013). It only means that segments and perhaps stone tools in general are not a good marker for social identity, even if we can infer social connections by the underlying production method and use.

3.3 Behavioural modernity in the light of Neanderthal birch tar production

In a series of papers by work group in Tübingen that I was a part of, engaged in the current debate about birch tar production in Neanderthals. An integral part of this project is experimental archaeology and the papers relevant for this thesis are the following:

- P. Schmidt, **M. A. Blessing**, M. Rageot, Radu Iovita, J. Pfleging, K. G. Nickel, L. Righetti, C. Tennie, Birch tar production does not prove Neanderthal behavioral complexity. *Proceedings of the National Academy of Sciences 116/36* (2019) 17707–17711 (*APPENDIX i.a*).
- P. Schmidt, M. Rageot, **M. A. Blessing**, C. Tennie, The Zandmotor data do not resolve the question whether Middle Paleolithic birch tar making was complex or not*. Proceedings of the National Academy of Sciences 117/9 (2020)* 4456–4457 (*APPENDIX i.c*).
- **M. A. Blessing**, P. Schmidt, On the efficiency of Paleolithic birch tar making. Journal of Archaeological Science Reports 38 (2021) 103096
- P. Schmidt, **M. A. Blessing**, T. Koch, K. G. Nickel, On the performance of birch tar made with different techniques. *Heritage Sciences 9*, 140 (2021) 1–9 (*APPENDIX i.d*).
- P. Schmidt, T. Koch, A. Charrié-Duhaut, F.A. Karakostis, K. Harvati, V. Dresely, **M.A. Blessing** (submitted), Birch tar documents cumulative culture in Neanderthals. *Submitted to Science* (*APPENDIX ii.c*)

These articles explore various aspects of birch tar, with a particular focus on Middle Palaeolithic birch tar. The starting point of the discussion around this aspect of behavioural modernity in Neanderthals was based on a perceived advanced technology with the identification of two organic lumps from the Middle Palaeolithic context of Königsaue in Germany. These lumps were identified as birch tar (Grünberg et al., 1999; Koller et al., 2001). Probably based on the known principles of pitch production and archaeological evidence from younger times (Dal Ri & Tecchiati, 2003; Kurzweil & Todtenhaupt, 1991), it was inferred that birch tar could only be produced in oxygen-restricted environments. Consequently, the following decades saw an impressive amount of experimental work that aimed to achieve oxygen depletion without the use of ceramics (Groom et al., 2015; Kozowyk et al., 2017; Osipowicz, 2005; Palmer, 2007; Piotrowski, 1999; Pomstra & Meijer, 2010; Schenck & Groom, 2018). Building on the hypothesis that this does most likely not reflect the starting point of birch tar production in the Middle Palaeolithic and that there must be a way to produce tar from birch bark that does not involve a complex setup, **Schmidt et al. (2019)** found a method of birch tar making that works in fully oxygenated conditions – the condensation method. In terms of setup and material requirements, this method still represents the simplest way of making birch tar that is currently known. It is an open-air method that only requires stones, birch bark and fire. A roll of birch bark is placed beneath a subparallel stone surface and lit. The whole process is observable at all times and only minor adjustments need to be made as the fire progresses. The tar condenses on the stone surface and can be scraped off using a flake or similar tool. This process can be repeated until the desired amount of tar has been scraped of the stone. The simplicity of the setup, as well as the tar forming in an environment without oxygen depletion made complex setups as an *a priori* assumption for Neanderthal birch tar production unnecessary and essentially invalid. However, rendering the necessity of a complex production method obsolete, does not mean that no other, more complex methods used by Neanderthals.

In order to approximate a solution to the complexity problem of aceramic birch tar production, **Schmidt et al. (2021)** tested the suitability of tar derived from the condensation against tar produced with other methods. The idea behind this was that if the birch tar made with the condensation method was outperformed by tars made with more complex methods, it would have rendered the condensation method as unlikely to be used by Neanderthals. The study reports on the tensile strength of differently produced tars and found all of them, including tar made with the condensation method, strong enough to be used as an adhesive for hafting. Actualised experiments outlined in the original publication of the condensation method had already hinted towards this finding (**Schmidt et al., 2019**). In order to further test the viability of the condensation method **Blessing and Schmidt (2021)** tested different methods of aceramic birch tar production regarding their efficiency, both in terms of time requirements and the material input/output. By testing for efficiency, we examined the possibility that some production methods could be not efficient enough to reliably produce birch tar. If an observable difference in efficiency could be achieved it would have been possible to exclude one or more production methods. Differences in success rate, visibility and possibilities to control the process justified an approach based on the risk hypothesis, according to which a technological system can be seen as a means to reduce the risk of resource failure (Collard et al., 2005, 2011; Torrence, 1983, 1986; Vaesen et al., 2016). Our study found that the condensation method could not only account for all known birch tar pieces from the Middle Palaeolithic, but even outcompeted methods known as ‘ash mound’ and ‘pit roll’ (see supplementary of Kozowyk et al., 2017 for a detailed description of the setup) in terms of material and time efficiency. The study also excluded raw material availability as a constraining factor, as birch bark was readily available when the known Middle Palaeolithic birch tar pieces were produced (Badino et al., 2020; Rageot et al., 2019). Risk of resource failure is not the only factor that can influence the development of complex technology, however. Another key factor are demographic variables, specifically effective population density and interconnectedness among groups (Henrich, 2004, 2017; Henrich et al., 2016; but see Vaesen et al., 2016). In the case of birch tar making, it is quite obvious that more complex setups lead to a higher tar yield with the ash mound method on the lower end of the spectrum and the raised structure at the higher end. Nonetheless, risk and demography are not necessarily mutually exclusive explanations for changes or innovation in a society, neither do they solely account for technological shifts on its own. There are two key factors setting these hypotheses apart from one another, making it very difficult to compare them. Firstly, the risk hypothesis compares toolkits of many different groups, regardless of temporal differences, whereas the demography hypothesis usually works on a diachronic scale. Secondly, the risk hypothesis deals with a technological system *in use*, in order to acquire a resource that is then either consumed or processed. The demography hypothesis is set up to shed light on transmission mechanism. Thus, they focus on different aspects of technological knowledge, which can be simplified as function vs. production. In order to invoke the risk hypothesis as an argument for the development of any complex technology, one would have to know about the technological system and its components, which is currently not the case for Late Middle Palaeolithic birch tar making. The demography approach should not be ruled out so easily by simply contrasting it to the risk hypothesis for the same reasons. When it comes to cultural innovation, anthropological studies (Henrich, 2004; Powell et al., 2009), and a large body of experimental laboratory work supports the demography hypothesis (Derex et al., 2013; Henrich, 2017, 2018; Henrich et al., 2016). Under this circumstance the development of a highly complex process like the raised structure seems unlikely, because of proposed low interconnectedness throughout the Middle Palaeolithic (Davies, 2012). The seeming accumulation of new traits for the time period of 50-45 ka might as well be “an artefact of our dating [and not necessarily] a behavioural reality” (Davies 2012, 120). A powerful line of evidence, which would allow us to unravel the complexity birch tar production in the past, would be the ability to identify chemical signatures caused by differing levels of surrounding oxygen.

To achieve this, we tried to settle the question of how Neanderthals might have produced birch tar (**Schmidt et al. submitted**). We employed a combination of Gaschromatography-Massspectrometry (GC-MS) and Infrared-Spectroscopy, in order to identify characteristic chemical signatures in the two Middle Palaeolithic birch tar pieces from Königsaue (Germany). GC-MS is a well-established method for the identification of birch tar as a substance (e.g. Grünberg et al., 1999; Mazza et al., 2006; Niekus et al., 2019; Rageot et al., 2019). We re-analysed the two tar pieces from Königsaue alongside samples from our own experimental sessions. These samples were produced using a variety of different production methods. We found that open-air methods like the condensation method or the cobble groove (Koch & Schmidt, 2022; Schmidt et al., 2019) have a profoundly different chemical signature than methods that rely on oxygen depletion. A distinction between the various underground methods (see above) was not possible. The two tar pieces of Königsaue share many chemical characteristics with the underground methods, which strongly suggests that the Neanderthals from Königsaue used one of these more ‘advanced’ methods to produce birch tar. While the discovery of the condensation method cast serious doubt on the *a priori* assumption that Neanderthals **had** to use a production method that relies on oxygen depletion, the latest paper on this topic proves that they most likely did. The combination of GC-MS and Infrared-Spectroscopy proved to be a valuable methodology. We were able to characterize the chemical signatures of tar made with different techniques and subsequently apply it to archaeological tar. All of these studies focussed on birch tar production come together to form a neat cycle starting with questioning the prevalent assumption by proving it unjustified, exploring explore several aspects and possibilities to find the solution that resolves the question. The condensation method retains its value in highlighting how birch tar forms in open-air conditions. While we will never be able to understand how Neanderthals began producing birch tar, our methodology has shown that it is possible to identify the production method they utilised given that there are enough experimentally derived comparative samples. Ultimately, we confirmed that the Neanderthals certainly had the capacity to invent and develop a method for birch tar production, which implies that their capacity to innovate on a technological level did not fall behind those of anatomically modern humans.

3.4 Technological complexity and behavioural modernity

Birch tar production and the presence of microliths are two key factors of identifying behavioural modernity in the technological realm (see chapter 1). To further understand what is the reasoning behind this and why it matters, we have to take a closer look at the concept of technological complexity.

Despite the heavy reliance on this concept for tracking cultural evolution, technological complexity in the archaeological contexts stands on very shaky grounds, because it is often only weakly defined (see also Perreault et al., 2013). Additionally, it is sometimes referred to, implied as, or paraphrased by words like ‘sophistication’, ‘refinement’, ‘advanced’, Conversely, terms like ‘crudeness’ and ‘simplicity’ are used to load the term with an implicit meaning. This loading as well as the vague nature of the concept itself are mostly tied to cognitive capacity where shifts in technological complexity are thought to reflect a change in cognitive abilities (Ambrose, 2001, 2010; Coolidge & Wynn, 2018; de Beaune, 2004; Foley & Lahr, 2003; Haidle, 2010; Mellars, 1989b, 2006b; Wadley, 2010a). As such, the concept of technological complexity can be viewed as one of the most central frameworks regarding the cultural evolution of the human lineage, which warrants a close look into its function and conceptualization in regards to the emergence of behavioural modernity.

Complexity in archaeological contexts is first and foremost a quantification problem (Hoffecker & Hoffecker, 2018; Perreault et al., 2013). There are many ways to measure complexity (e.g. Lloyd, 2001; Mitchell, 2009) but not all of them are suitable for archaeological contexts. Hence, I will only examine those measurements that have been proposed as suitable and have been applied to the archaeological record. Secondly, even if we agreed upon a quantitative method to measure complexity, a comparative analysis will still be required because there is no other way of contextualizing the derived value. As I will outline below, it is this relativity that is problematic when technological complexity is invoked as a proxy measure for behavioural modernity.

Measuring technological complexity

The best-known concept of technological complexity of hunter-gatherers was developed in the 1970s by W. H. Oswalt (1973, 1976), which is comparing the tool-kits of 20 different recent hunter-gatherer societies. He divided hunter-gatherer tool-kits into weapons, instruments and facilities incorporating these tool types into the term “subsistant”, in order to be able to address different types with the same term (Oswalt, 1973, 1976). Each subsistant is further divided into techno-units which correspond to the number of distinct parts comprised in a tool which then contribute to its finished form (Oswalt, 1976). In his system, simple subsistants do not change their physical form “[…] before, during, and after its brought into play […]” (Oswalt, 1973, 27). Complex subsistants, however, consist of at least two parts, that change their “[…] physical relationship to one another during use […]” (Oswalt, 1973, 28). His measurement of complexity counts the number of subsistants in a tool-kit (Oswalt, 1976). Instead of complexity, this number has also been referred to as the diversity of a tool-kit (Shott, 1986; Torrence, 1983, 1989). Additionally, counting the techno-units comprised in a finished tool also contributed to the overall complexity of a tool-kit (Oswalt, 1976). This way of measuring technological complexity is cross-culturally applicable and therefore a powerful tool not only for the ethnographic, but also for the archaeological record (see also Collard et al., 2005; Perreault et al., 2013).

Parallel to Oswalt’s measurement of technological complexity is the Perreault et al. (2013) method of counting “procedural units” in lithic technology. This approach is rooted in the *chaîne opératoire* method of lithic analysis (Boëda et al., 1990; Sellet, 1993) and lists thirty-five procedural steps that are associated with the production of lithic artefacts, which translates the *chaîne opératoire* into a number that represents the complexity of operational chains identified in the archaeological record. As the authors state themselves, the list is not to be considered exhaustive (Perreault et al., 2013). The independence of the analytical unit (procedural steps) and the content of the analysis (artefact or operational chains) is comparable, for example, to how biologists compare different ecosystems based on their species richness (e.g. Bonner, 1988). As with Oswalt’s system, this approach allows for cross-cultural comparisons of complexity, but shifts the focus from the finished artefacts to how much effort is required to produce them. Therefore, counting procedural units better accounts for differences in the complexity of a manufacture process of artefacts have the same count of subsistants. A good example would be wooden spears such as the ones found in Schöningen and a grinding stone (Osgood, 1940; Serangeli et al., 2012; Thieme, 1999). Both would have a techno-unit count of 1 in the Oswalt system, but, as has been shown by Haidle (2009), the manufacture of the spear is much more complicated than this number would reflect (see Hoffecker & Hoffecker, 2018). A disadvantage of procedural methods applied to essentially functional tools is, that ornamented artefacts with a functional purpose automatically score higher than ones that are not decorated even if the decoration does not contribute to the solution of a problem. Decorated Magdalenian projectile points or spear throwers again serve as a good example for this potential overstating of complexity (e.g. Cattelain & Pétillon, 2015; Garrod, 1956; Langley, 2014, 2018). Obviously, the decoration does not contribute to the function of the tool but it inflates the complexity measured in procedural steps taken to finish the artefact. Thus, it is not fully suitable to demonstrate complexity, if the goal is to establish the minimum number of steps required for the manufacture of a functioning artefact (Perreault et al., 2013). This line of thinking is how complexity is measured in other disciplines such as computer science (Chaitin, 1970) or ecology (Bonner, 1988). The approach is essentially information based, and includes the concepts of functional and structural complexity (Braha & Maimon, 1998; Hoffecker & Hoffecker, 2018; Simon, 1962). Here, information is viewed as the reduction of uncertainty or entropy (Shannon, 1948; Shannon & Weaver, 1963) in which the functional complexity of an artefact is defined as the uncertainty of it fulfilling its functional requirement, meaning the amount of information it contains (Braha & Maimon, 1998). Entropy or uncertainty is therefore the measurement of the complexity of the problem a tool is designed to solve and the count of hierarchical steps to reduce entropy (i. e. solve the problem) describes the complexity of the tool. Snares are an example of hunter-gatherer technology with a high functional complexity, because it effectively stores the knowledge about the mechanism and the animal behaviour in a kind of automaton (Hoffecker & Hoffecker, 2018). However, this kind of complexity can only be estimated by analogy in rare cases where all the information about time requirement, energetic expenditure, setup, and the like are readily available. In the archaeological context this is almost never the case or has to be estimated (Hoffecker & Hoffecker, 2018). Structural complexity, on the other hand, is closely related to the measurements of Oswalt or Perreault and colleagues, because it counts the hierarchical levels of artefacts. As such it can express the complexity of a finished tool or the production of it and can be applied to archaeological data, if the functional parts of an artefact can be reconstructed. Since functional complexity is expressed by hierarchical steps as well, measuring the structural complexity of an artefact or a *chaîne opératoire* appears to be a proxy measure for functional complexity, i. e. the reduction of entropy (Hoffecker & Hoffecker, 2018). Cognigrams can be considered a special variant of measuring structural complexity as they are also based on Shannon entropy and information theory (Haidle, 2006, 2009).

Functional and structural complexity only measure the complexity *necessary* for an artefacts function as they are aiming at the *minimum* number of steps or parts that are required. As such, they exclude non-functional parts of an artefacts like decorations, which is also part of Oswalt's measurement system for food-getting technology (Oswalt, 1976). Since structural complexity can entail both the function of a finished artefact or the operational chain of producing the artefact, both Oswalt's and Perreault and colleagues' approach are appropriate to use depending on the circumstance. Therefore, it is pivotal to reflect on what kind of complexity we are trying to grasp by the measurement. Are we attempting to assess the complexity of artefacts or tool-kits in use or the complexity of their production? As reflected by the Schöningen spears, the complexity of the technology in use as expressed by number of parts (n=1) can be significantly different from the complexity of its production (see Haidle, 2009). Here lies the first important distinction we have to make before using microliths or birch tar as a proxy measure for behavioural modernity. The complexity of both can be approximated by measuring the complexity of the finished artefact and the operational chain to get there.

Birch tar and technological complexity

The procedural unit approach was designed for the analysis of lithic artefacts, because there are general steps to accurately describe the production of every artefact. Such generality is not easy to achieve for birch tar production because of the many ways birch tar can be produced, which partly rely on entirely different extraction principles (Kozowyk et al., 2017; Rageot et al., 2019; Schmidt et al., 2019). Hence, an approach to counting hierarchical steps is the better option here, as it allows for detecting interdependencies among components. Put simply, the hierarchical levels reflect the necessary steps that build on each other. If one misses or fails, the whole process fails.

The argument for birch tar as a marker of behavioural modernity has been the assumed complexity of its production (Kozowyk et al., 2017 and references therein) and its use as an adhesive in composite weapons (Allué et al., 2022; Ambrose, 2010; Wadley, 2013). However, a close look at the known pieces of birch tar from the Middle Palaeolithic so far (Koller et al., 2001; Mazza et al., 2006; Niekus et al., 2019) reveals that there is in fact no evidence for the use of birch tar in hafting practices at all. The birch tar pieces that still have a lithic inserted show no other negatives of any kind of attachment to a shaft (Mazza et al., 2006; Niekus et al., 2019). The best contender for hafting evidence is the piece from Königsaue which has two negatives, one is for a lithic which was once inserted into the birch tar however the purpose for the second negative remains unidentified (Grünberg et al., 1999; Koller et al., 2001). Nonetheless, this evidence is inconclusive at best, because a) we don't know what the negative is and b) if this negative derived from a shaft, the mounting of the lithic would hardly be functional. The German Middle Palaeolithic site of Inden-Altdorf might provide evidence for hafting (Pawlik & Thissen, 2011), but the residue on the lithic artefacts there has yet to be conclusively identified as birch tar. It is clear that Neanderthals hafted tools (Rots, 2015, 2016) and even used adhesives (Boëda et al., 2008a; Boëda et al., 2008b; Boëda et al., 1996; Cârciumaru et al., 2012; Degano et al., 2019; Langejans et al., 2022) but birch tar has yet to be conclusively identified as a hafting agent used by Neanderthals. The argument for birch tar as an adhesive and thus its use in composite tools as a marker for behavioural modernity has to be rejected on the ground of current evidence. It should be noted that this rejection is only restricted to birch tar. The existence of composite tools and the use of adhesives other than birch tar in the Middle Palaeolithic is well supported by the current evidence (Boëda et al., 1996, 2008a, 2008b; Cârciumaru et al., 2012; Degano et al., 2019; Langejans et al., 2022; Rots, 2015, 2016).

With the rejection of birch tar in use as a marker of behavioural modernity, we have to turn to the production setup. In the absence of archaeological evidence in the form of artefacts or features related to birch tar production in the Middle Palaeolithic, we have to rely on experimental setups (Kozowyk et al., 2017; Schmidt et al., 2019). Applying either of the above-described measurements for complexity leads to comparable values across the different methods (Table 1)

		Complexity measure		
		Techno-units	Procedural steps	Hierarchical levels
Production method	Condensation method	3	3	3
	Pit roll	3	3	3
	Ash mound	2	2	2
	Raised structure	5	5	5

Table 1: Comparison of different birch tar production methods with different complexity measures.

In assigning the values the bark roll and the heat source are counted as a techno-unit, a procedural step or a hierarchical level because without these no tar production is possible. The values in Table X reflect the minimum amount of complexity necessary for tar formation in each method. Tar collection could have been added as an additional techno-unit, step or level, which would increase all values by 1.

Even though the condensation method would intuitively score the lowest, in terms of the measures applied it does not. While the condensation method scores equal to the pit roll, and even more complex than the ash mound method according to these measures, this entirely omits the fact that the formation of tar is observable in the condensation method but 'hidden' in the other two (see also Schmidt, 2021). Additionally, it is somewhat surprising that different ways of measurement, which rely on very different assumptions and definitions, all score the same. The reason for this, in my opinion, is that all of these measurements are designed to be applied to a technological repertoire rather than a single technological trait (Hoffecker & Hoffecker, 2018; Oswalt, 1973, 1976; Perreault et al., 2013). That means even if we quantify the complexity of production methods for birch tar the values mean relatively little without the context of the whole technological system that birch tar production is embedded into.

Microliths and technological complexity

Contrary to birch tar the use of microliths as a marker for behavioural modernity is only rooted in their use in composite weapons, rather than in their production method (Ambrose, 2001, 2002, 2010; Lombard & Haidle, 2012; Lombard & Phillipson, 2010; Lombard & Wadley, 2016). By extending our understanding of microliths into the larger picture that they have been used in composite weapons, we can go back to the sequences of actions that are necessary to produce an arrow (Coolidge et al., 2016). Backing in and of itself is therefore not considered a marker for cultural modernity. A broad definition of microliths however, also includes microblades or bladelets, or their respective production (Kuhn & Elston, 2002), based on four criteria:

1) An increasing occurrence of microblades and the various ways in which they can be produced
2) Backing of microblades or bringing them into a certain geometric form by blunting one edge of the blank from which they are formed
3) The combination of 1 and 2 leads to standardization in size and/or shape as a third feature that defines microliths
4) Lastly, to use microlithic technology as a term to describe an assemblage or part of an assemblage is only justified when criterion 1 and/or 2 makes up the majority or substantial part of the assemblages in question, so that they are identifiable as a distinct technological trait

It is evident that based on these criteria, size is not a primary feature of a microlith thus somewhat playing fast and loose with the term itself. Accordingly, it seems to be consensus to label for example Howiesons Poort segments as microlithic regardless of their size (e.g. Lewis et al., 2014; Wurz, 1999; Wurz & Lombard, 2007). Persistant arguments have been made that size is whether an artefact should be considered a microlith (backed or not) needs to be decided based on context (Kuhn & Elston, 2002; Pargeter & Redondo, 2016). An alternative approach to the definition of microliths has been proposed by Pargeter (2016), who suggests backing, miniaturization (as in systematic production of small blanks regardless of shape) and microblade production on prismatic cores as characteristics of microlithic technology.

The link between backed microliths and microblade production is notoriously overstated; both can exist without the other and there is no necessity to produce backed microliths from microblades (Clarkson et al., 2018; Pargeter, 2016). The Robberg techno-complex is a good example because it has a microlithic component that is considered characteristic (e.g. Deacon, 1984; Mitchell, 1995; Mitchell, 2002; Porraz et al., 2016), but backed microliths are a rare occurrence (e.g. Wadley, 1996). However, there is tentative evidence that Robberg bladelets have been used as unretouched tools (Binneman, 1997; Binneman & Mitchell, 1997; Porraz et al., 2016) and so there is some justification to the assumption of the use of microliths in composite tools, even without the occurrence of backing (see also Elston & Brantingham, 2002 for evidence from northern Asia). While it remains to be tested in different assemblages, it is an assumption – which can easily be transformed into a testable hypothesis – that backed pieces always fall into the smaller categories of an assemblage, which would justify their inclusion into the microlithic repertoire based on their production technique.

While on a superficial level all criteria describe behaviours, including backing and production, the outcome in the archaeological context is often very differently looked upon. Backed microliths are, rightfully so, identified as tools due to their intentional modification. Subsequently, emphasis is usually placed on the shape of backed pieces and not so much on the technique used to produce them, i. e., the backing itself. Within the realm of possible forms (see McGhee, 2018), there is no limit to the shape of a backed microlith which is why an emphasis on the form is not wrong. In contrast, the second class of microliths – bladelets – is not regarded particularly interesting in terms of shape. After all, there are very strict constraints of what we call a bladelet in the first place. Size, production technique, and standardization are the more interesting aspects about bladelets.

The subdivision of microliths into backed microliths and microblades is essential for structuring a lithic assemblage but as far as their use as a marker for behavioural modernity is concerned, this distinction might not be practical. This is because their identification as behaviourally modern traits rests on their standardization and their use in composite weaponry which is where backed microliths and microblades converge (Clarkson et al., 2018; Elston & Brantingham, 2002; Kuhn & Elston, 2002; Lombard & Haidle, 2012; Lombard &

Phillipson, 2010; Mellars, 2006a; Way et al., 2022; Wurz, 1999; Wurz & Lombard, 2007). Based on ethnographic data, Hoffecker and Hoffecker (2018) have assigned an arrow a techno-unit count of 3 to 9 and 3 hierarchical levels. This assumes that an arrow only works in combination with a bow, hence the two additional levels (bow + the action of shooting). If microliths were embedded in bow and arrow technology (e.g. Lombard & Haidle, 2012; Lombard & Phillipson, 2010) it would be reasonable to assume these complexity counts accurately represented past use. Here we can see how different complexity measures can lead to different outcomes, because in terms of techno-unit count and most likely also by counting procedural units, arrows outscore birch tar production by far. In terms of hierarchical levels, however, they do not.

In sum, technological complexity was always and still is to some extent, a measurement problem. The measurements deployed for ethnographic and archaeological contexts are only useful if they are applied to the whole range of artefacts that are present. Using them to examine the complexity of a single technological trait carries little information. While birch tar and microliths have been used as evidence for modern behaviour in similar ways, a closer look highlights that not all of these assumed ways are justified. A lithic partly covered in birch tar is still, of course, essentially a composite tool, but that is not what is implied or stated by most researchers. Hence, the argument for behavioural modernity based on technological complexity for birch tar is only justified in its production technique. Producing a backed microlith is rather simple in comparison and is consequently not used as an argument for behavioural modernity. Rather, their presence is taken as circumstantial evidence for composite or even complementary weapons.

The difficulty of linking artefact standardization and behavioural modernity

Standardization is part of the definition of microliths and microlithic technology. Its placement on the trait list revolves around the existence and increasing refinement of mental templates (Mellars, 1989a, 1989b, 1991; Wurz, 1999; see also CHAPTER 3.2). This notion has been repeatedly tested and subsequently rejected (Marks et al., 2001; Monnier, 2006; Monnier & McNulty, 2010). It was shown that the standardization of tools is more likely to be attributable to raw material characteristics, functionality and the very act of classifying artefacts (**Blessing & Will 2022 (submitted)**; Chase, 1991; Chase & Dibble, 1987; Dibble, 1989, 1995; Marks et al., 2001; Moloney, 1996). Furthermore, when the coefficient of variation is employed as a measure for standardization to a non-randomly produced set of artefacts, a certain level of standardization is to be expected. Hence, the standardization of tools in the past should not to be regarded as a proxy measure for behavioural modernity, because it lacks the theoretical justification. It can, however, still be a useful tool to detect processes and mechanisms in the past, which infer behavioural modernity, when it reflects interconnectivity among populations and high-fidelity social learning. A recent example for the former is a study on Howiesons Poort backed tools in South Africa which were used as a marker of social connectivity (Way et al., 2022). It does not mean that the backed pieces used in the study are social markers themselves (see CHAPTER 3.2), but their occurrence over multiple biomes in direct vicinity to each other cannot be explained by convergence. They are rather indexical of social ties between populations and it is in my opinion no coincidence that evidence for widespread social networks coincides with an early flare-up in symbolic behaviour as seen in the Howiesons Poort and, similarly, the Still Bay as well (d'Errico et al., 2005; d'Errico et al., 2008; Henshilwood et al., 2004; Henshilwood et al., 2009; Texier et al., 2013). The standardization of bladelets is very likely to be attributable to the very act of classification itself, because a bladelet is defined both in terms of size and shape. We should therefore expect comparable levels of shape and size standardization in bladelets, which are produced from handheld prepared cores and unprepared bipolar cores. If we were to find a higher degree of standardization in bladelets from prepared cores, it would mean that factors in addition to the classification play a role. These factors would likely be rooted in the core preparation and reduction strategy which require expert cognition (Wynn & Coolidge, 2019 and are likely a product of high-fidelity learning (Tennie et al., 2009; Tomasello, 1999).

To summarize, the standardization of stone artefacts can be attributed to a multitude of factors, but symbolic behaviour does not seem to be among them. Even though there is no theoretical justification for their original incentive to place them on the trait list for behavioural modernity, they can still be a useful trait to detect mechanisms and processes that are indicative of behavioural modernity, such as social connectivity and high-fidelity transmission.

CHAPTER 4 – CONCLUSION AND FUTURE PERSPECTIVES

There are several avenues to measure complexity and while we have explored the most pertinent in this research, it is not an exhaustive list. They represent the measures that have been successfully applied in the context of archaeological and ethnographic hunter-gatherers. Two things become evident, if we look at how complexity measurements are applied;

1) Their application is limited by the underlying assumptions made, which influences what exactly they measure – artefacts in use or the way artefacts are produced
2) Assigning a value does not mean that we know what this value means. The contextualization of the value rests upon the comparison to at least one other artefact or tool-kit. Therefore, complexity is always relative and a complexity value needs a reference point regardless of the measurement method

While these insights are ground breaking, they are pivotal for our understanding and interpretation of the archaeological record in general, and technological complexity and behavioural modernity in particular. The first insight highlights that there are two lines of evidence along which behavioural modernity is inferred from technological complexity, artefact use and production. As such their complexity, even if we assume a correct measurement, is not straightforward to compare because it reflects two different processes. The second insight calls for a reference point that is logical instead of arbitrary. If we make the comparison to something that is old enough, we will inevitably find something more recent to be more complex. If we were to compare today's material culture, for instance a smartphone, to Palaeolithic material culture, like a bifacial point, we must, conclude that today's material culture is by far more complex than Palaeolithic material culture (Chase, 2003). This is, of course, an extreme example but it is logically the same procedure as a comparison between microlithic technology (about 70 ka old) and the Schöningen spears (about 300 ka years old). Technology A (smartphones/microlithic technology) is compared to technology B (bifacial point/wooden spear) with regards to their complexity. As such, we are able to compare the complexity of two or more technological traits or tool-kits and make a decision about which one is more complex. Assigning a complexity value to a tool however, does not inform us about its suitability as a proxy measure for behavioural modernity, regardless of the measurement method. As with the link of symbolic behaviour and modernity, there is a substantial gap between technological complexity and behavioural modernity and this gap cannot be bridged by data alone (Botha, 2008, 2010; Coolidge et al., 2016; Haidle, 2016; Wadley, 2013). This results in a need for an underpinning theory, a need which has been at the centre of debate for more than two decades (Henshilwood & Marean, 2003 and comments therein). With respect to technological complexity, data only leads us to the recognition of how complex something is in comparison to something else, but not whether it is also something that should be considered behaviourally modern (see Coolidge et al., 2016). It has been pointed out by many researchers that the trait list was originally developed to contrast the European Upper Palaeolithic and the European Middle Palaeolithic and thus dictates our expectations of how modern human behaviour manifests (McBrearty, 2007; McBrearty & Brooks, 2000; Shea, 2011b). These expectations must therefore be seen as a Eurocentric approach that might not be suitable to archaeological contexts outside of Europe (Deacon, 2001; Foley & Lahr, 1997; McBrearty & Brooks, 2000; Shea, 2011b). Dismissing the entire concept of behavioural modernity (e.g. Shea, 2011a, 2011b; Zilhão, 2001b), however, is not helpful either because even flawed questions are worth asking (Conard, 2011) and replacing behavioural modernity with behavioural variability is equally hard to quantify (Conard, 2011; Nowell, 2011). Rather than abandoning the traits on the list or replacing it with another list adjusted to African contexts, it seems more promising to see which traits are theoretically justifiable to be regarded as a physical manifestation of behavioural modernity.

As I have outlined above, the archaeological evidence only justifies microliths as evidence for composite weaponry as there is no conclusive evidence for birch tar to be used as a glue by Neanderthals. The use of microliths in composite tools is undisputed and their use as armatures of arrows is more than likely as inferred from ethnographic and experimental data (Binneman, 1997; Binneman & Mitchell, 1997; Coolidge et al., 2016; Lombard & Haidle, 2012; Lombard & Phillipson, 2010). From there sequences of actions can be reconstructed, in order to make inferences about knowledge and expectations that had to be present in the mind of the makers (Coolidge et al., 2016; Haidle, 2014). In order to make a microlith relevant for discussion about behavioural modernity, hypotheses about the cognitive mechanisms enabling the reconstructed sequence of actions must be built with recourse on the archaeological evidence (Garofoli & Haidle, 2013). Since bow and arrow technology requires expert cognition, microliths are justifiable to be seen as evidence for behavioural modernity, when their use in composite weaponry is sufficiently documented (Coolidge et al., 2016).

The same line of arguments can be made for birch tar production now, as **Schmidt et al. (submitted)** have been able to show that Neanderthals used an underground technique to produce the birch tar pieces of Königsaue (Germany). Whether this is true for the other known pieces, particularly the oldest pieces from Campitello (Italy) (Mazza et al., 2006), remains to be tested. The hierarchical levels as well as the cognitive underpinnings of transformative technologies like birch tar production make it clear that Neanderthals possessed expert cognition as well (Wynn & Coolidge, 2004, 2019). As such it is safe to say that, from a technological point of view, behavioural modernity is not restricted to anatomically modern humans.

This could either mean that the technological aspect of behavioural modernity evolved in Neanderthals and *H. sapiens* independently or as a result of the cognitive prerequisites for it being present in the last common ancestor already. This by no means concludes that Neanderthals and *H. sapiens* were the same (Villa & Roebroeks, 2014). They are archaeologically distinguishable and cognitively different, but likely not to a great degree (van Schaik et al., 2019; Wynn & Coolidge, 2019; Wynn et al., 2016). If Neanderthals and *H. sapiens* achieved a behaviourally modern degree of technological complexity individually, then it retains its relevance for the search of the origins of modern behaviour and points towards a multi-species model (e.g. d'Errico et al., 2003; d'Errico & Stringer, 2011; d’Errico & Banks, 2013; Hovers & Belfer-Cohen, 2006). This could also be seen as an extension of the Mosaic Polycentric Model in the way that it allows archaic humans to have contributed to or developed behavioural modernity independently. If behaviourally modern technological traits were already present in the last common ancestor or earlier, the technological evidence for behavioural modernity coming from Neanderthals or *H. sapiens* would be of limited value for the question of its origin (Meneganzin & Currie, 2022). It would favour a model of gradual accumulation of behaviourally modern traits (McBrearty, 2007; McBrearty & Brooks, 2000), without being restricted to the African continent. The currently available evidence does not allow to make a conclusion which circumstance is to favour over the other, even less so the two technological traits this thesis focussed on. Overall, this highlights future avenues for scientific inquiry in the field of behavioural modernity.

Future perspectives

One way of deciding if behavioural modernity evolved in Neanderthals and *H. sapiens* independently or if it was already present in the last common ancestor, is looking for such evidence in the hominin species they shared the planet with – for instance, Denisovans, *H. floresienses, H. naledi.* If we were to find comparable levels of technological complexity that we can tie to behavioural modernity, it would be very unlikely, though not impossible, that these traits evolved independently. It would point towards the last common ancestor of all these hominins as the species where the physiological, genetic, and cognitive prerequisites for behavioural modernity evolved. Calling for more finds, more research, and more data is always a simple way to dodge a definitive answer but, in this case, I think it is a valid concern because we know very little about the material culture of these more recently discovered hominins. These hominins complicate the picture but also hold much potential for coming to a better understanding of what behavioural modernity could be, when and how it evolved, and what it means.

As far as further theoretical substantiation goes, there are several potentially interesting avenues to proceed in which technological complexity plays a role. Understanding the causes and mechanisms that lead to the development and retention of complex cultural traits is such an avenue. One explanatory framework that has gained no traction is the influence of demographic factors (Archer, 2021; Henrich, 2004; Powell et al., 2009). These frameworks highlight that cultural evolution is not a linear development. This is especially true give the retention and loss of complex traits and technological complexity throughout the past (e.g. Haidle, 2016; Henrich, 2004). This is seen in the comparison of technological complexity among recent and historical hunter-gatherers, for which we can postulate equal levels of cognitive capacity and yet observe substantial differences in the complexity of their tool-kits (Hoffecker & Hoffecker, 2018; Oswalt, 1973, 1976). If we assume that both Neanderthals and *H. sapiens* had comparable levels of cognitive capacity to develop complex technology – and the evidence for it is indisputable – we could turn to alternative explanations like the influence of environmental factors (Collard et al., 2011; Collard et al., 2005), prey choice (Osborn, 1999; Oswalt, 1973), risk of resource failure (Torrence, 1986, 1989), mobility patterns (Shott, 1986) or, again, demographic factors (Henrich, 2004; Powell et al., 2009). These are not necessarily mutually exclusive models and hypotheses. It is unreasonable to expect that one model, one explanation, or one line of evidence provides further progress in the inquiry of behavioural modernity.

Further interesting trajectories are the integration of Extended Evolutionary Synthesis (Kissel & Fuentes, 2021) and Material Engagement Theory (Hussain & Will, 2021; Malafouris, 2016). There is a noteworthy similarity between cues as connectors between long-term memory and working memory in the expert performance model (Wynn & Coolidge, 2019) and the influence material properties have on decision making (Malafouris, 2016). This similarity might point towards a potential connection between these two theoretical frameworks and seems worth further inquiry in the future. Focussing only on symbolic behaviour as 'true' behavioural modernity (e.g. Conard, 2008, 2010; Henshilwood & Marean, 2003) potentially omits other traits that were relevant for the development of this specific behavioural realm and explaining precursors of this behaviour is still necessary to fully understand the evolution of behavioural modernity. This is essentially what Extended Evolutionary Synthesis calls for (see Laland et al., 2015), which is why this specific theoretical framework could prove to be a powerful tool for future inquiry in behavioural modernity. As such technological complexity is far from being irrelevant for the question about the origins of behavioural modernity, nor for explaining its presence in the archaeological record and why it evolved (Wadley, 2013).

At the moment we have to accept that we are in a state epistemic ambiguity in which all explanations are equally valid because we cannot dismiss either one of them for sure. With respect to the art installation (described in chapter 1), picking one trait, one model, one explanation will only allow us to see a fraction of what makes the whole. This somewhat reflects the underdetermination problem of archaeology (Perreault, 2019) in that choosing one thing to explain a vast concept like behavioural modernity will not do much good. In his book “The Quality of the Archaeological Record” Perreault (2019) outlines the way out of this intellectual stalemate, by focussing on macroscale processes. The evolution of behavioural modernity is such a macroscale process and the archaeological record is ideally suited to answer these questions because it provides multiple lines of evidence for behavioural modernity spanning millennia. It is important to consider all lines of evidence in this endeavour individually but the ultimate goal should be to reconnect them and understand how they intertwine instead of treating them as mutually exclusive. Rather than dismissing the entire concept because of flaws, it is in the interest of archaeology to evaluate the flaws and try to overcome them. If we do not investigate the antiquity of the behavioural patterns observed in modern humans, who will (see also Conard, 2008, 2010)? I am convinced the most interesting and informative times for the evolution of behavioural modernity still lie ahead of us.

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APPENDIX

Appendix i.a

Birch tar production does not prove Neanderthal behavioral complexity

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Birch tar production by Neanderthals—used for hafting tools—has been interpreted as one of the earliest manifestations of modern cultural behavior. This is because birch tar production per se was assumed to require a cognitively demanding setup, in which birch bark is heated in anaerobic conditions, a setup whose inherent complexity was thought to require modern levels of cognition and cultural transmission. Here we demonstrate that recognizable amounts of birch tar were likely a relatively frequent byproduct of burning birch bark (a natural tinder) under common, i.e., aerobic, conditions. We show that when birch bark burns close to a vertical to subvertical hard surface, such as an adjacent stone, birch tar is naturally deposited and can be easily scraped off the surface. The burning of birch bark near suitable surfaces provides useable quantities of birch tar in a single work session (3 h; including birch bark procurement). Chemical analysis of the resulting tar showed typical markers present in archaeological tar. Mechanical tests verify the tar's suitability for hafting and for hafted tools use. Given that similarly sized stones as in our experiment are frequently found in archaeological contexts associated with Neanderthals, the cognitively undemanding connection between burning birch bark and the production of birch tar would have been readily discoverable multiple times. Thus, the presence of birch tar alone cannot indicate the presence of modern cognition and/or cultural behaviors in Neanderthals.

modern behaviors | cognitive complexity | early pyrotechnology | Neanderthal birch tar | adhesives

Early birch tar (henceforth tar) production by Neanderthals has been interpreted as a marker of complex technology (1), high planning depth (2) and enhanced cognitive capacity (3). It is known from the Middle Paleolithic sites of Campitello (~200 ka [4]), Königsaue (~84 to 40 ka [5]), and possibly Inden–Altdorf (~120 ka [6]), leading some to argue that Neanderthals were the first to create complex production of adhesive (2, 7). The potential implications of early tar contrast with the absence of direct archaeological data on the techniques used for early tar making (8). Most interpretations are based on experimental setups involving containers and intentionally created reducing conditions (e.g., refs. 9–12) and sometimes elaborate experimentation (13). For example, useable quantities of tar can be produced if bark is indirectly heated in an earthen oven-like structure, a construction known as a clay castle or raised structure (14). Among aceramic techniques, raised structures come closest to techniques using ceramics or metal containers in terms of tar yield (compare refs. 2 and 10). Tar can also be produced by covering bark rolls entirely with ash and embers, with or without a fire on top (2, 13, 15). The tar is then collected from the bottom of such structures, either with a receptacle or in the windings of the bark roll itself. Tar can also be produced from bark in shallow pits, the burning end pointing downward, and the tar collected at the base (16). However, all of these experimental techniques have relied on one main assumption, that tar can only be produced by dry distillation in reducing environments (where the lack of oxygen prevents the tar's immediate combustion). This idea likely goes back to the discovery of tar distillation apparatuses from the Bronze Age of Italy (e.g., ref. 17). The 2-container method is well-documented from Roman times, and medieval texts describe tar distillation (12). The first experimenters trying to replicate early tar making (e.g., refs. 10 and 18) adopted the assumption of the necessity for reducing conditions. The result has been that all proposed experimental techniques to date require a degree of complexity that is unlikely to have come about by chance. Moreover, these already specialized techniques presuppose the knowledge and expectation of the technique's outcome: i.e., that tar (as a useful material) can be produced intentionally using the applied (complex) technique. But where, then, did this knowledge come from in the first place? If an easier, more intuitive and more likely technique were to produce sufficient amounts of tar, then complex techniques of tar production might have been unnecessary. In turn, the identification of tar in the archaeological record would cease to be a proxy for technological and cultural complexity. Accordingly, we investigated whether such an alternative, uncomplex, and readily discoverable method of tar production exists.

Results

We conducted systematic experiments using readily occurring, open-air conditions. First, we tested whether tar forms during

Significance

We found a previously unknown way to produce birch tar. Instead of creating cognitively demanding structures (underground or in containers), this method consists of simply burning bark close to cobbles in a hearth. The tar is deposited on the stones and can be scraped off for use. This approach to interpreting early tar resolves the mystery of the associated and still not understood early technical complexity and provides a "discoverable" pathway to one of the earliest pyrotechnologies. These results have implications for our interpretation of birch tar in the archaeological record: Birch tar from early archaeological contexts alone can no longer indicate the presence of modern cognition and/or cultural behaviors in Neanderthals.

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burning while birch bark is still attached to wood in the pore space between bark and stem—when branches are only partially lit or when detached bark is placed onto embers. No tar formation was observed in these conditions, highlighting that birch tar is not a byproduct of open-air birchwood fires.

We then tested whether tar would form when burning birch (*Betula pendula*) bark alone, i.e., detached from the wood. This situation would likely have been frequent in the past, as birch bark is 1) a natural tinder (19) (burning well, even when wet) and 2) readily collectible both from trees or (even easier) from forest floors, where the birch bark tends to stay recognizable and useable for some time after the wooden core has already rotted away.

Burning birch bark on a stone surface did not yield recognizable amounts of tar. Then, we burned birch bark at the side of a stone, i.e., next to a subvertical hard surface. In this situation, a black shiny deposit formed at the interface between stone and flames (we used a variety of different river cobbles with flat surfaces during successive runs, including quartz, limestone, and silt-stone). Burning birch bark next to such stones would likely have occurred frequently in the past, and also, we obtained similar results using bone instead of stone. The adhering substance was immediately sticky to the touch and remained sticky when scraped from the warm surface. From this we deduce that our first goal was already reached: tar production can be an accidental, and indeed even a likely, outcome of everyday activities for any group building fires with birch.

From this observation, we established a minimally complex protocol that would accumulate the sticky material across multiple burning events. Each event repeated the basic technique, i.e., a birch bark piece (which naturally rolls) was lit and burned beside a river cobble (the flames of the burning bark were measured at 600 to 700 °C using a thermocouple). The cobble was put on the ground to provide a flattish, rounded surface slightly overhanging the burning bark, in our case forming angles between ~60° and ~80° with the ground (Fig. 1 *A* and *B*). After repeating this burning procedure 2 or 3 times, the stone was picked up, and the (black and sticky) material (henceforth tar) was scraped from the cobble with a stone tool (a small flake independently produced, a skill that can be taken for granted in Neanderthals) before the process was repeated (Fig. 1*C*).

One can produce tar with bark cut from living birch trees and/or dead bark picked up from the forest floor. To assess the productivity of the latter method in terms of tar yield, we collected dead birch bark (as it is more easily accumulated than fresh bark) from a 20-m-long transect with a breadth of 4 m in a birch forest (total area of 80 m^2). This yielded 600 g of dead bark in a collection time of 27 min. When burned with the condensation technique, each 100 g of the dead bark resulted in 0.18 g of tar (as averaged from 3 measurements: 0.11, 0.08, and 0.13 g of tar from 57.7, 59.5, and 60.2 g of bark, respectively). In another experiment, we obtained 0.1 g of tar from dead bark approximately every 25 min, using 1 cobble at the time (a total of 0.62 g was made during this experiment; see Fig. 1*D*). While the tar yield by our condensation technique is 5 1/2 times lower than with the bark-burned-under-ash-and-embers technique—the arguably "simplest" of the more complex reducing conditions techniques (2)—it nonetheless produced useable amounts of tar (see also below) in a comparable amount of time. (Tar making with the condensation technique was filmed and can be seen in Movie S1.)

To assess the actual suitability of our condensation method for tar production (and the amounts produced in sensible time frames) we used our tar to slot-haft a Baltic flint flake and performed 2 experiments using the tool, first in a controlled, robot-aided setting (scraping wood) (Fig. 2*A*) and, subsequently, in an actualistic one (bone defleshing) (Fig. 2*B*). For these experiments, we used 0.6 g of pure (unmixed) tar that was produced by the condensation method (accumulated in a single 3-h session, including raw material collection time). The hafting arrangement consisted of a stone bit inserted and fixed by the birch tar (heated with a flame and dripped onto the haft) into a wooden cylinder (31.5 mm in diameter, 75 mm length) with a 12-mm-deep slot on 1 end (7 mm wide).

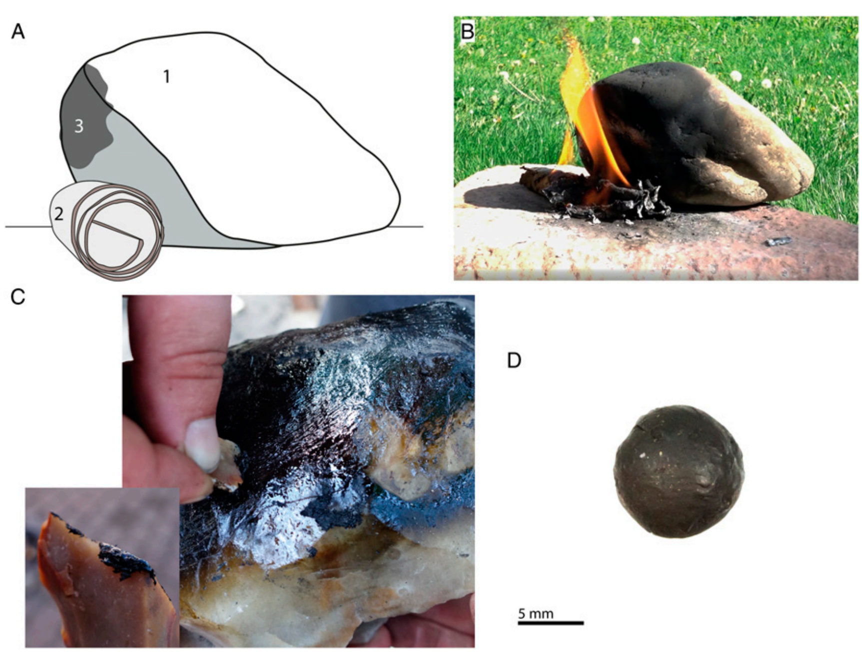

Fig. 1. Experimental birch tar making with the condensation technique. (*A*) Schematic drawing of the experimental setup: a cobble (1) with an inclined surface overhanging a piece of birch bark (2) is used as support for the condensation of birch tar directly above the burning bark (3). (*B*) Photo taken during experimentation using the setup shown in *A*. (*C*) Photo of the cobble surface where tar can be scraped off and the stone tool used for scraping. (*D*) Photo of a 0.62-g piece of tar produced in a single 3-h session (including bark collection).

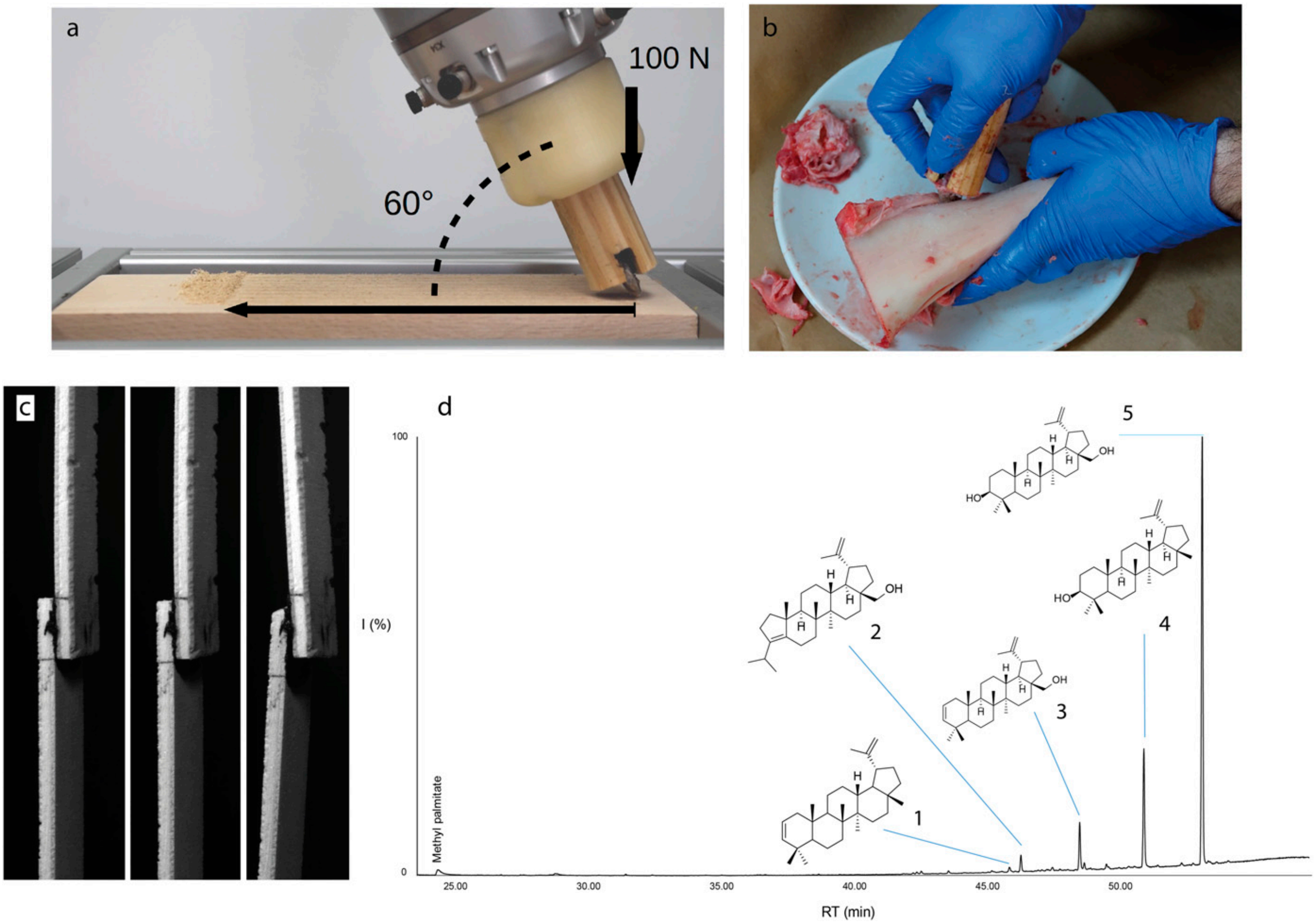

Fig. 2. Analysis of birch tar produced by the condensation technique. (*A*) experimental setup using the robot arm for wood scraping under controlled conditions. (*B*) Actualistic defleshing experiment using the same hafted tool as in *A*. (*C*) Three photos taken of a single sample at different moments during a lap shear test, (*Left*) 93.3 MPa before plastic deformation of the tar; (*Middle*) 90.7 MPa at the beginning of plastic deformation; and (*Right*) after failure of the tar. (*D*) Chromatogram of tar produced with the condensation technique showing biomarkers and markers of heat treatment: 1 = lupa-2,20 (29)-diene; 2 = α-betuline I; 3 = lupa-2,20 (29)-dien-28-ol; 4 = lupeol; 5 = betulin. RT, retention time.

We programmed the robot arm (KUKA LWR 14) to drag the hafted tool over a wooden panel under constant vertical load (Fig. 2*A*). After each stroke the arm repositioned the tool through the air to the same starting point (Movie S2). We chose a stroke length of 19 cm and downward force of 100 N and a working angle of 60°. The whole robot experiment took ∼19 min with a total of 170 strokes pulled by the robot arm; we did not observe any weakening of the adhesive connection between the stone and its haft.

Following this, the same hafted tool was reused in a manual cutting experiment, defleshing an ∼30-cm-long calf femur fragment (*Bos spec.*). The aim was to remove the remaining meat and periosteum. Transversal scraping and longitudinal cutting motions as well as hacking were performed using the full pressure needed to complete defleshing. The experimental goal was reached at ∼20 min, after which we cleaned and critically inspected the haft. We observed no detachment or weakening of the tar connecting the stone tool to its handle (the experiment was filmed and can be seen in Movie S3). Thus, tar produced with the condensation technique is perfectly useable under both controlled laboratory and real-world working conditions, while presenting the expected adhesive properties.

While these tests illustrate the suitability of tar produced with our condensation method for hafting, it remained unknown how it would perform relative to tar produced with other, more complex techniques. We therefore conducted a lap shear test (Fig. 2*C*) according to a protocol proposed for testing archaeological adhesives (following the ASTM D1002 guidelines but modified to use wooden laps instead of aluminum, following the reasons given by ref. 20). For this test we produced another 0.3 g of tar using our condensation method (again from dead bark collected from the floor of a birchwood forest). The mean of 10 lap shear tests resulted in a strength of 1.145 MPa +0.403 – 0.438 (as calculated from 10 tests; *SI Appendix*). This strength value is >3 times above the only published lap shear values obtained from birch tar produced with the 2-container method (0.32 MPa +0.19 – 0.18 from ref. 21) and agrees with strength values measured on pine pitch (with average values ranging from 0.37 to 1.77 MPa according to pretreatment [21]), being only slightly inferior to compound adhesives based on beeswax, conifer resin, and ochre (with average values ranging from 1.27 to >3 MPa; ref. 20). Thus, pure birch tar produced in our aerated environment has similar adhesive properties to other natural adhesives, and it actually outperformed birch tar produced in a reducing environment using a more complex technique.

Gas chromatography–mass spectrometry (GC–MS) was conducted to test if birch tar produced under air using the condensation method contains similar molecular markers as anaerobically made tar and known archaeological birch tar (Fig. 2*D*). Sample extraction and analytical conditions were performed following protocols established for birch tar analysis (22). GC–MS has previously been used to identify Paleolithic tar as being birch bark tar through the presence of characteristic pentacyclic triterpenes, in particular, betulin and lupeol (23), and their degradation markers that may indicate heat treatment (e.g., lupa-2,20[29] diene, lupa-2,20 [29]-dien-28-ol, and allobetul-2-en). This has been the case of the 2 oldest GC–MS-analyzed examples of birch tar from Campitello and Königsaue (24, 25). Analyzing our own experimental tar, we also identified both biomarkers (betulin and lupeol) in addition to 3 degraded markers (lupa-2,20 [29]-diene, α-betuline I, and lupa-2,20 [29]-dien-28-ol) that have been described to indicate heat treatment in previous experimental studies (22) and that were found in archaeological tar samples (26). Thus, tar produced in oxygenized environments with our experimental setup provides a molecular signature of birch bark tar. Future chromatographic analyses of archaeological tar should shed further light on the similarities and dissimilarities of tars produced in different environments.

Discussion and Conclusion

Birch tar production has long been thought to take place under oxygen exclusion only (2), i.e., in technologically complex and/or unlikely settings. Reducing environments allow the preservation of several chemical components that might otherwise burn off (5). This has led many researchers to propose birch tar production using heating systems that create anaerobic conditions in containers or underground (e.g., "clay castle," eggshell, ash mounts, ceramic containers, etc.; refs. 2, 8, and 27). However, we found that useable amounts of birch tar form in fully oxygenized environments, simply as a redisposition onto a surface, in what we call the condensation method. The underlying chemical process is likely dry distillation as for techniques using reducing conditions because the tar's chemical components transit by a gaseous phase before condensing on the surface. Whether it is oxygen depletion due to the nearby combustion or simply slow oxidation–reaction kinetics that prevent the tar from burning off cannot be decided without further analyses.

Thus, although our experiments do not elucidate the chemistry associated with tar production by our condensation method, they show that the creation of anaerobic systems as described by previous authors (see, e.g., ref. 5) are not necessary for tar making. The identification of birch tar at archaeological sites can no longer be considered as a proxy for human (complex, cultural) behavior as previously assumed (e.g., refs. 3, 14, and 28). In other words, our finding changes textbook thinking (29, 30) about what tar production is a smoking gun of.

As our results show, tar production does not require complex cognition, nor high planning depth, and it can derive from the simple juxtaposition of 2 everyday objects for Neanderthals (birch bark and stone or bone surfaces) derived from fire making/tending. While some parts (fire making/tending—see the current debate on whether Neanderthals were able to make fire [31, 32]—and perhaps hafting in itself) may or may not be good indicators of complex, modern human-like cognition, the condensation technique itself is not: a mere repetition of bringing 2 objects in close proximity and gathering of a resource is well within the cognitive power even of nonhuman great apes (33, 34). So, the natural (instead of cultural) intelligence of Neanderthals may have sufficed for the condensation method to 1) be innovated, possibly even multiple times, and 2) be preserved in populations via a process of "socially mediated serial reinnovations" (35). The latter is clearly a case of minimal culture (36). However, because minimal culture is very widespread in the animal kingdom, it is not only within the assumable abilities of Neanderthals, but also even for the earliest of hominins (37).

A more distinctive question, however, is whether birch tar making can be used as a proxy for Neanderthal's ability to show "cumulative culture" (38). In cumulative culture, cultural transmission, via actual copying of techniques rather than socially mediated reinnovation, over time necessarily leads to culture-dependent traits (39)—traits that cannot or are unlikely to be reinnovated. Arguably, this is not the case for tar production using a method as simple as the condensation method (see above).

This finding is important because modern human culture itself relies on culture-dependent traits, and it is currently debated which hominins (and when, and how often) had such culture-dependent traits (37, 40, 41). To throw light on these uncertainties loaded with implications for human evolution, we need a data-driven approach to archaeological finds to determine which and when they show signs of having been culture-dependent. As for tar production, the presence of tar in the archaeological record alone can no longer count as a secure case for culture-dependent traits in hominins, as the condensation method we describe even seems to be the likely method—potentially always serially reinnovated rather than copied—by which Neanderthals produced tar.

A future perspective that would allow further light to be shed on this hypothesis is comparing known artifacts associated with Paleolithic birch tar with the material produced by our own experimental tar making. Indeed, at Inden–Altdorf a sandstone cobble covered in a black tar (not yet confirmed to derive from birch) was found. Although the cobble is currently interpreted as a recipient for collecting tar in an underground structure (6), we note the striking similarity with the tar-covered cobbles we produced with our own condensation technique (compare Fig. 1 *B* and *C* with figure 3 in ref. 42). Thus, for now, the available archaeological data do not contradict our hypothesis, and we predict that future detailed analysis of new finds should strengthen our interpretations of early birch tar making.

Our findings do not necessarily lead to the conclusion that Neanderthals were not able to conduct complex procedures, nor that they were not capable of abstract thinking or high planning depths. In fact, Neanderthal modernity has been convincingly argued for based on a whole suite of behaviors (e.g., ref. 1). We merely note that, in archaeological science in general, arguing for abstract concepts like modernity or complex cognition in past populations should not rely solely on highly interpretative models of the production pathways of specific material finds. It should rather rely on the interpretation of the actually performed steps, as proven by direct archaeological data. If this is not possible, as in the case of birch tar, where direct evidence of the technique used by Neanderthals is still missing, our results highlight that the only viable interpretation of the implications of material remains is to admit the simplest possible pathway by which they can be produced. It is therefore no longer possible to use early birch tar making as proxy for complex cultural behaviors in Neanderthals.

Methods

Robot Arm. An industrial robot arm (KUKA LWR 14) was programmed to drag the tool with straight strokes of 19 cm in length over a wooden panel. After each stroke the tool was repositioned through the air to the same starting point. The downward force was kept at 100 N, and the working angle between underground and hafting was kept at 60°. In total, 170 strokes were executed, which corresponds to a duration of ∼19 min.

Manual Cutting Experiments. An ∼30-cm-long calf femur, purchased from a local butcher after preliminary removal of meat, was subjected to scraping and cutting motions by a 39-y-old, 75-kg city-dwelling male (R.I.), with the aim of removing the rest of the meat and the periosteum in the shortest time possible. Initially, a longitudinal cut along the periosteum was made using the tool longitudinally, followed by scraping motions using the tool transversally. To finally detach the periosteum, some mildly violent hacking motion was necessary, especially since the tool's edge had been dulled by the previous experiment.

Mechanical Testing. Lap shear tests were performed using an Instron 4502 universal test machine with kardanic suspended tensile grips, where laps were mounted vertically and pulled apart with a speed of 1 mm min^{-1}. Laps were cut and precision-ground from 4-mm-thick *Populus spec*. polywood measuring 100 × 25.5 mm. The 25.5 × 12.5-mm measuring contact zones (319 mm^2) were abraded with 100-grit sandpaper. Tests were repeated 10 times.

Chemical Analysis. Sample preparation and GC and GC–MS analyses were performed using the method described by refs. 22 and 43. Briefly, the sample was ground and then extracted in HPLC–grade dichloromethane (1 mg mL^{-1}). GC and GC–MS analyses were performed using an Agilent Technologies 7890B GC System series chromatograph including Agilent Technologies Capillary Flow-Technology Three-Way Splitter Kit coupled to an Agilent Technologies 5977A MSD and FID.

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Investigating the 1930s Kohl-Larsen collection from the Lake Eyasi Basin, Tanzania

Neue Forschungen an der aus den 1930er Jahren stammenden Sammlung Kohl-Larsen aus dem Becken des Eyasi-Sees, Tansania

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ABSTRACT

Since more than 80 years, the University of Tübingen hosts the archaeological collections excavated by Margit and Ludwig Kohl-Larsen between 1934 and 1939 in modern-day Tanzania. Despite the great scientific relevance of these collections, most of them were never published on an international scale and were thus unavailable for the broader Africanist archaeological community. In the light of new excavations around Lake Eyasi, conducted jointly by the Universities of Dar es Salaam and Tübingen and the Senckenberg Gesellschaft für Naturforschung, we decided to undertake a new inventory of the Kohl-Larsen collection, to analyze the assemblages using state of the art methods, link them with new excavation data and make them internationally available. As a first step, here we want to introduce the project by reporting on some preliminary observations from Njarasa Cave. Ultimately this research will help to create a coherent reconstruction of human cultural change and behavioral adaptions over the last ~200.000 years in this important archaeological landscape.

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Keywords: Tanzania, Njarasa Cave, Middle Stone Age, Later Stone Age, research project, Kohl-Larsen collection

Zusammenfassung
Seit mehr als 80 Jahren beherbergt die Universität Tübingen die archäologische Sammlung des Forscherehepaars Margit und Ludwig Kohl-Larsen. Die Kohl-Larsens führten zwischen 1934 und 1939 zahlreiche Ausgrabungen um den Eyasi-See im heutigen Tansania durch. Trotz des zweifellos hohen wissenschaftlichen Werts dieser Sammlung gingen die meisten Inventare daraus nie in international ausgerichtete Publikationen ein und blieben somit der Mehrheit der in Afrika forschenden Archäologen unzugänglich. Im Zuge neuer gemeinsamer Ausgrabungen um den Eyasi-See durch die Universitäten von Dar es Salaam und Tübingen sowie die Senckenberg Gesellschaft für Naturforschung lag es nahe, die Kohl-Larsen Sammlung von Grund auf neu zu inventarisieren, die archäologischen Inventare mittels moderner analytischer Verfahren auszuwerten und diese unter Einbezug der Resultate aus den neuen Ausgrabungen der internationalen Fachwelt zugänglich zu machen. An dieser Stelle soll zum einen das Projekt vorgestellt werden, zum anderen legen wir einige vorläufige Ergebnisse über die Njarasa Höhle vor. Das hier vorgestellte Forschungsprojekt wird dabei helfen, ein kohärentes Bild zu Kulturwandel und Verhaltensanpassungen früher Menschen in dieser wichtigen archäologischen Landschaft über die letzten 200.000 Jahre zu erlangen.
Schlagwörter: Tansania, Njarasa Höhle, Middle Stone Age, Later Stone Age, Forschungsprojekt, Sammlung Kohl-Larsen

Introduction
Ludwig and Margit Kohl-Larsen (Fig. 1) were researchers conducting archaeological and ethnographic fieldwork in and around the Lake Eyasi basin in Tanzania between 1934 and 1939. Ludwig, a German doctor by profession, was originally driven by a major ethnographic interest in the indigenous Hadza people, while his wife Margit from Norway was in charge of most of the archaeological excavations.

The most famous archaeological project led by the Kohl-Larsens was Mumba Cave. The site yielded one of the longest stratigraphic records in East Africa, spanning from the Middle Stone Age (MSA) to the Neolithic/Iron Age (Mehlman 1979; Prendergast et al. 2007; Bushozi et al. 2020). Most of the other sites excavated by the Kohl-Larsens, such as Njarasa Höhle (Njarasa Cave) or Straußenhöhle (Ostrich Cave), never gained attention beyond German-speaking countries. This was mainly due to Ludwig Kohl-Larsen publishing his opus magnum *Auf den Spuren des Vormenschen* (1943) in German, which was never translated into English. In the 1980s, Hansjürgen Müller-Beck, the former director of the Institut für Urgeschichte at the University of Tübingen, conducted a detailed review of the excavation history and published on several of the assemblages collected by the Kohl-Larsens (Müller-Beck 1978, 1981, 1985) all of them curated at the University of Tübingen until today. The results of this


Fig. 1: Ludwig (left) and Margit (right) Kohl-Larsen (photos: archive of the Department of Early Prehistory and Quaternary Ecology, University of Tübingen).

Abb. 1: Ludwig (links) und Margit (rechts) Kohl-Larsen (Fotos: Archiv der Abteilung Ältere Urgeschichte und Quartärökologie, Universität Tübingen).

work culminated in another monograph that was, with the exception of the fossil human remains (Müller-Beck 1981), again published in German. Although Rafalski et al. in 1987 published some of the assemblages also in English, and thus the majority of Africanist archaeologists may have heard about the many sites excavated by the Kohl-Larsens, only little information on the archaeological assemblages is available to the non-German-speaking scientific community. This is an unfortunate situation, especially since the Lake Eyasi basin, due to the high site density, holds the potential to contextualize debated research questions about human behavioral adaptations and the tempo and mode of cultural change in the MSA and Later Stone Age (LSA). Unlike one might expect from an excavation done in the 1930s, Margit Kohl-Larsen excavated the sites by following natural stratigraphic units, which were further subdivided into artificial subunits of between 10 and 20 cm thickness. She also took sediment samples from each stratigraphic unit and surface casts of the stratigraphic profiles conserved in resins. During fieldwork, the team sieved excavated sediments and labeled artifacts with corresponding stratigraphic information. Thus, even after more than 80 years since its excavation, the Kohl-Larsen collection provides substantial research potential.

Objectives

In 2018, the Volkswagen (VW) foundation awarded a research grant to Pastory Bushozi from the University of Dar es Salaam that included Nicholas Conard and Gregor Bader from the University of Tübingen as collaborative research partners. The project entitled "Evolving Human Minds" was extended in 2020 and generally aims to understand the rich archaeological landscape in the Lake Eyasi basin through renewed archaeological fieldwork. In the course of this project, we decided to create a new inventory of the Kohl-Larsen collection in Tübingen in order to test its potential to support the ongoing VW project with supplementary archaeological information. This project is funded by the Senckenberg Gesellschaft für Naturforschung and the University of Tübingen. Over the coming two years, we are planning to reanalyze the archaeological collections using different analytical methods including lithic technology, use wear analysis, petrography and zooarchaeology. We plan to publish our results in English and in international open access scientific journals. This project will take place in collaboration with students and researchers from Germany and Tanzania. As a first step, we started by assessing the size, integrity and research potential of the archaeological samples from different sites excavated by the Kohl-Larsens and curated them at the University of Tübingen. As many of the assemblages were recovered from stratified MSA and LSA sites, the collection offers large potential to improve the regional cultural and chronological framework in East Africa, where much archaeological information rests on unstratified open air sites (see Tryon and Faith 2013).

Fig. 2: a) Njarasa Cave with backdirt in front of the site 1935; modified after Kohl-Larsen (1943),
b) Njarasa cave in 2018,
c) Margit Kohl-Larsen next to the trench in front of Njarasa cave in 1935,
d) Margit Kohl-Larsen sorting sieved sediment during excavations at Mumba Cave.
(photos: 2c, 2d: archive of the Department of Early Prehistory and Quaternary Ecology, University of Tübingen, 2b: G. Bader).

Abb. 2: a) Die Njarasa-Höhle mit ausgehobenem Sediment davor im Jahre 1935; verändert nach Kohl-Larsen (1943), b) Die Njarasa-Höhle im Jahre 2018, c) Margit Kohl-Larsen neben dem Grabungsschnitt vor der Njarasa-Höhle im Jahre 1935, d) Margit Kohl-Larsen beim Aussortieren gesiebter Sedimente während der Ausgrabungen an der Mumba-Höhle.
(Fotos: 2c, 2d: Archiv der Abteilung Ältere Urgeschichte und Quartärökologie, Universität Tübingen, 2b: G. Bader).

Preliminary results

In the context of establishing a computer-based inventory of the Kohl-Larsen collection, we identified assemblages from 15 archaeological sites discovered by the Kohl-Larsens. The absolute count of the number of objects is not complete yet but is estimated to amount to over 200.000 pieces. Most of them are lithic artifacts and faunal remains as well as pigments, pottery, ostrich eggshell and soil samples. Three of the assemblages were considered to provide the highest research potential. These sites are Njarasa Cave, Ostrich Cave and Mumba Cave. The latter is subject to a monograph in preparation (Bretzke and Conard in prep.; see also Bretzke et al. 2006; Marks and Conard 2008). We decided to start this project with Njarasa Cave.

Njarasa Cave – stratigraphy

The site (Fig. 2) is located only 40 m north-east of Mumba and belongs to the same granite outcrop, the "Mumba Hügel" (Kohl-Larsen 1943). Margit Kohl-Larsen excavated the site between October 1935 and January 1936 (Kohl-Larsen 1943). Six archaeological units were defined from top to bottom, subdivided into further subunits. The excavations reached bedrock after ~7–8 m (Fig. 3). Below the surface layer I, which was a gray dust only 1–2 cm thick without any finds, layer II was described by Kohl-Larsen as orange sediment containing several stone artifacts, pottery and well-preserved faunal remains. Layer III at Njarasa Cave contained lithic artifacts, faunal remains and pottery. Layer IV can best be described as rockfall with numerous large, angular and also rounded stones. Kohl-Larsen mentions that all stones in this layer were covered with a whitish-gray crust as a possible result of percolating water. A similar layer was identified at Mumba both by Prendergast et al. (2007) (Level II-3) and our team. No artifacts from layer IV are mentioned and we found none during the inventory of the collection in Tübingen.

The underlying layer V could be further subdivided into three subunits, V1, V2 and V3 based on information provided on the old find tags and the Kohl-Larsen publication from 1943. Layer V1 at the top and V3 at the bottom were of whitish color, while V2 in between was gray (Fig. 3). Apart from numerous lithic artifacts and many faunal remains, several potential hearths where identified in this unit. Layer VI below was subdivided into VI1 and VI2. The sediment of the deeper unit was darker and siltier compared to the sandy, yellow matrix of VI1.

As the end of their first expedition was coming closer, the Kohl-Larsens were not able to excavate the entire cave. Layer VI was excavated down to bedrock only in a small test-trench and according to the profile drawing (Fig. 3), remnants of layer V may likewise still be preserved.

Njarasa Cave – dating

For our analysis of the Njarasa assemblages, we decided to start with layer III and V in order to get comparative information from the LSA (layer III) and MSA (layer V). We selected five bones from both layers for C14 dating. Unfortunately, none of them contained enough collagen to provide any results (MAMS-46631 – 46635). Based on this outcome, we are currently assessing other possibilities such as ESR dating on herbivore teeth with attached sediments. This being said, the nature and succession of the upper four stratigraphic units at Njarasa closely resemble the stratigraphy from nearby Mumba Cave. The orange layer II at Njarasa was also identified at the top of Mumba Cave by Prendergast and colleagues (2007) as level II-1 and dated to 398 ± 86 cal BP (OS-61330). During the new excavations at Mumba Cave by P. Bushozi, N. Conard and G. Bader since 2017, the same orange layer was identified. Furthermore, in Mumba Level III-2, which is overlying the rockfall Level III-3, a Kansyore potsherd was directly dated using radiocarbon to 4190 ± 20 BP, respectively 4825–4574 cal BP (ISGS-A2413) (Prendergast et al. 2014). Kohl-Larsen (1943) mentions several "decorated" sherd fragments in layer III at Njarasa which might be of Kansyore type. Although we could not find these decorated sherds in the collection (only several highly fragmented, undiagnostic pieces), the stratigraphic situation of layer III in between the orange sediment of layer II

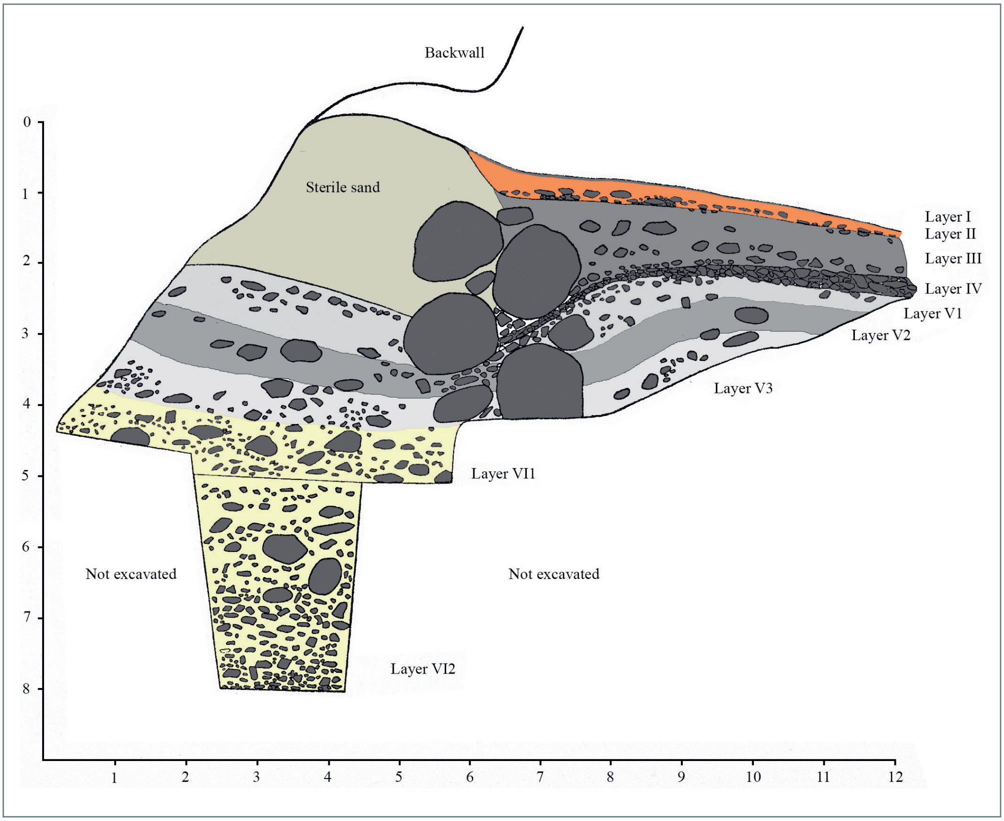


Fig. 3: Stratigraphy of Njarasa Cave; modified after Kohl-Larsen (1943).

Abb. 3: Stratigraphie der Njarasa-Höhle; verändert nach Kohl-Larsen (1943).

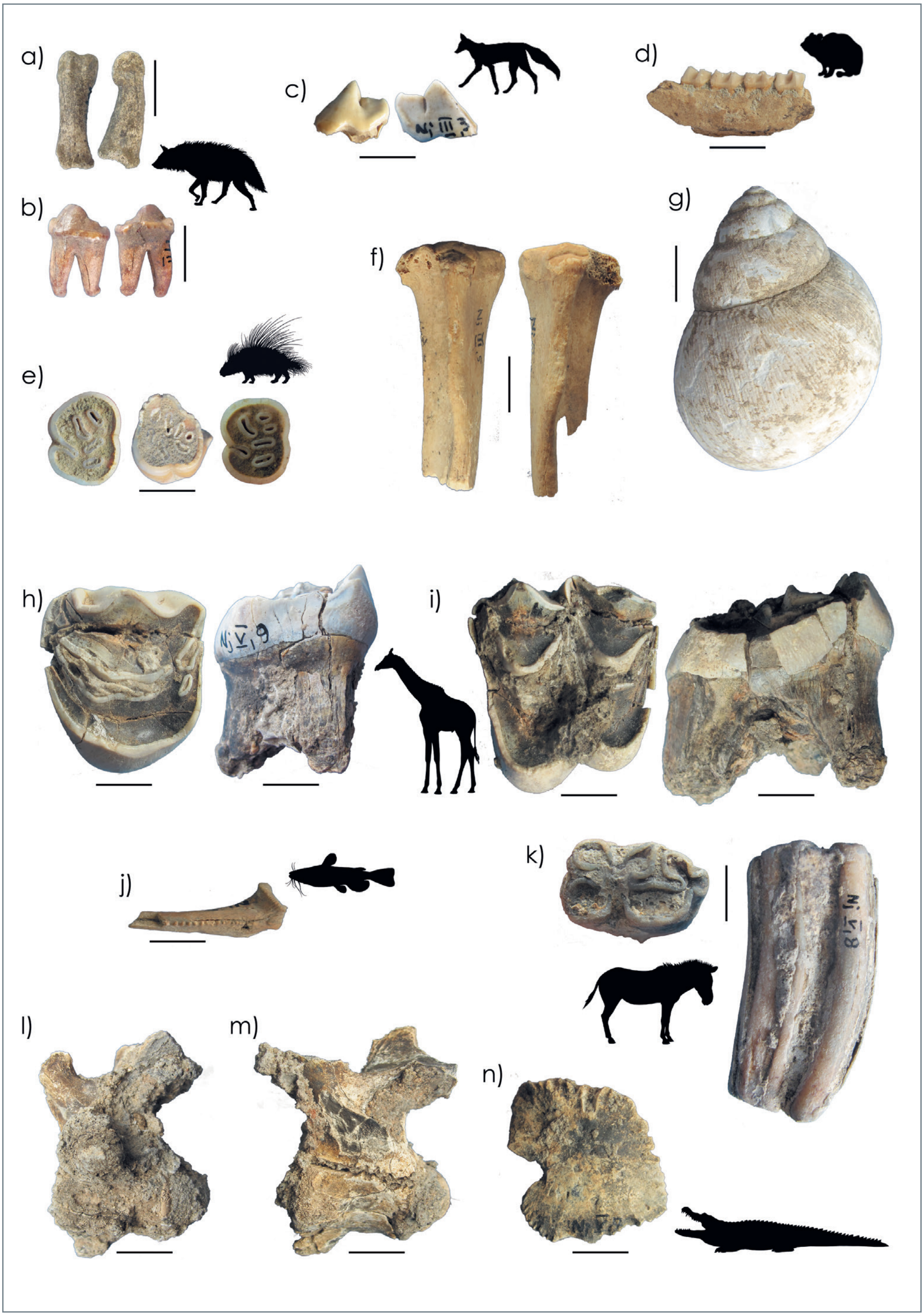
(similar to Level II-1 at Mumba) and a massive rockfall with a thick crust on the stones (similar to Level III-3 at Mumba) might indicate a similar age like Level III-2 at Mumba, falling roughly in the 5th millennium BP. The layers V and VI underneath the rockfall have not yet yielded absolute dates. Our analysis of the lithic material is still in progress but from our initial observations we can firmly state that both layers belong to the East African MSA. This assessment matches with Kohl-Larsen's (1943) observation that the assemblage shows broad similarities to the European Mousterian. Based on the fact that sediments are still left in situ from layer VI and probably also layer V, we plan to reopen the old Kohl-Larsen trench at Njasara in the coming field season in order to verify the stratigraphy, excavate a small control sample of artifacts and to gain absolute ages from Optically Stimulated Luminescence (OSL) dating.

Njarasa Cave – lithic artifacs

At the current stage, the lithic analysis of layer V and III is still in progress, but some preliminary findings are presented here. In both assemblages, most artifacts are made of hydrothermal quartz (Fig. 4.1), which is available in large quantities directly at the site in the form of large angular blocks. This raw material is also the most abundant lithic material at Mumba. Apart from this rock type we observed a large variability in different cherts (Fig. 4.4–8) and very few pieces of obsidian. Among the cherts are metasomatic sedimentary cherts from the Great Rift lakes and hydrothermal cherts formed in volcanic suites which are suitable for provenience tracing. The potential implications for our understanding of long-distance movements and territorial effects in the MSA and LSA of East Africa are obvious.

Fig. 4: Selection of different raw materials from layer III and V at Njarasa. 1) Quartz, 2) Basalt, 3) Rose quartz, 4–8) different variations of chert to be further investigated.

Abb. 4: Auswahl verschiedener Rohmaterialien aus Schicht III und V der Njarasa Höhle. 1) Quarz, 2) Basalt, 3) Rosenquarz, 4–8) verschiedene noch weiter zu untersuchende Silexvarietäten.


a)
b)
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The MSA assemblage from layer V is dominated by flakes with very little evidence of secondary modification. At least three different core reduction methods – (multi-)platform, Levallois and bipolar – were observed, while the latter is less common than expected from a quartz dominated assemblage. In general, we see a decrease in artifact density from layer V3 at the bottom to layer V1 at the top. In layer III, we found a similar raw material distribution as in layer V. The artifacts are considerably smaller and typical for LSA assemblages, and we discovered several ground stone tools which are absent in layer V. Due to the presence of several microlithic bladelet cores and the absence of the corresponding bladelets, we suggest that a large quantity of the assemblage may have ended up in the backdirt of the excavation as the mesh size (probably 2 cm) was almost certainly too big to retrieve these kinds of artifacts.

Fig. 5: Faunal remains from Kohl-Larsen's excavation at Njarasa Cave.
From layer III:
a) anterior (right) and lateral (left) views of the proximal phalanx of a juvenile hyenid;
b) buccal (left) and lingual (right) views of the lower left second premolar of an hyenid;
c) buccal (left) and lingual (right) views of the right upper fourth premolar of a black-backed jackal (*Canis* cf. *mesomelas*); e) series of molars and premolars of a porcupine (*Hystrix* sp.);
f) antimeric set of tibiae of a springhare (*Pedetes surdaster*); g) shell of a giant African land snail (*Achatina sp.*).
From layer V:
d) right mandible of a hyrax (*Hyrax/Heterohyrax* sp.) with the lower second, third and fourth premolars and first molar; h) distal (left) and occlusal (right) views of the left upper third premolar of a giraffe (*Giraffa camelopardalis*); i) distal (left) and occlusal (right) views of the left upper second molar of a giraffe;
j) left pectoral spine of a catfish (*Clarias* sp.); k) buccal (left) and occlusal (right) views of the left molar or premolar of a zebra (*Equus* sp.); n) osteoderm of a crocodile (*Crocodylus niloticus*).
From layer VI:
l) and m) two lumbar vertebrae of a crocodile.
Bar scales are 1 cm.

Abb. 5: Faunenreste aus Kohl-Larsens Ausgrabung in der Njarasa Höhle.
Aus Schicht III:
a) anteriore (rechts) und laterale (links) Ansichten der proximalen Phalanx einer juvenilen Hyäne;
b) bukkale (links) und linguale (rechts) Ansichten des unteren linken zweiten Prämolaren einer Hyäne;
c) bukkale (links) und linguale (rechts) Ansichten des rechten oberen vierten Prämolaren eines Schabrackenschakals (*Canis* cf. *mesomelas*); e) Serie von Molaren und Prämolaren eines Stachelschweins (*Hystrix sp.*);
f) antimerischer Schienbeinsatz eines Springhasen (*Pedetes surdaster*); g) Schale einer afrikanischen Riesen-Landschnecke (*Achatina* sp.).
Aus Schicht V:
d) rechter Unterkiefer eines Schliefers (*Hyrax/Heterohyrax* sp.) mit den unteren zweiten, dritten und vierten Prämolaren und dem ersten Molar; h) distale (links) und okklusale (rechts) Ansichten des linken unteren dritten Prämolaren einer Giraffe (*Giraffa camelopardalis*); i) distale (links) und okklusale (rechts)
Ansichten des linken oberen zweiten Molaren einer Giraffe; j) linke Brustwirbelsäule eines Welses (*Clarias* sp.);
k) bukkale (links) und okklusale (rechts) Ansichten eines linken Molaren oder Prämolaren eine Zebras (*Equus* sp.);
n) Knochenplatte eines Krokodils (*Crocodylus niloticus*).
Aus Schicht VI:
l) und m) zwei Lendenwirbel eines Krokodils.
Die Maßstäbe sind 1 cm lang.

Njarasa Cave – faunal remains

The faunal sample from the Kohl-Larsen's excavations at Njarasa comprises ~300 remains, the majority of which are from Layer III (n=208). It includes horncore, dental and bone material, as well as tortoise and mollusk shells, scales and osteoderms (Fig. 5). The sample is biased towards identifiable (e.g., teeth and carpals/tarsals) and/or large remains. Despite the small size of the sample, the faunal spectrum is taxonomically diverse and includes gastropods, fishes, birds, reptiles and a variety of small to large mammals (Fig. 5). The ungulate remains from layers VI, V and III include large browsers (*Giraffa camelopardalis*), as well as grazers (e.g., *Equus* sp.), consistent with savanna paleohabitats. The occurrence of crocodile remains in layers VI and V documents the proximity of a large body of freshwater (Fig. 5). The preservation of the material varies from well-preserved to highly weathered, heavily water-abraded, decalcified or completely encrusted specimens. The taphonomic analysis is currently underway but a preliminary appraisal of the material suggests the action of several geogenic and biogenic processes in the accumulation as well as in the post-depositional modifications of the Njarasa faunal sample that include carnivore damage, porcupine gnawing, water transport and anthropogenic consumption.

Future perspectives

Our multidisciplinary team plans to study each material group from the different layers at Njarasa Cave in detail with modern analytical methods, including flaked lithics, ground stone tools, ochre, fauna, and also botanical remains, which might be preserved in the sediment samples. We will proceed with the same strategy at all sites in the Tübingen Kohl-Larsen collection and thus follow creditable examples of reinvestigating forgotten collections from this region such as e.g. Nasera or Kisese II (Ranhorn and Tryon 2018; Tryon et al. 2019). Students from the University of Dar es Salaam will be included into the process and be given access to the collection for the purpose of Bachelor, Master and PhD theses. Further, we hope to publish the results together with our Tanzanian partners in international scientific journals. We plan to link the results from this collection work to the new fieldwork conducted at Mumba and beyond. We also plan to re-open Njarasa Cave in the coming field season to take sediment samples for OSL dating and to revise the archaeological stratigraphy. A further goal of the project is to contextualize the results from Mumba Cave within a regional chrono-cultural sequence in the Lake Eyasi region. The combination of new excavations and investigations of old collections will help to create a coherent reconstruction of hominin cultural change and behavioral adaptions over the last ~200.000 years in this important archaeological landscape.

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Appendix i.c

LETTER

The Zandmotor data do not resolve the question whether Middle Paleolithic birch tar making was complex or not

Patrick Schmidt[a,b,1], Maxime Rageot[a,c], Matthias Blessing[a], and Claudio Tennie[a]

Niekus et al. (1) present a find of Neanderthal birch tar from Zandmotor (The Netherlands), concluding that a cognitively complex underground production method was used. However, Schmidt et al. (2) recently showed that birch tar production can be simple [burning bark near stones: the condensation method (2)]. Two arguments are used by Niekus et al. (1) to claim that the Zandmotor tar was produced with a complex method: The efficiency of simpler techniques was too low, and their tar's composition indicates a complex technique. As we will argue, these arguments are invalid.

The Condensation Method's Efficiency

Producing 0.6 g of tar took 3 h with the condensation method (2), leading Niekus et al. (1) to calculate a 10-h production time for the Zandmotor tar. The experiment by Schmidt et al. (2) was done with one cobble to sequentially produce the tar. From the ∼6:20-min video showing the process in Schmidt et al. (2), ∼4:30 min correspond to bark burning and ∼1:20 min to scraping off tar (i.e., the experimenter's full attention is required during one-third of time). One can use three cobbles simultaneously, or even more, if several people work together. As for the quantity of bark needed, up to 2,500 g can be harvested from a single living tree (3). If dead bark is used, 600 g of bark can be picked up from 80 m^2 (2). Thus, birch forests provide plenty of bark. These theoretical considerations on the efficiency of tar production techniques are problematic for making inferences about the likelihood that they were used in the past.

Zandmotor Tar Composition

Betulin, lupeol, and the absence of degradation markers in the Zandmotor tar would indicate production temperatures of ∼350 to 400 °C (1), temperatures only reached with more complex production techniques (4). However, the condensation method also produces betulin and lupeol (2). Soft-heating degradation markers [lupa-2,20(29)-dien-28-ol; α-betuline I; lupa-2,20(29)-diene] form already <350 °C (3). Lupa-2,20(29)-dien-28-ol and lupa-2,20(29)-diene also form by postdepositional decay (5). No temperatures were published in Niekus et al. (1), and compositions of experimental tars produced in Kozowyk et al. (4) were not provided, i.e., we lack crucial data to compare the Zandmotor tar with experimental tar. Charcoal/mineral inclusions in the Zandmotor tar are said to indicate complex production (1). However, birch tar was kept and transported over long time periods in the past (3, 6). Tar is malleable and recyclable, and may result from several sessions [causing homogenization of inclusions during its life cycle—just as found by Niekus et al. (1)]. Thus, impurities cannot unambiguously be linked to specific production techniques.

Conclusion

Data presented in Niekus et al. (1) are explainable by different techniques and do not allow pinpointing of the complexity of Paleolithic tar making. We cannot rely on intuition or measures of effectiveness (1) to solve such debates. Contrary to what Niekus et al. (1) suggest, Schmidt et al. (2) never debate the degree of Neanderthal technological innovation—if anything, the conclusion of Schmidt et al. (2) is one of sophisticated innovativeness of Neanderthals. Schmidt et al. (2) merely show that Middle Paleolithic tar making must not necessarily be a complex process.

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Author contributions: P.S. and C.T. designed research; P.S. performed research; P.S. analyzed data; and P.S., M.R., M.B., and C.T. wrote the paper.

The authors declare no competing interest.

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Appendix i.d

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On the efficiency of Palaeolithic birch tar making

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A R T I C L E I N F O

Keywords:
Experimental archaeology
Ancient pyrotechnology
Adhesives
Modern behaviors
Early engineering
Materials transformation

A B S T R A C T

Birch tar is an adhesive dating back to the European Middle Palaeolithic. Several possible production pathways have been derived from experimentation and their complexity is often used to argue for complex behaviours or cognitive capacities of Neanderthals and early Homo sapiens. Efficiency may help to evaluate the likelihood that one technique or another was used in the Palaeolithic. Based on published and new experimental data, we analyse the efficiency of four birch tar production methods in terms of resource and time consumption. We found that there are differences in efficiency between all these methods, but they are not as great as previously thought. The most complex underground technique is most efficient in terms of tar yield but even the least complex aboveground condensation method produces usable amounts of tar in relatively short time intervals. Our findings highlight that efficiency cannot be used to evaluate the likelihood that specific techniques were used in the Palaeolithic. Only direct archaeological data on the techniques used in the Palaeolithic will allow to make inferences about the behavioural complexity of birch tar production.

1. Introduction

Some researchers (Wadley et al., 2009; Wadley, 2010, 2013; Wragg Sykes, 2015; Roebroeks and Soressi, 2016; Kozowyk et al., 2017; Hoffecker, 2018) have interpreted Palaeolithic birch tar making and use as evidence for behavioural complexity. This is because it was assumed that birch tar only forms in anaerobic conditions (see for ex: Koller et al., 2001). However, setting up environments that restrict air without the use of ceramics imposes specific actions und capacities. Most experimentally derived tar production processes therefore rely on indirect underground heating (e. g. Osipowicz, 2005; Groom et al., 2015; Kozowyk et al., 2017).

The discussion about potential Palaeolithic tar making techniques has recently been fuelled by the finding that birch tar can also be made more simply: a method called the condensation method (Schmidt et al., 2019). For this, birch bark is burned beside slightly overhanging cobbles, so that tar condenses on the stone surface. The tar can be scraped from the stone surface with a stone tool. The process takes place in a fully aerated environment. Thus, there are different pathways to make tar and the assumption that only underground techniques could have been used in the Palaeolithic was wrong.

Another argument about Palaeolithic birch tar was made when a hitherto unknown piece was found at the Dutch site of Zandmotor (Niekus et al., 2019). The discussion on which technique was used to make the Zandmotor tar mainly relied on theoretical evaluations of the efficiency of different methods (Niekus et al., 2019; Kozowyk et al., 2020; Schmidt et al., 2020). The authors of the find interpreted its production technique as probably being close to the more complex underground methods proposed by an earlier study (Kozowyk et al., 2017) because the condensation method was interpreted to be not efficient enough to produce the amount of tar found (a total volume of ~2 ccm, see: Niekus et al., 2019). However, the authors of the condensation method had not specifically tested for efficiency in their initial publication (Schmidt et al., 2019). We therefore investigate the efficiency of the condensation method experimentally and compare it to other known aceramic birch tar production methods. We expect differences in terms of material input and time investment in different production methods. Finding that these differences are great would support arguments in favour of using the efficiency of different methods for evaluating the likelihood of their use in the Palaeolithic. Finding that different techniques have similar requirements in terms of time and resources, would suggest that the efficiency of different birch tar making techniques is not helpful for identifying the actually used Palaeolithic techniques.

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2. Materials and methods

Efficiency may be understood in theoretical frameworks surrounding the optimization of behaviour (Jochim, 1983; Foley, 1985; Torrence, 1989), Human Behavioural Ecology being the most prominent among these (Winterhalder, 1981; Winterhalder and Smith, 1981, 2000, for an overview on optimization see: Kelly, 2013, p. 33-38). Our own paper aims to assess the efficiency of isolated methods (in a technical sense). We do not attempt to incorporate our findings into a bigger theoretical framework, because this would require more contextual data related to the known Middle Palaeolithic birch tar pieces than we currently have (Niekus et al. 2019; Mazza et al., 2006; Koller et al. 2001).

The experimental setup for birch tar making with the condensation method was as described in Schmidt et al. (2019), i.e. birch bark burned beside river cobbles to produce tar that can be scraped off the stone surface. Here, three cobbles were used at the time (Fig. 1). We used three river-rounded stones weighing 1964 g, 1611 g and 1590 g that consist of shale and hydrothermal quartz. Initially, we planned on using five stones at a time, but found that more than three stones were only manageable when the quality of the bark was sufficiently high. High quality bark has a longer burning time, which gives the experimenter time to scrape off tar and get cobbles working again while the other bark rolls are burning. Thus, the longer the burning time of an individual bark roll, the more cobbles can be handled at the same time. Experiments were repeated two times by each experimenter (both authors and one additional person) and went on for 30 min each. This resulted in six experiments over a total of three hours production time (Table 2). Birch bark was collected from dead trees lying on the ground. The first experiment used bark from branches and the trunk, while five other experiments used trunk bark only. The experimental setup for birch tar making with the "raised structure" followed the descriptions in Kozowyk et al. (2017) (also see Fig. 2): we dug four pits in loose ground, placed grates of thin sticks on each and placed bark rolls on the grates. The bark rolls were surrounded by domes made from damp medium to fine sediment and heated by a fire built around them. To minimize loss of tar forming in the pit, we placed a receptacle made from aluminium foil at the base. The reason for this was to avoid contamination with the sediment during and after the experiment, so to calculate clear values for tar yield that are not skewed by the additional weight of a potential sediment contamination. The structures were left to cool down over night before the tar was collected. We used bark from freshly cut trees for this experiment.

Both the birch bark collected from dead trees as well as the bark collected from freshly cut birches were *Betula pendula*.

3. Results

3.1. Literature survey

Fig. 1 shows schematic representations of the five methods discussed here. The most detailed published data on the efficiency of birch tar production are available from Kozowyk et al. (2017). They proposed three techniques: [1] in their raised structure, bark is placed in a chamber built from wet sediment on which a fire is lit. Tar is collected in a birch bark container, within a pit that forms a second chamber below. [2] Their second technique called "ash mound" consists of a roll of birch bark covered by a mound of hot embers and ashes. The tar forms within the roll itself. [3] Their "pit roll" technique consists of a bark roll placed upright in a pit in the ground that is covered by glowing embers. Kozowyk et al. (2017) report data from several runs of each of their three proposed techniques. We consider the means calculated from all runs for each technique: the raised structure was most efficient of all three methods in terms of material cost. Approximately 100 g of bark produced a mean of 5.81 g of tar. In terms of time efficiency, the average tar yield of the raised structure per hour was 1 g. The Pit roll techniques produced 0.66 g of tar from 56 g of bark in 101 min. The Ash Mound yielded a mean of 0,53 g of tar from ~100 g of birch bark in 264 min.

Groom et al. (2015) and Schenk and Groom (2018) also describe birch tar production techniques (Table 1) for which time investment data are available. Both report a series of techniques that either resemble the raised structure or that are based on underground pits. The time requirement for these structures are comparable with Kozowyk et al.'s (2017) raised structure. No data on tar yield are available from these publications.

There are other published descriptions of experiments attempting to produce birch tar under Palaeolithic conditions (Osipowicz, 2005;

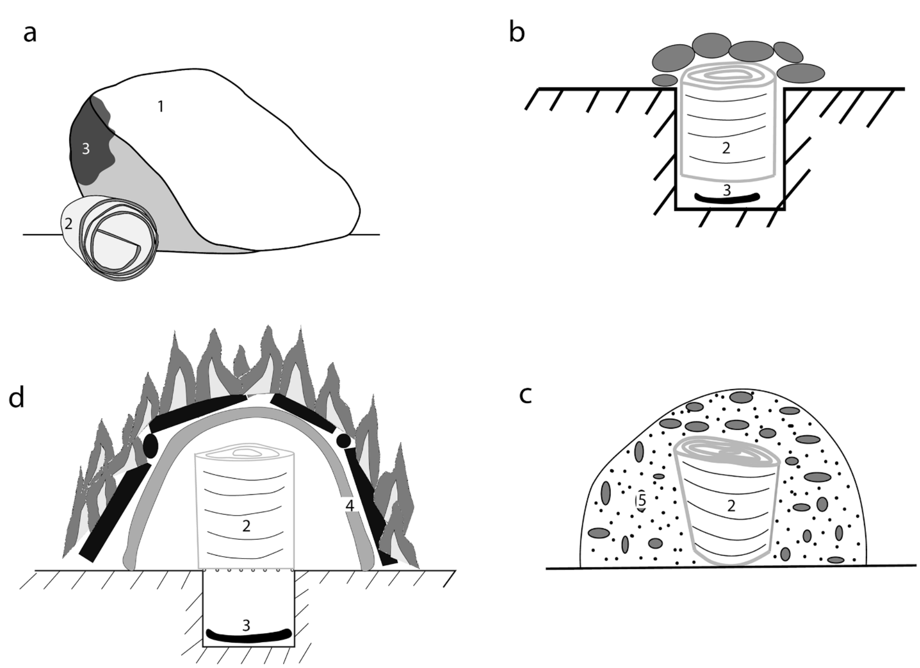

Fig. 1. Schematic representations of the birch tar production methods discussed in the main text. a: condensation method; b: pit roll; c: ash mound; d: raised structure; e: open-air groove. References in the main text. 1: river cobble; 2 birch bark; 3: birch tar; 4: damp sediment; 5: ashes and embers.

Fig. 2. Experimental setups used for the efficiency tests. Left: condensation method conducted with three cobbles; right: four raised structures.

Table 1
Mean values for material input, time investment (not including collection time for firewood) and tar yield of published aceramic birch tar production methods.

Method	Bark input (g)	Time (min)	Tar yield (g)	Tar/ h (g)	Tar/ 100 g bark (g)	References
Raised structure (4 runs)	93	333	5,8	1	6.6	Kozowyk et al. (2017)
Ash mound (5 runs)	93	244	0.5	0.1	0.6	Kozowyk et al. (2017)
Pit roll (7 runs)	56	113	0.7	0.4	1.2	Kozowyk et al. (2017)
Raised mound (7 separate experiments)	N/A	243	N/A	N/A	N/A	Schenck and Groom (2018)
Underground structures covered with sand (14 separate experiments)	N/A	288	N/A	N/A	N/A	Groom et al. (2015)

[1]As recalculated from the recovered volume.

Palmer, 2007; Pomstra and Meijer, 2010). None of these contains data on the efficiency of these methods.

4. Experimental results

Fig. 1 shows the experimental setups used to evaluate the efficiency of the condensation method and raised structure. The condensation method process can be seen in supplementary videos 1 and 2. We used a total of 592 g of birch bark for all experiments. The mean yield of the condensation method experiments was 0.3 g per 30 min, totalling in 1.8 g of tar in 3 h. If only trunk bark is used, ~50–80 g of bark are enough to produce 0.3 g of tar. Including bark from branches in the experiments more than doubled the amount of bark needed to produce similar amounts of tar (Table 2). The total tar yield of all four raised structures was 14.5 g produced during a total time span of ~20 h (composed of 45 min of building the structures, a burn time of 4,5h and an overnight cool down phase). We used 81 g of bark for these experiments. Thus, in total, the raised structure, as experimented here, allows to produce 44 times more tar from the same amount of bark as the condensation method. Both allow to produce very similar amounts of tar in one hour (Table 2)

supplementary video 1.

supplementary video 2.

Table 2
Results of six birch tar production experiments with the condensation method (CM), using three cobbles at the time, and four experiments with raised structures (RS) that were conducted simultaneously. 1) Preparation time not included.

Operator	Method	Bark from:	Used bark [g]	Time [min]	Tar yield [g]	Tar/h (g)	Tar/ 100 g bark (g)
PS	CM	Branches/trunk	162	30	0.4	0.8	0.2
MB	CM	Trunk	68	30	0.3	0.6	0.4
PS	CM	Trunk	70	30	0.3	0.6	0.4
MB	CM	Trunk	79	30	0.2	0.4	0.3
TK	CM	Trunk	80	30	0.3	0.6	0.4
TK	CM	Trunk	52	30	0.3	0.6	0.6
–	RS	Trunk	20	270[1]	3.3	0.7	16.5
–	RS	Trunk	18	270[1]	2.2	0.5	12.2
–	RS	Trunk	17	270[1]	3.1	0.7	18.2
–	RS	Trunk	26	270[1]	5.9	1.3	22.7

5. Discussion

5.1. Observations made during our experiments

Tar yield appears to depend on the quality of the used bark that, in turn, appears to depend on the part of the tree the bark comes from. This is partly in accordance with a previous categorization of the quality of birch bark (Rageot et al., 2019). Using Rageot et al.'s categories, the birch bark for all experiments was AA-quality, despite the bark used for the condensation method being harvested from dead trees. We hypothesize that it is also the thickness of the bark, which plays an important role. This can be expected to be so across all possible production methods and might at least partly account for the variations in tar yield between published experiments (compare the different tar yields in Kozowyk et al., 2017). Only future studies may answer this question. Overall, the material input is relatively high for the condensation method, as compared to other production pathways (Table 2). The reason for this might be the fully oxygenated environment, which caused part of the tar components to be released into the air and lost.

5.2. Choices made during our literature survey and comparison

The efficiency values of all methods reported here refer to successful trials only. The success rates for the ash mound and the condensation method are 100%, while the pit roll success rate is 77% and the raised structure, as published by Kozowyk et al. (2017), 50%. Considering success rate would cause the efficiency of the raised structure and the pit roll technique to appear lower. However, we chose to ignore this factor because the authors of Palaeolithic birch tar might have been significantly more skilled than modern-day experimenters. Another point we chose to ignore is the effort and time requirements for collecting bark, and firewood (the latter would only apply to some of the techniques). If they were included in the comparison, they would add to the total investment per tar yield for methods that rely on indirect heating (i.e. where burning wood is used to heat the bark).

5.3. Comparison of our experimental results with literature data

Kozowyk et al.'s (2017) raised structure was ~16 times more efficient than the condensation method in terms of raw material requirement (5.8 g of tar/100 g of bark vs. 0.35 g of tar/100 g of bark). Our own raised structure experiments were even more efficient. On average, our four structures produced 3 times more tar (relative to a standard quantity of bark) than published raised structures (17 g of tar/100 g of bark vs. 5.8 g of tar/100 g of bark). Thus, the raised structure is by far the most efficient of all known aceramic birch tar making methods in terms of material requirement. An exact understanding of the raised structure's time efficiency is hampered by the nature of the data available from published descriptions and provided by our experiments. The amount of birch bark used in a single raised structure can be expected to vary between boundaries set by external factors like the availability of firewood (the rationale behind this being that larger bark rolls impose larger structures that require more firewood). However, within these boundaries, time efficiency (i.e. tar yield/invested time) depends on the quantity of bark used. Each of our raised structures produced between 2 and 6 g of tar in 5 h burning time (i.e. between 0.4 and 1.2 g/hour) but all together, they produced more than 14 g in that time (i.e. 2.8 g/hour). Thus, it is not straightforward to compare the raised structure with the condensation method because the amount of bark that can be burned in one run can be multiplied if several raised structures are built. In the condensation method, the amount of bark is limited by the speed a single operator is able to work. It appears more important to highlight that with a raised structure, tar can be produced in no less than 3.5 to 5 h (Kozowyk et al. 2017), while all other methods allow tar to be produced in significantly shorter time spans. Kozowyk et al.'s (2017) pit roll technique was ~ 1.5 times more efficient than the condensation method in terms of raw material requirement (1.2 g of tar/100 g of bark vs. 0.35 g of tar/100 g of bark) but a single pit roll structure produces only 0.66 g of tar in 1 h40, while the condensation method allows to produce more than 1 g in the same time. Here again, if several pit rolls are built and lit simultaneously, more tar can be made with this technique but the total time requirement for a single pit roll can most likely not be reduced. Kozowyk et al.'s (2017) ash mound was ~1.4 times more efficient than the condensation method in terms of material investment but took ~2.2 times more time to produce similar amounts of tar as the condensation method. It takes 1.8 times less time to produce the same amount of tar as with the condensation method. These numbers can best be appreciated based on an example. The larger of the two Königsaue birch tar samples weighed 1.38 g when it was first described (Grünberg et al., 1999). Making this amount of birch tar with a raised structure would take ~5 h (more tar may be produced during this run but the total run time of the structure would be the same). Making the Königsaue piece would require approximately two ash mound and two pit roll runs that can be conducted simultaneously, representing a time investment of either ~1 h30 (pit roll) or ~4 h (ash mound). The same amount of tar can be made in ~2 h with the condensation method. Thus, all of the reviewed production techniques allow producing similar amounts of birch tar as used for the known artefacts in reasonable amounts of time.

Another factor that might be important for interpreting the investment in time necessary for different techniques is the level of activity required during that time. The condensation method is the only production pathway that needs almost constant attention and action. The ash mound, pit roll and raised structure include time spans during which nothing must be done. Production techniques can therefore be subdivided into tended (condensation method) and untended systems (ash mound, pit roll, raised structure) (Oswalt, 1973, term originally introduces tended and untended facilities). As stated above, further assessment of the implications of such classifications and their embodiment into greater systems, would require more contextual data than we currently have, which is why we refrain from doing so. However, this discussion highlights another aspect that is important for distinguishing different birch tar making techniques: the need of different planning depths. The condensation method requires less planning since the overall operation time is shorter and preparation time is negligible. The raised structure on the other hand, imposes a larger time investment because the structure must be prepared and the longer burning time, but it produces more tar. Using the condensation method would therefore constitute an advantage, especially if the need for tar was unforeseen.

5.4. Considerations on the availability of birch bark

While we did not include raw material availability in our comparisons, we acknowledge that birch bark derives from a dynamic ecosystem that might impose local variability. Niekus et al (2019) had made the argument that birch bark may have been rare at the time the Zandmotor (Niekus et al., 2019) and Königsaue (Koller et al., 2001; Grünberg, 2002) artefacts were produced. Since, compilations of the available pollen record from southern and Central Europe, covering MIS 3 and partially also older isotope stages, as well as geological data from northern Europe, have shown that the Fennoscandian Ice Shield retracted during the first half of MIS 3 (Lambeck et al., 2010; Wohlfarth, 2010) (Badino et al., 2020). This enabled plant growth in most of Southern and Western Europe (Badino et al., 2020). In the Atlantic zone of Europe, pine, oak and birch were readily available at this time (Badino et al., 2020), suggesting that for the Zandmotor piece birch bark raw material was available. It is not specified in Badino et al. (2020) which species of birch was prevalent in Europe at this time. Based on the environmental reconstruction provided we assume that it was most likely *Betula pendula* or *Betula pubscens* because they occur in comparable environments today. *Betula nana* would be another possibility which would have implication for our argument because it is reported to have smaller amounts of tar forming chemicals (Krasutsky, 2006) and is smaller so less bark could be harvested from a single tree. However, *Betula nana* is only common in tundric environments and higher altitudes. These findings, in conjunction with earlier findings that a single tree provides up to 2.5 kg of bark (Rageot et al., 2019), suggest that birch tar making was most likely not hampered by bark raw material availability when the Zandmotor and Königsaue artefacts were made.

We acknowledge raw material availability can influence time efficiency if bark supplies fall short in a given locale. A production method, which takes longer but has a higher relative tar yield could then become more time efficient, because it takes less time to collect the birch bark needed. However, critical assessment of the intertwining of material requirements and time efficiency calls for more data on procurement strategies and more localized palaeoenvironmental data, which we currently lack.

6. Conclusion

The raised structure is the most efficient aceramic birch tar production method in terms of required raw material input. However, we found that the availability of birch bark raw material is in all likelihood no restricting factor for any of the reviewed tar production techniques, as long as at least one birch tree is available. This puts strong emphasis on the time efficiency of different techniques as being the more important argument in the discussion on efficiency. In this regard, the raised structure is the most efficient method. The ash mound method is the least efficient technique in terms of time. The condensation method and pit roll technique lie somewhere in between. An evaluation of the other known underground techniques was not possible, due to the lack of data on tar yield.

We therefore conclude that efficiency cannot be used to evaluate whether one of these techniques was more likely used in the Paleolithic than another. Evaluating whether any of these techniques is more likely in terms of their complexity or the cognitive requirements they impose lies beyond the scope of this study.

Declaration of Competing Interest

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

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Appendix i.e

Heritage Science

RESEARCH ARTICLE

Open Access

On the performance of birch tar made with different techniques

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Abstract

Birch tar is one of the oldest adhesives known in human history. Its production has been discussed in the framework of early complex behaviours and sophisticated cognitive capacities. The precise production method used in the Palaeolithic remains unknown today. Arguments for or against specific production pathways have been based on efficiency or process complexity. No studies have addressed the question whether birch tar made with different techniques is more or less performant in terms of its properties. We therefore investigate the adhesive performance of birch tar made with three distinct methods: the open-air condensation method and two variations of underground structures that approximate the double-pot method in aceramic conditions. We use lap-shear testing, a standard mechanical test used for testing the strength of industrial adhesives. Tar made in 1 h with the condensation method has a shear strength similar to, although slightly higher than, tar made underground if the underground process lasts for 20 h. However, tars from shorter underground procedures (5 h) are significantly less strong (by a factor of about 3). These findings have important implications for our understanding of the relationship between the investment required for Palaeolithic birch tar production and the benefits that birch tar represented for early technology. In this regard, the simple and low-investment open-air condensation method provides the best ratio.

Keywords: Early engineering techniques, Shear strength, Neanderthal modernity, Early pyrotechnology, Adhesives

Introduction

Birch tar is the oldest known adhesive dating back to the European Middle Palaeolithic. There are five pieces of birch tar known from the Palaeolithic record, all attributed to Neanderthals. The oldest two pieces were found in Campitello (Italy) and indirectly dated to ~200 ka [1]. Two pieces were found at Königsaue (Germany) and estimated to between 40 and 80 ka [2, 3]. The most recently found birch tar artefact comes from Zandmotor (The Netherlands) and is ~50 ka old [4]. At Inden-Altdorf (Germany), there are other artefacts with residues that were claimed to be birch tar [5] but detailed identification with Gas-Chromatography has yet to be undertaken. One of the questions surrounding these Palaeolithic birch tar remains is how they were made in aceramic conditions. This question is important for our understanding of Neanderthals because birch bark does not exude visible resin that could be fortuitously discovered and identified as substance from which an adhesive can be made. Birch tar making requires a method that allows to distil tar from the bark and that has been interpreted to require advanced cognitive capacities (e.g., [6]).

Perhaps the best-understood birch tar production technique is the double-pot method. There are written and drawn historical sources (for an overview see: [7]) and there are well-preserved production sites that illustrate the use of this method in the fourteenth century [7, 8]. In a double-pot, bark is heated in a sealed container and tar drips into another connected container. The resulting tar is liquid at room temperature and needs to be reduced by boiling [8, 9]. This supplementary process of tar reduction is at the origin of the distinction between the terms 'tar'—the first product issued from the process—and

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'pitch'—the viscous product obtained by reducing the tar. Rageot et al. [10] termed the tar production pathway associated with this method per descensum because tar is separated from the bark by gravity during the process. Another technique, based on a single pot in which birch bark is heated, was proposed for Neolithic tar production [11, 12]. In this technique, tar is not directly separated from the bark but collected at the bottom of the container. The tar formation conditions in such single pots have recently been investigated and found to require rather precise temperature ranges [13]. These two techniques, the double-pot and the single-pot, may be the best interpretations for prehistoric birch tar production from the Neolithic on. The absence of ceramic containers in the Palaeolithic has given rise to a still ongoing debate about the aceramic counterparts of these techniques that may have been used by Neanderthals. The proposed techniques, all derived from experimentation, can roughly be separated into three groups:

The first group consists of techniques that use earthen structures, most often above ground, in which birch bark is enclosed. The bark is heated by a fire built around the structure (e.g., [14, 15]). Tar is collected in a receptacle that is held in a second chamber, normally below the bark. These methods are similar to the double-pot method in terms of their architecture and it can be expected that tar production follows a per descensum pathway. The second group consists of techniques based on pits in the ground, either open [16] or closed by ash and embers [15] or sediment [17]. The tar forms inside the bark rolls or drips out at the bottom. Those techniques resemble the architecture of Neolithic single-pot methods (for a single-pot technique based on a structure built above ground see: [18]). There is a third group of techniques that are based on fully or partly oxygenated environments: recently, the fully open-air condensation method was introduced [19]. There, tar is condensed on a stone surface from where it is collected by scraping during the process. Condensation tar is relatively solid and ready for use immediately after collection from the surface. A similar technique based on an open-air groove-like structure that is partly covered by a flat stone was proposed by Todtenhaupt et al. [20]. From their description, it is not entirely clear whether tar is condensed on the stone surface in a fully oxygenated environment in this method but, similar to the condensation method, the process takes place above ground. The open-air groove makes use of materials unavailable in the Palaeolithic (plane stone boards) but if future experiments will confirm that it can be performed with natural stones, it might be another interpretation of a potential Neanderthal birch tar making technique.

As it stands, there are three distinct pathways for aceramic birch tar making: per descensum; without separation in a single chamber; and condensation on stone surfaces. Which of these methods was used in the Middle Palaeolithic is still actively debated (e.g., [4, 15, 19, 21–23]). As of now, this discussion has concentrated on the likelihood that one or another technique was used by Neanderthals. One line of argumentation is on the complexity of different techniques: simpler open-air techniques have a higher potential to be discovered accidentally [4, 19] and may therefore be regarded as a more likely explanation of Palaeolithic tar making. However, another argument was made that the more complex underground techniques are more efficient and are therefore more likely [4]. None of these approaches alone has reached broader consensus so far. Here, we make a third argument in this debate: the performance of different birch tars. In a previous study [19], the authors investigated the lap shear strength of condensation tar, finding a higher strength than tar made per descensum in metal containers. What their study did not do is compare the strength of condensation tar with tar made with other aceramic tar making methods. We therefore conduct a comparative study that aims at understanding the differences in performance (using lap shear strength) of birch tars made with different techniques that may have been used in the Palaeolithic.

The question we attempt to answer with this study is: do different production methods produce birch tar with similar properties in terms of its adhesive performance? To answer this question, we conduct experiments with the aim of comparing birch tar made with the condensation method and the raised structure as described by Kozowyk et al. [15]. There are several ways of understanding the performance of adhesives in different conditions (see for example: [24]). In this paper, we use a type of standard mechanical testing (lap-shear testing) for which published comparative data on other experimental adhesives relevant for Palaeolithic archaeology (e.g., [25, 26]) are available. If different techniques allow to produce birch tar with similar strengths, then tar performance may be disregarded for the discussion on the likelihood that one technique or another were used in the Palaeolithic. If, on the other hand, we find significant differences between the strengths of birch tar made with different techniques, it becomes worthwhile to discuss the relationship between the investment imposed by specific techniques and the value of the tar that they allow to produce.

Materials and methods

Sample production

We made one sample of birch tar with the condensation method [19] and three other samples with raised structures [15]. The condensation method consists of burning birch bark near slightly overhanging stone surfaces (Fig. 1a). Tar condenses onto the stone surface adjacent to the flame. The process takes place in a fully aerated environment. Tar was scraped from the stones regularly during the process, using a stone tool (Fig. 1b). We used approximately 170 g of bark in this experiment.

In our raised structures, rolled birch bark is placed on a grate made of sticks (Fig. 1c) and enclosed in a dome built from wet sediment (Fig. 1d). A fire was built around this dome structure. Tar is collected in a second chamber dug below the grate. We conducted two raised structure experiments simultaneously, each containing receptacles made from aluminium below the grate to minimize loss of the tar. The fire around both structures was kept burning for 4 h by regularly adding firewood. We opened one structure after four hours of burning time and collected the tar immediately. The other structure was left to cool down over night and the tar was collected the next morning. With this procedure, we hoped to produce two distinct tar samples that were distilled during a similar duration but that had undergone different cooling histories. We expected the quenched sample to have low viscosity and the sample cooled overnight higher viscosity because the remaining heat of the structure had more time to thicken the tar before it was collected. We used approximately 20 g of bark in each raised structure. A third raised structure was built with a natural stone receptacle in the lower chamber. All other conditions remained the same and the fire was kept burning for the same time. The reason for this third raised structure was not to support the main argument of this study but rather to verify whether the use of aluminium in the other two raised structures has an influence on the resulting tar or whether it can be compared with raised structure tar made with naturally available materials only. Dead bark collected from trees lying on the ground in a forest was used for all experiments.

Fig. 1 Experimental set up for the aceramic birch tar making experiments. **a** Condensation method using several stones simultaneously and the resulting tar (**b**); **c** two raised structures during construction. Birch bark rolls are placed on grates bade from fine sticks. The lower chamber is covered by aluminium foil to minimize loss of the tar; **d** finished raised structure with the sediment covering the bark rolls; **e** tar produced in one of the raised structures, still adhering to the aluminium foil receptacle

Mechanical testing

The performance of the samples as adhesives was compared using lap-shear testing (see for example: [27]). Lap-shear tests, similar to the ones used here, have previously been applied to the study of birch tar and other natural adhesives [19, 25, 26]. All those tests were based on ASTM-D 1002 [28]. The norm was originally intended for adhesively bonded metal specimens (laps) that are tested with a single-lap-joint shear strength test. Such tests are commonly used to evaluate the strength of industrial adhesively bonded joints (e.g., [29]).

The rationale behind this is as follows: ideal brittle materials exhibit linear stress–strain behaviour. In this case, the basic relation under pure shear is $\tau = G \cdot \gamma$, where τ is the shear stress, γ the shear deformation and G the shear modulus. γ is then $\tan(\alpha)$, α being the angle of deformation of the flat adhesive cuboid as seen onto its side between the laps. However, materials such as natural tars, that are not ideally brittle, develop a non-linear stress–strain behaviour because of plastic deformation (see the detailed discussion in [30]). A great number of studies have discussed lap-shear tests of non-brittle samples (e.g., [31–34]), stressing the necessity of good control over the deformation for mechanical analyses. This can be achieved with a test similar to ASTM D-5656 [35], requiring a more complicated experimental set-up and that the laps' deformation be measured optically. The requirements for ASTM D-5656 cannot be fulfilled in our laboratories. Therefore, our tests only provide values of the apparent applied shear stress (henceforth τ) at any moment during the test. In this case, τ is the (tensional) force in N applied to the bonded area in mm^2. Although our tests cannot provide real values of G, it is still possible to compare our birch tar samples in terms of this shear stress. Data were therefore plotted in stress/strain diagrams reporting τ over percent elongation strain.

We performed lap-shear tests with an Instron 4502 universal test machine equipped with kardanic suspended tensile grips. All tests were performed at room temperature (21 °C in this case). Laps were mounted vertically and pulled apart with a speed of 1 mm/min. Laps were cut and precision ground from 4 mm thick *Populus* sp. plywood measuring 100×25.5 mm. The 25.5×12.5 mm measuring contact zones (319 mm^2) were abraded with 100 grit sand paper. Tests were repeated 10 times for the two raised structure samples produced with aluminium receptacle and the condensation method sample samples (by mistake, 11 times for the condensation method) and 5 times for the raised structure sample produced with a stone receptacle. Tar was applied to the laps by heating it over a flame and then smearing it onto the contact zone before the second lap was bonded to it. Clamping force was not measured but held approximately constant by using manual pressure exerted by the same person in all cases. We let the contact zone cool down to room temperature before testing began. Because this protocol does not allow to visually ascertain that the entire contact zone is covered by tar when gluing together both laps (i.e., there might still be holes in the middle of the bond that cannot be seen when the laps are joined together), we determined the actual bonded areas (in mm^2) by photographically measuring the extent of the tar-covered zone on both laps after each experiment and averaging both values.

Results

Birch tar making experiments

The condensation method produced 0.6 g in 1-hour working time (the experimental setup, using several stones simultaneously, is shown in Fig. 1a). The recovered tar was solid at room temperature and could not be deformed by hand (Fig. 1b). Building the two raised structures using aluminium receptacle took approximately 30 min altogether. Producing a sufficiently large fire on top of the structures took another 30 min. Building the raised structure with the stone receptacle took 40 min. The fires were kept burning for 4 h. Thus, the stone receptacle sample and the first aluminium receptacle sample required a total time investment of approximately 5 h each. The second aluminium receptacle structure was left when still surrounded by warm embers and the tar sample was retrieved the next morning. This accounted to a total time investment of 20 h before tar was collected (for a discussion of tended and untended technical systems, see: [36]). The 5 h experiment using the aluminium receptacle produced 1.4 g of tar with low viscosity that could be deformed by hand. The 20 h experiment produced 1.65 g of tar that was solid at room temperature and could not be deformed by hand. Tar yield could not be determined for the raised structure using the stone receptacle because some of the tar was lost and other parts were found to be mixed with sediment (see the photo of the stone receptacle after the experiment in the Additional file 1). We subsampled this sample to only include tar that was not contaminated with sediment.

Lap-shear tests

Figure 2 shows three typical stress/strain curves from each of the samples. Strength related values are summarised in Table 1. Tar made with the condensation method had a maximal shear stress τ_u of $1.14 + 0.46 - 0.52$ MPa, as averaged from 11 measurements (in this case, maximal shear stress is vaguely equivalent to ultimate tensile strength in tensile testing, hence we use the notation τ_u). At τ_u catastrophic failure of the bond occurs. Tar made during 20 h with the raised structure showed similar

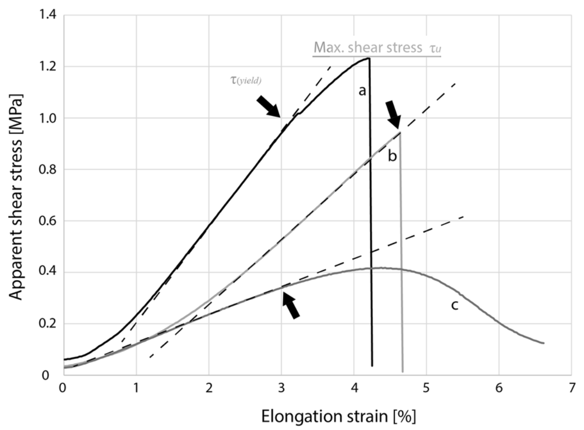

Fig. 2 Stress–Strain curves of birch tar made with the condensation method (**a**), the raised structure including overnight cool down (**b**) and the raised structure without cool down phase (**c**). The samples' shear strength values (i.e., the shear stress values in MPa at which elongation in the samples' stress–strain diagrams cease to be linear) are marked by black arrows. All values obtained from the three samples are marked with the same letters (**a**, **b**, **c**) in Table 1

behaviour: it failed catastrophically in a brittle manner (Fig. 2, curve b). τ_u was ~20% lower than condensation tar with a mean of 0.95 + 0.33 − 0.53 MPa.

Tar made in 5 h with the raised structure had significantly different τ_u at ~65% below that of condensation tar and ~55% lower than 20 h-raised structure tar with 0.417 + 0.45 − 0.21 MPa. Tar made with the raised structure using a stone receptacle had a τ_u of 0.24 + 0.24 − 0.15 MPa (some of the stress strain curves of this sample can be seen in the Additional file 1).

Once τ_u is reached, the 5 h-raised structure tar bonds underwent ductile deformation with apparent lowering of the shear stress (Fig. 2, curve c; this is true for aluminium and stone receptacle samples). This observed failure behaviour holds the key to understanding why τ_u might not be the only value to be considered here. Before failure, curves are not linear all along but the relative increase of τ slows down at greater elongation strains. Thus, our samples do not behave as brittle solids. Another way to interpret our stress/strain diagrams is therefore by calculating the tangent slope for small deformation intervals on the curves. The stress at which the curve deviates from this tangent (typically after a period of near linearity) is taken to reflect the stress at which creep becomes the dominant deformation (this is vaguely equivalent to the yield strength σ in tensile material testing). The method is schematically outlined in Fig. 2 (tangent slopes in broken lines, $\tau_{(yield)}$ marked by arrows). We call this point the shear strength $\tau_{(yield)}$. τ_u can be equal to or greater than $\tau_{(yield)}$, depending on the moment at which different samples begin to deform plastically. $\tau_{(yield)}$ values are reported together with their associated strain values in Table 1. Both values are plotted in Fig. 3. The scatter plot shows a linear trend, suggesting a roughly linear elastic behaviour of the samples up to their shear strength. Comparing the three tar samples in terms of $\tau_{(yield)}$, a similar trend emerges as for their τ_u value. Condensation tar has a $\tau_{(yield)}$ of 0.86 + 0.2 − 0.36 MPa; tar made during 20 h with the raised structure and an aluminium receptacle has a $\tau_{(yield)}$ of 0.7 + 0.4 − 0.4 MPa (19% lower); tar made with the raised structure and an aluminium receptacle for 5 h has a $\tau_{(yield)}$ of 0.28 + 0.32 − 0.13 MPa (67% lower than condensation tar). Tar made with the raised structure and a stone receptacle for 5 h has a $\tau_{(yield)}$ of 0.2 + 0.14 − 0.13 MPa.

Discussion

Choices made during our experiments and the quality of our data

Previous authors have performed impact tests along with lap-shear tests [25]. This combined approach may provide a more complete understanding of adhesives as it tests for bonding strength under static conditions like cutting with hafted stone tool and under impact conditions when a projectile is tipped with a hafted stone point. We decided not to test for impact strength as there are no indications that any of the known Palaeolithic birch tar artefacts were used for hafting stone tools to projectiles or handles (compare: [1, 2, 4]).

We chose to use aluminium receptacles for the two main raised structure experiments. In this way, sediment contamination could be limited and a relatively large quantity of uncontaminated tar could be collected after the experiments (because the earthen walls of the lower container were covered by aluminium, Fig. 1). One of the possible effects of this protocol is that the use of aluminium containers, obviously not available in the Palaeolithic, could influence the quality of the tar produced with the raised structures. Although the nature of the container is not expected to have an influence on the volatile components of the raised structure tar (which is lost through evaporation), it appears possible that an aluminium container allows to collect more of the low viscosity fraction of the tar because it is more impermeable than other natural materials. These low viscosity components might be absorbed by a container made from a more porous natural material. We had therefore conducted another raised structure test, using a more porous stone receptacle. The comparison between the tar from this stone container and tar made with the aluminium container, both produced during 5 h, showed that tar collected in a more porous stone container had a ~40% lower maximum shear stress value and a comparable, although slightly lower, shear

Table 1 Bonded surfaces, shear strengths and maximum shear stresses from the performed lap-shear tests of each of three analysed samples

Tar making method	Surface 1 (mm^2)	Surface 2 (mm^2)	Average (mm^2)	Shear strength $\tau_{(yield)}$ (MPa)	Strain (%)	Maximum shear stress τ_u (MPa)
Condensation	211.65	212.94	212.29	0.55	2.20	0.93
Condensation	304.50	305.51	305.00	1.00	4.40	1.24
Condensation	266.04	316.95	291.49	0.82	3.90	1.32
Condensation (a)	214.16	192.41	203.28	0.90	3.00	1.23
Condensation	278.82	283.89	281.36	1.10	4.20	1.60
Condensation	301.49	275.78	288.63	0.80	3.80	1.14
Condensation	290.81	273.09	281.95	1.10	4.60	1.22
Condensation	275.83	294.56	285.19	1.10	4.40	1.16
Condensation	311.12	290.88	301.00	0.80	3.30	1.31
Condensation	277.51	288.30	282.91	0.78	4.40	0.77
Condensation	322.07	287.43	304.75	0.50	2.60	0.62
Raised structure 20 h	298.66	272.99	285.83	0.90	4.30	0.99
Raised structure 20 h	275.42	299.95	287.69	0.85	3.80	1.08
Raised structure 20 h	304.93	337.93	321.43	0.60	3.30	1.01
Raised structure 20 h	213.96	226.67	220.32	1.10	4.20	1.15
Raised structure 20 h	322.58	322.58	322.58	0.80	3.50	1.28
Raised structure 20 h	303.57	264.90	284.23	0.30	3.60	0.42
Raised structure 20 h (b)	260.21	264.82	262.52	0.82	4.30	0.94
Raised structure 20 h	336.37	334.96	335.66	0.55	2.80	1.10
Raised structure 20 h	331.36	294.26	312.81	0.60	2.40	1.01
Raised structure 20 h	342.52	350.86	346.69	0.48	2.90	0.51
Raised structure 5 h	234.67	254.45	244.56	0.45	2.70	0.21
Raised structure 5 h	332.33	319.04	325.69	0.20	2.80	0.28
Raised structure 5 h	322.58	322.58	322.58	0.18	5.90	0.69
Raised structure 5 h	323.80	246.75	285.27	0.15	1.80	0.22
Raised structure 5 h	310.95	268.32	289.63	0.25	2.40	0.42
Raised structure 5 h	322.58	322.58	322.58	0.60	3.40	0.87
Raised structure 5 h (c)	324.25	295.36	309.80	0.30	2.40	0.45
Raised structure 5 h	330.95	338.62	334.79	0.30	2.60	0.37
Raised structure 5 h	318.88	315.45	317.16	0.20	1.60	0.35
Raised structure 5 h	286.64	299.29	292.97	0.20	2.30	0.31
Raised structure 5 h stone receptacle	322.58	322.58	322.58	0.07	1.60	0.09
Raised structure 5 h stone receptacle	322.58	322.58	322.58	0.12	2.03	0.14
Raised structure 5 h stone receptacle	322.58	322.58	322.58	0.34	1.94	0.37
Raised structure 5 h stone receptacle	322.58	322.58	322.58	0.12	3.47	0.13
Raised structure 5 h stone receptacle	322.58	322.58	322.58	0.33	2.33	0.48

Letters in brackets in the first column are the numbers of stress/strain diagrams shown in Fig. 2

strength value. Thus, using an aluminum container has the opposite effect to what we expected. This result suggests that the use of aluminum containers might cause the shear strength of tar made with the raised structure to be overestimated. As it stands, our quantitative comparison between condensation method tar and raised structure tar must be regarded with caution, although the overall trend is most likely correct based on our results from this comparison.

We also found that there are complex stress distributions present in the bonded areas of birch tar analysed with lap-shear tests, leading to non-linear behaviour even before failure. This can be expected to depend (at least in part) on the thickness of the bond and the quality of the bonding surface (see for example: [34]). Measuring bond thickness was not possible with the wooden laps used for this study, as their thickness is not uniform across the bonded surface (i.e., they were not sufficiently

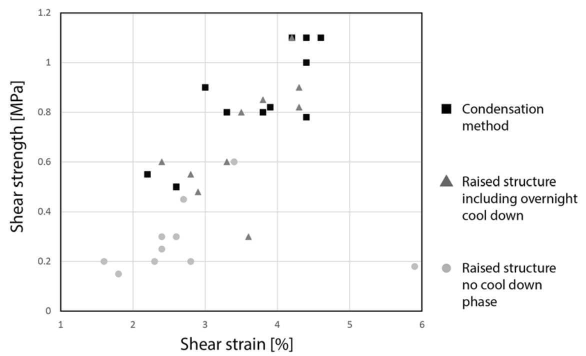

Fig. 3 Shear strength in MPa plotted over shear strain in percent. Note the near-linear trend, suggesting that samples exhibit nearly brittle behaviour below their shear strength

plan parallel). Measurements were therefore repeated at least ten times for the samples (except for tar made with a stone receptacle that was repeated 5 times, as this was only done to verify the validity of our experimental protocol). As highlighted above, we consider only the apparent shear stresses τ, attributing all measured forces to be shear only. This is not entirely true, as can be seen from the curves in Fig. 2, which are not linear even for tars that fail catastrophically. One of the reasons for this is that organic materials, such as some of our birch tar samples, do not respond to stress with elastic deformation up to their failure. They show plastic deformation by viscous processes or other creep phenomena. Furthermore, horizontal elongation in lap-shear tests cannot be expected to be linear because the tar samples' thickness at the bond varies with elongation (depending on Poisson's ratio of the adhesives). Thus, τ_u recorded by lap-shear tests is not a good indicator of the resilience of natural tars against shear. We still use this value here because previous authors have provided lap-shear data [19, 25, 26] with which our data may be comparable. Although our tests cannot yield absolute values of *G*, our approach to measuring τ_u provides comparability with previous works [25, 26] that reported similar values.

The performance of birch tar made with different production techniques

What does performance of adhesives made in the Stone Age actually mean? Two cases may be distinguished. Adhesives that have to work only one time (as may be true for a projectile hafting) can most likely be qualified by either the maximum shear stress they endure (including a plastic deformation modifying the shape of the joint permanently) or by the total energy they absorb during the shearing process. For such a rupture energy evaluation, other experiments with better strain control are needed. The other case consists of adhesives used for repeated actions (cutting, scraping, etc.). These may be better qualified by shear strength $\tau_{(yield)}$. A nearly brittle nature of the failure (the sample behaving almost elastically until the breaking point) might in this case be an advantage because tools either hold or break loose. A plastically deformed haft will perform less well in successive use cycles.

Our results highlight that tar made with the condensation method is similarly, although slightly more, performant when used as adhesive than tar made with the raised structure can be. A larger difference exists when raised structure tar is collected from the structure directly after the surrounding fire burned out. Our τ_u measured on 5 h-raised structure birch tar (0.417 + 0.45 − 0.21 MPa) is in accordance with, although lying slightly above, previously published lap-shear values of birch tar made with the double-pot method (using a metal container) that was subsequently boiled to thicken it (0.32 + 0.19 − 0.18 MPa, see: [26]). The raised structure is a good approximation of the double-pot architecture in aceramic conditions (for a detailed description of the double-pot, see: [7]) and it also appears to produce birch tar with similar properties. It is noteworthy however, that the aceramic raised structure allows the production of birch tar with similar strength as the metal-based double-pot without requiring the supplementary step of tar reduction by boiling. The reason for this might be a better availability of oxygen in the raised structure due to incomplete sealing because of the wet sediment. The strength of the raised structure tar can be improved by a factor of two, if the tar is allowed to cool slowly overnight. The reason for this might be oxidative reactions in the slowly cooling tar or tar reduction by degassing. Only further studies may shed light on these processes. The condensation method produced birch tar with the highest τ_u of the tested production methods. Our maximal strength (1.14+0.46–0.52 MPa) is well in accordance with previously published strength values of condensation tar (1.145 + 0.403 − 0.438 MPa, see: [19]).

The cost and return of birch tar made with different techniques

The differences in adhesive performance of our samples are best discussed with regards to the investment in time and effort required by different production methods. Recently, Blessing and Schmidt [36] found that the raised structure is the most efficient of the aceramic production techniques in terms of material requirement (supporting previous arguments made by: [15]). However, it can be inferred from the data in Badino et al. [37] that birch bark was readily available in northern Europe during the Late Middle Palaeolithic. It is therefore unclear whether efficiency in terms of required bark over tar yield may possibly have imposed constraints for making the birch tar artefacts from Zandmotor and Königsaue. Another raw material-related factor is that the raised structure requires the collection of firewood, imposing supplementary constraints on the environment in which tar is made and which are absent for the condensation method.

If time investment is compared for both techniques, the difference between the raised structure and the condensation method seems to be negligible. Both produced similar amounts of tar per hour in most experiments [36]. It is also noteworthy that the raised structure imposes a minimum requirement of time, which is roughly 4–5 h [15], while the condensation method allows to produce usable amounts of tar in approximately one hour [36] (e.g., the 0.87 g weighing smaller birch tar piece from Königsaue can be produced in ~1 h 20; these times cannot be compared in terms of attention required, see for example [36], but they do still represent time requirements). Thus, in terms of time requirement, the condensation method may be far more advantageous if tar is needed rapidly. In the light of our finding that condensation tar is similar to tar made with the raised structure in 20 h and superior to raised structure tar made in 5 h (in terms of shear strength at least), we note that this simple open-air technique provides the best value for the time investment it requires. Whether raised structure tar produced without the cooling phase may be improved by a supplementary step of tar reduction, in which the low viscosity tar is boiled over an open flame to produce a more viscous product, cannot be answered at this point. However, additional cooking of the tar would require larger investment than investigated here.

Conclusion

The relationship between the quality of the tar and the investment required for its production highlights the condensation method as the most likely of all known aceramic birch tar production techniques. There are however other adhesives that were used by Neanderthals (such as bitumen, see: [38], and pine resin, see: [39]). Data on the adhesive strength of pine resin suggest similar strength to birch tar made with the condensation method and even slightly higher adhesive strength either when an additive is added or if it is reduced by boiling [26]. The strength can be further improved by adding complex mixtures of additives [25]. Whether these differences are significant for our understanding of adhesives in the Middle Palaeolithic cannot be decided based on our study but we note that among all currently discussed birch tar production techniques, the simplest and most expedient condensation method provides the strongest tar.

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s40494-021-00621-1.

Additional file 1: Figure S1. Side (left) and top view (right) of the stone receptacle used in the raised structure (production time 5 h). Note that there is still tar adhering to the stone. This tar is contaminated with sediment. The middle portion was scraped to obtain tar without sediment impurities. **Figure S2.** Three stress strain curves obtained from lap shear tests on the raised structure birch tar sample using a stone receptacle and a total production time of 5 h.

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F. Lauxmann contributed to the experiments and R. Iovita assisted with the condensation method experiments.

Authors' contributions

PS and MB conceived the study. PS, MAB, TJK and KGN analysed the data and wrote the paper. All authors read and approved the final manuscript.

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Availability of data and materials

All data generated or analysed during this study are included in this published article.

Declarations

Competing interests

The authors declare that they have no competing interests.

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Publisher's Note

Appendix i.e

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ORIGINAL ARTICLE

Investigating the MIS2 Microlithic Assemblage of Umbeli Belli Rockshelter and Its Place Within the Chrono-cultural Sequence of the LSA Along the East Coast of Southern Africa

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Abstract South Africa is arguably one of the most studied regions in Stone Age research. There are, however, considerable differences in research intensity with respect to different regions and time periods. While KwaZulu-Natal is an epicenter for Middle Stone Age (MSA) research, the Late Pleistocene LSA record is largely understudied in this region. Here we present a lithic assemblage from the site Umbeli Belli near Scottburgh dated to 17.8 ± 1.5ka BP. The lithic analysis of the GH 3 assemblages revealed both gradual and abrupt changes within this stratigraphic horizon, indicating relatively short-term changes in material cultural traditions. A comparison with other Robberg sites in the wider surroundings highlights the regional variability of the Robberg techno-complex and indicates potential directions for future research.

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Résumé L'Afrique du Sud est sans doute l'une des régions les plus étudiées dans la recherche sur le paléolithique. Il existe néanmoins des différences importantes dans l'étendue de la recherche selon les différentes régions et périodes. Alors que le KwaZulu-Natal est un épicentre de la recherche sur le *Middle Stone Age* (MSA), le *Later Stone Age* (LSA) du Pléistocène supérieur est considérablement sous-étudié dans cette région. Nous présentons ici un assemblage lithique du site Umbeli Belli près de Scottburg daté de 17.8 ± 1.5ka BP. L'analyse lithique des assemblages de la couche stratigraphique GH 3 a démontré des changements à la fois graduels et brusques au sein de cet horizon stratigraphique, indiquant des changements de durée relativement courte dans les traditions de la culture matérielle. Une comparaison avec d'autres sites de Robberg dans les environs a mis en évidence la variabilité du techno-complexe Robberg et les orientations potentielles pour les recherches futures.

Keywords Later Stone Age · Robberg · Lithic technology · Microlithic technology

Introduction

The Later Stone Age (LSA) has had a long research tradition in South Africa ever since the term was introduced by Goodwin and Van Riet Lowe (1929). However, there are still major gaps in our

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understanding of the timing and attributes of the early LSA, and the relationships between the terminal Middle Stone Age and the advent of the LSA. This article contributes to clarifying the chrono-cultural sequence of the LSA along the east coast of Southern Africa, using the recent data from Umbeli Belli in the KwaZulu Natal region as the springboard of our discussion.

Research on the cultural stratigraphy of the LSA flourished between the 1970s and the 1990s (Barham, 1989a, 1989b; Deacon, 1979, 1984, 1989; Mazel, 1984, 1986, 1988; Opperman, 1987; Price-Williams, 1981; Wadley, 1978, 1996, 1997). Much work has been done recently on several previously known Late Pleistocene LSA sites. This has led to the reassessment of these sites' chronologies and archaeological assemblages (Bousman & Brink, 2018; Loftus et al., 2016, 2019; Low & Mackay, 2018; Pargeter et al., 2017, 2018; Porraz et al., 2016; Tribolo et al., 2016). A special focus has been given to the phenomenon of lithic miniaturization and its meaning for strategies of adaption to changing environmental conditions (Bader et al., 2020; Low, 2019; Low & Pargeter, 2020; Pargeter & Redondo, 2016; Porraz et al., 2016). Here, we use Late Pleistocene LSA to refer to Early Later Stone Age (ELSA) and Robberg, a common practice in South African contexts. This use of the term is somewhat different from how it is used outside of South Africa. At the site of Apollo 11 (Namibia), for example, the term refers to the assemblage post-dating the final MSA and with the absence of Robberg (Ossendorf, 2017).

The chrono-cultural unit of the Robberg techno-complex dates to roughly between 25 and 10 ka in South Africa (Bousman & Brink, 2018). It is characterized by the prevailing absence of formal tools, a strong signal for bipolar percussion on quartz in order to produce small, elongated products and large numbers of microliths (Mitchell, 2002). In addition, small handheld platform cores for bladelet production (e.g., on chert) occur in several Robberg assemblages (Bader et al., 2020; Pargeter & Redondo, 2016). Microliths are one of the most characteristic features of the Robberg complex. However, the term microlith or what constitutes a microlithic technology is not always used in the same way and often means different things depending on the researcher. The definition provided by Kuhn & Elston (2002) mentions technological and typological characteristics—bladelet or microblade production and backing—as the prevalent feature of modification of microlithic blanks. This definition combines backing and bladelet production as the third feature of microlithic technologies. A fourth characteristic is the high numerical frequency of bladelets or other microlithic artifacts. For the definition of the Robberg, however, only the technological aspects of this definition can be included; the typological aspect, mainly backed pieces, is rare, though not absent (e. g., Kaplan, 1990; Mitchell, 1995; Porraz et al., 2016). It is noteworthy that the bladelet production of the Robberg technocomplex, in contrast to what is more common in other periods and regions of the world, does not always rely on elaborate core reduction techniques. On the contrary, Robberg bladelets are frequently obtained using bipolar percussion. Other features mentioned by Kuhn & Elston (2002), such as a high frequency of microlithic artifacts alongside macrolithic ones and a high degree of standardization, are also to be found in Robberg assemblages (Mitchell, 1995; Porraz et al., 2016). Though not explicitly stated in the original publication, the list of characteristics of a microlithic assemblage provided by Kuhn & Elston (2002) should not be seen as an "all or nothing" definition. Like microlithic assemblages in East Asia, Robberg assemblages show little to no sign of modification of the bladelets. Hence, it is justifiable to call the Robberg a microlithic technology, even though it checks only some of the boxes given by Kuhn & Elston (2002).

First recognized by Abbe Breuil at Rose Cottage Cave (Wadley, 1996), the Robberg complex was subsequently defined using the assemblages from Nelson Bay Cave (Klein, 1974) and Rose Cottage Cave (Deacon, 1979, 1984; Wadley, 1996). It was then thought to mark the onset of the LSA in southern Africa during the Last Glacial Maximum (LGM) (*cf.* Villa et al., 2012). On a superficial scale, the Robberg appears uniform across the entire subcontinent of South Africa, but recent comparative studies of assemblages from different biomes suggest greater inter-regional variability than previously thought (e. g., Bader, et al., 2020; Low & Pargeter, 2020). This variability had been recognized even earlier and attributed to different geographical settings and differences in raw material availability (Mitchell, 1988a, 1988b). However, this interpretation and several others are currently debated (Low & Pargeter, 2020). Comparative studies are rare. Hence, the nature, timing, and causes of the variability within the Robberg of southern Africa remain somewhat obscure.

While considerable progress in the investigation of the Robberg has been achieved in recent years, the research has focused on distinct areas such as the highlands of Lesotho (e. g., Mitchell, 1990, 1995, 1996; Mitchell & Arthur, 2014; Pargeter, 2016; Pargeter et al., 2017) and the west coast of South Africa (e. g., Low, 2019; Low & Mackay, 2018; Porraz et al., 2016; Watson et al., 2020). Other regions, such as the coastal area of KwaZulu-Natal (KZN), remain largely understudied. With the exception of Umhlatuzana (Kaplan, 1989, 1990) and Shongweni (Davies, 1975; Davies & Gordon-Gray, 1977), little is known about the chrono-cultural expressions and variations of MIS2 assemblages in the area (see also Mackay et al., 2014).

Between 2016 and 2020, a research team led by Gregor Bader and Nicholas Conard from the University of Tübingen, Germany, conducted new excavations at Umbeli Belli, a rockshelter situated at the Mpambanyoni river, approximately 7 km inland from Scottburgh. The site has yielded extensive MSA and LSA horizons and was accurately dated using optically stimulated luminescence (Bader et al., 2018). The geological horizon 3 (GH 3) was dated to 17.8 ± 1.5-ka BP, and preliminary field observations indicated that the assemblage belongs to the Robberg tradition. Considering the gaps mentioned above and the weak chrono-cultural background for MIS2 assemblages in KZN, Umbeli Belli has the potential to provide valuable new data on the nature and timing of microlithic technologies in this part of the subcontinent. Here we provide a detailed technological study of the GH 3 assemblage from Umbeli Belli, aiming to (1) investigate the characteristic features, (2) test for inner assemblage variation, and (3) provide an estimate of the chrono-cultural assignment of the lithic inventory. We discuss our results within the overall MIS2 record of the broader region and interpret the nature, timing, and meaning of microlithic technologies at the onset of the LSA. Given our findings, a special focus of the discussion will be on the so-called early and late Robberg, as proposed by Kaplan (1990). Based on our findings, we will discuss whether or not this subdivision of the Robberg technocomplex is justifiable and, if so, how it manifests in the archaeological record.

Umbeli Belli: Background to the Site, Stratigraphy, and Dating

Umbeli Belli is a quartzite shelter situated above the Mpambanyoni river valley (Fig. 1). Charles Cable (1984) first excavated the site in 1979 with a particular focus on the uppermost layers covering the last 2000 years of hunter-gatherers in southern Africa. After a preliminary examination of the MSA assemblage recovered from Cable's excavation, a team from the University of Tübingen led by Gregor Bader and Nicholas Conard re-excavated the site and extended Cable's old trench in 2016 (Bader et al., 2016, 2018). These excavations yielded a rich stratigraphy of MSA and LSA occupational horizons (Fig. 2). A detailed description of the stratigraphy and the dating has been published recently, together with an in-depth lithic analysis of the upper MSA layers (Bader et al., 2016, 2018).

The LSA sequence at Umbeli Belli can be subdivided into seven stratigraphic units. The uppermost three (Layers 1, 2BE, and 2AL, following Cable's classification) were not part of the Tübingen excavations, and those are published in detail by Cable (1984). The radiocarbon dates obtained from layers 2AL and 2BE show a significant hiatus in the sequence, falling between the ninth and tenth century AD and the seventeenth to the nineteenth century, respectively. The stratigraphic sequence below was excavated by the Tübingen team and divided into subunits called geological horizons (GH). GH 3, 4, 5, and 6 are the Pleistocene LSA units under our investigation, and here we focus on GH 3. Preliminary results from the units underlying GH 3 imply an Early LSA sequence spreading over GHs 4, 5, and 6. GH 3 was dated by OSL to 17.8 ± 1.5-ka BP, and preliminary field observations by Bader et al. (2018) indicated a strong microlithic component.

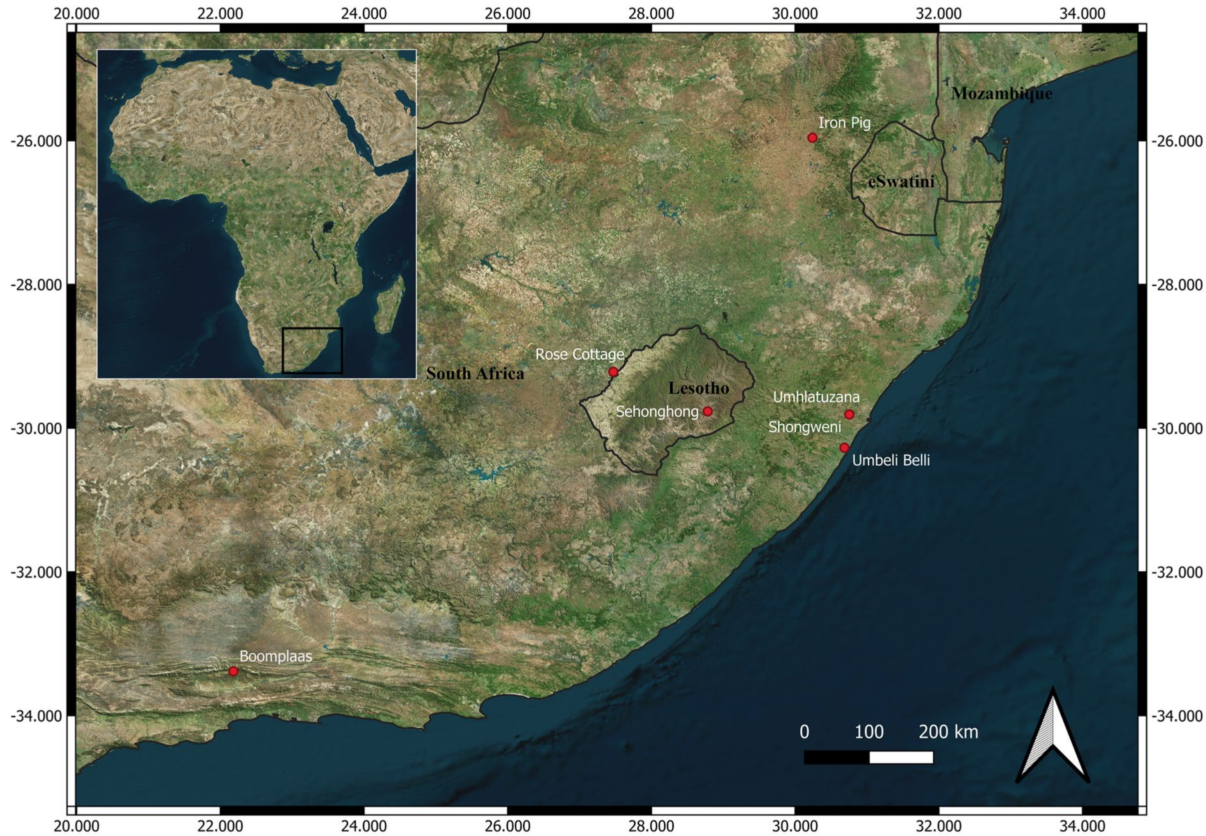


Fig. 1 Umbeli Belli and other Robberg sites in regional and supra-regional contexts

Materials and Methods

Excavation and Find Processing

The excavations at Umbeli Belli followed natural geological units, which approximate cultural stratigraphic units. The excavation grid is a meter-square system following Cable's original trench (see Bader et al., 2018). In total, 18 geological units were defined following a numerical system starting with 1 at the top and 18 at the bottom. GH 2 is subdivided into 2BE and 2AL, and GH11 is subdivided into 11, 11a, and 11b. The geological horizons at Umbeli Belli were further subdivided into subunits 1–3 cm thickness following the natural inclination of the sediments. Following the German taxonomy (and in the absence of a clear equivalent in English), we call these subunits "Abtrag" or in plural "Abträge." For further details, see Bader et al. (2018). GH 3 consists of a reddish brown (Munsell 5YR, 4/4) fine silty sand with numerous small pieces of quartzite spall.

In square 3/13, GH 3 was excavated in 28 Abträge allowing a high-resolution analysis of changes in lithic technology from bottom to top. For our examination of GH 3, we use lithic attribute analysis (Andrefsky, 1998; Auffermann et al., 1990; Odell, 2012; Scerri et al., 2016) based on the framework established at Umbeli Belli (Bader et al., 2016, 2018) and Sibhudu (Will et al., 2014). We recorded a total of 2402 lithic artifacts (> 2 cm) for attribute analysis. An additional 8626 artifacts (< 2 cm) were analyzed in terms of the total number and raw material.

Terminology

We subdivide blanks into flakes, blades, and bladelets. A blade is defined as an intentional product with parallel edges at least twice as long as wide (e. g., Hahn, 1991). Bladelets receive special attention as

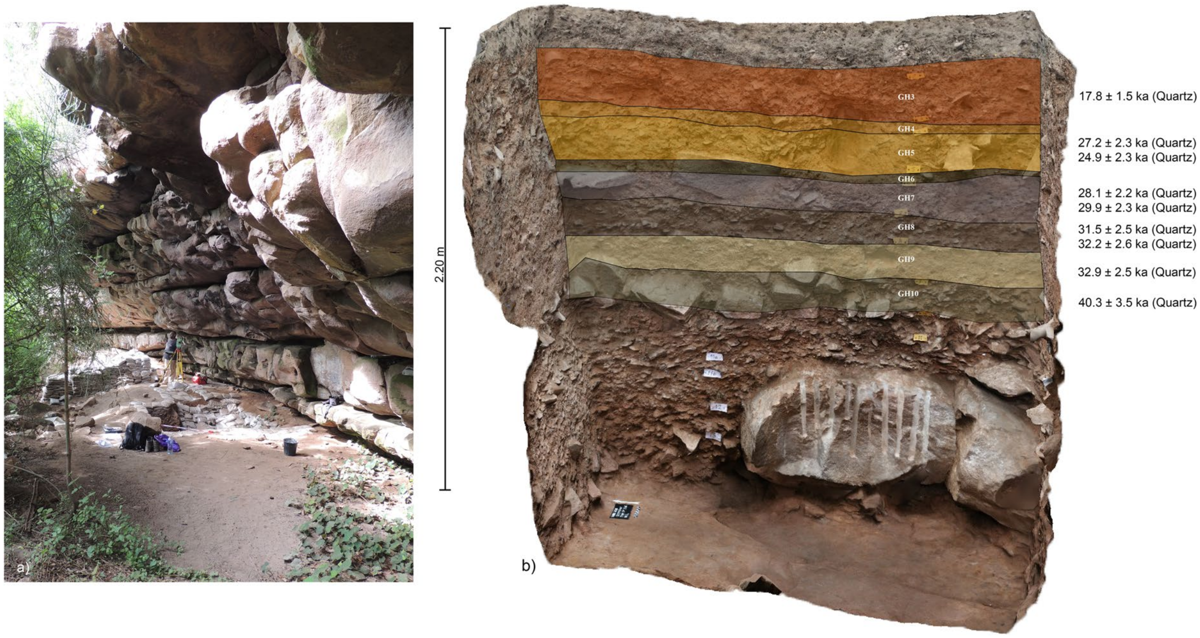


Fig. 2 Stratigraphic sequence of Umbeli Belli and view of the shelter from the north (modified after Bader et al. 2022)

they appear in high numbers in the GH 3 assemblage. Several definitions exist, but for intra-site comparability, we follow the same systematics of lithic analysis applied to the MSA layers of Umbeli Belli (Bader et al., 2016, 2018). Hence, a bladelet is a blade that is not wider than 12 mm. The same definition is also used in recent research on other microlithic assemblages in southern Africa (Bader et al., 2020; Pargeter & Redondo, 2016). We did not measure the width of the bladelets at the midpoint as the high degree of fragmentation would cause insufficient statistical results. Instead, we measured the width at the widest preserved part of the piece.

The core terminology for non-bipolar cores follows Bader et al., (2016, 2020) and Low and Pargeter (2020), which are based on the work of Deacon (1984). Bipolar cores are not further subdivided in the analysis. Bipolar cores are recognized based on smoothed edges on opposite sides (four smoothed edges if the core was rotated). Furthermore, a bipolar piece is identified as a core if it has negatives on at least two surfaces as opposed to bipolar flakes, which will only have negatives on the dorsal surface. In advanced reduction stages, bipolar cores often become cylindrical with negatives around the core surface (Davis, 1980; Pargeter, 2016). Other authors have noted difficulties discerning bipolar-reduced pieces from splintered pieces (de la Peña, 2015; Hayden, 1980), such that splintered pieces are sometimes accounted for as a subtype of bipolar-reduced pieces (Porraz et al., 2016). A recent series of experiments confirmed that a qualitative assessment to distinguish bipolar blank production from the use of splintered pieces (piecés esquillès) is not suitable for quartz (de la Peña, 2015). However, for raw materials other than quartz, the distinction between a bipolar core and a splintered piece rests mainly on the fact that the working edge of a splintered piece does not develop a splintered retouch, which is why a splintered piece will only have one such edge (de la Peña, 2011, 2015). Therefore, we emphasize that parts of the statistics on cores and tools might contain a slight overemphasis on bipolar cores made on quartz in the core assemblage and a slight overrepresentation of splintered pieces made of raw materials other than quartz in the tool assemblage. However, Pargeter and de la Peña (2017) noted that bipolar reduction performed on milky quartz in relationship to lithic miniaturization holds some advantages over freehand production, which offer an alternative explanation for the potential overrepresentation of bipolar quartz cores.

The tool taxonomy follows the system commonly used for South African LSA sites (Bader et al., 2020;

Deacon, 1984; Porraz et al., 2016). For retouched pieces, we will also use the term formal tools. Previous work has indicated that bladelets and flakes might have been used as tools without retouching them (e.g., Binneman, 1997; Binneman & Mitchell, 1997). Porraz et al. (2016) have noted the difficulty of distinguishing between intentional edge modification and edge modification deriving from the use of unretouched pieces. In the absence of backing, it seems likely that bladelets were used without retouch, but we have not yet tested our assemblage for this possibility. We assume that this also occurred at Umbeli Belli and wish to distinguish between retouched (formal) and unretouched (informal) tools.

Results

Out of the 2402 lithic artifacts larger than 2 cm, 24 (1%) were identified as manuports of non-quartzite raw material and 134 (6%) as angular debris of various raw materials. As shown in Fig. 3, the assemblage is dominated by unretouched blanks ($n = 2122$; 88%), while cores and formal tools are comparatively rare ($n = 88$; 4% and $n = 34$; 1%, respectively). There is a gradual increase in artifact density from bottom to top, with around 50 artifacts per Abtrag from Abtrag 28 to Abtrag 19. In Abtrag 11 to 1, the artifact density is around 100 artifacts per Abtrag, while Abtrag 18 to 12 reach intermediate values. The density of artifacts in the small debitage category follows a very similar trend. In Abtrag 28 to 19, the density of small debitage lies between about 86 and 175. The highest density is reached in Abtrag 11 to 1, where it reaches a maximum of 636 in Abtrag 9 and never drops below 250. Abtrag 18 to 12 show a gradual increase overall (Electronic Supplementary Material [ESM]-Fig. 1). Since undiagnostic angular debris and manuports mainly carry information about the raw material economy, they will be excluded from the analyses of the assemblage.

Raw Materials

While there is not much variability within the frequency of different lithic categories throughout GH 3, there is a notable change in the frequency of raw materials (Fig. 4). Concerning the entire GH 3 assemblage, quartzite (32.9%), quartz (32.3%), hornfels (25.4) and a yet to be determined coarse-grained material (7.2%) were most commonly used. Other raw materials such as shale, mudstone, or chert are extremely rare, so we will focus our analysis on the four most abundant raw materials mentioned before. Numerical data are provided in Table 1.

In Abtrag 28 to 18, between 50 and 60% of all lithics are knapped from quartzite. The frequencies of quartz, hornfels, and coarse-grained material range between 20 and 10%. Beginning with Abtrag 17 and up to Abtrag 10, quartzite, hornfels, and quartz are

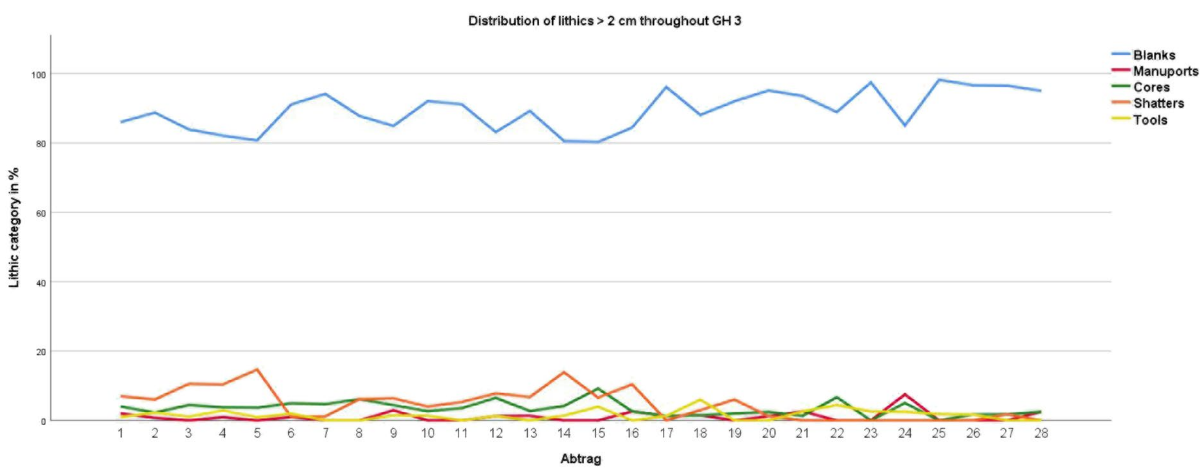


Fig. 3 Frequency of lithic categories > 2 cm throughout the sequence of GH3 of Umbeli Belli; df: 351, $p < 0.01$ (generated with SPSS 26)

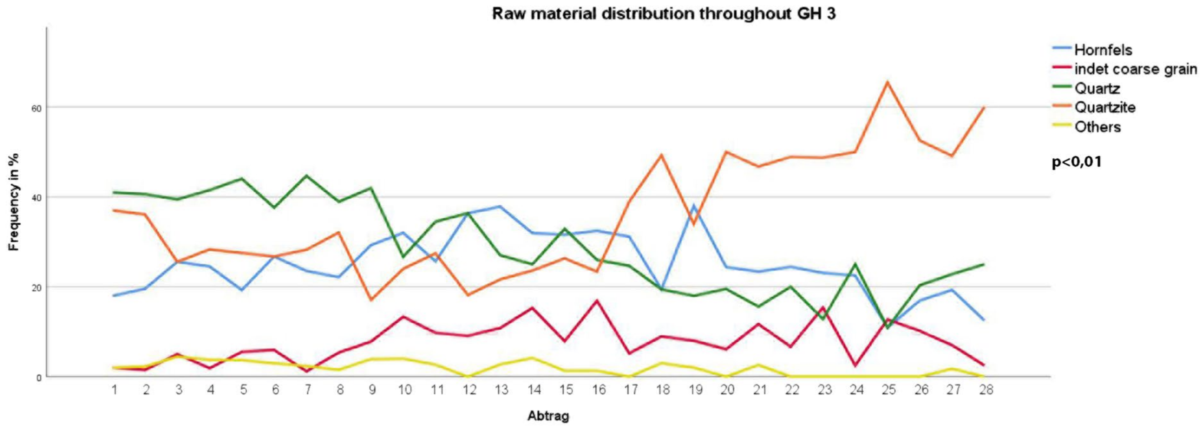


Fig. 4 Raw material frequency throughout the sequence of GH3 of Umbeli Belli (generated with SPSS 26)

about 30% each, while the coarse-grained raw material remains around 10%. In Abtrag 9 to 1, quartz is the dominant raw material accounting for up to 40% of the assemblage. Quartzite and hornfels range between 25 and 30%, while the coarse-grained raw material drops below 5% in frequency. We note that the undetermined coarse-grained raw material might be heavily weathered hornfels. If future mineralogical tests confirm this assumption, then the higher frequency of this particular raw material and its decreasing frequency in the upper part of GH 3 compared to the lower ones might reflect different stages of preservation.

Cortex

Only 23% ($n=549$) of all lithic artifacts from GH 3 exhibit cortex, most of them being blanks. We observed cortex only on six cores and eight tools. We classified the cortical parts in steps of 10, from 0% (no cortex) to 100% (blank dorsal surface fully covered with cortex). About 10–30% of the cortical pieces' dorsal surfaces are covered with cortex. We recorded the cortex percentage visible on the artifact regardless of preservation state and found no difference in cortex distribution between complete and broken artifacts. There is no clear trend in the sequence regarding how much cortex is left on the cortical artifacts. In general, cortical pieces are not very common and non-cortical pieces dominate. About 65% of the pieces in Abtrag 19 are non-cortical, and this value peaks at 94% in Abtrag 24. Likewise, there is no clear trend with respect to the frequency of cortical pieces throughout GH 3.

There is a trend, however, regarding raw materials and cortex: 49% of the hornfels artifacts exhibit cortex, while only 14% of the quartz artifacts and 16% of quartzite artifacts do so. With few exceptions, the cortex on hornfels and quartz artifacts is of cobble type, indicating a provenance from a secondary quarry, most likely the nearby Mpambanyoni River (see Bader et al., 2016, 2018). Slab cortex is rare. The cortex on most quartzite artifacts resembles the surface of the shelter, indicating a local provenance.

Knapping Technique

Out of the entire assemblage, 1450 (72%) blanks were knapped using a handheld core reduction technique, 516 (26%) pieces were knapped using bipolar reduction, and the other 38 (2%) blanks could not be classified into either category due to the poor state of preservation. Most pieces that could not be sorted into either category are angular debris made from hornfels. These lack any feature allowing a determination of the knapping technique. The ratio of the knapping technique is not uniform throughout the GH 3 sequence. There is a gradual change from the bottom to the top of the sequence (OSM 1—Fig. 2). In Abtrag 28 to 17, handheld knapping makes up around 80%. From Abtrag 16 towards the top of the layer, there is a steady decrease of handheld pieces in favor of bipolar reduction. This parallels the pattern of raw material use from bottom to top of GH 3.

Table 1 Frequency of raw materials per Abtrag in GH 3 of Umbeli Belli counted for artifacts > 2 cm. Dominant raw material in bold

Abtrag	Quartz %	Quartzite %	Hornfels %	Indet. coarse-grained %	Chert %	Other %	Total %	Total n
1 (9 l)	**41.0**	37.0	18.0	2.0	0.0	2.0	4.3	100
2 (15 l)	**40.6**	36.1	19.5	1.5	0.0	2.3	5.5	133
3 (19 l)	**39.4**	25.6	25.6	5.0	0.0	4.4	7.4	180
4 (11 l)	**41.5**	28.3	24.5	1.9	2.8	1.0	4.4	106
5 (10 l)	**44.0**	27.5	19.3	5.5	0.9	2.8	4.5	109
6 (9 l)	**37.6**	26.7	26.7	5.9	1.0	2.1	4.3	101
7 (10 l)	**44.7**	28.2	23.5	1.2	1.2	1.2	3.5	85
8 (11 l)	**38.9**	32.1	22.1	5.3	0.8	0.8	5.5	131
9 (17 l)	**42.0**	17.1	29.3	7.8	1.0	2.8	8.6	205
10 (9 l)	26.7	24.0	**32.0**	13.3	1.3	2.7	3.1	75
11 (11 l)	**34.5**	27.4	25.7	9.7	0.0	2.7	4.8	113
12 (10 l)	**36.4**	18.2	36.3	9.1	0.0	0.0	3.2	77
13 (10 l)	27.0	21.6	**37.8**	10.8	2.7	0.1	3.1	74
14 (10 l)	25.0	23.6	**31.9**	15.3	1.4	2.8	3.0	72
15 (11 l)	**32.9**	26.3	31.6	7.9	1.3	0.0	3.1	76
16 (10 l)	26.0	23.4	**32.5**	16.9	0.0	1.2	3.2	77
17 (12 l)	24.7	**39.0**	31.2	5.1	0.0	0.0	3.2	77
18 (11 l)	19.4	**49.3**	19.4	9.0	1.5	1.4	2.9	67
19 (11 l)	18.0	34.0	**38.0**	8.0	0.0	2.0	2.1	50
20 (16 l)	19.5	**50.0**	24.4	6.1	0.0	0.0	3.4	82
21 (18 l)	15.6	**46.8**	23.4	11.7	1.3	1.2	3.2	77
22 (10 l)	20.0	**48.9**	24.4	6.7	0.0	0.0	1.8	45
23 (9 l)	12.8	**48.7**	23.1	15.4	0.0	0.0	1.6	39
24 (9 l)	25.0	**50.0**	22.5	2.5	0.0	0.0	1.6	40
25 (9 l)	10.9	**65.5**	10.9	12.7	0.0	0.0	2.3	55
26 (12 l)	20.3	**52.5**	16.9	10.2	0.0	0.1	2.5	59
27 (11 l)	22.8	**49.1**	19.3	7.0	1.8	0.0	2.4	57
28 (9 l)	25.0	**60.0**	12.5	2.5	0.0	0.0	1.6	40
Total (319 l)	32.3	32.9	25.4	7.2	0.7	1.5	100.0	2402

A very strong pattern is observable in the relationships between knapping techniques and raw materials. Except for a few blanks ($n=8$) made from quartzite, hornfels, and rare raw materials, bipolar knapping was performed exclusively on quartz ($n=508$). There is a possibility that the bipolar flakes made from raw materials other than quartz are splintered pieces and were used like chisels. However, we are unable to identify the characteristics that resulted from the repeated hammering on one edge (e.g., de la Peña, 2015).

For the analysis of platform types, we could only include pieces that are either complete or in a state of preservation that includes the proximal end ($n=1019$). The most common platform types are plain (53%), crushed (33%), and cortical (6%). Other platform characteristics, such as linear, dihedral, and facetted, are rare (7%). While crushed platforms occur on pieces that were knapped from handheld cores, they are mainly a feature associated with bipolar knapping (OSM 1—Fig. 3). Among the handheld knapped blanks, plain platforms are predominant. Only five bipolar blanks have a plain platform. Prepared platforms rarely occur, most commonly on hornfels blanks, although the majority of hornfels blanks exhibit plain platforms. The rare raw materials were predominantly knapped without previous platform preparation. Cortical platforms are present in all main raw material categories, but all of these blanks

Fig. 5 Selection of blanks other than bladelets from Umbeli Belli GH3. **a–e** and **h–j** Flakes; **f**, **g** blades; **a** quartzite; **b**, **e**, **f** hornfels; **c**, **d** chert; **g–j** quartz (pieces are oriented with platform facing downwards)

are flakes; there are no cortical platforms on blades or bladelets.

Blanks (Fig. 5)

Flakes dominate the blank assemblage (Table 2), making up 83% ($n=1740$). With 212 specimens (10%), bladelets are the second most common blank type. Blades are not frequent ($n=52$; 3%). Slabs and other manuports account for 4% ($n=92$). The presence of slabs in the assemblage proves that the prehistoric people occasionally transported such raw material pieces to the site, likely intending to knap them. Further technological information cannot be generated from these pieces, however.

Only 29% of the blanks are completely preserved.

Bladelets (Fig. 6)

Only 33% ($n=66$) of the bladelets are completely preserved. Radial fractures are the most common kind of fragmentation. One hundred fifteen pieces (63%) are missing the proximal or distal end or both. Only ten bladelets (4%) are broken along the striking axis. Five pieces are missing a part of one lateral edge, thus still allowing for measuring width at the widest point. The mean width of the bladelets is 7.4 ± 1.9 mm. There is no clear pattern regarding the width of bladelets plotted against raw material (Table 3), but quartz bladelets are slightly narrower (7.1 ± 1.7 mm) than those made from hornfels (7.8 ± 2.2 mm) and quartzite (8.2 ± 1.9 mm). Sixty-six bladelets are completely preserved, and ten lack only parts of a lateral edge. Thus, 76 bladelets can be included in the analysis of mean length. The mean length of the bladelets is 17.6 ± 3.9 mm. Quartz bladelets are, on average, somewhat shorter than bladelets made from hornfels or quartzite (Table 4).

There is a strong emphasis on bladelet production on quartz. One hundred forty-one bladelets (66%) are made from quartz, 42 bladelets (20%) from quartzite, 27 (13%) from hornfels, and only two (1%) from the

Table 2 Number of blanks and slabs/manuports per Abtrag in GH 3 assemblage from Umbeli Belli

Abtrag	Flake		Blade		Bladelet		Slab/manuport		Total	
	n	%	*n*	%	*n*	%	*n*	%	*n*	%
1	77	89.5	2	2.3	3	3.5	4	4.7	86	4.1
2	94	80.3	2	1.7	19	16.2	2	1.7	117	5.6
3	123	85.4	4	2.8	15	10.4	2	1.4	151	7.2
4	69	81.2	1	1.2	14	16.5	1	1.2	87	4.2
5	75	86.2	0	0.0	11	12.6	1	1.1	88	4.2
6	68	78.2	1	1.1	15	17.2	3	3.4	92	4.4
7	64	81.0	1	1.3	10	12.7	4	5.1	80	3.8
8	99	86.1	2	1.7	8	7.0	6	5.2	115	5.5
9	146	83.9	1	0.6	21	12.1	6	3.4	174	8.3
10	60	87.0	1	1.4	4	5.8	4	5.8	69	3.3
11	90	88.2	0	0.0	3	2.9	9	8.8	102	4.9
12	51	79.7	2	3.1	7	10.9	4	6.3	64	3.1
13	56	84.8	0	0.0	7	10.6	3	4.5	66	3.1
14	46	79.3	1	1.7	7	12.1	4	6.9	58	2.8
15	46	75.4	3	4.9	8	13.1	4	6.6	61	2.9
16	51	78.5	3	4.6	5	7.7	6	9.2	65	3.1
17	61	85.9	1	1.4	6	8.5	3	4.2	74	3.5
18	48	81.4	3	5.1	5	8.5	3	5.1	59	2.8
19	43	93.5	0	0.0	1	2.2	2	4.3	46	2.2
20	66	86.8	4	5.3	5	6.6	1	1.3	78	3.7
21	56	80.0	4	5.7	5	7.1	5	7.1	72	3.4
22	36	92.3	2	5.1	0	0.0	1	2.6	40	1.9
23	30	78.9	2	5.3	5	13.2	1	2.6	38	1.8
24	21	61.8	0	0.0	9	26.5	4	11.8	34	1.6
25	44	81.5	4	7.4	3	5.6	3	5.6	54	2.6
26	46	80.7	4	7.0	6	10.5	1	1.8	57	2.7
27	41	74.5	3	5.5	6	10.9	5	9.1	55	2.6
28	33	86.8	1	2.6	4	10.5	0	0.0	38	1.8
Total	1740	83.0	52	2.5	212	10.1	92	4.4	2096	100.0

coarse-grained raw material (OSM 1, Fig. 4). Analogous to the preference of bipolar knapping for quartz, most of the quartz bladelets ($n = 131$) were knapped using bipolar percussion. Only two quartzite bladelets (1%) knapped from a bipolar core, and none of the hornfels bladelets were produced using this technique. Except for seven bladelets (3%) for which we were unable to determine the reduction technique (six quartz, one quartzite), all other bladelets ($n = 41$; 33%) were produced from handheld cores (OSM 1—Fig. 5).

Cortical bladelets are rare, 192 bladelets (91%) are non-cortical. It is hard to determine any clear temporal trend regarding cortex distribution on different raw materials because the sample size for raw materials other than quartz is relatively small. Bladelets made from hornfels have cortex remains on them more often than any other raw material category (10 out of 27), whereas bladelets made from quartz rarely have cortex remains (137 out of 140). Cortex is also rare on quartzite bladelets (5 out of 42). Quartz bladelets were found throughout every Abtrag of GH 3. While in the bottom part (Abtrag 28 to 20), bladelets from quartz, quartzite, and hornfels occur in almost similar low frequencies, quartz dominates the bladelet assemblage above Abtrag 20. Between 60 and 80% of bladelets in the upper levels are made from quartz. This parallels the increased use of quartz and the increase of the bipolar reduction method in the upper part of GH 3 (OSM 1—Fig. 6).

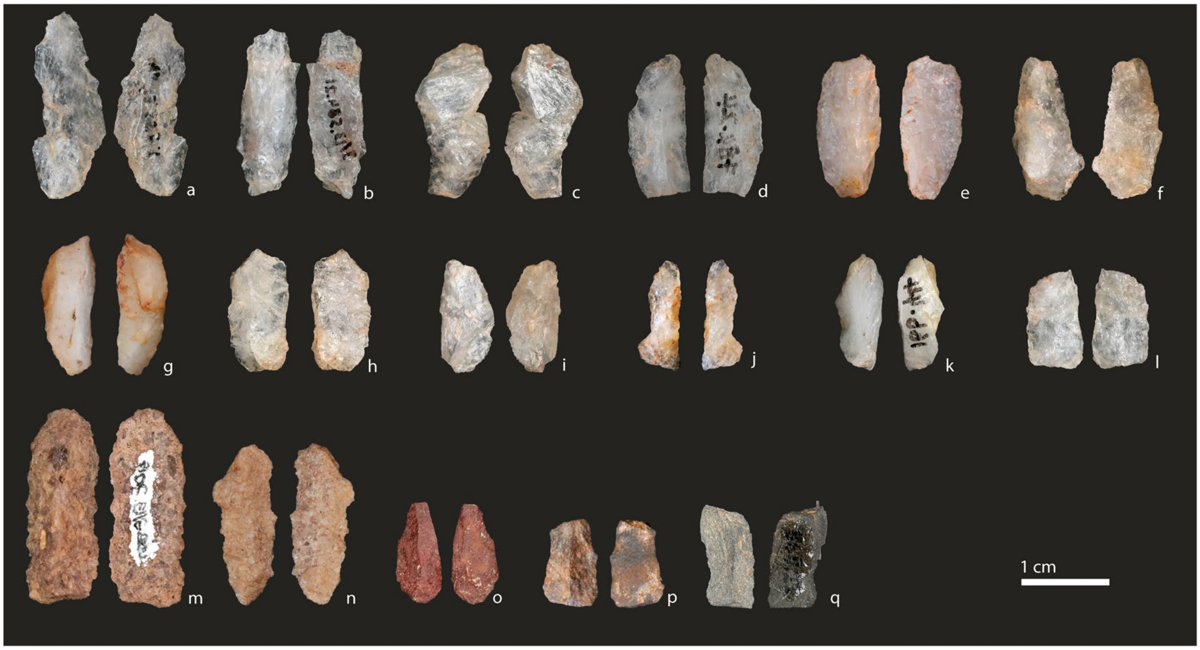


Fig. 6 Selection of bladelets from Umbeli Belli GH3. **a**–l Quartz; **m**, **n** quartzite; **o** chert; **p**, **q** hornfels (pieces are oriented with platform facing downwards)

Table 3 Mean width of bladelets in the GH 3 assemblage of Umbeli Belli

Raw material	Mean width	Total *n*	Std. deviation
Quartz	7.07	137	1.75
Quartzite	8.20	2	1.92
Hornfels	7.77	26	2.16
Indet coarse-grained	9.00	40	1.14
Total	7.40	205	1.89

Table 4 Mean length of bladelets per raw material in GH 3 assemblage of Umbeli Belli

Raw material	Mean length	Total (*n*)	Std. deviation
Quartz	17.1	61	3.57
Quartzite	19.4	8	2.62
Hornfels	19.7	7	6.53
Indet coarse-grained	N/A	0	N/A
Total	17.6	76	3.90

Tools (Fig. 7)

Only 11 formal tools (33%) are preserved completely, but except for one piece, all tools are at least 50% complete, allowing a typological classification. More than half of the tools ($n=20$; 59%) are splintered pieces, almost all of them made on hornfels, and 35% ($n=12$) are scrapers, with side scrapers being the most common ($n=10$). The other two formal tools are one retouched flake and one retouched blade. The one micro scraper in the assemblage is a tanged scraper made from quartz with a round working edge (Fig. 7k). The scraper is unifacially shaped, except for the cap, which is bifacially retouched. The tang is slightly v-shaped, and it is a complete piece, except for the little fracture at the end. We did not observe any traces of hafting on the tang. Backed pieces are absent in GH 3. About 73% of all formal tools are made from hornfels, although hornfels only accounts for 25% of the total raw material in GH 3. While chert is not very common in the overall lithic assemblage, three formal tools (two splintered pieces and one scraper) were made from this material (Table 5). The low frequency of tools throughout GH 3 does not allow us to observe any trends regarding changes in the frequency of tools. However, the distribution of tool types, specifically splintered pieces, and scrapers

Fig. 7 Selection of tools from Umbeli Belli GH3. **a** Retouched flake; **b**, **c**, **e**–**g**, **i** splintered pieces; **d**, **h** sidescrapers; **j** retouched blade; **k** microscraper

Table 5 Tools per raw material in GH 3 assemblage of Umbeli Belli

Raw material	Ret. blade	Ret. flake	End-scraper	Micro-scraper	Side-scraper	Splintered piece	Total (*n*)
Quartz	0	0	0	1	0	2	3
Quartzite	0	0	0	0	1	0	1
Hornfels	1	1	1	0	6	15	24
Indet coarse-grained	0	0	0	0	2	1	3
Chert	0	0	0	0	1	2	3
Total	1	1	1	1	10	20	34

reveals that scrapers are only part of the assemblage upwards from Abtrag 19.

Cores (Fig. 8)

Except for Abtrag 28 to 18, where the frequency of both cores and tools is generally low, cores are the second most common lithic category, accounting for 9% of the assemblage in Abtrag 15 (excluding undiagnostic shatters and manuports). Two broad types of cores were identified—platform cores and bipolar cores. Three of the 13 platform cores could not be further classified. Among the remaining ten, eight could be classified as semi-circumferential and two as circumferential (see Bader et al., 2016, 2020).

In terms of raw material preference for specific core reduction methods, a clear distribution can be observed. Bipolar cores are exclusively made from quartz, while platform cores are made from chert, hornfels, mudstone, quartzite, and quartz

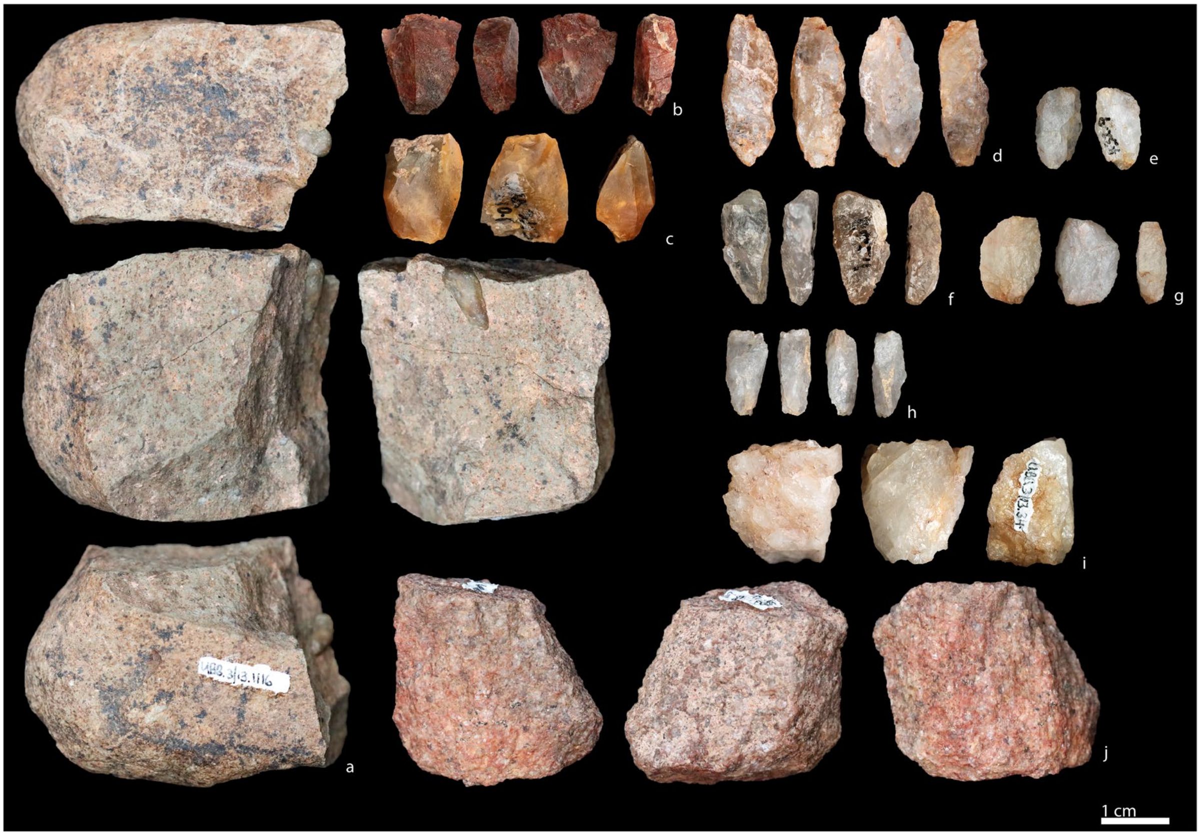


Fig. 8 Selection of cores from Umbeli Belli GH3. **a** Handheld core, hornfels; **b**, **c** handheld cores, chert; **d**–**i** bipolar cores, quartz; **j** handheld core, quartzite (pieces are oriented with platform facing upwards)

(OSM 1—Fig. 7). Thus, despite the high numbers of quartzite and hornfels blanks in the assemblage, there are only a few cores that can be attributed to these raw materials. The undetermined coarse-grained raw material is absent from the core assemblage. Among the bipolar cores, 40 (45%) preserve bladelet scars, and 33 (38%) preserve flake scars. However, we could not identify scars on one bipolar core because of the high degree of fragmentation. Knappers used platform cores to produce both bladelets ($n=5$; 6%) and flakes ($n=6$; 7%). Two platform cores were too fragmented to determine the intended product.

Both bladelets and flakes were detached from quartz cores. Hornfels and quartzite were used to produce bladelets and flakes, but their low numbers make it impossible to infer a potential pattern in raw material use. Because the majority of cores are bipolar cores, the distribution of removal direction is commonly parallel and bidirectional. Looking at the removal direction on platform cores, no clear patterns were observed, although the low sample size of that category might distort the picture. A parallel removal strategy seems prevalent, and evidence for other strategies, such as centripetal, irregular, or alternating, is rare.

Discussion

The Internal Chronology of GH 3

It is hard to estimate how much time is covered by GH 3. Firstly, this is due to the hiatus between GH 3 and

GH 2, which leaves us only with the minimum age of the Robberg technocomplex in general. Secondly, GH 4 has not been dated yet, but there are two OSL dates from GH 5, ranging between 22 and 21 ka (University of Bordeaux Montaigne, Archaeosciences Laboratory; see Bader et al., 2018). The OSL date from GH 3 (17.8 ± 1.5 ka; University of Bordeaux Montaigne, Archaeosciences Laboratory) has been taken from a different square, and the inclination of the sediments hampers a direct correlation, but the date most likely dates the upper part of the Robberg sequence above Abtrag 17. Based on these dates, the age range for the lower sequence is between 21- and 17-ka BP (perhaps less depending on the age of GH 4) and between 17 and ~ 10-ka BP for the upper part. These ranges are in the general timeframe for the Robberg technocomplex (Bousman & Brink, 2018; *cf.* Porraz et al., 2016). Micromorphological studies are underway that can potentially illuminate the period of GH 3. Based on the data and dates we currently have, we are unable to resolve the issue of how much time GH 3 covers.

Inner Assemblage Variability

The 28 Abträge of GH 3 provide a detailed resolution exhibiting substantial cultural change. These changes are both gradual and abrupt at times and involve many aspects of technology and typology. The most pronounced changes occur between Abtrag 19 and 17. At this position within the stratigraphy, we see shifts in raw material, bladelet production, and knapping technique. Although the sample size is small, changes in the tool and core assemblages coincide with the other developments in the lithic assemblage.

Splintered pieces occur throughout the sequence, but scrapers, for example, become part of the assemblage only above Abtrag 19. Among these scrapers is the tanged one with a round working edge, which is usually not characteristic of assemblages associated with the Robberg complex. A tanged scraper is more likely to be found in later periods of the LSA like the Wilton (but see Bader et al., 2020; Deacon, 1984). Among all raw materials, hornfels has the highest cortex percentages at Umbeli Belli. The change in core frequency is small, but in general, their absolute numbers increase above Abtrag 19 compared to the lower units.

Further, we observe a gradual shift in how bladelets are produced from Abtrag 18 upward. While bladelets are knapped mostly handheld in the lower Abträge and made from hornfels, they are knapped on quartz using bipolar percussion in the upper Abträge. Arguments have been brought forward that bipolar percussion is an inevitable outcome of using quartz as a raw material (Bousman, 2005; Jeske, 1992; Kaplan, 1990; Shott, 1989), but more recent studies of the assemblages from Klipfonteinrand (South Africa) and Sehonghong (Lesotho) suggest that the relationship between raw material and reduction technique might be more complex (Low & Pargeter, 2020). At Iron Pig Rockshelter further north in Mpumalanga, Bader et al. (2020) also observed the use of bipolar and handheld percussion to produce bladelets from quartz. In addition, well-flaked examples of bifacial quartz points in the MSA context of several sites, including Umbeli Belli (Bader et al., 2016, 2018) and Sibhudu (Will & Conard, 2018), strongly argue against a generalized assumption that the properties of quartz necessitate bipolar percussion. Nonetheless, in GH 3 at Umbeli Belli, knappers frequently apply bipolar technology to quartz. Our observation indicates that only eight bipolar blanks are made from a raw material other than quartz, and no bipolar cores are made from non-quartz raw materials.

We also tested the assemblage for differences in the size of the blanks, but we could not identify major changes. The difference is merely 1 mm with a large overlap in standard deviation. Thus, there was no increased lithic miniaturization at Umbeli Belli between the lower and upper part of GH 3. However, this is not the single decisive factor in lithic miniaturization. There is still a lively debate concerning the definition of "microlithic assemblages." There is a common understanding that size alone should not be the determining factor, but also bladelet production and/or proportions of backed tools should be included in our consideration. No backed tools were observed at Umbeli Belli, and we are therefore left with only bladelet production to make an inference about increasing lithic miniaturization over time. While there are more bladelets in total in the upper part than in the lower part, it is striking that the frequency of bladelets only differs by 0.5% between the two assumed phases. At the same time, as the number of bladelets increases, so does the overall find density. Hence, we see a general intensification of blank production rather than an intensification of bladelet production. It is debatable, if the existence of small blanks and tools alone justifies the use of the term "microlithic assemblage."

In our opinion, the tendency to produce small laminar blanks, which are present in the Umbeli Belli's Robberg assemblage alongside the corresponding cores that are specifically exploited to obtain bladelets, proves them to be the intended product. Therefore, we argue that the frequency of microliths in an assemblage should not be the main factor in classifying an assemblage as microlithic, nor can it be a simple presence/absence argument. Rather, the microlithic identity of an assemblage should be based on whether or not there is a distinct technological trait designed for obtaining bladelets to produce retouched tools or use them unretouched. Similar to biology, a technological trait in this context refers to a heritable cultural practice, which can be a mode of production, operational chain, or the form of a finished artifact (e.g., Foley & Lahr, 2003; Lycett & von Cramon-Taubadel, 2015). It is important to distinguish between the presence of microliths according to the definition by Kuhn and Elston (2002) and a microlithic assemblage. A microlithic assemblage, as we interpret it, rarely encompasses the entirety of the lithic technological system or even dominates it, but is always a subset of artifacts *within* a technocomplex (see Kuhn & Elston, 2002). Such a subset becomes diagnostic, if a clear mode of production can be identified for the production of bladelets. In our assemblage, this mode of production is predominantly bipolar percussion on quartz. If bladelets were not the intended end product, but products of core preparation or maintenance, we would expect to see more cortex, crested blades, or bladelets and a different percussion technique. Bipolar flakes, including larger ones, might as well be a by-product of reducing a quartz cobble to the desired size for bladelet production. However, without further experimental studies and/or refits, it cannot be determined whether this is an intended preparation within the *chaîne opératoire* or just the by-product of the expediency of bipolar knapping. After identifying a subset of artifacts as microlithic, it needs to be determined what its purpose might have been. In some cases, bladelets might derive from core preparation and/or rejuvenation strategies. In the case of the Robberg, it seems that they are intended products for further use. In this sense, the Robberg technocomplex comprises a variety of lithic technological traits, one of them being microlithic.

Summing up the observations provided in this article, we can conclude that the GH 3 assemblage at Umbeli Belli can securely be ascribed to the Robberg technocomplex based on the abundance of bladelets, the frequency of bipolar knapping on quartz, and the scarcity of tools. We further observed considerable technological variability throughout the chronological sequence, becoming most evident in the change in knapping technique and raw material use between the lower and upper parts of the sequence. An increase in the frequency of quartz as a raw material is paralleled by an increase in bipolar knapping, which is mostly performed on quartz. Comparable chronological trends have been observed at other Robberg sites in southern Africa (e.g., Bader et al., 2020; Mackay et al., 2014; Pargeter et al., 2018), raising questions about potential recurrent patterns in material culture based on similar subsistence strategies at specific times during MIS2. Thus, a detailed regional and chronological review of other Robberg assemblages in the wider surroundings of Umbeli Belli is required.

A Regional Perspective on the Robberg from Umbeli Belli

The closest Robberg sites near Umbeli Belli are Shongweni and Umhlatuzana, both in KwaZulu-Natal. Both sites are situated about 60 km to the northwest and further inland. Shongweni, although described as "microlithic" in the upper occupation zone, is not well suited for comparison because of the low number of finds recovered (Davies, 1975). It seems, however, that quartz was a major component of the raw material economy there—at least in the lower occupation—which dates between 13.5-ka BP and 27.7-ka BP (Davies, 1975). Thus, it seems likely that this assemblage represents a mix of Robberg and the Early Later Stone Age.

In contrast, Umhlatuzana is better suited for a techno-typological comparison because the lithic assemblage is richer. Initially, the integrity of the sediments that contained late MSA, so-called transitional MSA/LSA layers, and both Robberg and Holocene LSA assemblages at Umhlatuzana were thought to be compromised (Kaplan, 1990; McCall & Thomas, 2009), but in a recent geoarchaeological study, Sifogeorgaki et al. (2020) could not find any evidence for large-scale post-depositional sediment movements. Hence, the assemblages recovered in the 1985 excavation (Kaplan, 1989, 1990) can be considered unmixed and well suited for a techno-typological comparison.

The raw material composition in the Robberg assemblage at Umhlatuzana differs strongly from Umbeli Belli. Quartz is the most commonly used raw material at Umhlatuzana followed by hornfels, with only minor components of quartzite and chert present (Kaplan, 1990). Quartz is less commonly used in the lower part of the Robberg sequence of Umhlatuzana than in the upper part. Kaplan (1990) used these raw material differences, typological characteristics, and radiocarbon dates to subdivide the Robberg into "early and late Robberg."

The techno-typological features of the two sites are different as well. Umhlatuzana's Robberg assemblage shows a larger variety of tool types than the Robberg of Umbeli Belli. Backed tools, adzes, and unifacial points, which all occur in the Robberg layers of Umhlatuzana (Kaplan, 1990), are absent in the tool assemblage of Umbeli Belli. Furthermore, the cores from the two sites are fundamentally different. At Umhlatuzana, only 11% of the cores are bipolar, while this is by far the most common core type at Umbeli Belli. A comparison of the number of bladelets throughout the sequences of Umhlatuzana and Umbeli Belli is impossible because Umhlatuzana was analyzed without a cut-off size, and the published data are difficult to compare to our data from Umbeli Belli. At present, we can only say that systematic bladelet production occurred on both sites (Kaplan, 1990). It is also unclear whether the bladelets at Umhlatuzana were produced from handheld or bipolar cores. Given the changes within the GH 3 assemblage, Umbeli Belli may represent an early and a late Robberg phase. For these reasons, Umhlatuzana and Umbeli Belli can only be compared meaningfully on a broad level, and it is difficult to conclude anything with certainty.

Sehonghong, situated in the highlands of Lesotho, has yielded a long stratigraphy that is of major importance to the region (Carter, 1977; Mitchell, 1988a, 1988b). The bladelet-rich layers of Sehonghong were dated between 13.5-ka BP and 12.7-ka BP (Carter & Vogel, 1974; Mitchell, 1988a, 1988b, 1995; Pargeter et al., 2017). New excavations and dates have allowed the identification of periods of abandonment and (re-) occupation at Sehonghong. According to the new data, there was an occupation period prior to the Robberg (between 25- and 23-ka BP), after which the site was abandoned for most of the earlier millennia of the Robberg between 23- and 16-ka BP (Pargeter et al., 2017). An occupation period during the Robberg is only documented around 15- and 13-ka BP (Pargeter et al., 2017). Consequently, the GH 3 assemblage at Umbeli Belli likely predates the Robberg resettlement of Sehonghong by several hundred years at least.

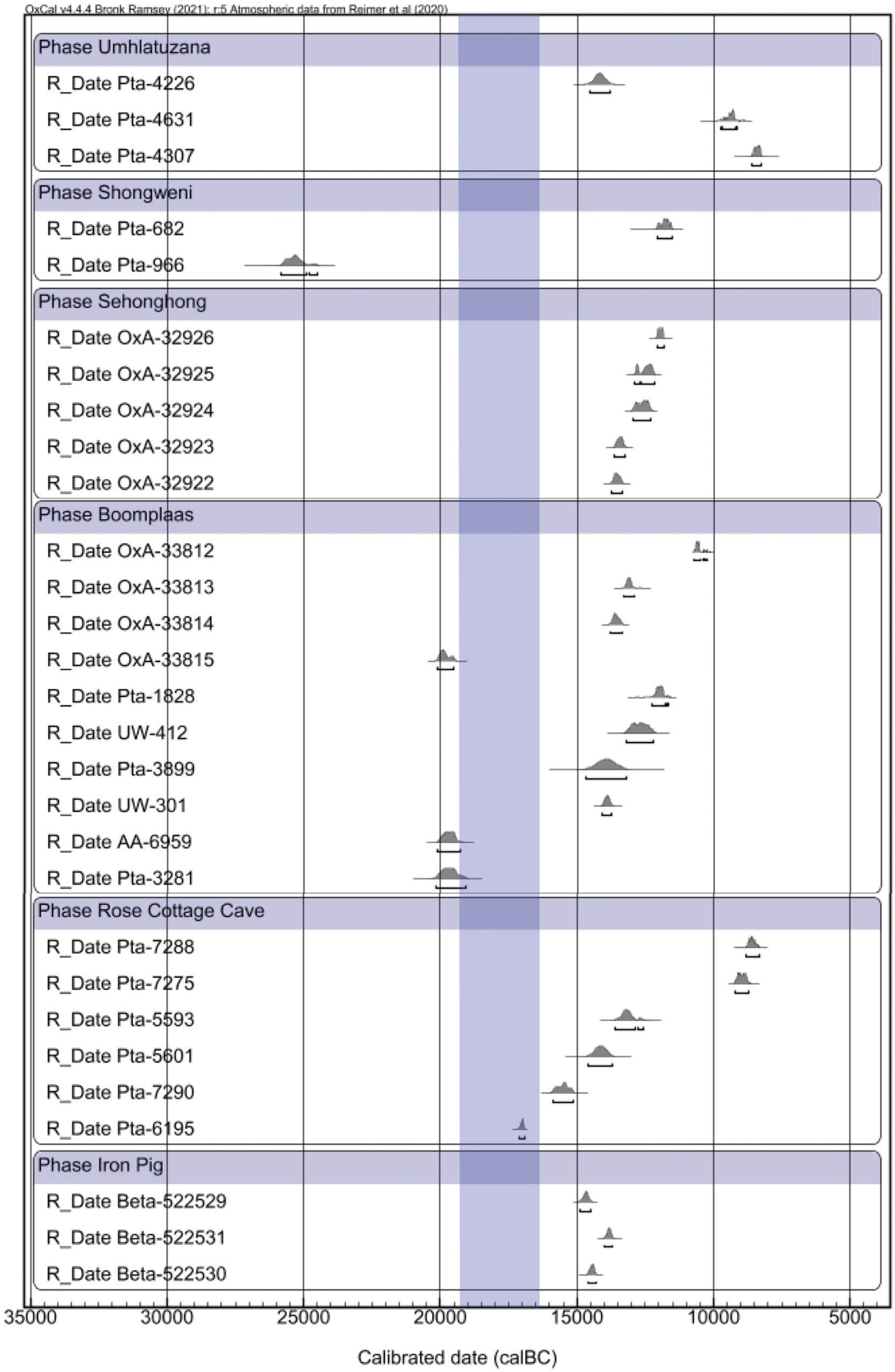
The main raw material used at Sehonghong is opalines. These were used for the production of all lithic artifact classes, especially bladelets. Tools, however, were also frequently made on hornfels/dolerite. The technology focuses on the production of bladelets as well, but mostly using handheld single-platform cores, and bipolar percussion is uncommon (Mitchell, 1995). Low and Pargeter (2020) proposed that bipolar flaking at Sehonghong was part of a continuous reduction sequence, in which bipolar percussion was used on handheld bladelet cores once they had gotten too small to be further reduced freehandedly. We could not find evidence for such a continuous reduction strategy at Umbeli Belli based on core mass values or damage that would be observable if a conical core was placed on an anvil (see Hiscock, 2015; Low & Pargeter, 2020). A similarity between GH 3 at Umbeli Belli and Sehonghong is the low frequency of tools. There are only a few scrapers, retouched blanks, and other formal tools at both sites. It seems that both sites indicate correlations between tool types and raw materials, though this should be treated with caution because of the problems of discerning splintered pieces from bipolar cores made on quartz. Sehonghong has what is considered to be a true microlithic assemblage that can easily be attributed to the Robberg (Mitchell, 1995). The high frequency of opaline in this assemblage is somewhat unusual in the Robberg of South Africa and Lesotho and can be explained by the intrinsically high knapping quality of opalines. In contrast, there is a low frequency of bipolar knapping at the site (Low & Pargeter, 2020; Mitchell, 1995).

On the western border of Lesotho, another key site for the Robberg is Rose Cottage Cave. Excavated for the first time in the 1940s, it was later dated to 16.5- to 14.5-ka BP, thus slightly overlapping with Umbeli Belli (Wadley, 1996). Opalines are also the most commonly used raw material at Rose Cottage Cave, but unlike Sehonghong, almost all tools are made from opalines (Wadley, 1996). Unfortunately, nothing has been published on the percussion techniques of the Rose Cottage Cave Robberg assemblages. However, the great similarity to Sehonghong, in terms of raw material, makes it likely that the bladelets at Rose Cottage Cave were also produced using handheld core reduction. Like in other Robberg assemblages, the frequency of tools is low; however, in contrast to Umbeli Belli, Rose Cottage Cave contained backed tools alongside unstandardized scrapers and retouched blanks (Wadley, 1996).

The Iron Pig rockshelter was recently excavated and analyzed by Bader and colleagues (Bader et al., 2020). The site, situated within the Komati valley in Mpumalanga province, yielded two layers with Robberg assemblages. The upper layer 5 was ^{14}C-dated to between 16.5- and 15.5-ka BP (Beta-522529, Beta-522531) and thus overlaps tightly with the Umbeli Belli assemblage. The lower layer 6 revealed insufficient dating results and can only be determined to be older than layer 5. Numerous bladelets and low percentages of retouched tools were found in both layers. Like in Umbeli Belli, there are chrono-cultural variations in the assemblage, specifically in the production of bladelets and raw material selection. Hornfels is the most commonly used raw material throughout the sequence, followed by quartz. Towards the top of layer 5, chert becomes more frequent. While knappers produced bladelets during both periods of occupation in comparable numbers, a clear shift is observed in their production technology linked to different raw material choices. During the older period, bladelets were mostly knapped in a bipolar fashion from quartz nodules. In the younger part of the sequence associated with layer 5, chert was increasingly more often used for bladelet production. They were detached from small narrow-sided, and semi-rotational handheld platform cores (Bader et al., 2020). The trend observed in raw material choice and knapping technique for the production of bladelets reflects exactly the opposite trend at Umbeli Belli, where the younger phase is associated with bipolar knapping on quartz and the older one with handheld percussion on a fine-grained raw material, in this case, hornfels (Bader et al., 2020).

Boomplaas (Southern Cape) is another interesting example of changing patterns in lithic technology throughout the Robberg. The preservation of organic material made it possible to get a fine chronology from the Robberg layers (CL and GWA), from 12.1- to 21.1-ka BP. Though not obvious in the stratigraphic sequence, the radiocarbon dates revealed a hiatus in the occupation between layers CL and GWA of about 3000 years (Pargeter & Faith, 2020), with the occupation in CL starting around 18 ka, a date comparable to the Robberg sequence at Umbeli Belli. Building on Deacon's work (1982, 1984), Pargeter and Faith (2020) identify patterns of change throughout the LGM and Late Glacial sequence of Boomplaas, which seem to chronologically coincide with the changes observed at Umbeli Belli. Pargeter and Faith (2020) identify a much higher frequency in bipolar cores in the Late Glacial member CL compared to the underlying layers dating to the LGM (GWA and LP). They also identify a higher bladelet core percentage in CL than GWA and LP. Finally, they observed a higher reduction intensity in CL, almost twice the intensity of the lower levels. None of these measures employed by Pargeter and Faith are mirrored in the Umbeli Belli assemblage. However, Umbeli Belli might still display an increase in occupation intensity as shown, by the generally higher abundance of lithic artifacts in the upper parts of GH 3. Thus, although the reduction intensity measured by Pargeter and Faith (2020) is more or less the same throughout GH 3, we might still observe a trend similar to that reported from Boomplaas (Pargeter & Faith, 2020). Additionally, Deacon (1982, 1984) reports a dramatic shift in raw material frequency from LP to CL which parallels our findings from Umbeli Belli.

The comparison between Umbeli Belli and other sites with a Robberg component in the regional and supra-regional surroundings reveals that they share some similarities on a broader level. However, striking differences also set them apart from Umbeli Belli and from each other. This might partly be due to the differing dates of those sites (Fig. 9, Table 6) and to different environmental settings such as distance to the ocean and altitude. Furthermore, a bias stemming from different analytical approaches cannot be excluded. The Robberg assemblages from Rose Cottage Cave are much younger than Umbeli Belli, as are the later Robberg phases at Sehonghong. These age differences might account for some of the differences between assemblages. In contrast, the differences in terms of raw material are best explained by the geological setting, although doubts about this connection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Phase Sehonghong
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Phase Rose Cottage Cave
R_Date Pta-7288
R_Date Pta-7275
R_Date Pta-5593
R_Date Pta-5601
R_Date Pta-7290
R_Date Pta-6195
Phase Iron Pig
R_Date Beta-522529
R_Date Beta-522531
R_Date Beta-522530
35000
30000
25000
20000
15000
10000
5000
Calibrated date (calBC)

◂**Fig. 9** Chronology of the comparative sites used. [Calibrations were made with SHCal20 (Hogg et al., 2020) and the figure was generated using OxCal 4.4 (Bronk Ramsey, 2009). Range of the OSL date from Umbeli Belli GH 3 is indicated as a blue bar

have been raised recently (Low & Pargeter, 2020). Moreover, the changes throughout the Late Pleistocene, compiled by Mackay et al. (2014), seem to be reflected in the GH 3 assemblage at Umbeli Belli.

Conclusions

The GH 3 assemblage of Umbeli Belli shares many features commonly associated with the Robberg techno-complex. These include the frequent use of bipolar percussion, bladelet production, a low frequency of formal tools, and the common use of quartz as raw material for knapping. Furthermore, the OSL date from GH 3 falls within the timeframe of the Robberg complex. A definite interpretation of the shifts and changes observed within the layer cannot be given at the moment. Since there seems to be evidence for an earlier and a later Robberg phase near Umbeli Belli, it is possible that the archaeological signal we found confirms this bimodality. However,

Table 6 Radiometric dates from comparative sites in South Africa and Lesotho

Site	Lab No.	Age (calBP)	Method	Reference
Umbeli Belli	N/A	19.3 to 16.3 ka	OSL	Bader et al., 2018
Umhlatuzana	Pta-4226	14.5 to 13.8 ka	^{14}C	Kaplan, 1989
Umhlatuzana	Pta-4307	8.6 to 8.2 ka	^{14}C	Kaplan, 1989
Umhlatuzana	Pta-4631	9.7 to 9.1 ka	^{14}C	Kaplan, 1989
Shongweni	Pta-682	12.1 to 11.5 ka	^{14}C	Davies & Gordon Gray, 1977
Shongweni	Pta-966	25.8 to 24.9 ka	^{14}C	Davies & Gordon Gray, 1977
Sehonghong	OxA-32926	14.0 to 13.7 ka	^{14}C	Pargeter et al., 2017
Sehonghong	OxA-32925	14.7 to 14.1 ka	^{14}C	Pargeter et al., 2017
Sehonghong	OxA-32924	14.9 to 14.2 ka	^{14}C	Pargeter et al., 2017
Sehonghong	OxA-32923	15.6 to 15.2 ka	^{14}C	Pargeter et al., 2017
Sehonghong	OxA-32922	15.7 to 15.3 ka	^{14}C	Pargeter et al., 2017
Border Cave	Pta-5598	23.3 to 22.0 ka*	^{14}C	Wadley, 1997
Border Cave	N/A	17.1 to 16.9 ka	^{14}C	Wadley, 1997
Border Cave	Pta-5601	14.5 to 13.7 ka	^{14}C	Wadley, 1997
Border Cave	Pta-7275	13.5 to 12.8 ka	^{14}C	Wadley, 1997
Boomplaas	OxA-33812	12.7 to 12.1 ka	^{14}C	Pargeter et al., 2018
Boomplaas	Pta-1828	14.1 to 13.6 ka	^{14}C	Deacon, 1982
Boomplaas	UW-412	15.1 to 14.1 ka	^{14}C	Deacon, 1982
Boomplaas	OxA-33813	15.2 to 14.6 ka	^{14}C	Pargeter et al., 2018
Boomplaas	Pta-3899	16.6 to 15.1 ka	^{14}C	Vogel, 2001
Boomplaas	OxA-33814	15.7 to 15.2 ka	^{14}C	Pargeter et al., 2018
Boomplaas	UW-301	17.9 to 16.5 ka	^{14}C	Fairhall et al., 1976
Boomplaas	OxA-33815	21.9 to 21.4 ka	^{14}C	Pargeter et al., 2018
Boomplaas	U-368	22.0 to 21.0 ka	^{14}C	Vogel, 2001
Boomplaas	AA-6959	21.9 to 21.1 ka	^{14}C	Miller et al., 1999
Heuningneskrans	Pta-114	12.7 to 11.7 ka	^{14}C	Porraz & Val, 2019
Heuningneskrans	Lj-3150	14.7 to 13.8 ka	^{14}C	Porraz & Val, 2019
Heuningneskrans	Pta-100	16.0 to 15.3 ka	^{14}C	Porraz & Val, 2019
Heuningneskrans	AA-5829	14.9 to 14.1 ka	^{14}C	Porraz & Val, 2019
Heuningneskrans	AA-8564	14.9 to 14.1 ka	^{14}C	Porraz & Val, 2019

in-depth analysis of the Umhlatuzana assemblage will be essential to further elaborate on this. Other possibilities are changes in site use and occupation intensity throughout the sequence of GH 3. Umbeli Belli adds another spot on the archaeological map providing useful insights into a better understanding of the Robberg techno-complex along the east coast of South Africa. Concerning Umbeli Belli and other Robberg assemblages investigated recently, there is increasing evidence that these assemblages exhibit regional and time-specific variations in lithic technology. In order to go beyond this preliminary descriptive conclusion, it will be essential to apply various statistical analyses to the archaeological data, integrate these into experimental data, and conduct more research on the use-wear patterns of unretouched bladelets. Moreover, provenance tracing of raw materials, using geochemical methods, can provide valuable information about raw material provisioning strategies and networks of exchange among prehistoric groups. Detailed investigations of sites with good organic preservation are needed to reconstruct past environmental conditions and their relationships to settlement dynamics. This study of the lithic assemblage of GH 3 from Umbeli Belli adds valuable data to ongoing research on the Robberg techno-complex. It also highlights potential avenues for future research at Umbeli Belli and beyond.

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Declarations

Conflict of Interest The authors declare no competing interests.

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Investigating the MIS2 microlithic assemblage of Umbeli Belli rock shelter and its place within the chrono-cultural sequence of the LSA along the east coast of southern Africa

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Supplementary Information

In order to enhance the readability of our paper, we decided to provide some additional graphs as supplementary material. These graphs are referenced in the text and are meant to visually support our findings.

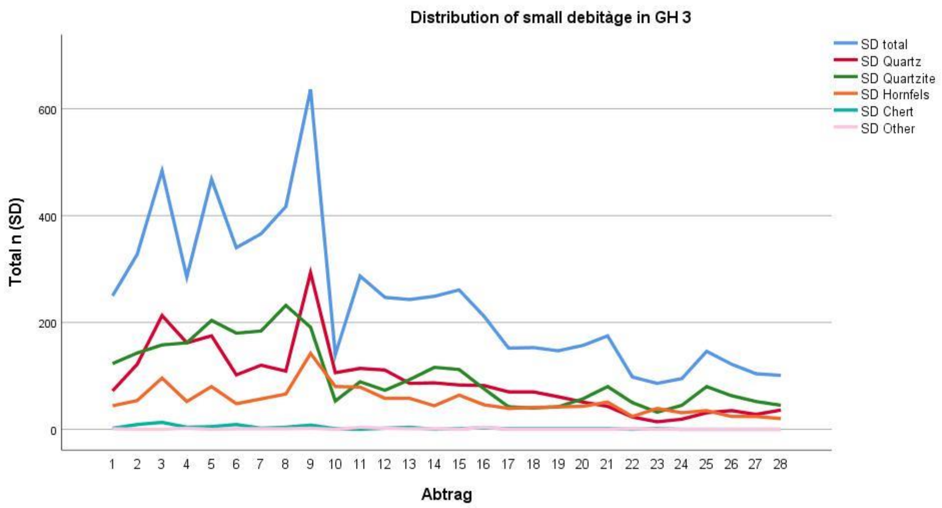

Fig. 1 Frequency of small debitage (lithics < 2 cm) throughout the sequence of GH3 of Umbeli Belli (generated with SPSS 26)

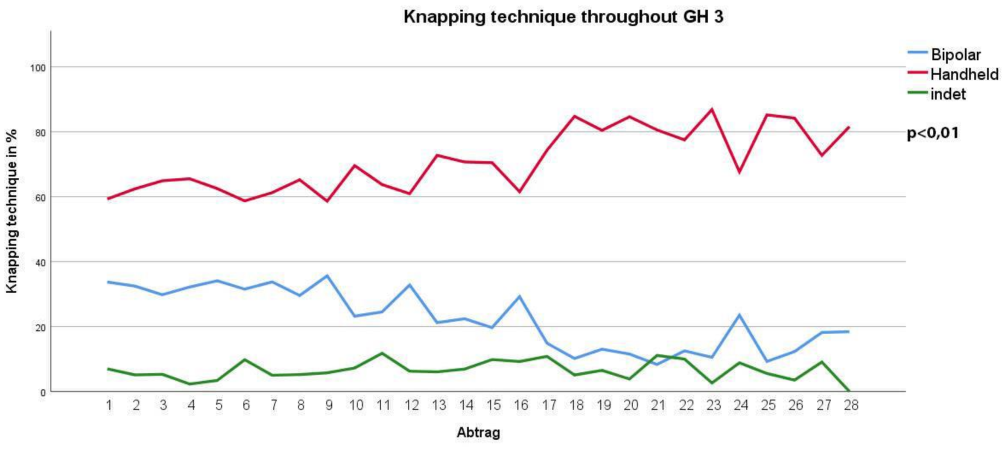

Fig. 2 Ratio of knapping technique throughout the sequence of GH3 of Umbeli Belli; df: 54, p<0,01 (generated with SPSS 26)

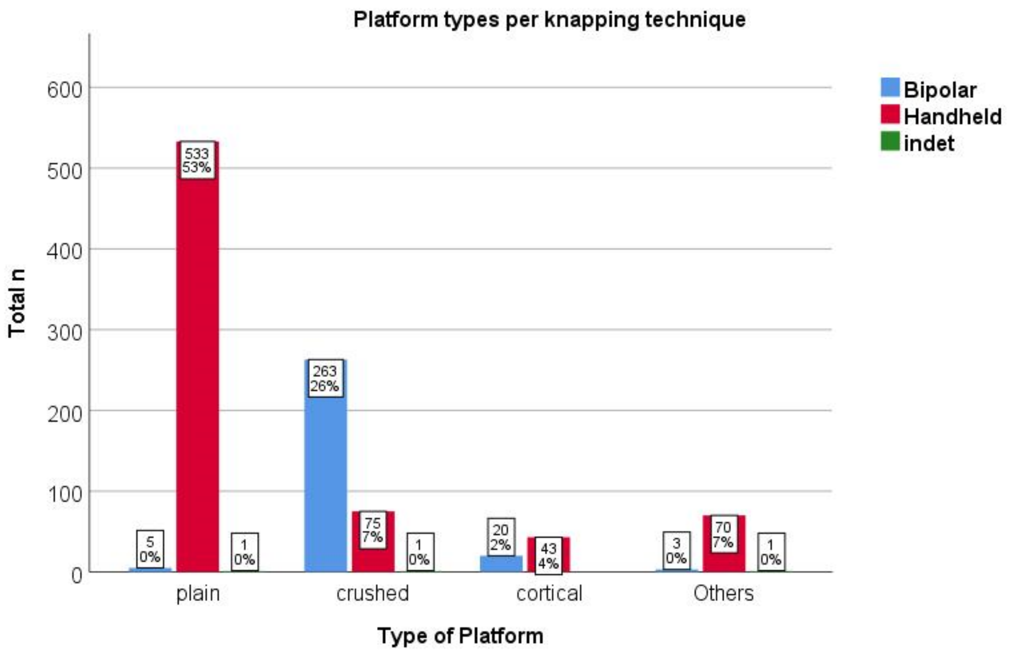

Fig. 3 Platform types in relation to knapping technique in GH3 of Umbeli Belli (generated with SPSS 26)

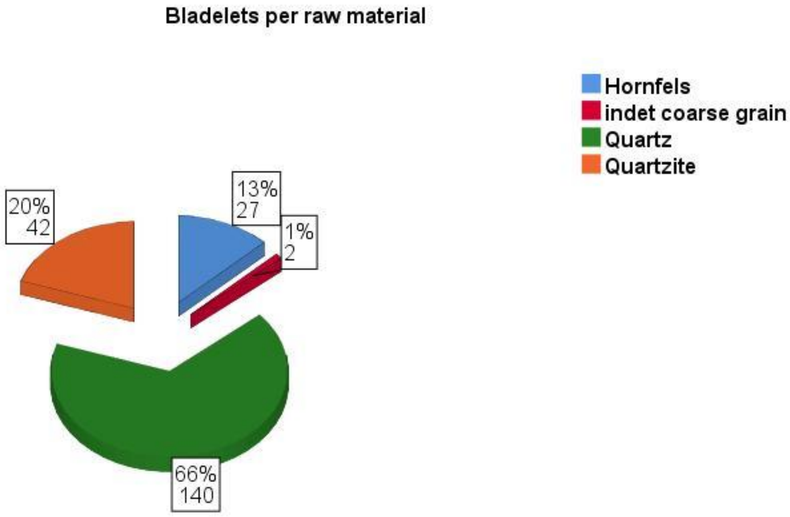

Fig. 4 Raw material frequency in bladelets from GH3 of Umbeli Belli (generated with SPSS 26)

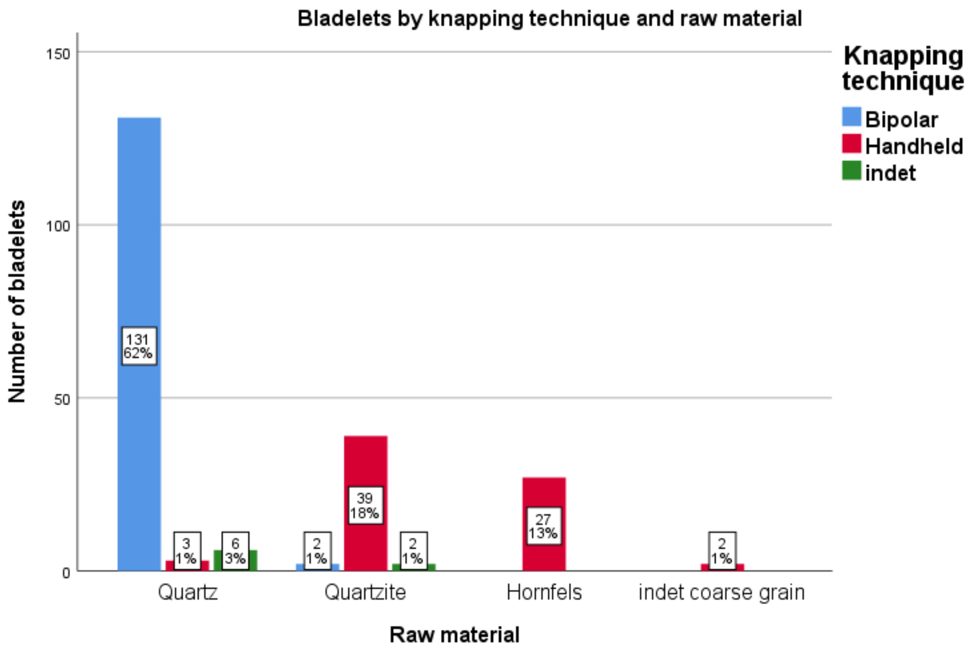

Fig. 5 Relation of raw material choice and knapping technique for bladelets in GH3 of Umbeli Belli (generated with SPSS 26)

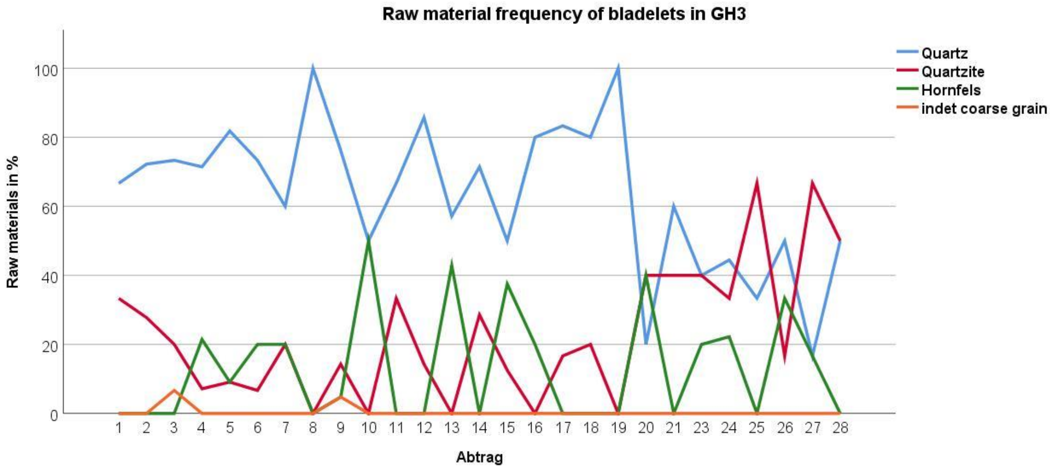

Fig. 6 Distribution of raw material frequency of bladelets throughout GH3 of Umbeli Belli (generated with SPSS 26)

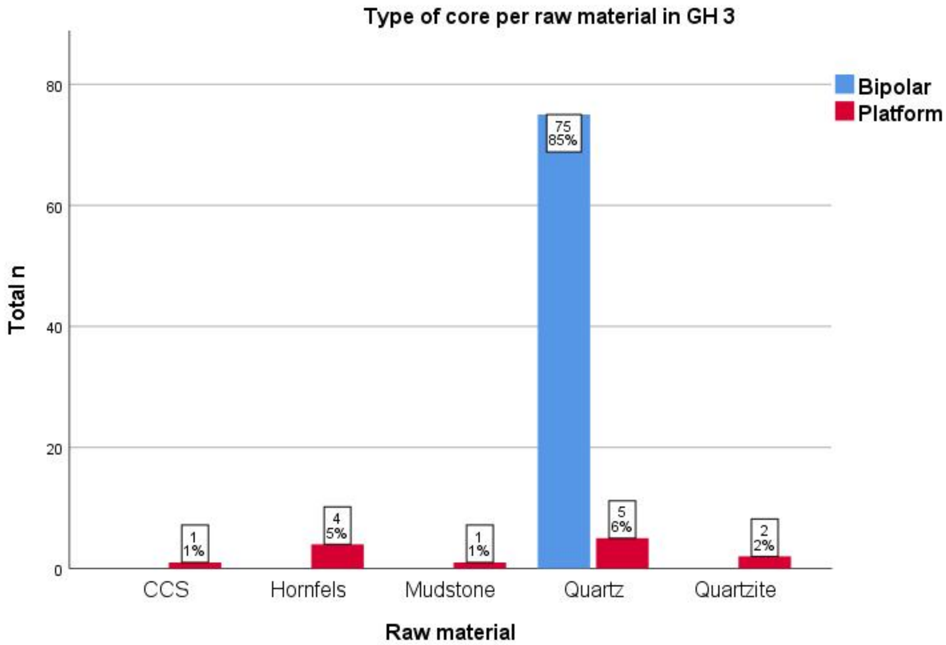

Fig. 7 Raw material choice for cores in relation to knapping technique in GH3 of Umbeli Belli (generated with SPSS 26)

Appendix i.f

Lithic Technology

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Lithic Standardization and Behavioral Complexity in the Middle Stone Age – A Case Study From Sibhudu, South Africa

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Lithic Standardization and Behavioral Complexity in the Middle Stone Age – A Case Study From Sibhudu, South Africa

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ABSTRACT
The concept of standardization has been applied in archaeological research as a proxy measure for cognitive and behavioral complexity since the late nineteenth century. Here we evaluate these issues in the context of the Middle Stone Age (MSA) examining microlithic technology and laminar blanks and their corresponding core reduction and tool assemblages from the Howiesons Poort (HP) and Sibhudan from Sibhudu (South Africa). We find both standardization and variability among different techno-typological components of these technocomplexes. Similar degrees of standardization characterize the metrics of the bladelet assemblages in the Sibhudan and the backed pieces in the HP, but they remain much more variable than products from craft specialists. We argue for a careful interpretation of standardization in lithic technology taking into account factors like raw material, technological redundancy, site use patterns, functionality and tool biographies. Standardization in lithic tools per se is not an ideal proxy measure for behavioral complexity.

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Microblade production; bladelet; backed piece; Howiesons Poort; Sibhudan

Introduction

Standardization and variability or variation are often seen as opposite ends of lithic technological organization (Chase, 1991; Eerkens, 1997, 1998; Eerkens & Bettinger, 2001). However, their interpretation frequently converges in the sense that archaeologists have considered both as a proxy measure of behavioral complexity (Ambrose, 1998; Deacon, 2001; Heckel, 2018; Klein, 1995; Mellars, 1989; Way et al., 2022; Wurz, 1999). In this line of thinking, standardization is equaled with adherence to specific social norms or mental templates (Chazan, 1995; Heckel, 2018; Mellars, 1989, 1996; Way et al., 2022; Wurz, 1999), whereas variability is frequently interpreted as a reflection of adaptive flexibility and cognitive fluidity in particular as a response to changing environmental conditions (Klein, 2001; Pargeter et al., 2018; Tryon & Faith, 2013).

The history of standardization as a measure for cognitive complexity dates back to the nineteenth century, when De Mortillet (1883) and later Commont (1908) linked the increasing refinement of handaxes throughout the Lower Paleolithic to evolving mental capacities of the hominins who produced them. In connection with the existence of a mental template *sensu* Deetz (1967), standardization has also been invoked as a proxy for behavioral complexity regarding the Middle to Upper Paleolithic transition (Mellars, 1989, 1991, 1996). Subsequently, this link has been subject to scrutinous tests, both theoretically in correspondence with the “imposition of arbitrary form” (Holloway, 1969) and empirically using a range of measures on lithic artefacts (Chase, 1991; Chazan, 1995; Marks et al., 2001; Monnier, 2006; Monnier & McNulty, 2010). These studies did not find increased evidence for a mental template in the Upper Paleolithic.

The Eurocentric view on the origins of “modern behavior” were ultimately questioned by a compilation of evidence for comparable traits in Africa long before *Homo sapiens* dispersed to Europe (McBrearty & Brooks, 2000). Subsequent discussion revolved around other criteria for identifying modern behavior (d’Errico et al., 2003; Henshilwood & Marean, 2003; Klein, 1995; McBrearty & Brooks, 2000; Wadley, 2001, 2003, 2013). Regarding lithic technology these traits mostly included blade production and standardized tools. Tool standardization in a South African context was first stated explicitly by Deacon (1989) for the backed pieces of the Howiesons Poort (HP). This standardization has later been interpreted and cited as indicating symbolic behavior (Henshilwood & Marean, 2003; McBrearty, 2007; Wurz, 1999) similar to Mellars’ argument for the emergence of a mental template during the Middle to

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Upper Paleolithic transition (Mellars, 1989). The notion that HP tools are standardized (Wurz, 1999) has, however, since been criticized on the grounds of using inadequate means of measuring standardization (e.g. Monnier & McNulty, 2010). By employing new approaches Way and colleagues (2022) have reopened the discussion of the potential social and symbolic meaning of HP backed tools. Nonetheless, significant doubts remain as to whether the link between stone tool standardization and symbolism is possible and observable in archaeological contexts (Chase, 1991; Chazan, 1995 and replies; Marks et al., 2001).

In sum, the supposed increase or mere presence of standardization has been used as a proxy for cognitive complexity, perhaps much longer than the concept of variability. This begs the question whether standardization and variability are two extremes on the same scale? And if so, does a sharp break exist between them or are we dealing with a continuous scale? In other words, if a lithic assemblage is not standardized, is it automatically variable and *vice versa*? In order to answer these questions, we must first define standardization. The Oxford Dictionary defines standardization as "the process of making objects or activities of the same type have the same features or qualities". In lithic technology, we must distinguish the standardization of form (Falcucci et al., 2022; Monnier, 2006; Way et al., 2022), of size (Marks et al., 2001; Wurz, 1999) and of production (Bar-Yosef & Kuhn, 1999; Marks et al., 2001). Only standardization of size is readily measurable using the coefficient of variation. By employing the coefficient of variation (CV), variability and standardization can be viewed on the same scale, at least for the specific class of artefacts (e.g. blades) under study. This variability expressed by a CV only describes the variation on the level of a specific artefact class and needs to be conceptually distinguished from the variability we can observe on the level of entire technological or behavioral systems. On these different scales, concepts of standardization and variability are not necessarily ends of the same spectrum but can also represent and capture different processes. Regarding form, with the advance of 2D and 3D technologies we are also more and more capable of measuring the standardization of form (e.g. Falcucci et al., 2022; Monnier & McNulty, 2010; Way et al., 2022). The standardization of production, however, is only measurable by indirect means, using qualitative features on blanks and cores – potentially in tandem with refitting studies – and thus not easily replicable among lithic analysts.

Standardization possesses another link to cognitive complexity, namely microlithic technology (see also Duches et al., 2018). By definition, microliths are standardized (Clarkson et al., 2018; Kuhn & Elston, 2002) and are most commonly interpreted as part of composite weaponry (e.g. Ambrose, 2002; Lombard & Wadley, 2016; Wurz & Lombard, 2007). This is even true for unretouched microliths, as we know them from the South African LSA (Binneman, 1997). It is worthwhile to explore their level of standardization in addition to retouched forms, since backed tools are absent in many assemblages of the MSA and LSA, while unretouched bladelets occur much more frequently. In MSA research, notions of the production and standardization of backed pieces have been recapitulated as part of the argument for cognitive complexity in the HP technocomplex (Lombard & Wadley, 2016; Way et al., 2022; Wurz & Lombard, 2007). Little quantitative work has, however, been done on measuring standardization on microlithic products from other MSA periods.

In this paper, we focus on standardization and variability in blade/let and microlithic technology in the MSA of South Africa along various analytical dimensions including size, shape, reduction methods and raw material use. We employ data from the long, well-stratified and rich occupation sequence of Sibhudu which allows a quantitative assessment of relevant stone tools across time. Chronologically, we examine both the HP and subsequent Sibhudan (or "post-HP") technocomplexes. Using different quantitative measures, this approach allows for comparing results on standardization/variability among but also between technocomplexes. As a final step, we evaluate these findings in relation to whether they can be taken to reflect behavioral complexity or invite other explanations.

Materials and Methods

The Site of Sibhudu and Its Stratigraphic Sequence

Sibhudu is a rockshelter overlooking the uThongathi River in KwaZulu-Natal, South Africa, located about 40 km north of Durban. Lyn Wadley excavated the site from 1998 to 2011 followed by Nicholas Conard since 2011. All lithic data in this study derive from the Conard excavations. Sibhudu preserves a long, well-stratified and rich MSA sequence dating to >100–138 ka (Jacobs et al., 2008b; Tribolo pers. comm; Wadley & Jacobs, 2006) encompassing various technocomplexes such as the Still Bay and HP but also periods before and after. Overall, more than 50 distinct MSA layers have been recovered, all featuring predominantly anthropogenic input as stone tools and most with excellent organic preservation and little post-depositional mixing.

The main occupation periods of interest in this study concern the HP and subsequent Sibhudan (previously "post-HP", see Conard et al., 2012) phases at the site deriving from the Conard excavations. The HP layers feature a succession of 8 find horizons which are almost entirely of anthropogenic origin with a large lithic assemblage ($n = 97{,}360$). From bottom to top these are layers Theodora, Thabo, Sarah, Saman, Rosa, Robert, Quincy and Quentin. The sequence has previously been dated to between ∼65 and 60 ka by OSL (Jacobs et al., 2008a). The Sibhudan deposits follow after the HP. This sequence contains 23 finely laminated find horizons, dated to ∼58 ka by OSL at its bottom, middle and top (Jacobs et al., 2008a; Wadley & Jacobs, 2006; see more information in Text S1).

Due to the extremely high density and absolute number of stone tools, the lithic analysis from the Conard excavations followed a larger cut-off point for analyzing individual artefacts at >3 cm. That being said, all cores and retouched pieces regardless of size were subjected to individual study. The lithic assemblages >3 cm of both the HP and Sibhudan were analyzed with the same ∼50 quantitative and qualitative attributes by the same analyst (MW) ensuring comparability across these samples. While it has been recognized by us and others that a 3 cm cut-off point leads to a loss in data, here we for the first time also provide a systematic study of the small unretouched laminar component <3 cm from the Sibhudan.

Approach and Methods in this Study

To examine standardization and variability in the HP and Sibhudan of Sibhudu, we employ different but connected sets of lithic data from blanks, tools and cores. By applying quantitative descriptive data and different measures of standardization we compare results among but also between technocomplexes. Two different sets of data are used: For the HP data on all lithics >3 cm is employed with a particular focus on blade technology and the numerous backed pieces. The subsequent Sibhudan features only few backed pieces ($n = 8$), precluding direct comparisons. Therefore, we conducted a new study on the small fraction (<3 cm) of these assemblages with a focus on (unretouched) bladelets which were not previously analyzed. Data on microblade/bladelet technology is used to assess standardization and variability compared to the HP backed pieces. The new Sibhudan data are contextualized with relevant information of bladelets >3 cm, and bladelet cores from these layers were included here as well (for a detailed analysis of the assemblages see Conard & Will, 2015; Will et al., 2014)

In terms of sample composition, the HP assemblages consist of $n = 7831$ lithics >3 cm and $n = 283$ backed pieces. General descriptive data on these assemblages have been published by Will and Conard (2020) with more quantitative information on backed pieces provided here. For the Sibhudan, we examined the entire small fraction (<30 mm and >5 mm) of six Sibhudan layers ($n = 38{,}657$) to identify bladelets and bladelet fragments which were previously not analyzed, sampling all four phases of the stratigraphic sequence. As a result of this work, the sample for this study consists of 1179 bladelets from layers BSp, SPCA, POX, WOG1, BYA2i and LBYA.

We focus on both quantitative descriptive data deriving from an attribute analysis of individual lithic artefacts as well as an assessment of standardization for the backed pieces (HP; 8 layers) and bladelet assemblages (Sibhudan; 6 layers). We chose the coefficient of variation (CV) as the preferred measure of standardization in size as it is readily calculable and widely used, rendering it ideal for inter-site comparisons (Eerkens & Bettinger, 2001; García-Medrano et al., 2022; Heckel, 2018; Marks et al., 2001; Monnier, 2006; Roux, 2003)

Due to a lack of geometric morphometric data, we examined shapes by qualitative and quantitative measures and calculated scores of tool diversity for both the Sibhudan and HP to assess (typological) standardization in the production of tool forms. Tool diversity was assessed by using the Tool Group Index (TGI) which is calculated by dividing the number of tool groups present in an assemblage by the maximum number of tool groups, which in this study was $n = 11$ (for more details see Kandel et al., 2016). Additional qualitative data from both blanks and cores provides insights on standardization of reduction methods. The descriptive data for the bladelet assemblages employs a mix of quantitative and qualitative attributes typically used in MSA studies (full attribute list in Text S2). The high resolution and multiple assemblages for both technocomplexes allow for detailed diachronic assessments instead of lumping all data within the broad categories of "HP" and "Sibhudan".

Results

Sibhudan

The bladelets for this study came from a full sample of small debitage recovered (<30–35 mm) comprising 38,657 pieces, out of which 1179 bladelets were identified (Figure 1). While POX has yielded by far the most bladelets ($n = 747$), the percentage of bladelets from the small debitage is not the highest (3.4%). The highest frequency of bladelets occurs in the two lowermost layers of this study BYA2i and LBYA (3.7% and 4.0%). The bladelet frequencies of WOG1, SPCA and BSp are the lowest ranging between 1.9% and 2.4% (see Table 1). Among the >3 cm fraction, only $n = 60$ bladelets occur across all levels (0.6% of all blanks), which are not part of the analyses in this article, showing the problems with the large size cut-off. Frequencies of these larger bladelets range from 0 to 1.2% with layers of this study including values from 0% (SPCA, WOG1) up until a highest of 0.7–0.8% (POX, BYA2i and LBYA) matching broadly with the results from the <30 mm fracture in relative order of frequency by layer.

Table 1. Numerical overview of the Sibhudan bladelet sample from Sibhudu coming from the fine fraction (<30–35 mm).

Layer	Bladelets	Total debitage analyzed	% Bladelets
BSp	165	6874	2.4
SPCA	99	5146	1.9
POX	747	21,357	3.4
WOG1	44	1963	2.2
BYA2i	45	1332	3.4
LBYA	79	1985	4.0
Total	1179	38,657	3.0

Raw Material

Dolerite dominates the bladelet assemblage ($n = 727$; 61%), followed by hornfels ($n = 323$; 27%). Sandstone, quartz, quartzite and especially chert varieties are less frequent (Table S3). However, there are clear trends regarding raw material preferences in different layers. In BYA2i, 43% of the bladelets are made from quartz, whereas other raw materials range from 8% (quartzite) to 18% (hornfels and sandstone). Sandstone is dominant in LBYA with 66% of bladelets made from it. Sandstone is also well represented in the bladelet assemblage of WOG1, where it makes up 27%, but dolerite remains most abundant (55%). POX is dominated by dolerite (76%), followed by hornfels (20%). This trend continues in the two uppermost layer SPCA and BSp where more than 98% of the bladelet assemblage are made from either hornfels or dolerite, hornfels being slightly more common (see Table 2). The picture from the bladelets matches observation from the assemblages >3 cm in which dolerite dominates the overall sample (70%). That being said, bladelets on quartz ($n = 1$) and sandstone ($n = 1$) are almost non-existent, showing a size bias of the large fraction against specific raw materials.

Metrics and Size Standardization

Looking first at absolute values of bladelet dimension, we failed to observe a clear trend regarding the mean weight and mean length of complete bladelets throughout the layers, fluctuating between averages of 0.5–0.8 g and 19–24 mm. In both cases, however, POX features the lowest values. For width, there is a slight trend of broader bladelets in the lower layers LBYA, BYA2i, and

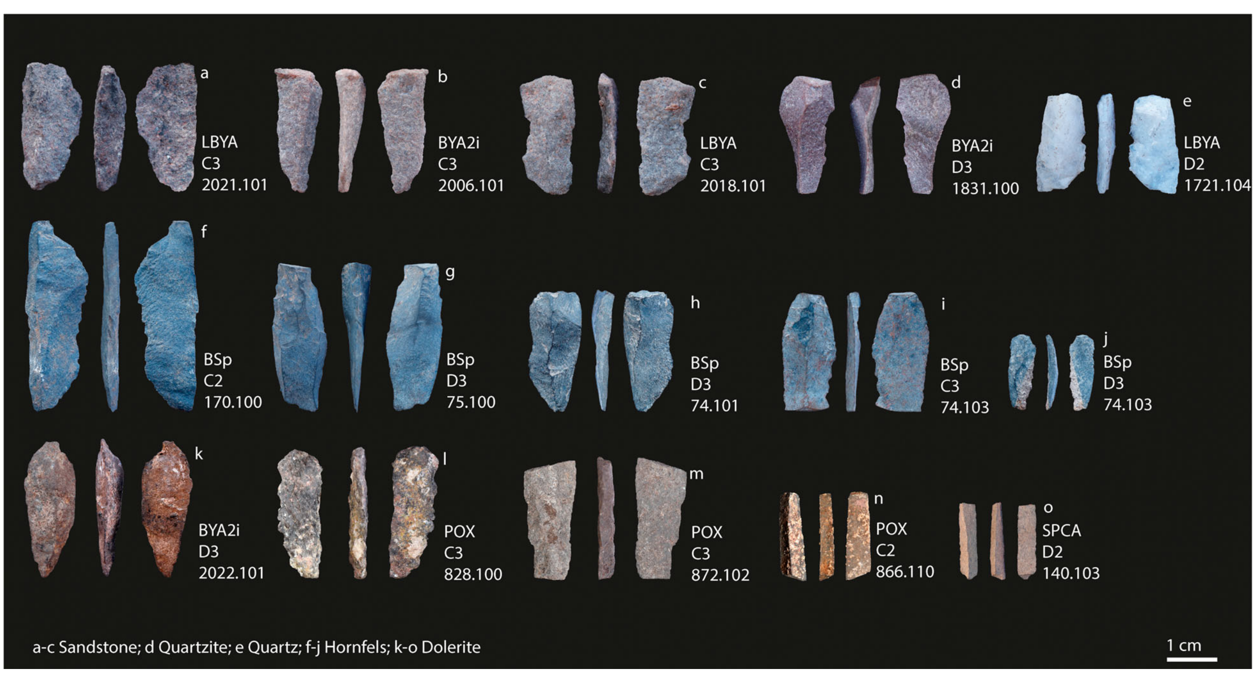

Figure 1. Selected sample of bladelets from the fine fraction (<30–35 mm) as part of this study from the Sibhudan.

Table 2. Distribution of raw material (in %) of the Sibhudan bladelet sample from the fine fraction of Sibhudu by layers.

Layer	Total *n*	Dolerite	Hornfels	Sandstone	Quartz	Quartzite	Chert
BSp	165	44.2	53.9	0.0	0.6	0.6	0.6
SPCA	99	46.5	52.5	0.0	0.0	1.0	0.0
POX	747	76.0	19.9	2.5	0.1	1.3	0.0
WOG1	44	54.5	15.9	27.3	2.3	0.0	0.0
BYA2i	45	15.6	13.3	17.8	44.4	8.9	0.0
LBYA	79	8.9	13.9	65.8	7.6	3.8	0.0

WOG1 (mean: 8.6–9.0 mm) compared to the upper POX, SPCA and BSP (mean: 7.4–7.6 mm; see Table 3). The same trend emerges for thickness of bladelets, with higher values in the lower compared to the upper layers. All raw materials feature similar widths but the thickest specimens come from sandstone and quartz (3.9 and 3.5 mm on average), noticeably thicker compared to dolerite (mean = 2.6), hornfels (mean = 2.1) and quartzite (mean = 2.9).

In terms of CVs, some interesting trends emerge (Table 3). Among all recorded metrics, weight shows by far the highest percentages ranging between 54 and 82%, with the upper layers BSP, SPCA and POX (63–82%) being much higher compared to the lower part WOG1, BYA2i and LBYA (54–59%). Some of this high variability might be driven by a higher use of hornfels in these layers which has the highest raw material CV for weight (89%). Length and width overall show comparable CVs, mostly ranging between 20 and 30% between layers and raw materials. While length exhibits no trend throughout the sequence, width shows the lowest values for layers WOG1, BYA2i and LBYA (~19–22%) with higher values for the upper three layers (~28–30%). Thickness is more variable compared to length and width (32–51%) and here the lowest two layers are again showing the lowest values (32–36%) among the sequence. For raw materials, the CVs for thickness and width are higher for dolerite and hornfels (44–49%; 27–30%) compared to quartz and sandstone (28–36%; 21–22%).

Table 3. Mean values and CVs for metric measures of bladelets in the Sibhudan.

Layer	Measure	Length	Width	Thickness	Weight
BSp	Mean	22.1 ± 6.3	7.5 ± 2.3	2.2 ± 1.0	0.7 ± 0.5
	CV	28.5%	30.1%	48.6%	73.3%
	n	25	164	73	23
SPCA	Mean	23.7 ± 4.8	7.4 ± 2.2	2.2 ± 1.1	0.7 ± 0.4
	CV	20.4%	29.4%	50.8%	62.7%
	n	10	97	44	10
POX	Mean	18.7 ± 5.3	7.6 ± 2.1	2.6 ± 1.2	0.5 ± 0.4
	CV	28.5%	27.7%	45.3%	81.5%
	n	68	738	562	70
WOG1	Mean	22.3 ± 5.7	8.8 ± 1.7	3.3 ± 1.4	0.8 ± 0.5
	CV	25.6%	19.4%	41.3%	59.0%
	n	8	44	24	7
BYA2i	Mean	20.4 ± 4.9	9.0 ± 1.7	3.6 ± 1.3	0.7 ± 0.4
	CV	24.2%	18.8%	36.0%	53.6%
	n	9	42	7	9
LBYA	Mean	19.6 ± 4.1	8.6 ± 1.9	3.5 ± 1.1	0.8 ± 0.4
	CV	21.0%	21.7%	31.5%	56.2%
	n	15	77	7	16

Length, width and thickness in mm, weight in g, one standard deviation given after the average value.

Morphology and Shape Standardization

Among all bladelets, 25% had lateral edges that were "truly" parallel. The majority of bladelets had sub-parallel (71%) edges and only a minor fraction had convergent laterals (4%). The lower layers WOG1, BYA2i and LBYA feature generally more parallel shapes (33–46%) compared to the upper layers (22–33%). Looking at a further dimension of morphology, most bladelets of all layers possess a triangular cross-section (90%) with much rarer trapezoid shapes. About a third of these are symmetrical, with equal amounts of left and right asymmetrical cross-sections making up the other two thirds. All layers exhibit asymmetrically triangular cross-sections between 69% in BSp and 62% in BYA2i (Table S4). When looking at raw materials, however, we see that sandstone and quartz bladelets are more often symmetrical in cross-section (Table S5). A final assessment of shape and its standardization was done by looking at the CVs width/thickness ratios (sample sizes too low for some layers to compare other indices). As a result, the absolute ratios increase from 2.7 at the bottom to 4.1 at the top indicating some shape changes. This, however, is not associated with a change in relative variability as most layers across the sequence feature consistent CVs between 37 and 43%.

Core Reduction

Bladelet cores ($n = 13$) derive from all layers of this study (BSP = 4; SPCA = 1; POX = 3; WOG1 = 3; BYA2i = 1; LBYA = 1). Matching with the data on bladelets, layers BSP, SPCA and POX feature platform cores with unidirectional removals of bladelets from one single plain platform in most cases (6/8), often on a broad removal surface. One multi-platform and bipolar bladelet core occur in these layers. In contrast, WOG1 features both unidirectional single-platform ($n = 1$) but more bipolar bladelet cores ($n = 2$) and the single bladelet cores in BYA2i and LBYA are bipolar. Some of these trends relate to raw materials of the cores with all cores from the lower layers being either quartz ($n = 4$) or quartzite ($n = 1$) whereas those from the upper layers feature more dolerite ($n = 4$) and hornfels ($n = 2$) specimens. Interestingly, quantitative attribute data on knapping techniques (see Text S6) rarely identified bipolar reduction. Instead, most data indicate handheld percussion close to the platform edges (average 2.2 mm) on primarily plain platforms (83%) with frequent lipping (39%) and EPAs ranging about 80°. The blanks provide additional information on methods of core reduction. The overwhelming majority of bladelets are without cortex (98%). Most of the bladelets have two or three dorsal negatives (79% and 17% respectively) which are predominantly oriented along the striking axis of the bladelets, indicating unidirectional removals (96%). Bidirectional, orthogonal negatives and convergent directions are rare without any trends across layers (Table S7).

Tool Assemblages

Bladelets are rarely used for retouch in the Sibhudan sequence, neither for the large nor small fraction. Among all bladelets, only $n = 5$ (0.4%) show retouch, mostly non-invasive lateral modifications. Instead turning to the overall tool assemblages in the Sibhudan layers, we used the Tool Group Index (TGI) to assess relative variability among the entire retouched component, with higher values indicating more diverse assemblages (see Kandel et al. 2015). The TGI is highest for layers BSP (0.93), POX (0.91) and SPCA (0.73). Much lower values characterize WOG1 (0.27), BYA2i (0.36) and LBYA (0.55). The upper assemblages BSP, SPCA, POX feature a more diverse repertoire of tools and are characterized by more frequent retouch. As such, there is significant diachronic change in the types and diversity of retouched pieces among the Sibhudan sequence (see Will & Conard, 2018 for more details).

Howiesons Poort

Here we focus on the laminar assemblages and backed tools from the HP layers, with additional information from the lithic collection >3 cm. In total, $n = 2133$ blades, $n = 128$ bladelets and $n = 283$ backed pieces were identified among the HP assemblages.

Raw Material

The lithic assemblages of the HP are characterized by a dominance of dolerite (69%) followed by much less sandstone (21%), quartzite (4%) hornfels (3%) and quartz (2%). There is a consistent diachronic trend of decrease dolerite from the bottom of the sequence (85%) to the top (60%; Figure 2) associated with a concomitant increase of sandstone (15% vs. 30%). Interestingly, the dominance of dolerite for the production of backed pieces is even higher (80%; Figure 2). Here, an opposite temporal trend emerges in which approximately three fourths of all pieces are dolerite at the bottom of the sequence, reaching nearly 100% in the upper two layers. There is no such trend when considering all retouched pieces, indicating a focus on dolerite only for the backed pieces. The middle and lower layers also show a higher diversity of raw materials, with backed pieces being made on quartz, hornfels,

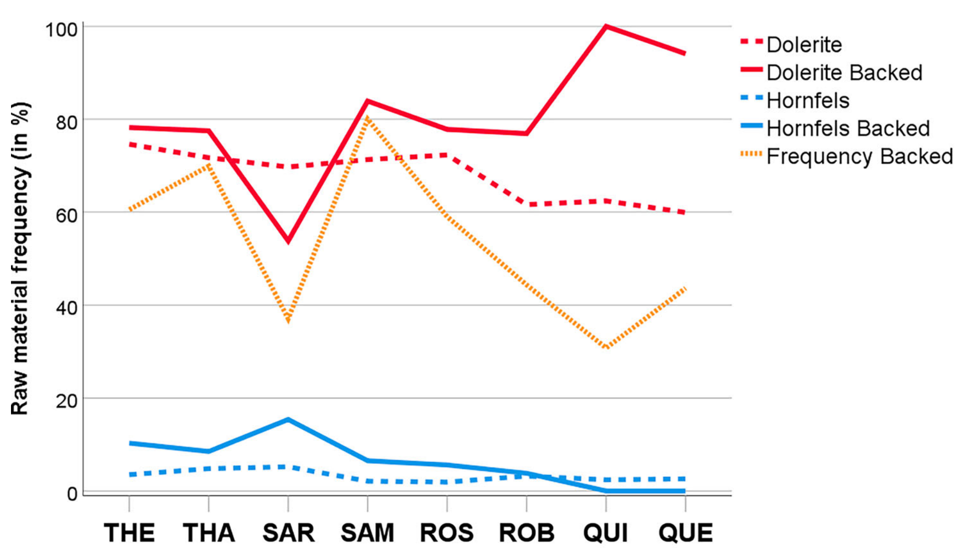

Figure 2. Line chart for frequencies (in %) of dolerite and hornfels, backed pieces on dolerite and hornfels and overall proportion of backed pieces by layer.

CCS, quartzite and crystal quartz, though in relatively low numbers. This pattern fits with raw material data on blades which show equal variability for the lower layers but a stronger reliance on dolerite (and sandstone) in the uppermost strata.

Blades and Bladelets

The HP has a strong laminar component, featuring an average of 29% of blades and 2% bladelets among the >3 cm fraction (Table S8). Again, there are consistent temporal trends with the lower assemblages featuring much more frequent blades (32–37%) and bladelets (3–4%) compared to the uppermost layers (16–20% and ~1%). A focus on blade and bladelet production is thus continuously replaced by more flake manufacture. In terms of shape, the large database of blades allows for a diachronic comparison of both length/width-ratio and width/thickness-ratio. Looking at dolerite only to circumvent influences by raw material, the ratios are broadly similar across the sequence. CVs are close in absolute terms to one another and relatively low for both ratios among all layers (21–23%; 29–31%). There is a slight decrease in CVs for both ratios when comparing the bottom and top of the sequence, with the uppermost Q-layers showing consistently the lowest values.

Regarding metrics (Table 4), there is a consistent decrease in absolute size among the HP sequence considering mean length (top 41.2 mm; bottom: 46.2 mm) and width (top 17.5 mm; bottom 18.6 mm), but not thickness (top: 6.3 mm; bottom 6.2 mm). In terms of variability, CVs are largest for thickness (32–48%), followed by length (23–32%) and particularly width (19–25%). No consistent diachronic trends emerge. That being said, the uppermost layer has particularly low CV values among the sequence for thickness and length.

Table 4. Mean values and CVs for metric measures of blades in the HP.

Layer	Measure	Length	Width	Thickness
Quentin	Mean	41.2 ± 9.5	17.5 ± 3.7	6.3 ± 2.0
	CV	23.1%	21.1%	31.7%
	n	46	135	131
Quincy	Mean	44.5 ± 13.6	17.5 ± 3.8	7.1 ± 3.4
	CV	30.8%	21.7%	47.9%
	n	31	81	78
Robert	Mean	42.4 ± 10.7	18.1 ± 4.6	6.1 ± 2.5
	CV	25.2%	25.4%	41.0%
	n	41	144	139
Rosa	Mean	43.2 ± 12.9	17.3 ± 3.8	6.0 ± 2.0
	CV	29.9%	22.0%	33.3%
	n	42	163	152
Saman	Mean	40.5 ± 11.4	17.5 ± 3.4	6.0 ± 2.0
	CV	28.1%	19.4%	33.3%
	n	41	159	153
Sarah	Mean	46.4 ± 10.6	18.5 ± 3.5	6.4 ± 2.2
	CV	22.8%	19.1%	40.8%
	n	40	124	122
Thabo	Mean	43.3 ± 14.0	18.4 ± 4.2	6.2 ± 2.2
	CV	32.4%	22.8%	35.6%
	n	93	423	400
Theodora	Mean	46.2 ± 12.5	18.6 ± 4.0	6.2 ± 2.6
	CV	27.1%	21.7%	35.5%
	n	218	744	710

Length, width and thickness in mm, one standard deviation in mm given after the average value. Values for length were calculated on complete specimens only, width and thickness whenever they were fully preserved.

Backed Pieces

The backed pieces ($n = 283$) are most abundant in the bottom part (65%) followed by a continuous decrease and a minimum abundance in the upper sequence (39%). In terms of shape, we distinguished trapezoids from crescents and other forms. Across the sequence, there is a relatively consistent frequency of trapezoids fluctuating between 26 and 39% without clear diachronic trends. Crescents are more frequent (46–63%) and increase in abundance through time with the lowest values (46%) at the bottom and the highest (59–63%) at the top of the sequence. Width/thickness ratio CVs on dolerite backed pieces only are used as a further indication for shape, as sample size is too small for length/width. The results indicate highly comparable indices of all levels (3.0–3.3) but larger CV values for the top (33%) and bottom (31%) of the sequence compared to the R-levels in between (20%).

In terms of absolute size, we can only examine length, width and thickness, as too many pieces are too broken to assess weight. There are dramatic differences between raw materials (Table 5, Figure 3): Quartz and crystal quartz specimens are much smaller (length = 17.3 mm; width = 8.2 mm; thickness = 3.0 mm) compared to dolerite (length = 40.0 mm; width = 14.1 mm; thickness = 4.7 mm) and hornfels (length = 37.3 mm; width = 15.3 mm; thickness = 4.3 mm). In terms of variability, the only strongly deviating value is an extremely low CV for the length of quartz backed pieces (11.2%), much lower compared to those for dolerite and hornfels (28.0% and 28.8%). Interestingly, CV values for width and thickness

Table 5. Mean values and CVs for HP backed pieces from Sibhudu.

Raw material	Measure	Length	Width	Thickness
Dolerite	Mean	40.0 ± 11.1	14.1 ± 3.5	4.7 ± 2.0
	CV	28.0%	25.0%	43.1%
	n	57	176	187
Hornfels	Mean	37.3 ± 9.6	15.3 ± 3.9	4.3 ± 1.2
	CV	28.8%	26.0%	37.3%
	n	6	14	15
Quartz & Crystal quartz	Mean	17.3 ± 1.8	8.2 ± 2.0	3.0 ± 1.6
	CV	11.2%	24.9%	40.6%
	n	10	17	19

Means in mm, one standard deviation in mm given after the average value.

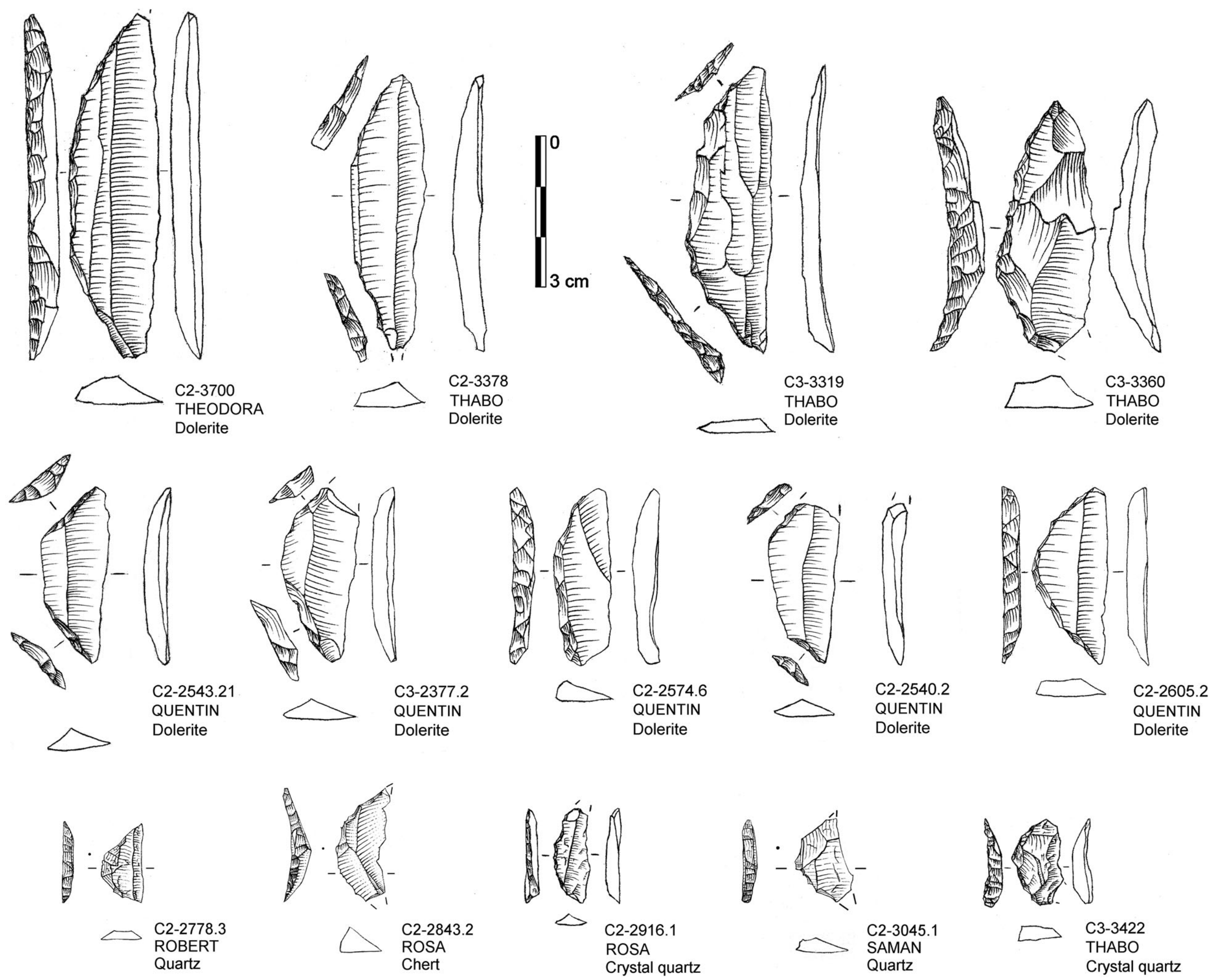

Figure 3. Selection of backed pieces highlighting the raw material differences in size. Top two rows dolerite, bottom row quartz, crystal quartz and chert.

are almost identical for the three raw materials. For comparing backed pieces among the sequence, we examine only dolerite specimens to remove any raw material effect. In terms of absolute size, there is a continuous decrease in length, width and thickness, with the smallest backed pieces at the top of the HP. CVs for length range from 31 to 15%, width from 29 to 23% and thickness slightly higher at 28–32% (Table 6). In general, CVs for length and width are highest in the bottom part (28–31%; 24–28%) and lowest toward the top of the sequence (15–23%; 23–25%), though the differences are relatively small (except for a very low CV of 15% for length in the R-layers). Thickness is slightly more variable at the top compared to the bottom of the sequence.

Core Reduction

The HP features abundant evidence for laminar core reduction, both among the cores and blanks. Many blades ($n = 39$) and bladelet cores ($n = 34$) occur, mostly as platform and some as bipolar variants. Among its platform cores, the assemblages feature typical unidirectional HP blade cores (*sensu* Villa et al., 2010). While HP cores occur in all analyzed layers, their

Table 6. Mean values and CVs for HP backed pieces (dolerite only).

Layer	Measure	Length	Width	Thickness
Q-layers	Mean	36.4 ± 8.1	12.8 ± 2.9	4.3 ± 1.3
	CV	23.1%	22.8%	31.8%
	n	7	19	21
R-layers	Mean	40.6 ± 13.2	13.6 ± 4.2	4.6 ± 1.7
	CV	15.0%	25.2%	31.8%
	n	8	32	37
S-layers	Mean	38.6 ± 11.8	14.4 ± 4.1	4.5 ± 1.4
	CV	28.4%	28.8%	25.3%
	n	8	26	30
T-layers	Mean	41.1 ± 13.7	14.6 ± 3.7	4.6 ± 1.7
	CV	30.7%	24.3%	28.4%
	n	36	101	101

Mean in mm.

relative abundance is much higher in the lower (T-layers; 31–43%) and middle part of the sequence (SARAH-ROSA; 17–40%) with a strong decline in the uppermost assemblages (ROBERT-QUENTIN; 6–14%). Noticeably, the uppermost assemblages also feature lower proportions of blades and fewer HP cores. We previously identified the emergence of a stronger independent flake production strategy in the uppermost layers (Will & Conard, 2020), suggesting a higher diversity of products and methods of core reduction.

Tool Assemblages

While backed pieces generally dominate the HP assemblages, other retouched forms do appear, including scraper and pointed forms, splintered pieces, quartz bifacial points, and notches and denticulates. Looking again at all tools with the Tool Group Index, the assemblages all feature high values (0.6–0.8) with equally diverse assemblages at the bottom and top without any clear trends in between. When adjusting the TGI for the absolute number of tools in the assemblages (TGI/*n*-tools*100) – which is much lower at the bottom – the resulting Relative TGI, however, suggests much more varied tool assemblages at the top (1.8–2.7) compared to the bottom of the sequence (0.6–0.9).

Discussion

The Coefficient of Variation and Standardization – Theoretical Considerations

The CV is widely used as a measure of standardization (Eerkens & Bettinger, 2001; García-Medrano et al., 2022; Heckel, 2018; Marks et al., 2001; Monnier, 2006; Roux, 2003). Some theoretical points require discussion before we can move on to interpreting our results, which in part rely on this measure. The CV is a standardized and dimensionless measure of variability within a sample. Its use as a direct measure of standardization reflects the assumption that standardization and variability are opposing ends of the same spectrum.

We can better assess the interpretation and meaning of CV values based on basic considerations from within and beyond archaeological research. On the lower end of a standardization spectrum is the Weber fraction (∼1.7% variation), which describes the limits of human's ability to perceive differences (Eerkens & Bettinger, 2001). Objects with a variation lower than 1.7% will be perceived as identical, reflecting an absolute minimum of variation to be expected for handcrafted materials. The maximum upper threshold above which a sample would no longer be considered standardized is 57.7% as this marks the outcome of random production in a uniform distribution of values from 0 to X *sensu* Eerkens and Bettinger (2001). From the foregoing it is clear that there is no absolute value for a CV that can be interpreted to equal standardization but rather a relative scale ranging between 1.7 and 57.7%, where much lower values mean more highly standardized. Examples to track standardization in performance relevant to our purposes report CV values of ∼2–15% which are associated with craft specialists or experts highly skilled at achieving the same products – including Paleolithic examples of bead working – and imply the operation of strong social norms and/or mental templates (Heckel, 2018; Roux, 2003).

As an aside, values above the upper threshold imply exceeding variability, which could be interpreted as historical variability. However, each artefact class is based on certain traits, meaning that a deviation above the upper threshold could also mean a flawed classification system (Eerkens & Bettinger, 2001). In the case of our samples, we observed high variability in those measures which are not part of definition of the artefact class in question, such as the high CVs in weight for bladelets. Hence, such excessive variability might be explained either by grouping distinct artefact classes together or by observing traits that are not relevant to the object classification. In order to examine this question in more detail, multivariate analyses with the use of unsupervised algorithms (e.g. cluster analyses) might help to distinguish between the effects of classification vs. other factors such as raw materials, which is beyond the scope of the current paper.

Lastly, interpreting the standardization of a lithic assemblage is hampered by our lack of knowledge on how much variation occurs during one production event or by one knapper over multiple production events. Comparing the degree of standardization of an archaeological assemblage to an assemblage made by a craft specialist (e.g. Roux, 2003) might not be straightforward, as the former mostly represents a palimpsest and time-averaged accumulation of material over multiple production episodes. Comparisons to Paleolithic bead production above that stem from such palimpsest situation (Heckel, 2018), however, show that on a basic level such comparison with objects likely produced by craft specialists or highly skilled experts can be maintained as in this context here. Still, gaining insights into the amount of variation as the result of one production event or of one knapper reducing a core using the same reduction strategy, and a comparison to archaeological refitting sets, would enhance our ability to interpret the CVs that common archaeological palimpsests of lithic assemblages provide.

Standardization in the Sibhudan and Howiesons Poort of Sibhudu

Here we discuss results concerning metrics and shapes of bladelets and backed pieces, but also modes of production and tool assemblages. This allows an interpretation regarding which parts of the assemblage are more standardized than others instead of an assessment of individual components that stand for the entire assemblages (i.e. only backed pieces).

Starting with the Sibhudan bladelets from the <30 mm fraction and their general metrics, weight and thickness are much less standardized compared to length and width, which show the narrowest range of variability in CVs of 20–30%. Overall, the bottom layers of the Sibhudan show more standardization in width and thickness. Some of these changes in thickness variability appear to be driven by the more abundant use of hornfels and dolerite in the upper sequence, which show the highest CVs among all raw materials. In contrast, sandstone and quartz which are much more used toward the bottom of the sequence feature generally reduced variability. Regarding the shape of bladelets, there is no clear diachronic trend in standardization and shape is quite variable with CVs for width/thickness of 37–43%. Standardization of width/thickness ratios is highest in POX and again coincides with the highest abundance of dolerite bladelets.

Bladelets in the Sibhudan were generally standardized across layers regarding their production. Bladelets are consistently produced without platform preparation mostly on unidirectional cores, knapped close to the platform edge, and with abundant asymmetrical cross-sections. More bipolar knapping in the lower layers is reflected in cores but not products. Hence, we suspect some of them to be missing from the sample, potentially linked to export and use strategies for unretouched bladelets, especially for quartz (see e.g. Binneman, 1997). Tool assemblages in the Sibhudan are more diverse at the top of the sequence and more homogeneous below, while still featuring many different types. In sum, both standardization and variability characterize different aspects of the Sibhudan (bladelet) assemblages without clear diachronic patterns: Whereas bladelet sizes and means of production are quite standardized across the sequence, shape and associated tool assemblages are highly variable.

Turning towards standardization within the HP, there is a clear diachronic trend towards less abundant production in bladelets and backed pieces. Accordingly, flake manufacture is increasing at the expense of laminar production. The top of the HP evidences a stronger focus on a single raw material – dolerite – to produce the fewer blades and fewer backed pieces. Looking at the sizes of bladelets and blades, CV values suggest no changes in standardization despite a decrease in their production. Length and width of the backed pieces in this study show a slight increase in standardization toward the top of the sequence, associated with a reduced manufacture and an almost exclusive use of dolerite for these tools.

Concerning shape, diachronic comparison of length/width and width/thickness-ratios suggests consistent shapes across the sequence with laminar products being slightly more standardized at the top. The shape of backed pieces both in term of overall form (trapezoid vs. segments) and ratios remain consistent. The bottom of the HP sequence has a more standardized unidirectional production of blades from typical "HP cores" with more variability towards the top, indicating a gradual abandonment of this standardized reduction strategy. Measures of variability for tool assemblages indicate that more standardized retouch components occur at the bottom of the sequence, associated also with a much stronger dominance of backed pieces.

Finally, we can assess differences in standardization between technocomplexes across individual aspects of the assemblages. When comparing the CVs of bladelets in the Sibhudan and backed pieces in the HP directly, the latter show generally higher standardization in length (HP 15–31% vs. Sibhudan 21–29%), width (HP 23–29% vs. Sibhudan 19–33%) and thickness (HP 25–32% vs. Sibhudan 32–51%). Yet, the differences are rather gradual, particularly considering that backed pieces were intentionally manufactured as tools whereas the bladelets likely include primary flaking products as well as secondary elements. All of these CV values lie well below random production at 57.7% but also above craft specialists with values of ~2–15%, suggesting some degree of standardization for all aspects of the Sibhudan bladelets and HP backed pieces.

Turning towards the assemblages more generally, both the Sibhudan and the HP at Sibhudu feature much variability in terms of raw material selection associated with some diachronic trends. Backed pieces were preferentially knapped on dolerite in the HP and there is clear preference by raw material for the production of bladelets in the Sibhudan, with standardization differing markedly between rock types. Our data on both the bladelets and HP backed pieces thus suggest that raw material choices strongly influence the degree of standardization in the assemblages. This observation is in line with previous notions conducted with different raw material spectra, from different regions and times (Chase, 1991; Chase & Dibble, 1987; Dibble, 1989). A further point uniting the assemblages is a consistent and standardized production of both Sibhudan bladelets and HP blades. Both the Sibhudan and the HP exhibit variable tool assemblages, with the main difference being a focus on backed pieces during the HP in its lowest layers and on unifacial points in the upper Sibhudan.

Lithic Standardization and Behavioral Complexity in the MSA of Southern Africa

Standardization in lithic technology has been a topic of interest in the MSA of southern Africa (Ambrose, 2002; Deacon, 198; McBrearty & Brooks, 2000), often linked explicitly or implicitly to questions of changing behavioral complexity in early modern humans (e.g. Henshilwood & Marean, 2003; Wadley, 2001; Wurz, 1999). Most recently, Way et al. (2022) examined the standardization of HP backed pieces across South Africa in relation to various environmental measures and concluded that the homogeneity of these tools reflects widespread social ties and a shared mental template. These studies focus predominantly on backed pieces as a symbolic marker, and partially ignore the theoretical problems of making such connections.

For a specific comparison to Sibhudu, we chose the study on HP backed pieces from Klasies River (Wurz, 1999), Pinnacle Point 5–6 (Brown et al., 2012), Diepkloof Rockshelter and Klein Kliphuis (Mackay, 2011). Unfortunately, no relevant data was available for the bladelet assemblages. Direct comparison to the HP segments from all these sites shows that standardization is frequently observed across all measures (Brown et al., 2012; Mackay, 2011; Wurz, 1999). The degree of standardization in backed pieces varies considerably between these sites and across different measures, with CVs mostly lying between 20 and 30% (in 18 out of 26 measurements). In terms of metric traits, the highest degrees of standardization are frequently found for width. Thickness commonly shows the lowest degree of standardization. Except for width and length in backed pieces from PP-5-6 SGS (but with very low sample sizes of only $n = 5$), none of the values lie at 15% or below. There is no obvious pattern in size standardization. However, all assemblages of backed pieces share a strong preference for one raw material for their production (see Brown et al., 2012; Mackay, 2011; Wurz, 1999) (Table 7).

Our results on bladelets and backed pieces from Sibhudu and comparisons to data on the HP backed pieces from other sites across South Africa found that they all indicate some degree of standardization (CVs <57.7% and mostly 20–30%) but not approaching high levels such as those observed in craft specialists or experts highly skilled at achieving the same products of 2–15% (Heckel, 2018; Roux, 2003). Similar to studies concerned with the MP/UP transition in Europe (Chase, 1991; Dibble, 1995; Marks et al., 2001; Monnier, 2006; Monnier & McNulty, 2010) we challenge the notion that purported standardization can be directly linked to behavioral complexity. Instead, we find a predominant relationship between raw material selection and standardization in size and variability in other technological domains such as core reduction methods. Other factors that can influence standardization include the utilized classification systems – with broader type definitions *a priori* allowing for more internal variability – or the overall technological system (Marks et al., 2001). Assuming an accurate classification system, standardization within an artefact class is to be expected, thus complicating a direct link between observed standardization and specific mental abilities. Standardization might further be a result of specific functional uses, allowing little variance in key performance aspects of stone tools, or related to specific patterns of land and site use (e.g. Chase, 1991; Marks et al., 2001).

A clear "mental template" does not seem to be the main or sole underlying factor guiding standardization, or at least it cannot positively shown to be the case (see also Chase, 1991). Furthermore, the existence of a

Table 7. Coefficients of variation of backed pieces from South African sites.

Site	Length	Width	Thickness	L/W ratio	Reference
KR1A	25% ($n = 412$)	22% ($n = 519$)	29% ($n = 519$)	n/a	Wurz (1999)
KR2	29% ($n = 58$)	27% ($n = 74$)	30% ($n = 74$)	n/a	Wurz (1999)
PP 5–6 DBCS	31.3% ($n = 8$)	22.7% ($n = 8$)	27.7% ($n = 8$)	20.2% ($n = 8$)	Brown et al. (2012)
PP-5-6 SGS	15.1% ($n = 5$)	10.5% ($n = 5$)	34.6% ($n = 5$)	24.5% ($n = 5$)	Brown et al. (2012)
PP 5-6 SADBS	25.2% ($n = 14$)	29.2% ($n = 14$)	40.2% ($n = 14$)	26.9% ($n = 14$)	Brown et al. (2012)
DRS	22.3% ($n = 44$)	23.8% ($n = 44$)	25.6% ($n = 44$)	22.7% ($n = 44$)	Mackay (2011)
KKH	16.8% ($n = 52$)	29.8% ($n = 52$)	34.1% ($n = 52$)	25.0% ($n = 52$)	Mackay (2011)
SIB-Q	23.1% ($n = 7$)	22.8% ($n = 19$)	31.8% ($n = 21$)		This study
SIB-R	15.0% ($n = 8$)	25.2% ($n = 32$)	31.8% ($n = 37$)		This study
SIB-S	28.4% ($n = 8$)	28.8% ($n = 26$)	25.3% ($n = 30$)		This study
SIB-T	30.7% ($n = 36$)	24.3% ($n = 101$)	28.4% ($n = 101$)		This study

KR1A: Klasies River Main, Cave 1A, KR2: Klasies River Main, Cave 2, PP 5-6: Pinnacle Point 5-6, DRS: Diepkloof Rockshelter, KKH: Klein Kliphuis, SIB: Sibhudu.

mental template can be itself rooted in functionality (see also Duches et al., 2018). Even if an archaeological type was indeed the reflection of a historical mental template, this does not automatically imply a symbolic use of the artefacts in question (Chase, 1991). From our analysis, we see both technological choices during production as well as classification of stone tools to greatly influence the degree of (relatively low) standardization. As an example, the higher degrees of standardization in width and thickness of backed pieces in comparison to length hints toward functional constraints rather than a mental template (Marks et al., 2001). This does not mean that symbolic behavior is absent in the archaeological record of the HP in South Africa, with likely evidence from abstract engravings on ostrich eggshell or the manufacture of specific shell beads (d'Errico et al., 2005; Henshilwood et al., 2004, 2009; Texier et al., 2013), but it does imply that stone tools might not be the ideal find category to study such an aspect. Given the versatility of backed microliths it seems unlikely that they were intended to convey a social message – even though it has been proposed that arrowheads can carry social information (e.g. Wiessner, 1983; but see Sackett, 1986) – because they are not limited to a single function even when they converge in shape and would not appear in a single specific social context (but see Way et al., 2022).

From a theoretical perspective, the argument of standardization being an indicator of symbolic behavior rests on the assumption that standardized artefacts convey a message intended by the maker and recognized by the observer, in other words that they represent a style. However, style does not automatically imply symbol (Sackett, 1982, 1986). The standardization we observed rather implies a passive and isochrestic style (Sackett, 1982, 1986), meaning that, while stylistic in the sense of standardized, there is no necessary link between this style and symbolic behavior. We could even equate standardization with style and it would still not be symbolic behavior. The artefacts in question have been produced habitually in a certain way that can be recognized as a style in the sense of "look similar", but since there was most likely no intent by the makers to convey specific social information, they only become an *index* that points towards the makers and the society they lived in "in the same way that a beaver dam points to the existence of a colony of beavers" (Chase, 1991, p. 198), but not a symbol.

Conclusion

Our study of lithic assemblages from Sibhudu found both variability and standardization in multiple aspects of lithic technology in the Sibhudan and HP technocomplexes. Similar degrees of standardization characterize the metrics of the bladelet assemblages in the Sibhudan and the backed pieces in the HP, but they remain much more variable than products from craft specialists or experts that are specifically tasked to manufacture the same items. While methods of core reduction are quite consistent, tool assemblages, raw material variability and some measures of shape all vary strongly throughout the Sibhudan and HP. In sum, we did not find a clear distinction within or between the technocomplexes, but rather a complex mix of gradual differences when assessing standardization of specific elements (bladelets and backed pieces), as well as overall production methods and tool assemblages.

Previous work in the Paleolithic of Europe and Stone Age of Africa has often linked standardization to behavioral complexity and symbolism. We could not substantiate a direct link between standardization and symbolic behavior, such as extremely low CV values indicating specific mental templates or craft specialization for the production of bladelets in the Sibhudan or backed pieces in the HP. Instead, our study found that raw materials often impacted the degree of standardization. In line with more recent scholarship, the degree and differences of standardization on the level found in this study among artefact groups and technocomplexes are more parsimoniously explained by raw material characteristics, classification systems, functional aspects and reduction methods.

In terms of methodology, our study constitutes the first reporting on a systematic sampling of bladelets from the sieved fine fractions from the MSA of South Africa, showing their ubiquity in such samples and the wealth of technological information to be gained. Doing so, we could show that different microlithic technologies in both the Sibhudan and HP show CV values well beyond the threshold of random variability. Some of these results may lie in the very act of classification of lithic artefacts, leading to relatively low internal variability in these find classes. Furthermore, our results underline the use of a continuous scale instead of simply using absolute end points of "standardized" vs. "variable". Ultimately, we can assess standardization best in relative terms. Such an approach requires some direct quantification of the degree of standardization (e.g. via CVs) with the broader relevance of these measures then deriving from a direct comparisons of such values across assemblages and technocomplexes (see also Eerkens & Bettinger, 2001; Heckel, 2018). For shape, this will require not just use of ratios as provided here but also the application of methods such as 2D and 3D morphometrics to quantify morphology (Falcucci et al., 2022; Way et al., 2022). We also caution against selecting individual elements of entire lithic assemblages and focusing on standardization/variability only in this regard as has often been made particularly for tools, often resulting in small samples (e.g. Way & Hiscock, 2021). Instead, our findings highlight the need to compare different parts of assemblages to get a more realistic assessment of (relative) standardization for the overall lithic technology. Standardization might lie in the shape or size of end products, or in specific ways of consistent core reduction, but only an approach using multiple elements of assemblages can assess such subtle differences.

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Lithic standardization and behavioral complexity in the Middle Stone Age – a case study from Sibhudu (KZN, South Africa)

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Supplementary Material

Text S1 Additional background to the Sibudhan and HP of Sibhudu

The main occupation periods of interest in this study concern the Howiesons Poort and subsequent Sibudhan (previously 'post-HP') phases at the site deriving from the Conard excavations. The Howiesons Poort layers feature a sequence of ~30-50 cm thickness, encompassing a succession of 8 find horizons which are almost entirely of anthropogenic origin with a very large lithic assemblage (n=97,360). From bottom to top these are layers Theodora, Thabo, Sarah, Saman, Rosa, Robert, Quincy and Quentin. The sequence has previously been dated to between ~65-60 ka by OSL (Jacobs et al., 2008; Jacobs and Roberts, 2017). The lithic assemblages are characterized by abundant laminar technology, common bipolar knapping and a high frequency of backed pieces plus some evidence for bifacial technology (de la Peña and Wadley, 2014; de la Peña, 2015). Recent studies found that these typical HP indicators decrease consistently across the sequence, signaling a gradual abandonment of this technology at the site (Will & Conard 2020).

The Sibudhan deposits with a thickness of ~1.2 m follow after the HP. This sequence contains 23 finely laminated find horizons, dated to ∼58 ka by OSL at its bottom, middle and top (Wadley and Jacobs 2006; Jacobs et al. 2008b). Originally addressed as 'post-HP', lithic analyses from the Conard excavations have provided a new picture that led to the renaming of these idiosyncratic assemblages to the 'Sibudhan' (Conard et al. 2012). The extensive lithic assemblages (n=172,369) are characterized by major shifts in raw material procurement, blank production and tool assemblages throughout the sequence, now differentiated into 4 different phases (Conard & Will 2015; Will & Conard 2018). At the very top, frequent unifacial points of various distinct shapes and reduction sequences are the most characteristic pieces of the assemblages (Conard et al. 2012; Will et al. 2014)

Text S2 Attribute list

General attributes

Find ID, Layer, Square, raw material, % cortex (on dorsal face), type of cortex, % completeness, *Metric attributes*

Weight (g), maximum dimension (mm), length (mm), width (mm), thickness (mm), platform width (mm), platform thickness (mm), EPA (°)

Qualitative attributes

Preserved parts, platform form, platform type, bulb, number of negatives, orientation of negatives, cross section

Presence/absence attributes

Parallel edges, sub-parallel edges, convergent edges, dorsal trimming, Siret fracture, bipolar, lip

Table S3: General distribution of raw material of the Sibudhan bladelet sample from Sibhudu.

Raw material	N	%
Dolerite	725	61.5
Hornfels	314	26.6
Sandstone	91	7.7
Quartzite	19	1.6
Quartz	29	2.5
Chert	1	0.1

Table S4: Cross-sections of the Sibudhan bladelets by layer.

Layer	Triangular symmetrical	Triangular asymmetrical	Trapezoid symmetrical	Trapezoid asymmetrical	Total n
BSp	21.4%	68.8%	3.9%	5.8%	154
SPCA	25.8%	65.6%	4.3%	4.3%	93
POX	30.3%	63.6%	2.6%	3.5%	723
WOG1	23.1%	66.7%	5.1%	5.1%	39
BYA2i	31.0%	61.9%	4.8%	2.4%	42
LBYA	33.8%	63.5%	2.7%	0.0%	74

Table S5: Cross-sections of the Sibudhan bladelets by raw materials.

Raw material	Triangular symmetrical	Triangular asymmetrical	Trapezoid symmetrical	Trapezoid asymmetrical	Total n
Dolerite	28.7%	65.5%	2.4%	3.4%	704
Hornfels	24.6%	65.9%	5.2%	4.3%	305
Sandstone	39.8%	53.0%	2.4%	4.8%	83
Quartz	37.5%	58.3%	4.2%	0.0%	24
Quartzite	26.3%	68.4%	0.0%	5.3%	19

Text S6 Additional information on knapping traits and preservation of the bladelets in the Sibudhan

Knapping technique

Due to preservation only 434 bladelets were suitable for an assessment of knapping technique. Unlike the bladelets from many South African LSA sites, the bladelets from the Sibudhan of Sibhudu are overwhelmingly produced from handheld cores. Out of the 434 bladelets, we only identified three (0,7%) as struck using bipolar technique. Most studies dealing with how different knapping techniques lead to differences in the manifestation of knapping features like bulbs, lips etc. have been conducted using flint or chert variants. Considering that one of the bladelets in this study were produced on comparable raw material and assuming that other raw materials behave differently, we will present our observations, but refrain from an interpretation regarding what kind of hammer might have been used for their production. We hope that, once experimental studies on the raw materials used in the MSA of Sibhudu are being undertaken and published, that our data can be interpreted properly then.

The knapping technique used for the production of the Sibudhan bladelets more often than not produced no lip (60,6%). Bulbs are mostly not strongly developed or not developed at all, but shattering of the bulb is also very rare. As we can infer from the bladelets alone, a preparation of the striking edge using dorsal trimming was rare. (7,8%). This corresponds with a low percentage of facetted or dihedral platforms (4,9%). Most platforms are plain (83,4%).

Preservation

As can be expected, the bladelet assemblage is not well preserved. Only 11,6% of all bladelets are complete. Radial fractures are the most common with no obvious trend as to what ends are missing. Lateral fractures make up only 0,5% in the total assemblage. With respect to the layers, we observe that 21,3% of the bladelets are complete in LBYA and 20,4% in BYA2i, respectively. The highest degree of fragmentation is exhibited in POX (9,3%). The degree of fragmentation is the lowest in sandstone and quartz, which corresponds well with those raw materials being dominant in LBYA and BYA2i.

Table S7: Orientation of dorsal negatives on bladelets from the Sibudhan.

Orientation	Total n	%
Parallel	543	46,1
Unidirectional	589	50,0
Bidirectional	25	2,1
Orthogonal	13	1,1
irregular/indet	5	0,4
Convergent	4	0,3

Table S8: Frequency of blank types in Howieson Poort sequence of Sibhudu.

Layer	Flakes	Blades	Bladelets	Points	Total n
QUENTIN	81.0%	15.8%	1.1%	2.1%	969
QUINCY	76.7%	19.9%	0.9%	2.5%	442
ROBERT	72.6%	21.8%	2.9%	2.7%	716
ROSA	71.3%	23.0%	3.2%	2.4%	778
SAMAN	68.4%	27.9%	2.4%	1.3%	630
SARAH	64.0%	32.0%	3.0%	0.9%	428
THABO	62.7%	32.0%	3.9%	1.5%	1420
THEODORA	58.5%	37.4%	2.9%	1.2%	2114

Table S9: Mean values and CVs for HP backed pieces from Sibhudu. Means in mm.

Layer		Length	Width	Thickness
Quentin	Mean	34.2	13.3	4.6
	CV	7.3%	16.7%	28.1%
Quincy	Mean	42.0	11.7	3.4
	CV	45.5%	36.0%	41.1%
Robert	Mean	30.4	13.7	4.7
	CV	41.6%	36.5%	45.3%
Rosa	Mean	33.3	12.8	4.6
	CV	45.3%	30.2%	33.5%
Saman	Mean	38.2	13.5	4.4
	CV	31.4%	30.6%	30.8%
Sarah	Mean	26.5	13.7	4.5
	CV	39.0%	32.9%	34.6%
Thabo	Mean	36.8	13.8	4.4
	CV	36.1%	25.4%	29.1%
Theodora	Mean	38.2	14.3	4.7
	CV	38.1%	27.9%	41.6%

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Königsaue birch tar documents cumulative culture in Neanderthals

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Abstract

Birch tar is the oldest synthetic substance made by Neanderthals. Recent work has found that birch tar can also be produced with simple processes, or even result from accidents. Here, we investigate the process by which Neanderthals actually produced tar. By comparative chemical analysis of the two exceptional birch tar pieces from Königsaue and the largest available reference birch tar collection made with Stone Age techniques, we found that Neanderthals did not use the simplest method to make tar. Rather, they distilled tar in an invisible underground environment restricting oxygen flow. This degree of complexity is unlikely to have been invented spontaneously. Thus, Neanderthals invented or developed this process based on previous simpler methods, one of the clearest indicators of cumulative cultural evolution.

One-Sentence Summary: Neanderthals made birch tar with a laborious method, documenting that they had cumulative culture.

Keywords: modern behaviors, cognitive complexity, early pyrotechnology, adhesives, transformative technologies

Introduction

The first time early humans used fire to produce a substance otherwise not existing in nature was when Neanderthals made an adhesive from birch bark ~200 ka (thousand years) ago (*1*), a tradition lasting all through the later part of the European Middle Paleolithic (*2, 3*) (~300-50 ka). This finding has implications for our understanding of Neanderthal cognitive evolution because birch trees do not show any visible exudate that could have been recognized as potential adhesive. To make glue from birch, the bark must be processed using a transformative process (*4, 5*). To date, it remains unknown which technology was used for this. Most researchers supposed laborious methods involving underground processes that restrict oxygen flow (*6-8*). This belief derived from experiments showing that heat treatment of birch bark in low-oxygen conditions allowed to make birch tar, in fact, that low-oxygen conditions were necessary to make tar (*4, 9, 10*). Following this interpretation, archaeologists understood birch tar as one of the best proxies pinpointing evolutionary concepts like cognitive complexity (*11*) or Neanderthal's ability to invent complex technology (*3, 12*). Indeed, most underground techniques producing low-oxygen conditions are resource consuming and difficult (*13*). Much of the energy of the used wood-fuel is lost in such processes (*14*) and a certain degree of temperature control is necessary (*15*), potentially lowering the expected success rate. Thus, birch tar may document advanced technology, forward planning and cultural capacity in Neanderthals (*12*).

This interpretation has recently been challenged by the finding that there is an alternative pathway for the production of birch tar (*16*). It was shown that tar condenses on the surface of stones from burning birch bark. From there, it can be collected by scraping. The process takes place aboveground and can be triggered accidentally when a fire is lit with burning birch bark (a natural tinder). Although no claim was made that Neanderthals actually produced birch tar with this condensation method (*16*), its discovery questioned our view that birch tar documents any cognitive processes *per se*. Tar making with the condensation method does not require imagination because processes take place aboveground and are visible, it has a high success rate (*17*), i.e. it is not difficult, and tar made this way might even be the result of an accidentally triggered process. Thus, to continue to use birch tar for understanding the behavior of Neanderthals, it must be demonstrated how the tar was made.

In this paper, we investigate the technique Neanderthals used to make tar, to help settle the question of how archaeologists may interpret early tar-making in the European Middle Paleolithic. For this, we analyze the two birch tar artefacts found at the German site Königsaue (Fig. 1a). The pieces weighed 1.35 g and 0.83 g before our analyses, the smaller one is broken in two pieces and both are curated at the Landesmuseum für Vorgeschichte in Halle (Germany). The Königsaue site, excavated in the 1960s (*18*), is located in an open pit soft coal mine that brought to light sediments of a paleo-lake. Neanderthals camped at the shore of this lake producing a site (*19*) that yielded three archaeological horizons. While Königsaue can unambiguously be assigned to the Middle Paleolithic, the exact date of the layers from which the two birch tar artefacts were recovered is debated (*18-20*). What is certain is that both tar remains date between 45 ka and 80 ka, not allowing further resolution in terms of their absolute chronology. The larger Königsaue 1 pieces was found in a layer below the smaller Königsaue 2 artefact and is thus, at least, relatively older. If these two pieces were made with an aboveground method like the condensation method, it would be difficult to argue that Neanderthal birch tar reflects complex technology (*11*) because they might be the results of an accidental discovery that was subsequently repeated. If, however, the Königsaue pieces were made with a method including invisible underground processes and intentionally created low-oxygen environments, such a finding would imply that Neanderthals *invented* or *developed* a technical process for transforming their material world. This, in turn, would provide valuable insight into their cognitive and cultural capabilities.

To answer this question, we produce a reference collection of birch tar made with the most common Stone Age techniques described in the experimental literature as having been used successfully (*6, 7, 9, 10, 16, 21, 22*). We compare their chemical fingerprint with the two tar artefacts from Königsaue to understand which of the experimental tars are most similar to the artefacts.

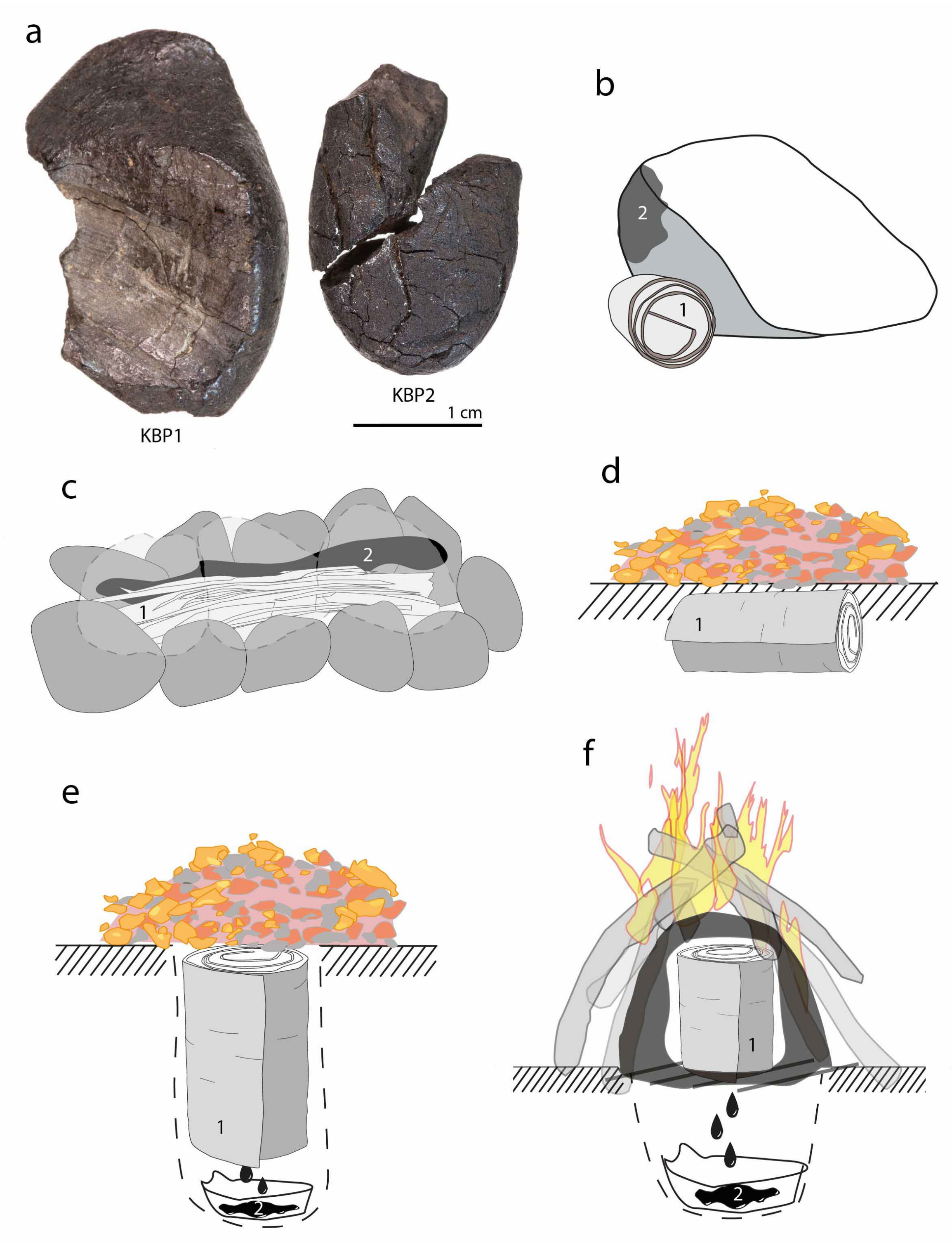

Fig. 1. Königsaue birch tar and experimental production techniques. a) KBP1 = Königsaue 1 (left); KBP2 = Königsaue 2 (right). b) Drawing of the condensation method; c) cobble-groove condensation method; d) the bark roll buried technique; e) the pit roll technique; f) raised structure. 1 = birch bark; 2 = birch tar. Explanations in the main text but also see supplementary information.

Results

We conducted an experimental program to produce a reference collection for this comparative chemical study. We made tar with five different techniques, using only materials available to Neanderthals. The first technique used is the condensation method (*16*) (producing 13 samples in separate runs), where bark is burned beside cobbles to let tar condense on the stone surface (Fig. 1b). We also made tar using the cobble-groove (*21*) (7 samples) where bark is burned in an elongated structure lined with flat river cobbles (Fig. 1c). After the bark burned, tar can be scrapes from the inside of the cobbles. These two techniques can be expected to allow relatively good oxygen flow, the fully open-air condensation method likely allowing most oxygen to be available during tar formation. We also employed three underground techniques where bark is heated by a separate fire (as opposed to the bark itself burning). We buried lying bark rolls under thin layers of sediment, building mounds that then were covered with embers (6 samples, Fig. 1d) (*7*). Tar forms in the windings of the rolls. In the second underground approach, we made tar with the pit-roll technique (*6*) (8 samples) where bark rolls are put upright in small pits (Fig. 1e). Embers are placed on the upper side of the roll and tar drips into a receptacle at the bottom of the pit. The third underground technique approximated a double-pot distillation apparatus (*5*) in aceramic conditions (i.e. without the use of ceramics). Similar techniques have been called 'raised structures' (*6*). For this, we heated bark rolls in an upper chamber made from sediment with a surrounding fire, allowing tar to drip into a lower chamber that is separated by a grate (8 samples, Fig. 1f). These three underground techniques can be expected to restrict oxygen flow, the sealed raised structure likely producing the most reducing conditions (a more detailed description of the five experimental techniques can be found in the Supplementary Material). This experimental program allowed us to produce 42 birch tar samples that, in a first step, were analyzed by transmission infrared (IR) spectroscopy (KBr pelleting) along with the two Königsaue tar artefacts.

Chemical analysis

To investigate this, we first averaged all IR spectra acquired on samples produced with the same techniques to obtain a representative tar spectrum for each technique (Fig. 2a). The fingerprint regions of these spectra were compared with each other and with spectra acquired on the Königsaue artefacts. Noticeable differences in the averaged spectra of the five experimental production techniques are restricted to few regions of their infrared spectra. The major difference is the inversion of the 1735 cm^{-1} and 1710 cm^{-1} double band in samples produced aboveground (condensation method and cobble groove) as opposed to samples made belowground (pit-roll, bark roll buried, raised structure) (Fig. 2a). The band at 1735 cm^{-1} is caused by C=O in suberin (*23*), the bark's polyester biopolymer epidermis that accounts for up to 6 % of birch bark. While the major band of suberin in the fingerprint region lies at 1735 cm^{-1} (*24*), the band's presence in birch tar does not exclude the simultaneous presence of other esters that also cause absorptions at these wavenumbers. The 1710 cm^{-1} band is caused by C=O in different acids and aldehydes, among which (and that are most relevant to our samples) are oxidized biomarkers oleanolic acid and betulinic acid (*25*) and their degradation markers. It is also present in degradation markers produced by oxidation of biomarkers betulin and lupeol (i.e. betulone, lupenone) (*26*). The band inversion thus reveals different concentrations of oxidized bio- and degradation markers in relation with the suberin content of the tars. In this sense, the Königsaue artefacts behave as experimental tars produced with the pit roll technique, both C=O bands having approximately equal heights. Experimental techniques are further set apart by a band at 1084 cm^{-1} that is only present in tars produced aboveground. The band is caused by the Si-O-Si stretching vibration of quartz (*27*). It is likely present in our samples because minor quartz impurities entered the tar when it was scraped from stone surfaces with a flint tool. The quartz band appears to be a proxy for tar making techniques that rely on condensation and subsequent scraping. The band is absent in both Königsaue artefacts. However, in general terms, the presence of such a quartz band for identifying aboveground birch tar production methods might be limited, as tar may be contaminated with quartz impurities after its production. The third obvious difference between experimental samples is that tars made with the three underground techniques contain a band at 727 cm^{-1} that is absent or only very weak in tar made with aboveground techniques. The band is caused by C-H deformation in aliphatic chains (*28, 29*) and is caused by the suberin fraction (*30*) of the bark or long-chain fatty acids bound in the polyester biopolymer. Aboveground techniques, where tar is evaporated from the bark and then condensed above the bark itself, did not trigger significant transport of suberin into the tar in our experiments. A high suberin content appears to be a proxy for techniques involving underground processes where tar drips downwards (there is no exception to this in any of the 42 reference samples' spectra: the suberin band is absent in condensation method tar, very weak in cobble-groove tar and significantly stronger in tar made underground, Fig. S7). This interpretation is strengthened by the main suberin band at 1735 cm^{-1} that is present as shoulder only in aboveground techniques. The 727 cm^{-1} suberin band is present in both Königsaue artefacts. Thus, the spectral signature of the artefacts is most consistent with our reference tar samples made with one of the three underground techniques.

There are however other minor spectral differences for which interpretation, in terms of the underlying molecular differences, is not straightforward. Some spectra contain weak supplementary bands that are absent in others. To use this chemical information concealed in the IR spectra of our samples, we conducted principle component analyses (PCA) on our spectral data. PCA of IR spectral data has been used to distinguish between birch tar and other adhesives (*29*). We amend this technique by using first derivative data calculated from our spectra, representing the slope on the original spectrum. This data are largely independent of variances in band height (differences in band height may be caused by impurities in unknown mixtures and background effects). Our PCA thus allows to make statements on the similarities and dissimilarities of the infrared spectra of different samples, with regard to the presence/absence of absorption bands. The plot of the first two principal components (Fig. 2b) separates the three underground techniques from the two aboveground methods. Tar made with the condensation method lies at one extreme of the plot, while tar made with the raised structure at the other. Separation appears to follow the predicted degree of oxygen availability during tar formation. The two Königsaue artefacts plot with the underground techniques, thus their spectrum is more similar to tar made belowground in low-oxygen conditions.

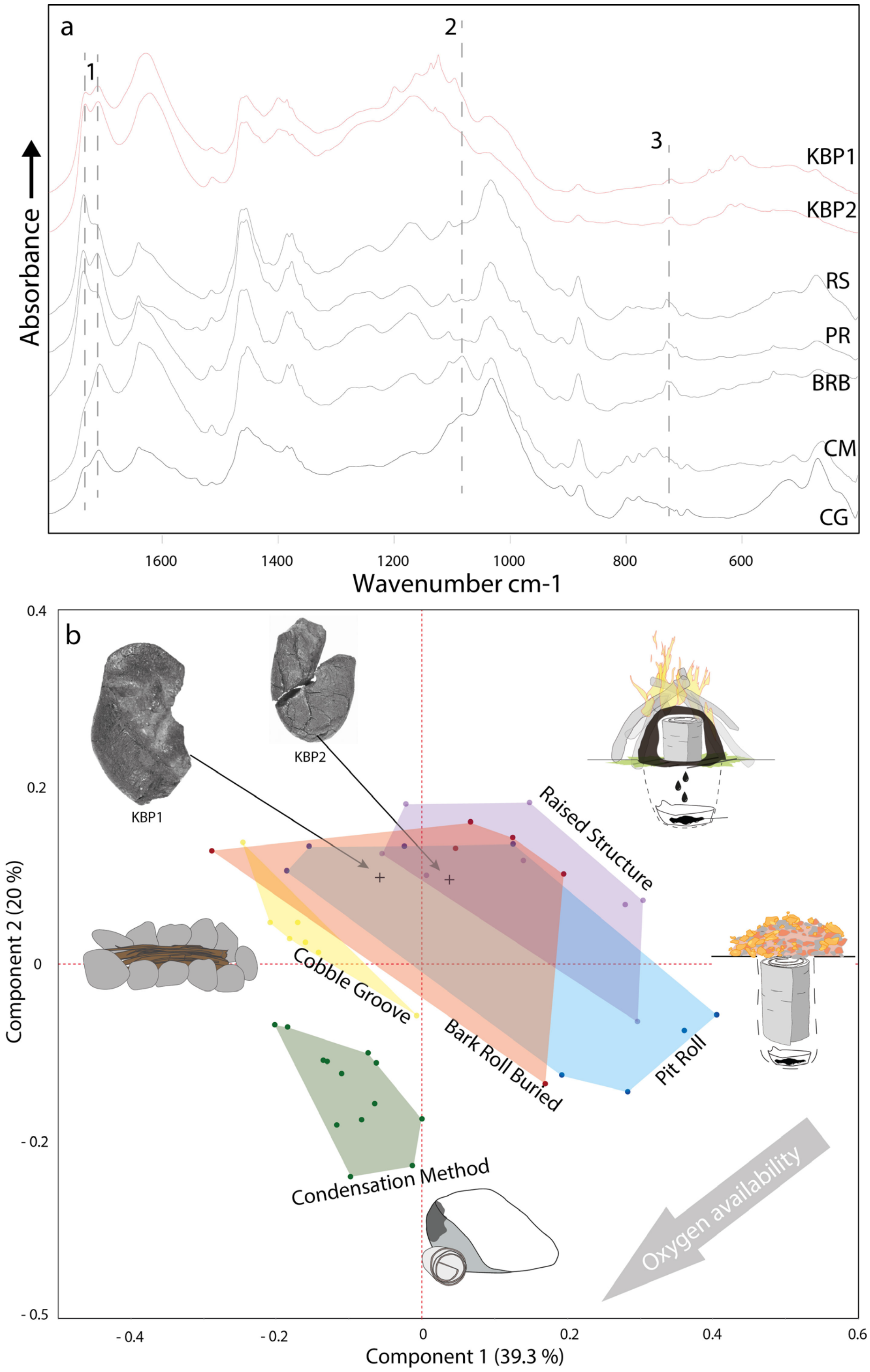

Fig. 2. Infrared spectra of Königsaue birch tar and Principal Component Analysis (PCA) data generated from them. a) Averaged absorbance spectra obtained by transmission analysis (KBr pellets containing 0.7 mg of sample) of experimental birch tar samples compared with spectra recorded from the two Königsaue samples. KBP1 and 2 = Königsaue artefacts; RS = raised structure; PR = pit roll; BRB = bark-roll buried; CM = condensation method; CG = cobble groove. Broken lines show the regions discussed in the text. 1 = double band caused by C=O in suberin (1735 cm^{-1}) and oxidized triterpenoid bio- and degradation markers (1710 cm^{-1}); 2 = main Si-O-Si band of quartz at 1084 cm^{-1}; 3 = 727 cm^{-1} band caused by suberin. b) PCA plot of first derivative data of infrared spectra recorded between 1800 cm^{-1} and 400 cm^{-1}. Note that the separation follows the predicted degree of oxygen availability during tar formation.

To support our IR data, we conducted Gas Chromatography–Mass Spectrometry (GC-MS) analysis on the two Königsaue artefacts and on two randomly chosen experimental samples made with the condensation method and the raised structure. The chromatograms of the two Königsaue artefacts (Fig. 3, but also see Figs. S9 and 10) contain the typical peaks of triterpenoid bio- and degradation markers, confirming previous identifications as birch tar (*8, 20*). The most abundant biomarker in both samples is betulin, although lupeol is also present. The most abundant degradation markers are lupa-2,20(29)-dien-28-ol, allobetulin, allobetul-2-ene and, in accordance with our IR spectra, both oxidised degradation markers betulone and lupenone. The younger Königsaue 2 contains an important contamination of phthalates that has previously been noticed (*8*) and the origin of which remains uncertain. One approach using GC-MS for understanding birch tar production methods is based on identifying a combination of different biomarkers in the linear and triterpenic acid regions of the tars' chromatograms (*31*). It has been proposed that the presence of even-numbered fatty acids C_{16} to C_{22}, together with triterpenic acids (in particular betulinic acid), odd-numbered fatty acids (e.g. $C_{21:0}$) and diacids is a proxy for double pot distillation in later periods where tar making relies on using ceramics (*31*). If this were applicable to aceramic tar making, it might be possible to separate raised structure birch tar from other tars on this basis. Both Königsaue artefacts contain fatty acids and alcohols C_{16}, C_{18}, and $C_{18:1}$ (Fig. 3b). Both experimental tars, raised structure and condensation method, contain only traces of fatty acids C_{16} and C_{18} but none of the others present in the artifacts. Behenic acid C_{22}, proposed to be the most characteristic fatty acid for identifying double pot distillation, $C_{21:}0$ and diacids (including C_{21} and C_{22}) (*31*), are absent in Königsaue artefacts and reference samples. Betulinic acid, if present at all, remains below the detection limit in all samples. It therefore does not appear that the presence of fatty acids in the Königsaue birch tar is indicative of an underground production method (i.e. reference tars do not contain amounts of fatty acids similar to the artefacts). The most parsimonious explanation of fatty acids and alcohols in the two Königsaue artefacts is therefore that they result from soil contamination (*32, 33*) and cannot be used to make statements on the production technique (soil contamination is also supported by the presence of fatty alcohols C_{28} and C_{30} that are frequently derived from plant roots (*34*), Fig. 3a). The chromatogram of reference tar made with the condensation method contains polycyclic aromatic hydrocarbons of different families (including di, tri- and tetra-aromatics). Such polyaromatic hydrocarbons are formed during incomplete combustion in wood/bark fires (*35*) and are common in soot (*36*). We therefore propose that their presence in birch tar is a good proxy for recognizing aboveground production methods, based on condensation, where soot is incorporated in the tar. Our raised structure reference tar and both Königsaue chromatograms are free from polyaromatic hydrocarbons. Although the chromatograms of the two artefacts show peaks at similar retention times, they are not caused by polyaromatics (Fig. 3b). Thus, the chromatographic signature of the two artefacts can be best explained by one of the belowground production techniques.

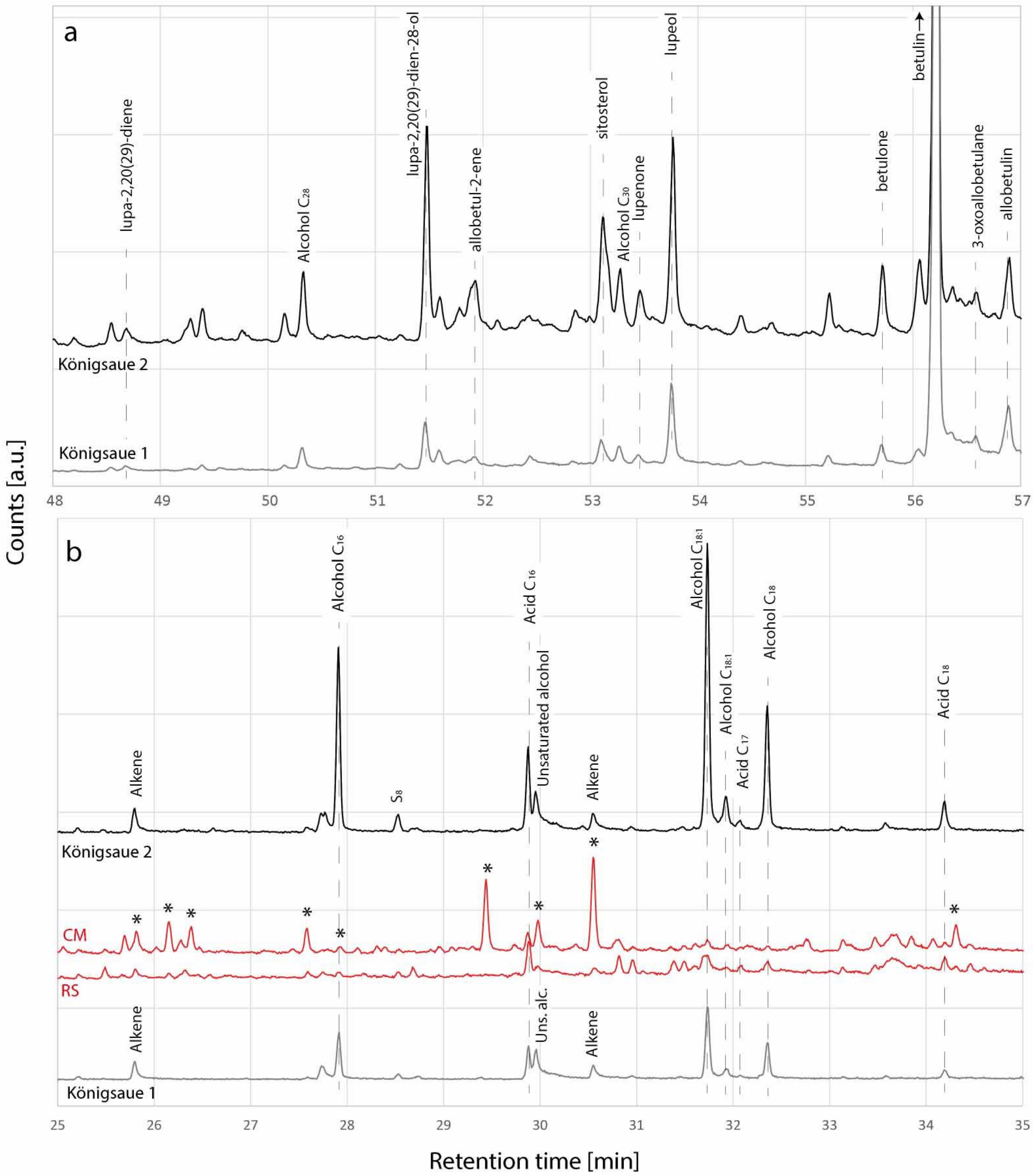

Fig. 3. Sections of the chromatograms of Königsaue and reference samples. (a) Partial chromatograms of the triterpenoid profile between 48 – 57 min and (b) of acid profile between 25 - 35 min. The acid profile in b is compared with the one of reference tars made with the aboveground condensation method (CM) and the underground raised structure (RS). * = polycyclic aromatic hydrocarbons. Cx:y = linear structure with x carbon atoms and y unsaturations.

The structure of the Königsaue birch tar

To gain further insight into the structure of the two Königsaue artefacts, we recorded micro-computed tomography (microCT) scans. Both pieces are similar in overall density (1.23 g/cm^3 and 1.18 g/cm^3 for Königsaue 1 and 2 respectively, as calculated from a total volume of 1.103 cm^3 and 0.705 cm^3 and 1.35 g and 0.83 g). The larger Königsaue 1 piece shows signs of folding around the negative left by the stone tool it was attached to (Fig. 4). Bright inclusions with sizes between 0.2 - 0.6 mm and apparently rounded edges appear throughout the tar. Their grey value is 2.15 times higher than that of the surrounding tar. Assuming a roughly linear relationship between grey values and density in our CT-scans (*37, 38*), the inclusions likely have a density of ~2.58 g/cm^3, a value reasonably close to minerals quartz and feldspar. It therefore appears that these inclusions comprise fine sand grains incorporated in the tar. This sediment contamination accounts for 0.5 % of the total volume of the piece (5 mm^3). The smaller Königsaue 2 artefact does not contain such inclusions and its structure appears more homogeneous (no folding). Its outer zone has a bright cloudy aspect parallel to the object's surface. This may be caused by taphonomic take-up of minerals that are denser than the tar itself. Thus, the two birch tar artefacts differ in that one is more contaminated and apparently more kneaded than the other. The sand grains in Königsaue 1 are likely too few and too separated to have the effect of a loading agent that might have been added to modify the strength of the tar (*39*). It is also uncertain if the soil contamination conceals information about the production technique. It may simply reveal that this piece was recycled more often than the younger Königsaue 2 artefact.

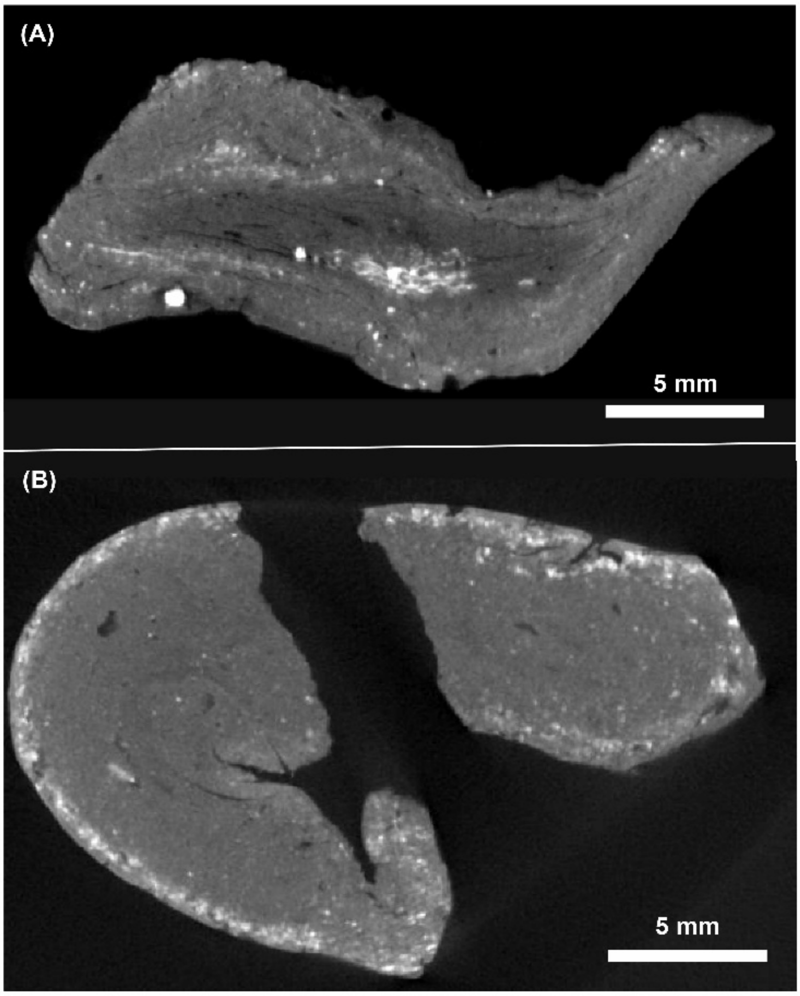

Fig. 4. MicroCT slice of Königsaue birch tar. Königsaue 1: (A); Königsaue 2 and 2 (B). The inclusions in Königsaue 1 appear to be small, rounded, and about 2.15 times denser than the surrounding tar. They are likely sand inclusions. Königsaue 2 shows a denser outer crust that is most likely due to taphonomy but no sand inclusions.

Discussion

Both Königsaue artefacts seem to have been made with a method that involved a restriction of oxygen flow, for example in an underground structure. Some authors have described such techniques as more technically (*6*) and cognitively complex (*40*) than others. While the concept of complexity as direct reflection of advanced cognitive processes has been criticized (*41*), early pyrotechnology has been described as a good indicator of cultural diffusion (*42*). Our finding of an elaborate birch tar making process therefore adds to previous arguments that Neanderthals were capable of complex expressions and cultural transmission (*12, 43, 44*). Many of these arguments are based on comparisons of the material culture of Neanderthals and contemporary *Homo sapiens*. And indeed, both species practiced similar techniques and used similar tools. Bone tools (*45*), personal ornaments (*46*) and ochre (*47*), most likely used for symbolic expressions, are amongst them. However, most of these manifestations appeared earlier in *Homo sapiens*, so that claims of acculturation were brought forward to explain some of the Neanderthal artefacts (*48*). This is not the case for adhesive making. Neanderthals made tar in the Middle Paleolithic (*1*), more than 100 ka before the earliest known instance of such behavior in *Homo sapiens* (*49*). Thus, European birch tar may be one of the, if not the best, proxy for independent cultural processes in Neanderthals. However, birch tar may be produced with a cognitively undemanding technique, or even be the result of unintentional processes in open air fires (*16*). What our study suggests is that, at least in the end of the presence of Neanderthals in Europe, this was not the case. Underground transformative techniques, like those used to make the Königsaue artefacts, are more difficult than aboveground techniques because some elements cannot be observed or corrected after the procedure began (*13, 50*). It also appears unlikely that Neanderthals fully understood these invisible elements. Incomprehensible processes have been called *cognitively opaque knowledge* (*51*), and might be a strong indicator of cultural transmission in Neanderthals. However, the implications of underground tar making may even go beyond documenting cultural transmission and social learning. Because of the higher likelihood of failure when performing underground techniques (*17*), specific recipes must be followed and copied precisely. Such high fidelity copying has been argued to be a key element of cumulative culture (*52*). While this is not unanimously accepted (*53*), the underground production of tar unambiguously documents a *ratcheting effect* indicative of cumulative culture (*54*). This is so because Neanderthals could not likely evolve such a technique *ex nihilo*. Only aboveground techniques may be the result of fortuitous discoveries (*16*). Underground tar making was more likely a technical improvement based on previous, simpler, techniques (ratcheting). Such a shift of tar making technology satisfies three of the core criteria proposed to be minimum requirements for a population to exhibit cumulative cultural evolution (*54, 55*): it is (i) a change in a behavior that must be (ii) transferred via social learning and that (iii) led to an improvement in performance (i.e. underground tar making is more efficient (*17*)). The fourth criterion proposed as core, the repetition of steps (i) to (iii) to generate sequential improvement over time, cannot be investigated unambiguously based on the few known Neanderthal tar artefacts. Our interpretation that the Königsaue tar documents cumulative cultural evolution is further strengthened by the fact that it was produced towards the end of the Neanderthal occupation in Europe. Thus, what we show here for the first time is that Neanderthals invented and refined a transformative technique, most likely independently of the influence from *Homo sapiens*. This might be supported by analyses of older tar fragments attributed to Neanderthals (e.g. the two Campitello artefacts), providing an exciting prospect for future research.

There are only a few other transformative techniques that may be understood to document cultural evolution to a similar degree. Heat treatment of stone for tool knapping and of ochre for artificially reddening it are amongst them. While stone heat treatment in Africa predates the Königsaue birch tar artefacts (*56*), it has been shown that, there, it did not involve invisible underground processes (*57*). Thus, Neanderthal birch tar making seems to be the first documented manifestation of this kind in human evolution. Our finding of cumulative cultural evolution in Neanderthals might be understood to mirror similar observations made on their stone tool industry. The central European traditions of bifacial leaf points (*58*) and the Keilmesser group (*59*) also appear towards the end of the Neanderthal occupation in Europe. Both may be interpreted as representing local evolutions that derive from previous stone tool traditions. The Königsaue birch tar artefacts support this interpretation.

Methods

Infrared spectra were recorded from KBr pellets by direct transmission, using a Bruker VERTEX 80v spectrometer, spectral acquisition between 1800 cm^{-1} and 400 cm^{-1} and a resolution of 2 cm^{-1}. Each ~ 0.3 g pellet contained 0.7 mg of sample. Principal Component Analysis (PAC), using a covariance matrix, was performed on first derivative data of the complete spectral range (yielding 1454 variables). All spectra were first normalised to the highest and lowest bands to reduce remaining differences due to variation in the 0.7 mg samples. Then, the first derivative was calculated over 5 spectral points to obtain data representing positive and negative slopes on the spectra that is only minimally influences by band height.

GC-MS analyses were performed with an Agilent 8890 chromatographer coupled with an Agilent 5977B MSD. The temperature of the source was set at 220°C. The mass spectrometer was operating in the electron impact (EI) mode at 70eV. Gas chromatographic separations were operated on a HP-5MS column (30 m x 0.25 mm x 0.25 µm film thickness) with He constant flow of 1,5 $mL.min^{-1}$ and a temperature gradient of 40 °C for 2 min, then 10°C/min until 100°C, then 4°C/min up to 320°C, hold time for 60 min. Samples were processed by ultrasonic-assisted extraction (Dichloromethane/methanol 60:40), filtration through diatomaceous earth and trimethylsilylation using N,O-Bis(trimethylsilyl)trifluoroacetamide (BSTFA). More detailed information about the sampling procedure (including sample preparation, GC-MS analysis and chemicals used) is given in the Supplementary Material.

CT-scans were recorded with the Phoenix v-tome-x s scanner (General Electric, Frankfurt am Main) of the Paleoanthropology High Resolution CT Laboratory, Tübingen, selecting a resolution of about 4.7 microns. The reconstructed volumetric data (.vol) was sliced and the ISO surface of the pieces generated, using the Avizo Lite software.

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Science Advances

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Supplementary Materials for

Königsaue birch tar documents cumulative culture in Neanderthals

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Supplementary Text
Figs. S1 to S14
Tables S1 to S4

Supplementary Text

The controversy surrounding the dating of Königsaue birch tar

The relative chronology of the two Königsaue tar pieces is unambiguous because the stratigraphic integrity of the site is unquestioned. Thus, we know that one piece is older than the other one, but not by how much and neither how old these pieces are.

The absolute age of the Paleolithic horizons of Königsaue has been widely debated (8, 11, 59-63). Reason for the controversy is the discrepancy between the radiocarbon dates taken from the tar pieces themselves and the geochronological assessment of the stratigraphic sequence where the tar pieces originate from.

Mania and Toepfer (*18*) attributed the Middle Paleolithic assemblages that accompanied the birch tar pieces to the Brörup interstadial in MIS 5c based on the geochronology of the lake sediments, an age estimate that has since been defended by Mania (*61, 64-65*). Additionally, a range of 1000 years between horizon A and C has been assumed based on the suggested length of the Brörup interstadial (*18*). This is the origin of the 80 ka date associated with the Königsaue tar pieces. More recent research placed the Brörup interstadial around the time of 100 ka, however, and today, the Odderade interstadial would coincide with an age of 80 ka (*66*). The original geostratigraphic dating was partly based on faunal remains associated with warmer conditions (*18*), so a final decision to which interstadial they might belong is not possible.

There are currently three radiocarbon dates associated with the Königsaue tar – two directly taken from the pieces themselves and one on a bone from horizon A. The sample from the tar piece Königsaue A yielded an age of 50.6 to 41.4 ka calBP (*20*). Trying to recalibrate the age for Königsaue B (48.4 ± 3.7 ka uncalBP) using OxCal 4.4 on the IntCal20 curve yielded an invalid age, meaning that the original age is most likely infinite. Given the time of when these dates were obtained, it seems likely that both should actually be treated as infinite ages, which is essentially Mania's position (*61*). Yet, a recent AMS age of a bone from horizon A yielded an age of 45.9 to 44.5 ka calBP (*19*) which would fall within the range of the tar piece Königsaue A. This is all the more puzzling as horizon A is the lowermost archaeological layer and the infinite age comes from the younger horizon. Mania has argued that all three layers cover a time span of about 1000 years. On first glance, it therefore seems possible that the lowermost horizon is that young. However, Mania's assessment is built upon the geochronology, which means accepting the short time succession of the archaeological horizons automatically means rejecting the radiocarbon dates given the available evidence as of today.

Hence, while the archaeological context of the tar pieces from Königsaue is undoubtedly Middle Paleolithic, the debate about their age and the chronological relationship between the pieces is far from settled. Based on the current evidence and (most likely failed) attempts to date the pieces using radiocarbon, one possible conclusion is that the pieces are older than the range of radiocarbon dating. We follow Picin's notion that an extensive dating program is necessary to resolve this problem (*19*), if it can be resolved at all.

A list of Middle Paleolithic adhesive finds from Europe and the Levant

Table S1. List of known adhesives attributed to Neanderthals.

Site	Country	Approx. age	Type	Reference
Inden Altdorf	DE	~120 Ka	Not yet analysed	(*68*)
Fossellone and Sant'Agostino caves	IT	40-55 ka	conifer resin (also mixed with beeswax)	(*69*)
Königsaue	DE	45-80 ka	Birch tar	See references in this work
Campitello	IT	~200 ka	Birch tar	(*1*)
Zandmotor	NL	50 ka	Birch tar	(*3*)
Umm el Tlel	SY	40-70 ka	Bitumen	(*70*)
Hummal	SY	50-80 ka	Bitumen	(*71*)

Precisions on the methods used for experimental birch tar production

The condensation method

First published in 2019 (*16*), the condensation method represents the simplest way of making birch tar we currently know. It is an open-air and readily observable method that only requires stones, birch bark and fire. A roll of birch bark is placed beneath a subparallel stone surface and lit. While the bark is burning only minor adjustments need to be made as the fire progresses. Tar condenses on the stone surface and can be scraped off using a flake or similar tool. The process can be repeated until the desired amount of birch tar has been produced. It is possible for one person to operate multiple stones at the same time, but three stones were found to be the best compromise between manageability and output rate.

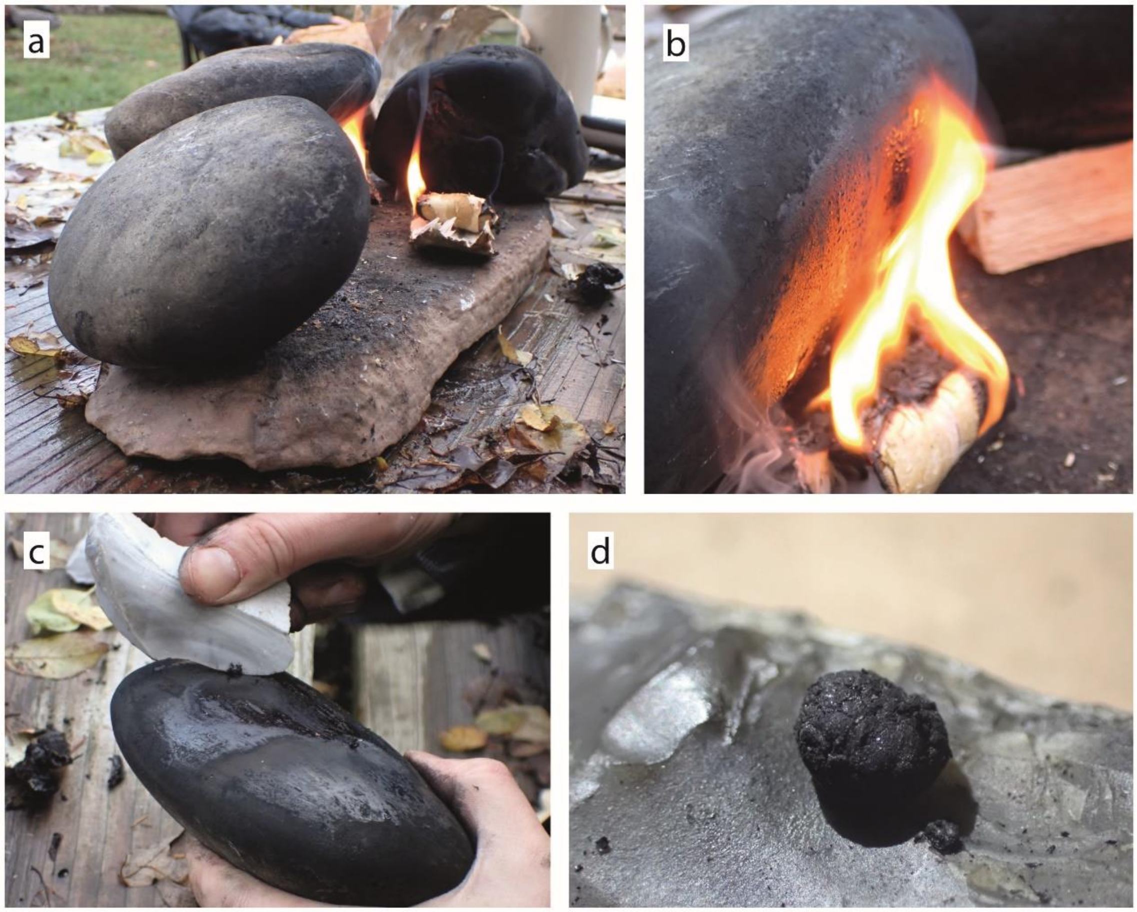

Figure S1. Experimental setup of the condensation method. (a) Three cobbles are operated simultaneously. (b) During the experiment, tar condenses onto the tilted cobble that can (c) be scraped off using a flint flake. (d) The amount of tar collected during one experimental run. Photos taken by Tabea Koch.

The cobble-groove technique

This method describes a variation of the condensation method (*21*). It is a semi-open-air method that takes place aboveground with restricted air in-flow. For the setup, an approximately 30cm long groove is dug using a wooden stick. Flat and smooth river cobbles are placed at the bottom of this groove and further stones are placed upright on each side. The structure is filled with birch strips of a similar length and width as to fit into the groove. This bark-filled structure is covered with additional cobbles, leaving just one opening at the extremity of the structure. The gaps between the side and top cobbles are filled with wetted sediment. At the opening, the bark is lit. Depending on the quantity of bark used, the flames extinguish after 15-30 minutes. In most cases, no additional attention is required. However, when the flames threaten to go out, air needs to be blown into the opening to keep the bark burning. When the bark strips are completely charred, tar that had condensed onto the top and side cobbles can be scraped off using flint flakes.

Figure S2. Experimental setup of the cobble-groove condensation method. (a-b) The groove filled with strips of birch bark. (c) The structure after lighting of the bark. (d) Tar condensed onto the side cobbles. Photos taken by Tabea Koch.

The pit roll technique

With this method, the reaction to make birch tar happens underground and out of sight of the operator. In our own experiments we also found it to be the most unreliable method of production. A small pit needs to be dug into the ground, just big enough to hold a roll of birch bark. Although the technique is sometimes described (see for example (*6*)) to derive from descriptions in ref. (*67*), where the bark roll would be set on fire and then put into the hole, we found no such description in ref. (*67*). Regardless, lighting the bark roll itself could not be reproduced and an external source of heat had to be added (*6*). Glowing embers on top of the pit with the bark roll inside provided this external heat source in our experiments. The tar drops into a receptacle placed at the bottom of the pit and can be collected from there. However, in our experience, the tar is mostly trapped within the layers of the bark roll, if it forms at all. The pit roll technique seems to be difficult to control, the tar output is minimal and the method is not consistently successful.

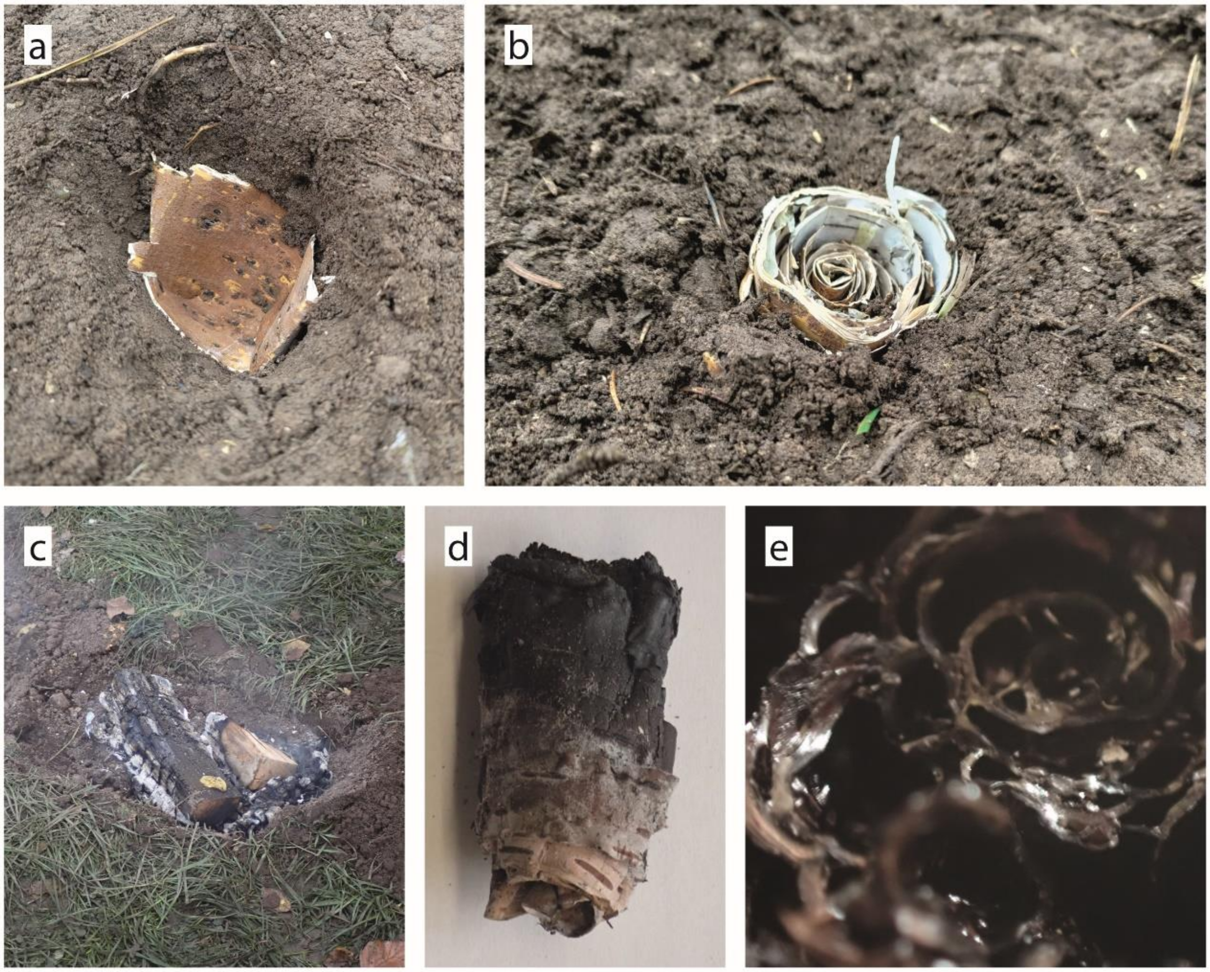

Figure S3. Experimental setup of the pit roll method. (a) The pit with a birch bark receptacle. (b) The bark roll before the experiment. (c) Ambers cover the buried roll. (d) A bark roll that did not char completely. (e) Close up image of tar that remained in the bark roll. Photos taken by Tabea Koch.

The bark roll buried technique

A roll of birch bark is placed lying horizontally in a pit of similar length. The roll is buried deep enough as to be covered with ~0.5 - 1 cm of sediment. A fire is lit on top of the buried bark roll. After approximately 30 minutes, the embers can be removed and the bark roll can be excavated. During the process, the bark chars and tar forms within the layers of the roll. Because the roll is placed in a horizontal position, only small amounts of tar are lost in the surrounding sediment. However, the remaining tar adheres to the charred bark roll and is difficult to collect.

Figure S4. Experimental setup of the buried bark roll method. (a) Top view of a bark roll. (b) The fire burns directly above the buried roll. (c) The bark roll completely charred during this experiment. (d) Close up image of the tar that adheres to the charred remains of the bark. Photos taken by Tabea Koch.

The raised structure

The raised structure could be considered an aceramic version of the historically known double-pot distillation using ceramic containers. In comparison to the other aceramic tar making techniques, the so-called raised structure requires the most steps to be carried out (*6*). First, a receptacle (e. g. made from birch bark) is placed in a small pit. This pit (lower chamber) is then covered with a grit made of thin twigs. A previously made birch roll is placed onto the grit and covered with an earthen dome (upper chamber) made of sediment and clay. A fire is lit around the structure. This technique requires a certain amount of time and effort, as well as skill in terms of temperature control. The bark roll chars and tar drips into the receptacle. After the fire has burnt out (2-3 hours), the dome can be opened, and the tar collected. The structure can also be left to cool down (e. g. overnight).

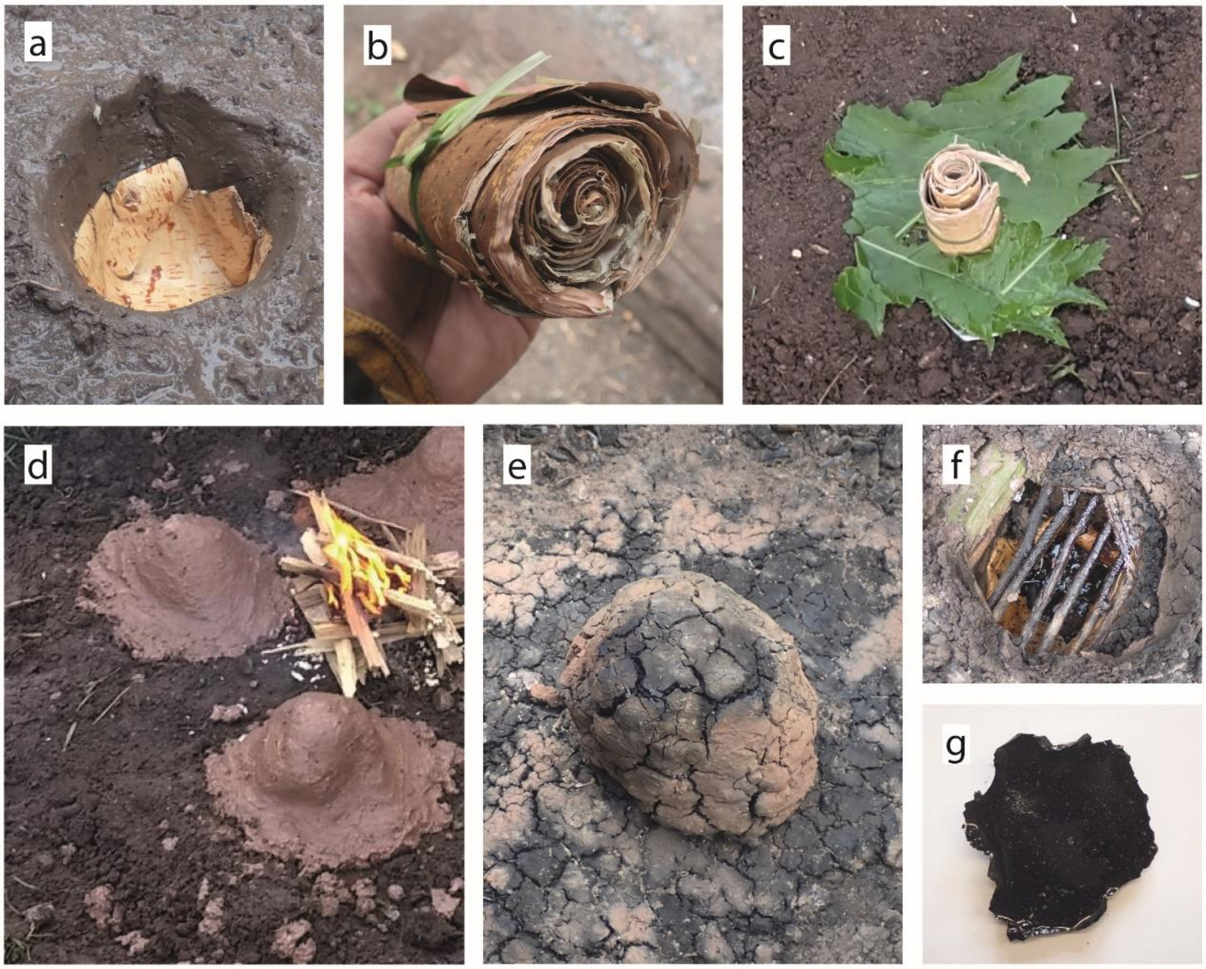

Figure S5. Experimental setup of the raised structure. (a) A bark receptacle placed at the bottom of the pit. (b) A tightly rolled bark roll to be placed onto the grit. (c) Fresh leaves are placed around to roll to prevent sediment falling down. (d) Two raised structures made of clay and sediment when lighting the fire. (e) Cracks in the earthen mound are visible after the firing. (f) Tar that dripped into the bark receptacle in the lower chamber below the grit. (g) Solidified tar after leaving a raised structure cool down over night. Photos taken by Patrick Schmidt.

List of experimental reference samples

The birch bark used to produce the 42 reference samples was collected from several trees. The exact number of trees was not recorded but can be estimated to > 50. Bark was collected from the stem section of trees older than 15 years. Dead bark was collected from fallen trees lying on the ground in forests. Fresh bark was removed from freshly cut trees (trees were cut with permission of the Mayor's office) that were felled the same day.

Table S2. Sample IDs, production methods, production dates, type of bark used and origin of the birch trees used to produce the 42 reference birch tar samples. BRB = Bark roll buried; CG = Cobble Groove; CM = Condensation method; PR = Pit roll; RS = raised structure.

Sample ID	Method	Date	Bark type	Species	Origin of the tree
2	BRB	05/07/2020	Dead Bark	*B. pendula*	Weil im Schönbuch, Baden-Württemberg, DE
3	BRB	05/07/2020	Dead Bark	*B. pendula*	Weil im Schönbuch, Baden-Württemberg, DE
25	BRB	21/11/2020	Fresh Bark	*B. pendula*	Bad Liebenzell, Baden-Württemberg, DE
26	BRB	21/11/2020	Fresh Bark	*B. pendula*	Bad Liebenzell, Baden-Württemberg, DE
27	BRB	21/11/2020	Fresh Bark	*B. pendula*	Bad Liebenzell, Baden-Württemberg, DE
28	BRB	21/11/2020	Fresh Bark	*B. pendula*	Bad Liebenzell, Baden-Württemberg, DE
37	CG	13/12/2020	Dead Bark	*B. pendula*	Weil im Schönbuch, Baden-Württemberg, DE
38	CG	13/12/2020	Dead Bark	*B. pendula*	Weil im Schönbuch, Baden-Württemberg, DE
39	CG	13/12/2020	Dead Bark	*B. pendula*	Weil im Schönbuch, Baden-Württemberg, DE
40	CG	13/12/2020	Dead Bark	*B. pendula*	Weil im Schönbuch, Baden-Württemberg, DE
41	CG	13/12/2020	Dead Bark	*B. pendula*	Weil im Schönbuch, Baden-Württemberg, DE
42	CG	10/01/2121	Dead Bark	*B. pendula*	Weil im Schönbuch, Baden-Württemberg, DE
43	CG	10/01/2121	Dead Bark	*B. pendula*	Weil im Schönbuch, Baden-Württemberg, DE
1.1	CM	28/07/2018	Dead Bark	*B. pendula*	Weißwasser, Saxony, DE
1.2	CM	19/07/2020	Dead Bark	*B. pendula*	Weißwasser, Saxony, DE
1	CM	05/07/2020	Dead Bark	*B. pendula*	Weil im Schönbuch, Baden-Württemberg, DE
7	CM	19/07/2020	Dead Bark	*B. pendula*	Weil im Schönbuch, Baden-Württemberg, DE
9	CM	03/08/2020	Dead Bark	*B. pendula*	Weil im Schönbuch, Baden-Württemberg, DE
10	CM	03/08/2020	Dead Bark	*B. pendula*	Weil im Schönbuch, Baden-Württemberg, DE
18	CM	15/11/2020	Dead Bark	*B. pendula*	Weil im Schönbuch, Baden-Württemberg, DE

19	CM	15/11/2020	Dead Bark	*B. pendula*	Weil im Schönbuch, Baden-Württemberg, DE
20	CM	15/11/2020	Dead Bark	*B. pendula*	Weil im Schönbuch, Baden-Württemberg, DE
32	CM	21/11/2020	Fresh Bark	*B. pendula*	Bad Liebenzell, Baden-Württemberg, DE
33	CM	21/11/2020	Fresh Bark	*B. pendula*	Bad Liebenzell, Baden-Württemberg, DE
34	CM	21/11/2020	Fresh Bark	*B. pendula*	Bad Liebenzell, Baden-Württemberg, DE
35	CM	21/11/2020	Fresh Bark	*B. pendula*	Bad Liebenzell, Baden-Württemberg, DE
11	PR	12/09/2020	Dead Bark	*B. pendula*	Weil im Schönbuch, Baden-Württemberg, DE
12	PR	12/09/2020	Dead Bark	*B. pendula*	Weil im Schönbuch, Baden-Württemberg, DE
13	PR	26/09/2020	Dead Bark	*B. pendula*	Weil im Schönbuch, Baden-Württemberg, DE
14	PR	26/09/2020	Dead Bark	*B. pendula*	Weil im Schönbuch, Baden-Württemberg, DE
15	PR	26/09/2020	Dead Bark	*B. pendula*	Weil im Schönbuch, Baden-Württemberg, DE
29	PR	21/11/2020	Fresh Bark	*B. pendula*	Bad Liebenzell, Baden-Württemberg, DE
30	PR	21.11.2020	Fresh Bark	*B. pendula*	Bad Liebenzell, Baden-Württemberg, DE
36	PR	15/11/2020	Dead Bark	*B. pendula*	Weil im Schönbuch, Baden-Württemberg, DE
5	RS	05/07/2020	Dead Bark	*B. pendula*	Weil im Schönbuch, Baden-Württemberg, DE
16	RS	24/10/2020	Dead Bark	*B. pendula*	Weil im Schönbuch, Baden-Württemberg, DE
17	RS	24/10/2020	Dead Bark	*B. pendula*	Weil im Schönbuch, Baden-Württemberg, DE
21	RS	21/11/2020	Fresh Bark	*B. pendula*	Bad Liebenzell, Baden-Württemberg, DE
22	RS	21/11/2020	Fresh Bark	*B. pendula*	Bad Liebenzell, Baden-Württemberg, DE
23	RS	21/11/2020	Fresh Bark	*B. pendula*	Bad Liebenzell, Baden-Württemberg, DE
24	RS	21/11/2020	Fresh Bark	*B. pendula*	Bad Liebenzell, Baden-Württemberg, DE

31	RS	15/11/2020	Dead Bark	*B. pendula*	Weil im Schönbuch, Baden-Württemberg, DE

Supplementary information on Infrared spectroscopy

Infrared spectra were recorded from KBr pellets by direct transmission, using a Bruker VERTEX 80v spectrometer, spectral acquisition between 1800 cm^{-1} and 400 cm^{-1} and a resolution of 2 cm^{-1}. Each ~ 0.3 g pellet contained 0.7 mg of sample.

Figure 2a of the main text shows the averaged absorbance infrared (IR) spectra of reference tars and the two Königsaue artefacts in the fingerprint region. The whole transmission IR spectrum between 4000-400 cm^{-1} before transformation to absorbance data are shown in Figure S6.

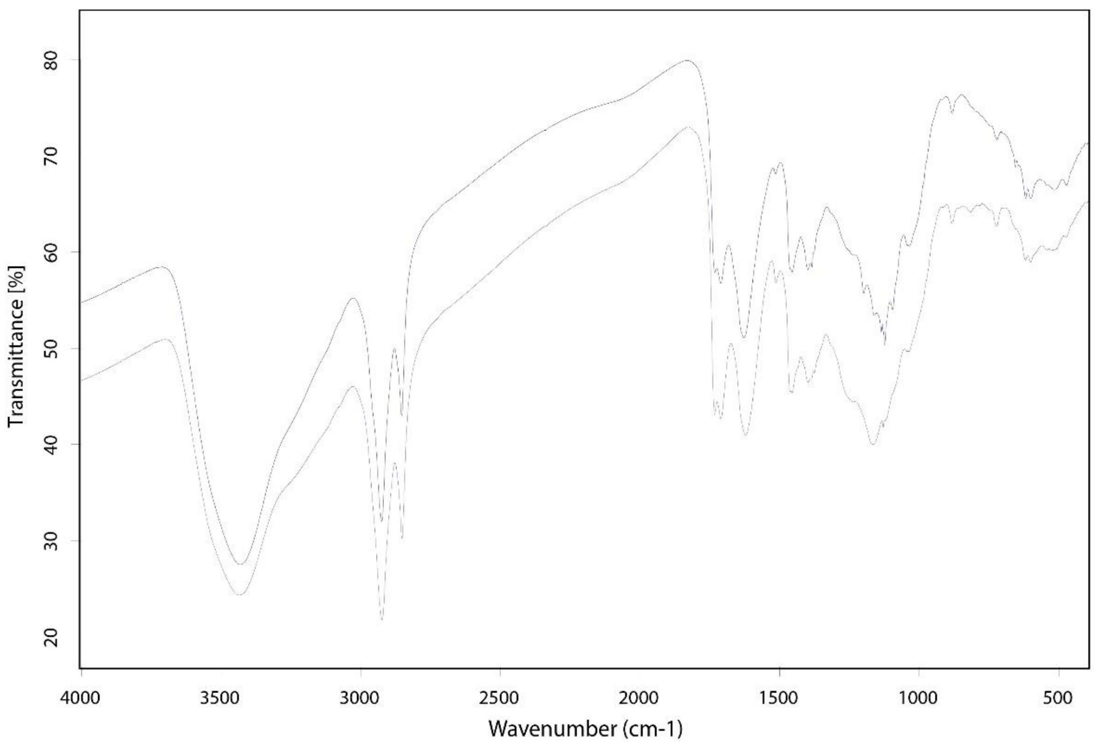

Figure S6. Complete transmission infrared spectra of the two Königsaue artefacts between 4000-400 cm^{-1} before spectral treatment. Upper spectrum: Königsaue 1, lower spectrum: Königsaue 2. Spectra are not offset so that the transmittance values are correct.

Table S3. Absorption bands in the spectra of the two Königsaue artefacts and band assignment. ν = Stretching vibrations, δ = bending vibrations. Bands labeled (KBP1) are only present in the larger Königsaue 1 piece.

Wavenumber (cm^{-1})	assignment
~3500	ν OH (in H_2O)
2925, 2852	ν CH
1735	ν C=O
1710	ν C=O
~1630	δ OH (in H_2O)
1515	δ CH
~1460	δ CH
~1400	ν CO
1200 (KBP1)	ν CO
1160	ν C-O-C
1128	ν C-O
1095 (KBP1)	C-O-C
1036	δ CH
882	δ CH
727	δ CH
622	δ CH
603	δ CH

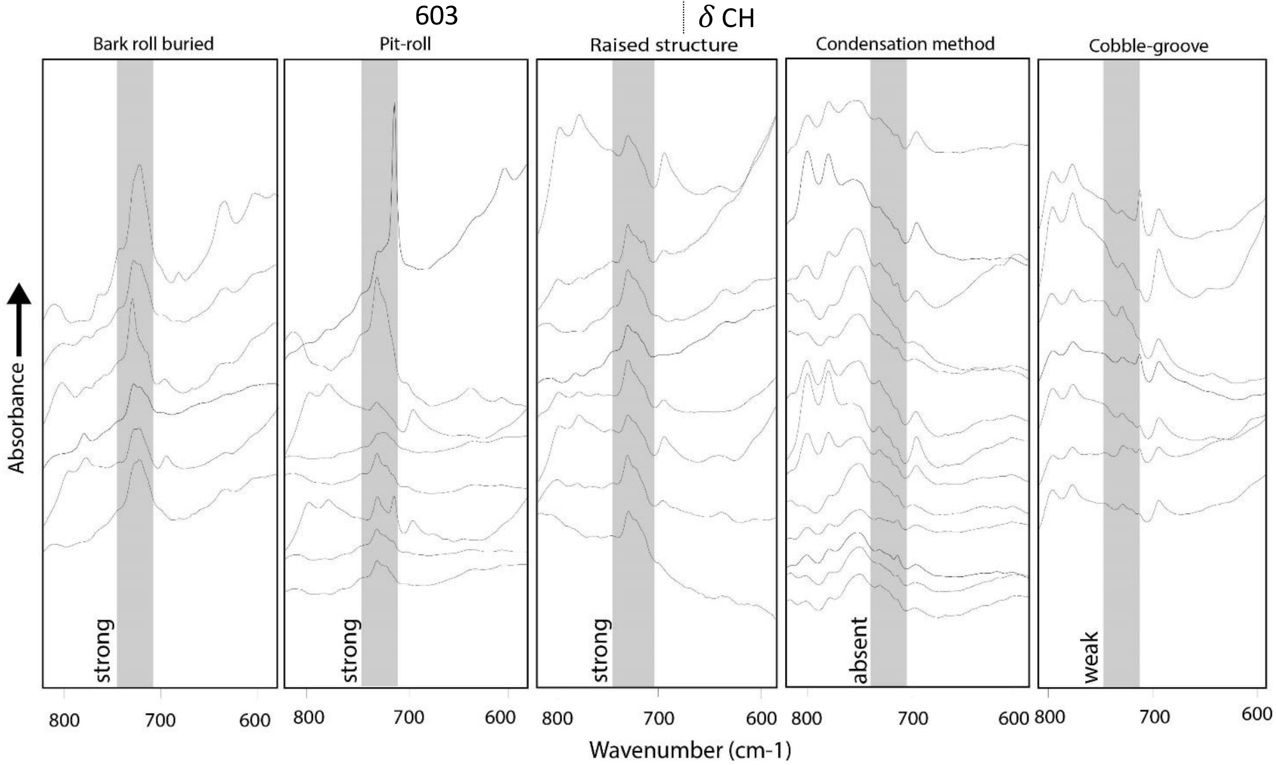

Figure S7. Infrared spectra of the region between 800-600 cm^{-1}, showing the specific absorption band caused by suberin (marked by the grey bar). A sharp band at 713 cm^{-1} occurs beside the suberin band in some of the spectra. This is caused by calcite impurities in the samples, most likely due to ash contaminants.

To increase to robustness of our analysis, we conducted a second PCA on a reduced set of 28 variables that were taken to be the peaks of the strongest positive and negative bands on the first derivative spectrum (Figure S8). This analysis yielded the same result as the PCA on the complete data set.

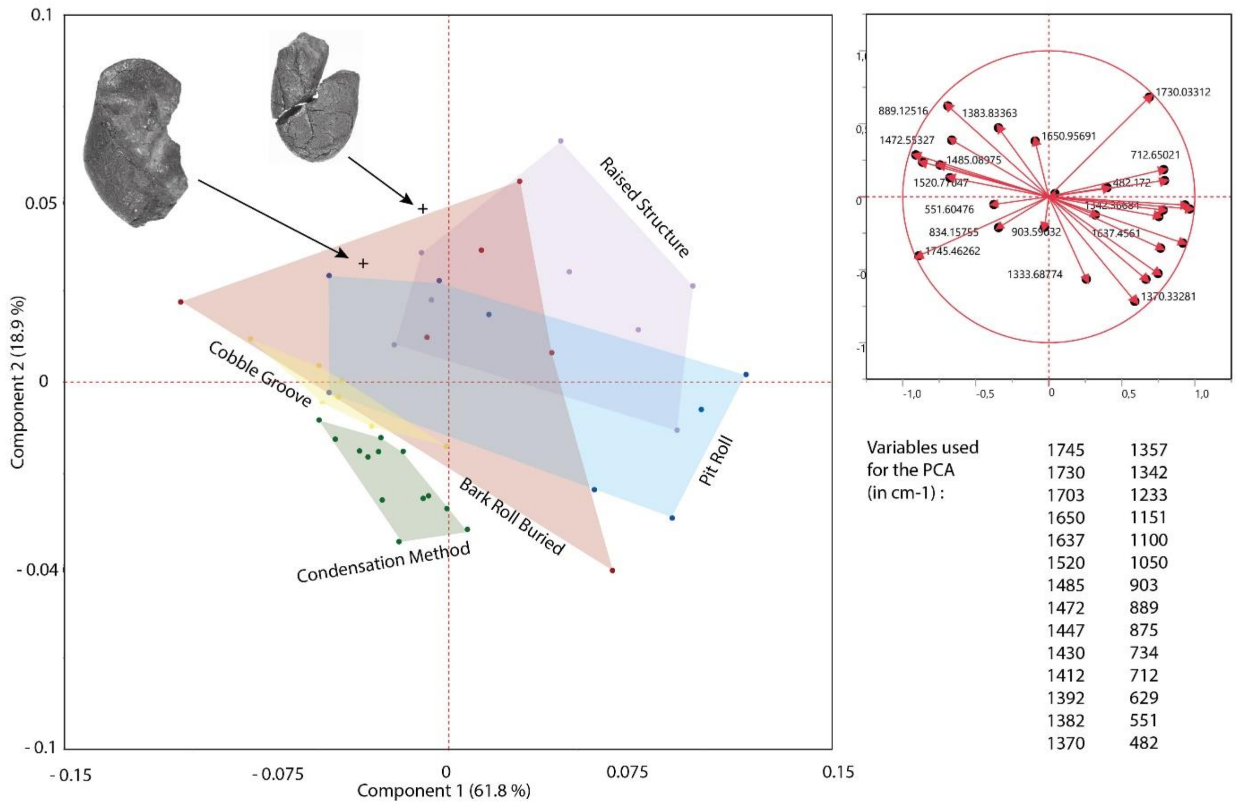

Figure S8. Principal Component Analysis (PCA) plot of first derivative data calculated from birch tar infrared spectra (between 1800 cm^{-1} and 400 cm^{-1}). Compared to the PCA plot in the main text, this plot was generated from a reduced set of 28 variables. Variables were chosen as maximum and minimum peaks in the first derivative spectra.

Supplementary information on our GC-MS analysis

Initial sampling

Both artifacts were sampled with a scalpel to obtain powders for IR and GC-MS analysis. The larger Königsaue 1 artefact was sampled on its lower side (as oriented in Fig. 1 of the main text) that is not shown in the exhibition showcase. The smaller Königsaue 2 artifact was sampled on a surface created by the recent fracture of the piece. This left behind a hole that remains invisible if the pieces is shown as a hole, i.e. if both fragments are shown refitted as they looked before the recent fracture occurred.

Chemicals

Dichloromethane (Fisher scientific) and methanol (Carbo Erba) were HPLC grade and were used without further purification. Pyridine, N,O-bis(trimethylsilyl)trifluoroacetamide (BSTFA) and diatomaceous earth (Celite® 545) were purchased from Sigma Aldrich. Only dichloromethane cleaned glassware and above all no plastic material was used to avoid any contamination.

Sample preparation

Concerning the two Königsaue artefacts, the molecular analyses were carried out on the tar that was still available after analysis by Infrared spectroscopy (sample amount: KBP1 < 1mg, KBP2 3 mg). 10 mg of reference tars, made with the aboveground condensation method (CM) and the underground raised structure (RS), were used. All samples were processed by ultrasonic-assisted extraction three times by means of a mixture dichloromethane/methanol 60:40 v/v (500µl per extraction step). After concentration under gentle nitrogen flow, the organic extract obtained was filtered through diatomaceous earth in order to remove any insoluble residue (elution with dichloromethane/methanol 60:40 v/v. The elution fraction was again concentrated under nitrogen flow to dryness and then engaged in the trimethylsilylation reaction. After addition of 40µl pyridine and 200µl BSTFA, the reaction medium was heated for 2 hours at 70°C and then evaporated to dryness before being injected for GC-MS.

GC-MS analysis

The silylated organic extracts are dissolved in dichloromethane (20 µl for KBP1 and KBP2, 400 µl for CM and RS) before being injected (2µl injected). GC-MS analyses were performed with an Agilent 8890 chromatographer coupled with an Agilent 5977B MSD. The temperature of the source was set at 220°C. The mass spectrometer was operating in the electron impact (EI) mode at 70eV. Gas chromatographic separations were operated on a HP-5MS column (30 m x 0.25 mm x 0.25 µm film thickness) with constant He flow of 1,5 mL/min and a temperature gradient of 40°C for 2 min, then 10°C/min until 100°C, then 4°C/min up to 320°C, hold time for 60 min. GC-MS interface was set at 320°C. Mass spectra were produced in full detection mode over 70-800 amu. Peak assignment was based on interpretation of mass spectra obtained with the OpenLab software and comparison with spectra available in literature and NIST library 2.0. The same procedure (extraction, purification, silylation, GC-MS analysis) was applied to the Königsaue samples and the experimental birch tar samples.

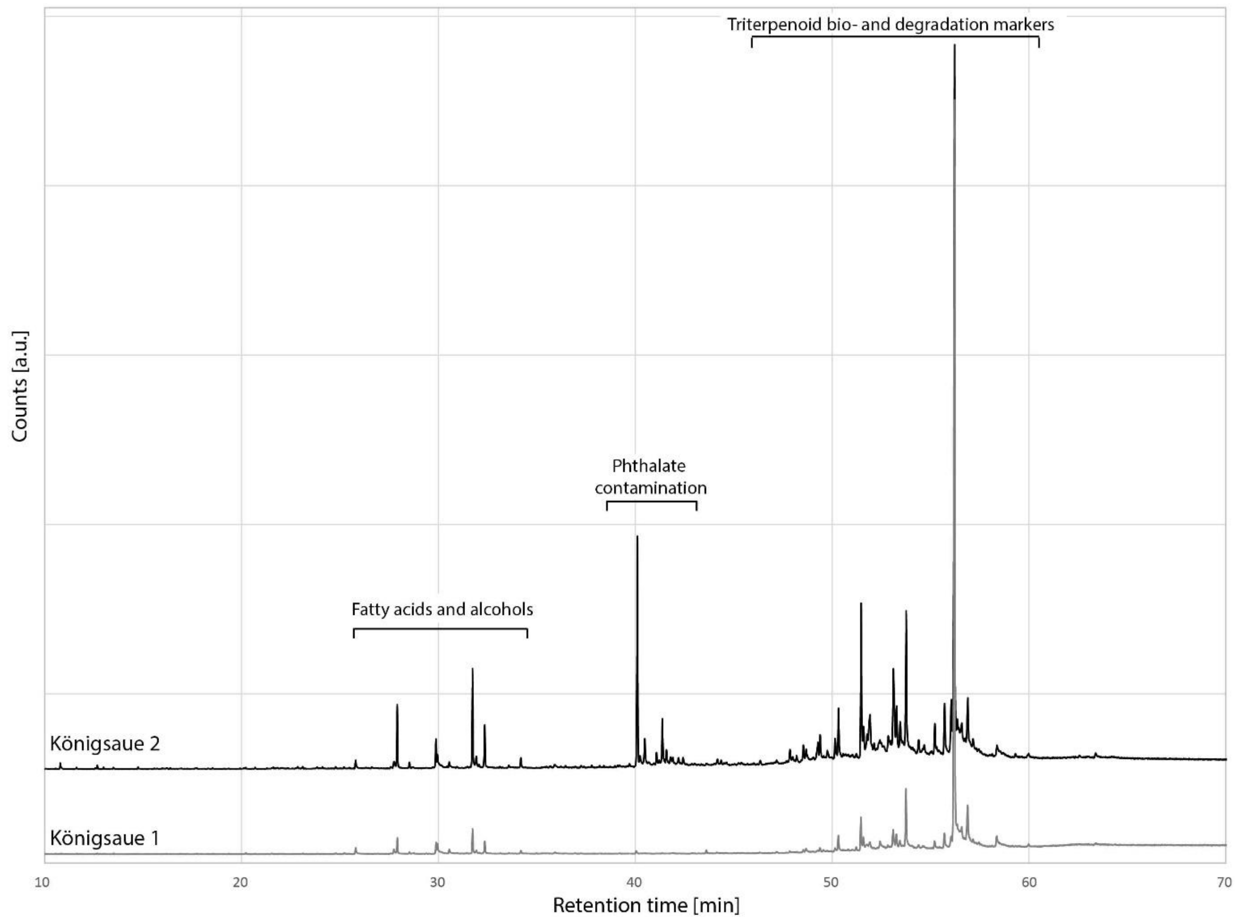

Figure S9. Complete chromatograms of the two Königsaue artefacts. Note that the phthalate contamination is only present in the younger Königsaue 2 piece. Both Chromatograms contain fatty acids and triterpenoid bio- and degradation markers. Descriptions of these two regions can be found in the main text.

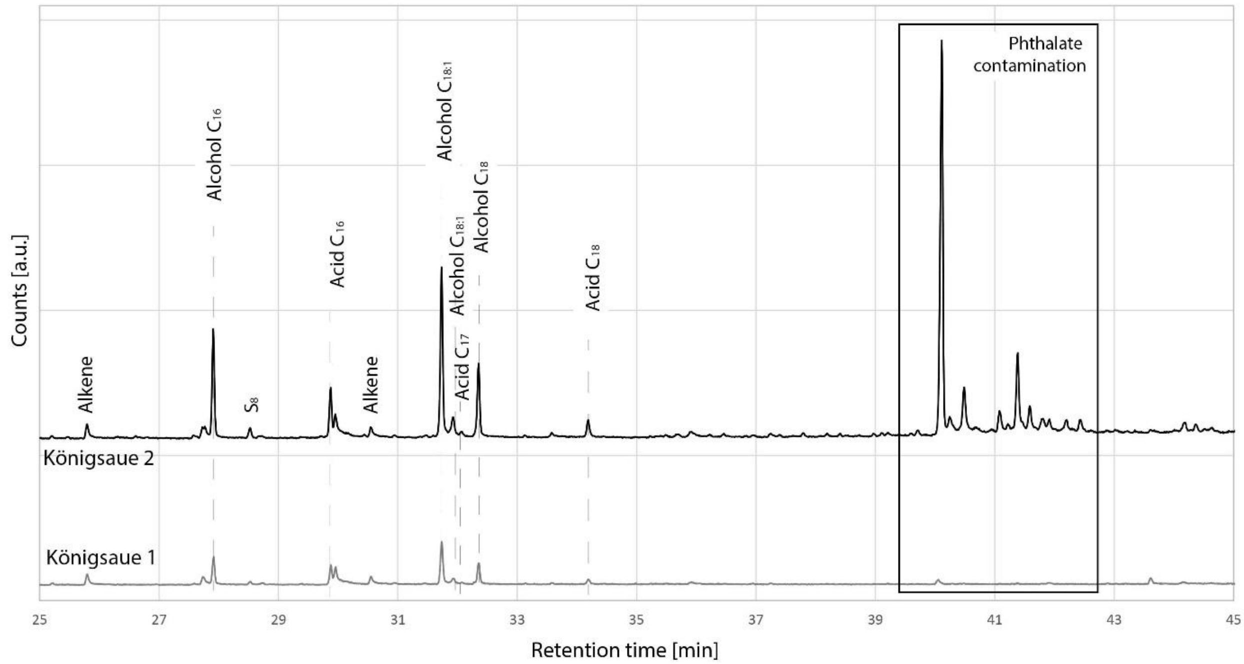

Figure S10. Chromatograms of the two Königsaue artefacts between 25-45 min. Note that only the younger Königsaue 2 is contaminated with phthalates (plasticizers).

Table S4. List of compounds identified by GC-MS in their trimethylsilylated form. Compounds are listed in ascending order of their retention time in the two Königsaue birch tar artefacts. Peak assignment was based on interpretation of mass spectra obtained with the OpenLab software and comparisons with spectra available in literature and NIST library 2.0.

Retention time (min)	Markers family	Compound	Königsaue 1	Königsaue 2
25.81	linear structure	alkene	√	√
27.92	linear structure	alcohol C_{16}	√	√
28.50	elemental sulphur	S_8	-	√
29.88	linear structure	acid C_{16}	√	√
29.96	linear structure	unsaturated alcohol	√	√
30.56	linear structure	alkene	√	√
31.73	linear structure	alcohol $C_{18:1}$	√	√
31.91	linear structure	alcohol $C_{18:1}$	√	√
32.06	linear structure	acid C_{17}	-	√
32.35	linear structure	alcohol C_{18}	√	√
34.19	linear structure	acid C_{18}	√	√
40.11	phtalate	phtalate	√	√
40.49	phtalate	phtalate	-	√
41.09	phtalate	phtalate	-	√
41.38	phtalate	phtalate	-	√
48.69	lupane derivative	lupa-2,20(29)-diene	√	√

50.33	linear structure	alcohol C_{28}	√	√
51.47	lupane derivative	lupa-2,20(29)-dien-28-ol	√	√
51.93	lupane derivative	allobetul-2-ene	√	√
53.11	plant sterol	β-sitosterol	√	√
53.27	linear structure	alcohol C_{30}	√	√
53.46	lupane derivative	lupenone	√	√
53.76	lupane derivative	lupeol	√	√
55.71	lupane derivative	betulone	√	√
56.21	lupane derivative	betulin	√	√
56.59	lupane derivative	3-oxoallobetulane	√	√
56.90	lupane derivative	allobetulin	√	√

√ = identified - = not present
Cx:y = linear structure with x carbon atoms and y unsaturations

Supplementary images obtained by microCT scanning

CT-scans were recorded with a Phoenix v-tome-x s scanner (General Electric, Frankfurt am Main) and selecting a resolution of about 4.7 microns. The reconstructed volumetric data (.vol) was sliced and the ISO surface of the pieces generated, using the Avizo Lite software.

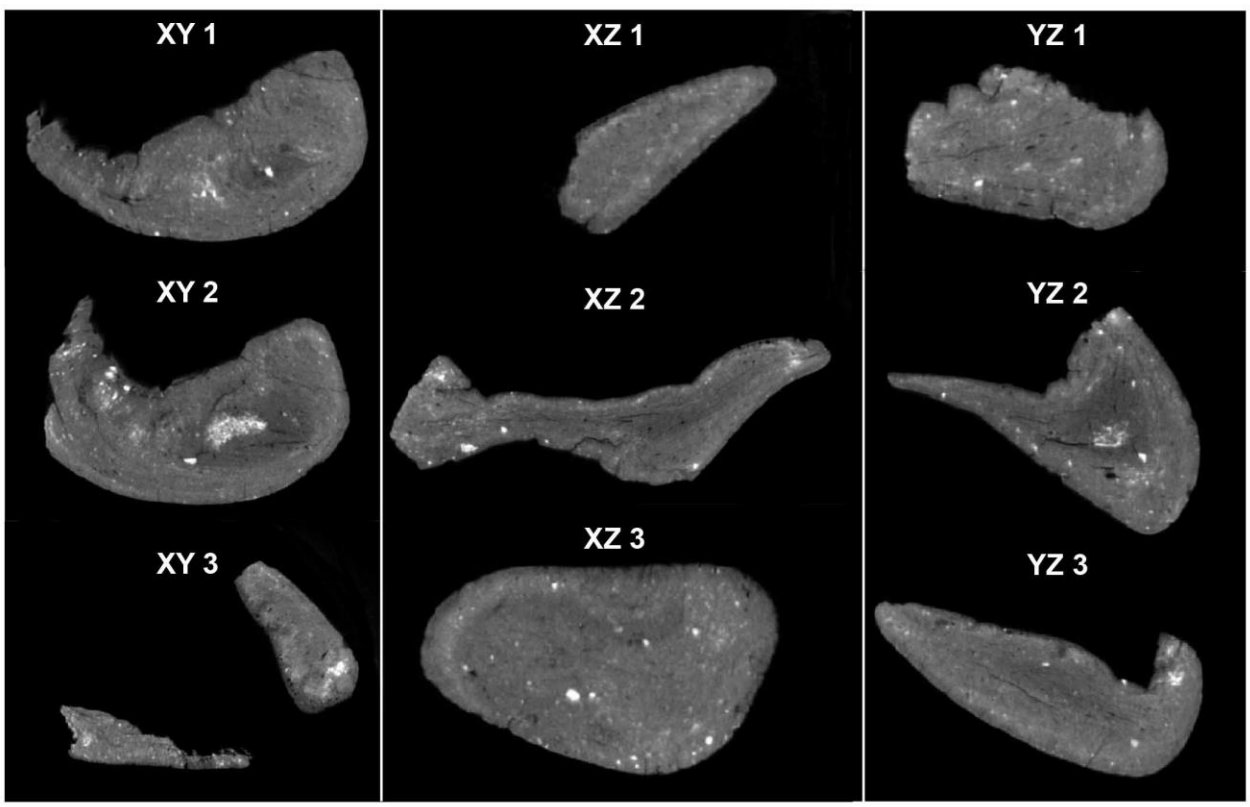

Figure S11. Three equidistant microCT slices of Königsaue 1, for each of the three axes of visualization (i.e., XY, XZ, and YZ).

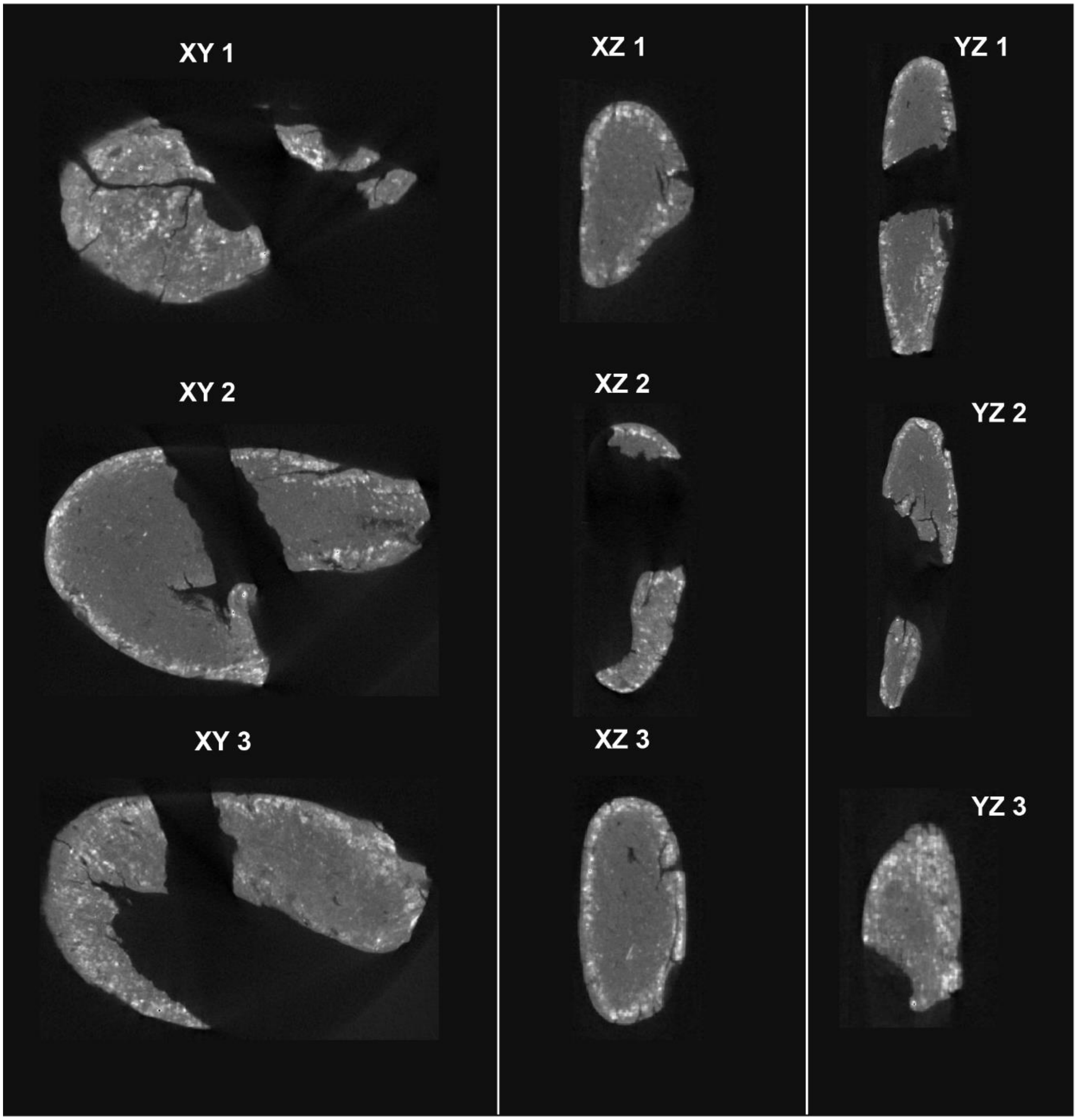

Figure S12. Three equidistant MicroCT slices of Königsaure 2, for each of the three axes of visualization (i.e., XY, XZ, and YZ).

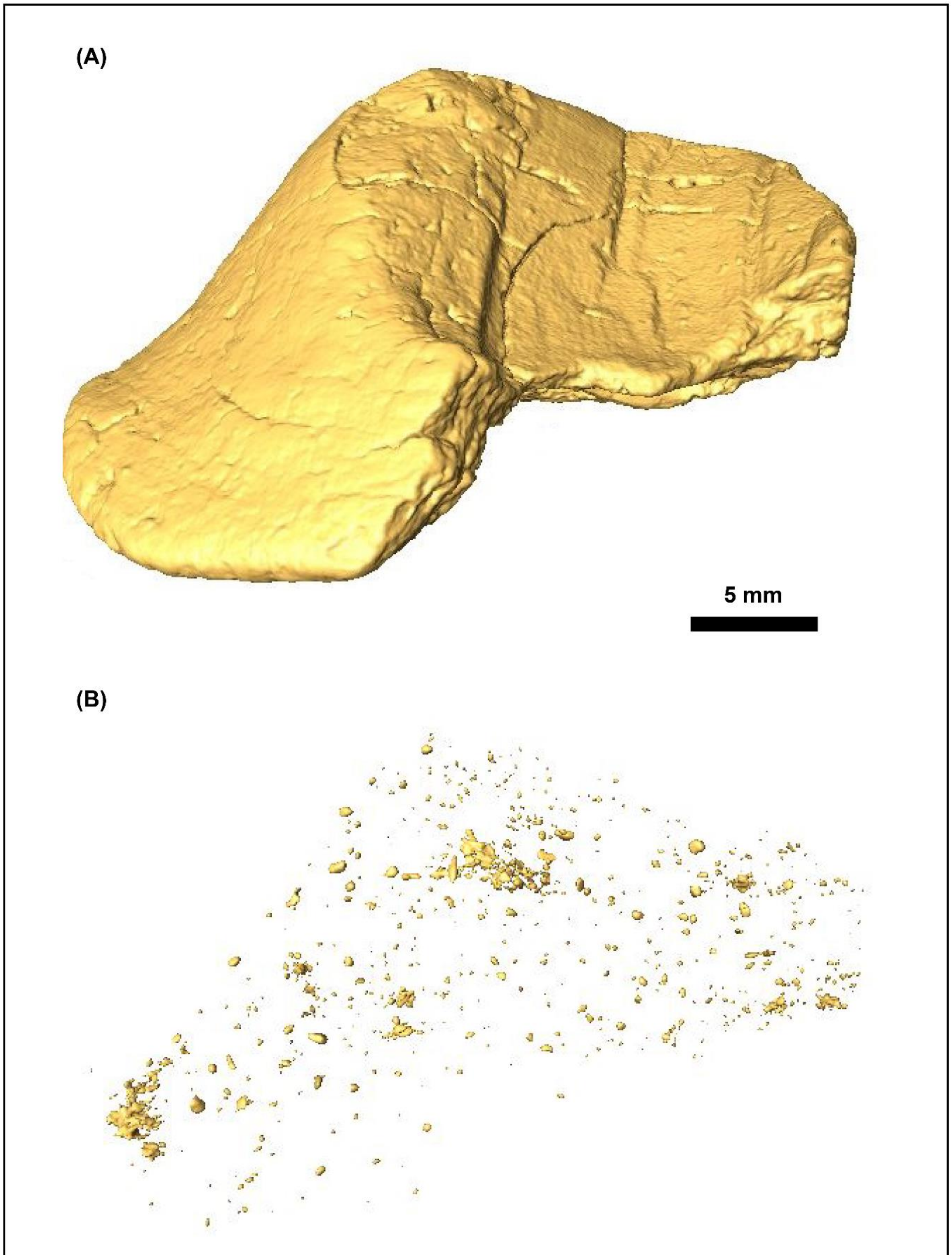

Figure S13. Extracted ISO surface of Königsaure 1 (A) and its segmented sediment inclusions (B).

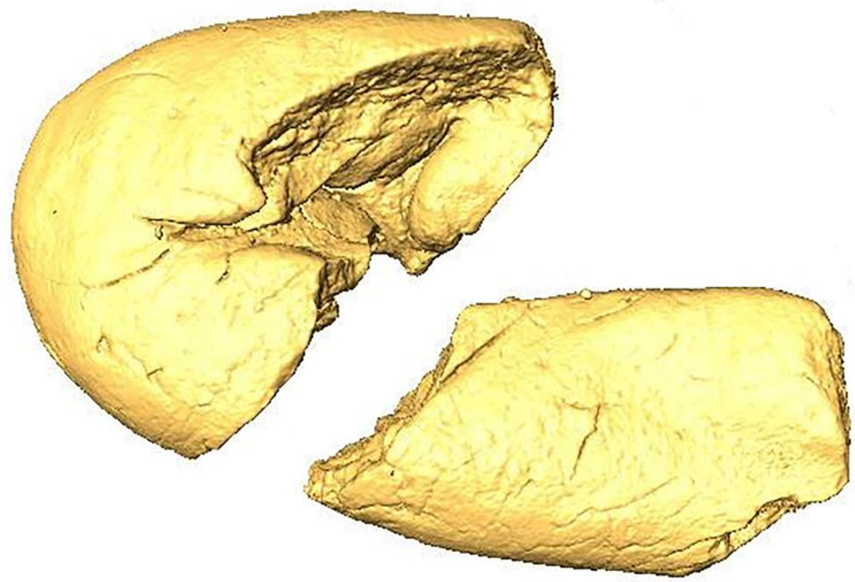

Figure S14. Extracted ISO surface of Königsaue 2.

All citations of this supplementary material refer to the reference list of the main text

Data and materials availability: All data needed to evaluate the conclusions in the paper are present in the paper and/or the Supplementary Materials.

This study did not include human or animal subjects.

Supplementary Materials include:

Supplementary Text
Figs. S1 to S14
Tables S1 to S4

Figure captions

Fig. 1. Königsaue birch tar and experimental production techniques. a) KBP1 = Königsaue 1 (left); KBP2 = Königsaue 2 (right). b) Drawing of the condensation method; c) cobble-groove condensation method; d) the bark roll buried technique; e) the pit roll technique; f) raised structure. 1 = birch bark; 2 = birch tar. Explanations in the main text but also see supplementary information.

Fig. 2. Infrared spectra of Königsaue birch tar and Principal Component Analysis (PCA) data generated from them. a) Averaged absorbance spectra obtained by transmission analysis (KBr pellets containing 0.7 mg of sample) of experimental birch tar samples compared with spectra recorded from the two Königsaue samples. KBP1 and 2 = Königsaue artefacts; RS = raised structure; PR = pit roll; BRB = bark-roll buried; CM = condensation method; CG = cobble groove. Broken lines show the regions discussed in the text. 1 = double band caused by C=O in suberin (1735 cm^{-1}) and oxidized triterpenoid bio- and degradation markers (1710 cm^{-1}); 2 = main Si-O-Si band of quartz at 1084 cm^{-1}; 3 = 727 cm^{-1} band caused by suberin. b) PCA plot of first derivative data of infrared spectra recorded between 1800 cm^{-1} and 400 cm^{-1}. Note that the separation follows the predicted degree of oxygen availability during tar formation.

Fig. 3. Partial chromatograms of the triterpenoid profile between 48 – 57 min (a) and of acid profile between 25 - 35 min (b) of the two Königsaue birch tar artefacts. The acid profile in b is compared with the one of reference tars made with the aboveground condensation method (CM) and the underground raised structure (RS). * = polycyclic aromatic hydrocarbons. Cx:y = linear structure with x carbon atoms and y unsaturations.

Fig. 4. MicroCT slice of Königsaue 1 (A) and 2 (B). The inclusions in Königsaue 1 appear to be small, rounded, and about 2.15 times denser than the surrounding tar. They are likely sand inclusions. Königsaue 2 shows a denser outer crust that is most likely due to taphonomy but no sand inclusions.

Appendix iii.a

Investigating chrono-cultural developments between the end of the final MSA and the beginning of the Robberg. A supra-regional perspective from Umbeli Belli, KwaZulu-Natal, South Africa

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Abstract

The Early Later Stone Age (ELSA) in southern Africa is one of the most poorly understood time periods in the subcontinent. This is due to a lack of sites covering the time period between the final MSA and the Robberg, but also due to a lack of agreement on what the ELSA actually is supposed to be. In this paper, we present the lithic evidence from the site Umbeli Belli (KZN, South Africa), covering the period between ~29,000 and 17,000. We find the changes that happen over the 12,000 years in between the final MSA and the Robberg at this site to be gradual and identify continuous technological and typological shifts. We compare these results to the lithic assemblages on a regional and supra-regional level and in doing so, we find the patterns evident at Umbeli Belli to be repeated across the entire southern African subcontinent. Linking this to the research historical development of the term ELSA we conclude that the MSA/LSA boundary is highly artificial and has become more of a hindrance than a means of structure in current archaeological research.

Keywords: Early Later Stone Age, lithic technology, transition, cultural taxonomy

Introduction

The transition between Early and Middle Stone Age (ESA & MSA) is linked to different hominin species, associated with entirely different technological systems. The proposed subdivision between MSA and Later Stone Age (LSA) is more complex, since behavioural changes occur within the same species raising questions about potential drivers such as environment (ref), society (ref), demography (ref), genetics (ref) and subsistence (ref) (see also Tryon 2019). The archaeological record and hence the potential to examine this transition or its actual validity is patchy. In their recent synthesis of the MSA of South Africa, Bader and colleagues (in press) point towards potential taphonomic issues leading to better preservation of organic materials in the relatively young LSA as compared to the much older MSA. The identification of almost all LSA characteristics previously identified by Deacon (1984), and taken into account for the distinction between LSA and MSA meanwhile have been found in several MSA sites in southern Africa up to 40,000 years before the onset of the LSA (Backwell et al. 2008; Henshilwood et al. 2001; Texier et al. 2013). It hence remains open weather the transition between MSA and LSA is sharp, blurry or existing at all. An abrupt and quick transition from the MSA to the LSA was deemed to be specific to Mediterranean ecozones at the northern and southern fringes of the African continent, while for East and Central Africa a long transition has been proposed (McBrearty and Brooks 2000).

In his review on the MSA/LSA transition in East Africa, Tryon points out, that the understanding of a (evolutionary) transition depends on "[…] solid [1] chronological, [2] stratigraphic and [3] terminological frameworks […]" (Tryon 2019, 276). Hence, we will examine the current state of research in southern Africa with respect to these three pillars.

[1] Regarding chronology, the timing of the ELSA in southern Africa has recently been examined by compiling radiometric dates from a multitude of sites, regions and biomes, that have been linked to assemblages described as ELSA or simply because they predate the Robberg, but postdate the final MSA (Bousman and Brink 2018). They give a maximum range for the transition of 26,750 years, which is somewhat thwarted by their framing of the transition as the "Early Later Stone Age event". This long chronology stems from their acceptance of Border Cave as the earliest appearance of the ELSA in southern Africa and the assumption that the new technology spread from there omitting more than 13,000 years. As recently pointed out by Bader et al. (Bader et al. 2022a) though, Border Cave cannot be accepted as the origin of the LSA since the site represents a clear outlier lacking support from any surrounding site. Contrary to Bousman and Brink (2018), Bader et al. (2022a) showed that there is strong evidence for a late persistence of MSA technologies in the eastern part of southern Africa and that Border Cave may represent one specific expression of the late MIS3 technologies which are characterized by strong regional and temporal variation (see also Bader et al. 2022b). Following this assumption, the potential time frame for the

transition from MSA to LSA is reduced to about 8,000 years overall ranging from approximately 28 ka to 20 ka, but with great variability on the inter-site level.

[2] Almost 100 years of archaeological research in South Africa yielded many sites with long stratigraphies from the MSA and LSA. Thus, in general, we can consider the stratigraphic record for both periods as good. However, sequences containing both final MSA and ELSA are still scarce, especially along the South African West Coast (Mackay et al. 2014). Sites that provided such stratigraphic sequences in southern Africa are Boomplaas (Deacon 1979; Pargeter and Faith 2020; Pargeter et al. 2018), Rose Cottage Cave (Clark 1999; Loftus et al. 2019; McCall and Thomas 2009; Wadley 1997) (all South Africa), Sehonghong (Mitchell 1995, 1996; Pargeter and Dusseldorp 2020; Pargeter et al. 2017; Pargeter and Redondo 2016) (Lesotho) and Apollo 11 (Ossendorf 2013, 2017) (Namibia). White Paintings Rock Shelter (Botswana) might contain such a sequence as well (Robbins et al. 2000), but the data currently available are not suitable for a meaningful comparison. Sites that yielded ELSA and Robberg assemblages are Sehonghong (Mitchell 1994; Mitchell 1995, 1996; Pargeter and Dusseldorp 2020; Pargeter et al. 2017; Pargeter and Redondo 2016) (Lesotho), Boomplaas (Deacon 1979; Pargeter and Faith 2020; Pargeter et al. 2018) , Heuningneskrans (Beaumont 1981; Porraz and Val 2019), Elands Bay Cave (Parkington 1980; Porraz et al. 2016a; Porraz et al. 2016b; Tribolo et al. 2016), Rose Cottage Cave (Clark 1997; Wadley 1996, 1997) Umhlatuzana (Kaplan 1990; Kaplan 1989; McCall and Thomas 2009) (all South Africa).

[3] Concerning the terminology, ELSA has become the standard designation for assemblages predating the Robberg technocomplex in South Africa (Lombard et al. 2012; Porraz et al. 2016a). In absence of the Robberg technocomplex in Apollo 11, Namibia, Ossendorf (2013; 2017) is using the term Late Pleistocene Later Stone Age (LPLSA) to describe the assemblage postdating the final MSA. Additional complication was added as the terms Early Later Stone Age and MSA/LSA transition were sometimes used interchangeably by different authors, but Clark (1997), and more recently also Villa and colleagues (2012) argued for those terms to represent two separate chrono-cultural entities and made a distinction between the Final Pleistocene assemblages from Rose Cottage Cave and the assemblages characterized as Early Later Stone Age from Border Cave (Beaumont and Vogel 1972; but see Villa et al. 2012). However, as research on the time frame between the final MSA and the Robberg increased and new assemblages had been published, the term Early Later Stone Age replaced the term MSA/LSA transition at least in the description and classification of assemblages. By retaining the division between the MSA and LSA though, the concept of the transition was simply subsumed under the predominantly technological paradigm of the ELSA. Hence, there are two ways the current terminology can be understood:

1) ELSA is to be seen as an extension of the ‘classical’ LSA succession and the LSA should be subdivided into ELSA, Robberg, Oakhurst, Wilton (see Lombard et al. 2012). This would imply a relatively sharp break between MSA and LSA.

2) The ELSA is not part of the ‘classic’ LSA succession, but also not part of the MSA and must in consequence be understood as transitional. In this reading of the term, the ELSA would have to been seen as entirely independent from the Early, Middle and Later Stone Age periodization.

Today we know, that there is a considerable time span between the earliest Robberg and the final MSA, which raises the question: What characterizes this time slice of about 8000 years? Firstly, this is an interesting epistemological problem, because the existence of one or even several chronological units, that exist after the final MSA, but before the Robberg as ‘benchmark’ LSA automatically means, that these assemblages can only be qualified by disqualifying it to be “true” LSA. However, by defining what is LSA in opposition to what is MSA, such chronological units must also disqualify to be MSA. Hence, we are left with the problem of how to fit something into pre-existing categories where no room was left to fit something. Clark (1997) identified the ELSA to be the technological elements of blank production from the LSA, mainly bladelet production, bipolar flaking and core reduced pieces while preserving MSA tool types in the form of bifacial and unifacial tools. This has been widely accepted as various degrees of these combinations have been observed at other sites as well (ref).

In this paper, we attempt to compile the lithic evidence for the ELSA from southern Africa, in order to add the techno-typological dimension to what lately has been focussed on chronology (Bousman and Brink 2018). We will combine this evidence with data from a previously unpublished lithic assemblage originating from the site Umbeli Belli, yielding a stratigraphic sequence that comprises the final MSA (Bader et al. 2016), a Robberg layer (Bader et al. 2018; Blessing et al. in prep.), and three layers in between. In doing so, we refrain from using the term ELSA to describe the assemblages from Umbeli Belli and only use the term in reference to other researchers who used it in their publications.

Background to Umbeli Belli

Umbeli Belli is a rock shelter formed in the Natal sandstone group situated above the Mpambanyoni river valley (Fig. 1). Charles Cable’s first excavation at the site in 1979 particularly focussed on the uppermost layers comprising the last 2000 years of hunter-gatherers in southern Africa (Cable 1984).

In 2016, a team from the University of Tübingen led by Gregor Bader and Nicholas Conard returned to the site and continued excavating Cable’s old trench (Bader et al. 2016; Bader et al. 2018). The extension of the old profile revealed a rich stratigraphic sequence of MSA and LSA occupations, which has been described by Bader and colleagues previously (Bader et al. 2022b; Bader et al. 2018). The LSA sequence is subdivided into six units. Layers 1, 2BE and 2AL on top (following Cable's taxonomy) were not covered by these recent excavations, but have been published before (Cable 1984). Accordingly, our analysis of the LSA horizons focusses on the geological horizons (GH) 3, 4, 5 and 6. GH 3 contained an assemblage attributed to the Robberg complex and this publication is currently under review (Blessing et al. in prep.). GH 4, 5 and 6 superimpose GH 7, which yielded a rich final MSA assemblage published by Bader and colleagues (Bader et al. 2018, 2022b).

GH 5 was dated to 27.2 ± 2.3 and 24.9 ± 2.3 ka using OSL on quartz grains (Bader et al. 2018). The feldspar ages are slightly younger placing GH 5 to 22.7 ± 1.8 ka and 21.0 ± 1.4 ka. GH 4 and 6 have not been dated yet, but we can use the dates obtained from GH 7, 5 and 3 to build our chronological framework for those layers. Hence, the lower age limit for GH 6 is 29.9 ± 2.3 ka, imposed by GH 7. The upper limit for GH 6 is 21.0 ka. Consequently, GH 4 dates between 21.0 ka and 17.8 ± 1.5 ka as indicated by the date from GH 3. Regardless of the deviation between quartz and feldspar ages, the dates from GH 5 are in stratigraphic order, thus giving at least some idea of the age of the assemblages presented here. The overall time frame for the transition from the MSA to the LSA and then into the Robberg is roughly 12,000 years, thus spanning the entire range for the ELSA given by Bousman and Brink (2018).

Materials and Methods

Excavation and find processing

The excavations at Umbeli Belli were undertaken following natural geological units, which approximate cultural stratigraphic units. Until bedrock was reached in 2020, 18 units were defined following a numerical system starting with 1 at the top and 15 at the bottom. In accordance with Cable's taxonomy (Cable 1984), layer 2 is subdivided into 2BE and 2AL and GH11 was split into 11a and b. Following the natural inclination of the sediments, these geological horizons were further subdivided into subunits of 1-3 cm thickness. Following the German taxonomy, and in the absence of a clear equivalent in English, we call these subunits "Abtrag" or in plural "Abträge". For further details, see Bader et al. (2018). GH 4 and GH 6 represent a period of increased rockfall, but still contain artefacts. GH 5 (5YR, 4/6) consists of reddish-brown fine sand with significantly less quartzite spall than GH 4 and GH 6.

In square 3/13, GH 4 was excavated in 7 Abträge, in GH 5 in 6 Abträge and in GH 6 in 3 Abträge, allowing a high-resolution analysis of changes in lithic technology from bottom to top in this part of the sequence.

For our examination of GH 4, 5 and 6 we use lithic attribute analysis (Andrefsky 1998; Auffermann et al. 1990; Odell 2012; Scerri et al. 2016) as previously employed at Umbeli Belli (Bader et al. 2016; 2018, 2022b; Blessing et al. in prep.) and Sibhudu (Will et al. 2014). We use the cut-off size of 2 cm previously used for lithic analysis at Umbeli Belli (Bader et al. 2018, 2022b; Blessing et al. in prep.). All three layers combined yielded an assemblage of 820 artefacts >2 cm. Additionally, 1742 pieces of debitage <2 cm are available for analysis.

Figure 1: Location of Umbeli Belli and other sites selected for comparison.

Terminology

Following previous work at the site, in order to maintain intra-site comparability, we subdivide blanks into flakes, blades and bladelets. In accordance with the established systematic for Umbeli Belli a blade is defined as an intentional removal twice as long as wide and with parallel edges (Hahn 1991). Bladelets are defined as blades with a width <12 mm as was done so at other LSA sites in southern Africa (Bader et al. 2020; Pargeter and Redondo 2016). The width of all blanks was measured at the widest preserved point an artefact.

We use the same core terminology for non-bipolar cores that Bader and colleagues (2020) and Low and Pargeter (2020) used, which are based on the work of Deacon (1984). In order to maintain comparability with our analysis of the Robberg assemblage (Blessing et al. in prep.), bipolar cores are not further subdivided in the analysis. As noted by other authors (de la Peña 2015; Hayden 1980), we as well acknowledge difficulties in discerning splintered pieces from bipolar-reduced pieces. Since a qualitative assessment for distinguishing bipolar blank production from the use of splintered pieces was rendered unsuitable for quartz (de la Peña 2015), we emphasize that parts of our results regarding cores and tools might be slightly distorted towards an overrepresentation on bipolar cores made on quartz. Similarly, splintered pieces made from raw materials other than quartz might be slightly overrepresented as well. Given the low artefact count, especially in the core and tool assemblage, these expectations should not majorly impact our analysis, however.

The tool taxonomy generally follows the system commonly used for South African LSA sites (Bader et al. 2020; Deacon 1984; Porraz et al. 2016). Since the use of unretouched bladelets and flakes as tools has been indicated by use-wear analyses on other sites (Binneman 1997; Binneman and Mitchell 1997; Porraz et al. 2016a), and such analyses are not yet undertaken at Umbeli Belli, we only refer to retouched pieces as tools.

Results

Assemblage structure

From the 820 artefacts >2 cm, almost half comes from layer 4 (46,8%, n=384). We recorded 255 (31,0%) artefacts from layer 5 and 182 (22,1%) from layer 6. The artefact density per Abtrag is, with the exception of Abtrag 6.2 very stable and undergoes only minor changes. Throughout the sequence blanks are the most common artefact class never dropping below 86%. Abtrag 4.4 and 5.4 even exclusively yielded blanks. In total, there are 32 cores (3,9%) and 18 tools (2,2%) with most tools occurring in Abtrag 6.3 and 6.2 (Fig. 2).

Figure 2: Frequency of artefact classes in Umbeli Belli GH 4, 5 and 6 per Abtrag.

Throughout the sequence, we observed short-term changes in raw material frequency (Fig. 3). There are three main raw materials represented in GH 4, 5 and 6: quartzite, hornfels and quartz. Other raw materials include variants of chert, shale and dolerite as well as rarer variants of the main raw materials like rose and smokey quartz. In GH 6 and the lower part of GH 5, hornfels is the most commonly used raw material, followed by quartzite. Quartz and other raw materials are comparably rare here. In the upper part of GH 5, the frequency of hornfels drops, while quartzite, quartz and other raw materials become more common. At the expense of quartz and other raw materials, the frequency of quartzite continues to rise in GH 4.

Figure 3: Raw material frequency in Umbeli Belli GH 4, 5 and 6 per Abtrag.

Knapping technique

With regard to our small sample size, we only discern handheld and bipolar knapping. The latter is generally rare, though a slight increase from bottom to top can be observed. Handheld knapping dominates the assemblage, accounting for more than 95% of the knapping strategy throughout GH 4, 5 and 6. There are only two bipolar flakes in GH 6, 13 in GH 5 and 20 in GH 4. In addition to the bipolar flakes in GH 4, five bladelets and one bladelet has been manufactured using this technique. With the exception of one quartzite flake in GH 4 which has been produced using bipolar technique, all bipolar blanks are made on quartz. Handheld knapping was performed on all raw materials throughout the sequence.

Blanks

A total of 768 blanks is included into this analysis. The blank assemblages are characterized by the dominance of flakes in all the layers (Tab. 1). In GH 4, they account for 85.1% (n=303), in GH 5 for 83.8% (n=201) and in GH 6 for 83.7% (n=144). Thus, blades and bladelets combined never account for more than 11% in neither layer. There are no trends between or within layers regarding changes in the frequency of blades or bladelets. Both range between 6% and 4% with only minor changes throughout the sequence.

Table 1: Blank assemblages from GH 4, 5 and 6 at Umbeli Belli.

	Abtrag	Flake %	Blade %	Bladelet %	Manuport/ angular debris %	Total n
GH 4	1	91.8	4.1	2.0	2.0	49
	2	77.6	12.1	1.7	8.6	58
	3	84.7	8.5	6.8	n/a	59
	4	94.7	3.5	1.8	n/a	57
	5	80.7	5.3	5.3	8.8	57
	6	79.5	2.6	5.1	12.8	39
	7	86.5	2.7	5.4	5.4	37
Total GH 4		85.1	5.9	3.9	5.1	356
GH 5	1	84.1	4.8	4.8	6.3	63
	2	78.3	10.9	2.2	8.7	46
	3	87.9	3.0	6.1	3.0	33
	4	78.0	2.4	4.9	14.6	41
	5	88.9	3.7	0.0	7.4	27
	6	90.0	3.3	3.3	3.3	30
Total GH 5		83.8	5.0	3.8	7.5	240
GH 6	1	86.1	5.6	2.8	5.6	36
	2	83.9	5.7	4.6	5.7	87
	3	81.6	4.1	10.2	4.1	49
Total GH 6		83.7	5.2	5.8	5.2	172

In GH 6 and 5 all blades and bladelets are knapped using a freehand technique. In GH 4 five out 14 bladelets and one blade are produced from a bipolar core. Thus, bipolar flaking was mostly used to produce flakes, though this reduction technique is not very common in general.

There is no preference of raw materials for specific blanks types in GH 6 and GH 5. This changes in GH 4, however, hornfels is more commonly used for blade and bladelet production despite quartzite being the most dominant raw material by far.

Most blanks carry only little evidence for platform preparation, plain platforms dominate throughout the sequence. Crushed platforms become more common from bottom to top of the sequence, partly because this is how we labelled the platforms of bipolar blanks thus mirroring the increase in bipolar knapping. Nonetheless, crushed platforms are a fairly common occurrence in handheld knapping as well and they seem to become more frequent from bottom to top of the sequence.

Cores (Tab. 2, Fig. 4)

There are 32 cores in the assemblage, but they are unevenly distributed throughout the sequence. There is a clear increase in number of cores from bottom to top, but also in relative frequency. In GH 6 only 1% of the lithic artefacts are cores, while this rises up to 5% in GH 5 and 11% in GH 4.

GH 4

In GH 4, 18 cores are made from quartz and four are made from quartzite. Other raw materials are entirely missing from the core assemblage. All cores made from quartz are bipolar cores, while the quartzite cores are all platform cores. Among these platform cores, there is one final MSA core *sensu* Bader et al. (2018; 2022b).

GH 5

The 10 cores that come from GH 5 are made from quartz (n=6), quartzite (n=3) and hornfels (n=1). They exhibit a clear pattern regarding reduction strategy and raw material. All quartz cores are bipolar cores, while the platform cores are made on quartzite and hornfels. One core is a core on flake, which was manufactured on a non-local fine quartzite variant.

GH 6

There is only one core in the assemblage of layer 6. It is a final MSA core as defined by Bader et al. (2018; 2022a) and made from quartzite.

Table 2: Core assemblages from GH 4, 5 and 6 by raw material and knapping technique at Umbeli Belli

	GH4		GH5		GH6	
Raw material	Handheld n	Bipolar n	Handheld n	Bipolar n	Handheld n	Bipolar n
Hornfels	n/a	n/a	1	n/a	n/a	n/a
Quartz	n/a	18	n/a	6	n/a	n/a
Quartzite	4	n/a	3	n/a	1	n/a
Other	n/a	n/a	n/a	n/a	n/a	n/a

Figure 4. Selection of cores from Umbeli Belli GH 4, 5 and 6.

Tools (Tab. 3; Fig. 5)

In total there are 17 tools from layers 4, 5 and 6. Eleven tools are made from hornfels, five from quartz and one from quartzite.

Bifacial pieces are only present in layers 5 and 6 and not in layer 4. There is one bifacial piece from layer 5, that cannot be further classified and two bifacial points from layer 6, where also a unifacial point is present. The bifacial points and the unidentifiable bifacial piece from layer 5 are made from quartz and quartzite respectively. The unifacial point is made from hornfels. The other tools are four side- and endscrapers, three retouched flakes, three splintered pieces and one naturally backed piece.

The unifacial point has a TPA of 59°, one of the bifacial points from layer 6 has a 36° TPA. The other bifacial from layer 6 and the bifacial from layer 5 don't have their tip preserved, so that a TPA measurement was not possible.

Two of the splintered pieces come from layer 6 and one from layer 5. All are made on hornfels and no splintered pieces are present in layer 4.

Three of the four scrapers are made on quartz, while one is made on hornfels. Their sizes vary widely between 46 and 18 mm of maximum dimension. No pattern can be observed due to small sample size.

The retouched flakes are all made on hornfels, where one comes from layer 4 and the other two from layer 6.

There is one naturally backed tool from layer 6, a tool class not present in the LSA layers of Umbeli Belli (see also Blessing et al. in prep.).

Table 3: Tool assemblage of GH 4, 5 and 6 at Umbeli Belli

Tool type	GH 4	GH 5	GH 6
Bifacial point	n/a	n/a	2
Bifacial indet	n/a	1	n/a
Unifacial point	n/a	n/a	1
Scraper	n/a	3	1
Splintered piece	n/a	1	2
Retouched blank	1	n/a	2
NBT	n/a	n/a	1

Figure. 5: Tools from Umbeli Belli GH 4, 5 and 6.

Discussion

Internal assemblage variability

The raw material trend observed at the top of layer 4 almost perfectly fits the raw material pattern at the base of GH 3 (Blessing et al. in prep.). Interestingly, the layers below GH 3 have almost no component of the 'indetermined coarse-grained raw material', which we suspected to be heavily weathered hornfels. If this were the case, the lack of this weathered hornfels, would most likely be attributable to different pedogenetic conditions between GH 3 and the underlying geological horizons, which must remain speculative at this point, however. At the lower end of the sequence, the dominance of hornfels mirrors the raw material frequency in GH 7 (Bader et al. 2018). Similar to GH 3, the most significant changes in raw material frequency happen within layers and not between them.

Assuming that layer boundaries were recognized sufficiently precise on excavation, we deem this as a sign of a very continuous occupational pattern. Unlike the changes in GH 3, however, the shifts in raw material frequency that we observe in the GHs 4, 5 and 6 are rather gradual. This matches the change in tool frequency and tool typology. While GH 6 – despite its thinness – yielded the most overall tools (n=10), among them two bifacials and a unifacial point, GH 4 more or less lacks tools (n=3), two of them being splintered pieces and one a retouched flake. In between is GH 5 with five tools total, among them a broken bifacial piece. Paucity of retouched tools is a core feature of LSA assemblages (Deacon 1984). Hence, the continuous decrease of tools from bottom to top of the sequence fits this characterization well.

The emerging preference of hornfels for the manufacturing of blades and bladelets from handheld cores exhibited in GH 4, finds its parallel in the lower part of GH 3 (Blessing et al. in prep.). The GH 3 bladelet assemblage is dominated by bipolar quartz bladelets, however, the few bladelets from handheld cores found there are mostly made on hornfels. Thus, the emerging pattern that we observe throughout GH 4, 5 and 6 seem to be part of continuous process culminating in a fully developed Robberg technocomplex in the upper part of GH 3.

Though cores are overall more common in the GHs 4, 5 and 6 of Umbeli Belli than they are in GH 7, their occurrence is not continuous. In GH 6 and the lower part of GH 5, cores are almost not present, thus making a good connection to the underlying final MSA horizon. Cores that we identified as typical final MSA cores previously (Bader et al. 2018; Bader et al. 2022b), occur in GH 4 and 6, thus spanning the entire sequence between final MSA and Robberg at Umbeli Belli. This contradicts earlier notions, according to which transitional assemblages preserve MSA tool types, but employ LSA core reduction techniques (Clark 1997). The presence of bipolar bladelet cores shows, that the increasing bladelet production over time is not an invention *sensu strictu* that marks the onset of the LSA, but rather an amplification of an already existing part of the technological repertoire of southern African hunter-gatherers.

The high tool frequency in the two lowermost Abträge of the sequence, connects the assemblage from GH 6 to GH 7, where retouched tools make up 7,7 % of the entire assemblage (Bader et al. 2018).

Given the good connection to both the underlying GH 7 and the superseding GH 3, we can infer a very gradual and continuous change of the lithic technology from the final MSA into the Robberg spanning three layers. Additionally, there are no abrupt changes in between geological horizons, but fluctuations occur rather within them. This amplifies our impression of a gradual change throughout the sequence.

A regional perspective on the MSA/LSA transition in southern Africa

The transition from the MSA to the LSA temporally coincides with the transition from MIS 3 to MIS 2. This period exhibits a fragmentation of occupational patterns, especially on the West Coast, contrasted by a surge in occupation intensity along the South African East Coast (Mackay et al. 2014). Umbeli Belli with its seemingly continuous occupation from late MIS 3 into MIS 2 fits well within this supra-regional pattern. Due to the scarcity of assemblages from this time and considerable temporal variability, an inter-site comparison is only possible on a broad scale. Furthermore, variability, may it be caused by environmental differences, site function, occupational intensity, social factors or even excavation technique, is to be expected due to the low number of assemblages known until today. It has also been suggested that the difference among ELSA-labelled assemblages reflects different analytical approaches (Porraz et al. 2016). Additionally, the overall number of sites containing ELSA sequences in southern Africa may also be too low for recognizing regional patterns. Therefore, instead of highlighting the expected variability without being able to attribute it to one or more of the above-mentioned factors, we draw on the similarities across the southern African subcontinent. We selected, Rose Cottage Cave, Umhlatuzana, Umbeli Belli (all South Africa), Sehonghong (Lesotho) and Apollo 11 (Namibia) for our comparative analysis of the ELSA in southern Africa. We will confine our comparison to the lithic technology and typology, due to the lack of organic preservation at Umbeli Belli and Umhlatuzana.

Umhlatuzana is a quartzite rock shelter like Umbeli Belli and was previously assessed as a difficult assemblage due to the complicated stratigraphy (Kaplan 1990; McCall and Thomas 2009), which, however, has recently been revoked (Sifogeorgaki et al. 2020). Therefore, the site became much less problematic as a comparative site. Probably due to the similar bedrock conditions, there is also no organic preservation at Umhlatuzana, but the lithic record is rich and fairly well documented. The final MSA at Umhlatuzana ends between 30 and 28 ka, while the Robberg begins at approximately 20 ka (Kaplan 1989; 1990; McCall and Thomas 2009), giving a time frame of at least 8,000 years for what Kaplan called the transitional MSA/LSA layers 14-18 at Umhlatuzana (Kaplan 1990).

The lithic assemblage is characterized by the presence of microlithic blanks, scrapers and hollow-based points. Even segments are present, though the assemblage is dominated by blanks (Kaplan 1990). We would like to point out that hollow-based points have been identified as a key characteristic of the Eastern Final MSA (e.g. Bader et al. 2022b). Even though the stratigraphic integrity of the site appears to be fine, we suspect their presence in the transitional layer to be the result of admixture caused by excavation technique. From layer 18 to 14 the percentage of quartz steadily increases at the expense of hornfels, but the latter remains the dominant raw material used for tools, especially for bifacial and unifacial points (Kaplan 1990). The changes that occur between the final MSA and the Robberg are more gradual and display a certain degree of continuity (McCall and Thomas 2009). Nonetheless, a more recent comparative analysis of Umhlatuzana's and Rose Cottage Cave's MSA/LSA transitional layers found the assemblages from both sites to be not a mixture of final MSA and Robberg, but as a distinct signature that is different from both (McCall and Thomas 2009).

This is somewhat consistent with a previous characterization for the Rose Cottage Cave MSA/LSA transitional assemblage by A. Clark (1997). Here, the transitional period begins before 27 ka BP (Beaumont and Vogel 1972; Clark 1997) and lasts until 15 to 13 ka BP, marked by the beginning of the Robberg at this site. Hence, the time frame given for the duration of the transition is at least 12000 years. Like in Umhlatuzana and Umbeli Belli, the changes occur gradual (Clark 1997; McCall and Thomas 2009). There is a microlithic component present that predates the Robberg, but it occurs together with prepared core that bear resemblance of final MSA core reduction technology (Clark 1997). The assemblage was deemed transitional in nature as LSA flaking technology becomes increasingly important while retaining artefacts typologically assigned to the final MSA (Clark 1997). Both Clark (1997) and McCall and Thomas (2009) find this assemblage to be a separate techno-typological unit that is neither Robberg nor final MSA even though Clark's characterization is somewhat ambiguous in this respect. Clark even argues for a differentiation between MSA/LSA transitional assemblages and ELSA assemblages (Clark 1997).

Sehonghong comprises a sequence predating the Robberg spanning from 26 ka BP to 20 ka BP, giving a 6,000-year time frame for the time between final MSA and Robberg (Mitchell 1994). Similar to the overlying Robberg layers, the dominant raw material for the ELSA layers at Sehonghong is opaline. There is little evidence for prepared core technologies and bipolar knapping is present in the pre-Robberg layers, though not very common (Mitchell 1994). Unsurprisingly, the microlithic signal from these layers is weaker than in the overlying Robberg, but still present. Tools are scarce in all three ELSA layers (Mitchell 1994). The assemblage can neither be attributed to the MSA, but also has features that are absent in the overlying LSA layers, such as prepared cores and MSA 'knives' (Mitchell 1994; Wadley 1997). Furthermore, the Sehonghong ELSA assemblage is characterized by an increase in opaline as a raw material, which peaks in the Robberg assemblages, at the expense of dolerite and hornfels (Mitchell 1994). It must be noted here, that Carter and colleagues refused to assign the assemblage the name ELSA, in order to avoid confusion in the literature (Carter et al. 1988; Mitchell 1994).

In the Western Cape, Elands Bay Cave yielded a sequence that includes ELSA layers (Porraz et al. 2016a; Tribolo et al. 2016). The sedimentary units K to F comprise MSA and ELSA, where the latter characterizes the collection from unit F and the former is represented in the units below F (Porraz et al. 2016a). Unit F has been dated to 24 to 22 ka BP, which falls within the range commonly associated with the ELSA in southern Africa (see Lombard et al. 2012). The raw material selection is very constant throughout this part of the sequence with quartz dominating. Bipolar knapping is frequently present both in the MSA and ELSA assemblages, with bipolar flakes sometimes accounting for 50% of the flakes. Blades and bladelets are much less frequent. The preliminary description of the assemblage hints towards a shift within blade technology, which was described as blades becoming less common and less regular in the younger part of the sequence (Porraz et al. 2016a). Bipolar knapping becomes increasingly important in H and F, while a discoidal reduction pattern is more common in the lower part of the sequence. In the tool assemblage denticulates are dominant. In the lower part of the sequence, bifacial and unifacial points alongside Asymmetric Convergent Tools (ACTs) and splintered pieces are present. Porraz and colleagues (2016a) note, that in the upper levels only denticulates are present, thus abandoning typical MSA bifacial and unifacial points (e.g. Archer et al. 2016; Soriano et al. 2015; Will and Conard 2016). Also, splintered pieces seem to be more common in the upper part of the sequence (Porraz et al. 2016a). Overall, the ELSA assemblage from Elands Bay Cave is described as an expedient technology with microlithic components. The almost complete absence of tools makes it difficult to characterize the assemblage typologically however, scarcity in tools compared to MSA assemblages has been identified as a marker for both ELSA and Robberg assemblages (Deacon 1984; Low et al. 2017; Porraz et al. 2016a; Wadley 1993).

An interesting and fruitful approach to clarify the ELSA in the western part of South Africa was recently undertaken by Low and colleagues in their comparative study of the Putslaagte 8 rock shelter and the open-air site Uitspanskraal 7 (Low and Mackay 2016; Low et al. 2017; Mackay 2016). They are aiming for a better understanding of time periods on a landscape level as opposed to the still more common single site approach taken in southern African archaeology (Low et al. 2017). This is especially important in addressing questions surrounding the regionality of chrono-cultural units in both the MSA and LSA. The Putslaagte 8 ELSA assemblage was dated between 25 ka BP and 22 ka BP, though all occupations seem to be organized in pulses and not necessarily continuous (Low and Mackay 2016; Mackay et al. 2015). They report shifts in raw material preference, blade size and production methods from the ELSA towards the Robberg of Putslaagte 8 (Low and Mackay 2016). Bipolar reduction and standardization of blades and bladelets are less common in the ELSA as opposed to the Robberg assemblage on the site. A final MSA is not reported from the site (Mackay et al. 2015, but see Bader et al. in press).

The open-air site of Uitspanskraal contains several temporally and spatially distinct lithic scatters, some of which have been assigned to a post-Howiesons Poort context (Will et al. 2015), but one area (AoA 3) has been assigned to the ELSA based on the similarity to the assemblage from Putslaagte 8 based on lithic technology and raw material preference (Low et al. 2017). Both assemblages have hornfels as the preferred raw material and a significant blade component produced on cores with only limited amounts of preparation or maintenance, if any. (Low et al. 2017). This is in strong opposition to the Robberg from Putslaagte 8, where silcrete is the preferred raw material and bipolar flaking plays a major role within the technological system (Low and Mackay 2016; Low et al. 2017). There are also marked differences between the stratified Putslaagte 8 assemblage and the open-air context of Uitspankraal 7, which indicate differing flake and discard patterns reflected by different ratios of cortex retention, higher numbers of cores at Uitspankraal 7 as well as the abundance of flaking tools like hammerstones and one anvil in the open-air context (Low et al. 2017). Therefore, the study of the open-air locality Uitspanskraal 7 highlights, that what we perceive as a similarity on a regional or even supra-regional level actually is a research bias grounded in the site-based approach, which most often only includes rock shelter sites (see also Low et al. 2017), instead of reflecting some sort of historical pattern.

At Apollo 11 (Namibia), the term Late Pleistocene Later Stone Age (LPLSA) has been employed to describe the assemblage postdating the final MSA (Ossendorf 2017). Ossendorf describes the assemblage as “highly informal” and as “characterized by extremely expedient technological behaviours” (Ossendorf 2017, 33). The LPLSA of Apollo 11 can be subdivided into an older and a younger phase, the latter dating between 24.2 ka BP and 20.4 ka BP, thus coinciding with ELSA signals and the early appearances of the Robberg technocomplex in South Africa (Ossendorf 2013; 2017; Bousman and Brink 2018). However, a Robberg component is absent at Apollo 11. This adds some difficulties in comparing the LPLSA assemblage from Apollo 11 with ELSA assemblages from South Africa and Lesotho, because integral part of the latter is an increase in bladelet production and bipolar knapping, both key features of the Robberg. The LPLSA of Apollo 11 only exhibits an increase of bipolar knapping (Ossendorf 2017). However, while bladelet production is characteristic for Robberg assemblages, they are rarely the dominant blank type (see also Mitchell 1995; Wadley 1996; Lombard et al. 2012; Deacon 1995), thus increasing the similarity between the Robberg and the LPLSA of Apollo 11 (Ossendorf 2017). We concur with Ossendorf’s notion that the LPLSA of Apollo 11 is distinguishable from other ELSA occurrences in southern Africa. We suspect this to be a taxonomic problem as the ELSA was defined in presence of the Robberg technocomplex and so it is only logical that at least parts of such a definition will not be mirrored in regions without it. Therefore, it might be premature to conclude that the LPLSA is a regional variant of the ELSA in southern Africa as proposed by Ossendorf (2017). It might as well be that the Late Pleistocene human populations in southernmost Namibia became isolated during late MIS 3 and MIS 2 (Ossendorf 2017), which might be an explanation why the Robberg technocomplex did not reach this particular region in the subsequent period of coalescence (Mackay et al. 2014). In this sense then, it would become more likely that the southern Namibian LPLSA is not a regional variant of the southern African ELSA, but mark the emergence a different technological tradition from a common ancestral tradition. However, we deem the data currently available from this region as too scarce to reach any conclusion in this matter – be it against the regional variant proposal or for it.

Historical context of the Early Later Stone Age in South Africa

26 years after Goodwin and van Riet Lowes initial definition of the Early, Middle and Later Stone Age (Goodwin and Van Riet Lowe 1929), the Pan-African Congress in 1955 formed the necessary platform in order to further refine the stone age sequence. By then researchers had become aware of specific assemblages which seemed not to fit accurately in either of the three previously defined units but seemed to represent a mixture in between and thus a first intermediate stage between ESA and MSA and a second one between MSA and LSA where introduced (Clark 1959; Malan 1949). This scheme placed the Howiesons Poort, for example, within the latter transition called Magosian (see also Clark et al. 1966). This however was formally rejected at the 6th meeting of the Pan-African Congress in 1967. From the state of research today, the Magosian should be viewed as a failed attempt to lump together distinct cultural entities such as the Howiesons Poort, late MSA and final MSA (Bader et al. 2022b; Bader et al. 2018; Villa et al. 2005). The very first LSA chronology only involved the so-called Smithfield and Wilton as technologically distinct units (Goodwin and Van Riet Lowe 1929). This was then revised by the work of H. J. Deacon (1976), and further developed by J. Deacon (1984), who subdivided the LSA into the Robberg, Albany and Wilton technocomplexes. Subsequently, it became standard that the Robberg would succeed the final MSA (Deacon and Deacon 1999), implying a comparably sharp and rapid technological change. This was despite the term Early Later Stone Age (ELSA) had been introduced, though only weakly defined, by Beaumont and Vogel (1972), already. The continuous adding and abandoning of cultural taxonomic units within the African Stone Age succession became an obstacle in some instances, rather than a means of structuring, which is especially true at the MSA/LSA boundary.

Over the past 40 years research in southern Africa began to emphasize the MSA after the realization that modern humans had evolved much earlier than previously thought (Bräuer 1984), radiometric dating pushed back to chronology of the MSA beyond 100 ka in the late 1970s already, and even further today (Lombard et al. 2012), and behaviours described as ‘modern’ were identified all over Africa long before 40 ka (McBrearty and Brooks 2000). In the wake of this research focus on the MSA, it became clear that microlithic technologies are not unique to the LSA, but occur much earlier in the MSA (e.g. Barham 2002; Brown et al. 2012; Clarkson et al. 2018; Gibson et al. 2004; Villa et al. 2010; Wadley et al. 2009). Likewise, as technocomplexes like the Oakhurst show, the LSA is not confined to microlithic technologies (Kaplan 1989; Mitchell 2002; Wadley 1993). Hence, the MSA and LSA cannot be understood as entirely opposing lithic technological traditions (see also McCall and Thomas 2009). Even before these realizations, though for different reasons, questions were raised about whether the subdivision of the Stone Age into ESA, MSA and LSA reflects the sharp distinctions that are implied by the terms themselves or whether they might be arbitrary (Deacon 1982; Sampson 1974). By defining or adhering to successive chrono-cultural units, questions about the timing, speed and nature of the transition from one unit to another are posed inherently, regardless of scale and whether or not we actively raise these questions.

All across the southern African subcontinent, changes in the organization of lithic technology have been observed post-dating the final MSA but pre-dating the Robberg. They are not a perfect mirror image of each other, however. This is most likely attributable to differences in raw material selection and site function. Hence, we refrain from defining regional variants of the ELSA, because we deem the archaeological record from this period as too scarce at the moment. Differences in the timing of the occupations further complicate the picture. If we accept the final MIS 3 and early MIS 2 as a time of fragmentation as suggested by Mackay and colleagues (Mackay et al. 2014), these differences in the time of occupation between sites might be a good explanation for the variability at hand, as the disconnect of populations would lead to different lithic technological traits emerging from a shared technological ancestor. After the Late Glacial Maximum, during a time of reconnection for some populations, southwestern Namibia seems not to be part of a subcontinent-wide network, if there was one, and developed its own LSA technology which differs from the Robberg. Major population shifts and movements have been proposed throughout the Late Pleistocene and as more genetic evidence becomes available, these early hypotheses seem to gain new support now and offer an additional line of evidence in explaining the fragmentation of the archaeological record during MIS 3 and MIS 2 (Lipson et al. 2022).

Finally, there is a question to be raised about how much of a transition the technological shift from MSA to LSA technology actually is. Given the long coexistence of MSA and LSA lithic technology across southern Africa, a pattern that can also be observed in other regions of Africa, such as Ethiopia, the Horn of Africa or West Africa (Scerri et al. 2021; Tryon 2019), the term transition seems inappropriate. It can even be argued, that the coexistence of these technological traits not only occur on an inter-site comparative level, but that the definition of the ELSA itself is evidence for the coexistence as it simply combines characteristics of MSA and LSA lithic technologies into a new chrono-cultural unit. This is important because the MSA and LSA should not be seen as time periods or cultural entities, but rather as large overarching technological complexes (see also Tryon 2019). In this sense it is also important to state, that there might not be an ‘origin’ of the Later Stone Age technological tradition. The lithic technological changes appear so gradual that we might as well call them continuous and “[o]rigins disappear in continuity.” (Foley et al. 2016, 1). An argument has been made that aside from changes in lithic technology, the seemingly sudden introduction of worked bone tools and figurative parietal art mark the beginning of the LSA as well (Klein 1995, 2000, 2009, 2019). However, bone tools are abundant in MSA contexts also after the Howiesons Poort (Backwell et al. 2008; Becher 2016; Henshilwood et al. 2001), figurative art is known from the MSA in Apollo 11 (Rifkin et al. 2015; Rifkin et al. 2016; Wendt 1976), and both are heavily affected by preservation issues rendering them not suitable for far-reaching interpretations based on presence/absence argument. Following this question is beyond the scope of this paper, but the organic component accompanying the lithic artefacts are certainly one major research trajectory, if we want to come closer to an answer what happened in southern Africa between 30 and 20 ka BP (see also Lombard and Parsons 2011; Mitchell 2012).

Conclusion

Due to the lack of organic preservation the radiometric chronology of Umbeli Belli is not as refined as those from other sites with stratigraphies covering the period from the final MSA to the Robberg. Nonetheless, enabled by the Abtrag-based excavation technique, the techno-typological analysis of the lithic assemblages from GH 4, 5 and 6 at Umbeli Belli revealed a gradual pattern of changes consistent with that from Apollo 11, Sehonghong, Rose Cottage Cave and to a lesser extent to sites from the Southern and Western Cape.

Despite efforts and successes in evaluating the timing, speed and nature of the transition from the MSA to the LSA, the period between final MSA and Robberg remains poorly understood. This is due to a lack of sites that contain assemblages from this time periods, which is further complicated by different research approaches and a strong emphasis on rock shelter sites. However, a short transitional phase between the MSA and LSA in southern Africa as proposed by McBrearty and Brooks (2000), does appear to hold against the evidence presented here. Rather, the current evidence hints towards gradual and continuous changes throughout southern Africa during this time period. This takes us back to the question asked at the beginning of this paper. Is there a ‘beginning’ of the LSA or is this question simply imposed on us because of the terminology developed almost a century ago? In the same way that the ELSA can be attributed to the LSA by acknowledging that it shows elements of it, but is not yet ‘fully developed’, an argument could be made to say it that it belongs to the MSA as it exhibits ‘classic’ final MSA technological traits and adds something that we call LSA from today’s perspective. Therefore, we find the term ELSA actually misleading because this distinct chrono-cultural unit could also be seen as a continuation of the MSA and not mark the beginning of the LSA at all. It almost appears that we use the term ELSA only because final MSA is already taken. Even though the continued use of the terms MSA and LSA might be beneficial, in order to maintain a certain kind of order in an archaeological record that spans well over 300 000 years, and an argument is to be made that the two cannot be understood as time periods in the southern African archaeological record, similarly to what recently has been proposed for East Africa as well (Tryon 2019).

They must be seen as purely organizational means for researchers who study the archaeological record, rather than culturally distinct periods that bore any meaning to the populations, who produced the artefacts. Ultimately, we have to ask the question whether the differences between MSA and LSA are substantially bigger than between individual technocomplexes, e.g. between Still Bay and Howiesons poort, between Sibudan and final MSA or between Oakhurst and Wilton? From our perspective, they are not and in consequence we have to ask if it is still appropriate to generically separate one from the other?

Based on the current evidence reviewed here, we argue that our perception of the ELSA as being transitional between the MSA and LSA is ultimately an artefact of our terminology rather than a reflection of (pre-)historical processes. The changes observed across the southern African subcontinent are spanning several thousand years and seem to be continuous and of regional indigeneity (see also McCall and Thomas 2009). Furthermore, *H. sapiens* authors both the MSA and the LSA. To us, these are all reasons that the distinction between the MSA and LSA is highly artificial. For those reasons we would like to see this contribution and other recent and related publications (Bader et al. 2022a; Scerri et al. 2021; Tryon 2019) as the starting point of an open discussion about reforming the cultural taxonomy of southern Africa in particular, but perhaps Africa as a whole. Rather than trying to fit new discoveries into a century-old concept that pays little to no tribute to the vastness and diversity of the African continent and the variability of the archaeological record, we suggest to adopt a more regionally focussed approach and abandon the terms Middle and Later Stone Age.

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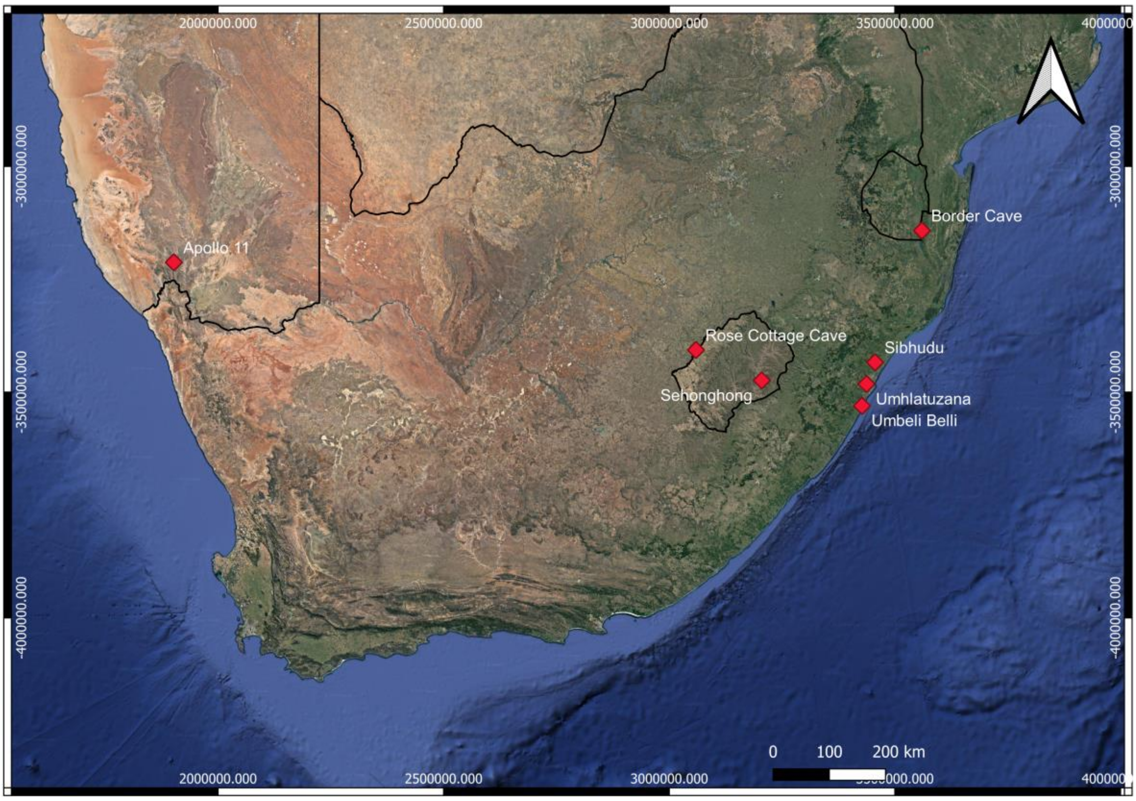


Figure 1

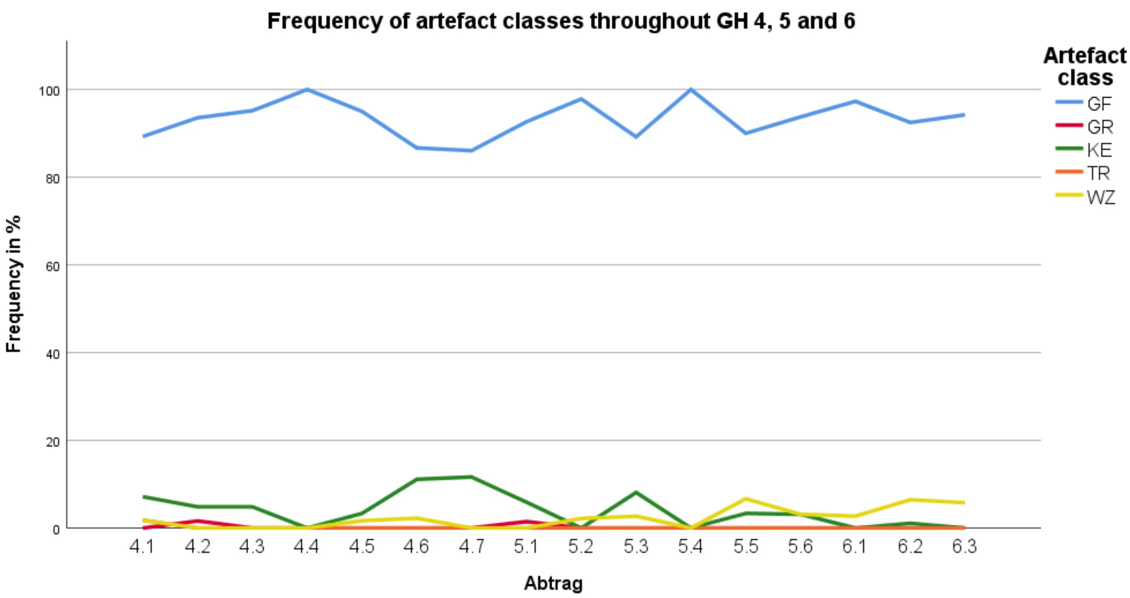


Figure 2

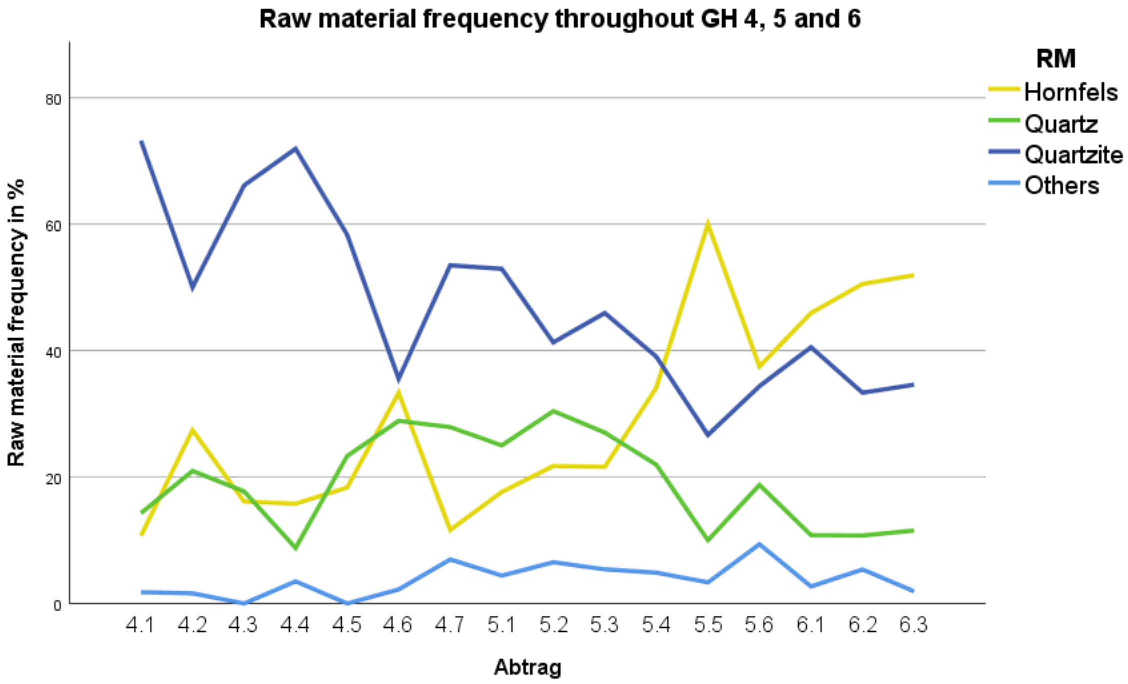


Figure 3

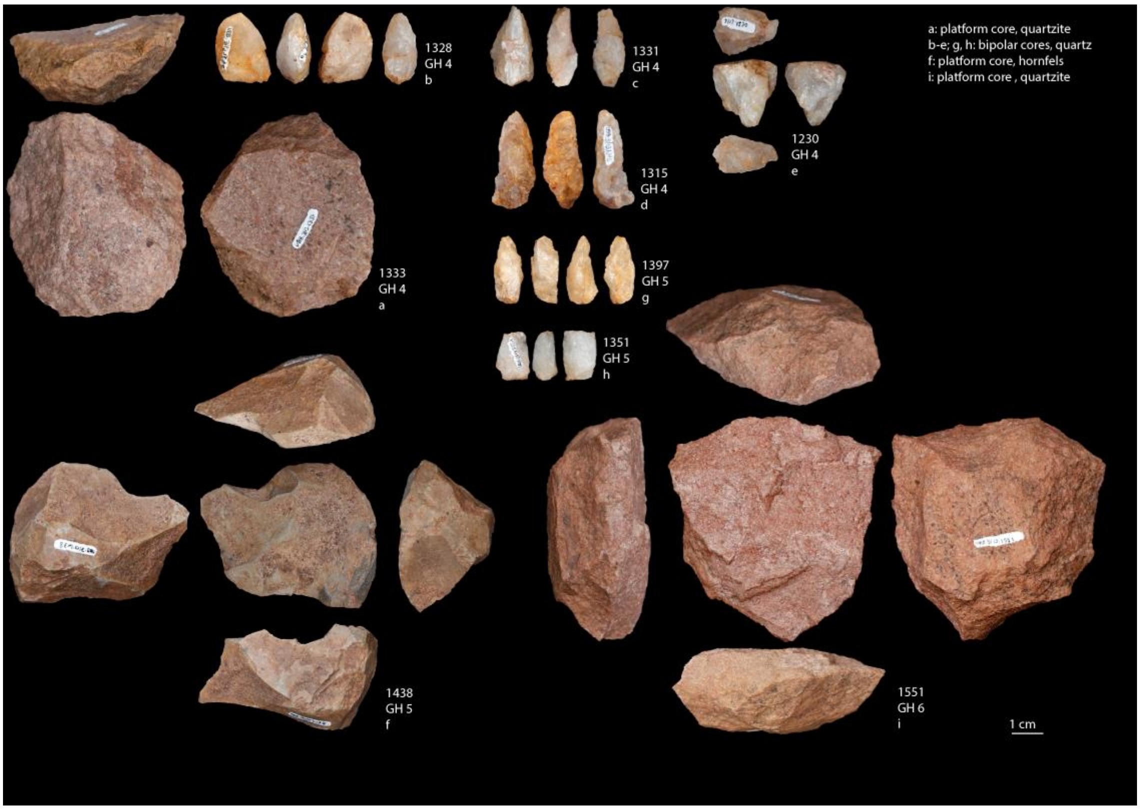
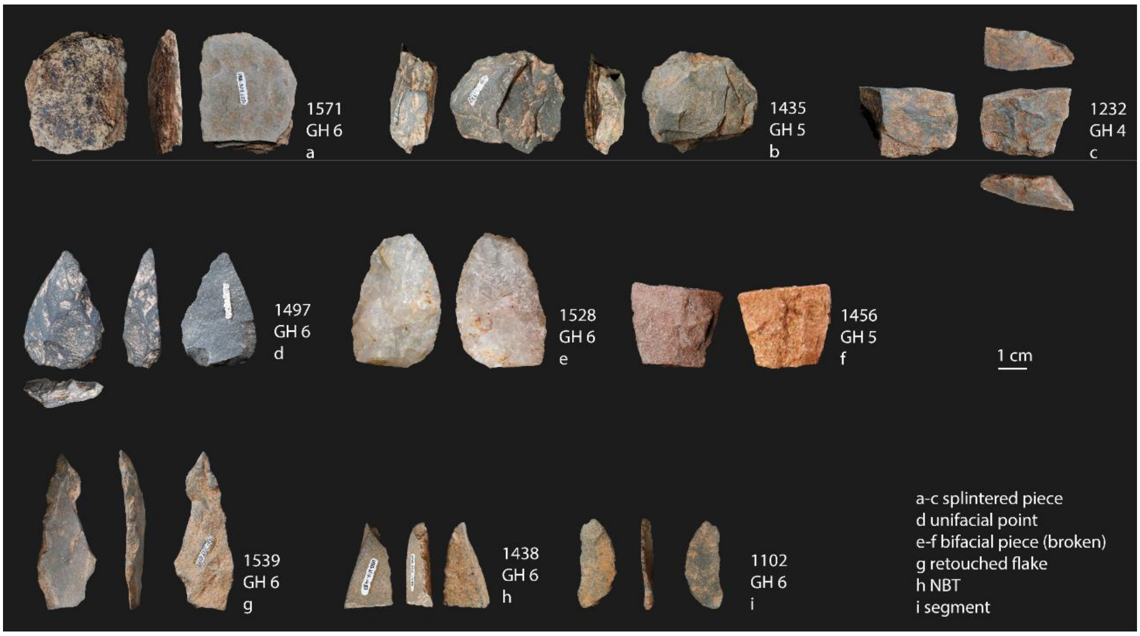


Figure 4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f
1 cm
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g
1438
GH 6
h
1102
GH 6
i
a-c splintered piece
d unifacial point
e-f bifacial piece (broken)
g retouched flake
h NBT
i segment

Figure 5