

**Lithic technology and behavioral variability during the
Middle Stone Age of southern Africa: Implications for the
evolution and dispersal of early modern humans**

Dissertation

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I DEDICATE THIS DISSERTATION TO MY PARENTS **MONIKA** AND **OTTO WILL**,

WHO NOT ONLY ACCEPTED MY DECISION TO STUDY ARCHAEOLOGY WITHOUT

A MURMUR, BUT WERE ALWAYS THERE FOR ME WITH ALL THEIR LOVE.

THIS DISSERTATION IS TO A LARGE EXTENT THE OUTCOME OF YOUR CARE AND UPBRINGING.

II. SUMMARY

The Middle Stone Age (MSA) of Africa, dating to roughly 300,000–30,000 years before present (300–30 ka), encompasses the archaeological background for the origin, early evolution and global dispersal of *Homo sapiens*. Research into the MSA is thus crucial for assessing fundamental questions of human evolution, such as the early cultural evolution of our species, the nature and causes of behavioral changes, as well as migrations out of Africa. Stone artifacts constitute the principle archaeological remains to address these subjects due to their unique durability, high information content and frequent spatiotemporal patterning. Owing to its long research history and the concomitant wealth of excavated archaeological sites, the MSA of southern Africa in particular plays a central role in current studies on early modern humans.

This dissertation uses behavioral information attained from the analysis of MSA stone artifacts, in concert with additional archaeological data and new theoretical concepts, to assess current questions regarding the cultural evolution of modern humans and their early dispersals within and out of Africa. The main research questions of this thesis can be divided into three topics, according to current debates in human evolution: What is the nature of coastal adaptations during the MSA and how did they affect the evolution and dispersal of *Homo sapiens*? Did modern humans in southern Africa possess a less complex behavioral repertoire and inferior cultural abilities before and after the Still Bay (SB) and Howiesons Poort (HP) as suggested by the influential “Synthetic Model”? To what extent can analyses of stone tools from the late MSA inform early migrations of *Homo sapiens* out of Africa? Stone artifact assemblages from six southern African MSA sites, dating to MIS 5 and MIS 3, provide the principle empirical basis to answer these questions. The study of the lithic assemblages follows a holistic approach in which multiple independent sources of evidence derived from discrete analytical methods converge to produce more inter-subjective, reliable and comparable results.

Regarding the first research question, based on analyses on the site (Hoedjiespunt 1), regional (sub-Saharan Africa) and continental levels (Africa), the findings of this dissertation demonstrate the systematic, stable and long-term character of MSA coastal adaptations by modern humans. The earliest evidence for the methodical exploitation of marine food resources and planned settlements of coastal ecosystems dates to at least MIS 5e (~130–119 ka). Modern humans adapted in a consistent and long-term manner to different coastal and marine ecosystems in northern, southern and potentially eastern Africa. This thesis develops scenarios on how these behaviors influenced reproductive success, cognitive capacities and cultural complexity, showing that coastal adaptations had ample potential to affect both the biological and cultural evolution of *Homo sapiens*. The ability to thrive in variable coastal ecosystems,

and a general increase in behavior flexibility, constituted a necessary prerequisite to disperse out of Africa along a mainly coastal route in a rapid and successful manner after ~130 ka.

This thesis fills an important research gap by providing new techno-typological data on lithic assemblages after the HP in southern Africa. At the main study site of Sibudu, the thick and high-resolution sequence dating to ~58 ka yields distinctive, sophisticated and structured lithic assemblages. These characteristics are used to refine the concept of the “Sibudan” as a new MSA cultural-taxonomic unit to structure MIS 3 archaeology. The sequence also yields evidence for abundant short-term behavioral variability, caused by differential organization of technology and cultural information transmission, instead of environmental forcing. On a larger spatial scale, this dissertation found increased regionalization of lithic technology in southern Africa during MIS 3, resulting from a complex combination of ecological, demographic and socio-cultural factors. The results also demonstrate that modern humans maintained complex cultural repertoires and, in some areas, dense populations, falsifying ideas of cultural regression and demographic collapses after the HP as posited by the Synthetic Model.

The third major topic evaluates the common approach by Paleolithic archaeologists to track large-scale dispersals of modern humans out of Africa by means of stone artifacts. This thesis, however, shows how the phenomenon of convergence, which is particularly frequent in reductive lithic systems, can confound such interpretations. The demonstration of an independent innovation of “Nubian” core technology during MIS 3 in southern Africa, with these artifact types having recently been used to monitor the earliest migrations of modern humans from north-eastern Africa to Arabia, provides a cautionary example that single core or tool types cannot adequately trace such dispersals on large temporal and spatial scales.

In conclusion, this thesis yields new insights into the bio-cultural evolution and dispersal of modern humans. The findings reject the dominant Synthetic Model by showing that complex behaviors were well-established in human populations before and after the HP and SB, but also challenge scenarios of a gradual accretion of cultural complexity during the MSA. Instead, this dissertation views cultural evolution from the perspective of complex fitness landscapes, emphasizing non-linear and asynchronous spatiotemporal trajectories, multiple causal mechanisms on various scales, and historical contingency. In addition to increased behavioral flexibility and favorable environmental conditions, coastal adaptations likely facilitated early dispersals of *Homo sapiens* to Eurasia. Tracing such migrations should proceed by technological and quantitative lithic analyses within a cross-disciplinary framework that also uses human fossil and genetic data. The application of new theoretical concepts to the results of this thesis highlights the need for a holistic and bio-cultural perspective on human evolution.

II. ZUSAMMENFASSUNG

Das Middle Stone Age (MSA) Afrikas datiert auf ca. 300.000–30.000 Jahre vor heute (300–30 ka) und umfasst damit die archäologische Zeitspanne des Ursprungs, der frühen Evolution und der ersten geographischen Ausbreitungen von *Homo sapiens*. Die Erforschung des MSA ist daher entscheidend, um grundsätzliche Fragen nach der frühen kulturellen Evolution unserer Art, dem Ausmaß und den Gründen von Änderungen im Verhalten früher Menschen sowie deren ersten Migrationen aus Afrika zu beantworten. Steinartefakte stellen aufgrund ihrer einzigartigen Haltbarkeit und Häufigkeit, ihrem hohem Informationsgehalt und der vielfach auftretenden raumzeitlichen Musterbildung die wichtigste archäologische Fundkategorie dar, um diese Themen zu erschließen. Das MSA des südlichen Afrikas spielt hierbei eine zentrale Rolle, da es aufgrund seiner langen Forschungsgeschichte eine Vielzahl an ausgegrabenen archäologischen Fundstellen aufweist.

Die hier vorliegende Dissertation verwendet aus der Analyse von MSA Steinartefakten gewonnene Verhaltensinformationen in Verbindung mit zusätzlichen archäologischen Daten und neuen theoretischen Konzepten, um aktuelle Fragen hinsichtlich der kulturellen Evolution und frühen Ausbreitungen des modernen Menschen innerhalb Afrikas und darüber hinaus zu beantworten. Die hauptsächlichen Forschungsfragen dieser Doktorarbeit beziehen sich auf gegenwärtige Debatten innerhalb der Erforschung der menschlichen Evolution und können in drei Themengebiete gegliedert werden: Was charakterisiert die ältesten Anpassungen an Küstengebiete und marine Nahrungsressourcen durch *Homo sapiens* und welchen Einfluss hatten diese Adaptationen auf dessen Evolution und räumliche Ausbreitungen? Besaßen moderne Menschen des MSA in Südafrika vor und nach dem Still Bay (SB) und Howiesons Poort (HP) weniger komplexe Verhaltensrepertoires und geringere kulturelle Fähigkeiten wie es das vorherrschende „Synthetic Model“ postuliert? Inwiefern kann die Analyse von Steinartefakten aus dem späten MSA Aufschlüsse über frühe Migrationsbewegungen von *Homo sapiens* aus Afrika geben? Steinartefaktinventare von sechs südafrikanischen Fundstellen des MSA, datierend in MIS 5 und MIS 3, bilden die empirische Grundlage zur Beantwortung dieser Fragen. Die Steinartefakte werden nach einem holistischen Ansatz ausgewertet, welcher mehrere unabhängige Informationsquellen aus unterschiedlichen analytischen Methoden kombiniert, um inter-subjektive, zuverlässige und vergleichbare Ergebnisse zu erhalten.

In Bezug auf die erste Forschungsfrage belegen die Befunde der vorliegenden Dissertation, ausgehend von Analysen auf Ebene der Fundstelle (Hoedjiespunt 1), der Region (subsaharisches Afrika) und des Kontinentes (Afrika), dass die Anpassung moderner Menschen

an Küstengebiete während des MSA einen planmäßigen, stabilen und langfristigen Charakter hatte. Die ältesten Belege für eine methodische Nutzung von marinen Nahrungsmitteln und die planmäßige Besiedlung von Küstenökosystemen datieren mindestens in MIS 5e (~130–119 ka). Im Folgenden passten sich moderne Menschen über mehrere zehntausende Jahre in beständiger und langfristiger Weise an die unterschiedlichen marinen und küstennahen Ökosysteme im Norden, Süden und möglicherweise Osten des afrikanischen Kontinentes an. Die Doktorarbeit entwickelt mehrere Szenarien, die ausführen, wie diese verhaltensmäßigen Anpassungen den Reproduktionserfolg, die kognitiven Fähigkeiten und die kulturelle Komplexität ihrer Träger beeinflussen konnten. Hierbei zeigt sich, dass evolutionäre Adaptationen an Küstengebiete ein umfangreiches Potential hatten, sowohl die biologische als auch die kulturelle Evolution von *Homo sapiens* mitzuprägen. Die Fähigkeit, sich unterschiedlichen Küstenökosystemen vorteilhaft anzupassen, zusammen mit einem allgemein flexibleren Verhaltensrepertoire, stellte eine notwendige Vorbedingung für eine schnelle und erfolgreiche Ausbreitung nach Eurasien entlang einer im Wesentlichen küstennahen Route ab ca. 130 ka dar.

Hinsichtlich des zweiten Themenkomplexes füllt die vorliegende Arbeit eine wichtige Forschungslücke des MSA, indem sie neue techno-typologische Informationen von Steinartefaktinventaren aus Südafrika vorstellt, die zeitlich auf das HP folgen. Die hier untersuchte lange und hochauflösende archäologische Sequenz der hauptsächlichen Forschungsfundstelle Sibudu, datierend auf ca. 58 ka, weist charakteristische, hochentwickelte und strukturierte lithische Inventare auf. Die typischen Eigenschaften dieser Inventare werden dazu genutzt, das Konzept des „Sibudan“ als neue kulturtaxonomische Einheit des MSA zu verfeinern, was hilft, eine bisher fehlende Struktur in die Gliederung der Archäologie von MIS 3 zu bringen. Die archäologischen Schichten von Sibudu bezeugen außerdem eine hohe Variabilität über kurze Zeiteinheiten, resultierend aus Veränderungen in der technologischen Organisation und Tradierung von kultureller Information, anstelle kausaler Einflüsse der äußeren Umweltbedingungen. Auf einen größeren geographischen Maßstab bezogen, zeigt die Dissertation eine wachsende Regionalisierung in der Steinartefakt-Technologie des MIS 3 in Südafrika an, die durch eine komplexe Interaktion aus sich verändernden ökologischen, demographischen und soziokulturellen Faktoren entstand. Die Erkenntnisse dieser Doktorarbeit belegen außerdem, dass moderne Menschen nach dem HP weiterhin hohe kulturelle Komplexität besaßen und in einigen Gebieten eine große Bevölkerungsdichte beibehielten. Diese Befunde widersprechen dem vorherrschenden Synthetic Model, welches für diese Zeit einen kulturellen Rückschritt und demographischen Zusammenbruch postuliert.

Die Beantwortung der dritten Forschungsfrage ergibt sich aus der kritischen Bewertung des oft gewählten Ansatzes paläolithischer Archäologen, die großflächigen Ausbreitungen von modernen Menschen aus Afrika durch die Analyse von Steinartefakten nachvollziehen zu wollen. Die hier vorgestellten Befunde zeigen jedoch, wie das Phänomen der Konvergenz, welches besonders häufig in reduktiven Systemen wie dem Steinschlagen vorkommt, solche Interpretationen erschweren kann. Der in dieser Arbeit erbrachte Nachweis einer unabhängigen Innovation „Nubischer“ Kerntechnologie innerhalb des MIS 3 von Südafrika an den Fundstellen Uitspankraal 7 und Mertenhof – besondere Artefakt-Typen, die in den letzten Jahren maßgeblich dazu benutzt wurden, die frühesten Migrationen von *Homo sapiens* von Nordost-Afrika auf die Arabische Halbinsel nachzuweisen – dient als ein warnendes Beispiel, dass einzelne Kern- oder Werkzeug-Typen frühe menschliche Ausbreitungen auf großen geographischen und zeitlichen Skalen nicht angemessen nachzeichnen können.

Abschließend lässt sich feststellen, dass die vorliegende Doktorarbeit neue Einsichten in die bio-kulturelle Evolution und räumlichen Expansionen früher moderner Menschen gibt. Die gewonnenen Erkenntnisse widerlegen das derzeit vorherrschende Synthetic Model anhand des Nachweises, dass menschliche Gruppen auch vor und nach dem HP und SB komplexe Verhaltensweisen aufwiesen. Zusätzlich stellen diese Ergebnisse auch Szenarien in Frage, die von einer graduellen, durch die Zeit stetig und kumulativ anwachsenden kulturellen Komplexität während des MSA ausgehen. Anstelle dieser Modelle betrachtet die Doktorarbeit die kulturelle Evolution des modernen Menschen aus der theoretischen Perspektive vielschichtiger „fitness landscapes“, welche mehrere nicht-lineare und asynchrone raumzeitliche Verlaufsbahnen, multiple kausale Mechanismen auf unterschiedlichen Skalenniveaus und historische Kontingenz betont. Zusätzlich zu einem allgemein flexibleren Verhaltensrepertoire und vorteilhaften Umweltbedingungen begünstigten die systematischen und langfristigen Anpassungen an Küstengebiete die frühen Auswanderungen moderner Menschen nach Eurasien. Die Rückverfolgung dieser Migrationsbewegungen mittels der Analyse von Steinartefakten sollte allerdings durch stärker technologisch und quantitativ geprägte Ansätze und innerhalb eines interdisziplinären Rahmens durchgeführt werden, welcher zusätzlich Informationen menschlicher Fossilien und genetischer Untersuchungen heranzieht. Die Anwendung neuer theoretischer Konzepte auf die empirischen Ergebnisse dieser Dissertation unterstreicht die Notwendigkeit einer holistischen und bio-kulturellen Perspektive auf die menschliche Evolution.

III. LIST OF PUBLICATIONS

i.) Accepted publications

- (1) **Will, M.**, Parkington, J.E., Kandel, A.W., Conard, N.J., 2013. Coastal adaptations and the Middle Stone Age lithic assemblages from Hoedjiespunt 1 in the Western Cape, South Africa. *Journal of Human Evolution* 64, 518–537 (*APPENDIX i.a*).
- (2) Kyriacou, K., Parkington, J.E., **Will, M.**, Kandel, A.W., Conard, N.J., 2015. Middle and Later Stone Age shellfish exploitation strategies and coastal foraging at Hoedjiespunt, Saldanha Bay, South Africa. *Journal of Archaeological Science* 57, 197–206 (*APPENDIX i.b*).
- (3) **Will, M.**, Kandel, A.W., Conard, N.J., 2015a. Coastal adaptations and settlement systems on the Cape and Horn of Africa during the Middle Stone Age. In: Conard, N.J., Delagnes, A. (Eds.), *Settlement dynamics of the Middle Paleolithic and Middle Stone Age, Vol. IV*. Kerns Verlag, Tübingen, pp. 61–89 (*APPENDIX i.c*).
- (4) **Will, M.**, Kandel, A.W., Kyriacou, K., Conard, N.J., 2016. An evolutionary perspective on coastal adaptations by modern humans during the Middle Stone Age of Africa. *Quaternary International* 404, 68–86 (*APPENDIX i.d*).
- (5) **Will, M.**, Bader, G.D., Conard, N.J., 2014. Characterizing the Late Pleistocene MSA lithic technology of Sibudu, KwaZulu-Natal, South Africa. *PLoS ONE* 9(5), e98359 (*APPENDIX i.e*).
- (6) Conard, N.J., **Will, M.**, 2015. Examining the causes and consequences of short-term behavioral change during the Middle Stone Age at Sibudu, South Africa. *PLoS ONE* 10(6), e013000 (*APPENDIX i.f*).
- (7) Bader, G.D., **Will, M.**, Conard, N.J., 2015. The lithic technology of Holley Shelter, KwaZulu-Natal, and its place within the MSA of southern Africa. *South African Archaeological Bulletin* 70, 149–165 (*APPENDIX i.g*).
- (8) **Will, M.**, Mackay, A., Phillips, N., 2015b. Implications of Nubian-like core reduction systems in southern Africa for the identification of early modern human dispersals. *PLoS ONE* 10(6), e0131824 (*APPENDIX i.h*).
- (9) Conard, N.J., Bader, G.D., Schmid, V., **Will, M.**, 2014. Bringing the Middle Stone Age into clearer focus. *Mitteilungen der Gesellschaft für Urgeschichte* 23, 121–128 (*APPENDIX i.i*).

ii.) Submitted manuscripts

- (10) **Will, M.**, Conard, N.J., submitted (revised). Assemblage variability and bifacial points in the lowermost Sibudan layers at Sibudu, South Africa. *Archaeological and Anthropological Sciences* (*APPENDIX ii.a*).

IV. PERSONAL CONTRIBUTION

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

- (1) I was first and corresponding author, as well as the main person responsible for conceiving the study design, conducting the reported research and lead author of writing the manuscript. The co-authors helped in the collection of data (Andrew Kandel), writing of the manuscript (Andrew Kandel, Nicholas Conard, John Parkington), were the principal excavators of the archaeological site (Nicholas Conard, John Parkington) and oversaw the study as supervisor (Nicholas Conard).
- (2) I was supporting co-author responsible for part of the data collection and analyses and wrote the manuscript together with the other authors.
- (3) I was first and corresponding author, as well as the main person responsible for conceiving the study design, conducting the reported research, interpretation of data and writing the manuscript. The co-authors helped in the writing of the article and gave editorial input.
- (4) I was first and corresponding author, as well as the main person responsible for conceiving the study design and theoretical models, executing the reported literature review, and writing the manuscript. The co-authors helped in writing the manuscript and provided editorial input.
- (5) I was first and corresponding author, as well as the main person responsible for conceiving the study design, conducting the reported research, interpretation of data and writing the manuscript. The co-authors helped in the collection of data (Gregor Bader), writing of the manuscript, and oversaw the study as supervisor (Nicholas Conard).
- (6) I was the main person responsible for conducting the reported research, interpretation of data and writing the manuscript. The study design was conceived together with the first author of the paper (Nicholas Conard) who was also the principle investigator and director of excavations at Sibudu and oversaw the study as supervisor.
- (7) I was supporting co-author responsible for part of the data collection and interpretation, and wrote the manuscript together with the other authors.

- (8) I was first and corresponding author, as well as the main person responsible for executing the reported research. The study design, interpretation of data and writing of the manuscript was conducted together with Alex Mackay, who was the director of surveys and excavations and principle investigator.
- (9) I was supporting co-author, provided editorial input and, together with the other authors, conceived the study design and wrote the manuscript.
- (10) I was the main person responsible for conducting the reported research, interpretation of data and writing the manuscript. The study design was conceived together with the second author of the paper (Nicholas Conard) who was also the principle investigator and director of excavations at Sibudu and oversaw the study as supervisor.

CHAPTER 1. INTRODUCTION

1.1. The Middle Stone Age of Africa and its role for human evolution

The field of human evolution covers the entire period of hominin existence. Starting in the late Miocene with the earliest putative members of our lineage such as *Sahelanthropus tchadensis* and *Orrorin tugenensis*, research extends all the way up to present-day humans, the last surviving hominin species on the planet after millions of years of biological and cultural evolution (Ambrose, 2001; Foley & Lahr, 2003; Wood & Lonergan, 2008; Klein, 2009; Wood, 2010). Within this vast time depth, the origin of our lineage (*Hominini*), genus (*Homo*), and species (*sapiens*) are important landmarks in the grander narrative of “becoming human”. Moreover, the nature, origin, and evolution of our own species are fundamental themes of human existence. Thinking about these issues on different levels and scales of inquiry has long since occupied diverse fields such as religion (e.g., Book of Genesis), philosophy (Aristotle, *Metaphysics I*; Kant, 1798; Scheler, 1928; Gehlen, 1940), biology (Darwin, 1859; Huxley, 1863; Haeckel, 1868; Darwin, 1871), and archaeology (Boucher de Perthes, 1847; Lartet, 1861; Lubbock, 1865; de Mortillet, 1883; Burkitt, 1921).

Current archaeological, paleoanthropological, and genetic data demonstrate that modern humans evolved in Africa. Both human fossils and genetic information pinpoint the biological origin of *Homo sapiens* to south of the Sahara around 200,000–150,000 years before present (=200–150 ka; Cann et al., 1987; Stringer & Andrews, 1988; Bräuer, 1992; Lahr & Foley, 1998; McBrearty & Brooks, 2000; Clark et al., 2003; White et al., 2003; McDougall et al., 2005; Conard, 2007; Relethford, 2008; Weaver & Roseman, 2008; Rightmire, 2009; Tattersall, 2009; The 1000 Genomes Project Consortium, 2015). From eastern Africa, modern humans dispersed to Eurasia and Australia sometime between 130–50 ka (Lahr & Foley, 1994; Forster, 2004; Liu et al., 2006; Mellars, 2006; Klein, 2008; Petraglia et al., 2010; Armitage et al., 2011; Boivin et al., 2013; Reyes-Centeno et al., 2014; Bolus, 2015; Groucutt et al., 2015a; Liu et al., 2015) and had colonized all continents except Antarctica by around 15 ka (Goebel et al., 2008; Davidson, 2013; Marangoni et al., 2014).

The Middle Stone Age (MSA) is an archaeological period confined to the African continent that was first defined by Goodwin and van Riet Lowe (1929) based on its characteristic stone artifacts (see *CHAPTER 1.4*). Today, the term denotes assemblages of the African Stone Age dating between ca. 300–30 ka which lie between the preceding Early Stone Age (ESA) and the following Later Stone Age (LSA; Sampson, 1974; Clark, 1988; Robertshaw, 1995; Deacon & Deacon, 1999; McBrearty & Brooks, 2000; Barham &

Mitchell, 2008; Lombard et al., 2012; Wurz, 2014; Wadley, 2015). The MSA shows many technological and cultural similarities to the broadly contemporary Middle Paleolithic of Europe (Volman, 1981; Clark, 1988; Klein, 2000; 2001; Wurz, 2002; d’Errico, 2003; Conard, 2005; Soressi, 2005; Villa et al., 2005; Straus, 2012; Rodríguez-Vidal et al., 2014; Villa & Roebroeks, 2014; but see: Foley & Lahr, 1997; McBrearty & Brooks, 2000; Marean, 2005; Dibble et al., 2013). In contrast to the Middle Paleolithic of Europe, however, the MSA is not associated with Neanderthals but with fossils of early modern humans and their direct ancestors (see Clark, 1988; Foley & Lahr, 1997; McBrearty & Brooks, 2000; Rightmire, 2009; Straus, 2012; Tryon & Faith, 2013; Wurz, 2014).

Due to its geographical extension and temporal duration, the MSA encompasses the archaeological background for the origin and early evolution of *Homo sapiens*. The MSA record thus represents the longest and oldest cultural archive of our species, and is crucial for characterizing the nature and variability of human behavior. Consequently, recent research in the MSA has focused on two overarching topics: first, the evolutionary origin of our species, including its early behavioral and cultural evolution (Clark, 1988; Willoughby, 1993; Robertshaw, 1995; Foley & Lahr, 1997; McBrearty & Brooks, 2000; Henshilwood & Marean, 2003; Conard, 2007; Basell, 2008; Conard, 2008; Klein, 2008; Powell et al., 2009; Ziegler et al., 2013; Wurz, 2014; Wadley, 2015). And second, the first dispersals of modern humans from the African continent to Eurasia (“Out of Africa 2”) and the ensuing global expansion (Lahr & Foley, 1994; Foley & Lahr, 1997; Mellars, 2006; Klein, 2008; Armitage et al., 2011; Rose et al., 2011; Boivin et al., 2013; Bolus, 2015; Groucutt et al., 2015b).

In hindsight, it is clear that the MSA acquired its prominent place within the field of human evolution only with the realization during the late 1980s and early 1990s that the early biological and cultural evolution of our species took place in Africa. Before, there had been little intrinsic interest in this period, with the scarcity of faunal remains and the lack of reliable dating methods further impeding research (Clark, 1988; Robertshaw, 1995; Willoughby, 2007; Lombard, 2008; Conard et al., 2014; Wadley, 2015). The changing role of the MSA for the study of human evolution – from the “muddle in the middle” to the forefront of archaeological research into the origins of humanity – explains the focus of international research in this period during the past 25 years that continues up to this day.

1.2. Models for the behavioral and cultural evolution of modern humans

One of the main interests of archaeologists studying the MSA of Africa is the nature, mode and tempo of cultural and behavioral evolution in early modern humans. Or, rephrased into

prevalent research questions: When and where did humans become like us in their behavior and cognition? How did these capacities evolve? While these issues are paramount for archaeology, anthropology and beyond, they are still highly debated with no consensus in sight (Klein, 1995; McBrearty & Brooks, 2000, Wadley, 2001; Bar-Yosef, 2002; d’Errico, 2003; Henshilwood & Marean, 2003; Parkington, 2003; Conard, 2005, Mellars, 2005; 2006; Zilhão, 2007; Conard 2008; Klein 2008; Conard, 2010; Nowell, 2010; d’Errico & Stringer, 2011; Henshilwood & Dubreuil 2011; Wurz, 2014; Kandel et al., 2015; Garofoli, 2016).

Regarding the empirical evidence, archaeological finds with unexpectedly early dates in the African MSA have led to a rethinking of the evolution of modern behavior in the past two decades. As a result, the African continent, and particularly southern Africa, replaced Europe – and the associated “Human Revolution”-paradigm (e.g., Mellars & Stringer, 1989; Bar-Yosef, 2002) – as the center of attention for studying the early cultural development of modern humans (Foley & Lahr, 1997; McBrearty & Brooks, 2000; Klein, 2001; Henshilwood & Marean, 2003; Mellars, 2006; Lombard, 2008; Henshilwood, 2012; but see Conard, 2005; 2008; 2010). Important archaeological finds include, among other things, abstract depictions (Henshilwood et al., 2002; Texier et al., 2010), personal ornaments (Henshilwood et al., 2004; d’Errico et al., 2005), bone artifacts (Henshilwood et al., 2001b; d’Errico et al., 2012), heat treatment of lithic materials (Mourre et al., 2010), multi-component tools such as bow and arrow technology (Lombard & Phillipson, 2010), compound adhesives (Wadley et al., 2009), plant beddings (Wadley et al., 2011) and microlithic technology (Brown et al., 2012). The MSA record also shows increased spatial and temporal structure and a higher tempo of technological change compared to the more static and homogeneous ESA (Clark, 1988; Robertshaw, 1995; McBrearty & Brooks, 2000; Van Peer & Vermeersch, 2007; Wurz, 2014).

Researchers relate these cultural novelties to changes in social structure and cognition (e.g., planning depth, abstract thought, creativity), including the emergence of symbolic communication and a fully developed syntactic language. The novel elements and higher variability in material cultural are further interpreted as showing the ability of people to adapt successfully to challenging and diverse environments by means of increased behavioral flexibility and technological innovations (e.g., Clark, 1988; McBrearty & Brooks, 2000; Wadley, 2001; Henshilwood & Marean, 2003; Conard, 2005; Villa et al. 2005; Wadley et al., 2009; Henshilwood & Dubreuil, 2011; Lombard, 2012; Wurz, 2014; Kandel et al., 2015).

On a theoretical level, most recent discussion on the early cultural evolution of *Homo sapiens* during the MSA have centered around the controversial concepts of cultural or behavioral modernity (McBrearty & Brooks, 2000; Wadley, 2001; Henshilwood & Marean,

2003; Conard, 2005; 2008; 2010; d’Errico & Stringer, 2011). In simple words, this term is used to describe the “*point in human evolution when people became like us*” (Conard, 2010: p. 7621), or alternatively the time when behavioral and cognitive patterns fell into the range of variability documented ethnographically for hunter-gatherer societies (Klein, 2000; Conard, 2005). Cultural modernity can be contrasted with the term anatomical modernity which denotes the morphology of fossil bones that fall within the variability of living and recent *Homo sapiens* (see Bräuer, 2008; Schwartz & Tattersall, 2010; Ackermann et al., 2015 for a critical review). While some researchers have devised widely used lists of traits or categories to assess the absence, presence or degree of cultural modernity (e.g., Mellars, 1989; Klein, 1995; McBrearty & Brooks, 2000; Bar-Yosef, 2002; d’Errico, 2003), these have been criticized as inadequate lately, as has the concept itself (Wadley, 2001; Henshilwood & Marean, 2003; Soffer, 2009; Nowell, 2010; Shea, 2011; Garofoli, 2016; see Wynn et al. (2016) for a detailed discussion of the major shortcomings of using trait lists). Instead, new and more complex theoretical concepts, such as phenotypic plasticity and flexibility, multi-dimensional fitness landscapes, non-directional and non-linear patterns of cultural change with a focus on historical contingency, environmental context and path-dependency, models of hybridization, and others have been proposed (Conard, 2008; Langbroek, 2012; Lombard, 2012; Straus, 2012; Malafouris, 2013; Wadley, 2013; Ackermann et al., 2015; Haidle et al., 2015; Kandel et al., 2015; Iliopoulos, 2016; Roberts, 2016; Wynn et al., 2016).

Apart from the notion of what “cultural modernity” precisely means – or whether it remains a valuable concept – researchers in the MSA and beyond have proposed different models for the cultural and behavioral evolution of modern humans during the last 20 years. They primarily differ with regards to the trajectory and timing of behavioral change, its causes, and whether other hominin species reached comparative levels of cultural complexity:

- 1) McBrearty and Brooks (2000) suggest a long, gradual and cumulative cultural evolution of modern humans within Africa, following a stepwise process that started around their biological origin at 200–150 ka. Modern culture is restricted to *Homo sapiens*.
- 2) Klein (1994; 2000; 2008; 2009; Klein & Edgar, 2002) favors a sudden origin of behavioral modernity within Africa at a late point around ~50–40 ka, exclusive to modern humans. It is initiated by a genetic mutation that caused neurological changes in the brain (e.g., linguistic capacities) which prompted a flourishing of behavioral innovations.
- 3) The “Synthetic Model” by Jacobs, Henshilwood and colleagues (Jacobs et al., 2008; Jacobs & Roberts, 2008; 2009; Henshilwood, 2012) maintains that the early behavioral evolution of *Homo sapiens* within Africa is characterized by abrupt and discontinuous

- cultural change. Archaeologically, this is materialized by two short and disconnected periods of exceptional cultural innovation and complexity – the Still Bay (=SB; 75–71 ka) and Howiesons Poort (=HP; 65–59 ka) – followed and preceded by less sophisticated phases, which might be due to differences in demography (see also *CHAPTER 1.4*).
- 4) Parkington (2001; 2003; 2010; Parkington et al., 2004) argues that the evolution of modern behaviors and complex culture is based on an increasing use of marine food resources within the coastal zone of Africa, which led to larger brains and increased cognitive functions beginning around MIS 5 (~130–74 ka) in a gradual fashion (see also the discussion below of models based on coastal adaptations).
 - 5) According to Zilhão and d’Errico, elements of “modern” behavior actually evolved in both anatomically archaic and modern humans. They appear in a mosaic manner in Eurasia and Africa between 200 and 40 ka before they become fully consolidated (Zilhão, 2001; d’Errico, 2003; Zilhão, 2007; d’Errico et al., 2009; d’Errico & Stringer, 2011).
 - 6) Based on a review of the global evidence for modern behavior in the archaeological record, Conard (2005; 2008; 2010) suggests a model of “Mosaic Polycentric Modernity”, rejecting the idea of a monogenetic origin in Africa. The model instead favors a more decentralized, heterogenic, and multi-origin pattern. It emphasizes historical contingency, with modern forms of behavior occurring gradually but at different times in different environmental, social and economic contexts.

An important point in the discussions above concerns the causal mechanisms behind the cultural changes observed within the MSA (Parkington, 2001; Jacobs & Roberts, 2009; Powell et al., 2009; Nowell, 2010; d’Errico & Stringer, 2011; Straus, 2012; Ziegler et al., 2013; Mackay et al., 2014a; Conard & Will, 2015; Kandel et al., 2015). Borrowing from ideas of evolutionary biology and ecology (e.g., Prothero, 2004; Begon et al., 2006; Lorenzen et al., 2011), drivers of behavioral and cultural change can be conceived as either external or internal to human populations. These causal factors encompass environmental and climate change (Deacon, 1989; Ambrose, 1998; Potts, 1998; Mellars, 2006; McCall, 2007; Basell, 2008; Ziegler et al., 2013), cognitive changes such as the emergence of language and symbolism (Noble & Davidson, 1991, 1996; Deacon & Wurz, 2001; Wynn & Coolidge, 2007) which are potentially caused by genetic mutations (Klein, 1994; 2000; Klein & Edgar, 2002), the consumption of new foods and their biochemical effects (Parkington, 2001; 2003; 2010; Marean, 2010; 2011), population movements (Singer & Wymer, 1982; Mellars, 2006; Jacobs & Roberts, 2009) or changes in demography, communication networks and social

structure (McBrearty & Brooks, 2000; Zilhão, 2007; Jacobs & Roberts, 2008; Jacobs et al., 2008; Powell et al., 2009; Straus, 2012; Porraz et al., 2013). Other explanations that are less often invoked, drawing from ideas of dual inheritance and cultural transmission theory (e.g., Richerson & Boyd, 1985; Shennan, 2001; Henrich, 2004), will be more thoroughly discussed and analyzed in *CHAPTER 3.2*.

Coastal adaptations, encompassing the consumption of marine foods and the settlement of coastal landscapes, have been of particular interest in the recent years as one potential causal factor underlying the biological and behavioral evolution of early *Homo sapiens* (e.g., Stringer, 2000; Walter et al., 2000; Broadhurst et al., 2002; Parkington, 2003; Cunnane & Stewart, 2010; Klein & Steele, 2013; Kyriacou et al., 2014; Marean, 2014; Jerardino, 2016). They constitute an important research focus of this dissertation and are thus discussed in more detail. The current archaeological record suggests that modern humans occasionally consumed marine resources during the late Middle Pleistocene (~164 ka; Marean et al., 2007; Marean, 2010) but only started to focus on these food items from MIS 5 onwards (Parkington, 2010; Langejans et al., 2012). Many case studies have focused on shellfish-bearing sites on the southern coast of South Africa along the Indian Ocean (Singer & Wymer, 1982; Thackeray, 1988; Marean et al., 2000; Henshilwood et al., 2001a; Marean et al., 2007; Henshilwood et al., 2014), the Atlantic coast of western South Africa (Parkington et al., 2004; Avery et al., 2008), the Red Sea coast along the Horn of Africa (Walter et al., 2000; Beyin, 2013), and north of the Sahara along the Mediterranean and Atlantic coasts (Ruhlmann, 1951; Arambourg, 1967; Klein & Scott, 1986; Ramos et al., 2008; El Hajraoui et al., 201a; Campmas et al., 2015) during this time frame. Overviews on larger spatial and temporal scales, contextualizing coastal adaptations during the Late Pleistocene on the entire African continent, are, however, still lacking. This makes it difficult to characterize the exact nature of these behaviors by modern humans and link them directly to models of evolutionary causality.

Regarding such causal chains, nutritional and medical studies have shown that marine foods such as fish or shellfish are particularly rich in long-chain polyunsaturated fatty acids (LCPUFAs), which constitute essential nutrients for the proper growth and maintenance of brain tissue in children and adults (Broadhurst et al., 2002; Cunnane & Stewart, 2010; Brenna & Carlson, 2014; Cunnane & Crawford, 2014; Janssen & Kiliaan, 2014; Witte et al., 2014). Based on these observations, Parkington (2001; 2003; 2006; 2010; Parkington et al., 2004) proposed that an increased intake of marine foods fostered encephalization in MSA populations and thus laid the neurological foundation for complex cognition. This could in turn have triggered the development of fully modern patterns of behavior seen in the early

evidence of complex material culture in Africa. An opposing model by Marean (2010; 2011; 2014) posits that coastal adaptations were a *consequence*, rather than a cause, of modern human brain evolution. According to this hypothesis, successful collection of shellfish requires understanding the connection between lunar patterns, tidal activities and shellfish return rate. Because this mental operation is more complex than tracking terrestrial animals, only populations of *Homo sapiens* that already possessed advanced cognitive functions were able to adapt successfully to coastal niches beginning some time during MIS 6. According to Marean (2010; 2011; 2014), the ability to efficiently exploit marine resources might have played an important role for the survival or even the evolutionary origin of early *Homo sapiens* during the harsh environmental conditions of MIS 6 on the African continent, a time window for which genetic studies indicate a demographic bottleneck.

Although the two models are largely incommensurable, they have both become influential in recent discussions on human evolution. Owing to their focus on the evolution of the modern brain and behavior, evolutionary causality in terms of reproductive success is, however, not directly addressed. Additionally, both models are strongly based on archaeological evidence from southern Africa, excluding the record from other parts of the continent. Current models on the role of coastal adaptations for the evolution of *Homo sapiens* thus possess limitations concerning long-term evolutionary perspectives from both theoretical and empirical viewpoints.

1.3. Human dispersals within and out of Africa

The first dispersals of modern humans from Africa into Eurasia constitute a second major topic in MSA research and one of the fundamental issues in studies of human evolution. These migrations (also summarized as “Out of Africa 2”) are inferred from archaeological, fossil and genetic evidence, and are variably dated to between 130 and 50 ka (Lahr & Foley, 1994; Forster, 2004; Liu et al., 2006; Mellars, 2006; Klein, 2008; Oppenheimer, 2009; Petraglia et al., 2010; Armitage et al., 2011; Dennell & Petraglia, 2012; Boivin et al., 2013; Reyes-Centeno et al., 2014; Bolus, 2015; Groucutt et al., 2015a; Liu et al., 2015).

While the initial timing of the African exodus is unresolved, modern humans had reached Sahul by ~50–45 ka (Oppenheimer, 2009; Rasmussen et al., 2011; Davidson, 2013; O’Connell & Allen, 2015), Europe by ~45–40 ka (Conard & Bolus, 2003; Benazzi et al., 2011; Higham et al., 2011; 2012; Nigst et al., 2014; Bolus, 2015) and the Americas by ~15 ka (Goebel et al., 2008; Marangoni et al., 2014). In this process, *Homo sapiens* effectively replaced other hominins that previously inhabited these regions – such as Neanderthals,

Denisovans or *Homo floresiensis* – and became the last surviving hominin on the planet by the beginning of the Holocene. Recent anthropological and genetic research shows, however, that this replacement process was spatiotemporally complex and mosaic in nature, including admixture with other hominin species outside of Africa (Soficaru et al., 2006; Trinkaus, 2007; Greene et al., 2010; Reich et al., 2010; Hammer et al., 2011; Reich et al., 2011; Meyer et al., 2012; Condemi et al., 2013; Prüfer et al., 2014; Sankararaman et al., 2014; Fu et al., 2015).

Why are these dispersals important for the study of human evolution? Dispersals indicate expansions of range and habitat by organisms which are often based on demographic expansions. Early migrations of modern humans from their homeland might thus be associated with particular new adaptations – such as increased cognitive skills, technological efficiency or hunting proficiency – and higher reproductive fitness in general. Successful adaptation to ecological niches outside the African center of origin also shows the ability to live and prosper in new and unknown habitats, indicating increased plasticity and flexibility in behavior, cognitive sophistication and social complexity (Lahr & Foley, 1998; McBrearty & Brooks, 2000; Mellars, 2006; Lombard, 2012; Kandel et al., 2015). Finally, as dispersing modern humans encountered other hominin populations – with *Homo sapiens* competing and finally replacing the long-established inhabitants – these expansions frequently feature in discussions of the demise of other representatives of our lineage such as the Neanderthals (e.g., Mellars, 2004; 2006; Straus, 2012; Mellars et al., 2013; Higham et al., 2014).

Five central, but unanswered, questions pertaining to the dispersal of *Homo sapiens* are as follows: i.) When did the initial dispersal(s) happen? ii.) How many waves of migration were there? iii.) Which routes did early humans take? iv.) What were the reasons behind these demographic expansions? v.) Where, when and to what extent did admixture with other hominins happen? (see Bolus, 2015 and Groucutt et al., 2015a for a recent summary of various models, relevant evidence and references). A new consensus emerging is a view that emphasizes the complexity of the dispersal process with several smaller and larger waves of expansions at various times, taking variable routes between 130–50 ka and including admixture with resident hominin groups (Petraglia et al., 2010; Dennell & Petraglia, 2012; Boivin et al., 2013; Reyes-Centeno et al., 2014; Sankararaman et al., 2014; Groucutt et al., 2015a; Liu et al., 2015; Reyes-Centeno, in press) instead of one single, major and late dispersal at 60–50 ka that swamped all previous hominins (Stringer, 2000; Forster, 2004; Mellars, 2006; Oppenheimer, 2009; 2012; Mellars et al., 2013). This being said, there are no definitive answers to questions (i.–v.) posed above, as many details continue to be disputed. Among the plethora of issues raised above, this dissertation is particularly concerned with two

major topics relating to early dispersals: the role of marine resources and a southern “coastal route”, as well as the relevance of stone tools in answering questions about human migrations.

The consumption of marine resources and the settlement of coastal environments have been interpreted as exaptations by modern humans to successfully and rapidly colonize the rest of the world along a coastal route from Africa eastward to south and southeast Asia, and ultimately Australia (Sauer, 1963; Lahr & Foley, 1994; Stringer, 2000; Field & Lahr, 2005; Bulbeck, 2007; Oppenheimer, 2009; Mellars et al., 2013; Erlandson & Braje, 2015). This archaeological viewpoint of a predominantly coastal route of dispersals via the Indian Ocean rim also draws on support by some genetic studies (e.g., Forster, 2004; Macaulay et al., 2005; Oppenheimer, 2009; but see Boivin et al., 2013). While the idea has attracted interest, much of the material evidence for such a route is missing, presumably due to changes in sea-levels during the Holocene which inundated Pleistocene sites (van Andel, 1989; Erlandson, 2001; Bailey et al., 2007; Bailey & Flemming, 2008; Bailey et al., 2015). Some researchers have criticized a mostly coastal route based on the scarcity and spatial dispersion of evidence for coastal adaptations by modern humans, arguing for a larger importance of terrestrial adaptations and dispersal routes (e.g., Bailey, 2009; Boivin et al., 2013; Bailey et al., 2015; Groucutt et al., 2015a). These authors claim that so far, it is unclear as to what extent early modern humans had adapted to successfully thrive in variable coastal environments, particularly regarding the fact that these habitats can differ a lot around the globe due to oceanographic, geographic and other environmental factors. In order to evaluate the importance and feasibility of a coastal route out of which to disperse from Africa, it is thus of utmost importance first to systematically assess the nature of coastal adaptations by modern humans in different areas within Africa.

Stone tools have played an essential role in past discussions about human and hominin migrations in the Stone Age, and they continue to do so even in light of mounting evidence from anthropology and particularly genetic studies. The identification of past populations with certain lithic assemblages has been consistently employed in the interpretation of human dispersals within, out of, and beyond Africa (recent examples include: Mellars, 2006; Petraglia et al., 2007; Van Peer & Vermeersch, 2007; Armitage et al., 2011; Rose et al., 2011; Petraglia et al., 2012; Blinkhorn et al., 2013; Boivin et al., 2013; Scerri et al., 2014a; 2014b; Blinkhorn et al., 2015). Some archaeologists have gone a step further, using morphological, typological or technological similarities between stone artifacts within and outside of Africa to directly infer population movements of modern humans. These approaches explain similarities in lithic artifacts between different regions by people carrying their material

culture with them as they go. The three most relevant representatives of this strategy for early dispersals out of Africa are:

- 1) The documentation of so-called “Nubian cores” in southern and central Arabia has been used to infer demographic exchange across the Red Sea, suggesting that modern humans entered the region with this particular technology before 100 ka (Rose et al., 2011; Crassard & Hilbert, 2013; Usik et al., 2013). If true, this would represent one of the earliest identified populations of modern humans outside of Africa, and has been used to support arguments for the southern migration route of *Homo sapiens* into Asia and Oceania (Crassard & Hilbert, 2013). The hypothesis maintains that the “Nubian technocomplex” in both northeast Africa and the Arabian Peninsula, defined largely on the presence of Nubian cores, reflects the same group of people using this specific reduction technology (Rose et al., 2011; Crassard & Hilbert, 2013; Usik et al., 2013). While the chronological control over many sites is weak, the slightly later presence of Nubian cores in Arabia is interpreted as evidence for modern humans dispersing from their source area in northeast Africa.
- 2) A second model is based on the archaeological site of Jebel Faya in the United Arab Emirates. Here, stone tools dating to the last interglacial are reported to show strong affinities to MSA lithic technology in eastern and northeastern Africa (Armitage et al., 2011). The authors base this assessment on the presence of reduction by façonnage which was used for the production of small hand axes and foliate tool forms. As the eastern African MSA was made by modern humans during roughly the same time, the technological affinities between these regions are interpreted as early dispersals from Africa across the Red sea during times of low sea level and increased rainfall which facilitated the early colonization of Arabia until the Persian Gulf at around ~120 ka.
- 3) Finally, Mellars (2006; Mellars et al., 2013) has used the occurrence of microlithic technologies with backed segments in southern and eastern Africa (from HP or “HP-like” sites in these regions) and a later appearance of similar tools in India and Sri Lanka (at Jwalapuram, Patne and Batadomba-lena) to infer population movements out of Africa and along a coastal route by ca. 60–50 ka.

In all of these cases, the MSA record and its tool stones are used as a baseline “African” signal for the source populations of modern humans that later dispersed to other continents. In other words, supposedly “African” elements of stone artifact technology in non-African contexts are used to infer dispersals out of Africa. Interestingly, although all three approaches

use lithics as such a signal, they either argue for an early (Armitage et al., 2011; Rose et al., 2011) or late exodus out of Africa (Mellars, 2006; Mellars et al., 2013).

The degree to which lithic artifacts can actually help in tracing migrations in general – and early dispersal of modern humans from Africa to Eurasia in particular – is an open debate that stretches far back in time (e.g., Mason, 1895; Sollas, 1911; Breuil, 1912; Goldenweiser, 1913; Hocart, 1923) and is ongoing (see McBrearty, 2003; Otte, 2003; Garcea, 2004; Hovers, 2009; Hiscock et al., 2011; White et al., 2011; Adler et al., 2014; O’Brien et al., 2014; Shea, 2014; Groucutt et al., 2015b). Recent studies emphasize that a major problem facing such approaches is the fact that similarities in material culture between different areas can arise by three principle pathways: convergence (independent invention; similar local adaptations), diffusion (movement of ideas and objects; cultural exchange) or dispersal (movement of people). Thus it becomes of utmost importance to devise criteria to distinguish between these processes in the archaeological record (see *CHAPTER 3.3*). Moreover, some of the above cited lithic “smoking guns”, such as Nubian cores, have been anecdotally reported from sites far away from eastern Africa and Arabia (e.g., Pasty, 1997; Blinkhorn et al., 2013). Questions thus arise on whether current definitions preclude the classification of cores from distant parts of Africa as Nubian, and whether any identified similarities in other areas might more likely arise from dispersal, diffusion or convergence (see *CHAPTER 3.3*).

Finally, dispersals within the African continent – which could have been even more widespread during the MSA – constitute an important but often neglected topic. Regional or inter-regional similarities in lithic technology, such as the wide geographic extension of the HP in the southern part of Africa, might be the result of migrating people or diffusion of ideas by interconnected populations (e.g., Lombard, 2009; Mackay et al., 2014a; Wadley, 2015). Dispersals within Africa certainly played a part in the spatiotemporal distribution of sites and artifact types, technological innovations and culture-stratigraphic groups alongside adaptations to local environments, raw material availability and cultural transmission. Such processes need to be discussed explicitly when analyzing geographical and chronological patterns of technology and behavior in the African MSA record.

1.4. Archaeology and lithic technology of the southern African MSA – Keys to open questions

For archaeologists working in the Stone Age of Africa, the eponymous stone artifacts play an essential role in various areas of research. From a general point of view, stone artifacts are of paramount importance as they “*encode human technological achievements during more than*

99% of the history of our genus” (Lombard et al., 2012: p. 120). Due to their abundance and durability, lithic artifacts also constitute the majority of information that researchers have to reconstruct past behavior and technological activities of extinct hominins. They represent the most tangible and immediate source that informs behavioral patterns of prehistoric people and thus lithic artifacts form the solid baseline for cultural and adaptive reconstructions. On a basic level, stone tools indicate the presence or absence of hominins in various regions and time frames. Furthermore, lithic artifacts can yield manifold behavioral information on diverse aspects such as technology, cognitive and physical capacities, cultural transmission, mobility and settlement strategies (e.g., Speth, 1972; Cotterell & Kamminga, 1987; Debénath & Dibble, 1994; Shott, 1994; Holdaway & Stern, 2004; Odell, 2004; Andrefsky, 2005; Conard, 2005; Shott, 2008; Tostevin, 2012; Groucutt et al., 2015b). The stone tools and lithic technology of the African MSA are thus keys to open questions concerning the behavioral adaptations, cultural evolution and dispersals of *Homo sapiens*.

Today, many prehistoric archaeologists use the term MSA as a descriptive shorthand to refer to a temporal stage or phase of the late Middle and Late Pleistocene south of the Sahara (e.g., Volman, 1981; Clark, 1988; Basell, 2008; Linstädter et al., 2012; Wurz, 2014) or on the entire continent of Africa (e.g., McBrearty & Brooks, 2000; Kleindienst, 2001; Garcea, 2004; Van Peer & Vermeersch, 2007; Garcea, 2012; Dibble et al., 2013) that dates to roughly 300–30 ka (see *CHAPTER 1.1*). Apart from the temporal duration and spatial extent, the MSA is defined on its characteristic stone artifacts. The production of blanks with predetermined size and shape from prepared cores, such as the Levallois method, constitutes the hallmark of MSA occurrences. That being said, discoid, platform and bipolar core reduction also feature commonly in MSA assemblages. Convergent or pointed flakes with prepared platforms are the most abundant blank types. While they played an important role in the earliest definition of the MSA (Goodwin & van Riet Lowe, 1929), blade and bladelet technology also occurs in various spatial and temporal contexts. In general, MSA assemblages are “flake-based” meaning that the production and use of preformed blanks from cores is the overarching goal of the lithic system. At many MSA sites, retouch of blanks features only in low frequency, often below 2% of the entire assemblage. There is, however, a high variability in the frequency and types of implements manufactured. Common tool forms in the MSA include various forms of unifacial and bifacial points, side scrapers, end scrapers, backed pieces, notches and denticulates. They mostly replace the large cutting tools (e.g., hand axes) of the preceding ESA. In terms of size, lithic artifacts during the MSA are on average smaller than those from the ESA, but larger than the mostly microlithic technologies of the LSA. From a

technological perspective, the MSA is characterized by several important innovations: the preparation of cores, the manufacture of distinct tool types crafted from blanks, an increased standardization and diversification of end products, hafting techniques and composite implements (see Goodwin & van Riet Lowe, 1929; Clark, 1959; Volman, 1984; Clark, 1988; Robertshaw, 1995; McBrearty & Brooks, 2000; Wurz, 2000; 2002; Foley & Lahr, 2003; Lombard et al., 2012; Tryon & Faith, 2013; Wurz, 2013; 2014; Wadley, 2015).

The MSA of southern Africa – south of the Zambezi and Kunene rivers – plays a central role in current research on the evolution of modern humans. This is due in large part to the long research history in this region and the concomitant wealth of excavated sites (Goodwin & van Riet Lowe, 1929; Clark, 1959; Sampson, 1974; Volman, 1981; 1984; Deacon, 1990; Klein, 2001; Lombard et al., 2012; Wurz, 2014; Wadley, 2015). Most importantly, the southern African MSA features many cave and rock shelter sites such as Klasies River (Singer & Wymer, 1982; Wurz, 2002), Blombos (Henshilwood et al., 2001a), Sibudu (Wadley & Jacobs, 2006), Diepkloof (Porraz et al., 2013), Pinnacle Point (Marean et al., 2007; Marean, 2010) and Apollo 11 (Vogelsang et al., 2010). These localities provide long and well-dated stratified sequences – which are rare in many areas of Africa – alongside a rich archaeological record of stone tools and other elements of material culture.

Collection of archeological materials dating to the Stone Age in South Africa has been ongoing for over a hundred years, beginning in the second half of the 19th century (Deacon, 1990; Gowlett, 1990). Bringing order into the complex temporal, spatial and formal variability of the recovered material remains has been one of the main challenges for archaeologists throughout this time. To this end, scholars devised classificatory schemes or taxonomies for the chronological succession of different periods, technocomplexes and stages. Early classifications (e.g., Goodwin & van Riet Lowe, 1929; Breuil, 1930; Clark, 1959) were, to a large extent, based on the typology of certain retouched stone tool forms (type fossils or *fossiles directeurs*), but recently more attention has been paid to technological aspects (e.g., Wurz, 2002; Lombard et al., 2012). Scholars developed several supra-regional cultural stratigraphic schemes for the MSA in South Africa, including those of Goodwin and van Riet Lowe (1929), Clark (1959), Sampson (1974), Singer and Wymer (1982), Volman (1981; 1984), Wurz (2002) and most recently Lombard *et al.* (2012). Current schemes encompass the following successive stages from older to younger: Early MSA (also MSA 1), Klasies River (also MSA 2a or MSA I), Mossel Bay (also MSA 2b or MSA II), “pre-SB”, SB, HP, “post-HP” (also MSA 3, MSA III or Sibudan), and “final MSA” (also MSA 4 or MSA IV).

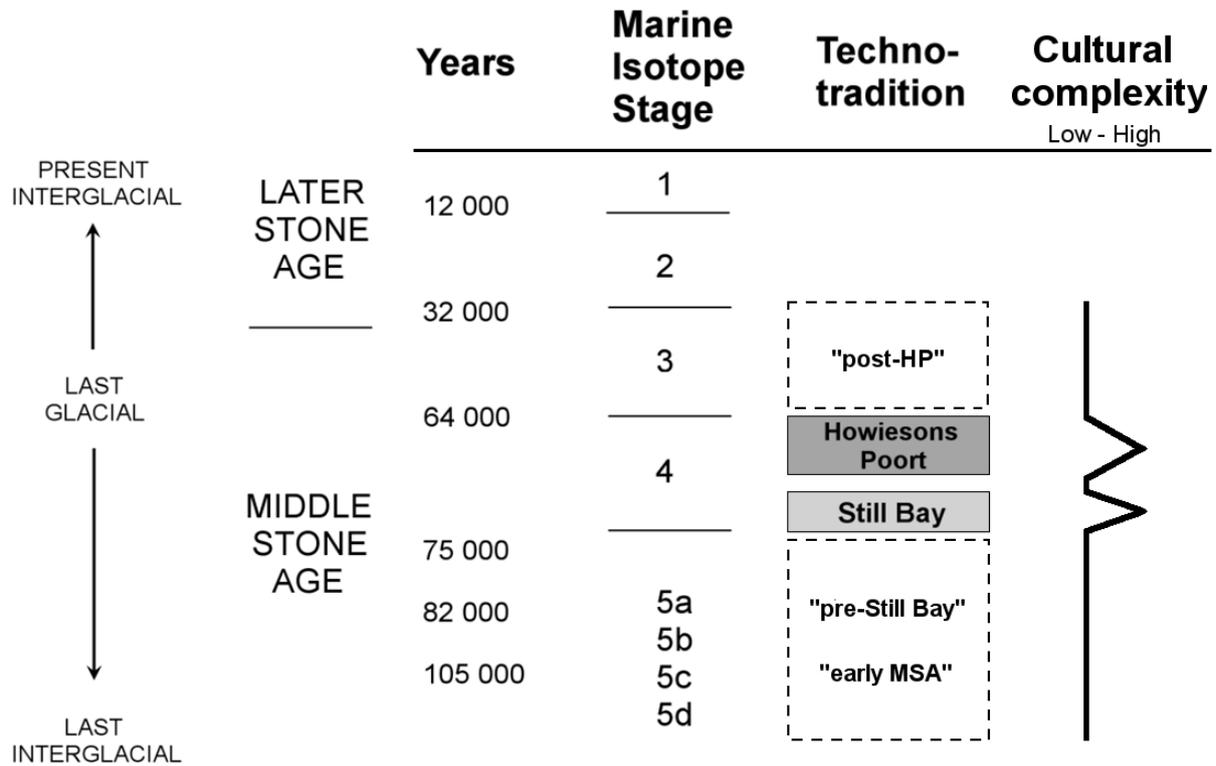


Figure 1. Schematic representation of the Synthetic Model and the cultural chronostratigraphy for the SB and HP technocomplexes within the MSA in southern Africa (modified after Henshilwood, 2012: Fig. 7).

Concerning questions of the spatiotemporal structure of the MSA record and its implications for the cultural evolution of early modern humans, the so-called “Synthetic Model” (*sensu* Conard et al., 2014) has become the influential paradigm of current research. This synthesis derives mostly from the integration of new dating results with long-term archaeological observations and is associated with Z. Jacobs, C. Henshilwood and colleagues (Jacobs et al., 2008; Jacobs & Roberts 2008; Henshilwood, 2012; Jacobs et al., 2012). Based on new results of luminescence dating from crucial localities such as Blombos, Diepkloof, Sibudu, Klein Kliphuis, Apollo 11 and Hollow Rock Shelter, the model proposes that the SB and HP represent two well-defined cultural entities of short duration that can be used as horizon markers (Fig. 1). Historically, the relative and absolute chronology of these two technocomplexes had been notoriously difficult to resolve (see discussion in Lombard, 2005; Tribolo et al., 2006; Jacobs & Roberts, 2009). According to the new model, the SB dates to ~77–72 ka and is characterized by finely shaped, bifacially worked foliate or lanceolate points that were in part produced by pressure flaking, whereas various geometric forms of backed tools and an elaborate laminar technology distinguish the HP. The latter always follows the SB after a short hiatus, dating to 65–59 ka (Jacobs et al., 2008; Wadley, 2008; Jacobs & Roberts, 2009; Lombard, 2009; Mourre et al., 2010; Henshilwood, 2012; Soriano et al., 2015).

Apart from interests in definitions and temporal relations, proponents of this model also emphasized that many complex elements of material culture that are associated with modern behavior (see *CHAPTER 1.2*) are found particularly often in these two sub-stages of the southern African MSA. The SB and HP were thus considered as periods of exceptional innovation, reflecting advanced cognition, technology and socio-economic behaviors. Some scholars also associate these innovative aspects with increased population sizes, exchange of information between groups over long distances, and subsequent dispersals of modern humans to Eurasia (Mellars, 2006; Jacobs et al., 2008; Jacobs & Roberts, 2009; Henshilwood & Dubreuil, 2011; McCall & Thomas, 2012; Mellars et al., 2013). Not surprisingly, the model has resulted in a strong research emphasis on the SB and HP. Researchers view these technocomplexes as two short-lived but culturally advanced episodes that are preceded and followed by less behaviorally sophisticated phases. Some scholars thus invoke a model of discontinuous cultural evolution in modern humans in which complex material culture appears and disappears abruptly in the South African MSA (McCall, 2007; Cochrane, 2008; Jacobs & Roberts, 2008; Henshilwood & Dubreuil, 2011, Jacobs et al., 2012; Ziegler et al., 2013; see Fig. 1). The Synthetic Model, if valid, has implications for many research questions discussed above (*CHAPTER 1.2* and *CHAPTER 1.3*), including the nature, tempo and causes of cultural change during the MSA as well as the earliest migrations out of Africa.

Notwithstanding its popularity, the Synthetic Model has recently come under criticism from several sides, including both empirical and theoretical objections. First, problems in reproducing previous dates for the HP at Diepkloof (Tribolo et al., 2009; 2013; Guérin et al., 2013) raised questions about the chronometric results by Jacobs and colleagues (Jacobs et al., 2008; but see the reply by Jacobs & Roberts, 2015). Based on the new dates by Tribolo and colleagues, the HP at Diepkloof starts far earlier, beginning at ca. 110 ka, and lasts much longer (~50,000 years) compared to other sites. Detailed lithic analyses at the site also showed that the HP represents a multi-phased period of technological development rather than a uniform cultural episode (Porráz et al., 2008, 2013). This conclusion supports recent results from other localities, suggesting that HP occurrences are more variable in time and space than previously acknowledged (Soriano et al., 2007; Wadley & Mohapi, 2008; Mackay, 2010; Villa et al., 2010; de la Pena et al., 2013; Conard & Porráz, 2015).

Similar issues have arisen about the SB regarding the presence of bifaces and bifacial technology in the MSA of southern Africa. Critical discussions on the ambiguous definition, integrity and status of the SB go far back in time (Malan, 1956; Clark et al., 1966; Sampson, 1974; Volman, 1981; Clark, 1988) and have re-surfaced today with the question of the extent

to which any assemblage with bifacial artifacts could be considered to belong to this cultural entity. A close look at SB localities such as Blombos, Sibudu, Apollo 11 and Hollow Rock Shelter shows that they feature variable quantities and modalities of bifacial technology (Henshilwood et al., 2001a; Wadley, 2007; Vogelsang et al., 2010; Högberg & Larsson, 2011; Porraz et al., 2013; Archer et al., 2015; Soriano et al., 2015). The recent finding of small bifacial points in an otherwise typical HP context at Sibudu – characterized by blade technology and abundant backed artifacts – can serve as a case in point (de la Pena & Wadley, 2014). Additionally, new excavations at Sibudu led by a team from the University of Tübingen have revealed an increase in bifacial pieces and bifacial technology far below the SB (Conard & Porraz, 2015) in horizons pre-dating ~77 ka, which the previous excavator had defined as “pre-SB” (Wadley, 2007). Together with new technological and chronometric data from Diepkloof (Porraz et al., 2013, Tribolo et al., 2013) these observations indicate a longer duration, less homogeneity and a more complicated internal and regional temporal trajectory for the SB than formerly recognized.

The hypothesis that the SB and HP represent periods of singular cultural florescence, or even the epicenter for the evolution of modern behaviors, has also been questioned. Researchers have remarked that the proposed model of cultural evolution is overly simplistic (Lombard & Parsons, 2010; 2011; Lombard, 2012; 2016). Based on the analysis of lithic and non-lithic material from the southern African MSA, some recent studies argue that modern humans after the HP maintained sophisticated lithic technologies (Soriano et al., 2007; Lombard, 2009; Lombard & Parsons, 2010; Villa et al., 2010; Conard et al., 2012, Lombard et al., 2012). Moreover, the archaeological evidence appears to contradict theories of a demographic collapse after the SB and HP. MSA people did not abandon sites such as Diepkloof, Sibudu or Klasies River after these technocomplexes. Instead, the inhabitants occupied these localities continuously without evidence for stratigraphic hiatuses, sometimes with high intensities of settlement (Lombard & Parsons, 2011; Conard et al., 2012; Conard & Porraz, 2015).

Finally, the selective research focus on the HP and SB in recent years has been regarded as a particularly problematic factor. The extreme emphasis put on these cultural units has often resulted in a view that earlier and later periods of the MSA are technologically simple, unsophisticated, and less innovative. Younger stages of the MSA after the HP are further seen as a return or reversal to an earlier “pre-SB” technology (Sampson, 1974; Singer & Wymer, 1982; Deacon, 1989; Henshilwood, 2005; McCall, 2007; Mellars, 2007; Jacobs & Roberts, 2008; 2009). This research bias is also exemplified by the usage of informal terms

such as “pre-SB”, “post-HP” and “final MSA” – the latter two denoting a more than 20,000 year-long period of cultural evolution following the HP. In sum, the emphasis on the SB and HP has resulted in relatively few detailed studies for other MSA phases in an otherwise well-studied region (see Soriano et al., 2007; Mitchell, 2008; Villa et al., 2010; Lombard & Parsons, 2011; Conard et al., 2012; Porraz et al., 2013; Wurz, 2013; Douze et al., 2015).

The later part of the southern African MSA provides a case in point, as was prominently argued by Mitchell (2008). Lithic assemblages that succeed the HP and fall within MIS 3 (~59–25 ka) comprise the so-called “post-HP” (Sampson, 1974; Wurz, 2002; Wadley & Jacobs 2006) “MSA 3” (Volman, 1984) or “MSA III” (Singer & Wymer, 1982). In their current use, these labels act as catch-all categories with little scientific value (Wadley, 2007; Mitchell, 2008; Conard et al., 2012; Wadley, 2010). Wadley (2010: p. 2404) aptly summarizes the current view of the “post-HP” as being poorly understood while at the same time regarded as “dark ages” that followed the HP. Even so, many sites from this time period exist in southern Africa and they can be found in various climatic and environmental contexts (Mitchell, 2008; Lombard et al., 2012; Mackay et al., 2014a). In the eastern part of southern Africa the number of sites during MIS 3 increases, with several localities yielding deep and rich occupation sequences such as Umhlatuzana (Kaplan, 1990; Lombard et al., 2010), Rose Cottage Cave (Wadley, 1997, Soriano et al., 2007) or Sibudu (Wadley & Jacobs, 2006; Conard et al., 2012).

As pointed out above, scholars defined the MSA lithic assemblages that follow the HP for the most part on the basis of what they lack, such as bifacial points or backed pieces, instead of what they contain (see Conard et al., 2012; Wadley, 2013). A high degree of spatial variability and the existence of frequent unifacial points constitute the only unifying traits that are frequently cited for the “post-HP” (e.g., Volman, 1984; Wadley, 2005; Mitchell 2008; Villa et al., 2010; Lombard et al., 2012; Wurz, 2013; Mackay et al., 2014a). The “informal” or “conventional” MSA character attributed to assemblages following the HP appears to derive mostly from the fact that lithic assemblages are often poorly studied and poorly published. Regarding other sources of evidence – and even though scholars have frequently mentioned the (near-) absence of elements of complex behavior for this period (e.g., Mellars, 2006; Mitchell, 2008; Jacobs et al., 2008; Wurz, 2013) – assemblages of the “post-HP” in southern Africa, and at the site of Sibudu in particular, have provided worked bone (Cain, 2004; d’Errico et al., 2012), potential engravings on ochre (Hodsgkiss, 2013), compound adhesives (Wadley et al., 2004; Lombard, 2005; 2006; Wadley et al., 2009), bedding constructions and other forms of site use and maintenance (Goldberg et al., 2009; Wadley et al., 2011).

In conclusion, these critical observations raise serious doubts about the validity of the Synthetic Model. The comparative lack of research for the periods following the HP constitutes one of the most prominent problems. As a result, the archaeology of MIS 3 in southern Africa lacks both a systematic treatment of the geographical and temporal variability and a consistent culture-stratigraphic structure (Mitchell, 2008: p. 58). This situation is exemplified by a recent article by Conard *et al.* (2012) in which the authors proposed the “Sibudan” as a new cultural sub-unit of the MSA in MIS 3 based on the type locality of Sibudu. Through a detailed analysis of the characteristic stone tool assemblages, the authors seek to replace the informal term “post-HP” – which is mostly defined in a negative manner by what it is not – with a new cultural taxonomic unit resting on positive features. At the same time, such a formal definition intends to provide a baseline for further comparative research. Conard *et al.* (2012) thus proposed the Sibudan as an organizational unit that constitutes a first step towards the nomenclature for structuring the cultural sequence after the HP. Even after this first step, however, Mitchell (2008: p. 52) is still correct in complaining that MIS 3 in southern Africa remains archaeologically unexplored relative to the preceding HP and the following LSA.

To summarize, the southern African MSA plays a key role in studying the cultural evolution of early modern humans due to its long research history and the wealth of excavated sites. While various cultural stratigraphic systems and explanatory models for behavioral change exist, the Synthetic Model (Fig. 1) has been particularly influential to these discussions during the last few years. Just shortly after its formulation, however, this approach has come under criticism. A strong research focus on the SB and HP has led to a comparative neglect of the archaeology and lithic technology preceding and following these technocomplexes. Yet, in order to adequately track behavioral change and the cultural evolution of early *Homo sapiens*, all phases of the southern African MSA must be studied with the same intensity. Due to the reasons discussed above, this applies in particular to the archaeology of MIS 3, the period post-dating the HP. On a more general level, an increased empirical database in combination with new theoretical concepts is required to evaluate the nature, tempo, trajectory and causes of behavioral change in early modern humans (*CHAPTER 1.2*) as well as their early dispersals (*CHAPTER 1.3*). Analyzing the lithic technology and behavioral variability of the uniquely rich MSA record from southern Africa is of paramount importance to assess these issues.

CHAPTER 2. RESEARCH QUESTIONS AND METHODS

2.1. Research questions and main objectives

This dissertation and the published articles use behavioral information attained from the analysis of MSA stone artifacts, in concert with contextual archaeological data, to tackle questions regarding the cultural evolution of modern humans and their early dispersals within and out of Africa. The principle objective of this thesis is to assess the variability in behavior and lithic technology during the MSA in relation to these topics, with a focus on coastal adaptations during the entire time span of the African record and stone artifacts during MIS 3 of southern Africa (ca. 59–25 ka).

Coastal adaptations have played an important role in MSA research during the last decades, both for the bio-cultural evolution of modern humans and their earliest dispersal out of Africa along a potential coastal route (see *CHAPTER 1.2.* and *CHAPTER 1.3.*). Current research into these topics is, however, limited by two factors. First, most studies focus their attention either on a single site or region – southern Africa in particular (Parkington et al., 2004; Marean, 2011; Jerardino, 2016) – to the exclusion of the rest of the African continent. Secondly, while scholars have repeatedly emphasized the impact of consuming marine foods on the evolution of the modern human brain and behavior (e.g., Broadhurst et al., 2002; Parkington 2003, 2010; Marean et al., 2014), they do not directly address questions of evolutionary causality. Current models thus possess limitations for answering long-term evolutionary questions regarding both theoretical and empirical viewpoints.

In order to overcome the situation at hand from the empirical side, this dissertation analyzes coastal adaptations by using three nested geographical scales within the entire time-span of the MSA: local and regional (Hoedjiespunt 1 and South Africa), sub-continental (sub-Saharan Africa) and continental (Africa). This more inclusive spatial and temporal approach aims to characterize the nature and variability of coastal adaptations by modern humans during the MSA. To contribute new theoretical perspectives to the current discourse, these behaviors are subsequently viewed from an explicitly evolutionary standpoint, linking coastal adaptations to evolutionary causality. This approach is implemented by evaluating the extent to which behaviors associated with coastal adaptations might have increased the reproductive success of early *Homo sapiens*. Finally, these new insights are harnessed to assess the feasibility of a coastal route of modern humans to migrate out of Africa and the general implications of such an adaptation for migratory behavior and demographic expansions.

This thesis addresses two additional aspects within the overarching topic of the behavioral evolution of modern humans during the MSA. First, a critical re-appraisal of the various models of cultural evolution (see *CHAPTER 1.2* and *CHAPTER 1.3*) based on an expanded empirical database from southern Africa and the application of new theoretical approaches to cultural change and information transmission. Second, an examination of the underlying reasons of cultural change at various scales of analysis, with a particular focus on lithic technology as the most prevalent and important behavioral trace during the MSA.

Until this day, stone artifact assemblages from MIS 3 in southern Africa, informally referred to as “post-HP”, are generally understudied and often poorly published. MIS 3 in southern Africa remains archaeologically unexplored relative to the preceding SB and HP as well as the following LSA. One of the aims of this dissertation, therefore, is to provide new data that can help to correct the research bias toward the HP and SB. Furthermore, such an approach constitutes a necessary prerequisite to create testable models of cultural evolution for the MSA: in order to adequately track behavioral change and the cultural evolution of early *Homo sapiens*, all phases of the southern African MSA must be studied with the same intensity. To this end, various lithic assemblages from different regions of southern Africa were studied (see below), with a focus on the exceptionally long and high-resolution MIS 3 sequence at Sibudu in KwaZulu Natal (see Wadley & Jacobs, 2006; Conard et al., 2012).

The stone artifact analyses aim to characterize the lithic technology at these sites while at the same time documenting the extent of diachronic variation (see *CHAPTER 2.2*). This approach includes an evaluation of the causes of behavioral change at several scales of analysis. At Sibudu, the long and multi-layered stratigraphy, along with its exceptionally high chronological resolution, allows to examine technological and behavioral change at a micro-scale throughout the sequence (Wadley & Jacobs, 2006; Conard et al., 2012; Wadley, 2013). Starting from the local view of Sibudu, the geographical comparisons are subsequently expanded to the regional and inter-regional scale. This approach intends to assess the spatiotemporal variability and structure of MIS 3 lithic technology in various parts of southern Africa and examines the potential reasons for the resulting patterns. Making use of new theoretical developments, this thesis also employs ideas from cultural transmission theory (Cavalli-Sforza & Feldman, 1981; Boyd & Richerson, 1985; Rogers, 1995; Shennan, 2000; Henrich, 2001; Henrich & McElreath, 2003; Henrich, 2004; McElreath et al., 2008; Mesoudi, 2011; Kolodny et al., 2015), which can serve as a bridging theory between the reproduction of cultural knowledge of Paleolithic people and the archaeological patterns in lithic technology that researchers can observe today (e.g., Bettinger & Eerkens, 1999; Lipo & Madsen, 2001;

O'Brien et al., 2001; Shennan, 2001; Eerkens & Lipo, 2005; 2007; Shott, 2008; Lycett, 2010; Tostevin, 2012). Combining new information on lithic technology and behavioral variability during the southern African MSA with new theoretical approaches, this dissertation tackles the nature, tempo and trajectory of cultural evolution of early modern humans and critically evaluates the validity of the Synthetic Model.

An additional research aim concerns the question of how MSA assemblages during MIS 3 can inform early dispersals of modern humans within and out of Africa. Part of this approach is to devise criteria that allow distinguishing between convergence, diffusion and dispersal in the archaeological record. These processes can all lead to similarities in material culture between different areas and periods (i.e., the problem of equifinality). Analyses of the open-air site Uitspankraal 7, combined with comparisons to the MSA record of northeastern Africa and the Middle Paleolithic of the Near East, form the main subject of this study, with additional information from other southern African localities dating to MIS 3. The discovery of Nubian-like cores – which scholars have used as technological markers to trace the earliest migrations of modern humans out of Africa (Rose et al., 2011; Usik et al., 2012; Crassard & Hilbert, 2013) – at the sites of Uitspankraal 7 and Mertenhof, raises the question regarding the processes by which these concrete similarities arose. More generally, this thesis asks to which degree stone artifacts can be used to trace migrations of Stone Age people in the absence of human fossils.

The three main areas of research within this dissertation can be summarized with the following questions. They are addressed in the respective three sections of *CHAPTER 3*:

- 1)** What is the nature and variability of coastal adaptations during the MSA of Africa? How can we relate coastal adaptations to evolutionary causality? What selective advantages did coastal adaptations confer to populations of early modern humans, if any? What are the implications for the bio-cultural evolution and early dispersal of modern humans?
- 2)** What characterizes MSA lithic technology during MIS 3 in southern Africa? Is there spatial and temporal variation or patterning in technological behavior, and if so, to what extent? What is the trajectory of behavioral change during the MSA after the HP in Africa? What factors drive cultural change during this time period at the site, local and regional level?
- 3)** To what extent can analyses of late MSA lithic assemblages inform early dispersals of modern humans within and out of Africa? In what way can stone artifacts resolve migrations of people in the Stone Age from a general point of view?

After answering these questions, the conclusion of this dissertation (*CHAPTER 4*) synthesizes the empirical findings with new theoretical ideas to tackle more general questions

of human evolution and dispersal: What are the implications of the new results on behavioral variability during the MSA for current models of the cultural evolution of *Homo sapiens* in Africa? Do modern humans in southern Africa show less sophisticated and complex behaviors during MIS 5 and MIS 3 compared to the SB and HP periods? How did these behavioral and cultural changes influence the earliest dispersal of modern humans out of Africa?

Table 1. Overview of assemblages and respective stone artifacts from the MSA of southern Africa used for this thesis.

Site	Age / MIS	Assemblages (n)	Lithics studied (n)	Total lithic finds ^a	Analyst ^b
Hoedjiespunt 1	~130–110 ka (MIS 5e)	3	1,212	2,095	MW
Sibudu	~58 ka (MIS 3)	22	10,440	155,762	MW
Klein Kliphuis	58–55 ka (MIS 3)	6	1,847	6,598	MW
Uitspankraal 7	MIS 3 (surface)	1	2,502	6,848	MW AM
Holley Shelter	MIS 3 (no absolute dates)	6	2,473	1,527	GDB
Mertenhof	MIS 3 (no absolute dates)	1	3,227	10,546	AM

^a Total lithic finds include small debitage products which were only assessed by raw material and other diagnostic products.

^b Analyst abbreviation: MW = Manuel Will; GDB = Gregor Donatus Bader; AM = Alex Mackay.



Figure 2. Map of MSA localities in southern Africa studied or used as part of this dissertation. Abbreviations: HDP1 = Hoedjiespunt 1; HOL = Holley Shelter; KKH = Klein Kliphuis; MRS = Mertenhof; SIB = Sibudu; UPK7 = Uitspankraal 7 (Map created by Reza Zakerinejad and Manuel Will).

2.2. Material and methods

Stone artifact assemblages of archaeological layers dating to MIS 5 and MIS 3 from six southern African MSA sites provide the principle empirical basis of this dissertation and the published articles. The localities include Hoedjiespunt 1 (HDP1), Sibudu, Holley Shelter, Uitspankraal 7 (UPK7), Mertenhof, and Klein Kliphuis (KKH; see Fig. 2). General descriptions and overviews for these lithic assemblages, including their composition, stratigraphic context and dating, can be found in the following: HDP1 (Will et al., 2013), Sibudu (Wadley & Jacobs, 2004; 2006; Wadley, 2013; Will et al., 2014; Conard & Will, 2015) Holley Shelter (Bader et al., 2015), UPK7 and Mertenhof (Will et al., 2015a), and KKH (Mackay, 2010; 2011). Table 1 provides an overview of all lithic artifacts that were individually studied by the author in relation to this dissertation project (n=16,001) and additional data used but gathered by other researchers.

Lithic artifacts from HDP1, Sibudu, UPK7 and KKH were analyzed with the same methodology by the author in order to allow for accurate cross-comparisons. Stone artifact assemblages from individual archaeological horizons constitute the principal unit of analysis at all sites (Table 1). The lithic studies encompass several domains of technological systems (*sensu* Tostevin, 2012): the acquisition and treatment of raw materials, the method of blank production, the technique of knapping, the manufacture of tools and the reduction sequences performed at the site. The author also examined further technological, functional, and economic behaviors in order to maximize the amount of information relevant for the questions posed in *CHAPTER 2.1*. To this end, multiple methods were combined, drawing from German, French and North American traditions of lithic analyses:

- Attribute analysis of all debitage products (Auffermann et al., 1990; Hahn, 1991; Shott, 1994; Tostevin, 2003; Odell, 2004; Holdaway & Stern, 2004; Andrefsky, 2005; Tostevin, 2012; size cut off point 30 mm; 15 mm at KKH) informs on technological behaviors by providing quantitative data of the numerous discrete and metric traces on individual artifacts that result from the knapping process. As a concrete example, knapping techniques can be reconstructed as part of this method (Speth, 1975; Dibble & Whittaker, 1981; Dibble & Pelcin, 1995; Dibble, 1997; Pelegrin, 2000; Soriano et al., 2007; Lin et al., 2013). Additional techno-economic approaches measure reduction intensities (Sullivan & Rozen, 1985; Roth & Dibble, 1998; Douglass et al., 2008; Lin et al., 2013), calculate flaking efficiencies (Braun & Harris, 2003; Mackay, 2008) and assess the economy of raw materials (Binford, 1980; Kelly, 1983; Bamforth, 1986; Kuhn, 1991; Andrefsky, 1994; Floss, 1994; Féblot-Augustins, 1997; Brantingham et

al., 2000; Brantingham, 2003; Orton, 2008). Individual stone artifacts and attributes constitute the unit of analysis in this approach. All recorded attributes are entered into a Microsoft Access Database, allowing for subsequent quantitative and statistical analyses on the level of the assemblage or selected samples.

- Reduction sequence (or *chaîne opératoire*) analysis of stone artifacts (Pelegrin et al., 1988; Boëda et al., 1990; Inizan et al., 1995; Conard & Adler, 1997; Bleed 2001; Shott, 2003; Soressi & Geneste, 2011; size cut off point 30 mm; 15 mm at KKH) evaluates the methods of core reduction and the stages of knapping, use and discard of stone artifacts that people performed on-site. These predominantly qualitative analyses operate on the level of entire assemblages and raw material units. Occasional refitting complemented this approach.
- Classic typological approaches (Bordes, 1961; Brezillon, 1983; Debénath & Dibble, 1994) of the entire retouched component of the lithic assemblage – with a particular consideration for South African tool taxonomies (Volman, 1981; Wurz, 2000; Villa et al., 2005) – provide comparable data on tool manufacture and tool types across sites, regions and supra-regional cultural sequences. Techno-functional analyses (Lepot, 1993; Boëda, 2001; Bonilauri, 2010; Conard et al., 2012) study the technological approach of knappers towards producing, using and recycling tools by investigating how people modified their blanks and used the cutting edges.
- Quantifying small lithic artifacts (30–5 mm or 15–5 mm) from each assemblage according to size class and raw material aids in calculating find densities and evaluating patterns in the raw material economy. Identifying diagnostic technical products such as retouch debitage quantifies the level of on-site tool production and recycling.

Following a holistic approach to lithic analyses in which multiple independent sources of evidence converge to produce more inter-subjective and reliable results, the findings derived from these methods are combined and subsequently used for both intra- and inter-assemblage comparisons. This methodology allows reconstructing and characterizing technological strategies of the individual assemblages in a first step. Subsequently, diachronic variability within sequences as well as across regions and periods are analyzed on this basis in a second step. These methods are adequate to assess and compare the overall lithic technology of early modern humans at various archaeological sites and to obtain information on behavioral variability during the MSA of southern Africa.

CHAPTER 3. RESULTS AND DISCUSSION

This chapter summarizes the principle findings of the published articles that form this dissertation – listed in *III. LIST OF PUBLICATIONS* and attached in the *APPENDIX* – and contextualizes these results within the larger framework of MSA research and human evolution. The synoptic presentation of results is structured by the three main areas of research outlined in *CHAPTER 2.1*. For each section, the relevant published papers are first listed with respect to their appearance in the *APPENDIX*, followed by an individual exposition and contextualization of the main findings for each article. A discursive summary concludes each section by integrating the results of individual articles into larger frameworks of current research topics and questions.

3.1. The nature and significance of coastal adaptations during the MSA

The following papers address the nature and variability of coastal adaptations during the MSA. After a presentation of the principal findings of these articles, the section concludes by discussing the wider implications of these behaviors for the bio-cultural evolution and early migrations of modern humans out of Africa.

- **Will, M.,** Parkington, J.E., Kandel, A.W., Conard, N.J., 2013. Coastal adaptations and the Middle Stone Age lithic assemblages from Hoedjiespunt 1 in the Western Cape, South Africa. *Journal of Human Evolution* 64, 518–537 (*APPENDIX i.a*).
- Kyriacou, K., Parkington, J.E., **Will, M.,** Kandel, A.W., Conard, N.J., 2015. Middle and Later Stone Age shellfish exploitation strategies and coastal foraging at Hoedjiespunt, Saldanha Bay, South Africa. *Journal of Archaeological Science* 57, 197–206 (*APPENDIX i.b*).
- **Will, M.,** Kandel, A.W., Conard, N.J., 2015a. Coastal adaptations and settlement systems on the Cape and Horn of Africa during the Middle Stone Age. In: Conard, N.J., Delagnes, A. (Eds.), *Settlement dynamics of the Middle Paleolithic and Middle Stone Age, Vol. IV*. Kerns Verlag, Tübingen, pp. 61–89 (*APPENDIX i.c*).
- **Will, M.,** Kandel, A.W., Kyriacou, K., Conard, N.J., 2016. An evolutionary perspective on coastal adaptations by modern humans during the Middle Stone Age of Africa. *Quaternary International* 404, 68-86 (*Appendix i.d*).

Will et al. (2013) report on the principal findings from renewed excavations at the MSA shellfish-bearing site of HDP1 conducted during 2011 by a joint team from the universities of Tübingen and Cape Town under the direction of N. Conard. A particular focus of this article was put on the analysis of lithic assemblages from the site, and the question of how far these assemblages can provide behavioral insights into the nature of coastal adaptations. HDP1 is located in Saldanha Bay (Western Cape, South Africa) about 110 km north-northwest of Cape Town and 100 m away from the modern Atlantic coastline. The coastal site was first recognized in 1973 during field trips and subsequent surface collections from exposed sediments. Small-scale excavations were conducted at HDP1 during 1994–1998 by J. Parkington (Berger & Parkington, 1995; Parkington et al., 2004), but no comprehensive data on the stratigraphy, shellfish assemblages, dating and stone artifacts were published.

The new excavations established three phases of occupation at HDP1, which are dated by luminescence methods (OSL, TL) and contextual data to the last interglacial (MIS 5e, ca.

130–119 ka). Each archaeological horizon contains abundant lithic artifacts, shellfish, terrestrial fauna, ostrich eggshell and ground ocher. Detailed analyses of the lithic assemblages aimed to reconstruct the human activities and technological strategies that were performed at the site. In addition to the methods outlined in *CHAPTER 2.2*, quartz fracture analysis (Knutsson, 1988; Callahan et al., 1992) and experimental knowledge about quartz knapping (Driscoll, 2010; Tallavaara et al., 2010) were applied due to the specific mechanical fracturing characteristics and the abundance of this raw material at the site.

The lithic analyses show that the main characteristics of the assemblages remain constant throughout the three archaeological horizons, and thus the use of the site. In terms of raw material procurement, knappers predominantly used local quartz, ranging in abundance between 61–91%. Overall, quartz dominates all other raw materials by almost four to one. These other raw materials include local quartz porphyry and calcrete as well as non-local silcrete. Comparisons with the Diepkloof Rockshelter silcrete database (Porraz et al., 2008) revealed that at least two silcrete varieties correspond to four primary outcrops on the Vredenburg Peninsula, thus being imported over at least 10–30 km. Knappers at HDP1 used multiple methods of core reduction throughout the sequence to produce different forms of flakes, including bipolar, platform, Levallois and discoid variants. These strategies generally involved little preparation of platforms. Blank types other than flakes are rare. Regarding tool manufacture, denticulates and notches represent the most frequent types, followed by some scrapers and lateral retouch. The assemblages document complete, bipolar and hard hammer reduction sequences for the locally available quartz, but truncated manufacture chains with many isolated end products for silcrete, which had to be transported to the site. The import of silcrete tools to HDP1 suggests that well-provisioned individuals executed planned movements from inland sites to the shoreline to exploit shellfish.

In terms of diachronic trends, the three successive lithic assemblages demonstrate a homogenous pattern with regard to both technology and typology. These observations suggest a conformist approach to raw material acquisition and stone knapping through the occupation phases without significant temporal change. From a regional perspective, the HDP1 lithic assemblages show a unique techno-typological signal when compared to other shellfish-bearing MSA sites in southern Africa (Will et al., 2013: p. 531–532). It is unclear whether this signal is due to a raw material economy dominated by quartz with its special flaking properties (see also Steele et al., 2012) or differences in the age and use of the site (see Douze et al., 2015). In any case, HDP1 highlights the technological diversity associated with early coastal adaptations during the MSA (Wurz, 2012; Will et al., 2016).

On a more general level, what behavioral information can be inferred from the lithic assemblages regarding the settlement and use of coastlines? Contextual evidence from the site confirms the anthropogenic accumulation of the shellfish and the direct association with the recovered material culture, allowing for further behavioral interpretations. Combining the lithic evidence with other sources of information, HDP1 demonstrates the simultaneous occurrence of anticipated long-distance transport and flexible use of raw materials, systematic gathering of shellfish and use of ground ocher. These behaviors are frequently cited as elements being indicative of “cultural modernity” or complex cognition (McBrearty & Brooks, 2000; Henshilwood & Marean, 2003; Conard, 2005; 2008) and occur at HDP1 already in early MIS 5. Moreover, the joint and uniform occurrence of these behavioral patterns during successive occupations document a robust pattern of land-use that can be interpreted as stable and inter-generational adaptations of mobile hunter-gatherer groups to coastal landscapes as early as MIS 5e. Together with Pinnacle Point 13B (Marean et al., 2007; Marean, 2010), HDP1 provides early evidence for coastal adaptations by modern humans and constitutes the oldest open-air locality indicative of such behaviors, indicating the untapped potential of these types of sites.

Combining information from the old and new excavations at HDP1, **Kyriacou et al. (2015)** build on this work by studying the shellfish remains of the site in more detail. Such an analysis is crucial as it provides the most direct evidence for the collecting strategies and consumption of marine foods by early modern humans during the MSA. In order to contextualize these behaviors, comparisons to local LSA shell middens and other malacological assemblages of MSA age were performed. The LSA shellfish assemblages derive from three middens at Lynch Point (LP 18, 19, 20), which is located in Saldanha Bay only 10 km from HDP1. The sites were excavated by a joint venture between the Archaeology Contracts Office and Club Mykonos (Langebaan) in 1988.

The analyses of the combined shellfish assemblages at HDP1 reveal many similarities to other MSA sites, particularly along the Atlantic coast of the Western Cape such as Ysterfontein 1 (Klein et al., 2004; Avery et al., 2008). In terms of species abundance, the inhabitants predominantly harvested granite limpets (*Cymbula granatina*; 56–69%) and black mussels (*Choromytilus meridionalis*; 15–32%), which together dominate the three archaeological horizons (84–88%). These shellfish species live in the inter-tidal zone, where they constitute abundant, sessile, accessible and predictable prey with relatively high meat yields. These resources can be collected with minimal effort and simple technology, while at the same time providing a reliable source of nutrition in an environment (i.e., Fynbos) that is

otherwise characterized by seasonal fluctuations in the availability of terrestrial resources. The large average sizes of the limpets at HDP1 indicate less intense collections compared to the LSA, a pattern consistent with observations on shellfish metrics from other MSA sites such as Ysterfontein, Klasies River or Blombos (Avery et al., 2008; Steele & Klein, 2008; Klein & Steele, 2013). A collection strategy geared towards the systematic and selective exploitation of a narrow range of accessible species with a focus on large specimens suggests acquisition during short, episodic and repeated visits to the coast by the highly mobile inhabitants of HDP1. These interpretations of settlement patterns deduced from the shellfish remains support previous behavioral inferences from the lithic assemblages: low lithic densities, expedient use of predominantly local raw materials, little on-site retouch and the importation of non-local silcrete tools all indicate short but scheduled trips to the sea by small groups of modern humans at HDP1 (Will et al., 2013).

From a diachronic point of view, the LSA shellfish assemblages from Lynch Point differ from their MSA counterparts at HDP1 with regard to the much smaller size of limpets and an overall higher species diversity. Based on ethnographic observations (e.g., Bigalke, 1973; Meehan, 1982; Moss, 1993; Bird et al., 2004), these differences can be interpreted as broader and more flexible strategies of coastal foraging with more intensive shellfish collection of hunter-gatherers during the LSA in this region. This more intense harvesting of shellfish remains could be a result of more people collecting marine resources, a general increase in the use of these foods, or a combination of both (Klein, 2001; Parkington, 2003; Avery et al., 2008; Steele & Klein, 2008; Klein & Steele, 2013; Jerardino, 2016). In contrast, MSA people at HDP1 harvested a narrow range of large, mid-intertidal mussels and limpets to satisfy their relatively low demands for shellfish meat without significantly impacting shellfish populations. These observations from Saldanha Bay fit a long-standing hypothesis that emphasizes the differences in the nature and intensity of coastal adaptations between the MSA and LSA (e.g., Klein, 2000; 2001; 2009; Klein & Steele, 2013; Jerardino, 2016). It is clear, however, that shellfish were an important part of the overall subsistence of modern humans during the MSA at HDP1: the systematic collection and consumption of a consistent range of marine invertebrates occurs throughout more than a meter of sediment, suggesting a planned, stable and inter-generational integration of shellfish into the diet.

In a chapter from an edited book concerned with settlement dynamics of the MSA and Middle Paleolithic, **Will et al. (2015a)** integrate the local findings from HDP1 on coastal adaptations into larger geographical scales. The article follows two main threads. First, it evaluates site use, mobility patterns and settlement strategies that are associated with coastal

sites during the MSA of sub-Saharan Africa. Secondly, the paper provides a hitherto lacking sub-continental review of coastal adaptations in Africa south of the Sahara. Combining these threads, the article aims to shed new light on the nature and variability of coastal adaptations during the MSA of sub-Saharan Africa and discuss diachronic trends.

Starting from the local view, Will *et al.* (2015a) combine several strands of archaeological evidence to reach a comprehensive interpretation of settlement strategies and site use at HDP1. This assessment shows that the locality likely functioned as a specialized and temporary camp during short but repeated occupations, with the main purpose of collecting shellfish from the nearby ocean. Long-distance transport of silcrete tools from inland outcrops indicates that the inhabitants executed planned movements to the coastline in order to exploit the resources there. The silcrete data also suggest that HDP1 was embedded in a larger settlement system, with groups of mobile hunter-gatherers shifting between coastal habitats and the hinterland, similar to Parkington's (1976; 1981) seasonal mobility model. These sequential phases of occupation led to the formation of three archaeological horizons with principally the same behavioral patterns for lithic technology, coastal foraging, butchering of small animals, and the use of ochre. The successive stratification and homogeneous behavioral signals indicate a consistent pattern of land-use that suggest that stable and systematic adaptations of modern humans over several generations to coastal landscapes were already in place during the last interglacial (ca. 130–119 ka).

In a larger geographical overview, these observations support findings from other sites in the Cape and on the Horn of Africa. Pinnacle Point 13B in southern Africa demonstrates that the occasional use of marine resources goes as far back as the late Middle Pleistocene (Marean *et al.*, 2007). Early sites from MIS 5e, such as HDP1, Abdur and Asfet (in Eritrea; Walter *et al.*, 2000; Beyin, 2013), show a slightly increased use of coastal resources and landscapes, associated with long-distance transport of tools to the coastlines. Only during later MIS 5 and MIS 4, however, did MSA people accumulate large amounts of shellfish in association with abundant debris of stone knapping, butchering, hearths and other site maintenance activities. Sites such as Klasies River, Blombos, Ysterfontein and Pinnacle Point show that the systematic and optimized exploitation of shellfish (Jerardino & Marean, 2010; Langejans *et al.*, 2012; Jerardino, 2016) is associated with residential sites during these times (e.g., Henshilwood *et al.*, 2001a; Avery *et al.*, 2008; Marean, 2010). In addition, MSA localities such as Pinnacle Point, Klasies River and Blombos yield occupation intensities that increase with shorter distances to the coast. These observations indicate that a coastal location was an important determinant for the MSA inhabitants in choosing sites for occupation (e.g.,

Fisher et al., 2010; Marean, 2010), and that mobility systems were strongly influenced by the exploitation of shorelines.

In sum, this review of recent evidence from the western and southern coasts of South Africa, and as far north as the Red Sea, demonstrates the use of coastal landscapes and resources by modern humans over more than 100 ka from late MIS 6 until early MIS 3. MSA people made use of shellfish in these ecosystems, even though they vary with regard to marine productivity, oceanographic, geographic and environmental attributes. Yet despite these dissimilarities, early modern humans exploited marine resources in a consistent manner. The archaeological record of the South African Cape region demonstrates that coastal ecosystems functioned as important areas for occupation during much of the MSA in this area. Here, the article observed a re-arrangement in the settlement system which expands its boundaries to include coastlines and their resources on a regular basis. From a sub-continental perspective, mobile hunter-gatherers systematically integrated variable coastal landscapes and their resources into their settlement strategies throughout much of the MSA. Such behavioral adaptations to coastal ecosystems during the preceding ESA are thus far unknown (e.g., Jerardino, 2010; Colonese et al., 2011; Kandel & Conard, 2012), although freshwater resources were occasionally consumed (Joordens et al., 2009; Braun et al., 2010; Archer et al., 2014). In contrast, people during the LSA exploited marine resources more intensely than MSA populations. Only in the LSA did the consumption and discard of shellfish lead to the repeated formation of true shell middens (see also Jerardino, 2010; 2016).

The summary of coastal adaptations also revealed consistent diachronic trends. The earliest sites during MIS 6 and MIS 5 are characterized by a relatively low intensity of shellfish use, mainly deriving from specialized camp sites. This being said, these localities already demonstrate the systematic integration of marine resources into overall land-use strategies. Subsequently, there is a strong signal of intensifying coastal settlements and use of marine resources throughout MIS 5 with coastal landscapes serving as focal points for occupations. At Blombos and Klasies River, occupations during later MIS 5 and MIS 4 demonstrate markedly higher settlement intensities and shellfish densities. Furthermore, these assemblages are sometimes accompanied by additional evidence of complex material culture such as the production of shell beads (Henshilwood et al., 2004; d'Errico et al., 2008), bone tools (Henshilwood et al., 2002a; d'Errico & Henshilwood, 2007) or geometric engravings on ocher (Henshilwood et al., 2002b; d'Errico et al., 2012c).

The question regarding whether the interpretations reached by Will *et al.* (2015a) apply to the entire MSA record of Africa, and what the implications of these coastal

adaptations might have been for the evolution of modern humans in general, remain open in the respective paper. These issues have been assessed in an article by **Will *et al.* (2016)**, which addresses the nature and variability of coastal adaptations by modern humans during the MSA at the scale of the entire African continent from the perspective of evolutionary causality. The work builds directly on previous local and regional (Will *et al.*, 2013; Kyriacou *et al.*, 2015) as well as sub-continental summaries (Will *et al.*, 2015a). From a theoretical standpoint, the article provides the first explicitly evolutionary perspective on coastal adaptations in order to answer questions about the importance and implications of these behaviors for the bio-cultural evolution of *Homo sapiens*. Accordingly, the central question of the article concerns ultimate evolutionary causality: How could coastal adaptations have increased the reproductive fitness of early modern human populations?

In order to make use of the evolutionary potential of the long-term MSA record regarding the use of marine resources and coastal settlements by modern humans, the article focuses on a multi-generational scale that examines coastal adaptations on a (meta-) population level, emphasizing both regional and temporal variability. The overarching aim is to link evolutionary concepts on biological adaptations with relevant archaeological data. To this end, the paper provides an explicitly evolutionary definition of coastal adaptations that is grounded in basic principles of evolutionary biology. Coastal adaptations in such an approach are defined as a “[...] *multifaceted array of behavioral traits in a population that incorporates the use of marine resources and the occupation of coastal landscapes*” (Will *et al.*, 2016: p. 70). This encompasses the regular consumption of food resources from (or adapted to) salt water seas by means of active and systematic acquisition, but excludes inadvertent, opportunistic or occasional use, as well as foods deriving from freshwater environments (which were already collected by *Homo erectus* in the ESA, see e.g., Braun *et al.*, 2010; Archer *et al.*, 2014). Additionally, coastal adaptations include the extension of the settlement system to include coastal and near-coastal areas as occupation spots on a regular and planned basis, in contrast to people simply traversing these ecosystems.

In order to relate information on coastal adaptations to questions of evolutionary causality, the article reviews published data on marine subsistence, technological systems and settlement patterns to assess the specific nature of these behaviors by modern humans and their temporal and spatial variability in the entirety of Africa during the MSA. A systematic overview of the published literature shows that 25 sites have yielded evidence for coastal adaptations as defined above (Will *et al.*, 2016: Table 1). At most sites in northern Africa, the Red Sea and southern Africa, people collected inter-tidal shellfish (n=21), but there is also

evidence for seal hunting (n=8), and rare fishing (n=5). The sheer caloric value of these marine resources is, however, low compared to the nutritional values of terrestrial fauna at MSA sites (Clark & Kandel, 2013). From a diachronic point of view, the current MSA record suggests that modern humans occasionally consumed marine resources during the late Middle Pleistocene, but systematic and optimized gathering of a variety of marine food items dates to MIS 5 and 4, where the number of sites increases dramatically. Archaeozoological studies show that people exploited marine resources in a flexible but methodical manner on the Atlantic, Indian, and Mediterranean coasts during this time frame (Steele & Alvarez-Fernandez, 2011; Langejans et al., 2012; Dusseldorp & Langejans, 2015; Kyriacou et al., 2015; Jerardino, 2016), although they differ in oceanographic parameters.

Regarding technological systems, lithic assemblages associated with coastal sites are characterized by a high variability in technology, typology and raw materials (Wurz, 2012; Will et al., 2013). These (near-) coastal sites yield a particularly high frequency and wide range of non-lithic material culture in both northern and southern Africa, including elements of complex material culture that are generally rare in the MSA, such as bone tools and shell beads. Although the coastlines of northern, north-eastern and southern Africa differ with regard to geographic, environmental and oceanographic parameters, there is ample evidence that mobile hunter-gatherers integrated these variable coastal landscapes into their settlement strategies for more than 100 ka during the MSA. This is shown by evidence for stable, repeated and planned occupations on coastlines from many archaeological localities over Africa. At several sites in northern and southern Africa, people intentionally abandoned sites at times when they were too far away from the ocean and settled more intensely when the shoreline was close by. These observations suggest a re-organization in the settlement system of MSA hunter-gatherers which expands its boundaries from exclusively inland locales to include novel, and at times challenging, coastal ecosystems on a regular basis.

Considering the reviewed evidence, what is it that characterizes the specific nature of coastal adaptations by *Homo sapiens* during the MSA of Africa? The current archaeological record shows that this suite of adaptive behavioral traits can be defined by its systematic character and long duration, as well as its verifiable impact on the overall adaptive suite of modern human populations. Both evidence from archaeozoological and lithic analyses show that people planned their trips to the coasts, taking lunar cycles and tidal changes (Marean, 2010; 2011; 2014), as well as meat yields of marine mollusks (Langejans et al., 2012; Jerardino, 2016), into account. Coastal adaptations are clearly a multi-generational phenomenon (duration of ~100 ka), with independent populations from various geographical

regions and technological traditions engaging in the settlement and exploitation of coastal ecosystems. Finally, elements of material culture such as marine shells as components of necklaces or ocher-processing kits indicate that coasts, oceans and their denizens were part of a complex web of dietary, technical, social and symbolic interactions for MSA modern humans (see Beaton, 1995; Marean, 2010; 2014). The components of this behavioral complex are all in place from MIS 5e onwards, suggesting that the beginning of the Late Pleistocene marks the potential start of coastal adaptations as defined above. Thus, even when taking potential bias into consideration and admitting less intense use compared to the LSA, there can be no doubt that coastal adaptations are an important and persistent signature of MSA people and their record between at least MIS 5 and MIS 3, based on data from 25 archaeological sites (see also Parkington, 2010; Marean, 2014; *contra* Bailey, 2009; Boivin et al., 2013; Groucutt et al., 2015a).

The article places these archaeological observations in the framework of evolutionary causality by proposing several hypothetical, but testable, evolutionary scenarios for how these behaviors could have increased the reproductive fitness of their bearers. This model building proceeds by combining archaeological data with biochemical, ethnographic, neurological, nutritional and medical studies (see respective references in Will et al., 2016: Section 6.2). Will *et al.* (2016) construct two independent evolutionary scenarios. First, the regular consumption of marine foods that are rich in nutrients important for the maintenance and development of neurological tissue by pregnant and lactating women during the MSA would have ensured the normal development of an infant's brain by fueling its specific nutritional demands. Such a diet would have also increased the survival potential of the child to reproductive age. A constantly higher intake of brain-selective nutrients over longer time periods can also prevent deficiency diseases caused by a lack of these substances, reducing mortality rates in the entire population, but particularly for demographically important individuals such as lactating women as well as children. Among modern coastal foragers, women of all ages and children participate most frequently in shellfish collecting (Bigalke, 1973; Meehan, 1982; Moss, 1993; Bird et al., 2004) and marine resources would have provided these group members with a reliable source of essential nutrients during the MSA (see also Yesner, 1980; Parkington, 2001; 2003; 2006; Kyriacou et al., 2014).

The second model proposes that MSA groups could have buffered against food shortages in terrestrial resources by relocating to coastlines and consuming marine resources as fallback foods. They would thereby reduce mortality rates in the entire population in the long run relative to groups without access to marine resources or the ability to exploit them.

This hypothesis matches the reviewed archaeological record, which shows that coasts and their resources were an integral part of the overall settlement and foraging system for some MSA populations, who shifted their settlements from interior to coastal areas. Moreover, the data summary demonstrated that MSA people consumed marine resource on a stable and regular basis over many generations, but did not change their overall subsistence to these foods. Rather, they added marine prey to a diet that mostly consisted of terrestrial taxa, such as bovids and ungulates (Jerardino, 2010), a pattern consistent with these resources serving as potential fallback foods (*sensu* Marshall & Wrangham, 2007; Marshall et al., 2009).

Combining both models, the consumption of marine foods by modern humans resulted in an increase in diet breadth, which was an active choice by MSA people. At the same time, a higher intake of nutrients essential for normal brain development was a passive consequence of the natural biochemical food composition. Coastal adaptations could thus act both as a buffer against terrestrial food shortages and help to maintain large brains in an increased proportion of the population by preventing against deficiency diseases. Coastal adaptations thereby increased average fecundity and reduced population-level mortality rates. In conclusion, the archaeological record, combined with data from nutritional, neurological, medical and ethnographic studies, shows that the specific nature of MSA coastal adaptations had substantial potential to increase the reproductive fitness of modern human populations via several evolutionary pathways.

The significance of MSA coastal adaptations for the evolution of early modern humans

How do the findings presented here relate to current challenges and open questions outlined in *CHAPTER 1.2* and *CHAPTER 1.3*? There are roughly two opposed factions in current research regarding the importance and implications of coastal adaptations for the bio-cultural evolution of modern humans. One group of scholars asserts that coastal foraging and settlements are short-term and geographically isolated behaviors of negligible importance for human evolution (Bailey et al., 2007; Bailey, 2009; Boivin et al., 2013; Groucutt et al., 2015a), while others have characterized coastal adaptations as long-term, widespread and inter-generational phenomena that were integral to the origin, behavioral and cognitive evolution of early modern humans (Walter et al., 2000; Parkington, 2001; Broadhurst et al., 2002; Parkington, 2003; 2006; Marean et al., 2007; Cunnane & Stewart, 2010; Marean, 2010; Compton, 2011; Marean, 2011; Cunnane & Crawford, 2014; Marean, 2014). In order to differentiate between these hypotheses, this thesis has presented findings on coastal adaptations by *Homo sapiens* during the MSA from a local (Will et al., 2013; Kyriacou et al., 2015), regional (Will et al.,

2015a) and continental scale (Will et al., 2016), the latter including an explicitly evolutionary perspective of these behaviors. In sum, these studies show that:

- i.) Coastal adaptations are an integral part of the behavioral repertoire of modern humans in Africa by at least MIS 5e (ca. 130–119 ka). The MSA evidence consists of a multitude of sites ($n > 20$) in various regions of the African continent indicative of coastal foraging and settlements from late MIS 6 until early MIS 3.
- ii.) The nature of these behavioral adaptations can be characterized by their systematic character and long duration (~100 ka). Coastal adaptations had a verifiable impact on the overall adaptive suite of modern human populations, such as the re-organization of settlement systems and the manufacture of shell beads. While there is diachronic and regional variability in the African MSA record, the main elements of coastal adaptations remain constant throughout many generations in several independent populations on the Africa continent, even under different ecological circumstances.
- iii.) Coastal adaptations had ample potential to increase the reproductive fitness of modern human populations by several evolutionary pathways. The combination of theoretical models and empirical data from archaeological, biochemical, biological, ethnographical, nutritional, neurological and medical research highlights the likely role that coastal adaptations could have played in both the biological and cultural evolution of modern humans. The frequent occurrence of complex elements of material culture in coastal sites – such as bone tools or shell beads which post-date the earliest evidence for systematic use of marine resources and landscapes – provides an additional level of connections between coastal adaptations and cognitive evolution (see McBrearty & Brooks, 2000; Cunnane & Stewart, 2010; Parkington, 2010).
- iv.) Finally, the evidence for coastal adaptations by modern humans contrasts markedly with the record for earlier hominins (with the potential exception of Neanderthals, see below), particularly during the ESA or generally all localities > 200 ka worldwide. It is thus parsimonious to suggest that these behavioral novelties arising in *Homo sapiens* influenced long-term evolutionary trajectories in this lineage, particularly in comparison to other hominins lacking comparable adaptations.

Regarding the conflicting ideas within current research outlined above, the notion that coastal adaptations constitute short-term and geographically isolated behaviors with minimal impact on the daily lives and evolution of modern humans can be firmly rejected, at least for the African MSA record. New results from various geographic and temporal scales not only

support previous models that emphasize the importance of coastal foraging and settlements for the evolution of modern humans (Parkington, 2001; 2003; 2006; Marean et al., 2007; Marean, 2010; Parkington, 2010; Marean, 2011; 2014) but also clarify their specific nature. These empirical observations form the basis for more complex theoretical approaches that aim to construct direct links from these behaviors to ultimate evolutionary causality. In order to test the hypothetical scenarios for the selective advantages of coastal adaptations for *Homo sapiens* proposed above (Will et al., 2016), we will need more data deriving from an expanded spatiotemporal archaeological record in combination with nutritional and clinical studies, as well as more formal evolutionary models and research strategies.

Coasting out of Africa? The impact of MSA coastal adaptations for early human dispersals

The second major topic of current research concerns the potential relation between the emergence of coastal adaptations in modern humans and their subsequent dispersal out of Africa. Based on recent genetic and archaeological data, some scholars have proposed a predominantly coastal pathway of expansion from Africa that involves rapid dispersal around the rim of the Indian Ocean from Arabia to Australia (Sauer, 1963; Lahr & Foley, 1994; Stringer, 2000; Walter et al., 2000; Field & Lahr, 2005; Macaulay et al., 2005; Mellars, 2006; Bulbeck, 2007; Oppenheimer, 2009; Mellars et al., 2013). That being said, criticism has been raised against these propositions recently. Critics maintain that most of the evidence for such a route – coastal sites between the Arabian Peninsula and Australia – are missing due to changes in Pleistocene sea levels (Bailey & Flemming, 2008; Bailey, 2013; Bailey et al., 2015). Thus, preservation bias limits our current understanding of dispersal routes taken during the Pleistocene. Others object to a purely coastal route out of Africa based on environmental and genetic data, also pointing out that coastal migration models do not take relevant archaeological evidence from inland sites into account (e.g., Bailey, 2009; Boivin et al., 2013; Blinkhorn, 2014; Bailey et al., 2015; Groucutt et al., 2015a). It is striking that some of these authors also question the extent of coastal adaptations by *Homo sapiens* in Africa from a general point of view (see above), and remain skeptical in how far modern humans had successfully adapted to thrive in the variable coastal environments around the globe.

The research presented in this chapter (in particular: Will et al., 2015a; 2016) provides new information on the feasibility of coastal routes in terms of the potential of modern humans to efficiently exploit the variable coastal ecosystems which they would have encountered on their way. This is a necessary precondition of models that emphasize a coastal route of migrations, as habitat tolerance, demographic success, and dispersals are intimately

linked (see also Jerardino, 2016). The findings of this dissertation demonstrate that modern humans expanded their settlement system to include coastal landscapes in a systematic and repeated manner. This firm move into the ecological niche of coasts opened new landforms as options for occupation and, crucial to models of dispersals, provided additional opportunities for demographic expansion. MSA populations were generally accustomed to geographic and ecological features of coasts and possessed the knowledge and abilities to acquire food resources efficiently from the surrounding ocean. While modern humans would have encountered novel coastal niches in Asia and Europe, the current evidence from Africa shows that MSA people were able to adapt successfully to various types of coastlines that differed in oceanographic, geographic and environmental parameters.

Together, these findings strongly suggest that the specific nature of coastal adaptations (Will et al., 2016), associated with increased behavior flexibility in general (e.g., Lombard, 2012; Kandel et al., 2015; Lombard, 2016), allowed both a general demographic expansion of modern human populations and opened the potential of a particular rapid spread along coastlines. Whether populations equipped with these adaptations actually spread exclusively or primarily along coastlines (Stringer, 2000; Field & Lahr, 2005; Bulbeck, 2007; Mellars et al., 2013; Erlandson & Braje, 2015), or rather in a combination of inland and coastal routes (Bailey et al., 2007; Boivin et al., 2013; Reyes-Centeno et al., 2014; Bailey et al., 2015; Groucutt et al., 2015a) thus becomes a matter of empirical study in various regions of Eurasia rather than theoretical speculation. At the very least, the research presented in this chapter highlights the ability by modern humans to efficiently use and thrive in variable coastal ecosystems, rendering these habitats as feasible routes for dispersals.

The coast is clear: future research directions into coastal adaptations during the Pleistocene

There are still many directions for future inquiry into coastal adaptations during the Pleistocene, which are outlined in detail elsewhere (Jerardino, 2016; Will et al., 2016). Most importantly, researchers have to take into account the various factors that might bias the current archaeological record on coastal adaptations – such as the loss of coastal sites due to global sea-level fluctuations during the Pleistocene (Van Andel, 1989; Bailey et al., 2007; Bailey & Flemming, 2008; Bicho & Haws, 2008; Bailey, 2009; Fisher et al., 2010; Bailey, 2013; Bailey et al., 2015) and different regional intensity of research – in order to come to balanced, robust and meaningful conclusions. Archaeologists will need to focus their work on the large strips of African coastline that remain *terra incognita*, such as western, central and eastern Africa, to correct for chronological and geographical bias in the MSA record (see Will

et al., 2016: Figure 1). Researchers might thus explore coastlines with a steep offshore bathymetric profile and narrow continental shelves or engage in underwater archaeology, which, though costly and logistically difficult, constitutes a promising research strategy that might yield qualitatively new insights (Erlandson, 2001; Bailey & Flemming, 2008; Gusick & Faught, 2011; Bailey et al., 2015; Erlandson & Braje, 2015).

Inter-species comparisons of coastal adaptations will be a particularly interesting research avenue from an evolutionary point of view. While there is no evidence for coastal adaptations before 200 ka for any hominin species at the moment (Colonese et al., 2011; Kandel & Conard, 2012; Will et al., 2016) the European Middle Paleolithic record provides potential, yet debated (Marean, 2014), evidence that Neanderthals also engaged in coastal foraging and settlements from MIS 6 onwards (Stiner, 1994; Finlayson, 2008; Cortés-Sánchez et al., 2011; Hardy & Moncel, 2011). Detailed comparisons of the specific nature of coastal adaptations by *Homo sapiens* and *Homo neanderthalensis* are required to assess the similarities, differences and potential evolutionary implications of these behaviors.

To conclude this section, it is fitting to give the floor to John Parkington, a pioneer and eminent scholar for the study of coastal adaptations in the African Stone Age. Reflecting a decade ago on the current state of research in South Africa, he concluded that MSA shellfish-bearing sites “[...] reflect some interesting combination of a shift in settlement strategy, an emphasis on shellfish collection and, perhaps, a spurt in hominid evolutionary change. We have much to discover from them” (Parkington et al., 2004: p. 19). Although researchers have made considerable progress during just the past 10 years in further characterizing coastal adaptations by modern humans – highlighted by recent findings from Pinnacle Point (Marean et al., 2007; Marean, 2010) and HDP1 (Will et al., 2013) – Parkington is still correct in maintaining that the African record holds large potential for future discoveries.

3.2. Lithic technology and behavioral variability during MIS 3 in southern Africa

The articles of this section report on findings that assess the variability and spatiotemporal structure of lithic technology during MIS 3 in southern Africa, with a particular focus on the thick and high-resolution sequence at Sibudu (~58 ka). The papers discuss the implications of these results for the cultural variability and complexity of MSA people after the HP and evaluate the causal mechanisms of behavioral change on various scales of analyses.

- **Will, M.,** Bader, G.D., Conard, N.J., 2014. Characterizing the Late Pleistocene MSA lithic technology of Sibudu, KwaZulu-Natal, South Africa. *PLoS ONE* 9(5), e98359 (*APPENDIX i.e*).
- Conard, N.J., **Will, M.,** 2015. Examining the causes and consequences of short-term behavioral change during the Middle Stone Age at Sibudu, South Africa. *PLoS ONE* 10(6), e013000. (*APPENDIX i.f*).
- **Will, M.,** Conard, N.J., submitted (revised). Assemblage variability and bifacial points in the lowermost Sibudan layers at Sibudu, South Africa. *Archaeological and Anthropological Sciences* (*APPENDIX ii.a*).
- Bader, G.D., **Will, M.,** Conard, N.J., 2015. The lithic technology of Holley Shelter, KwaZulu-Natal, and its place within the MSA of southern Africa. *South African Archaeological Bulletin* 70, 149–165 (*APPENDIX i.g*).

In order to further the understanding of MSA cultural variability during the Late Pleistocene, **Will et al. (2014)** set out to provide a detailed characterization of the lithic technology that follows the HP at Sibudu. Due to a research focus on the SB an HP, the archaeology of MIS 3 has received comparatively little attention, constituting an important research gap in current knowledge (see *CHAPTER 1.4*). Sibudu provides an apt case study as it preserves an exceptionally thick, rich, and high-resolution archaeological sequence (Fig. 3) that dates to early MIS 3 at ca. 58 ka (informally referred to as “post-HP” *sensu* Wadley & Jacobs, 2004; 2006). This sequence has recently been proposed as type assemblage for the “Sibudan” by Conard *et al.* (2012), based on a detailed analysis of the tool assemblages.

The current study analyzed the six uppermost lithic assemblages (BM–BSP) from the ca. 1.2 m deep sequence at Sibudu (n=2,649). The archaeological layers were excavated by the University of Tübingen from 2011–2013 using state-of-the-art field methods, and the assemblages constitute reliable analytical units due to this careful excavation strategy. The lithic analyses proceeded by the methods outlined in *CHAPTER 2.1*, studying raw material

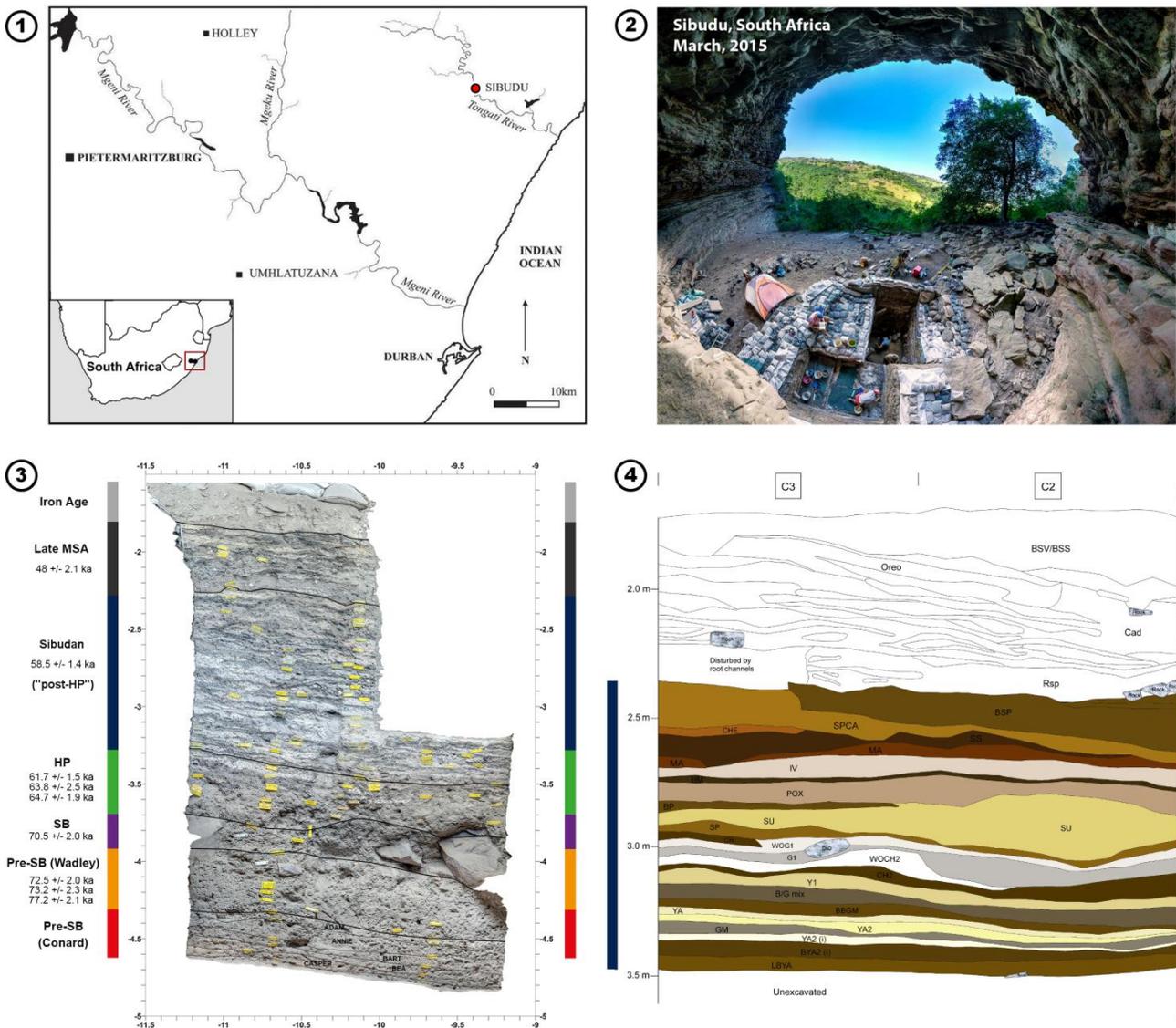


Figure 3. Overview on the principal archaeological study site of Sibudu. (1) Geographical location of Sibudu in relation to other sites in KwaZulu-Natal (modified after Will *et al.*, 2014: Figure 2). (2) Panoramic view on the excavations at Sibudu from within the rock shelter (created by M. Haaland). (3) Composite picture of the main archaeological profile at Sibudu in 2015, indicating the major culture-stratigraphic units. Absolute dates follow Wadley and Jacobs (2006) and Jacobs *et al.* (2008). Image created by M. Haaland, V.C. Schmid & M. Zeidi. (4) Zoom in the 1.2 m thick Sibudan sequence from squares C2/C3 excavated in 2015, showing layers LBYA–BSP. Note the fine lamination and high number of successive archaeological layers (created by M. Will & M. Zeidi).

procurement, core reduction strategies, blank manufacture, reduction sequences and tool production. This holistic approach allows reconstructing the key elements of the lithic technology that characterize the Sibudan, perform diachronic comparisons within the thick sequence of the site, and compare these findings to other assemblages post-dating the HP.

The results of the lithic analyses show that the six assemblages provide a distinct and robust cultural signal. The assemblages closely resemble each other in strategies of raw material procurement as well as various technological, techno-functional, techno-economic, and typological characteristics. These aspects occur in a homogenous manner in each

assemblage and can thus help to define the Sibudan (*sensu* Conard et al., 2012). In concrete terms, the inhabitants of Sibudu procured both raw material of local (e.g., dolerite, sandstone, quartzite) and non local (e.g., hornfels) origin, with a uniform approach to the use of the two main raw materials, dolerite and hornfels, in terms of reduction sequences and the production of blanks. Assemblages BM–BSP are all based on various blank types (flakes, convergent flakes, blades), with knappers producing blades of principally the same dimensions and morphology. Elongated and convergent products were preferentially selected for retouch and exhibit higher frequencies of prepared platforms. Furthermore, the coexistence of several reduction methods characterizes the layers of this study: parallel (or Levallois; *sensu* Boëda et al., 1990; Boëda, 1993) and platform systems are frequent, with inclined cores (or discoid; *sensu* Boëda, 1993; Peresani, 2003) playing a minor role. In terms of knapping technique, the inhabitants typically employed hard stone hammers with internal percussion to manufacture (convergent) flakes but soft stone hammers for blades in all assemblages.

The most prominent feature of BM–BSP is their strong emphasis on the distal part of the reduction sequence. The proportion of retouched artifacts is exceptionally high among pieces >25 mm (17–27%) in comparison to many other assemblages from the MSA that usually feature less than 2% tools (Volman, 1981; 1984; Wurz, 2000; 2002). The layers also exhibit a large amount of retouching debitage, supporting an intense on-site manufacture and recycling of tools. From a traditional typological point of view, unifacial points constitute the hallmark of retouched implements in BM–BSP (38–54%), while other typical MSA tools like scrapers, denticulates and notches occur rarely. From a techno-functional perspective, four tool classes which amount to more than two thirds of all retouched specimens characterize the assemblages. The large number of Tongatis, Ndwedwes, naturally backed tools (NBT) and asymmetric convergent tools (ACT) is a distinctive feature of the assemblages BM–BSP (for more detailed definitions, descriptions, and additional drawings of these tool concepts see: Conard et al., 2012; Will et al., 2014: p. 5–6). The highly repetitive pattern of organizing and modifying the working edges on these artifacts indicates a structured approach to tool manufacture that includes distinctive and well-defined reduction and resharpening sequences.

Contextualizing these findings within the framework of previous research, the findings from the stone artifact assemblages BM–BSP refute assertions that modern humans living after the HP possessed an unstructured and unsophisticated MSA lithic technology (e.g., Henshilwood, 2005; Mellars, 2007; Jacobs & Roberts, 2008; 2009). Instead, the results summarized above provide clear cultural signals that occur homogeneously in several independent technological and typological domains in six successively stratified assemblages

of different sample sizes and reduction intensities. Many of these characteristics, such as the well-recognizable tool assemblages with repetitive forms and distinctive resharpening sequences – or the production of morphometrically standardized blades by soft stone hammers – demonstrate a multi-step, structured and sophisticated approach to stone knapping (see also Conard et al., 2012). These findings are consistent with recent lithic studies of this time frame at Rose Cottage Cave (Soriano et al., 2007), Klasies River (Villa et al., 2010), Klein Kliphuis (Mackay, 2011) and Diepkloof (Porraz et al., 2013).

Regional comparisons of the findings at Sibudu constitute a first step towards structuring the lithic technological variability during MIS 3 in southern Africa. The lithic assemblages BM–BSP yield several techno-typological parallels with other contemporaneous MSA sites, particularly in the eastern part of southern Africa such as at the geographically nearby localities of Umhlatuzana (Kaplan, 1990; Lombard et al., 2010; Mohapi, 2013) and Rose Cottage Cave (Harper, 1997; Soriano et al., 2007). Having said that, the Sibudan assemblages contrast more strongly with sites from southern and western South Africa, particularly Klasies River (Singer & Wymer, 1982; Wurz, 2000, 2002; Villa et al., 2010) and Diepkloof (Porraz et al., 2013). The assemblages at Sibudu also demonstrate a distinctive and so far unique combination of techno-typological traits that include a particularly high abundance of unifacial points, and tools in general, clear patterning of production and recycling strategies for specific tool classes, the use of a soft stone hammer to produce blades, and the continuous co-existence of several core reduction methods that includes the discoid method. The findings presented in this article thus support the use of the Sibudan as a working model that can help to organize part of the cultural sequence of the MSA during MIS 3. At the same time, the study emphasizes the need for further research to identify the spatiotemporal extent of this proposed cultural taxonomic unit, with the most straightforward way being the study of the entire ~58 ka Sibudan sequence at the type site.

Conard and Will (2015) provide additional information on this issue by expanding the analyses of stone artifacts from this sequence to a total of eleven assemblages (WOG1–BSP). The article focuses on lithic analyses at a very fine scale, which has – with a few exceptions (e.g., van Peer et al., 2010) – usually not been the focus of MSA research. Previous results from OSL dating at Sibudu show that the bottom and top of the ca. 1.2 m thick deposits that directly overlie the HP indistinguishably date to ca. 58 ka, providing an exceptionally high temporal resolution of only a couple of centuries or millennia at most (Wadley & Jacobs, 2006; Jacobs et al., 2008; Wadley, 2013). In concert with findings from geoarchaeological work (Goldberg et al., 2009; Wadley et al., 2011; Miller, 2015), the high

number and fine lamination of the occupation horizons – with more than 20 often centimeter thin archaeological horizons (Fig. 3; see also Will et al., 2014: Figure 1) – and the sheer abundance and density of archaeological finds, the Sibudan sequence attests to repeated and intense occupations by MSA people that took place over short periods of time. The ~58 ka sequence at Sibudu thus provides an ideal case study to examine the causes and consequences of short-term variation in the behavior of modern humans during the MSA. Answering questions at this scale has implications for ongoing debates about the rates and mechanisms of cultural change during the MSA and the reasons why some innovations persist in the long run while others come and go.

Building on previous work (Conard et al., 2012; Will et al., 2014), the study analyzed 11 stratified lithic assemblages (WOG1–BSP; $n=7,799$) that form the uppermost ~70 cm of the Sibudan sequence. The study focuses on inter-assemblage comparisons based on various technological and typological attributes that aim to assess the nature and tempo of cultural change in the successive occupations at Sibudu. In addition, the article uses archaeozoological, paleoenvironmental and geoarchaeological information from the site to evaluate the underlying reasons for the observed variability in technological behavior. More specifically, the study investigated whether changes in demography, environment, subsistence and other socio-cultural dynamics were causal drivers of behavioral change at Sibudu.

The lithic analyses found considerable variation throughout the high-resolution sequence in raw material provisioning, technological and typological parameters (see Conard & Will, 2015: p. 7–23), demonstrating that knappers at Sibudu varied their technology over short time spans. In combination with the absolute dating results, these findings document an exceptional case of short-term cultural variability during the MSA. The trajectory of the observed changes is, however, not erratic or discontinuous, but follows clear temporal trends that are often gradual and cumulative in nature. In contrast to previous studies (Conard et al., 2012; Will et al., 2014), the results presented here depart from the six uppermost Sibudan layers (BM–BSP), which yielded a homogeneous cultural signature. Having analyzed a larger number of layers, the lithic assemblages can now be grouped into three cohesive units (WOG1–SP; SU–POX; BM–BSP), differing from each other in various domains of lithic technology, such as the procurement of raw materials, the frequency in the methods of core reduction, as well as the kind of blanks and tools made and used. These assemblage groups reflect different strategies of lithic technology, which build upon each other in a mostly gradual and cumulative manner. The lithic assemblages also show a clear pattern of development toward the techno-typological attributes that were previously defined as the

Sibudan cultural taxonomic unit (Conard et al., 2012; Will et al., 2014). The gradual trajectory of this change throughout the sequence encompasses: i.) a continuous increase in the procurement of non-local hornfels; ii.) a stronger emphasis on the manufacture of tools; iii.) a rise in the abundance of unifacial points; iv.) the gradual appearance and successive increase in the four main tool classes of the Sibudan (see Conard & Will, 2015: S7 Table).

Contextualizing these results on larger geographical scales, the later phase of the MSA during MIS 3 in KwaZulu-Natal and southern Africa can be characterized by dynamic cultural change rather than stasis or stagnation as has at times been claimed (see also Conard et al., 2012; Lombard et al., 2012; Villa et al., 2012; Mohapi, 2013; Mackay et al., 2014a). The findings also demonstrate that the Sibudan as a cultural taxonomic unit encompasses a larger degree of temporal and technological variability than previously acknowledged. To account for this heterogeneity, the article proposes several hypotheses and models for how to structure the Sibudan (Conard & Will, 2015: Figure 16), but favors those that emphasize gradual change and continuity consistent with the results presented here. Ultimately, there is no universally valid answer to the question of how much variability can be incorporated into one technocomplex (Brew, 1946). Additional synchronic and diachronic studies on various spatial scales – in Sibudu, KwaZulu Natal and southern Africa – are needed to test the definition and value of the “Sibudan” as a concept for structuring the MSA record of MIS 3 (see below).

In order to analyze the causal mechanisms behind the short-term cultural changes at Sibudu from various theoretical standpoints, the article applies models and ideas from organization of technology (Binford, 1980; Kelly, 1983; Nelson, 1991; Carr & Bradbury, 2011), ecological and evolutionary theory (Lewin & Foley, 2004; Prothero, 2004; Begon et al., 2006), and cultural transmission theory (Cavalli-Sforza & Feldman, 1981; Boyd & Richerson, 1985; Rogers, 1995; Henrich, 2001; 2004; Richerson & Boyd, 2005; Eerkens & Lipo, 2007; McElreath et al., 2008; Mesoudi, 2011; Kolodny et al., 2015). When looking at the archaeological material alone, there is no co-variation between published environmental information (summary in Conard & Will, 2015: S2 Text) and cultural change. Furthermore, the inhabitants of Sibudu constantly hunted the same types and range of animals in each occupation horizon of the sequence WOG1–BSP (Clark & Plug, 2008; Clark & Ligouis, 2010; Clark, 2011; 2013), suggesting that subsistence activities were not the main driver of different lithic technologies. In contrast, consideration of raw material properties and differences in mobility (Binford, 1980; Kelly, 1983; Bamforth, 1986; Kuhn, 1991; Andrefsky, 1994; Floss, 1994; Féblot-Augustin, 1997; Brantingham, 2003) as well as patterns of site use and reduction intensities of assemblages (Sullivan & Rozen, 1986; Roth & Dibble, 1988;

Mackay, 2008; Lin et al., 2013) were found to account for some of the observed patterns of changes such as the high amount of tools in assemblages that are also rich in non-local hornfels (Conard & Will, 2015: Figure 15; see also Wadley & Kempson, 2011).

The unidirectional temporal trajectory found for the four techno-functional tool classes fits the S-shaped cumulative distribution curve that is well-known from empirical and mathematical modeling work in cultural transmission theory as a typical pattern for the spread and adoption of many new technologies, practices and beliefs (Boyd & Richerson, 1985; Rogers, 1995; Henrich, 2001; Mesoudi, 2011). According to Rogers (1995) and Henrich (2001), an S-shaped uptake curve usually indicates local innovations of a particular feature with a subsequent increase in frequency by means of biased cultural transmission via social learning instead of random drift of a neutral trait (see also Eerkens & Lipo, 2005). While it is unclear why these techno-functional tool classes were increasingly transmitted to successive generations (e.g., superior function), social dynamics and various pathways of cultural transmission appear to have influenced the change in lithic technology observed at Sibudu.

In sum, the empirical observations coupled with various theoretical models on causal mechanisms suggest that short-term behavioral variability at Sibudu can best be explained by changes in technological organization and socio-economic dynamics, such as differential and biased pathways of information transmission instead of environmental forcing. This stands in opposition to dominant models of cultural change in the Paleolithic that commonly invoke external forcing by climatic and environmental factors (Vrba, 1995; Ambrose, 1998; Foley & Lahr, 2003; deMenocal, 2011; Potts, 2013), also in the MSA (Deacon, 1989; Ambrose & Lorenz, 1990; McCall, 2007; Ziegler et al., 2013). This being said, adaptive responses to variable environments by modern humans did certainly play a role in behavioral change throughout the MSA, even though the proposed causal links between environmental parameters and human behavior are often coarse-grained, underspecified or not demonstrated (Chase, 2010; Blome et al., 2012). To a certain extent, the findings of this study might be the result of the scale of analyses, which strongly influences the questions researchers can ask and answer with the archaeological record (Conard, 2001; Bentley & Maschner, 2003; Kuhn, 2013). On a fine temporal and spatial scale, internal causality emerging from social dynamics, settlement systems, independent technological innovations and the complex pathways of information transmission within and between groups might play a larger role than previously acknowledged. Moreover, this study demonstrates that external factors such as climate and environment should be used more prudently as causal explanations for cultural and behavioral change in the MSA (see also Chase, 2010; Villa et al., 2012; Clark, 2013; Porraz et al., 2013;

Discamps & Henshilwood, 2015), particularly with regard to the high behavioral variability and flexibility of early *Homo sapiens* (Lombard, 2012; Kandel et al., 2015; Lombard, 2016).

In a third article on the thick ~58 ka deposits at Sibudu, **Will and Conard (submitted)** report on the analyses of the final 12 lithic assemblages RB–G1 (>30 mm; n=3,081) that constitute the lowermost 50 cm of the Sibudan sequence directly above the HP. The article pursues two main research goals. First, it assesses the nature and diachronic variability of lithic technology in the lower Sibudan layers, the relation of these assemblages to the rest of the sequence, and their implications for models of behavioral change within the MSA of southern Africa. The second topic of the article concerns the use of so-called type fossils to define and identify archaeological cultures or chronological phases within the Stone Age. In past and recent studies within the southern African MSA, researchers have used the occurrence of finely crafted, bifacially worked foliate or lanceolate points as the typical markers of the SB (Goodwin & van Riet Lowe, 1929; Breuil, 1930; Clark, 1959; Henshilwood et al., 2001a; Wadley, 2007; Jacobs et al., 2008; Villa et al., 2009; Henshilwood, 2012). With recent criticism of this approach and the controversial status of the SB in general (see *CHAPTER 1.4*) the article asks whether bifacial points in southern Africa are largely confined to the SB or rather constitute dynamic elements of lithic technology. With regard to these questions, the paper reports on the presence of bifacial points in layers at Sibudu that directly overlie the HP, assesses the modalities of their production and discusses their wider implications.

Analyses of the lower Sibudan lithic assemblages reveal a much higher use of sandstone, quartz and quartzite compared to the upper stratigraphic units where dolerite and hornfels are the most abundant lithic raw materials. The older units are characterized by frequent use of informal, or expedient, core reduction methods, but also document regular bipolar reduction of locally available quartz and some use of Levallois methods. Platform production for blades and discoid methods are virtually absent as opposed to the upper assemblages POX–BSP. Assemblages RB–G1 are flake-based (92–96%), with few convergent flakes and almost no blades or bladelets. Within RB–G1, knapping characteristics indicate that flakes were produced by internal percussion with hard and soft stone hammers (*pierre tendre*). Knappers rarely retouched blanks during the deposition of RB–G1 (1–4% tools) and there is a less regular production of specific tool types compared to the upper layers. From a classic typological perspective, denticulates and notches, side scrapers and minimally retouched pieces constitute the most frequent implements in the lower sequence. While being the most abundant tool forms in the middle and upper part, and at many other

MIS 3 sites in southern Africa, unifacial points are absent in the lower stratigraphic layers of the Sibudan. From a techno-functional point of view, Tongatis, Ndwedwes and ACTs – which feature abundantly in the upper part of the sequence – are entirely absent. Although the studied assemblages directly overlie the HP occupations, RB–G1 do not feature any core reduction methods, blank categories or tool types typical for this technocomplex, attesting to little or no vertical displacement of artifacts.

Surprisingly, knappers manufactured bifacial points (n=7) – mainly made from quartz (n=5) with one specimen on CCS and quartzite each – during the earliest Sibudan occupations. They even constitute the most numerous tool type in the lowermost units RB and LBYA together with splintered pieces. A more detailed technological, morphometric and contextual analysis of the bifacial pieces showed that the inhabitants discarded these artifacts in advanced manufacturing stages, during which both surfaces are completely covered by invasive negatives from flakes used to shape the morphology of the blank (*façonnage*). Regarding the process of reduction, knappers shaped the small bifaces in an alternating fashion, in which removals alternate from one surface to the other in a non-hierarchical, non-sequential manner (Boëda, 1995; Soriano et al., 2015: Figure S11). The technological analyses suggest that the bifacial tools represent finished and potentially imported products, an interpretation supported by the observation that layers YA, BYA2i, LBYA and RB are not characterized by *façonnage* but by several debitage methods. This being said, the reduction of some bifacial tools on site is attested by the presence of bifacial shaping flakes of quartz (n=19) in a sample of artifacts (<30 mm) from the lowermost five assemblages RB-YA, and one discarded bifacial on quartzite in an early stage of production.

What are the implications of these results for the nature, technological variability and taxonomic status of the Sibudan sequence? The results from the lowest part of these deposits reveal an additional level of diachronic variability in relation to the upper three phases (Will et al., 2014; Conard & Will, 2015), with RB–G1 constituting a coherent fourth phase in the ~58 ka sequence. This adds to the previous picture (Conard and Will, 2015), underlining that the sequence after the HP at Sibudu is characterized by a high variability in raw material use, technological and typological aspects. This is an unexpected pattern as both the top and bottom of this meter-thick sequence are dated to ~58 ka, implying that archaeological material accumulated rapidly and occupations span only a duration of centuries, or at most very few millennia. The results thus highlight the great diversity and flexibility of human technological behavior (see also Kandel et al., 2015) over even short periods during the MSA, a factor that

Paleolithic studies with coarser scales – operating on the level of stratigraphic aggregates or technocomplexes instead of individual find horizons – either ignore or sweep under the table.

The sequence presented here raises the crucial issue of how to best view short-term cultural change over narrow time spans, particularly in regard to the taxonomic status of the Sibudan (see also Conard & Will, 2015). It is important to emphasize here that the utility of any cultural taxonomy can only be assessed in relation to research questions, how it helps us gain insight into past human lifeways and for testing specific hypotheses (Brew, 1946; Dunnell, 1971; Tschauer, 1994; Roberts and Vander Linden, 2011). In this regard, usage of the term Sibudan based on high-resolution lithic analyses, instead of a generic, informal and spatiotemporally coarse term such as “post-HP”, can help to lay the groundwork for comparative research aimed at characterizing and explaining patterns of cultural change within this time frame (see Mitchell, 2008: p. 58). By emphasizing both the distinctive elements (Will et al., 2014) and the high variability (Conard & Will, 2015) the results can help assess patterns and causes of short-term behavioral change in more detail and contextualize the disappearance of the HP. The Sibudan can also serve as a useful analytical tool that provides a hitherto missing structure to the geographical and temporal variation in the archaeological record of MIS 3, especially in its earlier part (see Will et al., 2014; Bader et al., 2015). A systematic comparison of the full ~58 ka sequence data with other assemblages of this time period as part of a general overview on lithic technology during the early part of MIS 3 in southern Africa is currently underway (Will et al., in prep) and will shed further light on the utility of the “Sibudan” as an analytical device. For now, the work at Sibudu helps to establish new research agendas in what, until recently, was an area of scientific stagnation. Further implications for more general models of cultural evolution during the MSA, particularly its later phases, are discussed at the end of this section and in *CHAPTER 4*.

Coming back to the second issue of the article, the study demonstrates for the first time the presence of bifacial technology from a stratigraphically and chronologically secure context during early MIS 3 in southern Africa. In contrast to the SB (Wadley, 2007; Villa et al., 2009; Högberg and Larsson, 2010; Lombard et al., 2010; Porraz et al., 2013; Soriano et al., 2015), the bifacials found in the Sibudan are few in number, characterized by smaller dimensions and the production by alternating removals in a non-hierarchical, non-sequential manner. Invasively-shaped bifacial points are generally not part of the tool inventories in the southern African MSA postdating the HP (Volman, 1984; Henshilwood et al., 2001a; Wurz, 2013; Mackay et al., 2014a; Wadley, 2015). They are absent in MIS 3 deposits of the long sequences at Klasies River (Singer and Wymer, 1982; Wurz, 2000), Rose Cottage Cave

(Wadley & Harper, 1989; Soriano et al., 2007) and other important sites (Mitchell, 2008). Yet, late MIS 3 assemblages from Sibudu (~38 ka) and Umhlatuzana (~36 ka) have also yielded distinct, bifacially retouched hollow-shaped points in the final MSA (Kaplan, 1990; Wadley, 2005; Lombard et al., 2010; Mohapi, 2013). Bifacial pieces are also present in other MSA phases of southern Africa (Mackay et al., 2010; 2014), most prominently in HP contexts at Diepkloof (Porráz et al., 2013) and Sibudu (de la Peña et al., 2013), but probably at many more HP sites (de la Peña et al., 2013: p. 133).

What do these observations mean with regard to the questions raised above? In a recent review of the SB, Henshilwood (2012: p. 218) states that “*bifacial points serve to identify the presence of a Still Bay phase at a site*”, an assertion to which many archaeologists in southern Africa currently agree. Based on the results presented in this paper, as well as other recent studies (de la Peña et al., 2013; Porráz et al., 2013; Mackay et al., 2014a), we must, however, conclude that bifacial technology is a dynamic aspect of the southern African MSA that comes and goes. On a larger geographical scale, similar forms of finely manufactured bifacial pieces also occur in other regions and phases of the African Stone Age (see McBrearty & Brooks, 2000; McBrearty, 2003) such as the Lupemban in central and eastern Africa (McBrearty, 1988; Taylor, 2011), the early Nubian complex of north-eastern Africa (Van Peer et al., 2003; Van Peer & Vermeersch, 2007), and the Aterian (or Atero-Mousterian) of North Africa (Debénath, 1992; Dibble et al., 2013; Scerri, 2013). In conclusion, the findings presented here, alongside other studies (e.g., de la Peña et al., 2013; Porráz et al., 2013; Conard et al., 2014) demonstrate that bifacial technology in the MSA of southern Africa constitutes a recurrent phenomenon. Its presence in different forms and contexts during the Late Pleistocene further erodes the old idea that bifacial technology in southern Africa is confined to the SB. More generally, bifacial technology constitutes a good example of an independent innovation – or technological convergence – within different phases of the MSA (see also CHAPTER 3.3). These results ultimately compromise the use of bifacial artifacts as *fossiles directeurs* or chrono-cultural markers (see also Otte, 2003; McBrearty 2003; Dibble et al. 2013; Porráz et al., 2013).

In order to compare and contextualize the evidence on lithic technology and behavioral variability during MIS 3 from Sibudu on a regional scale, **Bader et al. (2015)** studied stone artifact assemblages from the site of Holley Shelter, which is located only ~50 km away to the west in KwaZulu-Natal (see Fig. 2). In general, much research on the MSA in southern Africa has been conducted on coastal cave sites in the southern and western Cape, with studies of the east coast of South Africa only becoming more important in recent years

due to the (re-) excavation of well-stratified sites such as Sibudu, Umhlatuzana (Kaplan, 1990, Lombard, et al. 2010) and Border Cave (Beaumont, 1978, Villa et al., 2012). The overall scarcity of comparable localities, however, limits the current knowledge on the spatial and temporal variability of MSA lithic technology in KwaZulu-Natal. In order to rectify this situation, the article expands the research focus on other and lesser-known sites in the eastern part of South Africa. Holley Shelter constitutes such a locality: the site was excavated by G. Cramb between 1950–1960, but its archaeological material was only studied in a cursory manner. The paper presents a detailed technological study of the MSA lithic artifact from Cramb's excavations to derive new data from this site.

In terms of methodology, the study analyzed a total of 1,980 artifacts that derive from successive artificial spits in which Cramb excavated. These spits, which mostly consist of six-inch thick deposit, were used as analytical units for the assemblages (e.g., inch 6–12). Due to the fact that the excavations were conducted in the 1950s and the stratigraphic integrity was not completely clear, the first aim was to assess the degree of potential mixing and recovery bias among the lithic material. In this process, the study could confirm the integrity of the stratigraphy. The analyses also showed that the minor collection bias stemming from the old excavations does not ultimately compromise the nature and completeness of the lithic assemblages. This being a basis for meaningful further studies on technological behavior at Holley Shelter, the lithic analyses characterized the six-inch spit units as individual assemblages and investigated their diachronic variation throughout the occupation sequence.

The MSA assemblages at Holley Shelter are characterized by a blade and point technology that mostly derives from platform cores. In all assemblages, knappers used percussion by soft stone hammers for the manufacture of blades, but also for some other blank types. An outstanding feature of the site is the high frequency of tools in general, and the abundance of splintered pieces in particular, with the highest proportion of this artifact type (26–61%) reported from any southern African MSA site. These implements also show a high variability in overall morphology, the location and direction of splintered edges, and their orientation to each other. By using a techno-functional approach, comparable to the work of Hays and Lucas (2007) for Le Flagelot I in France, the article develops a new classificatory system which distinguishes three different sub-types of splintered pieces at Holley Shelter: single edge, opposed edge and diagonal splintered pieces (Bader et al., 2015: Table 8; Figures 3 & 4). These categories are present in most spits but vary in abundance throughout the sequence. Through detailed technological analyses, some of these pieces at Holley Shelter were shown to be used as tools instead of cores, resembling recent findings from the HP

layers at Sibudu (Langejans, 2012). In general though, the principal discussion on the function of splintered pieces, whether they were used as bipolar cores or wedges/chisels, is still ongoing (e.g., Villa et al., 2005; Le Brun-Ricalens, 2006; de la Peña, 2015),

In terms of diachronic trends, the results suggest three different phases of MSA occupation at Holley Shelter that vary in terms of raw material composition, core reduction, and tool manufacture. The lowermost spits (inches 30–36 and 36–42) are characterized by a predominant use of quartz that co-varies with intense use of bipolar reduction, and a comparatively low number of artifacts and tools (ca. 15%), with splintered pieces being the most frequent tool type. The technological phase in the middle of the sequence (inches 12–18, 18–24, 24–30) can be distinguished by an increase in hornfels procurement and a preferential production of long blades and elongated convergent flakes by platform methods. The highly abundant tools (19–43%) comprise the highest frequencies of unifacial points in the sequence (23–41%) – some of which are comparable to Ndwedwe and Tongati tools in the Sibudan (Conard et al., 2012; Will et al., 2014) – with splintered pieces being second in number. During the third and youngest phase (inch 0–6 and 6–12), knappers almost exclusively used hornfels to produce blades with prepared platforms from unidirectional platform cores. The number of retouched pieces is still high, but lower compared to the underlying spits (ca. 24%), and splintered pieces again replace unifacial points as the most frequent tool type.

The absence of reliable, absolute radiometric dates complicates the chronological placement of Holley Shelter into the chrono-stratigraphic framework of the southern African MSA. In order to obtain a rough age estimate of the so far undated sequence, the study compared Holley Shelter's lithic technology to other MSA sites in the eastern part of South Africa, using techno-typological and morphometric data. The lithic analyses demonstrate that the sequence does not feature SB, HP, final MSA or LSA industries. The exclusion of technologies that are mostly associated with MIS 4 and MIS 2 (and late MIS 3) implies that the Holley Shelter sequence belongs either to MIS 5 or early MIS 3. Compared to other sites in the general region – and while having some unique features such as the very high proportion of blades, tools and splintered pieces – the assemblages from Holley Shelter are most similar to lithic technology postdating the HP, particularly early MIS 3 assemblages at Umhlatuzana (Kaplan, 1990; Lombard et al., 2010; Mohapi, 2013), Rose Cottage Cave (Harper, 1997; Mohapi, 2007; Soriano et al., 2007) and Sibudu (Villa et al., 2005; Cochrane, 2006; Conard et al., 2012, Mohapi, 2012; Wadley, 2013; Will et al., 2014; Conard & Will, 2015). In contrast, they differ strongly from assemblages dating to MIS 5 or earlier (“early MSA”, e.g., Volman, 1981; Wurz, 2002; Lombard et al., 2012; Wurz, 2013; Mackay et al.,

2014a). The middle of the Holley Shelter sequence closely resembles the Sibudan layers at Sibudu (Conard et al., 2012; Will et al., 2014; Conard & Will, 2015) in various technological, typological and techno-functional characteristics, such as the occurrence of Ndwedwe tools and the use of soft hammer percussion for the production of blades. In sum, the comparative analyses suggest that the entire occupation sequence at Holley Shelter of about 100 cm falls broadly into the earlier part of MIS 3, and before ~35 ka.

The techno-typological markers found within the occupation sequence at Holley Shelter demonstrate that the inhabitants maintained a structured lithic technology with many diagnostic features outside of a HP or SB context, including clearly discernible tool classes and the frequent manufacture of long blades with soft stone hammer percussion. If the temporal placement of the settlements within MIS 3 is correct, these results support recent arguments that the MSA after the HP in southern Africa can be characterized by increased regionalization, but does not show evidence for cultural regression (e.g., Lombard & Parsons, 2010, 2011; Mackay, 2011; Conard et al., 2012; Lombard et al., 2012; Villa et al., 2012; Porraz et al., 2013; Mackay et al., 2014a). At Holley Shelter, the ultimate test of this hypothesis will be absolute dating of the sediments by radiometric methods.

The spatiotemporal structure of MSA lithic technology during MIS 3 in southern Africa

The main aim of the articles within this section was to correct the current research bias on the SB and HP by providing new data on MIS 3 lithic technology. Such a course of action was most prominently demanded by Mitchell (2008), but also many other leading MSA scholars (Villa et al., 2010; Lombard & Parsons, 2011; Conard et al., 2012; Porraz et al., 2013; Wurz, 2013). Having tried to answer to these calls, what conclusions can be drawn on the spatiotemporal pattern of lithic technology during MIS 3 and the cultural evolution of modern humans during the later part of the MSA after the HP? This dissertation is particularly interested in testing between the competing hypotheses that the MIS 3 can be considered as a time of cultural regression and reversal to earlier MSA lithic technology (Sampson, 1974; Deacon, 1989; Henshilwood, 2005; McCall, 2007; Mellars, 2007; Jacobs & Roberts 2008; 2009) – as most prominently argued by the Synthetic Model – or reflects increasing regionalization between more fragmented populations with principally the same degree of behavioral and cognitive complexity of preceding technocomplexes (Soriano et al., 2007; Lombard & Parsons, 2010; 2011; Conard et al., 2012; Porraz et al., 2013; Mackay et al., 2014a). Answers to these questions also bear on the underlying mechanisms for cultural change during MIS 3 and the reasons for the disappearance of the HP in southern Africa.

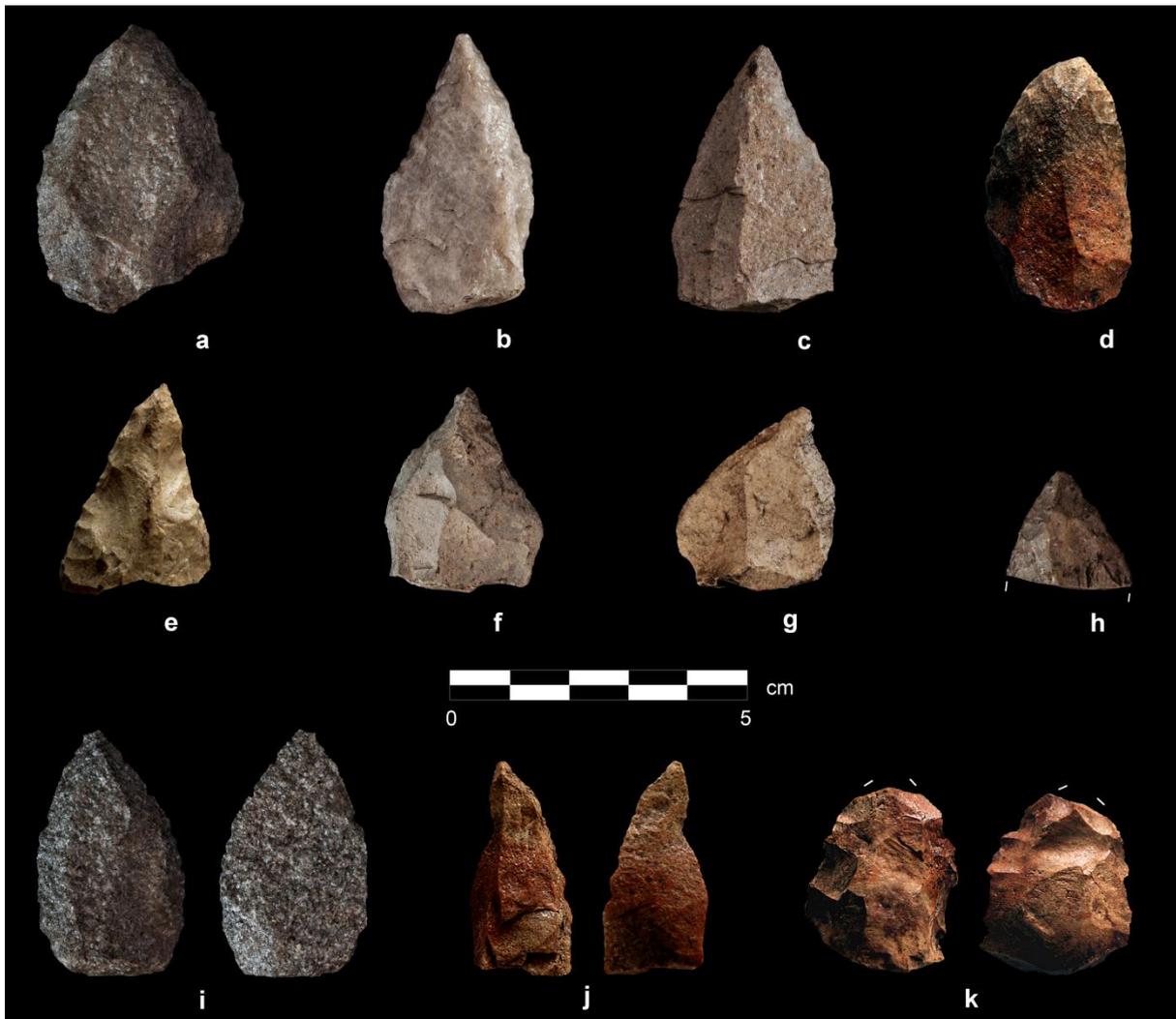


Figure 4. Selection of unifacial points from layers Dvi6–1 from Klein Kliphuis. Note the high variability in morphology, size and retouch patterns. Specimen *k* bears large retouch scars on both surfaces and can be classified as a partially bifacial point. Raw materials: *a, i* = quartzite; *b* = quartz; *c-h, j, k* = silcrete.

Regarding the pattern of lithic variability in space and time during early MIS 3 (~58–40 ka) of southern Africa, findings from the high-resolution sequence at Sibudu and regional comparisons (Will et al., 2014; Conard & Will, 2015; Bader et al., 2015) suggest broadly three cohesive regional zones: the Western Cape, the southern coast of Africa and the eastern part of South Africa (KwaZulu-Natal) plus Lesotho, corresponding broadly in environmental terms to the winter rainfall zone (WRZ), year-round rainfall zone (YRZ), and summer rainfall zone (SRZ; see Chase & Meadows, 2007). These zones constitute meaningful spatial units since paleoenvironmental research indicates important climatic and ecological differences with regard to precipitation, temperature, floral and animal communities during the Late Pleistocene, even though there were some temporal fluctuations during cooler glacial periods (Chase & Meadows, 2007; Chase, 2010; Blome et al., 2012; Mackay et al., 2014a; Chevalier & Chase, 2015). The newly introduced Sibudan assemblages at the type site show most

similarities in techno-typological attributes – and raw material use – to the close-by sites of Umhlatuzana and Holley Shelter, particularly the middle part of the latter sequence (Bader et al., 2015). The few dated and analyzed assemblages from the southern Cape (Klasies River, Pinnacle Point 5-6) differ in many regards, particularly in core reduction methods and tool assemblages (Wurz, 2000; 2002; Villa et al., 2010; Brown, 2011). As the comparisons with the Western Cape were ambiguous, requiring more comparative data (Will et al., 2014: p. 19–22), the author also personally studied MIS 3 assemblages at UPK 7 (Will et al., 2015b) and Klein Kliphuis (Mackay, 2010; 2011), although the latter form part of a larger, currently unpublished, synthesis of MIS 3 technology in southern Africa (Will et al., in prep.).

A brief summary of these unpublished results from an analysis of 1,847 lithic artifacts >15 mm from KKH – deriving from six layers (Dvi1–Dvi6) that lie above the HP and date to ca. 58–55 ka (Mackay, 2010) – can shed additional light on regional patterns of lithic technology during MIS 3. Apart from the similarities in blank production and core reduction noted in Will *et al.* (2014: p. 20–21), this study could show that the sequences at KKH and Sibudu share similar knapping techniques in which blades are predominantly manufactured by internal percussion by soft stone hammers. In contrast to the Sibudan sequence, however, the KKH assemblages show marked differences in their retouched component and diachronic trends. In terms of tool assemblages, unifacial points constitute the most frequent types (25%). They are present in all six assemblages in varying abundance (18–40%) but generally occur in low number, fluctuating between one to six pieces. The unifacial points show a great diversity in morphology, size and retouch pattern – sometimes with notched, ventral or partially bifacial retouch (Fig. 4) – lacking the standardization and clearly discernible categories from the Sibudan sequence, with few potential examples of Tongati or Ndwedwe tools. Other common tool types include scrapers (15%), splintered pieces (13%), denticulates and notches (11%) and backed pieces (3%). Backed blades occur only in the oldest spit Dvi6.

From bottom to top, the sequence shows a strong decline in formal core reduction methods, tool diversity, blade technology, and find densities. Particularly the uppermost assemblages Dvi1 and Dvi2 are characterized by expedient core reduction methods and a higher incidence of bipolar methods, more frequent use of coarse-grained raw materials (quartz and quartzite), a diminished diversity of tools and fewer lithic artifacts in general. These characteristics rather resemble the bottom of the Sibudan sequence that overlies the HP at the site (Will & Conard, submitted). In contrast, the assemblages that directly follow the HP at KKH (Dvi6–5) demonstrate a formal signal of blade production by platform and Levallois methods, high lithic densities, great tool diversity and many characteristics in core

reduction and tool production that show a gradual transition from the HP without an occupational hiatus (see also Mackay, 2010; 2011).

In sum, while the earliest lithic assemblages after the HP at KKH demonstrate similarities in core reduction methods and knapping techniques, there are marked differences in tool assemblages and the diachronic changes run counter to the Sibudan sequence. The decreasing find density and more expedient character of the younger lithic assemblages at KKH corresponds to declining site use and/or population densities in the Western Cape after ca. 50 ka (Mackay, 2010; Mackay et al., 2014a). Taking a regional perspective on techno-typological aspects in the Western Cape, preliminary results from the early MIS 3 layers “Upper BGG/WS” at Mertenhof, and the surface collections at UPK7, suggest the presence of Nubian core reduction technology and associated point blanks in addition to other Levallois methods (Will et al., 2015b: Text S2). The joint occurrence of unifacial points and backed microliths in these strata at Mertenhof is typical for the earliest assemblages following the HP in the Western Cape and resembles the patterns found at KKH and Diepkloof (Mackay, 2010; 2011; Porraz et al., 2013; Will et al., 2015b). A regional structure of lithic technology is also supported by the currently known distribution of Nubian core reduction methods in southern Africa, which is geographically confined to the Cederberg area within the higher elevation and drier parts of the Western Cape (Will et al., 2015b; Hallinan & Shaw, 2015), as well as the different and more informal technological signals from the few sites that stretch into mid-MIS 3 (after 50 ka) such as Putslaagte 1 and 8 (Mackay et al., 2014b; 2015).

Combining the results from the articles in this section with new data from KKH, UPK7 and Mertenhof, the spatiotemporal pattern of lithic technology in southern Africa during MIS 3 reveals a clear trend towards regionalization in various techno-typological attributes. These observations stand in opposition to the preceding and more homogeneous distribution of comparable characteristics during the HP. The spatial heterogeneity during MIS 3 can be roughly structured by the three main environmental zones in present day southern Africa (SRZ, YRZ, WRZ), which are reasonable approximations for climatic and environmental variability during the Late Pleistocene (Chase & Meadows, 2007; Chase, 2010; Blome et al., 2012; Mackay et al., 2014a; Chevalier & Chase, 2015). While regionalization of lithic technology might have been the result of flexible behavioral adaptations to geographically different environments installed during the transition from MIS 4 to MIS 3, a likely causal role of environmental change on this large and multi-millennial scale needs further support by demonstrating that behavioral variability fits neatly into actual boundaries of paleoenvironmental zones during prolonged parts of MIS 3 (Chase, 2010; Mackay et al.,

2014a). Future studies will also need to assess the effects of variable access, quality and quantity of raw materials on the technological organization of lithic assemblages (Binford, 1980; Kelly, 1983; Bamforth, 1986; Kuhn, 1991; Andrefsky, 1994; Floss, 1994; Féblot-Augustin, 1997; Brantingham, 2003), which crosscut environmental zones in southern Africa. The concept of the Sibudan as a novel cultural-taxonomic unit can help to structure the current and future debate by providing a clear comparative case for further studies that can reveal in which domains and to what extent regional similarities or differences in lithic technology exist and what reasons might have triggered cultural changes at different scales.

Interestingly, there is not only regionalization but also an increased diversification of techniques, methods, blank and tool classes produced *within* the SRZ during MIS 3, as shown even within the Sibudan sequence. On the regional level, this might be a result of the larger number of sites and studied assemblages in this region, but it could also be related to demographic variables. In contrast to the SRZ and YRZ, sites in KwaZulu-Natal and the Lesotho highlands during MIS 3 are characterized by intense occupation, often denser compared to the preceding HP (e.g., Sibudu; Ntloana Tsoana; Melikane). Localities in the YRZ (e.g., Klasies River; Blombos; Pinnacle Point 5-6), but particularly in the SRZ (e.g., Diepkloof; KKH; Klipfonteinrand, Hollow Rock Shelter; Varsche Rivier 003; Putslaagte 8), show an opposite pattern with only ephemeral signs of occupation in the period between 50–25 ka (data from Singer & Wymer, 1982; Mitchell & Steinberg, 1992; Evans, 1994; Mackay, 2010; Brown, 2011; Porraz et al., 2013; Mackay et al., 2014a; Will et al., 2014; Mackay et al., 2015; Miller, 2015; Stewart et al., 2016). This could imply that a gradual population shift from west to east lead to a greater density of people in the SRZ, resulting in the concomitant wealth of sites and intense occupations, but also promoting higher rates of innovations in this region due to demographic factors (e.g., Powell et al., 2009; see also below) and flexible adaptations to similar but periodically fluctuating environmental circumstances (Bar-Matthews et al., 2010; Ziegler et al., 2013; Chevalier & Chase, 2015; Wadley, 2015). A re-organization of landscape use in the WRZ could, however, have lead to a weaker archaeological signal in rock shelter and cave sites during MIS 3 (Mackay et al., 2014b) and there is also evidence of behavioral variation that cannot be explained by climatic changes on smaller scales of analyses (i.e., at Sibudu; Conard & Will, 2015).

Other than increased diversification and regionalization – or fragmentation (Mackay et al., 2014a) – compared to the preceding HP, are there any uniting elements of early MIS 3 technology in southern Africa? The presence of unifacial points poses the best candidate as these tool forms occur at many sites (e.g., Volman, 1981; Wadley, 2005; Mitchell, 2008; Villa

et al., 2010; Lombard et al., 2012; Wurz, 2013; Mackay et al., 2014a). A closer look, however, reveals that these assemblages boast a large difference in the quantity, size and morphology of unifacial points (see e.g., Fig. 4), with variable patterns of production and recycling (e.g., Will et al., 2014), best exemplified between KKH and Sibudu. The regionally and temporally variable distribution of techno-functional tool classes such as Tongatis, Ndwedwes and ACTs (Conard et al., 2012; Will et al., 2014), which constitute specific subclasses of unifacial points, constitute a case in point. Furthermore, some assemblages feature no unifacial points at all, such as “Takis” at Pinnacle Point 5-6 (Brown, 2011) and the lower Sibudan layers, with the latter instead yielding bifacial points that were previously unknown for this time frame (Will & Conard, submitted). In terms of core reduction methods, lithic assemblages are often characterized by a multitude of approaches to produce flakes, convergent flakes, blades or even bladelets, with some highly regional variants such as Nubian methods (Will et al., 2015b). Innovation, local and regional variability are thus key signals of MIS 3 lithic technology.

Regression, reversion or regionalization? Evaluating models for cultural evolution and causal mechanisms of behavioral change during the later part of the MSA

How do the findings presented above relate to the two competing models of cultural evolution and behavioral change during the later MSA as outlined above? The lithic technology of southern Africa during MIS 3 demonstrates the repeated development and use of technological innovations such as bifacial technology that is commonly seen as a sophisticated hallmark of the SB (Conard & Will, submitted), highly structured tool assemblages with repetitive forms and distinctive reduction chains (e.g., Tongati and Ndwedwe tools; Conard et al., 2012; Will et al., 2014; Bader et al., 2015), the production of morphometrically standardized blades executed by soft stone hammer percussion (Will et al., 2014; Bader et al., 2015), and the reduction of cores by the Nubian method, a specific and elaborated variation of Levallois reduction (Usik et al., 2013) which has so far been found only during this time frame in the Cederberg area of western South Africa (Hallinan & Shaw, 2015; Will et al., 2015). Based on these observations, the findings from this dissertation firmly reject the hypothesis that the lithic technology following the HP in southern Africa was less innovative, unsophisticated, without structure, or a return to an earlier “pre-SB” technology (see Sampson, 1974; Deacon, 1989; Henshilwood, 2005; McCall, 2007; Mellars, 2007; Jacobs & Roberts, 2008; 2009; Ziegler et al., 2013), as most influentially posited by the Synthetic Model (see *CHAPTER 1.4*). Instead, the work presented here demonstrates that early

MIS 3 in southern Africa is characterized by the occurrence of structured, complex and sophisticated technologies, dynamic cultural change with flexible approaches to stone knapping over short time spans, and an increased regionalization with more localized adaptations and circumscribed spheres of cultural transmission (see also Soriano et al., 2007; Villa et al., 2010; Lombard & Parsons, 2011; Mackay, 2011; Conard et al., 2012; Lombard et al., 2012; Porraz et al., 2013; Mackay et al., 2014a).

Lithic analyses, paleoenvironmental studies, geoarchaeological work and contextual data also show that there was no large-scale depopulation of southern Africa after the HP due to ubiquitous hyper-arid conditions (*contra* Thackeray, 1998; Deacon, 1995; Klein, 2000; Ambrose, 2002; Klein et al., 2004). Rather, this period shows subtle demographic shifts with people gradually abandoning the western and potentially southern coasts between 55–30 ka (e.g., Mitchell, 2008; Mackay, 2010; Porraz et al., 2013; Mackay et al., 2014a), re-locating more to the SRZ as evidenced by a multitude of densely occupied sites. Regarding the fact that there were complex and abrupt climatic and environmental changes both at the onset and during MIS 3 (Huber et al., 2006; Siddall et al., 2008; Bar-Matthews et al., 2010; Chase, 2010; Blome et al., 2012; Ziegler et al., 2013), MSA people might have seasonally or permanently migrated from arid or unstable environments in the southern and western Cape coasts to wetter and more hospitable regions in the inland, eastern or even highland areas of southern Africa (see also Stewart et al., 2012, 2016; Wadley, 2015). Such a multilayered and long-term process, with different groups of mobile hunter-gatherers shifting territories on temporary or permanent basis, likely led to reduced connections between spatially less integrated groups, and could also explain the variable abundance of sites in the YRZ, SRZ and WRZ in different timeframes (see also Mackay et al., 2014a). A combination of environmental and demographic factors, triggering an intricate cascade of changes in mobility patterns, technological organization, social dynamics and processes of cultural transmission within and between groups that played out on different scales as causal factors in their own right, might thus be the mechanism behind the increased regional character and short-term changes within lithic technology during MIS 3 (see also *CHAPTER 4*).

These new dynamics could have lead to the complex abandonment of HP lithic technology. This process is variably characterized as either abrupt (Singer & Wymer, 1982; Cochrane, 2008; Jacobs et al., 2008; Jacobs & Roberts, 2009) or gradual (Soriano et al., 2007; Villa et al., 2010; Mackay, 2011), and potentially happened at different times (Porraz et al., 2013; Tribolo et al., 2013), with increased environmental boundaries impeding interaction and long-distance exchange of information (e.g., Mackay et al., 2014a). Previous models that

explain the disappearance of the HP by single causal factors applying equally throughout southern Africa, such as population crashes (Jacobs & Roberts, 2008; 2009; Powell et al., 2009) or adaptations to changing environments (McCall 2007; McCall & Thomas, 2012; Ziegler et al., 2013), should thus be replaced by more nuanced and regional sensitive models which take environmental, cultural, and social factors into account which can interact to form a complex network of multiple causal agents (see *CHAPTER 4*).

The current state of research is, however, not yet in the position to finally resolve this complicated issue, and is much in need of more explicitly regional studies, detailed comparisons between sites, better paleoenvironmental data and more complex theoretical models. Such studies should also consider that at each scale of analysis different causal mechanisms might have been at work (Conard, 2001; Bentley & Maschner, 2003; Blome et al., 2012; Kuhn, 2013; Discamps & Henshilwood, 2015). For example, Conard and Will (2015) emphasized internal drivers for cultural changes during the MSA on a very fine scale. Environmental and climatic factors on the other hand might have played a role for the variability observed during MIS 3 on sub-continental scales over the course of tens of thousands of years: one of the most prominent sources of human variability in southern Africa is its particularly great ecological and climatic diversity, with frequent regional fluctuations in temperature and precipitation during the later part of the Late Pleistocene (Chase & Meadows, 2007; Barham & Mitchell, 2008; Stewart et al., 2012; Ziegler et al., 2013; Chevalier & Chase, 2015; but see Kandel et al., 2015).

It is becoming clear that different factors drive cultural change during the MSA at the site, local and regional level, which are often contingent on the scale of the analyses. At finer resolutions, this dissertation showed the value of applying ideas from cultural transmission theory as potential causal mechanisms of behavioral change, which have so far not played a prominent role in MSA research. Having come to the forefront only in recent discussion, demography is now seen as influencing both the development and continuation of cultural complexity: theoretical mathematical models predict that higher population sizes and densities, as well as increased interconnectivity between and within groups, lead to higher rates of technological innovation and a more likely retention of beneficial inventions. Population expansions, retractions and bottlenecks in the Pleistocene thus play an important role in cultural change, with technological innovations being more unlikely to emerge and successfully be maintained in small or isolated populations (Henrich, 2004; Stiner & Kuhn, 2006; Powell et al., 2009; Kline & Boyd, 2010; Derex et al., 2013; Muthukrishna et al., 2013; Kolodny et al., 2015; but see Collard et al., 2013; Querbes et al., 2014). Such ideas have also

been specifically applied to MSA research (Shennan, 2001; Jacobs & Roberts, 2009; Powell et al., 2009) and could have played a role during MIS 3 in the regional patterns described above, such as the high rate of innovations and behavioral flexibility in the SRZ of KwaZulu-Natal. Crucially, following this avenue of research requires the development of better proxies of late Pleistocene population size than mere site numbers or find densities (Surovell & Brantingham, 2007; Mackay, 2011), a problem that generally plagues Paleolithic research (see French, 2015).

Coming back to patterns of cultural evolution in the later part of the MSA, claims for the absence of other material elements of behavioral sophistication and cultural complexity, such as jewelry and art (Mellars, 2006; Jacobs et al., 2008; Mitchell, 2008; Wurz, 2013), also appear to have been overstated. At Sibudu for example, people produced small quantities of bone tools (Cain, 2004; d'Errico et al., 2012a), manufactured bedding made from sedges (Goldberg et al., 2009; Wadley et al., 2011) and ground ochre powder that was variably used as part of paints in combination with bovid milk (Villa et al., 2015) or as an ingredient of compound adhesives for hafting stone tools (Lombard, 2006; Wadley et al., 2009; Wadley, 2010; Hodgskiss, 2013) during the various pulses of MIS 3 occupation. At Border Cave, the earliest occupations after the HP (~60–58 ka and ~50 ka) feature a notched bone and a ground warthog or bushpig tusk. Moreover, the ELSA occupations at the site fall into the middle of MIS 3 (ca. 44–40 ka) and encompass new forms of personal ornaments and gathering equipment, and the potential adoption of the bow with poisoned bone arrows (d'Errico et al., 2012b; Villa et al., 2012).

From a more theoretical perspective, Lombard and Parsons (2010; 2011) have cautioned that scholars should not interpret the potential lack or lower quantity of particular archaeological finds such as shell beads or bone tools as a direct reflection of lower levels of cultural or cognitive complexity during MIS 3. Even if the archaeological record would reveal a simplification of technology for this time period, this could simply be an adjustment to different ecological or socio-cultural circumstances instead of cognitive or cultural devolution (see also Kuhn, 2006; Lombard, 2012; Haidle et al., 2015; Kandel et al., 2015; Lombard, 2016). In addition, Lombard and Parsons (2010; 2011) cite complex site maintenance activities, elaborate hunting methods, the manufacture of compound adhesives and beddings as ample evidence that technological simplification or regression of cognitive complexity did not take place after the HP (see also Clark, 2013; Kandel et al., 2015; Wadley, 2015). In combination with the findings on lithic technology presented here, recent archaeological research shows that only an increased focus on and knowledge of the archaeology and lithic

technology of MIS 3 can provide a realistic picture of the spatiotemporal patterning of behavioral variability and the cultural evolution of modern humans during the later part of the MSA in southern Africa. The implications on the work presented here for general models of the cultural evolution of early modern humans are discussed in *CHAPTER 4*.

3.3. Convergence, diffusion or migration? MSA stone artifacts and early dispersals

The article of this section addresses the question of how far late MSA lithic assemblages from southern Africa, and stone artifacts from the Stone Age in general, can help to track the earliest dispersals of modern humans out of Africa.

- **Will, M.,** Mackay, A., Phillips, N., 2015b. Implications of Nubian-like core reduction systems in southern Africa for the identification of early modern human dispersals. PLoS ONE 10(6), e0131824 (*APPENDIX i.h*).

Will et al. (2015b) report on the discovery of potential Nubian cores deriving from surveys at the open-air site of UPK7 and archaeological excavations at the rock shelter Mertenhof. As described in detail in *CHAPTER 1.3*, scholars have recently used these core types to trace the earliest dispersal of modern humans from northern Africa to Arabia (Rose et al., 2011; Crassard & Hilbert, 2013; Usik et al., 2013). Several questions emerge from these findings regarding early dispersals of *Homo sapiens* out of Africa: i.) How can we distinguish between dispersal, diffusion and convergence in the archaeological record of stone tools? ii.) Do current definitions preclude the classification of cores from distant parts of Africa as “Nubian”? iii.) How can the occurrence of potential Nubian cores in southern Africa be explained? iv.) What are the wider implications of these findings for studying early dispersals of modern humans within and out of Africa based on lithic assemblages?

From a general point of view, similarities in material culture, including lithic technology, can arise by three principle pathways: convergence (independent innovation), dispersal (movement of people) or diffusion (movement of ideas and objects or cultural exchange). The observations of similarities in lithic technologies have often been interpreted to reflect the latter, and were conversely used to trace dispersals of early human populations within and beyond Africa (see *CHAPTER 1.3*). Convergence in lithic systems, however, has the potential to confound such interpretations, as it implies connections between unrelated groups. Due to their essentially reductive nature, as well as morphometric limitations set by functional requirements of edge production and the physics of fracture mechanics, stone artifacts are unusually prone to this chance appearance of similar forms in unrelated populations. Empirically, this can be demonstrated by the fact that similar kinds of lithic artifacts, such as Levallois cores, handaxes, bifacial lanceolate points, tanged tools or backed microliths, were independently developed by Paleolithic populations widely spread in space and time,

precluding *a priori* assumptions of shared information systems or dispersal movements (Otte, 2003; McBrearty, 2003; Hiscock et al., 2011; White et al., 2011; Adler et al., 2014; O'Brien et al., 2014). In a first step, and in order to explain the finding of Nubian-like cores in southern Africa, the article thus formulates hypotheses and expectations of the specific archaeological patterns that the three different processes likely produce.

Dispersal and diffusion will yield an archaeological pattern of continuity. Technological elements will occur through contiguous ranges of space and time, because both processes involve the retention and movement of information. In addition, dispersals will leave a genetic signature in the populations involved (e.g., Ammerman & Cavalli-Sforza, 1984; Guglielmino et al., 1995; Brandt et al., 2014). More important from an archaeological point of view, experimental, theoretical and ethnographic studies suggest that cultural diffusion will mostly results in product copying and thus the adoption of more simple elements of lithic assemblages (e.g., blank types). Dispersals predominantly encompass process copying with high-fidelity transmission of more complex and multi-step systems such as core reduction methods (Eren et al., 2011; Nigst, 2012; Tostevin, 2012; Mackay et al., 2014a). In contrast, technological convergence in two unrelated populations will lead to: i.) large geographical and chronological gaps in the distribution of the technological elements under consideration, and; ii.) similarities in only a limited subset of the technological repertoire in two separated assemblages (e.g., only a certain tool type). More generally, the likelihood of an independent innovation increases with larger spatial and temporal scales, particularly where technologies are rooted in a shared system of technology (e.g., both Middle Paleolithic). In sum, convergence is the best explanation where a single technological element of an assemblage is similar between spatiotemporally separated samples across a large spatial range, such as continents. In order to limit the confounding potential of convergence, research in the Paleolithic has often focused on the most derived components of lithic assemblages, where elaborate, multistep flaking systems reduce the probability of chance morphological similarities, as is the case with hypotheses surrounding Nubian cores.

Initially, Will *et al.* (2015b) try to establish that the potential Nubian cores found at UPK7 and Mertenhof are fundamentally the same as their north-eastern African and Arabian counterparts. To this end, all cores at the sites were analyzed following the four necessary technological attributes for a core to be classified as Nubian outlined by Usik *et al.* (2013). These attributes encompass a triangular core shape (including triangular, cordiform, and pitched forms); a steeply angled median distal ridge $<120^\circ$ and generally $>60^\circ$; a prepared main striking platform and an opposed striking platform with an angle of intersection to the

exploitation surface varying from 50–90°. By applying these criteria, a total of 36 cores at UPK7 and Mertenhof matched this strict technological definition and can thus be securely identified as Nubian cores. They are mostly either type 1/2 (58%) or type 2 (36%) variants of the Nubian reduction system. The only difference to northern African and Arabian specimens is the generally smaller size of Nubian cores at UPK7 and Mertenhof, with an average maximum dimension of 46 mm (range 35–88 mm), which is a reflection of the small silcrete nodules predominantly used for their manufacture.

In terms of their age, the Nubian cores at UPK7 cluster within a silcrete-rich area associated with abundant unifacial points, both hallmarks of MIS 3 technology in southern Africa. Additionally, the stratified sequence at Mertenhof yields one Nubian core and two unretouched Levallois points that were manufactured from such cores within assemblage BGG/WSS which lies directly above the HP at the site. BGG/WSS is characterized by abundant silcrete use and frequent unifacial points, closely resembling nearby lithic assemblages from Klein Kliphuis and Diepkloof (earliest “post-HP”) that date to between 60–50 ka (Mackay, 2010; Porraz et al., 2013; Mackay et al., 2015). In sum, knappers at UPK7 and Mertenhof reduced cores with a specific strategy on various raw materials that resulted in forms that are virtually identical in terms of morphology and technology to Nubian cores from northern Africa and Arabia. The contextual data from UPK7, Mertenhof and regional sites associate the Nubian cores with the early “post-HP” in this region (Mackay et al., 2014a) which is confidently age bracketed to ~60–50 ka, or early MIS 3.

Based on the theoretical expectations and criteria outlined above, several lines of evidence suggest that the appearance of Nubian core reduction in southern Africa reflects convergence on the systems of north-east Africa and Arabia, instead of diffusion or dispersals. First, there is a large spatial gap between the northern and southern occurrences of Nubian reduction strategies, with a lack of evidence for such core types below the equator. In fact, this article constitutes the first demonstration of Nubian cores south of Kenya (see also Hallinan & Shaw, 2015). There is also a large chronological hiatus, with the youngest Nubian cores in north-eastern Africa and Arabia dating to late MIS 5, and the southern African specimens several (tens of) thousands of years later to early MIS 3. Finally, the lithic assemblages at UPK7 and Mertenhof show no techno-typological similarities to north-eastern African or Arabian sites other than the occurrence of Nubian cores. Overall, the replication of a single technological element between assemblages that are widely separated in space and time renders scenarios for dispersal or diffusion of these core types highly unlikely. Technological convergence is thus the most parsimonious conclusion.

Interpreting the manufacture of Nubian cores in the southern African MSA as an instance of independent innovation carries several implications. Regarding the Nubian hypotheses for early dispersals out of Africa (Rose et al., 2011; Crassard & Hilbert, 2013; Usik et al., 2013), the distribution of Nubian cores can no longer simply be assumed to reflect moving populations or information sharing networks. While this observation does not falsify the hypothesis, it shows that diffusion or dispersal must be substantiated by other arguments than just similarities in a single technological type – even in complex and multi-step core reduction methods. In particular, the validity of the Nubian hypothesis for early human dispersals rests on the argument that Nubian cores occur during restricted time intervals in contiguous areas, which makes information transmission with or without attendant population movements likely. The majority of relevant sites from north-eastern Africa and Arabia, however, lack chronological controls and reliable radiometric dates (see Olszewski et al., 2010; Goder-Goldberger, 2013; Groucutt et al., 2015b). A stronger case for diffusion or dispersals could also be made by finding similarities in several independent techno-typological domains (see Tostevin, 2012; Scerri et al., 2014a), but at the moment the existence of Nubian cores constitutes the only demonstrated similarity between assemblages of north-eastern Africa and Arabia (see Marks, 1968; Van Peer, 1998; Olszewski et al., 2010; Rose et al., 2011; Crassard & Hilbert, 2013; Usik et al., 2013). Lack of consent regarding the definition of the so-called “Afro-Arabian Nubian technocomplex” and the equation of this unit with a particular group of people constitute further caveats in this approach (Kleindienst, 2006; Goder-Goldberger, 2013; Scerri, 2013; Scerri et al., 2014a; Groucutt et al., 2015b).

A rocky road: stone artifacts and the identification of early human dispersals

What are the implications of the findings presented in this section within the larger framework of lithic technology and human dispersals in the Paleolithic (*CHAPTER 1.3*)? The results of this dissertation strongly question the utility of stone artifact types to trace early human dispersals at large spatial and temporal scales, particularly if convergence cannot be ruled out. This problem applies especially to studies that search for inter-continental dispersals or transmission of information (e.g., the Solutrean hypothesis for the colonization of North America: Straus, 2000; O’Brien et al., 2014; but see also Mellars, 2006; Mellars et al., 2013). This being said, lithic technologies could remain a critical guide to human population flux under favorable conditions, particularly when working at small scales of time and space and with similarities in several techno-typological domains. Such an approach is typical for regional studies of individual time periods (e.g., MIS 4 of South Africa) and thus particularly

apt for looking at migrations and cultural diffusion within different parts of Africa (e.g., Porraz et al., 2013; Mackay et al., 2014a).

The observations reported here challenge dominant models of cultural transmission in Stone Age research that often emphasize single contexts of innovation and feature direct equation of specific stone tools with past people. It is also clear that models of dispersals based on stone artifacts are necessarily problematic where they assume that the degree of similarity in lithic systems informs on the degree of population relatedness in assemblages that are widely separated in space and time (Petraglia et al., 2007). Additionally, we know of many instances where unrelated population manufactured similar artifacts (Hovers, 2006), and related populations made quite different artifacts over relatively brief amounts of time (Seguin-Orlando et al., 2014). Most problematic in this regard are hypotheses that are based on single core or tool types (Mellars, 2006; Armitage et al., 2011; Rose et al., 2011; Crassard & Hilbert, 2013; Mellars et al., 2013) which not only mask assemblage variability but also increase the chance of convergence.

While these interpretations carry a pessimistic connotation, they can also be viewed from a different and more positive perspective. The repeated and independent innovation of an elaborated core reduction method during the MSA of Africa highlights the flexibility and creativity in early modern human behavior. Nubian cores thus join a growing list of instances for technological convergence in the African MSA record such as bifacial technology (McBrearty, 1988; McBrearty & Brooks, 2000; McBrearty, 2003; Van Peer & Vermeersch, 2007; Taylor, 2011; de la Peña et al., 2013; Dibble et al., 2013; Porraz et al., 2013; Will & Conard, submitted), small backed pieces (Barham, 2000; Marks & Conard, 2008; Hiscock et al., 2011), Levallois methods (Tryon & Faith, 2013) and potentially shell beads, for which MSA people on both ends of the African continent used the same genus of marine shells (*Nassarius*; Henshilwood et al., 2004; Bouzouggar et al., 2007; d'Errico et al., 2009; Bar-Yosef Mayer, 2015). In line with other findings on MIS 3 lithic technology from southern Africa (*CHAPTER 3.2*), the results by Will *et al.* (2015b) underscore the innovative and regional character of this period, as Nubian cores have so far only been found in the Cederberg area of western South Africa (see also Hallinan & Shaw, 2015).

New approaches on lithic technology as stepping stones for future research

Coming back to the topic of human dispersals and lithic technologies, what are potential avenues for future analyses? This is an important question, as the unique durability of lithic artifacts and their tendency to pattern in space and time means that they will remain the basis

for most assessments of population flux in the Paleolithic, particularly where human fossils are scarce, ancient human DNA is unavailable and modern DNA alone can more easily isolate population changes in time than in space (Dennell & Petraglia, 2012; Groucutt et al., 2015a; Reyes-Centeno, in press).

From the theoretical side, it will be important to build on criteria that differentiate between dispersals, diffusion and convergence. Current models from ethnography and experimental knapping might be linked to advances in cultural transmission theory (Boyd & Richerson, 1985; Shennan, 2001; Henrich, 2001; Henrich & McElreath, 2003; Eerkens & Lipo, 2005; 2007; Mesoudi, 2011; Shennan, 2011) and the diffusion of innovations (Rogers, 1995), which can serve as bridging arguments between the transmission of cultural knowledge among past populations and the traces of lithic technology observed by modern archaeologists (see for example Bettinger & Eerkens, 1999; O'Brien et al., 2001; Tostevin, 2012; Scerri et al., 2014a). Empirical studies can increase the spatiotemporal resolution of lithic technological data in Africa and adjacent areas and construct clear and well-defined taxonomies of typo-technological characteristics and technocomplexes that allow for inter-subjective comparisons between assemblages (see Clark et al., 1966; Kleindienst, 2006; Lombard et al., 2012). The value of a strict technological taxonomic classification for Nubian cores by Usik *et al.* (2013) is a case in point as shown in Will *et al.* (2015b).

In combination, novel theoretical and empirical approaches might be able to evaluate how far and on which scales lithic technology can help to track early migrations within and out of Africa in the absence of human fossils or ancient DNA. More robust hypotheses could be built by using approaches that characterize variability across several lithic domains with a focus on quantitative data, multivariate statistical analyses and the various pathways of cultural information transmission (Tostevin, 2012; Scerri et al., 2014a; Groucutt et al., 2015b; 2015c). This being said, a cross-disciplinary strategy that combines archaeological data with fossil, genetic and paleoenvironmental evidence will be the most fruitful approach to study early human dispersals (e.g., Eriksson et al., 2012; Reyes-Centeno et al., 2014; Groucutt et al., 2015a; Reyes-Centeno, in press).

CHAPTER 4. CONCLUSION

The final chapter presents a grander summary that synthesizes the results of published articles from *CHAPTER 3* with new theoretical concepts. In so doing, it discusses the wider ramifications of these findings for models of the behavioral evolution and dispersal of *Homo sapiens* during the African MSA. The synopsis of one article on general questions regarding the cultural evolution of modern humans in southern Africa serves as a starting point for the ensuing discussion of the main conclusions derived from this dissertation.

- Conard, N.J., Bader, G.D., Schmid, V., **Will, M.**, 2014. Bringing the Middle Stone Age into clearer focus. *Mitteilungen der Gesellschaft für Urgeschichte* 23, 121–128 (*APPENDIX i.i*).

Conard et al. (2014) summarize the main outcomes of the international workshop “*Contextualizing technological change and cultural evolution in the MSA of southern Africa*”, held at Tübingen in September 2014. In addition to an overview on the state of current MSA research, the article criticizes prevailing models of cultural evolution, develops new ideas on behavioral change and points out future directions of research.

With the realization during the late 1980s and early 1990s that *Homo sapiens* originated in Africa at around ~200 ka, studies of the MSA have moved from relative obscurity to a central focus of international research in human evolution (see *CHAPTER 1.1*). Subsequently, favorable infrastructure, new excavations and collaborative projects made southern Africa the leading region for MSA research. The workshop participants reflected this increased and international scholarly activity, coming from Africa, North America and Europe. The recent scientific advances presented at the meeting results from projects at important MSA sites including Sibudu, Klasies River, Diepkloof, Enkapune ya Moto, Gademotta, Klein Kliphuis, Montagu Cave, Blombos, Elands Bay Cave, Hoedjiespunt, 1 and Bushman Rock Shelter. Most contributions and discussions centered around the variability of lithic technology during the MSA and its implications for models of behavioral evolution.

Presentations and discussions during the workshop, as well as a growing recent literature on lithic technology (Soriano et al., 2007; Mackay, 2010; Villa et al., 2010; de la Peña et al., 2013; Porraz et al., 2013; de la Peña & Wadley 2014; Will et al., 2014; Archer et al., 2015; Conard & Will, 2015) and absolute dating (Tribolo et al., 2009; 2013; Guérin et al., 2013) demonstrate that current models advocating a clear cultural sequence across southern Africa, with well-defined and largely homogeneous cultural-chronological units – as

propagated by the Synthetic Model (e.g., Jacobs et al., 2008; Henshilwood, 2012) – reflect an oversimplification of the archaeological reality (see also Conard & Porraz, 2015). It is becoming increasingly clear that the MSA archaeological record is more complex and regionally variable than has been previously recognized. A consensus is emerging on the fact that a selective research focus on the HP and SB in recent years has led to a distorted picture of the periods that preceded and followed these technocomplexes.

In sum, these observations undermine the significance of the Synthetic Model. While debate continues about how to resolve current debates, new interpretations and models are gradually surfacing. For example, the article proposes that technologies such as the manufacture and use of bifacial points should be viewed as dynamic functional adaptations that are historically and environmentally contingent, as well as mediated through learned behavior and cultural transmission, rather than as strict chrono-cultural markers or *fossiles directeurs* (see CHAPTER 3.2 and CHAPTER 3.3). Based on high-resolution observations presented at the workshop in Tübingen, the article proposes that MSA research is currently entering a phase in which a more complex archaeological record will come into clearer focus and more sophisticated models of behavioral change and spatial-temporal variation will be developed to examine the intricate dynamics of cultural evolution during the MSA.

4.1. The behavioral and cultural evolution of modern humans in Africa: Current models, new findings and future approaches

The previous summary can serve as a stringboard for contextualizing and synthesizing the findings of this dissertation presented in CHAPTER 3 and the APPENDIX. The thesis pursued two principle topics, following the main research questions of CHAPTER 2.1. Firstly, an evaluation of models for the cultural evolution of modern humans and the causal mechanisms behind the behavioral changes, studied predominantly by means of MSA lithic technology. Secondly, an assessment of the role of coastal adaptations and the analyses of stone artifacts with regard to early modern human dispersals within and beyond Africa. This work also addresses potential reasons for, and consequences of, early migrations to Eurasia.

What conclusions can be derived from the results presented in CHAPTER 3 regarding current models of the cultural evolution of early *Homo sapiens* in Africa (see CHAPTER 1.2)? The dissertation tackled this question largely from the perspective of southern Africa: does this region show evidence for less sophisticated and complex behaviors during MIS 5 and MIS 3 compared to the SB and HP periods as has been proposed by the Synthetic Model (CHAPTER 1.4)? Recent theoretical and empirical research (e.g., Lombard & Parsons, 2010;

2011; Conard et al. 2012; Lombard, 2012; Porraz et al., 2013; Tribolo et al., 2013; Conard & Porraz, 2015), including findings presented in this thesis (Will et al., 2014; Bader et al., 2015; Conard & Will, 2015; Will & Conard, submitted) raise fundamental doubts about the validity of the Synthetic Model (Jacobs et al., 2008; Jacobs & Roberts, 2008; 2009; Henshilwood, 2012). This work also questions the hypothesis that the SB and HP represented periods of exceptional cultural innovation or even the epicenter for the cultural evolution of *Homo sapiens*. As demonstrated in *CHAPTER 3.2*, new studies into MIS 3 lithic technology and archaeology reveal that modern humans maintained a complex and sophisticated behavioral repertoire after the HP (e.g., in the Sibudan). They also sustained high population densities in some parts of southern Africa – for example in the eastern part of southern Africa – falsifying the hypothesis of a large-scale population crash (*sensu* Ambrose, 2002; Klein et al., 2004; Jacobs & Roberts, 2008; 2009; Ziegler et al., 2013).

At present, the situation is less clear for MIS 5 (ca. 130–74 ka) and earlier periods. This being said, recent studies, including the findings presented here, demonstrate that as early as ~100 ka and well before the SB, people had mastered the heat-treatment of lithic raw material (Brown et al., 2009; Schmidt et al., 2013), successfully inhabited coastal landscapes and systematically exploited various marine resources (Will et al., 2013; Marean, 2014; Kyriacou et al., 2015; Will et al., 2016), used multi-component ochre-processing toolkits for painting (Henshilwood et al., 2011), produced abstract engravings on ochre (Henshilwood et al., 2009; d’Errico et al., 2012c), and manufactured bone tools (Conard et al., 2014; Conard & Porraz, 2015). If the dates at Diepkloof for an early onset of the SB and HP technocomplexes well back into MIS 5 stand the test of time (Porraz et al., 2013; Tribolo et al., 2013; but see Jacobs & Roberts, 2015), this would add to the picture of cultural and technological sophistication already in place at ~100 ka and likely even earlier.

On the larger scope of the African continent, there is ample empirical evidence from the MSA archaeological record of southern, eastern and northern Africa for rejecting Klein’s (1994; 2000; 2008; 2009; Klein & Edgar, 2002) model of a sudden origin of behavioral modernity within Africa at a late point around ~50–40 ka (see McBrearty & Brooks, 2000; Henshilwood & Marean, 2003; Conard, 2007; d’Errico & Stringer, 2011; Henshilwood, 2012; Lombard, 2012). Some of the above-mentioned complex behaviors, such as the manufacture of shell beads, abstract engravings or methodical adaptations to coastal landscapes and marine resources can be traced back to at least MIS 5 throughout various regions of the African continent (Bouzouggar et al., 2007; d’Errico et al., 2009; Lombard et al., 2013; Marean, 2014; Kandel et al., 2015; Will et al., 2016). These observations are more in agreement with the

early and gradual accretion model by McBrearty and Brooks (2000) and a similar scenario that emphasizes the important role of coastal adaptations in eliciting an early onset of cultural complexity (Parkington, 2001; 2003; 2010; Parkington et al., 2010). While it is premature to arrive at final conclusions, recent overviews, however, indicate that the actual pattern of technological change during the African MSA is more complicated than being of mostly incremental and cumulative nature (*sensu* McBrearty & Brooks, 2000), with multiple, complex, temporally variable and non-linear trajectories in different regions such as southern (Conard, 2008; Lombard, 2012; Conard et al., 2014; Mackay et al., 2014; Conard & Porraz, 2015; Wadley, 2015), eastern (Clark, 1988; Tryon & Faith, 2013), and northern Africa (Van Peer & Vermeersch, 2007; Dibble et al., 2013; Scerri et al., 2014a). Further evaluation of pan-African models for cultural evolution could be built on explicit inter-regional comparisons that take research and preservation bias into account. These studies should consider that causal factors, such as environmental change or demography, might act in an asynchronous manner in different areas of the vast and diverse continent of Africa (e.g., Chase, 2010; Blome et al., 2012), emphasizing the need for more complex theoretical models (see below).

The results of this dissertation are particularly adequate to evaluate the coastal adaptation model by Parkington (2001; 2003; 2010; Parkington et al., 2010; see *CHAPTER 1.2*). According to the findings of *CHAPTER 3.1*, the systematic and long-term character of MSA coastal adaptations had ample opportunity to influence the biological and cultural evolution of early modern humans on various parts of the African continent. These observations tentatively back the main propositions of Parkington's model from the perspective of causality, with the majority of evidence for cultural complexity in the MSA postdating the onset of systematic consumption of marine foods (Parkington, 2010; Will et al., 2016). In addition, this dissertation proposed several explicit and testable evolutionary hypotheses on the causal relationship between coastal adaptations, reproductive fitness and cultural evolution. In terms of the spatiotemporal trajectory of the cultural changes throughout the MSA, however, the same reservations apply as to the model by McBrearty and Brooks (2000) raised above.

From a more general theoretical angle of current discussions, there is a strong tendency to reject gradual, unilinear and cumulative scenarios of cultural evolution during the MSA, and the often associated concept of "cultural modernity", in favor of non-directional and non-linear patterns of cultural change with a focus on historical contingency, cultural capacities, environmental context and path-dependency (e.g., Kuhn, 2006; Conard, 2007; d'Errico & Stringer, 2011; Langbroek, 2012; Lombard, 2012; Straus, 2012; Malafouris, 2013; Wadley, 2013; Haidle et al., 2015; Kandel et al., 2015; Wynn et al., 2016; Garofoli, in press;

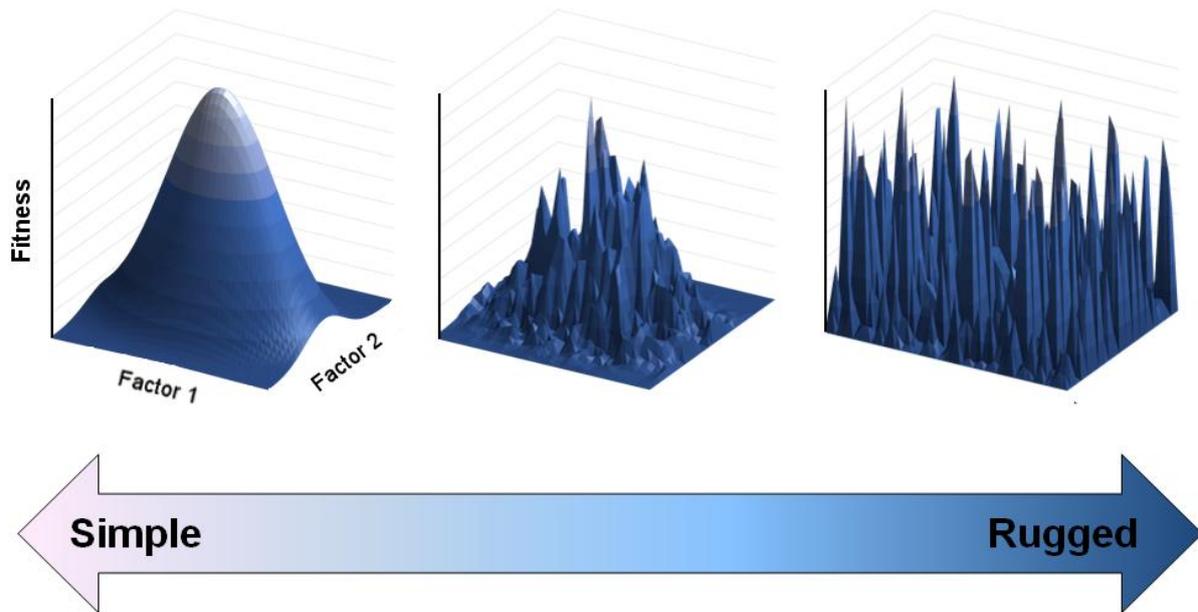


Figure 5. Idealized model of the theoretical concept of a fitness landscape, simplified to three dimensions. Simpler landscapes feature only one or a few evenly distributed peaks, whereas more rugged landscapes have several peaks of different heights with intersecting valleys (modified after Thomas Shafee; CC BY-SA 3.0).

Iliopoulos, 2016; Roberts, 2016). This dissertation promotes viewing behavioral, cultural and cognitive performances from the perspective of complex, multi-dimensional fitness landscapes. This theoretical topographic construct goes back to S. Wright's (1932; 1982) work on biological systems. Here, complex landscapes feature several adaptive peaks and valleys of different heights, corresponding to local fitness maxima and minima (see Fig. 5). Recently, archaeologists such as Kuhn (2006) or Lombard (2012; 2016; Lombard & Parson, 2011) have adopted this concept for socio-cultural systems. Kuhn uses the model of a “rugged fitness landscape” (e.g., Palmer, 1991) in which peaks of different height stand for higher fitness or cultural complexity and reflect the influence of many factors (e.g., environmental, demographic, socio-cultural; see also Lombard, 2012; 2016). Crucially, this theoretical construct rarely features singular, stable, and optimal solutions or adaptations, but rather a multitude of local, sub-optimal fitness states, since these landscapes are topographically complex and change over time due to external or internal stimuli. Such fitness landscapes generally reject unilinear trajectories of evolution and emphasize complicated processes of change that involve multiple environmental, social and cultural factors, which are historically contingent on the initial conditions of populations.

Based on this concept, Lombard (2012: Figure 4) proposes a mountaineering analogy for the mosaic pattern of cognitive and cultural complexity seen within the MSA record of southern Africa, in which people move along flexibly in different directions on a rugged and

hilly fitness landscape. This stands in opposition to a ratchet or ladder analogy where unilinear temporal changes build necessarily upon each other, leading to a cumulative increase in cultural complexity (see also Langbroek, 2012; Lombard, 2016). One can further develop such analogies by adding that fitness landscapes will feature visible footpaths of connected groups, with information transmission serving as “hiking guides” or signposts to other adaptive peaks. This is an important point in theoretical mathematical models that emphasize a link between demography, inter-group transmission of information and cultural complexity (Shennan, 2001; Henrich 2004; Stiner & Kuhn, 2006; Powell et al., 2009; Kline & Boyd, 2010; Derex et al., 2013; Muthukrishna et al., 2014; Kolodny et al., 2015) and the ideas of complex systems in which the number and interconnectivity of agents (“NK landscapes”) plays a crucial role in governing cultural complexity and change (Kauffman, 1995; 2000; Bentley, 2003; Bentley & Maschner, 2003).

Empirical examples of such a complex process of cultural evolution can be found in recent research of the southern African MSA. The absolute dates of the cultural sequence found at Diepkloof (Porraz et al. 2013; Tribolo et al., 2013) negate the prevailing idea of a uniform succession of technological traditions in this region, instead being “*characterized by distinct evolutionary trajectories in different places*” (Porraz et al., 2013: p. 3549). In an overview on a larger geographical scale, Mackay *et al.* (2014a) found high interactions (or coalescence) between technological behaviors in southern Africa during MIS 4 and MIS 2, with maximum fragmentation during MIS 5 and MIS 3, matching data presented in *CHAPTER 3.2* of this dissertation. Crucially, neither the study by Mackay *et al.* (2014a) nor the findings presented here imply lower levels of technological or cultural complexity for the observed technological heterogeneity. Other causal models, particularly those combining ideas from demography and cultural transmission theory with complex fitness landscapes that change over time, appear to be better candidates. Following such an explanatory model (see above), this thesis suggests that populations of modern humans during MIS 3 in southern Africa experienced topographically more chaotic, complex or rugged fitness landscapes with many different adaptive peaks of variable heights. Contingent on variable environmental (WRZ, SRZ, YRZ) and socio-cultural factors (e.g., variable population density and interconnectivity caused by migration), gradually fragmenting populations of modern humans reached different behavioral solutions that lead to a regionalization from the initial conditions of more homogeneous lithic technologies. This scenario stands in contrast to more simple and stable fitness landscapes with just one or a few evenly distributed fitness peaks, resulting in fewer potential adaptive solutions and thus a more homogeneous technological character across

populations (see Fig. 5). Such an ordered state of simpler or “frozen” fitness landscapes (*sensu* Bentley, 2003) could have characterized SB and HP times.

Forging a bridge to general models of cultural evolution for modern humans in Africa (and Eurasia), novel empirical observations and theoretical ideas presented above match best with Conard’s (2005; 2007; 2008; 2010) ideas of “Mosaic Polycentric Modernity”. This model rejects a single-origin and unilinear trajectory of cultural evolution in Africa and Eurasia in favor of spatiotemporally variable and intricate historical developments that were contingent on biological, ecological and socio-cultural factors. At the moment, Conard’s model fits to the increasingly complicated archaeological record of the African MSA in space and time, and can be reasonably extended by the ideas of rugged cultural and fitness landscapes (Kuhn, 2006; Lombard, 2012; 2016; see also Kandel et al., 2015). The findings from this thesis also add further layers of complexity to this model. Apart from the theoretical ideas outlined above, independent innovation or convergence was twice demonstrated within the scope of this work – for Nubian cores and bifacial points – and should be explicitly incorporated in models of behavioral change as it complicates the formulation of general hypotheses on cultural diffusion and evolution (Will et al., 2015b; Will & Conard, submitted).

The causal mechanisms of behavioral change that underlie cultural evolution have been an important point of debate that has taken off recently. *CHAPTER 3.2* discussed drivers of cultural change within the MSA on various scales of analyses. External environmental causation has a long tradition in archaeological explanation and there is considerable evidence that people during the Paleolithic, including the MSA, successfully adapted to climatic and ecological changes (e.g., Finlayson, 2005), a notion also brought forward for some of the changes observed during MIS 3 on large spatial and temporal scales (see above). This dissertation, however, showed that environmental change should be used more prudently and not as default explanation of behavioral change, as demographic and socio-cultural factors might be more important on finer scales of analyses (see also Villa et al., 2012; Clark, 2013; Porraz et al., 2013; Discamps & Henshilwood, 2015). There is also a need to better demonstrate causal links between particular environmental changes and patterns in the archaeological record other than mere correlation (see Chase, 2010; Blome et al., 2012; Marean et al., 2015).

Patterns of cultural evolution become more complex not only due to increasing archaeological data, but also with the realization that the underlying reasons for cultural change are often multi-layered and intricate. Models resting solely on environmental change or demography neglect the observation that causal factors are not always hierarchic,

particularly in complex systems like human cultures, and that they can act in fundamentally different ways on different scales of time and space (Conard, 2001; Bentley, 2003; Bentley & Maschner, 2003; Blome et al., 2012; Kuhn, 2013). Apart from issues of scale, seemingly small initial changes within populations might have had unpredictable, qualitatively different outcomes owing to the complexities and interconnectedness of human societies and cultures, and dependent on initial conditions. This is one of the central tenets of complexity theory (Kauffman, 1995; 2000; Bentley, 2003; Bentley & Maschner, 2003).

Demographic aspects, including population density and interconnectivity, but also the variable pathways of cultural transmission, constitute additional key variables to study and explain complex patterns of cultural change, such as the appearance and disappearance of cultural variants, but also their differential uptake or varying trajectories in separate regions (Cavalli-Sforza & Feldman, 1981; Boyd and Richerson, 1985; Rogers, 1995; Henrich, 2001; Bentley & Maschner 2003; Henrich, 2004; Stiner & Kuhn, 2006; Eerkens & Lipo, 2007; Derex et al., 2013; Kolodny et al., 2015). As discussed above, the spatial heterogeneity seen in the MSA record of southern Africa during MIS 5 and particularly MIS 3 might not at all be contingent on different levels of cognitive capacities, but could be explained in large part by changes in socio-demographic structure, connectivity between groups and processes of cultural transmission (Lahr & Foley, 1998; Shennan, 2001; Stiner & Kuhn, 2006; Powell et al., 2009; Lombard & Parson, 2011; Mackay et al., 2014a; Conard & Will, 2015; see also Scerri et al., 2014a). Testing this hypothesis will require the development of better approaches to reconstruct information networks and population sizes during the MSA (see French, 2015).

Apart from these ideas, models of cultural evolution should also consider constraints and potentials set by human diet, anatomy and biology (e.g., Rogers, 1988; Lieberman, 2007; Wells & Stock, 2007; Tattersall, 2009; 2014), such as the reciprocal impact of changes in genetic makeup and neuroanatomy on cognition and culture (e.g., Laland et al., 2010; Nowell, 2010; Lombard et al., 2013; Hublin et al., 2015; Wynn et al., 2016). The potential influence of marine food items on brain evolution and cognitive capacities during the MSA, providing micronutrients that are essential for the proper growth and maintenance of neural tissue, constitutes a case in point (Crawford et al., 1999; Broadhurst et al., 2002; Cunnane & Stewart, 2010; Parkington, 2010; Will et al., 2016).

In sum, enhanced models for the cultural and behavioral evolution of modern humans should be regionally sensitive, taking environmental, biological, demographic, cultural, and social factors into account, which can interact to form a complex network of multiple causal agents on several scales. These are also central tenets of gene-culture co-evolution (e.g.,

Cavalli-Sforza & Feldman, 1981; Boyd & Richerson, 1985; Shennan, 2002; Richerson & Boyd, 2005; Laland et al., 2010; Mesoudi, 2011), niche construction (Odling-Smee et al., 2003; Laland et al., 2007; Laland & O'Brien, 2010), and multiple inheritance theory (Jablonka & Lamb, 2014). Combining complexity theory with bio-cultural models of evolution, processes of cultural transmission, and complex fitness landscapes could provide novel and holistic views on old problems in MSA research within Africa and Paleolithic studies in general.

4.2. Bio-cultural perspectives on the dispersal and evolution of early modern humans

Open questions concerning the earliest dispersals of *Homo sapiens* out of Africa form the second pillar of this dissertation (*CHAPTER 1.3*). Findings of *CHAPTER 3.1* addressed the underlying reasons for early migrations by modern humans, whereas *CHAPTER 3.3* critically evaluated how lithic technology can assess such expansions of range. By combining results from the entire thesis, the section ends with a discussion of how research on the dispersal and evolution of *Homo sapiens* might be combined: How did the behavioral and cultural changes found here influence the earliest dispersal of modern humans out of Africa?

The discussion on dispersals started with the question of the extent to which the analyses of lithic assemblages can inform early migrations of modern humans out of Africa, and in general. Based on the example of Nubian core technology (Will et al., 2015b), this thesis highlighted the difficulties to track dispersals on large scales with lithics when convergence cannot be excluded, particularly on large, inter-continental scales (*CHAPTER 3.3*). While it is well-known that the problem of convergence is particularly acute in lithic knapping systems, this observation still needs to be incorporated on a regular basis into research that assesses early population movements of *Homo sapiens* and other tool-producing hominins. Based on current knowledge and potential pitfalls outlined in *CHAPTER 3.3*, the specific hypotheses put forward on early migrations out of Africa by modern humans based on stone tools alone (Mellars, 2006; Armitage et al., 2011; Rose et al., 2011; Mellars et al., 2013; see *CHAPTER 1.3*) cannot be verified. These models are in need of additional data, methodological rigor and analytical testing (see also Groucutt et al., 2015b). In general, results from lithic analyses might be more applicable to questions of population flux on smaller regional and temporal scales. Recent genetic evidence indicates the importance of Pleistocene dispersals within Africa in shaping past population structures and modern human genetic diversity (Behar et al., 2008; Tishkoff et al., 2009; Campbell & Tishkoff, 2010;

Lombard et al., 2013). Migrations within Africa might also explain the differential density of sites as well as technological differences and similarities (e.g., Mackay et al., 2014a; Stewart et al., 2012; 2016). In this dissertation, inter-regional dispersals were employed as part of the explanation for the regionally variable pattern of MIS 3 lithic technology in southern Africa (*CHAPTER 3.3* and *CHAPTER 4.1*).

Despite the above-mentioned stumbling blocks, stone tools will remain a crucial part of the archaeological evidence used by scholars to track ancient human dispersals on various scales due to their unique durability, high frequency and frequent spatiotemporal patterning. Future research should, however, refrain from using single tool or core types as tracking devices, and explicitly test between the possibilities of diffusion, dispersal and convergence for similarities observed in the archaeological record. Such studies might build upon recent theoretical advancements (see *CHAPTER 3.3*) such as models of cultural information transmission that can serve as bridging theory between past realities and the results deriving from present-day quantitative and qualitative analyses of lithic assemblages (e.g., Tostevin, 2012; Scerri et al., 2014a; Groucutt et al., 2015b).

Apart from methodological issues, there are manifold theories concerning the main drivers responsible for the dispersals by early modern humans from their African homeland. These mechanisms include climatic, ecological, biological, geological, demographic, cognitive and socio-cultural factors, often depicted as singular causes that propelled *Homo sapiens* out of Africa (see summaries in Lahr & Foley, 1998; Groucutt et al., 2015a; Hölzchen et al., in press). This thesis evaluated in how far the specific character of behavioral adaptations to coastal niches by MSA modern humans might have influenced their early demographic expansions. The idea of coastlines playing an important role in early modern human dispersals goes far back in time and remains popular (Sauer, 1963; Lahr & Foley, 1994; Stringer, 2000; Walter et al., 2000; Field & Lahr, 2005; Bulbeck, 2007; Oppenheimer, 2009; Mellars et al., 2013; Erlandson & Braje, 2015). Yet, most of these theories have rather assumed than demonstrated that modern humans were: i.) well-adapted to coastal landscapes and resources and; ii.) able to use coastal ecosystems of different character in an efficient or optimal manner. As emphasized in *CHAPTER 3.1*, these are necessary preconditions for coasts to serve as “highways” or corridors of early modern human dispersals, as they would have encountered various novel coastal niches in Asia and Europe (see also Jerardino et al., 2016). The results of this dissertation (*CHAPTER 3.1*) demonstrate that MSA people were able to efficiently exploit different marine resources and successfully live in variable coastal ecosystems over long periods of time. These findings suggest that the specific nature of

coastal adaptations (Will et al., 2016), associated with increased behavioral flexibility in general (*sensu* Kandel et al., 2015), allowed both a general range expansion of modern human populations under the right circumstances (see below) and opened the potential to use coastlines as feasible and rapid routes for dispersals, in addition to terrestrial corridors.

Aside from discussing the role of coastal adaptations in the earliest dispersal of modern humans out of Africa, this work exemplifies the use of a bio-cultural perspective. Based on combining archaeological, biochemical, ethnographical, neurological and medical research, this thesis could show that behavioral adaptations to coastal landscapes and marine foods likely initiated a cascade of biological, behavioral and cultural changes. They encompass a higher intake of brain-selective nutrients as a basis for neurological changes connected to increased cognitive capacities, larger dietary breadth and overall higher reproductive fitness, re-organization of settlement systems, and the production of complex elements of material culture such as marine shell beads (*CHAPTER 3.1*). Coastal adaptations are thus a prime example for the close relationship between behavioral adaptations, biological, genetic and dietary setup, cognitive capacities and social complexity (see Cunnane & Stewart, 2010; Parkington, 2010; Marean, 2014). The holistic character of coastal adaptations was likely part of the package that made MSA modern humans so plastic and flexible in their behavior, culture, cognition and social lives.

Dispersal and evolution are two closely intertwined processes in hominin history, as they are in the whole animal kingdom, with explicitly biogeographical approaches investigating the important role of spatial factors in the evolutionary process (Lahr & Foley, 1998; Finlayson, 2005; Wells & Stock, 2007; Stewart & Stringer, 2012; Reyes-Centeno et al., 2014). Synthesizing the findings from lithic technology and behavioral variability during the MSA on the early evolution and dispersal of modern humans (*CHAPTER 3*) from a bio-cultural perspective directly bears on the underlying drivers that enabled our lineage to migrate out of Africa and to successfully colonize all environments on earth. As part of the model of a predominantly southern and coastal route out of Africa, MSA coastal adaptations were shown to have the potential to increase reproductive success, influence human brain evolution and unlock coastal ecosystems as new settlement areas. Archaeological evidence suggests that modern humans had achieved high levels of cognitive and cultural complexity from MIS 5 onwards at least (see *CHAPTER 4.1*). The clustering of these elements after the earliest evidence for systematic use of marine resources and coastal landscapes also tentatively supports Parkington's view that coastal adaptations could have triggered the development of fully modern patterns of behavior (Parkington, 2001; 2003; 2010; Parkington et al., 2010).

Crucially, this dissertation also demonstrated that *Homo sapiens* maintained high levels of behavioral flexibility and cultural complexity throughout the Late Pleistocene – starting at least in MIS 5, during the SB and HP, but also in MIS 3 (*CHAPTER 3.3* and *CHAPTER 4.1*). In combination, biological changes, increased cognitive capacities and cultural innovations endowed early modern humans with plastic behavioral solutions to open new environments for habitation between at least ~130–40 ka, and probably during the entire Late Pleistocene. This increased and long-term behavioral flexibility might have been a key ingredient (Lombard, 2012; Kandel et al., 2015), particularly in opposition to other hominin species, to successfully thrive in the various environments around the world after ~130 ka, including temperate zones, tropics, coastal areas, (semi-) deserts, and even arctic zones, all by at least 40 ka (Davidson, 2013; Nigst et al., 2014; Bolus, 2015; Groucutt et al., 2015a; O’Connell & Allen, 2015; Pitulko et al., 2016; Reyes-Centeno, in press).

Evolutionary contingency might have played an important role in the timing of “Out of Africa 2”, explaining the temporal lag between the origin of *Homo sapiens* around 200 ka and the successful and large-scale dispersals to Eurasia after ca. 130 ka. While climate change and ecological conditions were important to remove barriers and provide temporal windows favorable for migrations (e.g., Lahr & Foley, 1998; Finlayson, 2005; Eriksson et al., 2012; Stewart & Stringer, 2012; Boivin et al., 2013; Parton et al., 2015), these factors promoted successful dispersals only under the precondition that early modern human populations were already in possession of a highly flexible behavioral repertoire and also capable to disperse along a coastal route by efficient adaptations to this environment, which can be traced back to at least MIS 5e (*CHAPTER 3.1*). Or in the words of complex systems theory: “*Similar events at different times had vastly different consequences because the setting had to be right for a certain chain of events to occur*” (Bentley & Maschner 2003: p. 2). In addition to these considerations, the demographic changes that likely resulted from coastal adaptations within populations of modern humans after ca. 120 ka (*sensu* Will et al., 2016) might have been an important part of this multi-component chain of causality.

There are further interactions between human evolution and dispersal that could be studied in the future. From the perspective of methodology, scholars should take advantage of all available sources of information in order to assess human bio-cultural evolution and adequately track population movement in the Paleolithic (e.g., Lombard et al., 2013). While studies of ancient DNA, modern genomic information, human fossils, site formation processes, lithic and other cultural data all have their own intrinsic problems and shortcomings, a combined cross-disciplinary approach has the potential to yield

fundamentally new insights (see Boyd & Richerson, 1985; Shennan, 2002; Mesoudi, 2011; Jablonka & Lamb, 2014). Regarding topics of future research, migration to new environments and between groups potentially had a strong impact on patterns of cultural change and complexity. Dispersal events introduced new variation, influenced spatial structure and changed demographic variables, thereby affecting trajectories of both biological and cultural evolution. Expansions into new habits are also expected to trigger technological innovations, behavioral and/or biological adaptations in order to cope with previously unknown environmental circumstances (e.g., Stiner & Kuhn, 2006; Powell et al., 2009; Eriksson et al., 2012; Stewart & Stringer, 2012; Kolodny et al., 2015). Increased archaeological, anthropological and paleoenvironmental research is needed to test these theoretical prepositions, particularly at the gateways of the Near East and southern Asia (Blinkhorn et al., 2013; Dennell & Porr, 2014; Bailey et al., 2015; Bosch et al., 2015; Hershkovitz et al., 2015; Liu et al., 2015; Petraglia et al., 2015).

In conclusion, this dissertation showed how the analyses of lithic technology and behavioral variability during the MSA can shed light on the early evolution and dispersal of modern humans. The approach taken here, as exemplified in the case of coastal adaptations or the reasons for cultural change, highlights the fact that the evolution of modern humans during the MSA and beyond is characterized by a complex and interacting web of biological changes, behavioral adaptations, and cultural innovations working on multiple scales. The work on MSA coastal adaptations in particular shows the value of combining theoretical models and empirical data from archaeological, biochemical, biological, ethnographical, nutritional, neurological and medical research in both the evolution and dispersal of modern humans. Biology and culture are two sides of the same coin when it comes to the human story, and they should be studied together on a regular basis. Such a genuine bio-cultural perspective on human evolution, transcending the Humanities and Sciences, is one of the most promising routes of future research into fundamental questions of human existence.

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B) APPENDIX

The ensuing accepted publications (*i.a– i.h*) and the submitted manuscript (*ii.a*) are listed in this appendix following the order in *III. LIST OF PUBLICATIONS*.

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Coastal adaptations and the Middle Stone Age lithic assemblages from Hoedjiespunt 1 in the Western Cape, South Africa

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ABSTRACT

New excavations at the Middle Stone Age (MSA) open-air site of Hoedjiespunt 1 (HDP1) on the west coast of South Africa advance our understanding of the evolution of coastal adaptations in *Homo sapiens*. The archaeological site of HDP1 dates to the last interglacial and consists of three phases of occupation, each containing abundant lithic artifacts, shellfish, terrestrial fauna, ostrich eggshell and pieces of ground ocher. The site provides an excellent case study to analyze human behavioral adaptations linked to early exploitation of marine resources.

Here we reconstruct human activities through a detailed study of the lithic assemblages, combining analyses of the reduction sequences, artifact attributes and quartz fracturing. These methods provide insights into raw material procurement, lithic reduction sequences, site use and mobility patterns, and foster comparison with other MSA coastal sites.

The main characteristics of the lithic assemblages remain constant throughout the use of the site. Quartz dominates silcrete and other raw materials by almost four to one. Knappers at HDP1 produced different forms of flakes using multiple core reduction methods. Denticulates represent the most frequent tool type. The assemblages document complete, bipolar and hard hammer reduction sequences for the locally available quartz, but highly truncated reduction sequences with many isolated end products for silcrete, a material with a minimum transport distance of 10–30 km. This observation suggests that well provisioned individuals executed planned movements to the shoreline to exploit shellfish. Our excavations at HDP1 furthermore demonstrate the simultaneous occurrence of flexible raw material use, anticipated long-distance transport, systematic gathering of shellfish and use of ground ocher. The HDP1 lithic assemblages document a robust pattern of land-use that we interpret as a stable adaptation of modern humans to coastal landscapes as early as MIS 5e.

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Introduction

Since Singer and Wymer's excavations at Klasies River Mouth in the late 1960s, the importance of coastal Middle Stone Age (MSA) sites in southern Africa containing abundant shellfish has been clear (Voigt, 1973; Singer and Wymer, 1982; Thackeray, 1988). Well studied MSA sites that preserve shellfish and other marine resources along the west coast (Fig. 1) now include Hoedjiespunt 1 (HDP1) (Volman, 1978; Parkington et al., 2004) and Ysterfontein 1

(Halkett et al., 2003; Klein et al., 2004; Avery et al., 2008). On the south coast (Fig. 1), sites with shellfish remains comprise Klasies (Voigt, 1973; Thackeray, 1988; Langejans et al., 2011), Die Kelders Cave 1 (Grine et al., 1991; Marean et al., 2000), Blombos Cave (Henshilwood et al., 2001; Langejans et al., 2011) and Pinnacle Point Cave 13B (Marean et al., 2007; Jerardino and Marean, 2010; Marean, 2010). Middle Stone Age sites containing marine resources in southern Africa are documented as far north as Boegoeberg 2 near the mouth of the Orange River (Klein et al., 1999; Parkington et al., 2004), with the easternmost site currently represented by Klasies (Singer and Wymer, 1982).

Following on the work of Klein (1974, 1979, 2008, 2009) and Parkington (1976, 2001, 2003), subsequent research has increasingly emphasized the potential importance of coastal adaptations in moderating and perhaps even shaping human evolution. With

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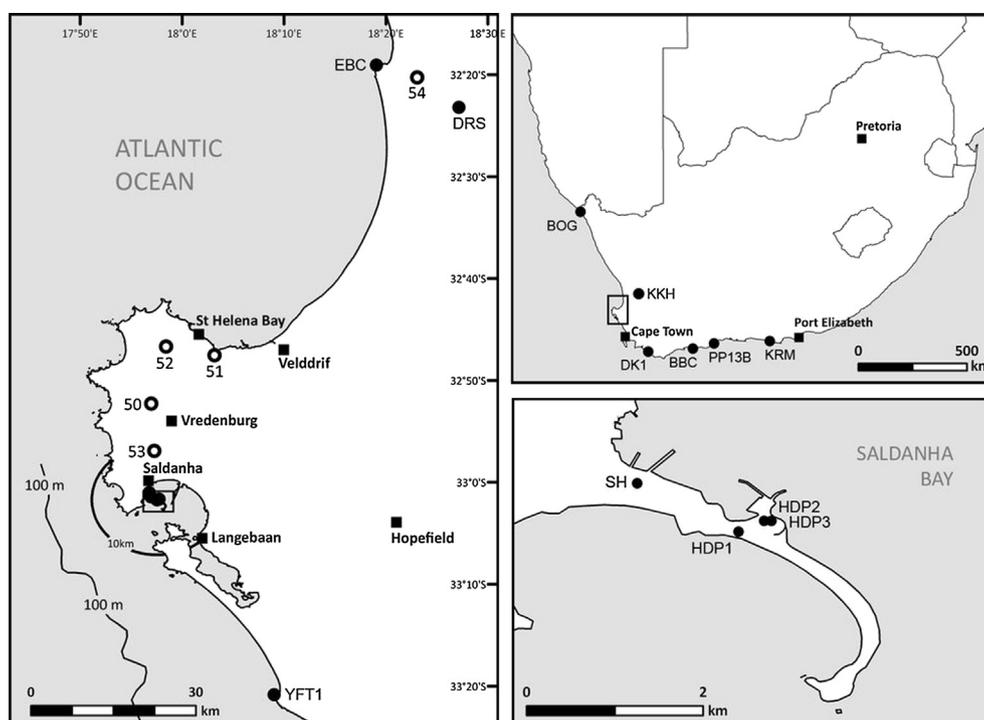


Figure 1. Location maps depicting sites mentioned in text (BBC-Blombos Cave; BOG-Boegoeberg 2; DK1-Die Kelders 1; DRS-Diepkloof Rock Shelter; EBC-Elands Bay Cave; HDP-Hoedjiespunt; KKH-Klein Kliphuis; KRM-Klasies River Mouth; PP13B-Pinnacle Point Cave 13B; SH-Sea Harvest; YFT1-Ysterfontein 1). Map on left shows raw material outcrops (sites 50–54) from the Diepkloof Rock Shelter Silcrete Database (Porraz, 2007) and bathymetric contour of 100 m drawn after Avery et al. (2008). The 10 km arc drawn from HDP1 represents the maximum distance that foragers would be expected to transport shellfish to the site (Map: G. Quénéhervé).

evidence for the use of marine resources documented in the late Middle Pleistocene at ca. 164 ka (thousands of years ago) (Marean et al., 2007), little doubt remains that people of the MSA regularly exploited shellfish (e.g., Voigt, 1973; Thackeray, 1988; Klein et al., 2004; Marean et al., 2007; Jerardino and Marean, 2010). While Klein's work (Klein, 1979, 2008, 2009; Steele and Klein, 2005) has focused on the size of shellfish in relation to human population density and the availability of resources, human exploitation of marine resources can also be viewed in a broader framework of evolutionary causality.

Parkington (2001, 2003, 2010) in particular argued that a shift toward more intensive use of marine resources over the course of the MSA may have played a causal role in the evolution and geographic spread of modern humans (see also Stringer, 2000; Cunnean and Stewart, 2010; Marean, 2010, 2011). The crucial point of Parkington's encephalization model revolves around the adaptive advantages that hominins may have gained by increasing their intake of omega-3 fatty acids. These essential nutrients are difficult to procure from terrestrial resources, while being abundant in coastal resources including black mussels and limpets (Crawford et al., 1999; Broadhurst et al., 2002). According to this model and a wealth of studies of human nutrition (e.g., Crawford et al., 1999; Broadhurst et al., 2002; see articles in Cunnean and Stewart, 2010), consumption of omega-3 fatty acids fosters the growth of brain tissue prior to birth and in the years thereafter until maturity is reached. Thus while all people profit from increased consumption of seafood and shellfish, children and adolescents especially depend on a diet that supports periods of high rates of brain growth. These groups would prosper when their diets contained increased amounts of omega-3 fatty acids, bringing major evolutionary advantages for societies using coastal resources. If this model is correct, researchers can expect to document an increased use of coastal resources including shellfish over the course of the Middle and Late Pleistocene.

To test Parkington's model, the authors reopened the excavation at HDP1 in 2011 to examine the extent to which this site could provide information into anatomical, dietary and behavioral evolution during the MSA. We do not address the anatomical and dietary questions here, but rather examine the behavioral adaptations documented at HDP1. Given that lithic technology provided MSA hominins a means to extract their livelihood from the environment, we examine the stone artifact assemblages from HDP1 and compare them with other MSA coastal sites. Our goal is to put the exploitation of shellfish in a broader contextual and behavioral framework by characterizing how early coastal adaptations are reflected in the lithic economies of the inhabitants of HDP1. This approach not only refines our current knowledge about behavioral adaptations to coastal landscapes in the Late Pleistocene, but also helps evaluate the importance of marine resources for human evolution.

While the lithic assemblages from HDP1 have been mentioned briefly in earlier publications (Volman, 1978, 1981; Berger and Parkington, 1995; Parkington et al., 2004), this paper presents the first comprehensive assessment of stone artifacts from this open-air site containing shellfish and other evidence for coastal adaptations. This research is important because of the paucity of published lithic analyses from southern African MSA sites containing shellfish. Thus, this paper represents a step toward gaining an improved understanding of MSA coastal adaptations during the time when modern forms of behavior evolved in Africa (McBrearty and Brooks, 2000).

Geographic and stratigraphic setting

The Hoedjiespunt Peninsula separates the Atlantic Ocean from Saldanha Bay and is located in the municipality of Saldanha, Western Cape Province, South Africa, about 110 km north-northwest of Cape Town (Fig. 1) (HDP1: S 33°01'42", E 17°57'34").

During a foot survey of the peninsula, we examined three known MSA localities (Fig. 1: HDP1–3) and documented an additional 14 Later Stone Age (LSA) localities, which we named HDP4–17. The locality of HDP1 includes two sites: the archaeological site at 15 m above mean sea level, and the paleontological site at 12 m above mean sea level.

The archaeological site yielded shell-bearing deposits associated with MSA artifacts. A 2 m thick sterile sand body separates the archaeological horizons from the underlying paleontological layers. The paleontological layers represent a Middle Pleistocene hyena den rich in fauna that yielded 14 human fossils, but no stone artifacts or marine shell (Berger and Parkington, 1995; Churchill et al., 2000; Stynder et al., 2001). Excavations conducted by the University of Cape Town under the supervision of J. Parkington between 1993 and 1998 focused mainly on the paleontological deposits, and to a lesser degree on the overlying archaeological horizons (Stynder, 1997; Parkington et al., 2004). In 2011, excavations at HDP1 were conducted by a joint team from the University of Tübingen and the University of Cape Town under the direction of N. Conard, concentrating on the archaeological layers.

The geological setting of the archaeological and paleontological horizons on a fossil dune (aeolianite) has favored the preservation of terrestrial and marine faunal remains. The ridge consists of three prominent calcrete layers and intercalated, calcified, sandy sediments resting on bedrock of quartz porphyry (Butzer, 2004). We observed no obvious cave, rock shelter or overhang during excavations. Therefore, HDP1 can be best described as an open-air site that we presume was protected by a low calcrete wall to the north. During our foot survey of the peninsula, we observed outcrops up to 1.5 m high along the main calcrete horizons. More pronounced outcrops were fronted by level terraces, and we assume that the setting of HDP1 represented a similar situation.

During the 2011 excavation campaign, we developed a new stratigraphic framework for the archaeological site based mainly on, and completely consistent with, the observations of previous fieldwork (Table 1) (e.g., Stynder, 1997; Parkington et al., 2004). We excavated the archaeological deposits over an area of ca. 18 m² exposing a maximal thickness of 1.5 m. The strata are in primary context, slope slightly downwards to the south and lie either directly under a thick calcrete carapace or the modern surface layer called HUMUS. The strata, although intact, have been truncated by erosion in the downslope direction toward the beach (Fig. 2).

We divided the stratigraphy into three main occupational phases or archaeological horizons (AH) I–III (Fig. 2; Table 1). Each AH contains abundant lithic artifacts, shellfish, terrestrial fauna, ostrich eggshell and other. Sometimes these major divisions exhibit more subtle facies within them. AH I and III are light colored layers composed of consolidated, fine sand containing many complete and fragmented marine shells. Sandwiched between these layers, AH II consists of compact, dark brown clay and organic-rich sediments and yielded many, mostly broken, marine shells. AH II is readily distinguished from the other two strata based on its darker

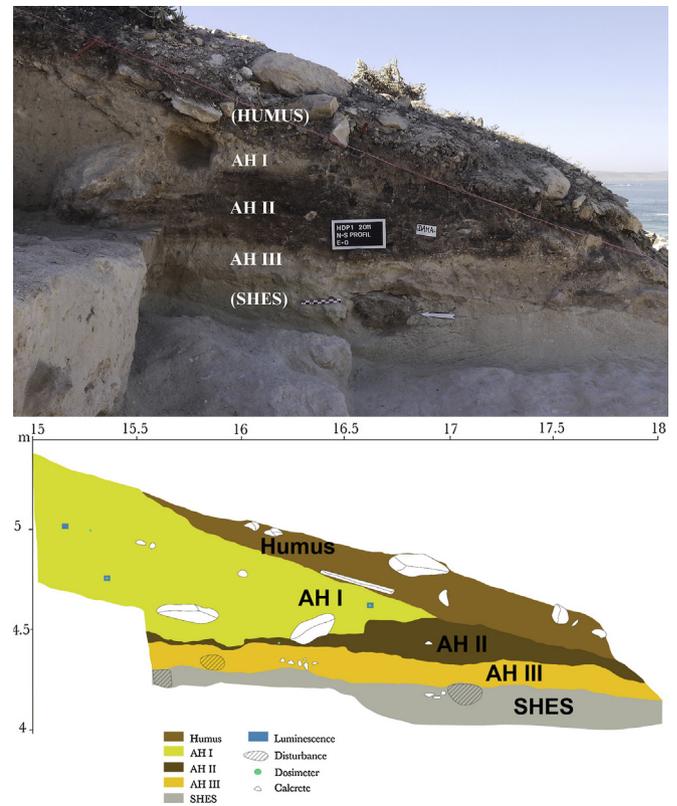


Figure 2. North–south profile along the East = 0 m line showing HUMUS = modern top soil, AH I–III = three main archaeological horizons and SHES = shelly sand (Photo: N.J. Conard; Section: S. Rudolph).

color and finer grain size. AH II averages 20 cm in thickness and clearly divided AH I from AH III. The oldest archaeological horizon, AH III, is directly underlain by a 2 m thick, sterile, calcareous, shelly sand (SHES) named for its abundant land snails (*Trigonephrus*). SHES caps the paleontological layers of the site.

The chronological placement of the human occupations at HDP1 can be determined using several lines of evidence. On a broad scale, the existence of an MSA lithic assemblage indicates an age range from ca. 280 to 40 ka. Dating methods applied during the field campaigns of the 1990s achieved better resolution. Absolute age determinations based on IRSL (Infrared stimulated luminescence) readings of sediments and ESR and U-series dates of marine shell and ostrich eggshell indicate an age between 130 and 100 ka for AH II (Yoshida, 1996; Woodborne, 1999, 2000; Parkington, 2003). Faunal assemblages and other climatic indicators can be used as additional lines of evidence to narrow the relative age of occupation. Just as the vertebrate fauna suggest a warm climate (e.g., angulate tortoise; *Chersina angulata*), marine avian species such as African penguin (*Spheniscus demersus*) and Cape cormorant (*Phalacrocorax capensis*) confirm the proximity of HDP1 to the seashore (Stynder, 1997). The same conclusion can be drawn from the frequent shellfish remains. While ethno-historical and ethno-graphic studies of hunter and gatherer societies suggest a maximal transport distance of 8–10 km for marine resources from the sea to a specific site, most observations point to the processing of shellfish directly on the shoreline (Bigalke, 1973; Moss, 1993; Erlandson, 2001; Jerardino and Marean, 2010; Marean, 2011). The predominance of granite limpets (*Cymbula granatina*) comprising more than 60% of the shellfish assemblage based on the minimum number of individuals (K. Kyriacou, Personal communication) indicates that sea level was very close to HDP1 at the time of the archaeological occupations (see Halkett et al., 2003; Klein et al., 2004).

Table 1
Comparison of the old and new stratigraphic frameworks for HDP1.

Stratigraphy 1990s	Unit name	Stratigraphy 2011
CESA	Cemented sand	AH I
SHEM	Shell midden	AH I
NOSA	Upper nodular sand	AH I
DAMA	Dark material	AH II
NOSA2	Lower nodular sand	AH III
SHES	Shelly sand	SHES

The underlying paleontological layers are not included here. For an overview of the old stratigraphic framework see Stynder (1997: Fig. 3.4) and Parkington et al. (2004: Fig. 2).

By integrating the results of absolute dating with information about global sea level fluctuations (e.g., Miller et al., 2005; Hearty et al., 2007), an assignment to MIS 5 seems reasonable. Only during the warmer phases of the early Late Pleistocene would the site have been situated less than 8–10 km from the coastline (see Stynder, 1997; Avery et al., 2008). The location of the 100 m bathymetric contour (Fig. 1) indicates that HDP1 would have been an unlikely shellfishing site during glacial periods, when sea level was ca. 15 km offshore. Moreover, the large quantity of shellfish in general, and the high proportion of granite limpets in particular, strongly suggest that the seashore was in the direct vicinity of the site, as it is today. Therefore, the placement of the MSA occupations at HDP1 during the high sea level stand of the Eemian Interglacial (MIS 5e; 130–119 ka) is the most plausible interpretation. We expect to fine tune the chronology with new thermoluminescence samples taken during the 2011 excavations.

Unlike the low-lying sediments of Ysterfontein 1 situated 7 m above mean sea level (Avery et al., 2008), the sediments at HDP1 would not have been significantly eroded by high sea stands. Despite Avery et al.'s (2008) rejection of OSL dates for Ysterfontein 1, the reported ages ranging from 132.1 ± 8.8 to 120.6 ± 6.6 ka are remarkably consistent with the previous dating results from HDP1 and correspond with MIS 5e. While Butzer's (2004) geological interpretation places nearby Sea Harvest in MIS 5, he attributes the archaeological occupation to the transition from MIS 5 to 4. Based on the geological and archaeological similarities of Sea Harvest with HDP1 and Ysterfontein 1, however, we favor correlation with MIS 5e.

Field and laboratory methods

The 2011 excavations at HDP1 were conducted in 18 m² units with designations that followed Parkington's grid from the 1990s (e.g., M12). In each quarter meter, excavation proceeded in 2–3 cm thick 'Abträge' (similar to spits) that followed the slope of the sediments and never crosscut geological layers. The maximum volume of one 'Abtrag' was a 10-liter bucket of sediment.

Single finds larger than 2 cm were piece-plotted in the field using a Leica total station and the EDM program (Dibble and McPherron, 1996). Single finds included lithic artifacts, ocher, faunal remains, ostrich eggshell and marine shell. While data from the Parkington excavations in the 1990s were recorded in a similarly detailed manner, finds were piece-plotted using a measuring tape for coordinates and a surveyor's level for elevation. When excavators encountered compact sediments, they occasionally damaged artifacts while digging. In addition, Conard's excavation used seawater to wet screen each bucket through 5 mm and 2 mm screens to increase the recovery of finds. This method enabled the reliable collection of lithics and ocher, plus a sample of identifiable faunal remains, ostrich eggshell and marine shell.

The analysis of stone artifacts included all lithic finds from the 1993–1998 and 2011 excavations. The stratigraphic fit of the old and new excavations justified pooling the lithic assemblages into the selected analytical units. We examined the three AHs separately and also analyzed the assemblage as a whole. The lithic assemblages of HDP1 contain a total of 3307 stone artifacts, with 1212 single finds (>2 cm) and 2095 pieces of small debitage (<2 cm) (for a similar approach see Villa et al., 2005, 2010; Soriano et al., 2007). Table 2 illustrates the distribution of single finds and small debitage for each AH, showing that the occupation horizons contain a sufficient number of lithics to conduct a meaningful comparative analysis. We interpret the high ratio of small debitage to single finds (63:37) as an indication that no size sorting and only little post-depositional disturbance has occurred.

Stone knapping activities during the early part of the MSA can generally be characterized by the preparation of cores and the

Table 2

Distribution of single finds (≥ 2 cm) and small debitage (<2 cm) in each AH.

	Single finds	Small debitage	Total lithics
AH I	397	903	1300
AH II	574	841	1415
AH III	241	351	592
Total	1212	2095	3307

subsequent production of predetermined, unretouched blanks. This contrasts with tool manufacture during later periods when the retouch of blanks to create desired end products predominates. MSA assemblages usually contain fewer than 2% retouched pieces (Volman, 1981, 1984; Wurz, 2000, 2002; Porraz et al., 2008; Klein, 2009). Therefore, this analysis, like several recent ones on South African lithics (e.g., Wurz, 2000; Minichillo, 2005; Soriano et al., 2007; Porraz et al., 2008; Mackay, 2009; Villa et al., 2010), focuses more on technology and reduction sequences of stone artifacts rather than typology.

The underlying aim of this study was to develop behavioral interpretations of the lithic artifacts from HDP1 by inferring the different activities associated with the exploitation of marine resources. To accomplish this, we applied four different methods:

- Reduction sequence analysis of stone artifacts larger than 2 cm (e.g., Boëda et al., 1990; Chazan, 1997; Bar-Yosef and Van Peer, 2009).
- Attribute analysis to examine the numerous traces on artifacts resulting from the knapping process (e.g., Wurz, 2000; Odell, 2004; Högberg and Larsson, 2011).
- Quartz fracture analysis (Knutsson, 1988; Callahan et al., 1992) and experimental knowledge about quartz knapping to account for the specific characteristics of this material (Barham, 1987; Knight, 1991a,b; Driscoll, 2010, 2011; Tallavaara et al., 2010). In fact, this study represents the first application of fracture analysis on an MSA assemblage.
- Small debitage quantification for each AH according to size class (0–10 mm and 10–20 mm) and raw material.

Results

The following sections describe the analytical results of the lithic assemblages from each of the three archaeological layers including a discussion of: 1) raw material selection; 2) technological and typological attributes; 3) differences in the raw material economy; and 4) description of the modified ocher found at the site.

Raw material selection

We examined the first step in the production of stone tools by analyzing how MSA people selected lithic raw materials. In doing so, we distinguished five principal raw material categories among the lithic assemblages (Fig. 3): quartz, quartz porphyry, calcrete, silcrete and other. The category 'other' included raw materials such as greywacke, cryptocrystalline silicate and sandstone, as well as single specimens of hornfels, indurated shale, granite and quartzite. A short description of the principal properties, knapping quality and origin of these raw materials follows to better appreciate their differential use.

The quartz at HDP1 consists mainly of vein quartz, which after Ballin (2008) can be best classified as milky vein quartz. The vein quartz is mostly milky white, but sometimes gray, massive, opaque, and exhibits fracture planes (Fig. 3). Both coarse and fine-grained variants of vein quartz are present. The presence of smooth,

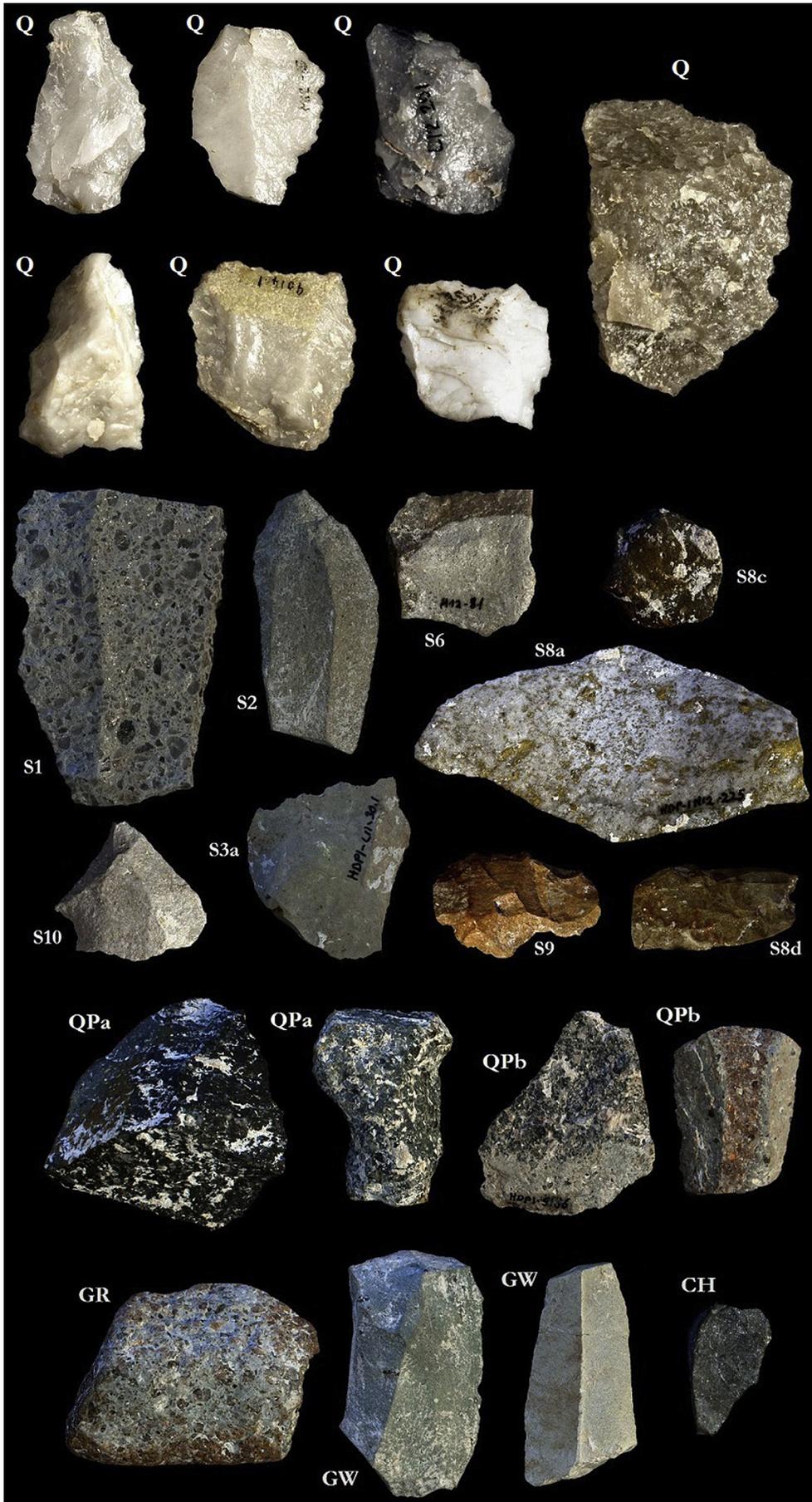


Figure 3. Illustration showing variability of raw materials in the lithic assemblages of HDP1: Quartz (Q), silcrete (S), quartz porphyry (QP), as well as other materials including granite (GR), greywacke (GW) and chert (CH) (Photo: C. Hahndiek).

rounded and discolored cortex on some artifacts indicates the use of pebble quartz from secondary sources. A hammerstone in the form of a 55 mm by 48 mm quartz pebble (Fig. 6) supports the use of this material by the inhabitants of HDP1. In the following text, we refer to all knapped variants as 'quartz'. Since quartz occurs very close to the site in the form of pebbles, cobbles and vein quartz, it can be considered a local raw material (Theron et al., 1992). While quartz produces sharp edges when flaked, its heterogeneous composition and tendency to shatter make the control of the attributes of blanks difficult to predict. Furthermore, vein quartz does not exhibit conchoidal fracture and tends to break along crystal boundaries. In sum, it is a 'problematic' raw material for stone knappers (see Tallavaara et al., 2010). For these reasons, quartz needs to be analyzed differently when compared with the other raw materials (Knight, 1991a; Driscoll, 2010, 2011). Yet, as Tallavaara et al. (2010: 2447) point out, "these differences do not mean that the same methods, such as techno-typological and aggregate analyses of debitage or use wear and reduction analyses of tools, cannot be applied [...], only that fragmentation has to be taken into account when a quartz assemblage is under study". While we successfully conducted attribute analysis on the quartz artifacts, knapping traits were more difficult to observe than on the other raw materials (see also Bisson, 1990; Cornelissen, 2003).

The second raw material at HDP1 is quartz porphyry, a dense, very coarse-grained, igneous rock. On account of its porphyritic texture, quartz porphyry exhibits less than optimal fracturing properties resulting in irregular edges when knapped. It is therefore considered as a low quality raw material. Since quartz porphyry constitutes the bedrock of the Hoedjiespunt Peninsula, it is strictly of local origin (Theron et al., 1992; Butzer, 2004). The third important raw material at HDP1 is calcrete. This sedimentary rock generally exhibits poor knapping characteristics, although it becomes more predictable and shows conchoidal fracture as the degree of silicification increases. The existence of a thick calcrete horizon capping the site attests to its local origin.

In contrast to these three raw materials, the fourth raw material is silcrete, a fine-grained siliceous rock that exhibits good flaking qualities and is non-local in origin when considering the regional geology (Roberts, 2003). Silcrete shows conchoidal fracture and yields sharp working edges when flaked. At HDP1 this raw material occurs in several distinct varieties with regard to its quality, texture and color.

We used the Diepkloof Rock Shelter Silcrete Database, a catalog of silcrete outcrops in the West Coast region, to source this raw material and determine the transport distance to HDP1 (Porráz, 2007; Porráz et al., 2008). Our comparative study revealed that two silcrete varieties comprised one-third of the silcrete artifacts in HDP1 and correspond to four primary outcrops on the Vredenburg Peninsula (Fig. 1: sites 50–54). The presence of outcrop cortex, which compares well with present-day exposures, and the absence of pebble cortex rule out secondary sources for these silcrete variants (see Minichillo, 2006). From these observations, we established a minimum transport distance of 10–30 km for the silcrete brought to HDP1. The remaining silcrete varieties did not match materials in the database and likely originate from further afield. This being said, the existence of pebble cortex on several of the unmatched silcrete variants supports the use of secondary sources. While there are no rivers in the direct vicinity of the site (in contrast to Klasies River or Blombos Cave; see Minichillo, 2006), a possible source for these pebbles is the Berg River located a minimum of 30 km northeast of HDP1.

Finally, the fifth raw material category is 'other', represented by greywacke, cryptocrystalline silicate and sandstone. Some further raw materials are present as single specimens, including hornfels, indurated shale, granite and quartzite. Based on the regional geology, five of the 'other' materials (greywacke, cryptocrystalline

silicate, hornfels, indurated shale and quartzite) can be considered as unequivocally non-local (Theron et al., 1992).

The distribution of raw materials for each AH, as well as the entire assemblage, is presented in Table 3. Quartz (80.2%) clearly dominates at HDP1, followed by calcrete (7.2%) and silcrete (6.4%). Quartz porphyry (3.4%) and 'other' raw materials (2.8%) account for only a small share.

Of all the raw materials, quartz is most likely to shatter when knapped and therefore tends to be overrepresented in number. The breakage frequency and form of all blanks were analyzed using quartz fracture analysis (Knutsson, 1988; Callahan et al., 1992). This analysis confirmed that quartz fractures at a higher rate and with a different breakage pattern compared with non-quartz materials. This was noted in the increased number of Siret breaks that occur parallel to the striking direction (Table 4). Even when controlled for weight, quartz remains the most abundant raw material, though to a slightly lesser extent (Table 5). Despite its higher rate of fragmentation, quartz is not significantly overrepresented by weight in the assemblage.

When we analyzed raw materials in terms of transport distance, it became apparent that more than 90% of the knapped stones were locally available, including quartz, quartz porphyry and calcrete. Only silcrete and some of the 'other' raw materials were brought on-site from non-local sources. While transport distances of ca. 10–30 km were established for two silcrete varieties, the sources of the 'other' raw materials remain unknown.

Although quartz predominates in all AHs, it varies in abundance (Table 3). The difference in raw material selection between AH III and AH II demonstrates variability in resource acquisition behavior. While AH III exhibits the lowest proportion of quartz (61%) and the largest amount of non-local raw material (~17%, including ~12% silcrete and ~5% 'other'), AH II yields the highest percentage of quartz (91%) with an equivalent reduction in 'other' raw materials. The youngest horizon AH I displays an intermediate pattern with 77% quartz. In summary, the three occupational horizons show differences in the quantitative selection of raw materials.

Technological and typological analysis

This section presents the technological analysis and typological description of the lithic assemblages for each AH. The analysis aims to explain the reduction sequences by determining the method and technique of stone artifact production. The technological study begins with a quantitative analysis of single finds (Table 6) (Geneste, 1991; Porráz et al., 2008). Blanks (81.0%) dominate the lithic assemblage of HDP1, followed by angular debris (11.7%), tools (4.4%), and finally cores (2.9%). Compared with other MSA assemblages, the percentage of retouched tools is relatively high (Volman, 1984). Quartz occurs far more often than all other raw materials as angular debris (making up 83% of this category), explaining the relatively high representation of this artifact class in the entire assemblage. (We define angular debris as a chipped artifact >20 mm with no clear ventral or dorsal surface.)

Table 7 summarizes the frequency of blanks present in the stone artifact assemblage. Previous studies of MSA assemblages from

Table 3
Raw material distribution for the single finds (≥ 2 cm).

	AH I	AH II	AH III	Total
Quartz	304	520	148	972
Silcrete	29	20	29	78
Calcrete	39	19	29	87
Quartz porphyry	13	4	24	41
Other	12	11	11	34
Total raw material	397	574	241	1212

Table 4
Blank breakage pattern in quartz and non-quartz raw materials.

	Quartz (%)	Non-quartz (%)
Transverse	48.7	66.1
Siret	26.8	12.1
Other	14.0	14.5
Indeterminate	10.5	7.3

Transverse breaks are perpendicular to the direction in which a blank was struck, while Siret breaks are parallel to the striking direction.

South Africa have created considerable confusion through their inconsistent definition of blank types (see Mackay, 2006 for discussion). Therefore, the following definitions aim to clarify the categories used in this analysis for the purpose of transparency and comparison. Blades are defined as blanks with parallel or sub-parallel, lateral edges and a length to width ratio $\geq 2:1$ (Hahn, 1993; Mackay, 2009). Bladelets exhibit the same characteristics as blades, but with a maximal width of 12 mm (e.g., Tixier, 1963). Flakes include blanks with clear dorsal and ventral surfaces whose length to width ratio is $< 2:1$. The only exception is unretouched points, which are convergent, triangular flakes with clear distal tip (e.g., Hahn, 1993).

As can be seen in Tables 7 and 8, the entire assemblage is dominated by flakes (96.2%), with blades playing a minor role (3.6%). Only one possible bladelet and one point occur among the blanks. A similar pattern is observed when comparing raw materials. Flakes predominate each raw material, with blades rarely exceeding 10% of an assemblage. The following sections provide further details about the specific technological and typological aspects of each AH, with selected artifacts illustrated in Figs. 4–8.

AH I For the youngest occupation horizon, the quantitative representation of analytical categories and blanks conforms to the pattern of the lithic assemblage as a whole (Fig. 4; Tables 6 and 7). Blanks account for 78% of debitage, while tools comprise 4%. The proportion of angular debris (15.1%) is the highest for all AHs. Among blanks, flakes (97.7%) clearly outnumber blades (2.3%).

Classification and analysis of cores is crucial for technological studies. The resulting information can be used to determine the method and main strategy of core reduction (Wurz, 2000, 2002). In this study, we apply the unified core taxonomy of Conard et al. (2004).¹ Of 11 cores in AH I, three inclined, three platform, three bipolar, and two parallel cores were identified (Table 9). While the three inclined forms roughly correspond to a discoid concept, the two parallel cores are not strictly Levallois in nature. All specimens can be characterized as flake cores because no negative scars of blades or bladelets are present on the main removal surfaces. The high number of flake removals on relatively small cores (mean maximum dimension (MD) = 41.8 mm; mean weight (W) = 25.2 g;

¹ Conard et al. (2004: 15–16) define their core categories as follows. *Inclined cores* “have two surfaces with removals inclined relative to the plane defined by the intersection of the surfaces. Either or both surfaces may be used for the main removals. The removals have an angle of roughly 45° relative to the plane of intersection. All significant removals originate from the intersection of the two surfaces. [...] Discoid cores [...] fall in this category”. *Parallel cores* “have two surfaces whose main removal surface must include one or more major removals parallel to the plane that intersects the two surfaces. The main removal surface is on a broad surface of the core and usually includes three or more removals. These cores are usually asymmetrical in cross-section with a slightly convex main removal surface and a more inclined ‘underside’. All significant removals originate from the intersection of the two surfaces. [...] Levallois cores fall within this taxonomic group”. *Platform cores* “have more than two faces and are not defined by the plane of intersection of two surfaces as in the above two approaches. Removals do not need to be on the broad surface of the core and are often on narrow surfaces. One or more well organized and well developed striking platforms with three or more contiguous, successful removals from the corresponding knapping surfaces must be recognizable”.

Table 5
Quartz and non-quartz artifacts by number and weight (blanks and tools only).

	Quartz	Non-quartz	Total
Number (n)	825	210	1035
% n/total	80	20	100
Weight (g)	6088	2032	8121
% g/total	75	25	100

Table 11) leads us to conclude that these cores were heavily reduced and can be considered as exhausted.

The presence of four core categories suggests a variable, non-standardized strategy for core reduction. This observation is corroborated by the low incidence of preparation negatives on the cores and by an equally low proportion of faceted butts (5.8%) on the blanks, representing a low frequency of faceting for an MSA assemblage (Table 10). The end products also show no standardization in shape or size, though they are relatively small (Table 11). Complementary to the cores, the dorsal negative patterns of the blanks reveal a high variability in both arrangement and number. In sum, the quantitative and qualitative characteristics of the cores and blanks testify to a reduction sequence aimed at one primary goal: the production of small, somewhat elongated flakes of varying morphology by employing a range of reduction methods.

The technique used to detach blanks from cores can be assessed based on knapping attributes and measurements of the proximal end and butt (Dibble and Whittaker, 1981; Dibble and Pelcin, 1995; Pelegrin, 2000; Soriano et al., 2007). Flake removals in AH I were carried out exclusively by hard hammer and bipolar reduction. Hard hammer can be deduced from developed bulbs of percussion (71.5%), a high incidence of crushed striking platforms (Table 10), thick butts (mean 6.4 mm), and frequent Siret breaks (24.5%) in quartz blanks (see Driscoll, 2011). Infrequent proximal lipping (n = 3; 1.3%) precludes the systematic use of a soft hammer.

Bipolar reduction (hammer and anvil technique) was identified by using criteria derived from experiments on vein quartz (e.g., Barham, 1987; Knight, 1991b; Ballin, 1999). These include the simultaneous occurrence of proximal and distal splintering which produces one or two chisel-like ends, frequent crushed or shattered platforms often preserving little surface area (Table 10), as well as the existence of unequivocal bipolar cores. At HDP1, most of the bipolar cores derive from quartz pebbles (Figs. 5.1 and 5.2). In general, bipolar reduction occurs exclusively on quartz and is observed in almost one-quarter of the resulting blanks (23%). In contrast, the application of the bipolar technique could not be observed on any of the non-quartz blanks, which were solely reduced by hard hammer.

The typology of AH I (Table 12) comprises 15 chipped stone tools and one hammerstone. Five denticulates represent the most common tool form, followed by four side scrapers, four minimal retouched pieces and two notches. One granite hammerstone was found in this occupation horizon. Only the denticulates exhibit a high degree of systematic retouch. All retouched pieces were made on flakes, which supports the notion that the production of flakes, and their subsequent retouch, was the main goal of reduction. The high fragmentation rate of quartz partially explains the unusually

Table 6
Numerical distribution of analytical categories for single finds (≥ 2 cm) in each AH.

	AH I	AH II	AH III	Total
Blank	310	476	196	982
Tool	16	27	10	53
Core	11	17	7	35
Angular debris	60	54	28	142
Total	397	574	241	1212

Table 7
Frequency of blank types within each AH and the entire assemblage.

	AH I	AH II	AH III	Total
Flake	303	461	181	945
Blade	7	14	14	35
Bladelet	–	–	1	1
Point	–	1	–	1
Total	310	476	196	982

Blank types are defined in the text.

Table 8
Number and relative proportion of blades for each raw material.

	<i>n</i>	% ^a
Calcrete	11	14
Silcrete	6	9
Quartz porphyry	2	7
Other	1	4
Quartz	15	2
Total blades	35	4

^a Percentages result from dividing the number of blades by the number of blanks for each raw material.

high degree of broken retouched pieces (80%). A comparative fracture analysis on the breakage patterns of the tools suggests that not all were broken by use or post-depositionally (Knutsson, 1988; Callahan et al., 1992). Instead, it seems likely that some quartz flake fragments were also selected for retouch.

AH II The stone artifact assemblage of the intermediate occupation horizon exhibits the same pattern in the frequency of analytical

categories and blank types as AH I (Figs. 5–7; Tables 6 and 7). Blanks (82.9%) clearly dominate the assemblage. Angular debris (9.4%) shows the lowest percentage of all AHs, and tools (4.7%) reach their highest proportion. The predominance of flakes (~97%) over blades (~3%) is also clear.

Among the 17 cores recovered in AH II (Table 9), seven are bipolar, followed by four inclined and three parallel variants (Fig. 5). Platform cores ($n=1$) are rare, and two further pieces are too fragmentary to classify. As in AH I, typical Levallois cores are absent and the same features were observed on cores and their corresponding end products. Only small, heavily reduced flake cores exist (mean MD = 36.3 mm; mean $W=14.4$ g; Table 11). Cores and blanks show rare signs of preparation (4% faceted platforms; Table 10). Neither the dorsal negative configuration nor the shape of the blanks attest to the manufacture of specific end products. All in all, the reduction method of cores is variable and primarily aimed at producing partly elongated, small flakes.

Similar to AH I, the stone knappers used only bipolar and hard hammer techniques. However, the dominance of bipolar cores is not mirrored in the frequency of bipolar blanks (20.2%). Hard hammer detachment is indicated by the high frequency of developed bulbs (65.6%), thick butts (mean 5.93 mm), a high incidence of Siret breaks (29.1%) on quartz blanks, and rare proximal lipping ($n=3$; 0.8%). As with AH I, a clear dichotomy between technique and raw material exists, with bipolar employed exclusively on quartz, and hard hammer on all other raw materials.

The basic flaked tool types of AH I also occur in AH II, but with a slightly greater variability (Table 12). The toolkit ($n=25$) contains seven denticulates, six minimally retouched pieces, five notches and five scrapers (Fig. 7). Two lateral retouches on blades complete

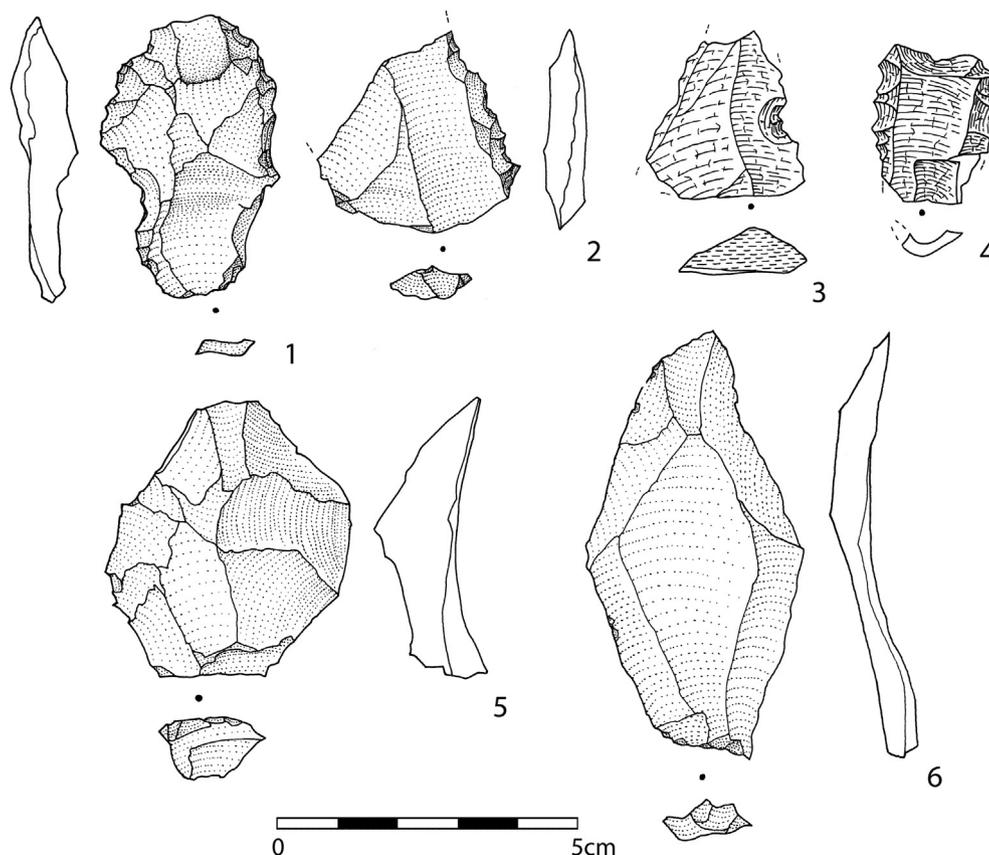


Figure 4. Artifacts from AH I: 1) M11–229, silcrete, denticulate; 2) L11–30.1, silcrete, denticulate; 3) 9006.9, quartz, notch; 4) M11–251.1, quartz, side scraper/denticulate; 5) K11–16, silcrete, unmodified flake; 6) M12–225, silcrete, unmodified flake (Illustration: F. Brodbeck).

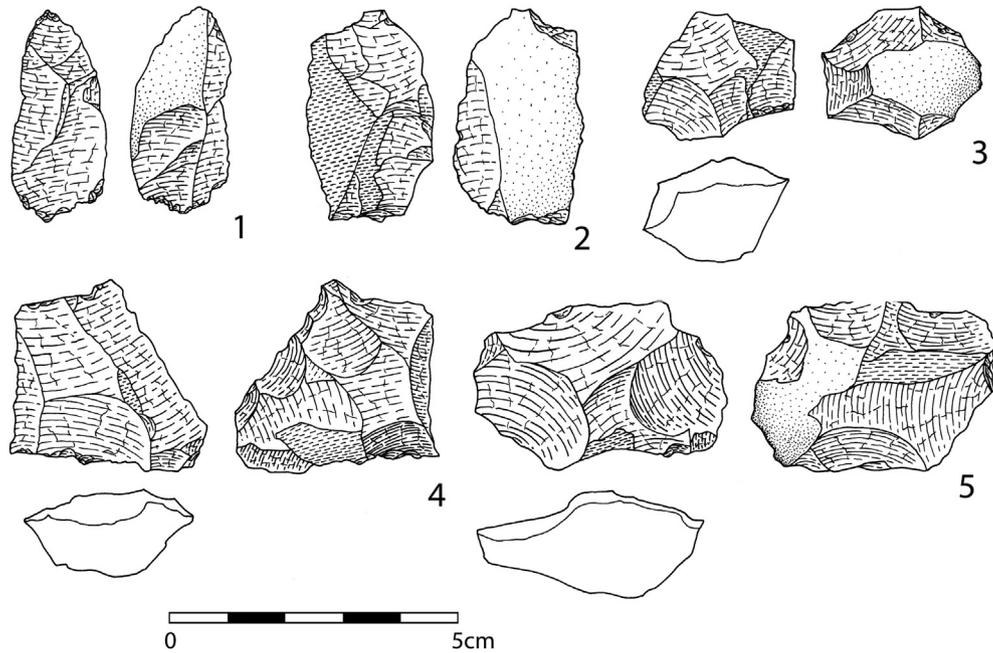


Figure 5. Cores from AH II: 1) M13–460, quartz, bipolar core; 2) M13–256, quartz, bipolar core; 3) M12–40, quartz, inclined core; 4) M12–115, quartz, parallel core; 5) N13–30, quartz, inclined core (Illustration: F. Brodbeck).

the list. Furthermore, the assemblage includes two hammerstones, one made from sandstone and one from a quartz pebble (Fig. 6). The most noticeable and standardized edge modifications are single and multiple notched retouch on almost half of the tools. Flakes (92%) were primarily chosen for retouch, but blades (8%) were also transformed into tools. The same explanation for the high fragmentation rate (56%) of retouched forms in AH I applies to this occupation horizon as well.

AH III The lithic assemblage of the oldest occupation horizon is dominated by blanks (81.3%) and exhibits an intermediate percentage of angular debris (11.6%) as well as tools (4.1%) compared with the other AHs (Fig. 8; Table 6). Flakes (92.3%) represent the vast majority of blanks (Table 7), but blades (7.1%) are twice as frequent as in the other archaeological strata. In general, AH III reveals the same pattern as in AH I and II.

The method of blank production can be deduced from a total of seven cores (Table 9). The assemblage includes three inclined, one bipolar and one parallel variant, as well as two unclassified core fragments. Typical Levallois and platform cores are absent. While the sample is too small to help distinguish it from the other assemblages, in terms of additional core attributes, this assemblage conforms to the patterns of the younger occupation horizons. Only flake cores occur, with heavy reduction illustrated by several removal scars. The cores from AH III are the largest at HDP1, but still rather small in size (mean MD = 49.7 mm; mean W = 51.2 g; Table 11). Faceted butts (5.1%) are rare (Table 10), reflecting a low degree of platform preparation, which is also apparent from the cores. Detached flakes are mainly small, with a slightly higher incidence of blades (Table 7), and exhibit highly variable dorsal negative patterns. In sum, the main reduction sequence resembles AH I and II with its focus on the production of flakes of varying morphology and generally small size by employing a variety of reduction methods and minimal core preparation.

Only hard hammer and bipolar techniques were applied to the cores of AH III. Thick butts (mean 6.3 mm) and infrequent lipping ($n = 3$; 1.9%) preclude soft hammer use. Hard hammer is substantiated by developed bulbs (64.9%) and frequent Siret fractures (22.7%) on quartz blanks. The proportion of pieces produced by

bipolar reduction (24%) reaches a peak value in AH III. In sum, the use of the two techniques with regard to raw material parallels that of AH I and II.

With regard to retouched pieces (Table 12), six denticulates account for more than half of the tools. Two minimally retouched pieces, one convergent scraper and one notched piece constitute the remaining tools. As in the other occupation horizons, denticulated retouch is the most conspicuous and standardized edge modification. Concerning blanks, 90% of the tools were made on flakes, with 10% on blades. The factors previously mentioned help explain the high fragmentation rate (60%) of the retouched pieces.

Differential raw material economy

The most remarkable technological aspect exhibited by the HDP1 lithic assemblage is the differential approach chosen by MSA stone knappers in their use of raw materials. Since these characteristic patterns were found to be similar in each AH, we present them for the entire assemblage as a whole. We studied raw material economy by analyzing the number and proportion of small debitage, percentage of cortex, reduction sequence and raw material retouch index for each raw material.

Small debitage originates as a waste product during stone artifact manufacture and attests to on-site knapping of a raw material (Odell, 2004; Mackay, 2009). Fig. 9 illustrates the frequency of the two small debitage categories (0–10 and 10–20 mm) for each raw material. Small debris of quartz predominates both size classes (97.9% and 88.8%, respectively), even more than it does for single finds >20 mm (80.2%). Calcrete also shows a similar distribution of small debitage versus single finds. However, the opposite pattern holds true for silcrete, and to a lesser extent, the ‘other’ raw materials. The clearly recognizable small debitage of silcrete was observed at a much lower frequency (0.1% and 2.2%, respectively) compared with single finds (6.4%). In the case of quartz porphyry, the extremely low frequency of small debitage can be explained by the intrinsic difficulty of recognizing artifacts made of this material. Not only does quartz porphyry bedrock outcrop <100 m from the site, but also its coarse texture and irregular breakage pattern

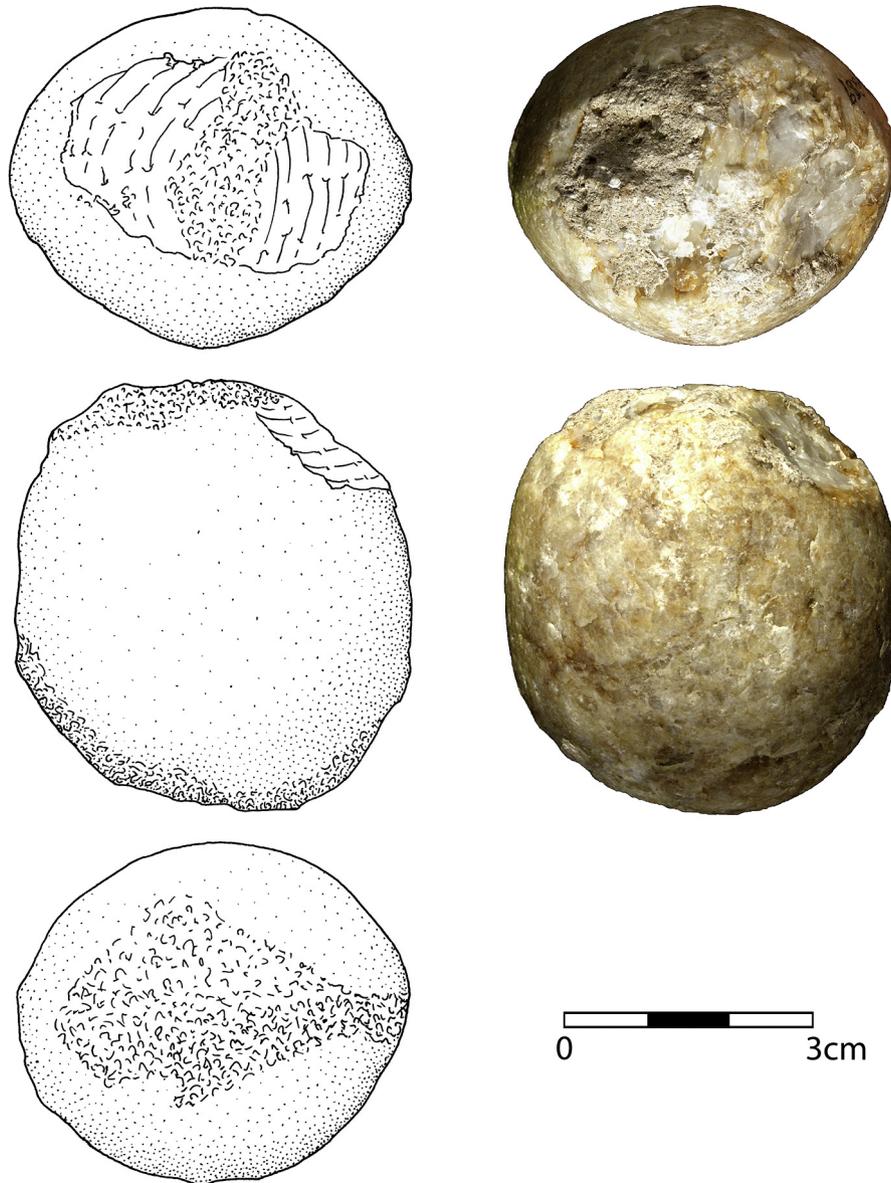


Figure 6. Hammerstone made on a quartz pebble (M12–289) from AH II as illustration (left side) and photograph (right side) (Illustration: F. Brodbeck; Photo: C. Hahndiek).

confound the identification of chipped artifacts. For these reasons, quartz porphyry was often considered as non-artifactual during sorting. In summary, the high amount quartz small debitage indicates intensive on-site knapping for this material. This stands in contrast to silcrete and ‘other’ non-local raw materials, of which only a few waste products of flaking are present.

The amount of cortex, whether outcrop (primary) or pebble (secondary), on an artifact informs us about its position in a reduction sequence. The presence of cortex on each artifact was assessed in increments of 20% from completely non-cortical (0%) to fully cortical (100%) and compared among the raw materials. The highest proportions of cortical specimens (>50%) occur in quartz and quartz porphyry, attesting to local knapping of these materials (Table 13), although the sample size for the latter is small. In contrast, silcrete and ‘other’ raw materials generally exhibit lower cortex cover. Most silcrete specimens preserve no cortex, suggesting little primary reduction on-site. Because vein quartz does not have cortex, cortical specimens derive exclusively from pebble sources. Thus, the cortex measures for quartz systematically

underestimate on-site reduction. On the other hand, silcrete blocks found in the field are often large and exhibit high amounts of cortical cover, as seen on the samples of the Diepkloof Rock Shelter Silcrete Database. Considering these observations, the larger overall proportion of cortical cover on quartz compared with silcrete becomes more distinct, and can be best explained by different reduction strategies performed on-site.

We also analyzed the reduction sequences of each raw material using the schematic classification system developed by Conard and Adler (1997) to determine the stages of knapping that occurred on-site. Each lithic object was scored on a numerical scale from one (unchipped raw material) to 12 (recycled, retouched tool) in categories that represent the steps of an idealized reduction sequence. Silcrete and ‘other’ raw materials show a low amount of primary production (few cores and preparation flakes). Conversely, quartz porphyry, calcrete and especially quartz exhibit many products from the early stages of reduction (many cores and preparation flakes). The opposite picture emerges for the final steps of the lithic reduction sequence. Silcrete and ‘other’ raw materials occur mostly

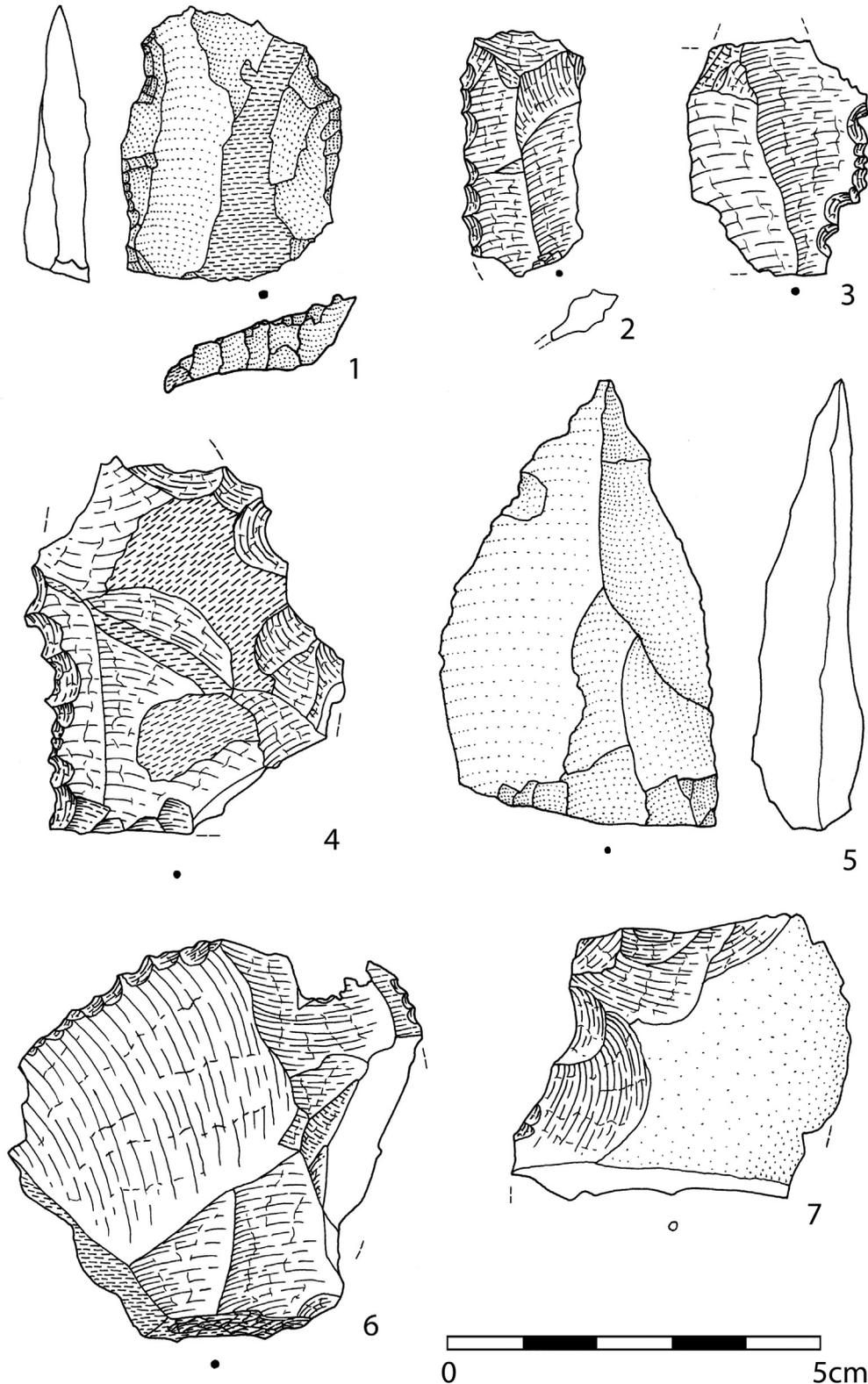


Figure 7. Retouched pieces and flakes from AH II: 1) M12–319, silcrete, retouched flake; 2) M13–429, quartz, laterally retouched blade; 3) M12–15, quartz, denticulate; 4) M13–321, quartz, double denticulate; 5) N13–41, quartzite, unretouched point; 6) M13–237, quartz, transverse scraper; 7) M12–6, quartz, notch (illustration: F. Brodbeck).

in the form of end products and tools, whereas such forms are absent or rare for quartz porphyry and calcrete. In summary, silcrete and the ‘other’ raw materials show clearly truncated reduction sequences with relatively low primary production (e.g., cores and decortification debitage) and a high incidence of retouched end

products. On the other hand, artifacts made on calcrete, quartz porphyry and especially quartz exhibit more complete sequences of reduction.

Finally, the raw material retouch index (RMRI) (Orton, 2008) for single finds was calculated and compared within the assemblage.

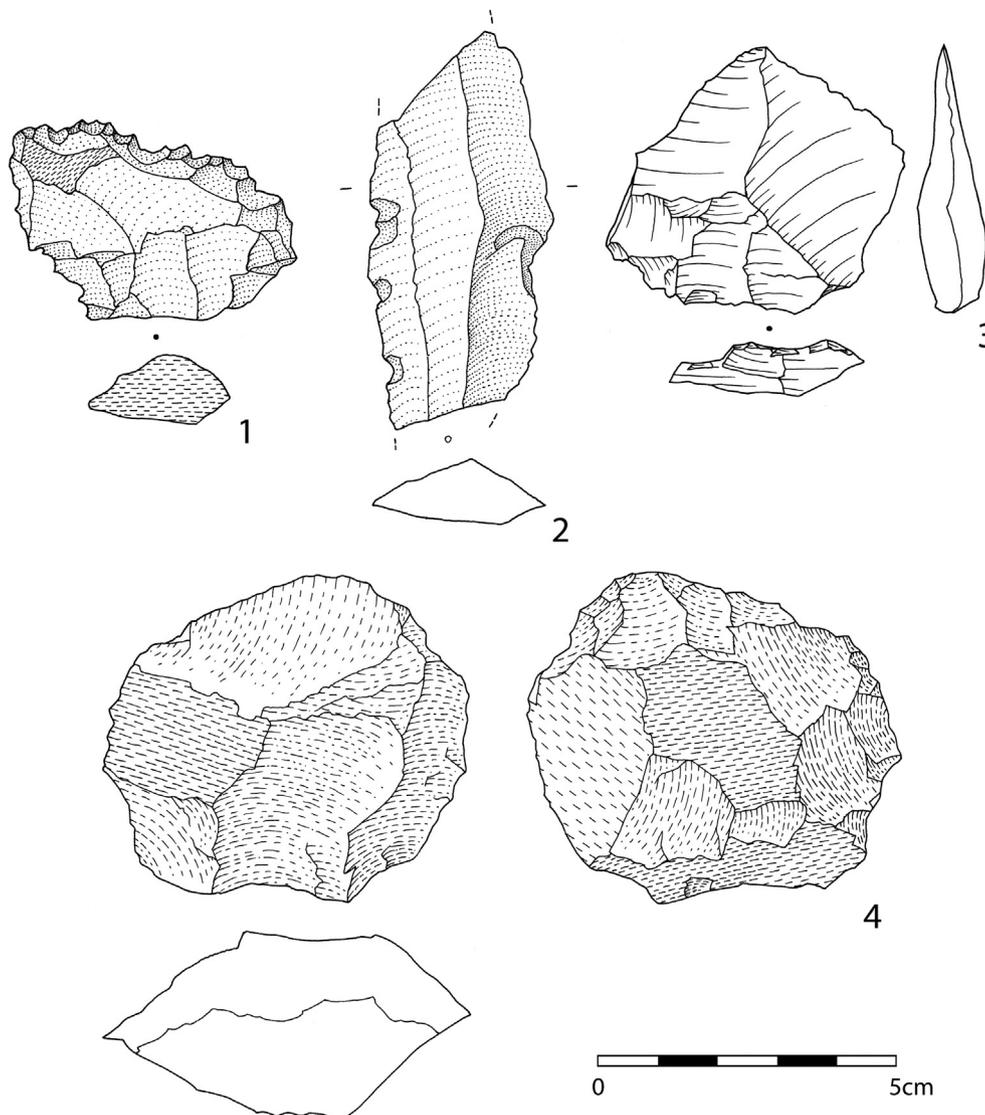


Figure 8. Artifacts from AH III: 1) 6537, silcrete, denticulate; 2) L12–397, silcrete, denticulate; 3) L12–96, hornfels, unmodified flake; 4) L12–337, quartz porphyry, inclined core (Illustration: F. Brodbeck).

Orton (2008: 1090) developed the index “to gauge the desirability of various raw materials for the manufacture of retouched artefacts”. At HDP1, silcrete was the favored raw material for retouch, followed by quartz (Table 14). ‘Other’ raw materials and calcrite show lower RMRIs. Quartz porphyry was not used to make tools. A direct statistical comparison between the frequencies of non-retouched and retouched artifacts of quartz and silcrete (Table 14), however, indicates that the observed retouch differences are not significant (Yates’ $\chi^2_1 = 1.19$; $p = 0.28$). Having said this, the chance of finding significant differences is low given the small

sample size of tools. There is an additional option with which to analyze the abundance of retouched artifacts for each raw material. We can compare the observed frequency of tools of a particular raw material with expectations based on a raw material’s frequency in the sample as a whole. The chi-square tests find a significant under-

Table 9
Distribution of core categories in the lithic assemblage of each AH and the entire assemblage following Conard et al. (2004).

	AH I	AH II	AH III	Total
Bipolar	3	7	1	11
Inclined	3	4	3	10
Parallel	2	3	1	6
Platform	3	1	—	4
Indeterminate broken	—	2	2	4
Total cores	11	17	7	35

Table 10
Distribution of striking platform characteristics in the lithic assemblage of each AH and the entire assemblage.

	AH I	AH II	AH III	Total
Cortical	10	23	9	42
Plain	91	140	68	299
Fracture plane	19	18	13	50
Point	—	—	1	1
Shattered/crushed	105	191	65	361
Faceting, coarse ^a	8	12	9	29
Faceting, fine ^b	4	4	—	8
Indeterminate	8	11	4	23
Total platforms	245	399	169	813

Only complete platforms are included in the analysis.

^a Faceting, coarse = striking platform with 2–3 facets.

^b Faceting, fine = striking platform with >3 facets.

Table 11
Mean dimensions and standard deviations of the standard blank measurements for each AH.

Layer	Mean length (mm)	Standard deviation	Mean width (mm)	Standard deviation	Mean thickness (mm)	Standard deviation
AH I	32.8	11.3	27.0	9.0	8.1	3.6
AH II	32.4	10.2	27.3	8.8	8.0	3.5
AH III	36.0	12.8	28.3	11.1	8.1	3.5

Length, width and thickness are based on the maximum dimensions for all artifacts which could be accurately measured.

Table 12
Frequency of tools for each lithic assemblage and the entire assemblage.

	AH I	AH II	AH III	Total
Denticulate	5	7	6	18
Minimal retouch	4	6	2	12
Scraper	4	5	1	10
Notched piece	2	5	1	8
Lateral retouch	–	2	–	2
Hammerstone	1	2	–	3
Total tools	16	27	10	53

representation of tools for quartz ($\chi^2_1 = 498.10$; $p < 0.001$) and calcrete ($\chi^2_1 = 4.22$; $p = 0.04$), meaning that there are fewer retouched artifacts for these raw materials than expected from the overall abundance. However, the same pattern was not observed for silcrete (Yates' $\chi^2_1 = 0.12$; $p = 0.73$) or the 'other' raw materials (Yates' $\chi^2_1 = 0.65$; $p = 0.65$). In summary, the RMRI provides a broad indication of the preferentially retouched raw materials, and this conclusion is borne by the statistical evidence for the observed frequency of retouched tools for each raw material with expectations based on their abundance in the sample as a whole. While the observed difference of tool frequencies of silcrete and quartz cannot be shown to be statistically significant, this might be a result of the small sample size of silcrete in general, and tools in particular. For example, an increase of two silcrete tools would have rendered the test significant. Further, the possibility that retouch scars on quartz were overlooked is another factor that might influence statistical analyses. Modifications on quartz are less visible and thus more difficult to observe than on silcrete or 'other' raw materials (e.g., Cornelissen, 2003; Ballin, 2008; Driscoll, 2010). A comparable pattern to the RMRI is shown by the faceting of platforms, an indicator of the degree to which cores were prepared. A predominance of silcrete (~19%) and 'other' raw materials (~17%) is

Table 13
Percentage of cortex cover present on complete blanks and tools by raw material.

% cortex	Quartz	Silcrete	Quartz porphyry	Other
0	158	23	9	12
1–20	28	4	–	1
21–40	22	1	1	–
41–60	8	–	1	2
61–80	12	3	3	–
81–99	6	–	–	–
100	1	–	–	–
Total	235	31	14	15

0% indicates that no cortex is present on a specimen, while 100% denotes a completely cortical piece.

followed by calcrete (~8%), while quartz (~1.5%) illustrates low values for faceting. Quartz porphyry shows none whatsoever.

What can be inferred about the use of raw materials at HDP1 from the observations of these technological aspects? The assemblage testifies to a distinctly differential usage of raw materials. The varying technological approaches can be used to separate the raw materials into local and non-local groups. Local raw materials (quartz, calcrete, quartz porphyry) were mostly reduced on-site, as exemplified by the high frequency of small debitage, products of the complete sequence of reduction and the frequent occurrence of core preparation and decortification specimens. In contrast, non-local raw materials were reduced elsewhere and subsequently transported to the site in the form of finished end products and tools. Products of primary reduction (cores, cortical flakes, small debitage) rarely occur. Silcrete exhibits an especially high percentage of retouched forms compared to a low number of waste products from on-site knapping.

Modified ocher

An additional and noteworthy aspect of the archaeological assemblage is the occurrence of modified ocher. Such pieces are often cited as evidence for 'behavioral modernity' (McBrearty and Brooks, 2000; d'Errico, 2003; Henshilwood and Marean, 2003; Barton, 2005; d'Errico et al., 2008; Mackay and Welz, 2008). Some consider ocher as evidence for ritualistic or symbolic behavior (e.g., Watts, 2002), while others see the mundane or profane, for example, as an ingredient of adhesive compounds used to manufacture composite tools (Wadley, 2005; Lombard, 2006).

Regardless of its interpretation, 70 ocher pieces weighing ~0.8 kg were recovered from HDP1 (Table 15). Of these, 20 specimens (~29%) bear signs of modification. The ocher is exclusively

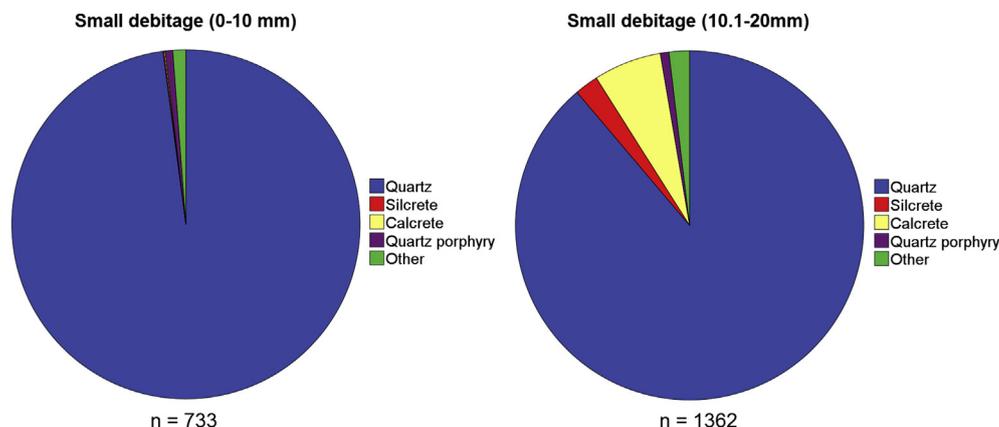


Figure 9. Charts comparing the frequency of small debitage. Quartz dominates both size classes, but comprises a smaller proportion of the fraction from 10 to 20 mm (Graphic: M. Will).

Table 14

Number of tools versus non-tools and raw material retouch index (RMRI) for each raw material.

	Number of tools	Number of non-tools	% tools ^a	% total ^b	RMRI
Silcrete	6	72	12	6.4	1.90
Quartz	42	930	84	80.2	1.05
Other	1	33	2	2.8	0.71
Calcrete	1	86	2	7.2	0.27
Quartz porphyry	0	41	0	3.4	0.00

RMRI = % tools / % total (see Orton, 2008).

^a % tools = absolute frequency among all chipped tools.

^b % total = absolute frequency among all raw materials.

red or reddish-brown in color and appears in all three AHs. AH II exhibits the highest density of both modified and unmodified ocher, followed by AH III and AH I. Compared with Blombos, the ocher density of HDP1 is slightly higher than in BBC1 and BBC2 (0.32 kg/m³; 0.17 kg/m³), but much less than BBC3 (2.7 kg/m³; Henshilwood et al., 2001). The largest pieces of ocher reach a maximum dimension of 62 mm and do not exceed a weight of 96 g. The modified ocher ranges in size from 11 to 59 mm, with pieces larger than 30 mm selected more often than pieces smaller than 30 mm. While the source of the ocher is unknown, it is not found in the direct vicinity of the site today, indicating the likely import of this raw material.

The modifications appear as multiple, parallel striations on one or several surfaces (up to four), or in the form of ocher pencils (Fig. 10) and compare well with experimental ocher that was ground against a hard surface (Hodgskiss, 2010). None of the pieces exhibit abstract designs, such as those reported from Blombos, Klein Kliphuis and Klasies (Henshilwood et al., 2002, 2009; Mackay and Welz, 2008; d'Errico et al., 2012). The stone artifacts show neither macroscopic traces of ocher, nor does the assemblage contain typical components of composite tools that would have been hafted. Plausible interpretations for the use of ocher at HDP1 include hide tanning, insect repellent, medicinal applications, adhesive, pigment, as well as ritual use. Regardless of the interpretation, it is clear that grinding ocher was incorporated into the routine behavioral repertoire of MSA people as the traces of this activity are invariably found throughout the entire sequence of occupation (McBrearty and Brooks, 2000; Watts, 2010).

Discussion

In this section, we discuss the lithic assemblages of HDP1 and compare them with other MSA stone artifact assemblages from South Africa. Subsequently, we make behavioral interpretations and discuss the importance of these observations for the evolution of coastal adaptations by modern humans.

Comparison of the lithic assemblages

Analysis of the archaeological horizons shows that all three lithic assemblages reveal a distinctly homogenous pattern with

Table 15

Distribution of ocher specimens, modified ocher, weight and density for each AH.

	AH I	AH II	AH III	Total
Total ocher (<i>n</i>)	24	26	20	70
Modified ocher (<i>n</i>)	9	9	2	20
Weight total (g)	200	393	223	816
Density total (kg/m ³) ^a	0.29	0.68	0.44	0.41

^a Density total = ocher find density could only be calculated for the Conard excavations, as no data on excavated sediment (m³) exist for the Parkinson excavations.

regard to both technology and typology. In each MSA occupation horizon, the main reduction sequence involved the production of flakes, some of which were modified into tools. The method of core reduction was variable and non-standardized, making use of at least four reduction strategies (bipolar, inclined, parallel, platform) that only rarely included the preparation of striking platforms. Hard hammer and bipolar techniques were used exclusively and in similar ways during each phase of settlement with regard to its frequency and application on raw materials. The toolkits strongly resemble each other both in the reduced spectrum of retouched forms and the emphasis on denticulates. The only real disparity among the assemblages is the differential selection of raw materials in terms of relative abundances. Each layer is dominated by quartz, however, and the basic raw material categories remain the same. Moreover, specific variants of silcrete can be found throughout the sequence, showing a striking consistency in raw material procurement.

These observations suggest a conformist approach to raw material acquisition and stone knapping through all occupation phases without significant temporal change. The lithic assemblages from all three AHs can therefore be viewed as belonging to a consistent techno-complex encompassing technology, typology and raw material choice. Considering the successive stratification of the AHs and the relatively low density of the lithic finds, we interpret each of the three archaeological layers at HDP1 to reflect multiple, brief, occupation events by small groups at the same location, accumulating over relatively short periods of time during the early part of MIS 5.

Comparing HDP1 with other MSA lithic assemblages from South Africa

The past century of research (e.g., Goodwin and Van Riet Lowe, 1929; Sampson, 1974; Volman, 1981; Singer and Wymer, 1982) has laid the foundation for modern studies of the southern African MSA. With the renewed interest of the past two decades (Wurz, 2000, 2002; Tribolo et al., 2005, 2009; Jacobs et al., 2008; Lombard et al., 2012) great efforts have been invested in strengthening the cultural chronology of the MSA, most notably through dating and analysis of its lithic assemblages. The integration of HDP1 into this sequence is an important goal of the present study. For the reasons mentioned above, the most important aspects in comparing MSA assemblages are technological parameters, with a lesser focus on typology (e.g., Wurz, 2002).

The results of this analysis make it clear that neither bifacially retouched points nor backed or truncated segments occur at HDP1. These are the typological markers of the Still Bay (~77–70 ka) and Howieson's Poort (~65–59 ka), respectively (Rigaud et al., 2006; Wadley, 2007, 2008; Jacobs et al., 2008). Additionally, technological aspects of HDP1, such as production of flakes as principal end products and lack of soft (stone) hammer use, preclude the presence of these two formally defined techno-complexes of the South African MSA (Wurz, 2002; Soriano et al., 2007; Villa et al., 2010). Hence, the most reasonable way to elucidate the position of HDP1 is to establish comparisons with geographically and temporally similar assemblages and with other MSA shellfish-bearing sites.

Sea Harvest (Volman, 1978; Grine and Klein, 1993) lies about 1 km west-northwest of HDP1 and dates to the last interglacial. Its lithic assemblage consists mainly of unstratified MSA finds including denticulates and minimally retouched pieces. The pronounced diversity of raw materials conforms with HDP1 (Volman, 1978, 1981). Due to the likely disturbed nature of the finds and the absence of technological analyses, only a close match in typology and raw materials can be confirmed for now. These questions may be resolved by future excavations.



Figure 10. Examples of ground ochre pieces showing traces of processing and abrasion (scale = 1 cm) (Photo: C. Hahndiek).

The most suitable comparison is the MSA shellfishing site of Ysterfontein 1 (YFT1) located 40 km south-southeast of HDP1. Avery et al. (2008) tentatively date YFT1 to MIS 5c or 5a, discrediting their published OSL dates ranging from 132 to 120 ka. Although the lithic assemblages have not yet been published in detail, preliminary results show some striking similarities. Like HDP1, YFT1 is a flake-based assemblage with little core preparation and with “few faceted butts” (Wurz, 2012). The breadth of raw materials is very similar, although silcrete dominates the YFT1 assemblages (Halkett et al., 2003; Klein et al., 2004; Avery et al., 2008; Wurz, 2012). Furthermore, denticulates and notches are the most abundant tools and retouched pieces are frequent (about 4% excluding chips, calculated from Halkett et al., 2003: Table 1). Finally, the lithic assemblages of all 13 archaeological layers are described as belonging to one single techno-complex (Wurz, 2012), a comparable situation to HDP1. While the parallels between the assemblages seem promising, a more detailed technological comparison must wait.

Elands Bay Cave (EBC) is situated 85 km north-northeast of HDP1 along the Atlantic coast. This site was first excavated in the 1970s by Parkington (1992) and more recently in 2011 by G. Porraz. Below the rich LSA strata, are two stratified assemblages that Porraz splits into an upper and lower MSA (G. Porraz, Personal communication). Volman (1981) characterizes the lower MSA by its low frequency of tools, few points and short blanks made on mainly local quartzite and uses EBC as an example of his MSA 1 phase. Although no dates are presently available, the assemblages appear to be older than the Still Bay (Volman, 1981; Parkington, 1992). Porraz’s team is performing a detailed analysis of the assemblages underlying the Still Bay from EBC and will likely be able to clarify some of these issues.

Diepkloof Rock Shelter (DRS) with its thick stratigraphic sequence is located 85 km northeast of HDP1 and ~15 km inland from EBC. DRS is a promising candidate for comparison. So far lithic assemblages from the Howieson’s Poort, the Still Bay and one intermediate layer (Jeff) have been described (Rigaud et al., 2006; Porraz et al., 2008). Although the assemblages contain many denticulates, the technological data regarding blade and bladelet production and use of soft stone hammer (Porraz et al., 2008) diverge from our observations of HDP1, in part, because the published sequence of DRS appears to postdate HDP1.

Geographically further removed and situated on the south coast of South Africa are two MSA shellfishing sites, Die Kelders 1 (Grine et al., 1991; Avery et al., 1997; Marean et al., 2000) and Pinnacle Point Cave 13B (Marean et al., 2007; Marean, 2010). Although the high number of denticulated pieces resembles HDP1, the main reduction sequences of both assemblages (production of blades and

points) differ markedly (Grine et al., 1991; Thackeray, 2000; Thompson et al., 2010). The sole parallel, a high incidence of denticulates, cannot justify pooling these south coast assemblages with the techno-complex of HDP1.

Finally, we compare HDP1 with the supra-regional MSA sequences employed by Singer and Wymer (1982) and characterized by Volman (1981, 1984), Wurz (2000, 2002), and most recently Lombard et al. (2012). We rule out Singer and Wymer’s (1982) MSA stages I–III for Klasies due to their focus on either blade or point production (see also Wurz, 2002). We can also eliminate the equivalents of Volman’s MSA 2a, 2b and 3 and Lombard and colleagues’ Klasies River, Mossel Bay and Sibudu (Volman, 1981; Wurz, 2002; Lombard et al., 2012). Volman’s (1981) MSA 1 matches better with HDP1 and compares favorably with the early Middle Stone Age of Lombard et al. (2012). This cultural stratigraphic unit is characterized by a high number of short and broad flakes, a low frequency of faceted platforms, denticulates as the most abundant retouched tools, and a complete absence of retouched points (Volman, 1984). Nonetheless, MSA1 assemblages differ from HDP1 in being characterized by an abundance of volumetric core technologies, cores with intersecting negative scars and very few retouched forms. Although HDP1 dates to the last interglacial, the lithic assemblages do not match very well with any broadly contemporary supra-regional techno-complex.

In summary, we know of no lithic assemblages in the MSA of southern Africa that compare with HDP1, with the possible exception of Ysterfontein 1. It remains unclear whether this is due to a raw material economy dominated by quartz with its problematic flaking properties (cf. Varsche Rivier 003; Steele et al., 2012), or differences in the chronology and use of the site. These questions may be resolved by forthcoming results from other chronologically and functionally similar stone artifact assemblages at Ysterfontein 1 and future excavations planned at Sea Harvest. New data from these sites and their comparison with HDP1 will help us reevaluate the existing chronocultural sequences of the southern African MSA.

Behavioral interpretation and raw material economy

The central aim of this analysis was to develop a behavioral interpretation of HDP1, in order to learn more about the early MSA coastal adaptations of *Homo sapiens*. Which techno-economic activities performed at the site can be inferred from the study of the lithic artifacts? As mentioned above, the main reduction sequence was the production of flakes regardless of raw material. In contrast to many other MSA assemblages (e.g., Wurz, 2002; Soriano et al.,

2007), blades were rarely produced at HDP1. Points and bladelets are virtually non-existent. Additionally, the stone knappers of HDP1 made no use of soft (stone) hammer or pressure flaking, techniques found in several MSA assemblages of South Africa (Soriano et al., 2007; Porraz et al., 2008; Mourre et al., 2010; Villa et al., 2010). The exploitation of cores appears non-standardized and more or less opportunistic, and the resulting highly variable end products give the assemblage an 'informal' appearance.

However, the most informative conclusions regarding behavior can be drawn from the conspicuous differences in the raw material economy. Locally available varieties such as quartz, calcrete, and quartz porphyry exhibit a generally low flaking quality and were processed directly on-site. This approach stands in marked contrast to non-local raw materials of high knapping quality such as silcrete, hornfels, quartzite and greywacke. These materials occur mostly or exclusively in the form of isolated end products or tools, suggesting that they were produced in other places and subsequently brought on-site. This clear dichotomy in terms of transport distance and knapping quality suggests a highly selective, flexible and anticipated use of raw materials by the MSA stone knappers.

Considering the transport of silcrete to HDP1, we observe high-quality end products and tools imported over a minimum distance of 10–30 km. Such behavior suggests 'curated gear' (Binford, 1979) or the 'provision of individuals' (Kuhn, 1992). Hence, implements were manufactured elsewhere and carried along as safeguards against unexpected or planned contingencies encountered on the landscape. In our interpretation, these finished implements were taken to special places along the foraging round in anticipation of future activities. In the case of HDP1, this planned shift of settlement was most likely performed to exploit marine food resources at specific times of the year (see below; also Parkington, 1976; Jerardino and Marean, 2010; Marean, 2011). The most important behaviors observed at HDP1 are the occurrence of flexible raw material use, anticipated long-distance transport, systematic gathering of shellfish, a distinct pattern of land-use and use of ground ocher. These behaviors are frequently cited as elements of 'cultural modernity' (McBrearty and Brooks, 2000; Henshilwood and Marean, 2003; Mellars, 2006; Marean et al., 2007). We interpret the joint and uniform occurrence of these behavioral patterns during successive occupations as stable adaptations of highly mobile hunter-gatherer groups to coastal landscapes.

One final aspect can be added to the observations about the raw material economy. The application of bipolar reduction is often cited as evidence for overcoming raw material scarcity in the vicinity of a site (Barham, 1987; Orton, 2002). Therefore, we hypothesize that the use of the bipolar technique on quartz at HDP1 signals an approach for conserving other sparse raw materials, thus optimizing the use of silcrete. This is also supported by the fact that most quartz cores are small, show heavy reduction and can be described as exhausted.

Coastal adaptations at HDP1

In this paper, we set out to evaluate the importance of shellfish exploitation for human evolution by better characterizing coastal adaptations of modern humans. In order to achieve this goal, we considered the entire site in its behavioral context by integrating archaeological data and shellfishing behavior. We focused on lithic artifacts because they are the most abundant category of finds at HDP1.

Some studies of coastal adaptations have focused exclusively on marine resources without providing detailed discussions of the lithic assemblages (e.g., Walter et al., 2000; Bruggemann et al., 2004; Cortés-Sánchez et al., 2011). This stems from the difficulty in establishing a direct connection between stone artifacts and shellfish remains. First, we know of no artifact types associated

exclusively with shellfish collecting, and indeed stone tools are not even necessary to gather the majority of these resources (Moss, 1993). Furthermore, there are no use wear or residue studies which directly link stone artifacts with shellfish remains, although there might be for fish (see Höglberg et al., 2009; Hardy and Moncel, 2011). So how can we establish a direct connection between the lithic artifacts and shellfish remains? The most direct relationship between these cultural remains is their close association in one or preferably several stratified archaeological layers at the same site. Even in this case, however, it must be shown that the shellfish assemblage has been deposited by humans and not by natural agents (e.g., Bailey et al., 2007; Bailey and Flemming, 2008). The anthropogenic accumulation of shellfish at HDP1 is supported by several lines of arguments. The shellfish are strictly confined to the archaeological layers and do not occur anywhere else in the sedimentary sequence. The shellfish remains also show signs of human impact through burning. Finally, the shellfish species and their size correspond to collection patterns observed at other MSA sites (K. Kyriacou, Personal communication). Since the association between the two find categories is clear at HDP1, the lithic assemblages can be seen to represent part of the same behavioral package and can therefore be linked to the shellfish remains.

The lithic assemblages at HDP1 suggest that the use of marine resources was an integral part of the settlement system of the local hunter and gatherer groups, with HDP1 being deliberately chosen as a location to exploit shellfish. Several observations from the lithic assemblages and the geographical location of the site support this interpretation. The import of non-local silcrete in the form of tools and finished end products indicates that people moved to this location from further away. But what was the reason to stop at HDP1? The location has no logistic value under interglacial conditions because it is located at the very end of a peninsula. While the hilltop of the peninsula offers a good vantage point over the surrounding marine environment, its view of the terrestrial landscape is limited. The peninsula lacks fresh water sources, as well as substantial places of shelter such as true caves and rockshelters. In fact, our experience makes it clear that the site offers little protection from frequent southerly winds. Furthermore, by choosing a coastal location like HDP1 for occupation, MSA people sacrificed a large proportion of their potential foraging radius. Thus if marine resources were not being exploited, the site offered few reasons to stay. Based on these arguments, we suggest that people actively chose this spot to exploit shellfish (see also Parkington, 1976; Jerardino and Marean, 2010; Marean, 2011). Moreover, the consistent association between non-local silcrete tools and shellfish throughout more than 1 m of successively stratified occupations suggests planned activities and not simply opportunistic foraging. The thickness of the deposits and the existence of three separate archaeological strata indicate a certain time-depth involved in the accumulation of these occupation remains during the early part of MIS 5. Because the exploitation of shellfish is associated with the same patterns of raw material procurement and inferred mobility, lithic technology, ocher use and animal hunting in each occupation phase, we interpret the evidence at HDP1 as stable and perhaps sustained integration of marine resources into the economic system. In contrast, if the shellfish remains derived from occasional forays or opportunistic use of shellfish as emergency food, we would rather expect to see horizons of just a few centimeters thickness with fewer shellfish and individual events separated by sterile sediments. While the long-term character of these adaptations at HDP1 is for now based on contextual evidence, in the future, our interpretations can be tested against the results of absolute dating of the individual occupation phases, as well as taphonomic and micromorphological investigations of site formation.

Regarding the overall settlement strategy, we interpret the site to reflect regular and repeated short-term occupations by small groups of highly mobile hunter and gatherers. We base this conclusion on several factors: first, the density of the lithic materials is relatively low compared with other MSA sites; second, finer subdivisions exist within each of the AHs; and third, the lithic assemblages all belong to the same techno-complex. Put another way, HDP1 reflects frequent and recurrent ‘picnic on the beach’ carried out on a planned basis over a prolonged period of time, rather than a few large-scale and long-term occupations.

Since no human remains are found in the archaeological horizons of HDP1, the hominin species that gathered the shellfish remains must be inferred indirectly. After ~200 ka only the remains of *H. sapiens* are known from Sub-Saharan Africa. Relevant sites include Klasies, Border Cave, Die Kelders Cave 1, Sea Harvest, Blombos and Equus Caves in South Africa, as well as the Omo Kibish Formation and Herto in Ethiopia (e.g., Klein, 2001, 2009; White et al., 2003; McDougal et al., 2005; Grine, 2012). Since the dating of HDP1 to MIS 5e is supported by several lines of evidence, including absolute and relative dating, fauna, ethnographic analogy and sea level correlations, *H. sapiens* is the most likely shellfish collector.

How can these observations be linked to the larger theoretical framework of human evolution? Parkington (2001, 2003, 2010) has emphasized the role that coastal adaptations and the exploitation of shellfish might have played in human evolution. According to Parkington’s model, the adaptation of marine resources must be constant over many generations to have an evolutionary impact. Also, the shellfish themselves are particularly important for certain subsets of the entire population (e.g., children). Finally, this model predicts that shellfish intake increases during the Late Pleistocene compared with earlier times, indicating its importance for the evolution of modern humans. As described above, HDP1 generally supports these hypotheses: shellfish are part of the routine foraging round across 1 m of stratified archaeological deposits, suggesting consistent adaptations to coastal landscapes and their resources over generations. Second, the cultural remains are relatively sparse and indicate short occupations of a small group of people for the consumption of shellfish instead of large-scale accumulations. Third, the stable coastal adaptations seen at HDP1 date as early as MIS 5e.

In contrast, while the use of marine and aquatic foods has been claimed for the Early to Middle Pleistocene (e.g., Joordens et al., 2009; Braun et al., 2010; Steele, 2010), these reports provide only circumstantial evidence for the opportunistic use of marine and aquatic resources, which is scattered through time and space. Furthermore, the anthropogenic accumulation of the marine fauna is not always certain (e.g., at Trinil). HDP1 itself sustains this point: several meters below the archaeological horizons, the paleontological layers provided a hominin tibia and several teeth attributed to *Homo heidelbergensis* or another African Middle Pleistocene hominin (Churchill et al., 2000; Stynder et al., 2001). Yet, no artifacts or shellfish have been found in any of the levels that lie below AH I–III. The absence of marine resources at the time of this hominin (~300 ka) suggests that shellfish were not yet exploited as a routine part of the diet. Sustained and systematic collection of marine resources first emerge in both modern humans and Neanderthals at the end of the Middle Pleistocene (MIS 6; Marean et al., 2007; Jerardino and Marean, 2010; Colonese et al., 2011; Cortés-Sánchez et al., 2011; Hardy and Moncel, 2011), with HDP1 already showing an advanced pattern of coastal adaptations by *H. sapiens* during the last interglacial.

In conclusion, the evidence from HDP1 and other shellfish-bearing sites from the MSA is generally consistent with Parkington’s model that marine resources played an important role in the evolutionary trajectory of modern humans. Future work should

address the exploitation of shellfish by archaic and modern humans, in order to interpret the similarities and differences of their coastal adaptations from an evolutionary viewpoint.

Conclusion

HDP1 joins other archaeological sites, such as Pinnacle Point 13B and Ysterfontein 1, in elucidating early coastal adaptations of *H. sapiens* in southern Africa. Furthermore, this study presents the first data on the lithic assemblages from an open-air MSA site rich in shellfish. While studies of the shellfish and other faunal remains, as well as the micromorphology and further dating of HDP1 are currently underway, for now we draw conclusions about stone knapping and other behavioral coastal adaptations in the Western Cape of South Africa during the last interglacial period.

Our data show that small groups of well provisioned hunter–gatherers, carrying toolkits with finished implements that originated from inland sources of silcrete, returned repeatedly to HDP1 to collect shellfish from the rocky coastline. During the course of what appear to be a series of short occupations, they processed and presumably consumed these shellfish, occasionally butchered mammals, tortoises and waterfowl, and made use of ostrich eggshell and ocher. The inhabitants of the site left these and other materials on a sandy hillside along the Atlantic coast. The prevalence of burned materials, including shell, bone and ostrich eggshell, also documents the use of fire at the site. These occupations reflect something closer to multiple brief episodes of collecting, preparing and consuming shellfish along with social encounters near the shore (‘picnic on the beach’ model) than major accumulations that resulted from a few long-term settlements. Furthermore, the inhabitants collected, knapped and eventually discarded artifacts of locally available quartz, quartz porphyry and calcrete over the course of these episodes of occupation. They used diverse knapping methods and techniques depending on their needs. However, these behaviors ultimately led to the formation of three main archaeological units at HDP1 that contain very similar lithic assemblages.

In summary, the HDP1 lithic assemblages document a robust pattern of land-use that we interpret as stable and sustained adaptations of small and highly mobile bands of hunters and gatherers to coastal landscapes as early as MIS 5e. As comparable early adaptations are known only from archaeological sites dating to MIS 6 or 5 (e.g., Pinnacle Point, Blombos, Ysterfontein), the results from our study are consistent with Parkington’s model that the exploitation of marine resources played a crucial role in the evolution of modern humans. Future work should contextualize these results within a broader evolutionary framework that examines coastal adaptations by archaic and modern humans in multiple regions from a diachronic perspective.

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Middle and Later Stone Age shellfish exploitation strategies and coastal foraging at Hoedjiespunt and Lynch Point, Saldanha Bay, South Africa



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ABSTRACT

Hoedjiespunt 1 has long been recognized as one of the earliest Middle Stone Age (MSA) shell-bearing sites on the southwestern Cape coast. Together with the closely adjacent and roughly contemporary site at Sea Harvest, and the extensively documented site of Ysterfontein, Hoedjiespunt provides a record of MSA people's adaptations to coastal environments and systematic exploitation of marine resources at a crucial time in human evolution. The site was re-opened for excavation in 2011, and the combined shellfish assemblage from the original 1994–1996 excavations and the more recent field season was analysed. This augmented assemblage displays a number of commonalities with those from other MSA sites along the Atlantic west coast. The abundance of granite limpets (*Cymbula granatina*) and black mussels (*Choromytilus meridionalis*), and large size of limpets recovered from Hoedjiespunt is consistent with the small-scale and selective exploitation of a limited range of accessible species during short, episodic visits to the coast by highly mobile hunter–gatherers. The nature of the stone artefact assemblages that are associated with the shellfish remains, characterized by low lithic densities, expedient use of predominantly local raw materials, little retouch on-site but import of non-local silcrete tools, supports this interpretation. As a regional comparison, the shellfish assemblages from three Later Stone Age (LSA) middens at Lynch Point in Saldanha Bay were also analysed. The diversity of the shellfish remains from Lynch Point, in combination with much smaller limpet sizes, are indicative of broader and more flexible coastal foraging strategies and more intensive shellfish collection during the LSA in this region.

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1. Introduction

Hoedjiespunt (HDP) 1 is located at the southern edge of the Hoedjiespunt peninsula near the harbour town of Saldanha Bay (Fig. 1). This open-air site is one of several archaeological and palaeontological assemblages that form part of a large fossil dune formation resting on a wave-cut platform approximately 12–15 m above the current sea level (Grine and Klein, 1993; Stynder et al., 2001; Will et al. 2013). The site first came to light through collections made by G. Avery and R. Klein in the 1970s. The first systematic excavations at HDP1 were conducted between 1994 and

1996 by J. Parkington and colleagues and focused mainly on the palaeontological site. These yielded a small sample of stone artefacts including a range of informal MSA tools manufactured on locally occurring quartz and some pieces of worked ochre; a small faunal assemblage comprised of intertidal mussels and limpets, marine mammals and birds, and small terrestrial species; as well as large quantities of ostrich eggshell. Based on uranium series, infrared stimulated luminescence, and electron spin resonance dates, the occupation of the site most likely occurred during MIS 5e ca. 115–130 ka (Berger and Parkington, 1995; Parkington, 2003; Woodborne, 1999, 2000; Yoshida, 1996). These previous dates agree with preliminary results from thermoluminescence dating undertaken in 2011 (C. Tribolo, pers. comm.). Based on these age determinations, HDP1 is the oldest known shell-bearing site along the Atlantic west coast.

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Fig. 1. Map showing the location of MSA (Sea Harvest and Hoedjiespunt) and LSA (Lynch Point) shell-bearing sites near Saldanha Bay in relation to other archaeological sites on the southwestern Cape coast. Illustration by Neil Rusch.

Hoedjiespunt 1 was re-excavated in 2011 by a joint team from the Universities of Cape Town (UCT) and Tübingen (Fig. 2), under the direction of N. Conard, in response to intense scholarly interest in coastal adaptations following large-scale excavations at the MSA sites of Ysterfontein and Pinnacle Point. The renewed excavations were conducted to assess the extent of the archaeological horizons, refine the chronology of the site's occupation, and augment existing collections of artefactual and faunal remains. Analysis of the enlarged lithic and shellfish assemblages from HDP1 represents a significant contribution to the early MSA archaeological record of this region. One of us (MW) analysed lithic material previously considered as adiaagnostic (Stynder et al., 2001), pooling the samples from 1994 to 1996 and 2011 (Will et al. 2013). Shellfish remains from all field seasons have also been pooled, augmenting the sample considerably. Limpets and black mussels from a surface collection designated as Hoedjiespunt 3 further increase the sample of measurable specimens from this locality. Hoedjiespunt 3 is located a few kilometres away from HDP1, is comprised

predominantly if not exclusively of archaeological rather than palaeontological material, and has been dated by means of electron spin resonance to the last interglacial, making it roughly contemporary with HDP1.

The Lynch Point sites include several fairly homogenous LSA middens located almost directly opposite the entrance to Saldanha Bay. These are comprised predominantly of shellfish remains, with other faunal remains and lithic and non-lithic artefacts thinly dispersed throughout the shelly matrix. Excavations at these sites were conducted in 1988 as a joint venture between the Archaeology Contracts Office (ACO) of UCT and Club Mykonos, Langebaan, in an attempt to minimise damage caused by the construction of the club's new harbour and housing facilities. The material from these excavations is hitherto unpublished. Shellfish remains from three of the shell middens, namely Lynch Point (LP) 18, 19 and 20, are discussed in this paper. Three other sites, designated LP14, 15 and 16, were partially or wholly destroyed by earthmoving equipment prior to the beginning of systematic excavations.



Fig. 2. The re-excavation of HDP1.

The Hoedjiespunt and Lynch Point sites are of considerable importance in documenting the prehistory of coastal foraging in the Saldanha Bay region. HDP1 currently represents the most thoroughly researched and oldest open-air site on the Atlantic west coast. The previously unreported Lynch Point middens provide insight into the shellfish exploitation strategies of the Late Holocene inhabitants of Saldanha Bay. Two consistent, quantifiable differences between MSA and LSA shellfish assemblages, which have been recognized at numerous sites along the South African coast, are apparent in the shellfish remains from the nearby localities of Hoedjiespunt and Lynch Point. The first of these relates to the relative abundance and diversity of molluscan fauna in MSA and LSA assemblages, while the second concerns the mean size of limpets recovered from MSA and LSA sites. These patterns are interpreted and discussed alongside ethnographic observations of modern coastal foragers and explanations grounded in optimal foraging theory.

2. Materials and methods

2.1. Excavation, stratigraphy and dating

During the renewed excavations at HDP1, a stratigraphic framework based on and consistent with that set up during the earlier investigation of the site was employed. The deposits were comprised of distinct archaeological horizons in primary context. Stratified layers of occupational debris were preserved beneath a thick calcrete carapace or modern surface layer designated as HUMUS (Fig. 3). A firmly cemented shell midden (SHEM; AHI) consisting of mussels and limpets and some artefactual remains lay at the base of up to two metres of calcrete carapace capping the Hoedjiespunt hill. This was underlain by a layer of nodular sand (NOSA; AHI), overlying a fauna- and artefact-rich deposit of dark loamy sediment (DAMA; AHII). The lowest occupational horizon consists of another stratum of nodular sand (NOSA 2; AHIII). The lowest occupational horizon is followed by a layer of fine, shelly sand (SHES) that demarcated the end of the archaeological and beginning of the palaeontological horizons (Stynder et al., 2001; Will et al. 2013). The archaeological horizons represent three phases of occupation characterised by fairly consistent lithic production and shellfish exploitation strategies (Will et al. 2013).

In each square, the deposits were removed in 2–3 cm “Abträge” or spits following the natural slope of the sediments and geological layers, but never cross-cutting these strata. In total, an area of 18 square metres was excavated to the depth of 1.5 m. Some of the sediments were highly compacted and difficult to

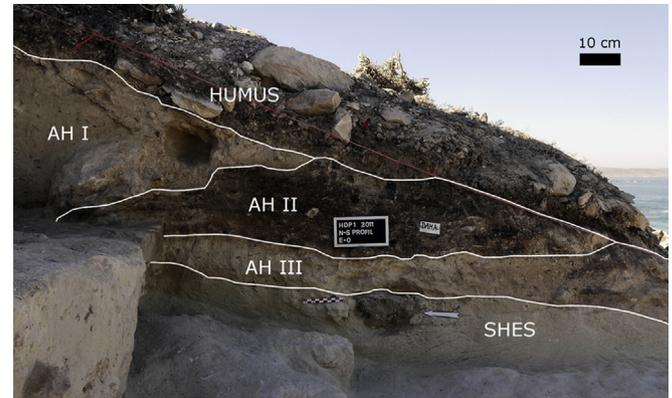


Fig. 3. Photograph of the stratigraphic section at Hoedjiespunt 1. White lines mark the boundaries between the archaeological horizons (AHs) as well as the over- and underlying geological layers (HUMUS; SHES). Photograph taken by N.J. Conard.

remove without damaging artefactual and faunal remains. Individual finds >2 cm were piece plotted in the field using a Leica Total Station and EDM programme (Dibble and McPherron, 1996). Buckets of sediment were wet-screened with seawater and put through 5 mm and 2 mm mesh sieves in order to increase the recovery of archaeological material (Will et al. 2013). The material was then sorted into lithic and non-lithic components. The lithic and shellfish remains were further sorted, identified and analysed. The results from the lithic analyses (Will et al. 2013) are published elsewhere, and are referred to in the discussion section of this paper only in so far as they support our interpretations of the shellfish assemblage.

In common with other MSA shell-bearing sites along the Atlantic west coast, HDP1 has yet to be definitively dated. Infrared stimulated luminescence and thermoluminescence dates on sediments from DAMA date this archaeological horizon to 117ka during marine isotope stage 5e. The presence of large quantities of marine faunal remains including molluscs and vertebrates is consistent with dates falling within the last interglacial (Parkington, 2003; Stynder et al. 2001; Woodborne, 2000). New thermoluminescence dates on samples taken during the recent re-excavation of the site are still pending. On the basis of an electron spin resonance date, the shell midden at HDP3 appears to be contemporary with HDP1, and occupies a similar place in the local stratigraphy (Parkington, 2003; Yoshida, 1996).

Shellfish remains from Lynch Point were recovered in the course of rescue excavations aimed at minimising damage to archaeological deposits caused by construction. Lynch Point 18 represents a scatter of shell and bone rapidly accumulated in a series of uneven rocky platforms above the high water mark. A four metre long trench was dug perpendicular to the shoreline and shellfish remains, fish and mammal bones and some ceramic sherds were recovered from the shallow archaeological deposits. Lynch Point 19 was comprised of more extensive and deeper shell midden deposits which, like those at LP18, were focused on a series of granite platforms. Ten one metre test holes were dug down to the granite bedrock, yielding the remains of shellfish, fish, and sheep. The sheep bones, as well as some ceramics, derive from the basal layers of the deposit. Lynch Point 20 was similar in structure and contents to its two counterparts. The excavation of this site, which proceeded parallel to the shore, revealed the existence of an emerged shoreline presumed to be the remnants of a previous high sea level at around 4000–5000 BP. Among the excavated remains were shellfish residues, the bones of small bovids, sheep and/or goats, dune molarats, snakes and tortoises, some fragments of ostrich eggshell and a single ceramic sherd.

Standard excavation techniques were employed during all of these excavations. Deposits were removed using brushes and trowels, in accordance with their stratigraphy. The sediments were screened and artefactual and faunal remains retained for sorting and identification. Radiocarbon dates place the accumulation of the Lynch Point sites within the Late Holocene. Lynch Point 19 is the youngest of the three sites: dates of 580 BP, 1300 BP and 2370 BP have been obtained for shells samples from the top, middle and bottom of the stratigraphic sequence (Table 1). Lynch Point 20 is the oldest of the middens, dating to between 1990 and 4250 BP. Lynch Point 18 dates to 2680 BP.

2.2. Shellfish analysis

Shellfish remains were identified to generic or specific level where possible, and MNI's (Minimum Number of Individuals) determined for the different taxa. For bivalves, left and right hinges were counted separately and the higher number used for the MNI. For limpets, whelks and turban shells, apices were counted. To determine the mean size of limpets, the total length of unbroken specimens was measured. Specimens <20 mm were considered as subadults, and excluded (Jerardino, 2012). Measurements of the mean size of black mussel hinges were derived from the prismatic band located along the border of the shell opposite the anterior retractor scar (Kilburn and Rippey, 1982). The width of the prismatic band is proportional to the total length of the shell and thus serves as a useful proxy for size in incomplete and broken specimens (Buchanan, 1985). Specimens with a prismatic band width <4.5 mm are juveniles, and were excluded from measures of size and relative abundance. Counts and measurements of shellfish from the Lynch Point sites were recorded on shellfish analysis forms, and subsequently collated for analysis. The statistical significance of size differences in limpets and mussels within and between sites was determined using non-parametric Mann–Whitney U tests, which measure the difference between two medians in samples where data are not normally distributed. Statistical analyses were conducted using Graphpad Prism.

3. Results

The shellfish assemblage from HDP1 (Table 2) is dominated by the granite limpet (*Cymbula granatina*) and, to a lesser extent, the black mussel (*Choromytilus meridionalis*). These two species account for 61.3% and 24.5% of the recovered shellfish remains, respectively. There is some variation in the relative abundance of black mussels and granite limpets within the HDP1 sequence. For instance, proportions of *C. granatina* and *Ch. meridionalis* are quite even in AH I and AH II, while AH III is characterised by greater proportions (>80%) of granite limpets. Argenville's and granular limpets (*Scutellastra argenvillei* and *Scutellastra granularis*) are present in much smaller proportions of 4.9% and 3.3%, respectively. Other limpets, bivalves and whelks are a very minor component of the assemblage.

C. granatina from HDP1 ($n = 72$) and the nearby surface collection HDP3 ($n = 32$) are relatively large, with mean sizes of

Table 2
Shellfish species abundances for HDP1.

Layer	AH I		AH II		AH III		All	
	MNI	%	MNI	%	MNI	%	MNI	%
<i>Scutellastra argenvillei</i>	11	3.3	10	5.6	20	7.3	41	4.9
<i>Scutellastra granularis</i>	8	2.4	6	3.3	14	5.1	28	3.3
<i>Scutellastra tabularis</i>	1	0.3	0	0.0	0	0.0	1	0.1
<i>Cymbula granatina</i>	187	56.2	102	57.0	226	82.5	515	61.3
<i>Cymbula miniata</i>	0	0.0	0	0.0	1	0.7	1	0.1
Unidentified limpet	2	0.6	2	1.1	0	0.0	4	0.5
<i>Aulacomya ater</i>	1	0.3	2	1.1	3	1.1	6	0.7
<i>Choromytilus meridionalis</i>	106	31.8	50	28.0	50	18.6	206	24.5
<i>Donax serra</i>	2	0.6	1	0.6	0	0.0	3	0.3
<i>Perna perna</i>	2	0.6	2	1.1	0	0.0	4	0.5
Unidentified bivalve	1	0.3	0	0.0	4	1.5	5	0.6
Whelk	8	2.4	2	1.1	5	1.7	15	1.8
<i>Crepidula porcellana</i>	1	0.3	0	0.0	2	0.7	3	0.3
Terrestrial snail	2	0.6	2	1.1	3	2.2	7	0.8
Unidentified	1	0.3	0	0.0	0	0.0	1	0.1
Total	333		179		328		840	

69.6 mm and 68.3 mm, respectively. Very few measurable specimens of the other limpet species were recovered from HDP1. HDP3 yielded more complete and measurable shells. Mean sizes of 47.1 mm and 46.6 mm were recorded for *S. granularis* from HDP1 ($n = 4$) and HDP3 ($n = 67$). Large mean sizes of 80.3 mm ($n = 11$) and 78.8 mm ($n = 14$) were obtained for *S. argenvillei* from these two assemblages. There are no statistically significant differences ($p < 0.05$) in size between granite ($p = 0.26$), granular ($p = 0.89$), and Argenville's ($p = 0.20$) limpets from HDP1 and HDP3. Mean sizes for all three limpet species are similar to those reported for Ysterfontein and Sea Harvest (Avery et al. 2008). Black mussel hinges from HDP1 ($n = 125$) are small, and have a mean prismatic band width of 7.4 mm; hinges from the larger sample from HDP3 ($n = 566$) yielded an even smaller mean of 7.1 mm. Mean prismatic band widths <8 mm were recorded for specimens from YFT (Avery et al. 2008).

The Lynch Point middens (Table 3) are dominated by *C. granatina*, *S. granularis* and *S. argenvillei*. Some variation in the relative proportions of these species is apparent in the three different assemblages. Two other species, namely pear and goat's eye limpets (*Scutellastra cochlear* and *Cymbula oculus*) are also present in significant quantities and varying proportions in all three sites. Whelks of the genus *Burnupena* are fairly abundant in all of the Lynch Point middens. Black mussels are not a major component of these assemblages, and white mussels (*Donax serra*) are completely absent. Barnacles, which were recovered from all of the Lynch Point middens, account for only a small percentage of the recovered remains, by weight.

The shellfish assemblage from LP18 is characterised by slightly higher proportions of *S. granularis* than *C. granatina* and *S. argenvillei*. The former accounts for 22.3% of the countable shells recovered, while the latter constitute 15.5% and 15.9% of the assemblage, respectively. *S. cochlear* is only slightly less numerous, at 11.3%. Whelks (*Burnupena* spp.) are present in similar proportions to *S. granularis*, and constitute 22.6% of the identified shellfish remains. Black mussels make a negligible contribution (2.9%) to the assemblage. In the assemblage from LP19, *C. granatina* and *S. granularis* are present in similar proportions of 22.8% and 23.5%, respectively. Proportions of *S. argenvillei* and *S. cochlear* are slightly lower (9.5% and 7.5%) than at LP18. Whelks are less numerous in the assemblage from LP19 (16%), while black mussels are more numerous (7.4%). The shellfish assemblage from LP20 is characterised by an abundance of *S. granularis*. This species accounts for 25.1% of the identified shellfish remains. *C. granatina*, is present in slightly lower proportions (20.7%) while *S. argenvillei*,

Table 1
Radiocarbon dates for samples from LP18, LP19 and LP20.

Pta#	Site	Material	Stratigraphic context	Calibrated age
5009	LP18	marine shell	J5, 25 cm	2860 BP
5014	LP19	marine shell	K6, 25 cm, top midden	580 BP
5016	LP19	marine shell	K6, 40 cm, Limpet 1	1300 BP
5004	LP19	marine shell	K6, 75 cm, base midden	2370 BP
5027	LP20	marine shell	Sq3, 105 cm	4250 BP
4884	LP20	marine shell	1M	1990 BP

Table 3
Shellfish species abundances for LP18, LP19 and LP20.

Site	LP18		LP19		LP20	
	MNI	%	MNI	%	MNI	%
<i>S. argenvillei</i>	164	15.9	470	9.6	1019	16.3
<i>S. barbara</i>	21	2.0	124	2.5	165	2.6
<i>S. cochlear</i>	117	11.4	372	7.6	582	9.3
<i>S. granularis</i>	230	22.4	1154	23.5	1571	25.1
<i>C. granatina</i>	160	15.6	1123	23.0	1295	20.7
<i>C. miniata</i>	2	0.2	1	0.0	11	0.2
<i>C. oculus</i>	22	2.1	216	4.4	159	2.5
<i>A. ater</i>	0	0.0	4	0.1	1	0.0
<i>Ch. meridionalis</i>	30	2.9	366	7.5	245	3.9
<i>Argobuccinum</i> sp.	4	0.4	20	0.4	39	0.6
<i>Burnupena</i> sp.	233	22.7	788	16.1	837	13.4
<i>Oxysteles</i> sp.	2	0.2	176	3.6	53	0.8
<i>Haliotis</i> sp.	10	0.9	18	0.4	36	0.6
<i>Amblycheps</i> sp.	1	0.2	0	0.0	0	0.0
<i>Bullia</i> sp.	0	0.0	0	0.0	2	0.0
<i>C. porcellana</i>	31	3.0	60	1.2	223	3.6
<i>Deutella</i> sp.	1	0.1	3	0.1	0	0.0
<i>Pentunculus</i> sp.	0	0.0	2	0.0	1	0.0
<i>Scutella</i> sp.	0	0.0	7	0.1	3	0.1
<i>Turitella</i> sp.	0	0.0	3	0.1	0	0.0
Total	1028		4907		6244	

accounts for 16.3% of the assemblage. Whelks constitute 13.4% of the identified remains while black mussels make up only 3.9%.

Median sizes of 57.7 mm, 57.4 mm and 55.5 mm were obtained for granular limpets from LP 18 ($n = 15$), LP19 ($n = 282$) and LP20 ($n = 286$), respectively. There are no statistically significant differences at the 0.05 level for *C. granatina* from the Lynch Point sites. Granular limpets ranged between 33.3 mm ($n = 45$) at LP18, and 36.6 mm at LP19 ($n = 503$) and LP20 ($n = 584$). Specimens from LP18 are significantly smaller than those from the two larger sites ($p = 0.03$). This is probably due to differences in sample size. Median sizes of 72.2 mm ($n = 41$), 74.4 mm ($n = 165$) and 69.9 mm ($n = 272$) were obtained for Argenville's limpets from LP18, LP19 and LP20, respectively. *S. argenvillei* from LP19 are significantly larger than those from LP20 ($p = 0.01$). Granite, granular and Argenville's limpets from the LP sites are all significantly smaller ($p < 0.05$) than those from HDP1 and HDP3 (Figs. 4–6). Black mussel hinges from LP18 ($n = 24$) have the same mean prismatic bandwidth as those from HDP1 (7.4 mm), while those from LP19 ($n = 359$) have the same mean as hinges from HDP3 (7.1 mm).

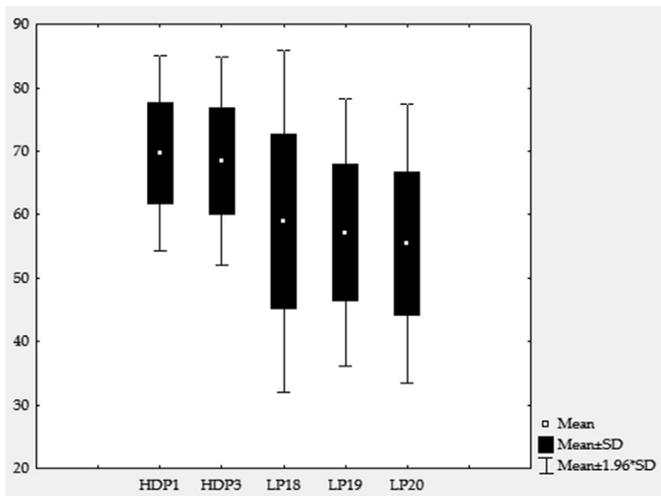


Fig. 4. Box and whisker plot showing the mean total length (mm) of *C. granatina* from the Hoedjiespunt (MSA) and Lynch Point (LSA) sites.

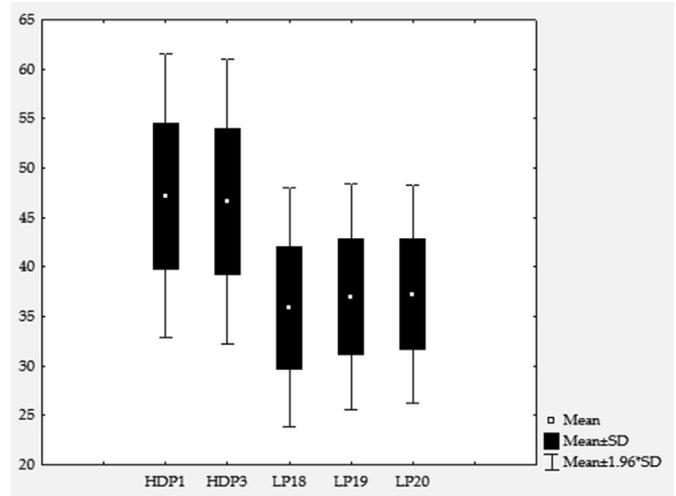


Fig. 5. Box and whisker plot showing the mean total length (mm) of *S. granularis* from the Hoedjiespunt (MSA) and Lynch Point (LSA) sites.

Specimens from LP20 ($n = 181$) are significantly smaller (6.2 mm, $p = 0.01$).

4. Discussion

4.1. Coastal foraging at Hoedjiespunt during the Middle Stone Age

Environmental conditions and coastal morphology determine the molluscan fauna available to human collectors (Steele and Klein, 2008). Nevertheless, the relative proportions of different taxa represented in an archaeological assemblage provide insight into prehistoric coastal foraging with regard to prey choice, the scheduling of gathering events and activities, transport and mobility, resource exploitation strategies and land-use patterns. *C. granatina* and *Ch. meridionalis* are the most significant components of MSA shell-bearing sites along the Atlantic west coast (Avery et al. 2008; Halkett et al. 2003; Klein et al. 2004; Steele and Klein, 2008). Both species are quite large, with relatively high meat yields (Dusseldorp and Langejans, 2013; Langejans et al. 2012) and form dense populations or colonies in the relatively accessible mid-intertidal zone (Bustamante and Branch, 1996a, 1996b, 1997;

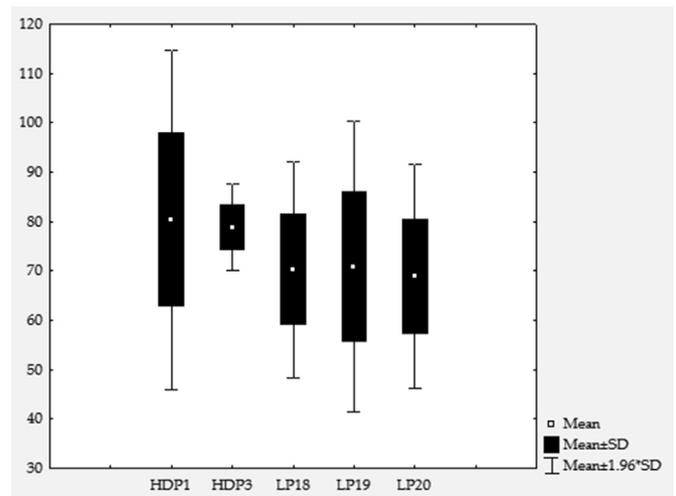


Fig. 6. Box and whisker plot showing the mean total length (mm) of *S. argenvillei* from the Hoedjiespunt (MSA) and Lynch Point (LSA) sites.

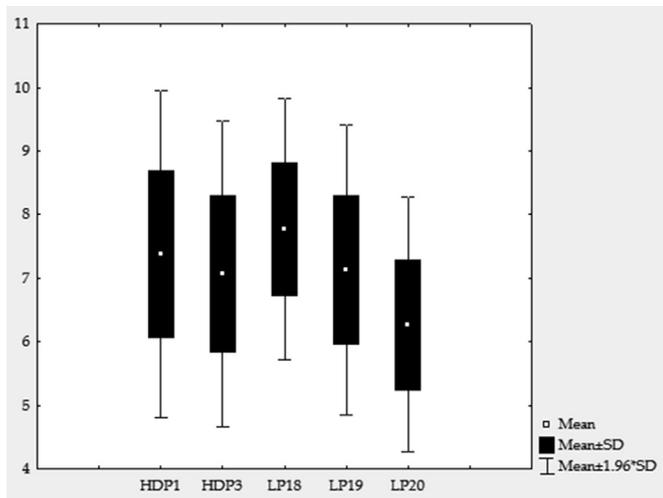


Fig. 7. Box and whisker plot showing the mean prismatic bandwidth (mm) of *Ch. meridionalis* from the Hoedjiespunt (MSA) and Lynch Point (LSA) sites.

Langejans et al. 2012). Granite limpets, followed by black mussels, are the predominant taxa throughout the sequence at HDP1. Black mussels are more abundant than granite limpets in the assemblage from Ysterfontein (Avery et al. 2008). Some variation within shellfish collection strategies focused on these particular mussels and limpets is apparent within the three occupational horizons at HDP1, and has also been documented at Ysterfontein (Avery et al. 2008).

S. argenvillei and *S. granularis* constitute a much smaller part of the shellfish assemblages from HDP1 and other MSA sites in the western Cape. These species are always less well-represented than *C. granatina* in MSA contexts. Argenville's limpets are consistently present in slightly greater proportions than granular limpets (Avery et al. 2008; Steele and Klein, 2008). *S. argenvillei* are larger and have correspondingly higher meat yields than most other limpet species, but inhabit the lower intertidal zone which is only accessible to human foragers during spring low tides. Their presence in significant numbers in some archaeological deposits therefore signifies a willingness on the part of prehistoric hunter–gatherers to collect species with very high returns in spite of the high costs involved in locating and collecting them. Granular limpets, on the other hand, are highly abundant and accessible, but are much smaller and have considerably lower meat yields (Langejans et al. 2012). They appear to have been largely ignored by MSA people at HDP1, Ysterfontein and Sea Harvest in favour of large taxa, despite the relative ease with which they could have been collected (Avery et al. 2008).

The MSA inhabitants of HDP1 and other sites along the Atlantic west coast routinely exploited a fairly narrow range of large mid-tidal mussels and limpets, with occasional contributions from other, mostly limpet, taxa. MSA assemblages from southern Cape coastal sites also reflect the systematic exploitation of between four and seven frequently collected species, with an emphasis on large mid-tidal turban shells, brown mussels and limpets (Jerardino, 2010a; Langejans et al. 2012). These collection strategies are similar to those of modern coastal foragers in southern Africa and Australia, and should not necessarily be regarded as evidence for limited foraging proficiency or experience by MSA hunter–gatherers. Shellfish collecting is highly selective among many contemporary foragers. For instance, bivalves make up 98%, by weight, of the thirteen mollusc species regularly exploited by the Anbarra of Australia (Meehan, 1982). On almost half of the collection days observed and documented by Betty Meehan, only a single species was harvested. Meriam Torres Strait Islanders target

specific clams and conches when collecting on flat reefs (Bird et al. 2004; Bliege Bird and Bird, 2002). Black and brown mussels are the most frequently and intensively collected molluscs currently harvested along the rocky shores of southern Africa (Bigalke, 1973). Collections by modern coastal foragers in parts of southern Africa and Australia are scheduled to coincide with the maximal exposure of the littoral zone during spring low tides, allowing them to access the mid- and lower-intertidal species (Bigalke, 1973; Bird et al. 2004; Meehan, 1982).

The preference for relatively high meat yielding mussels and limpets from the mid-intertidal is remarkably consistent within and between MSA assemblages from sites along the Atlantic west coast. The collection of these particular shellfish may represent an important component of a stable hunter–gatherer adaptation to coastal environments at this crucial time in the evolution of anatomically modern people. Variation within and between shellfish assemblages from MSA coastal sites can be attributed to differences in site-use, settlement and resource exploitation patterns, as well as changes in coastal morphology and littoral environments. Hoedjiespunt and Sea Harvest are likely to have served as specialised camps from which shellfish were collected during planned coastal visits (Volman, 1978; Will et al. 2013). In addition to systematically harvesting mussels and limpets, MSA hunter–gatherers left small lithic assemblages at HDP1. The lithic assemblages from all three archaeological horizons are characterised by similar use of raw materials, technological behaviours and tool inventories. Knappers made expedient use of the local quartz but manufactured few tools on site. Instead, they mainly imported finished tools from high-quality silcrete which comes from inland sources that were at least 10–30 km away (Will et al. 2013). Additionally, the find densities of lithic remains are low (~350–1200/m³, >2 cm).

The results from the lithic analyses fit well with the observations from the shellfish remains presented here. The low densities of stone artefacts left by the inhabitants, their expedient use of predominantly local raw material and the production of tools on-site all point to short-term stays at the locality, presumably by small groups. The import of non-local silcrete tools to HDP1 indicates planned movements from inland sites to the coast in order to exploit marine resources. This interpretation is supported by the location of the site itself, which offers no sources of drinking water or shelter and has little logistical value as it lies as the very end of a peninsula during interglacial conditions. Other than abundant and accessible marine foods, notably intertidal molluscs, HDP offered few resources or reasons to stay. In conclusion, both the lithic and shellfish assemblages, as well as contextual evidence, suggest that the site reflects a specialised temporary locale for gathering marine resources and not a long-term residential camp. The new data from the shellfish thus support our previous assessment of HDP1 as reflecting short-term “picnics on the beach” by small groups of highly mobile hunter–gatherers (Will et al. 2013). Finally, there is a remarkable consistency in both foraging and technological behaviour of the inhabitants during the early phase of the MSA, documented throughout more than one metre of sediment. In our view, this consistency reflects a systematic adaptation of MSA people to both marine resources and coastal landscapes over many generations.

In contrast to HDP1, MSA cave sites in the southwestern and southern Cape, including Diepkloof Rock Shelter, Klasies River Mouth, Blombos Cave and Pinnacle Point 13b, are residential camps with considerably larger volumes of occupational debris reflecting more intensive exploitation of shellfish and other marine resources, as well as the production of a range of lithic and non-lithic artefacts. Black or brown mussels are particularly abundant in assemblages when sites are located >10 km from the shore, as at Diepkloof Rock Shelter and some of the younger MSA levels of Blombos Cave

(Dusseldorp and Langejans, 2013; Steele and Klein, 2013; Avery et al. 2008). These bivalves are typically harvested in large aggregates of individuals stuck together by fibrous threads and plucked from extensive intertidal beds; are fairly easy to transport from one location to another; and remain fresh longer than limpets (Dusseldorp and Langejans, 2013; Parkington, 2012). Their collection therefore remained profitable even during times of coastal regression (Dusseldorp and Langejans, 2013).

Granite, granular and Argenville's limpets from the adjacent and, most likely, contemporary sites of HDP1 and HDP3 are all relatively large. Similarly large mean sizes have been recorded for these three limpets at Sea Harvest and Ysterfontein (Avery et al. 2008; Halkett et al. 2003; Klein et al. 2004; Steele and Klein, 2008; Volman, 1978). A number of environmental factors influence the maximum size and growth rates of limpets and other mollusc taxa. These include mean water temperature, salinity and turbidity; coastal topography and geomorphology; exposure to wave action; nutrient availability; and the density and composition of intertidal communities (Bustamante and Branch, 1996a, 1996b; 1997; Klein and Steele, 2013; Steele and Klein, 2008). Human predation also has a measurable effect on the size and structure of shellfish populations, especially in the case of slow-growing, attractive and accessible species (Klein and Steele, 2013), and those amenable to highly selective exploitation (Parkington et al. 2013).

Large, mature individuals are preferentially targeted by modern collectors, while smaller immature ones are avoided or discarded (Bigalke, 1973; Bird and Bliege Bird, 1997; Meehan, 1982; Parkington et al. 2013). This preference for large adult molluscs is often extrapolated to prehistoric coastal foragers. The selective exploitation of similarly sized individuals by the Late Holocene inhabitants of the Verlorenvlei region is actually documented in the limpet assemblage from Dunefield Midden (DFM). At this site, the largest specimens of *C. granatina* and *S. granularis* were found together in the same squares. The smallest granite and granular limpets were also recovered from the same squares in this extensive horizontal sequence (Parkington et al. 2013; Tonner, 2005).

Variation in the size of limpets within and between sites and assemblages most likely reflects short and longer-term changes in the intensity of human predation and resulting impact on shellfish stocks (Klein and Steele, 2013; Parkington et al. 2014). The large mean size of limpets recovered from HDP1 and HDP3 indicates that fully grown, adult individuals were available to and exploited by the MSA inhabitants of Saldanha Bay. This suggests that small groups of MSA people were able to satisfy relatively low demands for shellfish meat through the limited collection of large, mature limpets without significantly impacting shellfish populations. As discussed above, the shellfish at Hoedjiespunt were probably collected during relatively short episodes of coastal residence.

Consistent, statistically significant variation in mean size has been documented in limpets from Middle and Later Stone Age assemblages which accumulated under equivalent ecological conditions. On the other hand, the mean size of black mussels from MSA contexts along the Atlantic west coast often overlaps with that of specimens from much younger shell middens (Klein and Steele, 2013). Specimens from MSA sites are also sometimes larger than those from LSA ones (Avery et al. 2008; Klein et al. 2004; Steele and Klein, 2008). There are a number of explanations for these inconsistencies. For instance, slow-growing limpet species which take ten years or more to reach maturity and their full adult size are more vulnerable to the effects of human predation than fast-growing and rapidly re-colonizing black mussels (Jerardino et al. 2009a, 2009b; Klein and Steele, 2013; Steele and Klein, 2008). Furthermore, the collection of limpets, which are harvested individually, is considerably more selective than that of mussels, which

are plucked out in aggregates comprised of several individuals stuck together by byssal threads (Dusseldorp and Langejans, 2013; Parkington, 2012; Parkington et al. 2013).

Patterned size differences between limpets and black mussels are sometimes attributed to environmental factors that influence the growth and productivity of these molluscs. Specifically, while black mussels are more productive and achieve larger sizes on exposed shorelines, most limpets grow larger in bays offering some shelter from wave action (Bustamante and Branch, 1996a, 1996b). Jerardino et al. (2009a) argue that differences in size between *Ch. meridionalis* from two Late Holocene sites in the Verlorenvlei region, namely Elands Bay Cave and Connies Limpet Bar, reflect the proximity of these sites to exposed rocky shores and sheltered bays, respectively. However, this does not account for variation in the size of mussel hinges from the sites of Hoedjiespunt and Lynch Point. Given the location of the former site on an open, exposed point, and of the latter in the sheltered confines of Saldanha Bay, one would expect mussels to be larger and limpets, smaller, at Hoedjiespunt, and limpets to be larger and mussels, smaller, at Lynch Point. To the contrary, limpets from HDP1 and HDP3 are considerably larger than those from LP18, 19 and 20, and black mussels from HDP1 and HDP3 and LP18 and LP19 vary, and sometimes overlap, in size.

Environmental factors can also not account for statistically significant differences in the mean size of black mussels within the large horizontal sequence at DFM (Tonner, 2005). Parkington et al. (2014) suggest that some of the largest black mussels recovered from Elands Bay Cave and Dunefield Midden may have been collected as wash-ups uprooted from subtidal beds by storm surges and deposited onto nearby beaches. At these sites, stratigraphic units with very large black mussels (>100 mm in total length) also have the highest frequency of barnacles which live on large adults inhabiting the subtidal. Squares with smaller mussels which most likely represent younger individuals found in the intertidal have higher frequencies of water-worn shell and stone which are often caught up in the byssus of live mussels and incorporated into archaeological sites. Prismatic bandwidths for black mussels recovered from the Hoedjiespunt sites are consistent with the collection of individuals ranging between 60 and 74 mm in total length from the mid-intertidal. The exploitation of very large stranded mussels, or mature individuals from the subtidal, does not appear to have been part of the coastal foraging strategies employed by MSA people in this region. This further supports our interpretation of the shellfish assemblage from HDP1 as representing short episodes of coastal residence, as the collection of large stranded individuals from unpredictable storm surges is more likely to have taken place among people engaged in more intensive coastal foraging during longer stays at the coast.

The systematic exploitation of marine foods and, specifically, inclusion of shellfish in the diet, would have had a number of economic and nutritional benefits for MSA hunter-gatherers. Intertidal mussels and limpets are abundant, sessile and predictable, and can be harvested with minimal effort and simple technology, little risk of injury and none of failure. They would serve as a reliable source of energy when terrestrial resources were scarce or seasonally unavailable (Jerardino, 2010b; Klein and Steele, 2013; Parkington, 2003). Marine molluscs are also one of the best and most accessible sources of micronutrients and essential fatty acids (Broadhurst et al. 2002; Crawford, 2010; Cunnane, 2010; Kyriacou, 2014; Kyriacou et al. 2014; Parkington, 2003, 2010). As such, they have been ascribed an important role in the emergence of large-brained, anatomically modern humans in coastal southern Africa (Jerardino and Marean, 2010; Marean, 2010; Parkington, 2003, 2010; Will et al. 2013).

Women, especially when pregnant or lactating, and very young children, have the highest requirements for brain-specific nutrients

including iron, copper, zinc, iodine, and longer-chain polyunsaturated fatty acids (LCPUFAs). Among modern coastal foragers, women of all ages are the most regular participants in shellfish collecting. Thus, MSA women visiting the Atlantic west coast would have been able to provision themselves and their dependent offspring with shellfish rich in LCPUFAs and other essential nutrients (Crawford, 2010; Cunnane, 2010; Erlandson, 2010; Kyriacou, 2014; Kyriacou et al. 2014; Parkington, 2003, 2010). The undertaking of planned treks to the coast to harvest and consume shellfish, as implied by patterns in the lithic and shellfish assemblages of HDP1, is indicative of increasingly complex cognition and modern behaviour on the part of early modern people routinely exploiting shellfish (Will et al. 2013). The broadening of subsistence strategies to include a regular marine component may furthermore have facilitated the migration of small populations of *Homo sapiens* out of Africa (Jerardino, 2010a; Marean, 2010).

4.2. Later Stone Age shellfish exploitation strategies at Lynch Point

For much of the LSA, shellfish continued to be an important source of nutrition for prehistoric people in the southwestern Cape, a region characterised by sharp seasonal fluctuations in the availability, productivity and palatability of terrestrial plants coupled with a paucity of large terrestrial animals (Jerardino, 2010a; Marean, 1986; Parkington, 2003). The abundance of granite limpets and black mussels in shellfish assemblages from MSA sites in the southwestern Cape reflects subsistence strategies focused on the collection of highly abundant, visible and accessible species (Avery et al. 2008; Steele and Klein, 2008). In contrast, a wider range of limpet and other mollusc species is well-represented in LSA assemblages, and the relative proportions of species from different intertidal zones are more varied. The Lynch Point middens are less heavily dominated by *C. granatina* and *Ch. meridionalis* than HDP1, Sea Harvest and Ysterfontein, as well as some other Late Holocene sites in the Verlorenvlei (Parkington et al. 2013, 2014; Tonner, 2005). Relative proportions of granite, granular and Argenville's limpets are fairly even in these LSA assemblages.

Whelks constitute a significant component of the Lynch Point middens, and are present in proportions similar to, or even greater than, limpets. Like *S. granularis*, whelks are highly abundant, visible and accessible, but have very low meat yields and caloric returns. In addition, considerably more time must be invested in removing the edible soft tissue from the shells, as with *Turbo sarmaticus*, and is more easily accomplished after cooking (Dusseldorp and Langejans, 2013; Langejans et al. 2012). The abundance of granular limpets, winkles and whelks in LSA assemblages is indicative of flexible, opportunistic subsistence strategies in which a broad spectrum of immediately available foods are exploited (Jerardino et al. 2009b). The increased demands for shellfish meat by larger numbers of collectors during the Late Holocene (Jerardino et al., 2009b) is thought to have necessitated the collection of small molluscs deemed unprofitable by MSA people.

Other aspects of LSA exploitation strategies at Lynch Point are more consistent with careful planning, deliberation and scheduling than with opportunism. *S. argenvillei* contributes significantly to the shellfish assemblages from all three Lynch Point middens, and accounts for ~10–15% of the recovered and identified mollusc remains. The focused collection of this large limpet during low spring tides appears to have been an important foraging strategy for LSA hunter–gatherers in Saldanha Bay, as well as further north in Namaqualand (Halkett et al. 1993; Kyriacou, 2014; Kyriacou and Parkington in prep.). Venus ear abalones or *Haliotis spadicea* are also present in small proportions at LP18, 19 and 20. The larger abalone (*Haliotis midae*) is very friable, and as a result is represented by fragments rather than countable individuals. These very

large molluscs are probably underrepresented in the Lynch Point assemblages. Pear limpets, which are accessible between low and high spring tides, occur in slightly lower proportions than granite, granular and Argenville's limpets. They have low flesh yields relative to most other well-represented mollusc species, but may have been opportunistically collected while foraging for larger, more profitable species in the mid- and lower-intertidal. *C. oculus*, another mid-tidal species, was also collected. The favourable conditions around Saldanha Bay seem to have facilitated the exploitation of a particularly wide range of taxa.

Granite, granular and Argenville's limpets from the Lynch Point middens are between 10 and 15 mm smaller than those recovered from Hoedjiespunt and other MSA sites along the Atlantic west coast. Differences in the mean size of limpets from Middle and Later Stone Age assemblages most likely reflect shifts in the scale and intensity of human exploitation (Avery et al. 2008; Klein and Steele, 2013; Steele and Klein, 2008). As has been previously stated, protected conditions within Saldanha Bay should have allowed limpets to attain large maximum sizes. Nevertheless, intense predation on slow-growing limpet species by large groups of foragers is likely to have driven these sizes down (Fig. 7).

The relatively small mean size of limpets during the LSA can be attributed to an increase in predation by larger numbers of human collectors during this time (Klein and Steele, 2013; Steele and Klein, 2008). However, this does not necessarily attest to the existence of large, semi-sedentary coastal populations, as suggested by other researchers (Jerardino, 2010a,b; 2012; Jerardino et al. 2009b). Even small-scale fluctuations in supply and demand have a significant impact on shellfish stocks. These short-term changes are visible in the sequence from DFM (Parkington et al. 2013; Tonner, 2005). The small numbers of measurable specimens recovered from most individual layers within the stratigraphic sequences at LP18 and LP19 preclude the statistical analysis of changes in the mean size of limpets throughout the occupation of these sites. The occupational sequence from LP20, which yielded considerably larger samples of measurable limpets, is characterised by variation and overlap in the mean size of shells from different stratigraphic layers, with no clear pattern of change through time. Differences in the size of black mussels from the MSA Hoedjiespunt sites, and LSA Lynch Point middens are less consistent than at DFM. Black mussels from all of these Saldanha Bay sites are considerably smaller than the largest recorded specimens from Elands Bay Cave and Dunefield Midden. Like their MSA counterparts at Hoedjiespunt, the LSA inhabitants of Lynch Point collected these bivalves from the mid-intertidal, and did not engage in some of the strandloping behaviour documented at Late Holocene sites in the Verlorenvlei (Parkington et al. 2014; Tonner, 2005).

5. Conclusions

Hoedjiespunt 1 represents one of the earliest documented coastal adaptations by MSA hunter–gatherers in southern Africa, and provides a record of their interactions with marine food resources, notably intertidal shellfish. Small groups of foragers engaged in the selective exploitation of a narrow range of mussels and limpets, particularly large species from the mid-intertidal, during relatively short excursions to the coast. This small-scale predation on abundant, sessile and predictable marine molluscs does not appear to have had any impact on targeted shellfish communities. However, the integration of simple marine resources into the diets of people visiting the Atlantic west coast probably had major implications for the evolution of modern humans in this region. Shellfish represent an easily accessible and reliable source of nutrition on a landscape characterised by seasonal fluctuations in the availability of terrestrial resources. The consumption of even

small quantities of mussels and limpets would have helped pre-historic people meet their requirements for essential nutrients, especially trace elements and polyunsaturated fatty acids ((Broadhurst et al. 2002; Crawford, 2010; Cunnane, 2010; Kyriacou, 2014; Kyriacou et al. 2014; Parkington, 2003, 2010). By buffering against shortages in terrestrial resources, marine resources could potentially reduce mortality in populations. Similar coastal adaptations during the MSA are documented at several coastal sites in the southwestern Cape from at least 164–50 ka (Avery et al. 2008; Langejans et al., 2012; Marean, 2010; Steele and Klein, 2013; Volman, 1978).

The LSA inhabitants of the Saldanha Bay region exploited a wide range of differently sized shellfish species from the upper reaches of the shore to the lower-intertidal. This includes small granular limpets and whelks which are not well-represented in the Hoedjiespunt assemblages; larger, mid-tidal mussels and limpets; as well as several low-shore dwelling limpets and abalones accessible during low tides within the sheltered bay. The LSA shellfish exploitation strategies display more flexibility than those of Middle Stone Age collectors. The relatively intense exploitation of shellfish by larger groups of LSA hunter–gatherers had a demonstrable affect on targeted limpet communities, further emphasizing the difference in the nature and intensity of coastal adaptations between the MSA and LSA.

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Chapter 4 | Coastal Adaptations and Settlement Systems on the Cape and Horn of Africa during the Middle Stone Age

Manuel Will, Andrew W. Kandel,
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Abstract. *The Middle Stone Age (MSA) of sub-Saharan Africa currently provides the earliest and longest record of marine resource exploitation by modern humans. Here we present data on coastal settlement systems from our excavations at the shellfish-bearing MSA locality of Hoedjiespunt 1 (HDP1), Western Cape, South Africa. We also review recent advances in research on MSA coastal adaptations, with a focus on mobility patterns and land-use. The archaeological assemblages of HDP1 indicate that the inhabitants executed scheduled movements to the coastline for exploiting shellfish during three sequential phases of occupation. HDP1 documents a consistent pattern of land-use that suggests stable adaptations of modern humans to coastal landscapes as early as MIS 5e. Results from other coastal MSA sites on the Cape and Horn of Africa support these findings, suggesting the occasional use of marine resources as far back as the late Middle Pleistocene. Recent studies from the western and southern coasts of South Africa, and as far north as the Red Sea, demonstrate that coastlines provided important resources for occupations between MIS 6 and 4. However, these coastlines are not the same. Each represents a region of variable marine productivity with differing oceanographic parameters and exhibits a wide array of geographic and environmental attributes. Yet despite these dissimilarities, the available data document that early modern humans exploited marine resources in a consistent manner. Mobile hunter-gatherers systematically integrated variable coastal landscapes and their resources into their settlement strategies throughout much of the MSA over a widespread area.*

Résumé. *Le Middle Stone Age (MSA) d'Afrique sub-Saharienne présente actuellement les vestiges archéologiques les plus anciens et les plus complets qui témoignent de l'exploitation des ressources marines et côtières de l'homme anatomiquement moderne. Nous présentons ici les résultats concernant l'occupation des régions côtières issus de nos fouilles sur le site Hoedjiespunt 1 (HDP1) (Cap-Occidental, Afrique du Sud), site qui présente des restes coquilliers. Nous analyserons également les récentes avancées de la recherche sur l'adaptation à la zone côtière au MSA, en*

mettant l'accent sur la mobilité et l'exploitation des ressources du territoire. Les vestiges archéologiques de HDP1 indiquent qu'au cours de trois phases d'occupation successives, les habitants du site ont effectué des expéditions ponctuelles régulières sur le littoral afin de s'approvisionner en malacofaune marine. Ce site atteste d'un schéma cohérent de l'utilisation du territoire, suggérant que les hommes se sont adaptés au littoral de manière permanente dès le MIS 5e. Les résultats issus d'autres sites côtiers des régions du cap et de la corne d'Afrique étayent ces résultats en suggérant l'utilisation occasionnelle des ressources marines depuis le Pléistocène moyen. Des études récentes, portant sur les côtes ouest et sud de l'Afrique du Sud ainsi que sur la région de la mer rouge plus au nord, montrent que les côtes ont fourni d'importantes ressources lors de l'occupation des sites depuis le MIS 6 au 4. Toutes ces régions côtières ne sont toutefois pas identiques. Chacune d'entre elles représente une zone de production marine variable avec différents paramètres océanographiques et montre des caractéristiques géographiques et environnementales variées. Malgré toutes ces dissimilitudes, les données actuelles témoignent de l'utilisation constante des ressources marines par les premiers hommes modernes. Les chasseurs-cueilleurs mobiles d'une grande partie du MSA ont systématiquement intégré les différents paysages côtiers et leurs ressources dans l'organisation logistique du territoire.

INTRODUCTION

Adaptations to coastal landscapes and the exploitation of marine food resources are important topics in the study of the biological and behavioral evolution of modern humans. Scholars have frequently emphasized the role that the consumption of marine foods had on brain evolution and demography (Broadhurst et al. 2002; Crawford et al. 1999; Cunnane and Stewart 2010; Marean 2011; Parkington 2001, 2003, 2006, 2010) as well as the potential of coastal landscapes to facilitate the dispersals of *Homo sapiens* out of Africa (Jerardino and Marean 2010; Marean et al. 2007; Stringer 2000; Walter et al. 2000).

In this paper, we use the terms “coast” or “coastal landscape” to describe the 1/2 km interface between land and ocean, including embayments and lagoons. This geographical zone includes terrestrial, beach, intertidal and sub-tidal environments. However, coastal ecosystems are regions of variable biological productivity. Where upwelling is pronounced, nutrient rich water supports diverse marine fauna. Meanwhile, hypersaline conditions combined with terrestrial aridity can create coastlines that are much less productive (Burke et al. 2001; Erlandson 2001; Parkington 2006). Some coasts are rocky and difficult for humans to navigate, but they shelter vast supplies of shellfish, while others are sandy, offering corridors that are easy to travel but provide little nutrition. Some coastlines offer easy accessibility but others impede mobility. Due to long-term changes in global sea levels and short-term actions of winds and waves, coastal areas are continuously changing. As we will discuss later when addressing coastal adaptations by modern humans during the Pleistocene, it is also important to consider how global fluctuations in sea level triggered changes in coastal landscapes (Bailey 2009; Bailey and Flemming 2008; Miller al. 2005).

Sub-Saharan Africa continues to provide the oldest and longest record for the use of coastal landscapes and its resources by modern humans. As early as the 1970s and

1980s, the importance of marine resources in coastal MSA sites was recognized in South Africa at sites like Klasies River Mouth (KRM) (Singer and Wymer 1982; Voigt 1973), Hoedjiespunt 1 (HDP1), and Sea Harvest (Volman 1978). Since then, several more coastal sites with shellfish-bearing strata of MSA age have been excavated. The most important sites lie in three geographical areas (fig. 1). On the southern coast of South Africa, early use of marine resources is well documented from Pinnacle Point Cave 13B (Jerardino and Marean; 2010; Marean et al., 2007), KRM (Thackeray 1988; Voigt 1973), Blombos Cave (Henshilwood et al. 2001; Langejans et al. 2012), Die

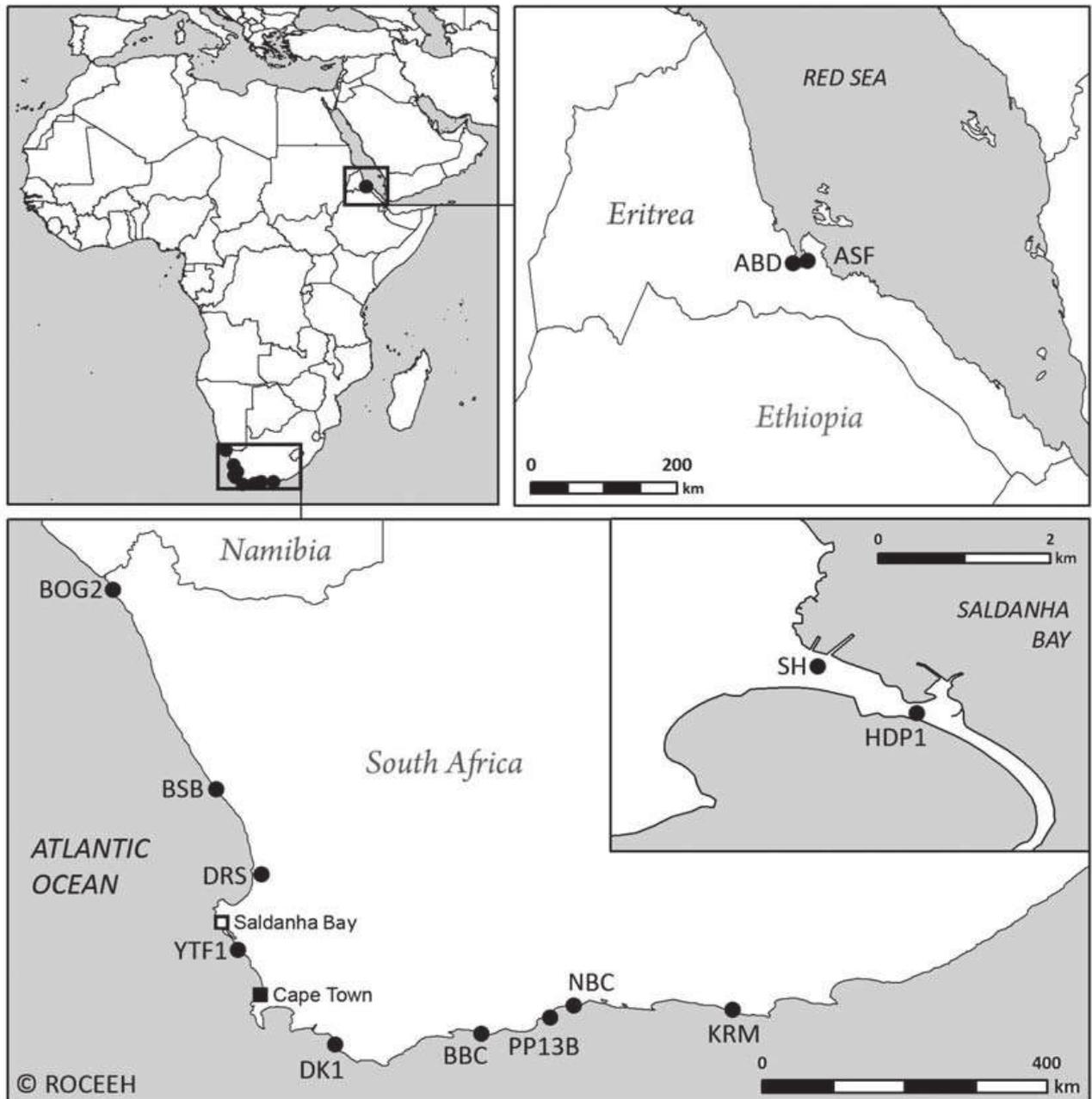


Fig. 1. Location maps depicting MSA sites at the Cape and Horn of Africa with evidence for coastal adaptations (ASF-Asfet; ABD-Abdur; BBC-Blombos Cave; BOG2-Boegoeberg 2; BSB-Brand se Baai; DK1-Die Kelders 1; DRS-Diepkloof Rockshelter; HDP1-Hoedjiespunt; KRM-Klasies River Mouth; NBC-Nelson's Bay Cave; PP13B-Pinnacle Point Cave 13B; SH-Sea Harvest; YTF1-Ysterfontein 1) (map, G. Quénéhervé).

Kelders Cave 1 (Grine et al. 1991; Marean et al. 2000), and Herolds Bay Cave (Brink and Deacon 1982). On the western coast of South Africa, Ysterfontein 1 (YFT1) (Avery et al. 2008; Klein et al. 2004), Boegoeberg 2 (BOG2) (Klein et al. 1999), Sea Harvest (Volman 1978), and HDP1 (Volman 1978; Will et al. 2013) constitute the principle sites indicative of coastal adaptations. The third geographical region, the Red Sea coast along the Horn of Africa, has provided evidence for the early use of shellfish and other marine resources at Abdur and other open-air sites in Eritrea (Beyin 2013; Bruggeman et al. 2004; Walter et al. 2000). In sum, despite geographical and environmental differences, both the Cape and Horn of Africa have yielded important information on coastal adaptations and settlement systems during the MSA.

Starting from this growing body of evidence, researchers have discussed the potential evolutionary relevance of adaptations to coastal landscapes and the consumption of marine foods. Based on the archaeological evidence and modern nutritional studies, several scholars argue that the shift towards more intensive use of marine resources over the course of the MSA may have played a causal role in the evolution and geographic spread of modern humans (Broadhurst et al. 2002; Crawford et al. 1999; Cunnane and Stewart 2010; Marean 2010, 2011; Parkington 2001, 2003, 2006, 2010; Walter et al. 2000). Yet current evidence indicates that modern humans developed in East Africa before the first signs of coastal adaptations (McDougall et al. 2005; White et al. 2003).

In the second volume of *Settlement Dynamics*, Parkington et al. (2004) presented an overview of the current knowledge on coastal adaptations in South Africa. Since this publication, many new and significant findings concerning the early use of marine resources by modern humans in the MSA have been made in both the Cape and Horn of Africa. In the following, we present new data on coastal settlements from our own excavations at the shellfish-bearing MSA site HDP1. We also review the developments in research on MSA coastal adaptations of the last ten years, with a focus on mobility patterns and land-use. The aim of this contribution is to contextualize and evaluate the current evidence from the MSA for the early use of coastal landscapes by modern humans in Africa south of the Sahara.



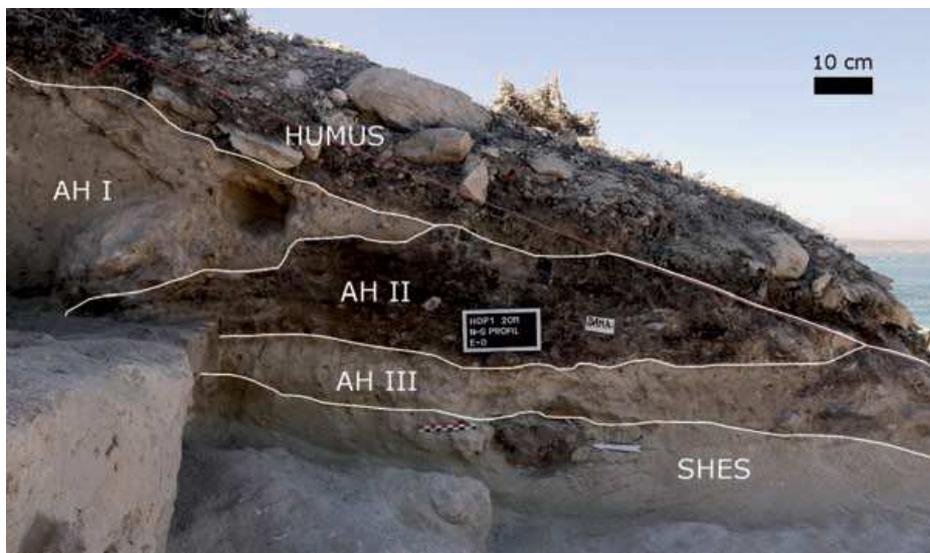
A CASE STUDY: THE MSA SHELLFISH-BEARING SITE OF HOEDJIESPUNT 1

Hoedjiespunt 1

In 2011, a joint team of the University of Tübingen and the University of Cape Town re-opened the excavation at HDP1 (Will et al. 2013). This open-air locality is situated directly on the Atlantic coastline of South Africa, about 110 km north-northwest of Cape Town (figs. 1 and 2; S33°01'42", E 17°57'34"). The archaeological site lies 15 m above mean sea level and yielded stratified deposits of MSA artifacts associated with shellfish remains. The locality was discovered in the 1970s (Volman 1978) and the University of Cape Town conducted excavations at HDP1 between 1993 and 1998. The Parkington team published preliminary results on the archaeological remains (Berger and Parkington 1995; Parkington et al. 2004). With the new excavations in 2011, we aimed to develop an improved stratigraphic framework for the site, recover a larger sample of archaeological material and analyze the finds in more detail. We excavated the archaeological deposits over an area of ca. 18 m² and exposed a maximal thickness of 1.5 m. The sequence at HDP1 consists of three successive archaeological horizons (AH I–III), each containing lithic artifacts, ocher, shellfish, terrestrial fauna and



Fig. 2. Hoedjiespunt. 1. **Left, facing page:** View of the excavation in progress during 2011. **Above, this page:** Horizontal distribution of shellfish in square L12 of AH II. **Bottom, this page:** North-south stratigraphic profile of HDP1 along the East = 0 m line showing: HUMUS = modern top soil, AH I–III = three main archaeological horizons, and SHES = shelly sand (photos, N. J. Conard and M. Will).



ostrich eggshell (fig. 2). The strata are in primary context and lie directly under either a thick calcrete carapace or the modern humus horizon.

The chronology of HDP1 rests on several lines of independent evidence. Absolute dates based on IRSL readings of sediments and ESR and U-series methods indicate an age between 130 and 100 ka for AH II (Woodborne 2000; Yoshida 1996). The vertebrate fauna suggests a warm climate (e.g., angulate tortoise), and the frequent occurrence of shellfish and marine avian species confirm the proximity of HDP1 to the seashore at the time of its formation (Stynder 1997). Combining the results of absolute dating with information on global sea level fluctuations, we assign the deposits to MIS 5 (Will et al. 2013). In our interpretation, the MSA occupations at HDP1 most probably date to the high sea level stand of the Eemian Interglacial (MIS 5e; 130–119 ka). Preliminary dating results from thermoluminescence samples taken in 2011 support this attribution. Will et al. (2013) present further details about the excavation methods, geology, stratigraphy and dating of the site.

Evidence for coastal adaptations and site use at HDP1

The importance of HDP1 rests upon the frequent occurrence of shellfish and the early date for such finds in an MSA context. Abdur on the Red Sea coast (Bruggeman et al. 2004; Walter et al. 2000) and HDP1 represent particularly early open-air localities providing evidence for the exploitation of marine resources. As such HDP1 constitutes an ideal case study for examining land-use and mobility patterns in a coastal setting. How did the inhabitants of HDP1 incorporate the coastal landscape and its resources in their overall settlement strategy? In order to answer this question, we combined the results from the lithic analysis with information on the shellfish exploitation, additional archaeological data from the stratified deposits and contextual information from the geographic position of the site.

Here we focus on those aspects of the lithic assemblages which are important for deriving information on land-use and mobility. Will et al. (2013) provide a detailed description of the MSA stone artifacts from HDP1. The lithic assemblages encompass 1212 finds >2 cm and 2095 pieces of small debitage <2 cm. The high ratio of small debitage to single finds (63:37) suggests no size sorting and only little post-depositional disturbance. The lithics show no signs of abrasion or weathering, although some are encrusted by carbonates. We are thus confident in the primary context of the archaeological finds and our behavioral interpretations. Our results show that the assemblages from all three AHs derive from one consistent techno-complex with similar raw material economy, technology and typology. Quartz constitutes the main raw material (~80%), vastly outnumbering silcrete, calcrete, quartz porphyry and other raw materials combined. The knappers employed multiple core reduction methods to produce predominantly small flakes. Blades and pointed flakes are extremely rare. The bipolar technique was applied to quartz, while all other raw materials were reduced by hard hammer only. Tools comprise about 4% of the assemblages. Compared to other MSA assemblages from South Africa, HDP1 compares most closely with YFT1 and Sea Harvest. Both of these sites lie on the western coast of South Africa, date roughly to MIS 5 and have yielded evidence for the early use of shellfish (Avery et al. 2008; Grine and Klein 1993; Volman 1978; Wurz 2012). HDP1, howev-

er, is unique in the South African MSA due to the predominance of quartz and the near absence of blades and points.

The differential use and reduction of raw materials at the site provide important information on settlement strategies and mobility. The raw materials at HDP1 can be divided into a local and a non-local group. Local raw materials make up ~90% of the assemblages and include quartz, calcrete and quartz porphyry. They are generally of low flaking quality. The non-local group consists of silcrete and “other” raw materials. Silcrete is a high-quality raw material that exhibits conchoidal fracture and produces sharp working edges. We used the Diepkloof Rock Shelter Silcrete Database (Porraz et al. 2008, 2013) to identify the source of the silcrete and determine the distance it was transported. Our comparative study revealed that two silcrete varieties at HDP1 correspond to four primary outcrops on the nearby Vredenburg Peninsula. From these observations, we established a minimum transport distance of 10–30 km for the silcrete brought to HDP1. We could not determine the precise origins or transport distances for the “other” raw materials of non-local origin.

The different approach of knappers to the use of raw materials at HDP1 is one of the most remarkable features of the lithic assemblages. The local raw materials of low flaking quality show complete reduction sequences with many products from the early stages of manufacture, including abundant small debitage products (Table 1). These observations testify to the on-site production of artifacts from the local raw materials. In contrast, the non-local raw materials demonstrate truncated reduction sequences with an overrepresentation of finished blanks and retouched forms (fig. 3). The low number of small debitage products and cortical specimens suggests that non-local raw materials were manufactured elsewhere and subsequently brought to the site. Knappers provisioned themselves with end-products of high-quality raw material from non-local sources and carried these implements to HDP1. Such a behavior indicates a “curated gear” (Binford 1979) or the “provisioning of individuals” (Kuhn 1992). This pattern is found throughout the occupation sequence.

Table 1. Hoedjiespunt. Frequencies of small debitage (n) by raw material.

Raw material	n (5-10 mm)	n (10-20 mm)
Quartz	702	1188
Quartz Porphyry*	5	11
Calcrete	1	84
Silcrete	1	30
Other	8	26
TOTAL	717	1339

* The low frequency of small debitage of quartz porphyry can be explained by the intrinsic difficulty of differentiating small artifacts from geofacts.

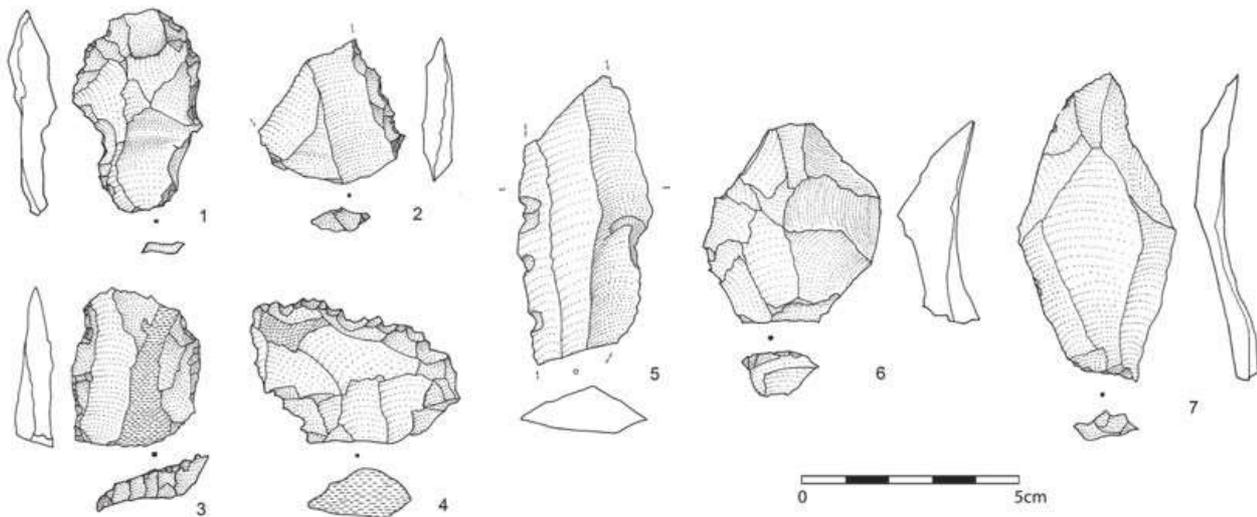


Fig. 3. Hoedjiespunt. Illustrations showing a selection of finished blanks and tools made on silcrete. 1) M11-229, silcrete, denticulate; 2) L11-30.1, silcrete, denticulate; 3) M12-319, silcrete, retouched flake; 4) 6537, silcrete, denticulate; 5) L12-397, silcrete, denticulate; 6) K11-16, silcrete, unmodified flake; 7) M12-225, silcrete, unmodified flake (drawings, F. Brodbeck).

The shellfish remains constitute another important source of information on the land-use of the MSA populations at HDP1 (fig. 2). While these finds are still under study and will form part of the PhD thesis of Katharine Kyriakou from the University of Cape Town, here we present preliminary results. Limpets dominate the assemblages, comprising between 70–90% of the entire shellfish assemblage based on the minimum number of individuals (Table 2). The granite limpet (*Cymbula granatina*) represents 60–80% of the limpet assemblage, with Argenville’s limpet (*Scutellastra argenvillei*) being second most common. Another important taxon is the black mussel (*Choromytilus meridionalis*). Several lines of arguments support the anthropogenic accumulation of these shellfish at HDP1. First, they are confined to the archaeological layers and do not occur in any of the natural strata. Second, the shellfish show signs of human impact through burning. Finally, the shellfish species and their size distribu-

Table 2. Hoedjiespunt. Distribution of main shellfish categories showing calculation of nutritional yield. PAT = limpet species; CM = *Choromytilus meridionalis*. Preliminary shell data provided by K. Kyriacou.

Layer	PAT (kg)	PAT* (kcal)	CM (kg)	CM* (kcal)	Total (kg)	Total* (kcal)	% PAT
AH I	5.6	4760	2.5	900	8.1	5660	69%
AH II	2.2	1870	0.7	252	2.9	2122	76%
AH III	5.5	4675	0.8	288	6.3	4963	87%
TOTAL	13.3	11,305	4	1440	17.3	12,745	77%

* Nutritional values derived from Buchanan (1988): PAT = 85 kcal/100 g shell; CM = 36 kcal/100 g shell.

tion correspond to collection patterns observed at other MSA sites such as HDP3, Sea Harvest, YFT1 and BOG2 (Conard et al. 2011; K. Kyriakou, pers. comm.).

Additional archaeological data provide information on the settlement patterns at HDP1. Table 3 lists density values for lithics (>2 cm), small debitage, shellfish and faunal remains at HDP1 that serve as indicators of occupation intensity. All layers show low concentrations of archaeological material. For illustrative purposes, the density values of small debitage at HDP1 (~600–3000/m³) amount to less than a tenth of the average find densities of the rich upper Sibudan (“post-HP”) layers from our excavations at Sibudu Cave (~44,000/m³). Low occupation intensities at HDP1—either few people or short stays—are supported by the absence of built structures such as hearths. Preliminary analyses of other categories of archaeological remains demonstrate that people performed principally the same activities throughout the sequence. For example, the inhabitants of HDP1 collected and modified red ocher, used ostrich eggshell and hunted the same range of small animals (see Stynder 1997).

Table 3. Hoedjiespunt. Excavated volumes (m³) and find densities for the archaeological horizons.

Layer	m ³	Lithics >2 cm (n/m ³)	Small debitage (n/m ³)	Fauna (NISP/m ³)	Shellfish (kg/m ³)
AH I	0.672	475	1188	188	12.1
AH II	0.253	1221	2925	265	11.4
AH III	0.479	351	582	138	13.1

Finally, the geographic position and regional environment of HDP1 must be taken into account as hunter-gatherers choose occupation spots deliberately. For what reasons did people decide to settle at HDP1? In terms of providing basic needs such as drinking water and shelter, the site is not an ideal location. Due to its geology, the Hoedjiespunt peninsula offers no fresh water sources. It also lacks true caves and rockshelters, so that HDP1 does not offer protection from heavy wind or rain. From a strategic point of view, HDP1 has little logistic value during interglacial conditions, as the site lies at the very end of a peninsula. Due to its low elevation above sea level and its exposure towards the open ocean, the peninsula does not provide a good vantage point to survey the surrounding terrestrial landscape. Finally, by choosing a coastal location at the end of a peninsula, MSA people sacrificed most of their potential terrestrial foraging radius.

A model for coastal settlements and mobility patterns at HDP1

Based on the foregoing results and observations, we developed a model for the use of the site and the mobility of the inhabitants at HDP1. Considering the nature and density of the archaeological deposits, we interpret the site as a temporary locale for exploiting the nearby marine resources with a focus on intertidal shellfish. The pattern of shellfish gathering and other archaeological signatures are constant throughout the

sequence, indicating a certain time depth for these activities. Thus, we interpret the occupations at HDP1 as repeated, short-term “picnics on the beach” by small groups of mobile hunter-gatherers rather than large-scale and long-term occupations (Will et al. 2013). This interpretation is further supported by the preliminary shellfish data from HDP1 (K. Kyriacou, pers. comm.) Using Buchanan’s (1988) values that convert shell weight to energy yield, the shellfish from the excavated squares at HDP1 amount to 12,745 kcal, or about 6.5 people-days of food.

Our interpretation of the function of the site is backed by the geographic position of HDP1. Other than marine resources, this locality offered few reasons to stay for prolonged periods. We thus suggest that people deliberately selected HDP1 as a place to exploit shellfish (see also Marean 2011; Marean et al. 2007; Parkington 1976). Combined with the evidence for long-distance transport of finished blanks and tools from non-local sources to the site, we propose that the inhabitants executed planned movements to the coastline in order to exploit the resources there. Taking into account that the occupation horizons with shellfish occur throughout more than one meter of stratified sediments, these scheduled visits were undertaken repeatedly over a prolonged period of time, spanning at least several generations.

A locality like HDP1 did not exist in isolation, but was embedded in the regional settlement system of mobile groups of hunter-gatherers along the western coast and its interior. Due to the strong seasonality of this region, the inhabitants of HDP1 probably moved between the coastline and its hinterland on a specific schedule, similar to the “seasonal mobility model” proposed by Parkington (1976, 2001; Parkington et al. 2004). In this model, the main camp sites are located inland where people procured high-quality raw materials such as silcrete, hunted terrestrial animals and used the floral resources of the Fynbos biome. The scarcity of large mammals in the assemblages of HDP1 is consistent with this assertion. More detailed studies of the shellfish and faunal remains at HDP1 might inform us on whether the inhabitants executed settlement shifts on a strictly seasonal basis or another rhythm (e.g., lunar cycles, see Jerardino and Marean 2010; Marean 2011). For now, the strong dominance of limpets might indicate more intense use of the site during the summer (Buchanan et al. 1978; Moss 1993).

To sum up, the occupations at HDP1 reflect multiple brief episodes of collecting, preparing and consuming shellfish along with the knapping and discard of stone artifacts, occasional hunting of small animals, the use of ocher, and social encounters near the shore (“picnics on the beach” model). Modern human populations at HDP1 integrated marine resources and coastal landscapes into their settlement system in a systematic manner, reflected in successive occupation phases with similar archaeological signatures. The site documents a deliberate pattern of land-use that indicates stable adaptations of local populations to coastal landscapes on the Western Cape as early as MIS 5e. The findings from HDP1 complement other recent research on coastal adaptations in the MSA of sub-Saharan Africa.

RECENT DEVELOPMENTS IN THE UNDERSTANDING OF COASTAL ADAPTATIONS IN SUB-SAHARAN AFRICA

During the last decade, the MSA of sub-Saharan Africa has yielded important data on coastal settlements from already known and new sites. We review the most important

localities with a focus on land-use and mobility. The new data are derived from three principal areas which we discuss separately: the highly productive western coast of South Africa, the year-round rainfall zone along the southern coast of South Africa and the arid Red Sea coast along the Horn of Africa, particularly in Eritrea (fig. 1).

The western coast of South Africa

The new excavations at HDP1 are not the only new source of data on MSA coastal adaptations from the western coast of South Africa. The Atlantic coast is known for its high marine productivity fueled by the upwelling of cold, nutrient-rich seawater provided by the Benguela Current that runs parallel to the coastline. The continental shelf is narrow compared with the southern coast, reaching up to 60 km. The terrestrial climate is arid in the north to semi-arid in the south. Most of the annual precipitation falls during the austral winter months, resulting in a high seasonality in terrestrial resources.



Fig. 4. Ysterfountain 1. **Top left:** View of the archaeological locality (photo, J. Parkington). **Top right:** Horizontal distribution of shellfish remains from 4 m² towards the base of stratigraphic group 4 (Avery et al. 2008, Fig. 5). **Bottom:** Distribution of shellfish remains in the stratigraphic section (photo, J. Parkington).

Ysterfontein 1 (YFT1) is located directly on the modern Atlantic coastline about 40 km southeast of HDP1 and has become a key point of reference for the evidence of marine resource exploitation during the MSA (fig. 4). Since 2003, several publications have discussed the archaeology of the site (Avery et al. 2008; Halkett et al. 2003; Klein et al. 2004; Wurz 2012). Avery et al. (2008) tentatively date YFT1 to MIS 5a or 5c based on correlations with sea levels, challenging their published OSL dates of 132–120 ka. The thick occupation sequence at YFT1 accumulated below a calcrete shelter. It consists of ~3.5 m stratified sands made up of several individual lenses and horizons, characterized by a moderate density of archaeological finds. The deposits contain MSA stone artifacts, faunal remains, modified ocher and abundant shellfish (Halkett et al. 2003; Klein et al. 2004).

YFT1 constitutes a flake-based assemblage with little core preparation and few faceted platforms (Wurz 2012). The range of raw materials is diverse and similar to HDP1; however, silcrete dominates the YFT1 assemblages. The silcrete likely derives from nearby weathering zones but might also have been imported to the site from inland sources further away. Tools are relatively rare (Avery et al. 2008; Halkett et al. 2003; Wurz 2012). According to Wurz (2012), the lithic assemblages of all 13 archaeological layers belong to one single techno-complex. Intertidal shellfish constitute the most abundant faunal remains at YFT1 by number, with larger mammals and birds common, but playing a secondary role in subsistence (Avery et al. 2008). Similar to HDP1, black mussels, granite limpets and Argenville's limpets dominate the shellfish assemblages. In contrast to HDP1 though, black mussels constitute the most abundant shellfish species. Due to the consistent stratification with MSA stone artifacts and the large number of shells, the marine resources are interpreted as human-made collections. The high frequency of shellfish and the occurrence of penguin and fur seal indicate the close proximity of YFT1 to the coastline (Avery et al. 2008; Klein et al. 2004).

No concrete evaluation of settlement strategies and land-use at YFT1 has yet been published. Having said that, we can deduce several conclusions from the published data. The homogeneity of the lithic assemblages, shellfish and faunal remains throughout the sequence indicate stable adaptations to the coast at YFT1. The descriptions of the site suggest moderate densities of archaeological finds within each horizon, reflecting more intense occupations over a longer period of time compared to HDP1. Supporting this interpretation, Klein et al. (2004) report the occurrence of multi-storied hearth features. The existence of several stratified occupation lenses and horizons with moderate find densities indicates repeated settlements by small groups over a long period of time, but not a residential camp. The low number of mammalian and avian remains supports this interpretation.

The second site with promising new data on coastal adaptations is **Sea Harvest** located on Saldanha Bay just 1 km northwest of HDP1 (fig. 1). Sea Harvest was first surveyed and partially excavated in the 1970s (Grine and Klein 1993; Volman 1978). This open-air site provides evidence for the association of MSA tools with shellfish in a coastal setting, similar to HDP1. Non-local silcrete occurs among the lithic assemblages. Based on geological and archaeological similarities of Sea Harvest with HDP1—and potentially YFT1—we favor a chronological attribution of the site to MIS 5e (Will et al. 2013, but see Butzer 2004). Future work at this locality plans to reopen the site to gain more information on the stratigraphy and to increase the sample of archaeological material (Parkington, pers. comm.). Sea Harvest will provide an

additional point of comparison to evaluate YFT1 and especially HDP1 in the coming years. Future studies can then start to examine local and regional variation in the settlement systems and use of marine resources in the coastal landscapes of the Western Cape during the MSA.

The Atlantic coast of the Western and Northern Cape Provinces retains great potential for future discoveries and will continue to play an important role in the study of early coastal adaptations by modern humans. Surveys have detected many coastal MSA sites that are deeply buried and sometimes exposed during commercial mining activities (e.g., Brand se Baai, fig. 1; see Parkington 2001, 2003, 2006; Parkington et al. 2004). Such sites stretch north all the way to the barely studied coastline of Namaqualand (Dewar 2008: fig. 1.3c; Dewar and Stewart 2012) and beyond.

The southern coast of South Africa

The southern coast of South Africa between Cape Town and Port Elizabeth has provided crucial evidence for coastal settlements along the Indian Ocean during the MSA (fig. 1). In contrast to the western coast, the continental shelf is broad, extending up to 200 km. The climate along this coastline is mild and moderated by year-round rainfall. The warm waters of the Agulhas Current that derive from the Indian Ocean result in a higher species diversity but lower biomass in marine mollusks compared to the west coast of South Africa.

Pinnacle Point 13B (PP13B) lies on the coastal cliffs about 6 km southwest of Mossel Bay (figs. 1 and 5). This locality has yielded the oldest evidence for the use of marine resources by modern humans at ~164 ka (MIS 6), pushing the evidence back to the late Middle Pleistocene (Marean 2010; Marean et al. 2007). The site consists of discrete settlement phases with horizontally disconnected sets of archaeological horizons. Occupations with shellfish occur in MIS 6 and from MIS 5e to 5c. Micro-morphological and taphonomic analyses



Fig. 5. Pinnacle Point 13B. **Above:** View of the entrance to the cave within the coastal cliff. **Below:** Section of the stratigraphy (photos, A. Kandel).



suggest a primary context for these sediments. The oldest layers with shellfish are associated with faunal remains, modified ocher and a bladelet technology. Hearths occur in the deposits from MIS 5e–5c. Compared to the occupations during MIS 6, the layers from MIS 5e–5c feature higher densities of lithics, faunal remains and shellfish remains, indicating more intense phases of settlement during the later occupations of the site (Jerardino and Marean 2010; Karkanas and Goldberg 2010; Marean 2010; Thompson et al. 2010).

A GIS model of shoreline changes during the last 400 ka demonstrates that PP13B varied between being a fully terrestrial and fully coastal site. The MSA inhabitants exploited shellfish only at times when the coast was close, between 0–6 km away,



Fig. 6. Blombos Cave. **Above:** View on the entrance to the cave within the coastal cliff (photo, M. Haaland, Creative Commons BY-SA 3.0). **Below:** Section of the stratigraphic sequence (K. J. Stenersen, Creative Commons BY-SA 2.5).



similar to modern hunter-gatherers (Bigalke 1973; Moss 1993). The frequencies of marine resources and other archaeological remains correlate with the distance of the site to the ocean, so that proximity to the sea increases settlement intensity. These observations indicate that a coastal location of PP13B was an important determinant for the MSA inhabitants in choosing the site for occupation (Fisher et al. 2010; Marean 2010). The knappers at PP13B predominantly used the local quartzite, but fine-grained silcrete occurs in low amounts. The silcrete probably derives from local beach cobbles. The main characteristics of the lithic assemblages remain principally unchanged throughout the occupation sequence, suggesting a stable coastal technology and constant adaptations to the shoreline (Thompson et al. 2010). During MIS 5, the local hunter-gatherers focused increasingly on marine resources, reflected both in terms of their abundance and species diversity. Regarding temporal changes, shellfish frequencies are very low during the MIS 6 occupations (0.1–0.29 kg/m³), indicating only occasional use of this resource. In the later horizons (e.g., MIS 5d–5c) the density values of shellfish remains rise markedly to a maximum of 8.7 kg/m³ (Jerardino and Marean 2010, Tab. 3; Marean 2010). In contrast to sites on the western coast, PP13B also yielded evidence for abundant use of large mammals with butchering activities on-site (Marean 2010).

Marean (2010) interprets the settlements at PP13B as residential sites of large social groups during times when the ocean was within reach. He also provides a concrete settlement model for the occupations on the southern coast (Marean 2010, 2011). According to this model, the MSA hunter-gatherers used coasts as their primary residential area throughout most of the year to maximize the exploitation of shellfish. Unlike the more seasonal environment of the western coast of South Africa, the southern coast offered sufficient resources throughout the year. People scheduled their use of marine resources mainly by lunar cycles, with peaks during spring low tides as the most productive and safest times for collecting shellfish. These interpretations are in keeping with ethnographic accounts (Bigalke 1973; de Boer et al. 2002; Moss 1993). In conclusion, Marean (2010, 2011) suggests relatively stable and long-term occupations along the south coast of South Africa, with marine resources as an integral part of the settlement system throughout the entire year.

Blombos Cave lies on the southern coast of South Africa ~90 km southwest of Mossel Bay (figs. 1 and 6). The site has produced some of the earliest evidence for abstract depictions, bone tool use, a processing kit for ocher, marine shell ornaments, and ample remains of shellfish (d'Errico et al. 2005; Henshilwood et al. 2001, 2002, 2011). Three successive MSA deposits are documented at the site: M1 at ~72 ka, M2 at ~85–74 ka and M3 at ~130–100 ka (Henshilwood et al. 2001; Jacobs et al. 2008). Marine mollusks constitute the most abundant category of food waste at Blombos in all three strata. Their consistent and direct association with occupation remains and the similar composition of species in the MSA and overlying LSA deposits support the intentional accumulation of the marine resources by humans (Henshilwood et al. 2001). Initial analyses showed a decline of shellfish remains through time, with M3 exhibiting the highest density (68.4 kg/m³) and M1 the lowest (17.5 kg/m³).

New data on coastal adaptations and mobility patterns come from a re-evaluation of the shellfish remains by Langejans et al. (2012). They employ a behavioral ecology approach encompassing optimal foraging theory and a diet breadth model. Shellfish species are first ranked by their yield and handling costs. Subsequently, the patterns found at Blombos are compared to expectations from the theoretical models and related to changes in sea levels. In this analysis, Langejans et al. (2012) found that the MSA inhabitants focused on high yield species from the mid-intertidal zone. During the M2 and M1 phases, when the ocean was about 5–6 km away from the cave, people modified their prey choice due to the increase in transport costs compared to the older M3 phase, when it was just ~2 km away. According to the authors, the observed change in the composition of species may indicate that shellfish collection intensified during later phases. Higher shellfish densities in M3 are thus just a reflection of the ocean being closer to the site than during the formation of M1 and M2.

Klasies River Mouth is a complex of caves and shelters located on the southern coast of South Africa about 200 km east of Mossel Bay (figs. 1 and 7). The locality is famous for its almost 20-m thick sequence which long served as the type site for the cultural stratigraphy of the South African MSA (Deacon and Geleijnse 1998; Singer and Wymer 1982; Wurz 2002). The site yielded deposits from ~110 ka until <58 ka (d'Errico et al. 2012; Wurz 2002, 2012). Results on the use of marine resources were already published in the 1970s and 1980s (Thackeray 1988; Voigt 1973). Worth reiterating is the fluctuating density of shellfish remains throughout the sequence. The frequencies are particularly high in the LBS (22.5–71.8 kg/m³; MIS 5d) and SAS com-

plexes (4.0–162.5 kg/m³; MIS 5c–5a). The Howiesons Poort (0.8–8.8 kg/m³) and MSA III (0.3–2.0 kg/m³) layers contain marine resources of comparably lower densities (Thackeray 1988).

The same study by Langejans et al. (2012) which examined the shellfish from Blombos Cave also presents new data on the use of marine resources and coastal adaptations at KRM. For this site, the authors found that MSA inhabitants mainly collected high ranked mid-intertidal shellfish. High-ranked species comprise those marine mollusks that are not only easy to access and handle, but also provide a high nutritional yield. Changes in the coastal environments around the site, such as the distance from the sea, strongly affected the foraging strategies. The nature of the latest shellfish assemblages in MIS 4/3, where the ocean would have been approximately 5 km away, suggests that the inhabitants scheduled collecting trips to coincide with low tides (Langejans et al. 2012). Wurz's (2012) analysis of stone artifacts from KRM relates the lithic assemblages to the use of shellfish in the stratigraphic members LBS and SAS. She notes that the coastal occupations at the site show a thick depositional sequence with high densities of stone artifacts. Together with modified ocher and hearth features, this suggests intense occupations. While the principal raw material is the local quartzite of poor quality, low proportions of fine-grained and potentially non-local silcrete and other raw materials are also present (see Deacon and Wurz 1996; Singer and Wymer 1982; but also Minichillo 2006).

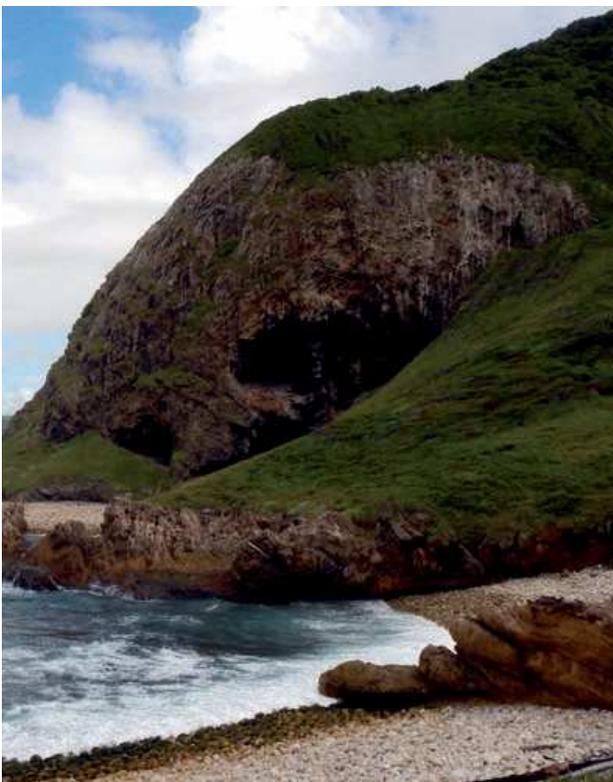


Fig. 7. Klasies River Mouth. **Left:** View of the entrance of the cave within the coastal cliff (photo, S. Mentzer). **Right:** Section of the stratigraphy from SAS5 at the bottom to SM1 at the top (photo, C. Miller).

Summing up their new findings for Blombos and KRM, Langejans et al. (2012) conclude that during the MSA inhabitants at the Southern Cape optimized their foraging trips by collecting the highest ranked shellfish taxa, considering both the distance to the resources and their yield. The modern human populations were aware of the effect that tidal changes had on the availability of marine foods and scheduled their visits to the coast accordingly. Wurz (2012) shows that the occupational intensity was high at KRM, with widespread knapping activities taking place on site in addition to collecting and consuming shellfish. To these results we add that the MSA inhabitants at Blombos and KRM made repeated use of coastal landscapes and their resources over a long period of time (from ~120–70 ka at Blombos and from ~110–58 ka at KRM) despite the fluctuating distance of these sites to the ocean.

The Red Sea coast along the Horn of Africa

The Red Sea coast along the Horn of Africa is markedly different from South African coastlines. Unlike the southern and western coasts of South Africa, the Red Sea is hypersaline and very warm, with a corresponding reduction in marine productivity. Not only is the climate along the coast arid, but the region is tectonically active. Nonetheless, the region has become known through the discovery of evidence for marine food use in a last interglacial context near the village of Abdur at the Gulf of Zula, Eritrea (fig. 1; Walter et al. 2000). Recent studies have elaborated on the context of this site and studied other open-air localities in the same region (Beyin 2013; Bruggeman et al. 2004; Buffler et al. 2010).

The Abdur Reef Limestone is dated to 125 ± 7 ka, but stone artifacts occur in older strata as well (Bruggeman et al. 2004; Walter et al. 2000). At the **Abdur Archaeological Site**, MSA artifacts associated with marine invertebrates and large land mammals are derived from multiple localities within the emerged reef terraces, which are the remnant of a shallow marine reef system (Bruggeman et al. 2004; Walter et al. 2000). The occurrence of these archaeological remains in several horizons of the Abdur Reef Limestone implies the use of marine resources over a prolonged period of time in a beach context. The excavators postulate that people collected large oysters in the shallow waters in an earlier phase, and gathered other shellfish and crustaceans during the later occupations. In their interpretations, the inhabitants of the coastline varied their foraging activities and lithic technology based on changing environments. The authors also report on the potential transport of lithic raw materials from 20 km or more to the sites (Bruggeman et al. 2004; Buffler et al. 2010; Walter et al. 2000), indicating planned moves from inland localities to the coastline. No precise data on the number or density of archaeological finds are published. Bruggeman et al. (2004) mention “several hundred stone tools” that were found within various stratigraphic levels over an area of 6.5 km². Hence, the sites at Abdur constitute ephemeral occupations of the coastal landscapes. As some scholars question the direct association of marine invertebrates with the MSA stone artifacts at Abdur (Bailey 2009; Bailey and Flemming 2008), the extent of coastal adaptations remains to be clarified at these sites. Having said this, the existence of human occupations on the coastal marine landscape of the Red Sea remains unchallenged.

More recent findings of surface MSA assemblages at **Asfet** and other localities along the coast of the Red Sea in Eritrea (Gulf of Zula) attest to the potential of this

region to inform researchers on early coastal adaptations by modern humans (fig. 1; Beyin 2013; Beyin and Shea 2007). At Asfet, stone artifacts were found together with shells on the surface. The anthropogenic accumulation of the shell is not yet verified. Most artifacts are in fresh condition, and the assemblage consists of shaped tools, cores and debitage. Knappers mainly used basalt, quartz and obsidian as raw materials. Since the nearest source for obsidian is located 15 km away from the site, the inhabitants of Asfet imported this raw material. The transport of non-local lithic raw materials from the inland to coastal sites and the intense use of low-quality local raw materials resembles the pattern at Abdur as well as HDP1 (Bruggeman et al. 2004; Walter et al. 2000; Will et al. 2013). Due to the surface nature of the finds, neither age nor duration of this settlement could be reconstructed. The existence of numerous shells suggests a short distance of the site to the Red Sea during its formation and a most probable date to early MIS 5 (Beyin 2013).

In conclusion, the Red Sea coast of Eritrea provides tantalizing but debated evidence for the use of marine resources and the existence of occupations on these coastal landscapes as early as MIS 5e. The repeated association of MSA artifacts with marine invertebrates at several localities tentatively supports the integration of coastal landscapes into the settlement systems of modern humans in this region. The open-air sites are best comparable in their occupation characteristics with HDP1 and Sea Harvest, constituting places for small short-term stays rather than large-scale accumulations during early MIS 5.

DISCUSSION

From the data of HDP1 and a review of research from the last decade, we derive several inferences on coastal settlement systems and adaptations in the MSA of the Cape and the Horn of Africa (Table 4):

- 1) Currently the earliest evidence for coastal adaptations in Africa south of the Sahara dates to MIS 6 (~164 ka) at PP13B. However, there is only evidence for the occasional use of shellfish. These coastal occupations are characterized by low densities of archaeological remains.
- 2) During the last interglacial (MIS 5e) several sites in southern and eastern Africa, such as HDP1, PP13B and Abdur, demonstrate the systematic integration of shellfish into the settlement system. A frequent aspect of these shellfish-bearing sites is the long-distance transport of tools made of high quality raw materials to coastal locations. This import of tools and raw material, presumably in the form of personal toolkits, indicates scheduled movements from the inland to coastal zones. The coastal settlements during MIS 5e are characterized by a low to moderate density of occupation remains, reflecting their function as short-term camps for specialized tasks including shellfishing.
- 3) Throughout MIS 5 there is a strong signal of intensifying coastal settlements and use of marine resources, with coastal landscapes serving as focal points for occupations. In contrast to the small-scale occupations of coasts during MIS 6 and MIS 5e, the later MIS 5 and MIS 4 deposits demonstrate markedly higher settlement intensities and shellfish densities. Occupation horizons at Blombos (M1–M3), KRM (LBS, SAS) and PP13B (Shelly Brown Sand, Upper/Lower

Table 4. Summary of coastal adaptations and settlement systems during the MSA in sub-Saharan Africa from the sites discussed in the text ordered by time.

Site	Date	Coastal adaptations
Pinnacle Point 13B	MIS 6 (~164 ka)	<ul style="list-style-type: none"> Occasional use of shellfish Low density of occupation remains Coastal location as important determinant for site occupation
Asfet	MIS 5e ? (~130-115 ka)	<ul style="list-style-type: none"> Long-distance transport of high quality raw materials to the coast Low density of occupation remains
Hoedjiespunt 1	MIS 5e (~130-115 ka)	<ul style="list-style-type: none"> Long-distance transport of finished tools of high-quality silcrete to the coast Low density of occupation remains Scheduled movements to the coastline for exploiting shellfish Stable adaptations to coastal landscapes over several generations
Abdur	MIS 5e (~130-115 ka)	<ul style="list-style-type: none"> Long-distance transport of raw materials to the coast Low density of occupation remains Coastal foraging is scheduled and varies with changing environments Stable adaptations to coastal landscapes over several generations
Pinnacle Point 13B	MIS 5e - 5c	<ul style="list-style-type: none"> Coastal location as important determinant for site occupation More intense coastal occupations than in MIS 6 with hearth features and increasing density of shellfish remains Stable adaptations to coastal landscapes over several generations
Ysterfontein 1	MIS 5e(?) - 5c	<ul style="list-style-type: none"> Moderate intensity of coastal occupations with multi-storied hearth features Stable adaptations to coastal landscapes over several generations
Blombos	MIS 5d - MIS 4 (~115-72 ka)	<ul style="list-style-type: none"> High density of shellfish remains Shellfish collection intensified during later phases (MIS 5a and MIS 4) Optimization of shellfish foraging with scheduled visits to the coasts Adaptations to coastal landscapes over very long periods of time
Klasies River	MIS 5d - MIS 3 (~115 - <58 ka)	<ul style="list-style-type: none"> Potential import of non-local silcretes of high quality to the coast Intense coastal adaptations with hearth features and high density of shell fish remains (in MIS 5d and 5c-5a) Optimization of shellfish foraging with scheduled visits to the coasts Adaptations to coastal landscapes over very long periods of time

Roof Spall) show generally higher densities of archaeological finds along with combustion features. The assemblages are sometimes accompanied by evidence of complex behaviors such as the production of shell beads or geometric engravings on ocher. People intensified their collection of shellfish during these later phases, suggesting that they focused their occupations on the coastline during MIS 5 and 4, at least on the western and southern coasts of South Africa. From the sites discussed, only KRM has yielded shellfish-bearing layers from early MIS 3. It is unclear whether this is due to a decrease in the use of marine resources, differential preservation, a change in sea level, or a general decline in

regional populations. In summary, the archaeological record of South Africa, and to a lesser degree the Horn of Africa, demonstrates the use of coastal landscapes and resources by modern humans over more than 100 ka from late MIS 6 until early MIS 3.

- 4) The archaeological record of the South African Cape demonstrates that coastal ecosystems functioned as important areas for occupation during much of the MSA in this region. Here we observe a re-arrangement in the settlement system of the hunter-gatherers which expands its boundaries to include coastlines and their resources on a regular basis. MSA sites such as PP13B, KRM and Blombos yield occupation intensities that co-vary with distance to the coast, indicating that the mobility system was strongly influenced by the exploitation of shorelines. Coastal locations are integrated in a systematic manner in the settlement strategies, with sites being either used as short-term camps for seasonal visits or as long-term residential camps throughout the year. The difference in the nature of these occupations is partially influenced by ecological factors. This is best exemplified by the marked environmental differences between the western and southern coasts of South Africa with their different seasonality of resources as well as the diversity and abundance of marine mollusks (e.g., Fisher et al. 2010; Jerardino 2010; Jerardino and Marean 2010; Thackeray 1988).

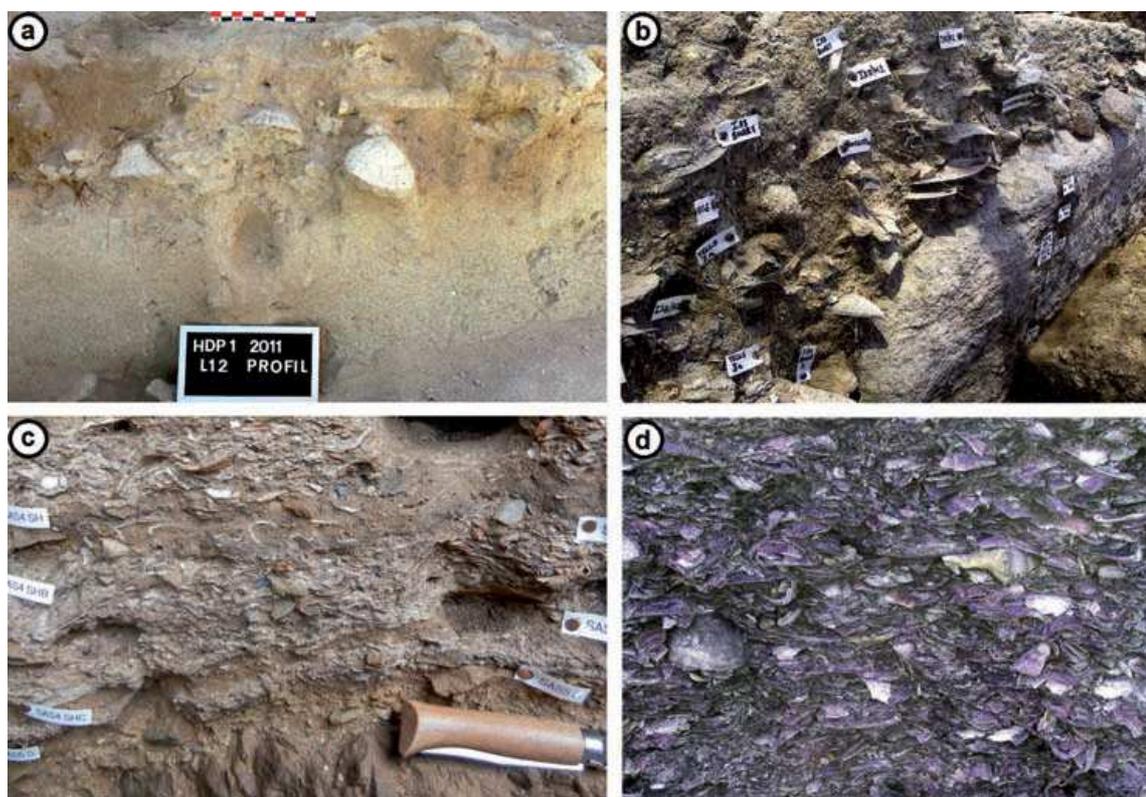


Fig. 8. Composite picture showing the variability in shellfish densities between sites from the MSA and LSA. **a)** HDP1, AH III (MSA): low shellfish density (photo by M. Will); **b)** YFT1, YELLS (MSA): moderate shellfish density (photo, J. Parkington); **c)** KRM, SAS 4 (MSA): high shellfish density (photo, C. Miller); **d)** Elands Bay Cave, Megamidden (LSA): very high shellfish density, true shell midden (photo, J. Parkington).

Some more general issues on coastal settlements and adaptations during the MSA of sub-Saharan Africa deserve further discussion. We deliberately refrained from using the term “shell midden” for the shellfish-bearing sites of the MSA in this paper. A “shell midden” is variably defined as “an extensive rubbish heap consisting largely of shells” (Darvill 2008: 415), “a cultural deposit in which particles of animal shell are the dominant class of refuse” (Muckle 1985: 16), or a “cultural deposit of which the principal visible constituent is shell” (Waselkov 1987: 95). In our view—and based on the foregoing definitions—the vast majority of coastal MSA sites cannot be labeled as “middens,” with the possible exception of some layers at KRM (fig. 8; Table 5). Shellfish remains make up only one among many constituents of the assemblages that we have discussed. The MSA sites are rather characterized by a multitude of components such as stone artifacts, faunal remains, ostrich eggshell or ocher within a matrix of sediment. The localities also differ from the various kinds of LSA shell middens (e.g., “megamiddens”) of the Late Holocene in South Africa which are characterized by “tons of marine shell and low densities of artifacts and terrestrial fauna” (Jerardino 2010: 28). In the LSA, the archaeological strata are composed mainly of shells, whereas in the MSA the occupation horizons consist largely of sediment (fig. 8).

A comparison of shell densities between MSA sites and true LSA shell middens illustrates our argument (Table 5). Although density values of shellfish remains are influenced by many factors, such as taphonomy, they provide a rough proxy for the intensity of shellfish use among comparable sites. PP13B and HDP1 exhibit 10–40 times lower densities compared to LSA shell middens and even the highest densities of shellfish in the MSA at KRM fall at their lower end or out of their range. In conclusion, we think it is best to restrict the term “shell midden” to true midden sites in the sense defined above when discussing the early exploitation of marine resources by modern humans. Certainly the nutritional data for the shellfish from HDP1 and other MSA sites support this concept (e.g., Clark and Kandel 2013).

Table 5. Comparison of shellfish densities (kg/m³) between MSA sites and selected LSA shell middens.

Site	Shellfish (kg/m ³)	Period	Data source
Pinnacle Point 13B	0.1-9	MSA	Jerardino and Marean 2010
Hoedjiespunt 1	11-13	MSA	This study
Blombos Cave	18-68	MSA	Henshilwood et al. 2001
Klasies River Mouth	0.3-163	MSA	Thackeray 1988
Steenbokfontein Cave	129-348	LSA ca. 4000-2000 BP	Jerardino 2010
Pancho’s Kitchen Midden	306-468	LSA ca. 4000-2000 BP	Jerardino 2010
Mike Taylors Midden	130-530	LSA ~ 2000 B.P	Jerardino 1997

The previous discussions on the term “shell midden” is not simply a nitpicking exercise, but has important bearings on the diachronic evaluation of coastal adaptations and settlement systems in the Stone Age of Africa. In contrast to the MSA and LSA, the Early Stone Age (ESA) has to date yielded little evidence for enduring occupations of coastal landscapes or the systematic use of marine resources (e.g., Jerardino 2010; Kandel and Conard 2012). Recent reports of marine and aquatic food consumption in the ESA (e.g., Braun et al. 2010; Joordens et al. 2009) provide only circumstantial evidence, scattered through time and space, for the opportunistic use of these resources. Comparisons of the exploitation of marine resources between the MSA and LSA have most often focused on the size of archaeological shellfish specimens. The generally larger sizes of shells in the MSA compared to the LSA implies lower predation pressure on the shellfish populations during the former period. Lower predation pressure is either a function of fewer people collecting marine resources, less intensive use of these foods, or both (e.g., Halkett et al. 2004; Klein and Steele 2013; Steele and Klein 2008). These authors have also stated that in contrast to coastal LSA localities, MSA sites provide less evidence for the exploitation of fish and marine mammals. Combined with data on the density of shellfish in LSA sites (Table 5) we can infer that people adapted differently to coastal niches. Coastal adaptations during the LSA are characterized by more people regularly using marine resources more intensely than during the MSA. Having said this, marine resources (e.g., shellfish) constitute the most abundant food remains at MSA sites like Blombos or YFT1. There is also increasing evidence that MSA people already optimized the gathering of shellfish and scheduled their visits to the coast as early as the Late Pleistocene. The repeated use of ecologically differing coastal landscapes and marine resources over long periods at several sites with similar behavioral adaptations demonstrates the stable incorporation of coastal ecosystems in the foraging and settlement strategy as early as the MSA.

There are also several problems and limitations in the study of coastal adaptations in the Stone Age of sub-Saharan Africa, which also apply to other regions. Their consideration and discussion is necessary to contextualize the conclusions that we have reached in this paper. Most importantly, archaeologists must acknowledge the loss of potential coastal sites due to global sea-level fluctuations during the Pleistocene (Bailey 2009; Bailey and Flemming 2008; Bailey et al. 2007; Erlandson 2001; Hearty et al. 2007; Miller et al. 2005). The marked rise in sea levels during interglacials (e.g., MIS 5e and MIS 1) led to the inundation of large landmasses that were exposed in glacial times. As a result of this, the geographical and chronological pattern of MSA sites with evidence for coastal adaptations that we have discussed might be severely biased (see Bailey and Flemming 2008). While these cautionary arguments still apply, they do not negate the importance of studies of early coastal adaptations by modern humans. In this paper, we have outlined the archaeological evidence that exists and derived conclusions on this basis. Furthermore, as can be seen from recent work, we now have a few windows into times that are rarely present in the archaeological record, such as the MIS 6 occupations at PP13B. In order to correct for a potential bias in the MSA, archaeologists will need to examine localities that have escaped the global high-stands due to their relatively high position on the modern coastline, explore coastlines with a very steep off-shore bathymetric profile or engage in expensive and logistically difficult underwater archaeology (see Bailey and Flemming 2008; Erlandson 2001).

Distinguishing between natural and anthropogenic accumulations of marine resources in Stone Age sites also remains a serious problem. In order to evaluate coastal adaptations by hominins, it is of paramount importance to first establish the anthropogenic nature of the collection of the marine remains and not to assume their direct connection with the archaeological remains *a priori* (e.g., Bailey 2009; Bailey et al. 2007; Bailey and Flemming 2008). In the absence of use-wear or residue studies which can directly link MSA stone artifacts with shellfish remains (but potentially with fish; see Hardy and Moncel 2011; Högberg et al. 2009) and remaining aware of the problems involved in identifying modifications on bones of aquatic taxa (e.g., Archer and Braun 2013), most arguments are based on taphonomy, site formation and the nature of the shellfish assemblages (see list in Hughes and Sullivan 1974).

It has only been in recent decades that researchers have begun to understand the importance of shellfish and other marine resources for the evolution of modern humans. There are still many avenues of research open for the study of coastal adaptations in the MSA of sub-Saharan Africa. A better chronological and especially geographical resolution of coastal MSA localities could greatly improve our current picture, which is derived predominantly from sites in South Africa (see fig. 1). Beyin (2013: 210) states that “numerous sites [...] may yet be discovered along the African side of the Red Sea basin by future systematic research.” This actually applies to the majority of coastlines on both sides of the African continent which remain largely unexplored. There are also sites that are already known, such as Sea Harvest on Saldanha Bay, which lend themselves to more detailed studies.

Comparisons of coastal adaptations between modern and archaic humans constitute another promising route of research. For example, while there is increasing evidence for Neanderthals showing similar adaptations to modern humans at sites on the Mediterranean coast in Italy (e.g., Grotta dei Moscerini), Spain (e.g., Bajondillo Cave) or Gibraltar (Gorham’s and Vanguard Cave; see Colonese et al. 2011; Cortés-Sánchez et al. 2011; Hardy and Moncel 2011), detailed comparative studies are still lacking. Furthermore, starting from the recent evidence of Grotte des Contrebandiers in Morocco and other North African MSA sites on the Mediterranean coast (Erlandson 2001; Steele 2012; Steele and Álvarez-Fernandez 2011, 2012), scholars could also compare coastal adaptations between modern humans who lived north, south and east of the Sahara. Such approaches would make for a more complete understanding of the importance of coastal landscapes and resources for human evolution. Future research could work within an evolutionary framework that analyzes coastal adaptations by both archaic and modern humans in multiple regions from a diachronic perspective. Depending on the research questions, studies might be conducted on a local, regional, continental or even global scale.

CONCLUSION

Based on the current state of scientific knowledge, sub-Saharan Africa, and South Africa in particular, has provided the earliest and longest record of coastal adaptations by modern humans. The majority of information that we have discussed in this paper comes from sites that have been excavated and analyzed with modern methods. Recent studies from the Cape and Horn of Africa show that, despite their difference in oceanographic, geographic and environmental parameters, coastlines provided impor-

tant resources for planned and stable adaptations by modern humans during MIS 5 and 4 in these regions. People often abandoned sites in times when they were too far away from the ocean and settled more intensely when the shoreline was within close reach. The available data document that modern humans systematically integrated coastal landscapes and their resources in their settlement strategies throughout much of the MSA. This evidence stands in marked contrast to the preceding ESA in which such behavioral adaptations are to date unknown. Having said that, people during the MSA exploited marine resources less intensely than many LSA populations. Only in the LSA did the consumption and discard of shellfish lead to the repeated formation of true shell middens.

For now, the patterns that we describe apply to the South African coastline only and to a lesser degree to parts of the African Red Sea coast. Large strips of African coastline remain to be studied and provide promising avenues of future research. We are thus only beginning to understand the extent and importance of coastal adaptations during the MSA.

Settlement at coastal landscapes and consumption of marine foods have been proposed as causal factors in human evolution, potentially boosting brain evolution, increasing survival and reproduction, and facilitating dispersals within and out of Africa along coastal routes (Broadhurst et al. 2002; Cunnane and Stewart 2010; Marean et al. 2007; Marean 2011; Parkington 2001, 2003, 2006, 2010; Stringer 2000). Yet, the actual evolutionary role of coastal adaptations remains open to debate (e.g., Bailey 2009; Bailey and Flemming 2008; Steele and Klein 2013). From our data review it appears that the quantity of marine foods in the diet of MSA people was rather low (see also Clark and Kandel 2013). Nutritional studies and evolutionary models thus need to consider whether these small amounts could have had a causal influence on brain development or demography, for example, by providing critical amounts of important nutrients like omega 3-fatty acids. For now, our summary of the current evidence from a geographically limited sample of sub-Saharan Africa suggests that people during the MSA adapted to coastal landscapes and marine resources in a systematic and stable manner. In the process of expanding to these new ecological niches, modern humans adopted novel strategies of subsistence and mobility and increased the diversity of their diet.

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An evolutionary perspective on coastal adaptations by modern humans during the Middle Stone Age of Africa



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ABSTRACT

The Middle Stone Age (MSA) of Africa documents the earliest and longest record of marine resource use and coastal settlements by modern humans. Here, we provide a long-term and evolutionary perspective of these behaviors. We propose a definition of “coastal adaptations” rooted in the principles of evolutionary biology as a workable analytical device and review the MSA archaeological record from Africa to characterize the specific nature of coastal adaptations by *Homo sapiens*. On this basis we evaluate current models addressing the importance of coastal adaptations for human evolution and formulate new hypotheses within the larger framework of evolutionary causality by linking these behaviors directly to reproductive success. While the current archaeological record suggests that modern humans occasionally consumed marine resources during the late Middle Pleistocene, systematic and optimized gathering of a variety of marine food items dates to MIS 5 and 4. Archaeozoological studies show that people exploited marine resources in a methodical manner on the Atlantic, Indian, and Mediterranean coasts of Africa during this time frame. Despite the similarities in coastlines, mobile hunter–gatherers also integrated these variable coastal landscapes into their settlement strategies for more than 100 ka, as shown by evidence for stable, repeated and planned occupations. Additionally, elements of complex material culture, such as bone tools and shell beads, occur particularly often in (near-) coastal MSA sites. The specific nature of coastal adaptations by modern humans can thus be characterized by their systematic nature, long duration and verifiable impact on the overall adaptive suite. By combining archaeological data with ethnographic, nutritional and medical studies we propose several evolutionary scenarios for how modern humans could have increased survival and fecundity rates by their specific adaptations to coastal environments. In order to test these hypothetical scenarios for the selective advantages of coastal adaptations for *Homo sapiens*, we need more data deriving from an expanded spatiotemporal archaeological record, just as much as more formal evolutionary models and research strategies.

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1. Introduction

The Middle Stone Age (MSA) of Africa provides the earliest and longest record of marine resource exploitation by modern humans, spanning more than 100,000 years. These coastal adaptations are associated with different populations on various parts of the African continent, particularly in southern Africa. Due to their spatial and temporal extent, they have become important topics in the

study of the biological and behavioral evolution of *Homo sapiens* (e.g., Stringer, 2000; Walter et al., 2000; Parkington, 2001, 2003; Broadhurst et al., 2002; Marean et al., 2007; Cunnane and Stewart, 2010; Parkington, 2010; Klein and Steele, 2013; Will et al., 2013; Kyriacou et al., 2014; Marean, 2014).

As early as the late 1960s, scholars recognized the importance of marine resources in coastal MSA sites in South Africa such as Klasies River Main site (Speed, 1969; Voigt, 1973), Hoedjiespunt 1 and Sea Harvest (Volman, 1978). Since then, archaeologists have excavated many additional sites with shellfish-bearing strata in Africa dating to the MSA. The most important localities (Fig. 1) lie on the southern coast of South Africa along the Indian Ocean (Singer and Wymer, 1982; Thackeray, 1988; Grine et al., 1991; Marean et al.,

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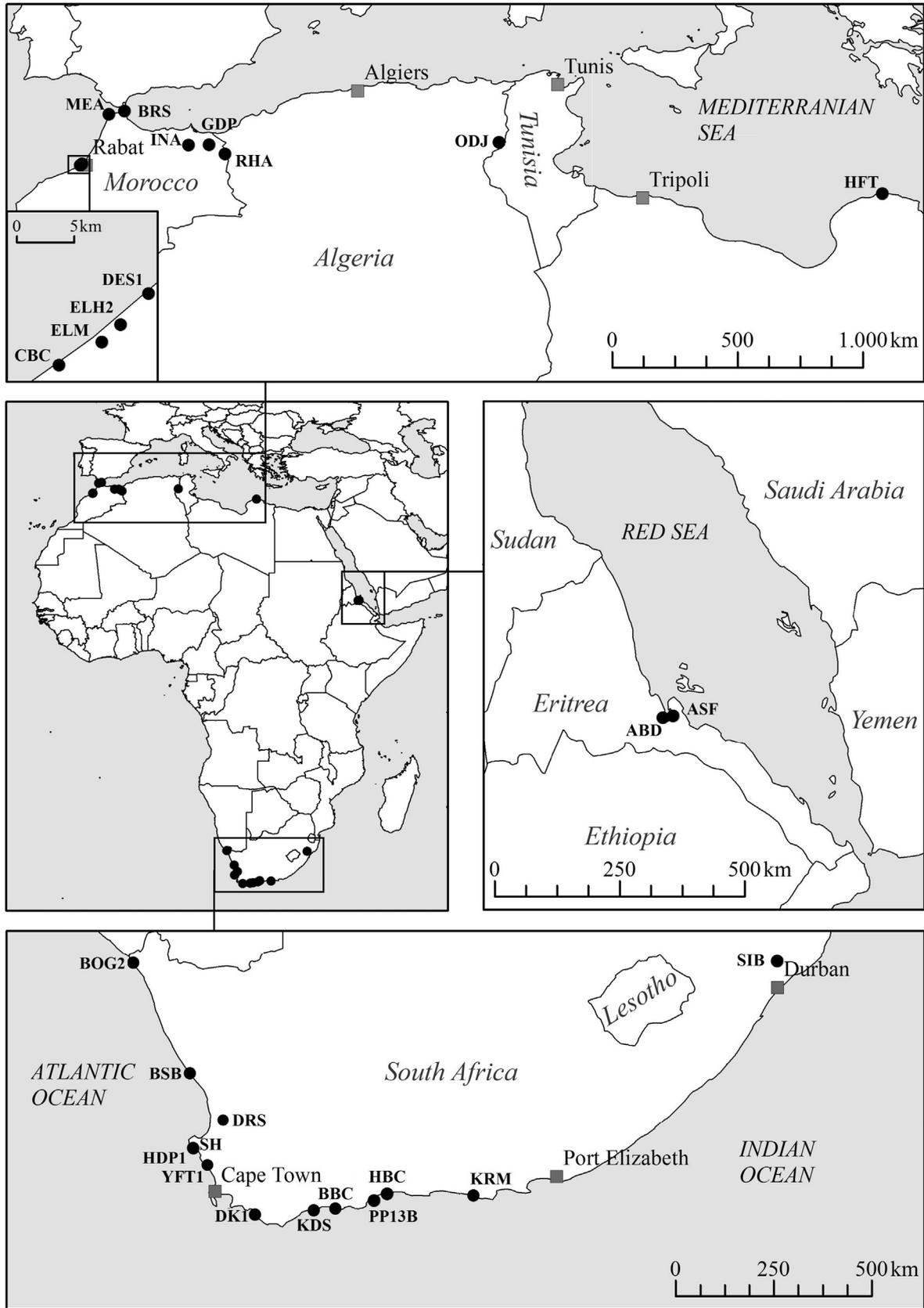


Fig. 1. Location maps depicting MSA sites in Africa with evidence for coastal adaptations (ASF-Asfet; ABD-Abdur; BBC-Blombos Cave; BOG2-Boegoeberg 2; BRS-Benzú Rockshelter; BSB-Brand se Baai; CBC-Contrebandiers Cave; DES1-Dar es Soltane 1; DK1-Die Kelders 1; DRS-Diepkloof Rockshelter; GDP-Grotte de Pigeons; ELH2-El Harhoura 2; ELM-El Mnasra; HBC-Herold's Bay Cave; HDPI-Hoedjiespunt 1; HFT-Haua Fteah; INA-Ifri n'Ammar; KDS-Klipdrift Shelter; KRM-Klasies River Mouth; MEA- Mugharet el 'Aliya; ODJ-Oued Djebbana; PP13B-Pinnacle Point Cave 13B; RHA-Rhafas; SH-Sea Harvest; YFT1-Ysterfontein 1). (map by E. Schmalz).

2000; Henshilwood et al., 2001; Marean et al., 2007; Henshilwood et al., 2014) the Atlantic coast of western South Africa (Parkington et al., 2004; Avery et al., 2008; Will et al., 2013), the Red Sea coast along the Horn of Africa (Walter et al., 2000; Beyin, 2013), and north of the Sahara along the Mediterranean and Atlantic coasts (Ruhlmann, 1951; Arambourg, 1967; Klein and Scott, 1986; Ramos et al., 2008; El Hajraoui et al., 2012a; Campmas et al., 2015).

Regarding its long-history of study and the amount of evidence produced from various regions of Africa over the past 50 years, we think that the time is ripe to explicitly assess the long-term aspects of coastal resource use that the MSA record provides. To this end we focus on a multi-generational scale that examines coastal adaptations on a (meta-) population level, emphasizing both regional and temporal variability. It is this evolutionarily relevant scale of the MSA record that allows us to study the potential advantages and consequences of coastal adaptations for the bio-cultural development of modern humans.

The overarching aim of this article is to link evolutionary concepts on biological adaptations with archaeological data on the consumption of marine foods and the settlement of coastal areas. In order to achieve this evolutionary perspective, we will first provide a definition of coastal adaptations rooted in basic principles of evolutionary biology. This is followed by a discussion of current thinking about the emergence, selective advantages and potential consequences of coastal adaptations. After a critical evaluation, we then review data on marine subsistence, technological systems and settlement patterns to assess the specific nature of coastal adaptations by modern humans and their temporal and spatial variability in the whole of Africa during the MSA. In a final step, we place the archaeological evidence in the framework of evolutionary causality and propose several hypothetical, but testable, scenarios for how the specific nature of coastal adaptations by modern humans could have increased their reproductive fitness.

2. Coastal adaptations from an evolutionary perspective

2.1. An evolutionary definition of coastal adaptations

Paleolithic archaeology has the unique opportunity to shed light on behavioral adaptations and changes in our species over a vast breadth of time. Here, we aim to harness this potential by integrating archaeological data with basic principles of evolutionary biology. In order to put the concept of coastal adaptations into a larger evolutionary framework, scholars need to provide a clear definition grounded in evolutionary biology, which is so far lacking.

Adaptation as understood from the perspective of evolutionary biology refers to both the dynamic process of natural selection, whereby an organism becomes better able to live or reproduce in a given environment (*i.e.* fitness), as well as its product (Dobzhansky, 1956, 1968; Stern, 1970; Brandon, 1978; Bock, 1980; West-Eberhard, 1992; Futuyma, 2009, p. 279; Depew, 2011). Adaptation as a product again consists of two components. First, an adaptive trait (or an adaptation) denotes one or more phenotypic features that increase the fitness of an organism in a specific environment in relation to alternative character states. Adaptive traits encompass physiological, structural or behavioral novelties. Additionally, many evolutionary biologists distinguish adaptedness, or the state of being adapted, as the variable propensity of an organism to survive and reproduce in a particular environmental context (*i.e.* organism *a* is better able to survive and reproduce in a certain environment than organism *b* (Brandon, 1978, p. 200)). Wright's concept of multi-dimensional fitness landscapes, with several adaptive peaks that correspond to local fitness maxima, can serve as an illustration of the idea of different degrees of adaptedness (Wright, 1932, 1982).

How can archaeologists detect such behavioral adaptations in the record of material culture? Strictly speaking, any behavior inferred from material culture – as part of the overall human phenotype – should be scrutinized to determine whether it increased the reproductive fitness of its bearer during a specific time in a particular ecological setting (O'Brien and Holland, 1992). There are, however, practical barriers to this endeavor, such as our inability to directly test differences in the reproductive fitness of Paleolithic individuals, or the coarse-grained nature of the chronological and environmental record. We suggest that behavioral adaptations in the archaeological record should meet certain minimum requirements in that they can be found: i) repeatedly and consistently; ii) in widespread geographical areas; iii) from broadly similar environmental settings; and iv) persist through large spans of time – instead of fluctuating randomly as expected from neutral drift – implying successful intergenerational transmission (*cf.* Braun, 1990; O'Brien and Holland, 1992). In practice, we need to closely examine the nature and temporal trajectory of behaviors in different regions and relate them in a meaningful way to reproductive success (see O'Brien and Holland, 1992, p. 50–52).

Based on the foregoing discussion, we define coastal adaptations as a multifaceted array of behavioral traits in a population that incorporates the use of marine resources and the occupation of coastal landscapes. First, it includes the regular consumption of food resources from (or adapted to) salt water seas by means of active and systematic acquisition, including mollusks, mammals, birds, or fish, often encompassing the subsequent transport of prey to occupation sites. With the term “systematic” we imply that the acquisition of marine food resources is executed in a methodical manner, part of a plan or strategy and a habitual component of the overall diet. We exclude inadvertent, opportunistic or occasional use, and foods deriving from freshwater environments. Additionally, coastal adaptations encompass the expansion of the settlement system to include coastal and near-coastal zones as occupation spots on a regular and planned basis, in contrast to people simply traversing these areas. One of the key questions of this article examines in what way these behaviors increased the reproductive fitness of their bearers.

Different from other more exclusive uses that are based on modern ethnographic analogies (Fitzhugh, 1975, pp. 342–344; Yesner, 1980, p. 728; Beaton, 1995, p. 802; Erlandson and Fitzpatrick, 2006, pp. 8–9; Marean, 2014, p. 20), we see our broader definition as a useful analytical device to assess the status of coastal adaptations in different hominin species, which is necessary when operating within a diachronic, comparative and evolutionary framework. In terms of archaeological correlates of coastal adaptations, we expect sites that once had a coastal or near-coastal location to yield remains of marine resources that were actively acquired, found throughout several occupation horizons and associated with traces of other activities, such as stone knapping, fire making or butchery. They should also harbor traces suggestive of a systematic integration into a larger settlement system. Such localities would form a more or less continuous and behaviorally consistent record over multi-generational time spans – meaning hundreds or thousands of years – deriving from one or several large regions.

When strictly applying our definition and expectations to the current archaeological data, the only hominins for which coastal adaptations have been demonstrated are classic Neanderthals (*sensu* Stiner, 1994; Finlayson, 2008; Stringer et al., 2008; Cortés-Sánchez et al., 2011; Hardy and Moncel, 2011; but see Marean, 2014) and *Homo sapiens* (*sensu* Erlandson, 2001; Jerardino, 2010a; Parkington, 2010; Marean, 2014; Will et al., 2015), with the earliest evidence for both species potentially dating to late MIS 6 (see also below). Since we review the archaeological record of the MSA here, we only discuss the modern human evidence.

It is clear, however, that hominin species or populations can show a different adaptedness to coastal environments, such as the repetitiveness and duration of coastal foraging, the relative amount of marine resources in the diet, the time spent on coasts and its impact on other aspects of their overall adaptive suite. While even certain species of primates (e.g. *Macaca fascicularis*, *Pongo pygmaeus*) occasionally harvest freshwater and marine resources (e.g., Stewart, 2010; Gumert and Malaivijitnond, 2012; Russon et al., 2014), these behaviors do not constitute coastal adaptations as defined above. Researchers also showed that species of early *Homo*, including *Homo erectus*, consumed aquatic resources (Joordens et al., 2009; Braun et al., 2010; Archer et al., 2014; Stewart, 2014). This evidence from the Lower Pleistocene, however, derives mostly from freshwater environments (cf. Foley and Lahr, 2014). Compared to coastal and marine ecosystems, freshwater environments present a different ecological setting and nutritional composition (Burke et al., 2001; Smith and Smith, 2012, pp. 701–760; Stewart, 2014), which likely required different behavioral adaptations.

2.2. Models for the origin and evolutionary advantages of coastal adaptations

What were the selective advantages of coastal adaptations? How and when did they evolve? Researchers have formulated several hypotheses to account for the evolutionary process that lead to the adoption and persistence of coastal adaptations in modern humans, and their potential evolutionary consequences (e.g., Parkington, 2003; Cunnane and Stewart, 2010; Marean, 2010, 2014; Parkington, 2010). Before we briefly summarize these ideas, it is important to reiterate that models advocating ultimate evolutionary causality via natural selection (cf. Tinbergen, 1963; Lewin and Foley, 2004, pp. 32–33) need to invoke differential reproductive success, a proxy for direct fitness. This measure describes the probability of an organism's survival to reproductive age and the number of fertile offspring produced for a given population (Lewontin, 1970; Brandon, 1978; Maynard-Smith, 1989; West-Eberhard, 1992). In other words, once evolved, adaptations ultimately persist because they enhance the fitness of individuals relative to others, which in turn also leads to a higher probability of the adaptive trait being transmitted to subsequent generations by various processes.

The recent years have produced many hypotheses surrounding the origins as well as the advantages and consequences of coastal adaptations for the evolution of modern humans. One influential model, most strongly advocated from an archaeological perspective in several publications by Parkington (2001, 2003, 2006, 2010), Parkington et al. (2004) focuses on brain evolution and the origins of behavioral modernity. It is strongly based on results from nutritional studies (e.g., Crawford et al., 1999; Broadhurst et al., 2002; Crawford, 2010; Cunnane, 2010; Cunnane and Stewart, 2010). This theory posits that a dietary expansion by modern humans to include marine foods stimulated and fueled their brain evolution. Relative to marine food chains, most terrestrial food resources are low in certain brain-selective nutrients – particularly long-chain, polyunsaturated omega 3-fatty acids. These are needed for the maintenance and growth of neural tissue, making the savannah an unlikely setting for the evolution of the behaviorally modern human brain (*sensu* Crawford et al., 1999; Crawford, 2010; Cunnane, 2010; Cunnane and Crawford, 2014). Instead, this hypothesis maintains that marine foods in a coastal environment were critical sources to foster encephalization and sustain large brains, particularly for pregnant and lactating women as well as children. Researchers thus associate the increasing evidence for the use of marine resources in the MSA by modern humans with higher cognitive abilities, which in turn could have triggered the

development of fully modern patterns of behavior seen in the early evidence of complex material culture in Africa.

The second important model proposes that coastal adaptations were a *consequence*, rather than a cause, of modern human brain evolution. According to this hypothesis, understanding the connection between lunar patterns, tidal activities and shellfish return rate is different and more complex than tracking terrestrial animals, which is the reason why coastal adaptations originated comparatively late in human evolution (see Marean, 2011, 2014). For Marean, only populations of *Homo sapiens* that already possessed advanced cognitive functions were able to adapt successfully to coastal niches beginning some time during MIS 6. According to the “Cape Flora-South Coast Model for the origins of modern humans” (Marean, 2010, p. 432; see also Marean, 2014), the southern Cape was also the location of the progenitor population for later *Homo sapiens* (for a different model of allopatric speciation within South Africa see Compton, 2011). As indicated by genetic research, the harsh conditions of MIS 6 led to a drop in modern human populations in Africa. A small group resulting from this demographic bottleneck survived in an area stretching from the southern Cape into the Eastern Cape. This refuge zone was the ideal habitat for the development of modern humans and their advanced cognition as it had both a high density of geophyte plants and a rich coastal ecosystem.

While both models have justifiably become influential in recent years, they possess limitations concerning long-term evolutionary perspectives. The encephalization model does not address the origins of coastal adaptations but focuses strongly on their potential evolutionary advantages. While there is no simple temporal covariation between larger brains and use of marine resources by MSA modern humans, particularly in the Late Pleistocene (Rightmire, 2004; Tattersall, 2010; Hublin et al., 2015), Parkington (2001, 2010) has emphasized that encephalization is not simply the selection for an absolutely larger brain, but rather a higher encephalization quotient (EQ). Modern humans do possess higher EQs than other *Homo* species and recent studies point to major increase in encephalization within *Homo* either during the Middle Pleistocene (e.g., Rightmire, 2004) or with the emergence of *Homo sapiens* (cf. Aiello and Wheeler, 1995; Ruff et al., 1997; McHenry and Coffing, 2000). Many complex elements of material culture also post-date the first use of marine resources by modern humans during the MSA (see e.g., McBrearty and Brooks, 2000; Conard, 2005, 2007; Wadley, 2015).

The “brain first” model proposed by Marean focuses on the origins of coastal adaptations, with a combination of environmental factors and necessary cognitive preconditions leading to their adoption. Marean, however, defines coastal adaptations not from the perspective of evolutionary biology (see above), but on the highly derived evidence from modern hunter–gatherers (e.g., Fitzhugh, 1975; Yesner, 1980; Beaton, 1995). This narrow definition includes only those cases where people are *focused* on coastal resources (Marean, 2011, pp. 425–426) or even transform their overall behavior with relation to marine foods (Marean, 2014, pp. 18–20). This ethnographic analogy makes it difficult to find comparable evidence in the early archaeological record, as it does not distinguish between the concepts of adaptation and adaptedness. Most importantly for the purpose of this article, neither model provides an evolutionary definition of coastal adaptations or proposes explicit scenarios that relate coastal adaptations directly to reproductive fitness; they are more concerned with the evolution of the modern brain and behavior.

Generally speaking, the origin of any behavioral adaptation is hard to detect. As such a change emerged, it would start at a very low frequency before increasing through selective forces, and it might initially arise through various processes such as chance or by

accident (cf. Brandon, 1990; O'Brien and Holland, 1992). The situation is even more complicated in the archaeological record, where preservation bias resulting from sea level changes might have concealed the earliest evidence of coastal resource use by modern humans before MIS 5 (van Andel, 1989; Bailey et al., 2007; Bailey and Flemming, 2008; Fisher et al., 2013; Bailey et al., 2015; Erlandson and Braje, 2015). That being said, we now have data from sites predating the last interglacial high stand of sea level, such as Bajondillo Cave (Cortés-Sánchez et al., 2011) and Pinnacle Point 13B with the oldest evidence for the use of marine resources by modern humans at ~160 ka (Marean, 2010). At Hoedjiespunt and Pinnacle Point, no earlier evidence for coastal adaptations was recovered, although it could have been preserved based on those sites' elevation above sea level (e.g., Pickering et al., 2013).

From a global perspective, there is still little evidence for the use of marine resources before MIS 6. Potential sites include Trinil (Joordens et al., 2009) and Terra Amata (de Lumley, 1966), but anthropogenic accumulation of the marine fauna is not demonstrated. The observed archaeological pattern – discontinuous in space and time, lacking systematic character – contrasts markedly with the Late Pleistocene record (Marean, 2010, 2011; Colonese et al., 2011; Kandel and Conard, 2012; Jerardino, 2010a; Marean, 2014; Will et al., 2015) and fits the expected outcome for groups not fully adapted to coastal niches. Additional support for the idea that coastal adaptations originated after 200 ka could come from sites along coastlines with a steep offshore bathymetric profile and narrow continental shelf, yielding no or only few remains of a limited range of the most easily acquired marine resources along with short-term, ephemeral occupations that date before MIS 5 and escaped erosion by pre-Holocene high stands (see also Fisher et al., 2013). This implies the possibility that earlier species of *Homo* possessed lower adaptedness to coastal niches, a likely precursor of coastal adaptations as defined here. While only future discoveries can answer these questions, we think that scholars should give precedence to the available archaeological record, consider potential sources of bias and derive balanced and falsifiable conclusions on this basis (see 6. Discussion).

In sum, it is difficult to pinpoint the exact time and causes of when and why modern humans started to use coasts more intensely. They may have been driven from inland habitats by environmental pressures (Compton, 2011) and then recognized the potential of this new niche through their increased cognitive skills (Marean, 2011) or perhaps simply by chance events contingent on already existing freshwater adaptations (Stewart, 2014) and a longer daily exposure to coastal ecosystems (Fisher et al., 2013). While these remain open questions, we can still investigate the nature of these behaviors, how they developed, and why they persisted.

3. Subsistence: the exploitation of marine food resources

The introduction of marine food resources into the diet of modern humans has become an important focus of research during the last decades. We will characterize the subsistence strategy used by MSA populations in various parts of Africa in terms of its species composition, acquisition strategies and nutritional relevance. We also analyze diachronic changes within the MSA to characterize the temporal trajectory of marine food consumption.

The ecology of edible marine organisms depends upon oceanographic, geographic and other environmental factors. Additionally, climate change can influence the nature and bio-productivity of shorelines through time (e.g., Langejans et al., 2014). Although these parameters vary greatly along African coasts (see Bustamante and Branch, 1996, 1997; Burke et al., 2001; Fa, 2008; Steele and Klein, 2008; Dusseldorp and Langejans, 2013; Bailey et al., 2015),

there is evidence for the exploitation of marine food resources from the Atlantic, Indian, Mediterranean and Red Sea coastlines of Africa by modern humans during the MSA. For almost all of these sites, taphonomic and archaeozoological research demonstrates that humans were the primary accumulator of the marine organisms (Table 1; e.g., Thompson, 2010; Thompson and Henshilwood, 2011; Dibble et al., 2012; Steele and Klein, 2013; Will et al., 2013; but see Bailey and Flemming, 2008; Bailey, 2009; Buffler et al., 2010 for the Red Sea evidence).

What kinds of marine organisms did humans routinely consume during the MSA? Table 1 provides an overview of data deriving from 25 African sites: Marine mollusks, particularly shellfish, are found in every coastal MSA site (n = 21) and constitute the most abundant food refuse deriving from oceans within these archaeological contexts. The MSA hunter–gatherers predominantly exploited large individuals of intertidal shellfish species, to the exclusion of taxa from the subtidal zone (e.g., Avery et al., 2008; Steele and Klein, 2008; Jerardino, 2010a; Langejans et al., 2012). At around a third of the sites, marine mollusks are accompanied by evidence for the consumption of marine mammals (n = 8; Table 1), mainly Cape fur seal (*Arctocephalus pusillus*; Klein, 1976; Marean, 1986a; Klein and Cruz-Urbe, 1996, 2000). As stressed by several scholars (Parkington, 2001; Klein, 2009; Steele and Klein, 2009; van Niekerk, 2011), marine birds (n = 8; mostly African penguin (*Spheniscus demersus*) and Cape cormorant (*Phalacrocorax capensis*)) and fish (n = 5) are relatively rare at coastal MSA sites.

On the Atlantic west coast of South Africa, shellfish species with high meat yields, deriving from extensive beds in the occasionally accessible mid-intertidal zone, characterize the consumption of marine foods at the shellfish-bearing sites Hoedjiespunt, Sea Harvest and Ysterfontein 1. Other taxa constitute a much smaller part of these assemblages, as do sea birds and Cape fur seals. Fish were not part of the regular diet (Klein et al., 2004; Avery et al., 2008; Steele and Klein, 2008; Langejans et al., 2012; Dusseldorp and Langejans, 2013; Kyriacou et al., 2015). Chronologically, the coastal sites from the Western Cape date to early MIS 5 (~125–100 ka; Table 1) and show the continuous use of a narrow range of shellfish species throughout their occupation sequences (Avery et al., 2008; Will et al., 2013, 2015).

On the Indian Ocean coast of South Africa, archaeozoological studies also demonstrate a systematic rather than opportunistic exploitation of a narrow range of collected taxa, with an emphasis on large mid-intertidal turban shells (*Turbo sarmaticus*), brown mussels (*Perna perna*) and limpets (*Scutellastra argenvillei* and *S. tabularis*; Thackeray, 1988; Jerardino and Marean, 2010; Langejans et al., 2012; Dusseldorp and Langejans, 2013; Henshilwood et al., 2014). Pinnacle Point 13B has yielded the earliest evidence for the occasional consumption of marine mollusks in southern Africa at ~160 ka (Jerardino and Marean, 2010), but shell remains are much scarcer compared to sites dating to MIS 5 and 4. In contrast to the Western Cape, there is better evidence for the consumption of marine mammals, and to a lesser degree, of fish. At Klasies, Blombos Cave and Die Kelders, people procured substantial amounts of predominantly adult Cape fur seal on a regular basis between ~120 and 55 ka (Klein, 1976; Marean, 1986a; Klein and Cruz-Urbe, 2000; Henshilwood et al., 2001). The Blombos and Klasies fish remains suggest some active fish catching, but their quantities remain low (Henshilwood et al., 2001; Van den Driesch, 2004; Van Niekerk, 2011).

While there is comparatively little information on marine subsistence deriving from the Red Sea and northern Africa (cf. Steele and Álvarez-Fernández, 2011), current data indicate many similarities with the southern African record. People predominantly harvested marine mollusks, usually dominated by a narrow range of limpet (e.g., *Patella caerulea*; *P. intermedia*) and mussel (e.g., *Mytilus*

Table 1
Overview of coastal adaptations by modern humans during the MSA of Africa encompassing marine resource use, material culture and coastal settlements. Relevant references and a more detailed discussion of the evidence regarding the consumption of marine resources and settlement of coastal landscapes can be found in the text.

Site	MIS	<i>in situ</i> ^a	Shellfish (density) ^b	Marine mammals	Marine birds	Fish	Techno-complex ^c	Non-local RMU ^d	Ocher (engraved) ^e	Bone tools	Shell beads	# Occup. horizon ^f	Hearths	Site type	Occupation density	Site location ^g
<i>Southern Africa</i>																
Pinnacle point 13B	6 – 5c	Y	Y (0.1–9.0)	Y	–	–	EMSA	–	Y	–	–	>10	Y	Cave	Low – high	Coastal Near-coastal
Hoedjiespunt 1	5e	Y	Y (11–13)	–	Y	–	EMSA	Y	Y	–	–	3	–	Open air	Low	Coastal
Sea harvest	5 (e?)	?	Y	–	–	–	EMSA	Y	–	–	–	?	–	Open air	Low	Coastal
Herold's Bay Cave	5 e/d	Y	Y	–	–	–	EMSA	–	–	–	–	1	Y	Cave	?	Coastal Near-coastal
Boegoeberg 2	5 e/c/a	Y	Y	–	Y	–	EMSA	–	–	–	–	?	–	Rock shelter	Low	coastal
Ysterfontein 1	5e (?) 5c–a	Y	Y	Y	Y	–	EMSA	–	Y	–	–	13	Y	Rock shelter	Low – high	Coastal
Blombos Cave	5d–4	Y	Y (10–164)	Y	Y	Y	EMSA SB	Y	Y (Y)	Y	Y	>10	Y	Cave	High – very high	Coastal Near-coastal
Klasies River	5d–3	Y	Y (0.3–163)	Y	Y	Y	EMSA, HP, post-HP	Y/- ^d	Y (Y)	Y	–	>10	Y	Cave	High – very high	Coastal Near-coastal
Diepkloof Rock Shelter	5d–3	Y	Y	Y	Y	–	EMSA, SB, HP, post-HP	Y	Y	–	–	>10	Y	Rock shelter	High – very high	Inland
Klipdrift Shelter	4–3	Y	Y (<1–183)	–	–	–	HP, post-HP	–	Y	–	–	>10	Y	Rock shelter	High	Coastal Near-coastal
Sibudu	4–3	Y	Y	Y	–	Y	SB, HP, post-HP	Y	Y	Y	Y	>10	Y	Rock shelter	High – very high	Inland
Die Kelders	4	Y	Y	Y	Y	–	EMSA (?)	–	Y	–	–	>10	Y	Cave	Low – high	Near-coastal
<i>Red Sea</i>																
Abdur	5e	Y/N ^a	Y	–	–	–	EMSA	Y	–	–	–	2	–	Open air	Very low – low	Coastal
Asfet	5(e) ?	N	Y	–	–	–	EMSA	Y	–	–	–	(surface)	–	Open air	Very low – low	Near-coastal
<i>Northern Africa</i>																
Benzú Rockshelter	7 (?) – 4	Y	Y	–	–	–	Mousterian	–	–	–	–	7	–	Rock shelter	Low – moderate (?)	Coastal Near-coastal
Contrebandiers Cave	5e–c	Y	Y	–	–	–	Mousterian Aterian	?	Y	–	Y	11	Y	Cave	Very low -moderate	Coastal Near-coastal
Dar es Soltane I	5e, 5c, 4, 3	Y	Y	–	–	–	Aterian	–	–	–	Y	3	Y	Cave	Very low – low	Coastal Near-coastal
Haua Fteah	5 (e?) – 3	Y	Y	–	Y	Y	Mousterian “Pre-Aurignacian”	–	–	Y	–	>10	Y	Cave	Low – high	Coastal Near-coastal
El Harhoura 2	5c, 5a, 3	Y	Y	–	–	–	Mousterian Aterian	Y/- ^d	–	Y	Y	9	Y	Cave	Very low – low	Coastal Near-coastal
El Mnasra	5c, 5a	Y	Y	–	–	–	Aterian	Y/- ^d	Y	Y	Y	8	Y	Cave	Low – moderate	Coastal Near-coastal
Grotte de Pigeons	5b/a	Y	–	–	–	–	Aterian	–	Y	–	Y	1 ^e	Y	Cave	High	Inland
Ifri n'Ammar	5b/a	Y	–	–	–	–	Aterian	Y	Y	–	Y	2 ^e	Y	Cave	High	Inland
Rhafas	5a/4	Y	–	–	–	–	Aterian	Y	–	–	Y	1 ^e	–	Cave	Moderate	Inland
Mugharet el 'Aliya	5a, 3	Y	Y	Y	–	Y	Mousterian Aterian	–	–	–	–	3	–	Cave	Very low – low	Coastal Near-coastal
Oued Djebbana	5	? ^a	–	–	–	–	Aterian	?	–	–	Y	1 ^e	–	Open air	Moderate	Inland

^a Primary (anthropogenic) or non-primary context of the archaeological remains. The direct association between shellfish remains and lithic artifacts at Abdur is contested (Bailey and Flemming, 2008; Bailey, 2009), as is the association of a single shell bead with Aterian occupations at Oued Djebbana (see Bouzouggar et al., 2007).

^b Shellfish densities in kg/m².

^c Abbreviation of techno-complexes: EMSA = Early MSA; SB = Still Bay; HP = Howiesons Poort; post-HP = post-Howiesons Poort. EMSA encompasses variants in southern Africa during MIS 6 and 5 such as “Klasies River”, “Mossel Bay” and “pre-Still Bay” (see Wurz, 2002; Lombard et al., 2012). Mousterian = generic North African variant of the Middle Paleolithic (e.g., Linstädtler et al., 2012), or alternatively interpreted as equivalent to the MSA (see Dibble et al., 2013).

^d Raw material units (RMU) reported to be >10 km away from the site. The occurrence of non-local raw materials at Klasies is disputed (Singer and Wymer, 1982; Deacon and Wurz, 1996; but also Minichillo, 2006). At El Harhoura 2 and El Mnasra, the majority of raw materials is local, but a small proportion could originate from further away (Stoetzel et al., 2014).

^e Encompasses modified (e.g. rubbed, grounded) and non-modified ochre. Brackets (Y) indicate sites which also feature abstract engravings on ochre.

^f Number of occupation horizons, counted as individually recognized archaeological horizons and thus underestimate actual occupation events. In the case of inland sites with evidence for shell beads, numbers reflect the count of occupation horizons from which these artifacts derive.

^g We distinguish the coastal zone as the ca. 1/2 km strip of land along the shoreline from the near-coastal zone that extends up to ca. 10 km inland. This definition is based on the distance that hunter-gatherers might cover in one day. We consider areas further than 10 km from the coastline as inland (see Conard and Kandel, 2006, p. 333; Kandel and Conard, 2013, p.24). Due to global sea level changes, the location of some sites fluctuated between categories.

edulis; *M. galloprovincialis*; *Perna perna*) taxa. Along the North African coastline, there is also some rare evidence for the consumption of sea birds, marine mammals (*Monachus monachus*) and fish (Arambourg, 1967; Klein and Scott, 1986; Walter et al., 2000; Ramos et al., 2011; Steele and Álvarez-Fernández, 2011; Barker et al., 2012; Steele, 2012; Stoetzel et al., 2014; Nouet et al., 2015). At Benzú Rockshelter, human use of marine resources could date back to ~250 ka (Ramos et al., 2011, p. 106), but more faunal data and taphonomic studies are needed to substantiate this claim.

How did MSA people acquire and process these marine food resources? As there are no obvious examples of special gathering, hunting, extracting or fishing equipment in the MSA, we focus on relative proportions of different species of marine organisms represented in archaeological assemblages, as they can provide insights into prehistoric coastal foraging with regard to prey choice, the scheduling of gathering activities, resource exploitation and transport strategies. The predominant collection of a narrow range of large mid-intertidal mussels and limpets during the MSA compares well with indigenous coastal foragers in southern Africa and Australia. Here, gathering activities are scheduled to coincide with the maximal exposure of the littoral zone during spring low tides, allowing access to the mid- and lower-intertidal species (Bigalke, 1973; Meehan, 1982; Buchanan, 1988; Bird et al., 2004). People usually harvest the bivalve species typical of the southern Cape record in large aggregates of individuals stuck together by fibrous threads. Thanks to their natural packaging, bivalves remain fresh longer than limpets, making them profitable even during times of coastal regression; a pattern reported at Pinnacle Point, Diepkloof Rock Shelter and Blombos (Jerardino and Marean, 2010; Dusseldorp and Langejans, 2013; Steele and Klein, 2013).

In a recent study concerned with MSA exploitation strategies of marine resources at Blombos and Klasies, Langejans et al. (2012) found that the inhabitants optimized their foraging trips by collecting the highest ranked shellfish taxa, considering both distance to resources and their yield. Their findings imply that people were aware that tidal changes influence the availability of marine food and scheduled their visits to the coast accordingly, but also that they made flexible decisions on the transport of resources. This systematic and flexible exploitation of marine resources appears to apply to the entire African MSA record between ~120 and 50 ka (Steele and Álvarez-Fernández, 2011; Kyriacou et al., 2015). At many MSA localities in southern and northern Africa, the frequency of marine resource use also increases with inferred proximity to the sea (Thackeray, 1988; Jacobs et al., 2006; Fisher et al., 2010; Marean,

2010; Langejans et al., 2012; Stoetzel et al., 2014; Campmas et al., 2015).

There has been considerable discussion about hunting vs. scavenging of Cape fur seals in southern Africa, particularly at Klasies (Klein, 1976; Binford, 1986; Marean, 1986a, 1986b; Klein and Cruz-Urbe, 1996, 2000). In sum, the seal remains likely reflect systematic acquisition by modern humans via active hunting and some scavenging of washed-up carcasses, with subsequent transport to occupation spots (Dusseldorp and Langejans, 2013, 2015).

How large was the proportion of marine food items in the overall diet of modern humans during the MSA? According to Henshilwood et al. (2001, p. 441), marine mollusks constitute the most abundant category of food waste at Blombos in all three archaeological complexes (M1–M3). Some horizons at Klasies, Blombos and Klipdrift Shelter consist almost exclusively of shell, and their density values are close to LSA shell middens (Thackeray, 1988; Henshilwood et al., 2001, 2014; see also Table 2). At Klasies, seals are the most abundant mammal species in the MSA II and Howiesons Poort (Marean, 1986b). At other sites such as Pinnacle Point, Hoedjiespunt, or Abdur, remains of shellfish are common, but of low prevalence compared to other classes of archaeological finds (Walter et al., 2000; Jerardino and Marean, 2010; Will et al., 2013).

In order to assess this issue in a quantitative way, researchers have calculated the density of various marine food items, particularly shellfish. Table 2 demonstrates the large differences in shellfish densities (kg/m^3) between, but also within, MSA sites (Fig. 2). Unfortunately, only a few coastal MSA sites in Africa, exclusively from its southern part, have published density values. Furthermore, density values merely provide an approximate measure of the proportion of marine food in the diet, as various natural and cultural taphonomic processes influenced them (e.g., Jerardino, 1995, in press; Goldberg, 2000).

In a recent re-evaluation of the actual nutritional proportion of marine food in the diet of MSA modern humans from southern Africa, Clark and Kandel (2013) assessed the relative contribution of shellfish by converting shell weights into nutritional values, using data from Buchanan (1988). Their results show that even for the largest assemblage of shellfish in sub-Saharan Africa (Blombos, M3), the combined nutritional value amounts to only 38 person-days of food. With 1.5 person-days (ca. 3000 kcal), the combined layers of Pinnacle Point show even lower quantities (Clark and Kandel, 2013, S280). Since many of the early MIS 5 sites are more comparable to the latter locality, marine shellfish themselves do not appear to have

Table 2
Comparison of shellfish densities (kg/m^3) between MSA sites and selected LSA shell middens for illustrative purposes. Values per layer vary and can be found within the respective data sources.

Site	Shellfish (kg/m^3)	Period	Data source
Pinnacle point 13B	0.1–9.0	MSA (MIS 6 – MIS 5c)	Jerardino and Marean (2010)
Hoedjiespunt 1	11–13	MSA (MIS 5e)	Will et al. (2013)
Blombos Cave	<10–164 ^a	MSA (MIS 5d – MIS 4)	Henshilwood et al. (2001)
Klasies river mouth	0.3–163	MSA (MIS 5d – MIS 3)	Thackeray (1988)
Klipdrift shelter	<1–183	MSA (MIS 4 – MIS 3)	Henshilwood et al. (2014)
Steenbokfontein Cave	129–348	LSA ca. 4000–2000 BP	Jerardino (2010a)
Pancho's Kitchen Midden	306–468	LSA ca. 4000–2000 BP	Jerardino (2010a)
Mike Taylors Midden	130–530	LSA ca. 2000 BP	Jerardino and Yates (1997)

^a Range of shellfish densities for individual layers. For complexes M1–M3: 18–68 kg/m^3 .

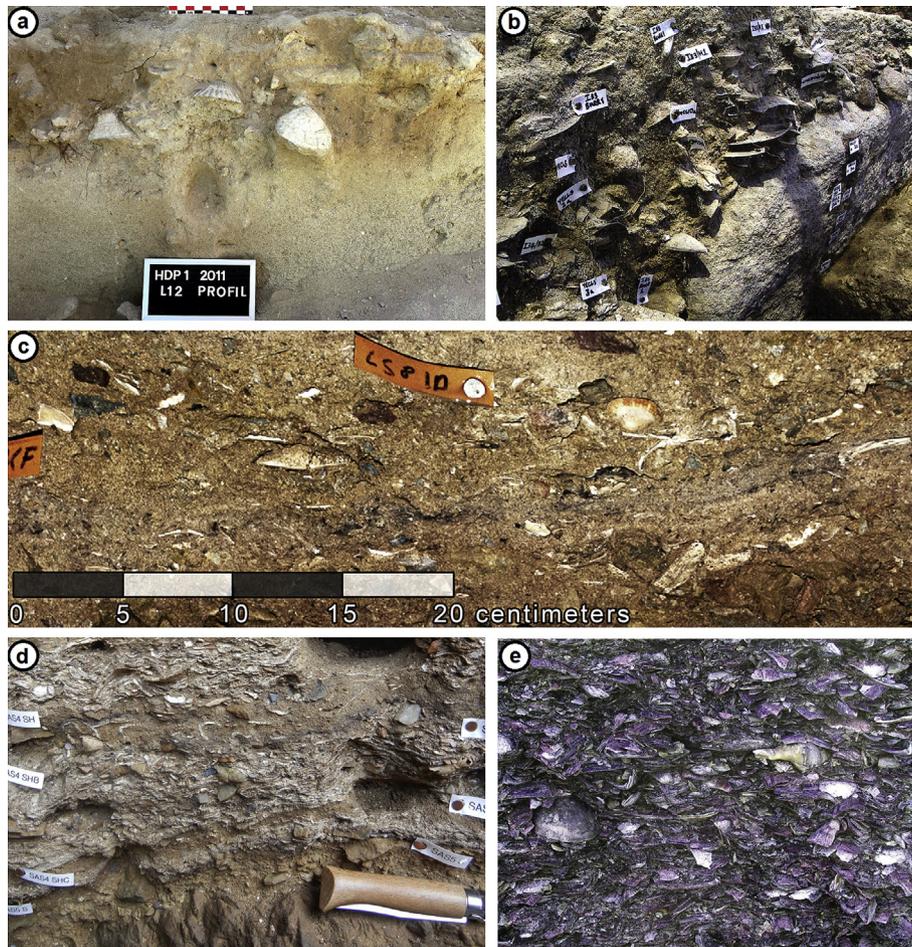


Fig. 2. Variability in shellfish densities between sites from the MSA and LSA. a) Hoedjiespunt 1, AH III (MSA): low shellfish density (photo by M. Will); b) Ysterfontein 1, YELLS (MSA): moderate shellfish density (photo by J. Parkington); c) Pinnacle Point 5–6, LBSR (MSA), moderate shellfish density (Marean, 2014: Fig. 5). d) Klasies River Mouth, SAS 4 (MSA): high shellfish density (photo by C. Miller); e) Elands Bay Cave, Megamidden (LSA): very high shellfish density, true shell midden (photo by J. Parkington).

played a major dietary role during the MSA when compared to terrestrial mammals.

Unfortunately, Clark and Kandel's study could not include data from all marine food resources. Their combined caloric value could have accounted for a larger part of the diet. Assessing the proportion of marine food in the diet of MSA people is also complicated by the fact that people harvesting marine resources might prepare or consume large portions of their catch on the spot, transporting only a small fraction of shells back to occupation sites (e.g., Meehan, 1982; Bird and Bliege Bird, 1997, 2000). While the amount of information lost is difficult to judge, the evolutionary importance of these food items might not lie in their caloric value alone, but also in the amount of certain nutrients they provide (see 6. Discussion). There is, however, no question that MSA people regularly consumed marine resources, as shown by multiple shellfish-bearing occupation horizons at many sites in different regions (Table 1).

Regarding diachronic trends, there is a consistent signal of intensifying use of marine resources from MIS 6 to MIS 4, at least in the MSA of sub-Saharan Africa. The only MIS 6 site, Pinnacle Point, exhibits very low shellfish densities and little use of other marine resources. Coastal sites during MIS 5 and MIS 4, including Ysterfontein 1, Blombos, Klasies and Klipdrift, exhibit higher average densities and diversities of shellfish associated with more frequent use of other marine foods, and generally show a more methodical execution of coastal foraging (e.g., Langejans et al., 2012;

Dusseldorp and Langejans, 2015; Will et al., 2015). Although marine foods continue to be used in MIS 3, with the highest frequency of shellfish at Diepkloof dating to this period (Steele and Klein, 2013), there is no simple uniform increase in the relative frequency of shellfish from MIS 5 to 3 in Africa (e.g., at Klasies; see Thackeray, 1988). For now, it remains unclear whether this pattern reflects actual changes in the use of marine resources, differential preservation, fluctuations in sea level or demography (Bailey and Flemming, 2008; Steele and Klein, 2008; Clark and Kandel, 2013). Nonetheless, the reviewed data demonstrate the continued, systematic and habitual consumption of marine resources over more than 100 ka in several regions of Africa.

4. Technology: the use of lithic and non-lithic material

Compared to the study of subsistence based on marine resources, technological adaptations associated with coastal settlements during the MSA have received little attention from scholars. We address the role of lithic technology as part of coastal adaptations, and also consider the use of non-lithic material such as bone, ocher, ostrich eggshell, and perhaps most importantly, marine shell. In general, the acquisition of marine resources during the MSA has few technological correlates. We know of no stone artifact types directly associated with shellfish gathering. Lithic tools are not even necessary for this activity (Moss, 1993; but see Bird and Bliege-Bird, 1997, 2000). Other organic devices observed in

ethnographic studies, such as baskets, wooden sticks or nets (Moss, 1993), are unlikely to preserve from the MSA.

Looking at lithic technology from coastal sites with marine resources in Africa during the MSA from a long-term point of view, variability is the key behavioral signature (cf. Wurz, 2012; Will et al., 2013, pp. 531–532). Coastal MSA sites are associated with a wide array of knapping technologies, tool types, raw materials and technocomplexes (Table 1), including various industries of the early MSA before ca. 80 ka (Singer and Wymer, 1982; Walter et al., 2000; Halkett et al., 2003; Marean et al., 2007; Ramos et al., 2008; Thompson et al., 2010; Dibble et al., 2012; Wurz, 2012), as well as the Aterian (Bouzouggar et al., 2002; Dibble et al., 2012; Debénath and El Hajraoui, 2012; Nespoulet and El Hajraoui, 2012), the Still Bay and Howiesons Poort (Henshilwood et al., 2001; Wurz, 2002, 2012; Porraz et al., 2013) and technocomplexes after ~60 ka (Wurz, 2002; Nespoulet and El Hajraoui, 2012; Wurz, 2012; Porraz et al., 2013). Variation in lithic technology of these sites depends on temporal position and cultural attribution, but not primarily on their coastal location or the exploitation of marine resources. The use of marine resources during the MSA apparently had no perceptible effect on lithic technology itself, but rather on its organization (see below). Since bare hands alone can manage the task of harvesting most marine resources, it was not necessary for MSA people to invest in lithic technology related specifically to their extraction.

Coastal sites with evidence for the exploitation of marine foods also yield a wide range of non-lithic material culture, including elements that feature prominently in the discussion of modern behavior (see McBrearty and Brooks, 2000; Henshilwood and Marean, 2003; Conard, 2008). Many coastal sites from late MIS 6 to early MIS 3 have yielded evidence for the use and modification of ocher (n = 13; Table 1; Klein et al., 2004; Avery et al., 2008; Henshilwood et al., 2009; Watts, 2010; El Hajraoui et al., 2012b; Dayet et al., 2013; Will et al., 2013), for various functional or ritual reasons (e.g., Watts, 2002; Wadley, 2005). At Klasies and Blombos, the inhabitants engraved some of the ocher pieces with abstract geometric designs and these objects are found associated with marine resources in several layers of the occupation sequence (Henshilwood et al., 2002a, 2009; d'Errico et al., 2012). The inhabitants of Diepkloof and Klipdrift also manufactured complex sets of engravings on ostrich eggshell during the Howiesons Poort (Texier et al., 2010; Henshilwood et al., 2014).

The production of bone tools constitutes another technological innovation during the MSA, although they are generally rare at MSA localities in Africa. Some of the best examples come from the (near-) coastal sites of Klasies, Blombos, El Harhoura 2, El Mnasra and Haua Fteah, but they are also present in the inland localities of Sibudu and Katanda. At MSA sites in both southern and northern Africa, the inhabitants manufactured a variety of bone tools, including awls, points, polishers or smoothers (Henshilwood et al., 2002b; d'Errico and Henshilwood, 2007; Barker et al., 2012; d'Errico et al., 2012; El Hajraoui and Debénath, 2012; Stoetzel et al., 2014). These bone tools are directly associated with marine resources (Table 1), but do not comprise harpoons or recognizable fishing equipment.

The use of marine resources for non-dietary purposes arguably constitutes the most interesting aspect in terms of non-lithic technology associated with coastal adaptations. MSA localities north (n = 8) and south (n = 2) of the Sahara have provided evidence for perforated marine shells that were used as ornaments (Table 1). In southern Africa, these artifacts occur in the ~75 ka old Still Bay layers from both Blombos, where more than 60 *Nassarius kraussianus* specimens were recovered (Henshilwood et al., 2004), and Sibudu (d'Errico et al., 2008). The latter constitutes an inland site, today located around 15 km from the Indian ocean. Regardless

of this distance, the inhabitants imported low numbers of *Afro-littorina africana* shells which they perforated on-site (d'Errico et al., 2008). The northern African Mediterranean and Atlantic coasts have yielded even more abundant and roughly contemporaneous evidence (Table 1; Bouzouggar et al., 2007; d'Errico et al., 2009; Nami and Moser, 2010; Dibble et al., 2012; El Hajraoui et al., 2012b). The MSA inhabitants of Oued Djebbana, currently 200 km away from the Mediterranean, transported a single marine gastropod *Nassarius gibbosulus* over very long distances (Vanhaeren et al., 2006). Most interestingly, MSA people on both ends of the African continent used the same genus of marine shells, *Nassarius* or tick shells (see Bar-Yosef Mayer, 2015). These shells contain just minute amounts of edible flesh and were often collected from thanatocoenoses, reinforcing the idea that they were collected for non-dietary purposes. The frequent anthropogenic perforations and wear facets suggest that beads were strung and worn as necklaces, potentially acting as personal ornaments or identity markers (Bouzouggar et al., 2007; d'Errico et al., 2009; Vanhaeren et al., 2013; Bar-Yosef Mayer, 2015).

Modern humans also used marine shell as part of a ~100 ka old ocher-processing tool-kit at Blombos, potentially for painting. The two kits consist of *Haliotis midae* shells – a marine gastropod from the rocky subtidal zone – which stored a liquid ocher mixture, closely associated with stone artifacts (Henshilwood et al., 2011). These finds demonstrate that coastal adaptations encompassed more than just the mundane purpose of satisfying one's appetite.

5. Settlement systems: patterns of site use and mobility

The second part of our definition of coastal adaptations includes the regular occupation of coastal and near-coastal landscapes. This shift in occupation locales reflects an important expansion of the settlement system to incorporate new, highly variable and at times challenging ecological niches. While some terrestrial ecosystems such as lake basins or riverbanks provide ample freshwater and both rich faunal and floral resources, coasts sometimes feature less productive terrestrial environments, particularly under seasonal conditions (Parkington, 2003; Jerardino, 2010a, 2010c; Kappelman et al., 2014). Some types of coastal landscapes feature abundant drinking water, but its distribution can be highly variable and patchy (Van Niekerk et al., 1998; Bulbeck, 2007; Erlandson and Braje, 2015; Groucutt et al., 2015). Exposure to strong winds, tidal fluctuations or storm tides also constitutes novel and difficult circumstances (De Vynck et al., 2015). It must be emphasized, however, that coastal ecosystems range from very productive and pleasant to unproductive and hostile habitats, depending on various oceanographic, geographic and environmental parameters (e.g., Burke et al., 2001).

Here, we summarize observations on the types and intensity of occupation in coastal landscapes, and the overall organization of mobility. For a more detailed site-by-site review of the patterns of site use and mobility at coastal localities in sub-Saharan Africa during the MSA we refer to Will et al. (2015).

There are few coastal sites dating to MIS 6 and MIS 5e with enough data to assess settlement patterns. At Pinnacle Point, shellfish are rare during the MIS 6 occupations (0.1–0.29 kg/m³), indicating only occasional use. Evidence of more intense settlement is visible in the younger horizons (e.g., MIS 5d–c) where the density values of lithics, faunal remains and shellfish rise markedly, and hearths occur for the first time (Jerardino and Marean, 2010; Karkanas and Goldberg, 2010; Marean, 2010). Based on a GIS model of shoreline changes, the MSA inhabitants of Pinnacle Point exploited shellfish only at times when the coast was between 0 and 6 km away, potentially abandoning the site during other times to conduct coastal foraging closer to the shoreline. Conversely,

settlement intensity increased with proximity to the sea, suggesting that a coastal location and ready access to marine resources was an important determinant in choosing the site for occupation (Fisher et al., 2010; Marean, 2010).

The MIS 5e site of Hoedjiespunt is characterized by low densities of stone artifacts, the expedient use of local raw materials and little tool production on-site, which point to short-term stays by small groups (Will et al., 2013). Results from the analysis of shellfish support these interpretations (Kyriacou et al., 2015). In all occupation horizons, the inhabitants repeatedly imported tools of non-local silcrete from inland sources to the site, suggesting planned trips to the coast instead of random or spontaneous visits. HDP1 thus reflects a specialized temporary locale for gathering marine resources used by small groups of mobile hunter–gatherers. The consistency in foraging and technological behavior of the inhabitants, documented throughout more than a meter of sediment (Fig. 3), reflects uniform and temporally stable adaptations by MSA people to marine resources and the inclusion of coastal landscapes into the overall settlement system over many generations as early as MIS 5e (Will et al., 2013, 2015).

At Contrebandiers Cave, El Mnasra, El Harhoura 2 and Mugharet el 'Aliya, low lithic densities, little on-site tool production, and the import of fine-grained raw materials and pre-shaped blanks and tools (Howe, 1967; Bouzouggar et al., 2007; Dibble et al., 2012; Debénath and El Hajraoui, 2012; Nespolet and El Hajraoui, 2012; Stoetzel et al., 2014; Campmas et al., 2015) are comparable to Hoedjiespunt. These data indicate settlements of generally low density, with short but scheduled visits to the coast by small and highly mobile groups with curated tool kits in MIS 5. Similar to Pinnacle Point, increased settlement intensity is reported to co-vary with proximity to the sea at these sites (Stoetzel et al., 2014; Campmas et al., 2015; Nouet et al., 2015).

In contrast to early open-air sites like Hoedjiespunt or Abdur, MSA caves and rockshelters, such as Klasies, Blombos, Diepkloof, Ysterfontein 1 and Pinnacle Point (MIS 5d–c), constitute residential camps indicative of longer stays by larger groups. These localities

show considerably larger volumes of occupational debris, a wide range of lithic and non-lithic artifacts and multi-storied hearths (Table 1). They also yield higher diversity and densities of marine resources (Fig. 4), reflecting their more intensive exploitation (Thackeray, 1988; Henshilwood et al., 2001; Klein et al., 2004; Avery et al., 2008; Karkanas and Goldberg, 2010; Miller et al., 2013; Porraz et al., 2013). The repetitiveness of African MSA coastal settlements is a remarkable but sometimes overlooked feature. Sites such as Klasies, Blombos, Pinnacle Point, Contrebandiers Cave, Benzú Rockshelter, Haua Fteah, El Mnasra and El Harhoura 2 feature many occupation horizons with evidence for consumption of marine resources (Table 1; Thackeray, 1988; Henshilwood et al., 2001; Ramos et al., 2008; Marean, 2010; Barker et al., 2012; El Hajraoui et al., 2012a; Dibble et al., 2012; Stoetzel et al., 2014; Nouet et al., 2015), suggesting that people made repeated use of coastal resources over long periods of time despite the fluctuating distance of these sites from the ocean. These data indicate stable and transgenerational use of coastal landscapes and their resources by modern human populations along the Indian, Atlantic and northern African Mediterranean coasts.

The import of tools of non-local raw materials deriving from inland sources constitutes a repetitive pattern from at least 12 coastal MSA sites (Table 1). This pattern suggests that coastal locations were an integral part of the overall settlement system of MSA groups whose settlement system encompassed scheduled trips to the coasts, instead of the random or opportunistic encounters of people traversing these areas. There is also evidence from the inland sites of Diepkloof and Sibudu that people transported low numbers of edible marine mollusks, fish and coastal birds more than 10 km away from the coasts (Plug, 2004, 2006; Plug and Clark, 2008; Steele and Klein, 2013; see also Creamer et al., 2011). While these data show that inland sites were part of the overall settlement system of MSA groups adapted to coastal niches (cf. Bailey and Milner, 2002), obtaining more information is difficult as the principal archaeological correlates of coastal adaptations are likely missing. Re-fitting of lithic artifacts between



Fig. 3. Hoedjiespunt 1. Top left: View of the excavation in progress during 2011. Top right: Horizontal distribution of shellfish in square L12 of AH II. Bottom left: North-south stratigraphic profile of Hoedjiespunt 1 along the East = 0 m line showing HUMUS = modern top soil, AH I–III = three main archaeological horizons, and SHES = shelly sand. Bottom right: Selection of imported silcrete tools (denticulates) from AH I–II, not to scale (photos by N. J. Conard, M. Will, C. Hahndiek).



Fig. 4. Klasies River Mouth. Left: View on the entrance of the cave within the coastal cliff (photo by S. Mentzer). Right: Section of the stratigraphy from SAS5 at the bottom to SM1 at the top (photo by C. Miller).

coastal and inland sites or isotopic analyses of human fossils from inland MSA sites (cf. Sealy, 2006) might reveal more direct evidence of their dynamic relationship.

Diachronic changes in coastal settlement systems are comparable to those observed in the use of marine resources for southern and potentially northern African sites, although the latter data do not yet allow a final conclusion (cf. Steele and Álvarez-Fernández, 2011). A low density of occupational remains and marine foods characterizes the earliest coastal settlements, particularly during MIS 6, with slightly increasing values in MIS 5e (Table 1). These locales functioned as short-term camps for specialized tasks, including shellfishing. Throughout MIS 5 there is a strong signal of intensifying coastal settlements and use of marine resources, with coastal landscapes serving as focal points for occupations. The later MIS 5 and MIS 4 deposits demonstrate markedly higher settlement intensities, along with combustion features and the production of bone tools, geometric engravings, and shell beads. A total of six southern and northern African sites yielded shellfish-bearing layers from early MIS 3 (Table 1), testifying to continued use of coastal settlements until at least 50 ka.

What does this evidence tell us about the impact of marine resource use on the organization of technology and settlement systems by modern humans during the MSA? The archaeological record of Africa provides evidence for the occupation of coastal ecosystems by modern humans over a time span of more than 100 ka (~160–50 ka). Moreover, the reviewed data suggest a consistent, stable and systematic integration of variable coastal landscapes into the settlement systems of hunter–gatherers over many generations starting at least in MIS 5e, despite differences in oceanographic, geographic and environmental parameters. In general, coastal ecosystems were strong attractors for occupations during MIS 5 and MIS 4: Research in southern (Fisher et al., 2010; Marean, 2010) and northern Africa (Stoetzel et al., 2014; Campmas et al., 2015; Nouet et al., 2015) suggests that people sometimes abandoned sites at times when they were too far away from coasts, probably relocating to other places with more ready

access to marine or terrestrial resources within a fluid system of mobility. In contrast, settlement intensity at these sites increased when the shoreline was close by, indicating that the exploitation of marine resources strongly influenced mobility patterns. In general, we observe a re-organization in the settlement system of MSA hunter–gatherers which expands its boundaries from exclusively inland locales to include novel and at times challenging coastal ecosystems on a regular basis.

6. Discussion

6.1. The nature of coastal adaptations during the MSA of Africa

Based on the archaeological evidence, how can we characterize the specific nature of coastal adaptations by *Homo sapiens* during the MSA of Africa? In our view, this suite of adaptive behavioral traits can be defined by its systematic character and long duration, as well as its verifiable impact on the overall adaptive suite of modern human populations. The active acquisition of most marine food resources and the narrow range of targeted species suggest a systematic and non-opportunistic foraging strategy. Archaeozoological evidence for planned and optimized foraging trips underscores the methodical character of marine subsistence, with people taking lunar cycles and tidal changes, as well as meat yields of marine mollusks, into account. The strong integration of coastal landscapes into the settlement systems of mobile hunter–gatherers, encompassing planned moves to coastal locales as suggested by data on raw material transport from inland sources found at many sites north and south of the Sahara, is similarly methodical in execution. Furthermore, contextual data at some localities suggest that people intentionally abandoned sites at times when they were too far away from the ocean and settled more intensely when the shoreline was close by.

Equally important for an evolutionary perspective is the long duration of coastal adaptations during the MSA, spanning at least

100 ka on both the southern and northern coasts of Africa, making them a multi-generational phenomenon. It is not just the mere duration of the evidence, but also the fact that independent populations from various geographical regions and technological traditions engaged in the settlement and exploitation of coastal ecosystems. Virtually all coastal sites consist of multiple occupation events with evidence for marine resource exploitation (Table 1), suggesting transgenerational use of coastal landscapes, sometimes with dense occupational remains. Finally, elements of material culture such as marine shells as components of necklaces or ocher-processing kits indicate that coasts, oceans and their denizens were part of a complex web of dietary, technical, social and symbolic interactions for MSA modern humans (cf. Beaton, 1995; Marean, 2010, 2014).

The components of this behavioral complex appear to co-occur from MIS 5e onwards – with precursors in the MIS 6 record showing a lower degree of adaptedness – thus marking the beginning of the Late Pleistocene as the potential start of coastal adaptations. Although temporal variation exists, there is an overall consistent signature of marine food exploitation and the settlement of coastal landscapes after MIS 6. This diachronic pattern for the evolution of coastal adaptations is in agreement with expected temporal trajectories for selected, as opposed to neutral, traits (e.g. O'Brien and Holland, 1992; Eerkens and Lipo, 2005; Shennan, 2011). Moreover, the nature and temporal trajectory of these activities fit all expectations regarding material signatures of behavioral adaptations in the archaeological record.

Because the quality of our data set (Table 1) varies with regard to research history and resolution, we need to acknowledge that it is currently difficult to assess to what degree these behavioral signals are affected by fluctuations in sea level, climate change or sedimentation rates. Behavioral factors themselves, such as processing and transport decisions, can influence the chronological trajectory (Thackeray, 1988; Bird and Bliege Bird, 1997; Dusseldorp and Langejans, 2013; Jerardino, in press), but it is unclear in what way they might have affected MSA assemblages. The high densities of shellfish at Diepkloof in MIS 3, despite a distance of over 10 km to the ocean, are a case in point (Steele and Klein, 2013). Even though there are shortcomings regarding the resolution of our data set, there can be no doubt that coastal adaptations are an important and persistent signature of MSA people and their record between at least MIS 5 and MIS 3, based on current data from 25 archaeological sites.

6.2. Evolutionary advantages and consequences of coastal adaptations during the MSA

In the following we relate our own results on the specific nature of coastal adaptations by *Homo sapiens* to the question of their evolutionary advantages and consequences, additionally using results from nutritional, medical and ethnographic studies. The proposed scenarios can serve as building blocks for an explicitly evolutionary perspective of coastal adaptations by modern humans. What makes consumption of marine foods and the settlement on coastal landscapes “adaptive” or provides “selective advantages”? In other words, how does this set of behavioral traits increase reproductive success in relation to populations lacking this trait?

Nutrition has always played a central role in human evolution, as diet is as a strong driver of adaptations and divergent evolutionary pathways (e.g., Leonard et al., 2007; Marshall et al., 2009; Strait et al., 2013; Tattersall, 2014). High-quality diets have often been seen as a prerequisite and consequence of encephalization (Dart, 1953; Washburn and Lancaster, 1968; Aiello and Wheeler, 1995; Hawkes et al., 2001). In recent years, the focus has grown

to include aquatic – and particularly marine – foods, even though shellfish have modest flesh yields and thus low caloric values (Buchanan, 1988; Clark and Kandel, 2013).

Apart from calories, the consumption of marine resources would have had a number of other selective advantages in the form of nutritional and health benefits for MSA hunter–gatherers. Marine mollusks, seaweed and liver tissue of marine mammals are among the best sources of long chain polyunsaturated fatty acids (LCPUFAs) and micronutrients such as iron, copper, zinc, and iodine, which are essential for proper brain development and maintenance. Only few terrestrial foods – such as brain tissue, bone marrow or egg yolk (e.g., Cordain et al., 2002; Speth, 2010) – possess comparable values. As humans have a limited ability to synthesize LCPUFAs, the majority of these essential nutrients need to come from the diet (Broadhurst et al., 2002; Crawford, 2010; Cunnane, 2010; Brenna and Carlson, 2014; Cunnane and Crawford, 2014; Kyriacou et al., 2014). Women, especially when pregnant or lactating, neonates and young children have the highest requirements for brain-selective nutrients. Deficiencies in these substances have a detrimental effect on cognitive development, particularly during gestation and infancy, with symptoms such as impaired learning ability, inattentiveness, and reduced memory. These effects can persist even beyond infancy (Lozoff and Brittenham, 1986; Roncagliolo et al., 1998; Al et al., 2000; Cunnane, 2010; Brenna and Carlson, 2014; Janssen and Kiliaan, 2014; Stonehouse, 2014). Higher intake of LCPUFAs also exerts positive effects on brain functions in older adults (Witte et al., 2014), and may thus be essential throughout life (Janssen and Kiliaan, 2014).

The multi-generational and consistent nature of coastal adaptations by modern humans during the MSA can be related in a twofold way to both reproductive success and brain evolution. First, the regular consumption of marine foods by pregnant and lactating women during the MSA ensured the normal development of an infant's brain by fueling its specific nutritional demands. Most importantly here, this diet would also increase the survival potential of the child to reproductive age. Late Pleistocene modern humans could also have better sustained themselves with important nutrients by participating in coastal subsistence activities, resulting in a larger number of people that could maintain and even increase cognitive performance. Second, a constantly higher intake of brain-selective nutrients over longer time periods would have prevented against deficiency diseases caused by a lack of these substances, reducing mortality rates in the entire population, but particularly for demographically important individuals such as lactating women and children. Among modern coastal foragers, women of all ages and children are the most regular participants in shellfish collecting (Bigalke, 1973; Meehan, 1982; Moss, 1993; Bird et al., 2002). With high success rates, shellfish gathering could have provided these group members with a reliable source of essential nutrients during the MSA (see also Yesner, 1980; Parkington, 2001, 2003, 2006; Crawford, 2010; Cunnane, 2010; Parkington, 2010; Kyriacou et al., 2014).

More general, marine mollusks are not only rich in certain nutrients, but are an easy accessible, predictable, abundant and thus reliable source of nutrition. Compared to hunting most terrestrial animals, harvesting of those intertidal shellfish common at MSA sites can generally be conducted with minimal effort and simple technology, little risk of injury and almost none of failure (Yesner, 1980; Jerardino, 2010b; Dusseldorp and Langejans, 2013; Kyriacou et al., 2014), although coastlines differ with regard to health hazards like storms and tidal amplitudes (e.g., Fa, 2008; De Vynck et al., 2015). These characteristics made shellfish and other marine resources ideal fallback foods in times when preferred terrestrial foods were unavailable (cf. Marshall and Wrangham, 2007;

Marshall et al., 2009; Wrangham et al., 2009). Shellfish could thus serve as a reliable source of energy available to all members of MSA communities, in addition to other fallback foods such as underground storage organs (e.g., De Vynck et al., 2015), but particularly when terrestrial resources were scarce or seasonally unavailable (e.g., Parkington, 1976; Yesner, 1980; Dusseldorp and Langejans, 2013). Their potential role as fallback foods could also explain the observation that marine resources, while being systematically acquired and consumed on a regular basis, were not a substantial part of the MSA diet with regard to their caloric yield compared to terrestrial resources (cf. Clark and Kandel, 2013).

Relating these observations to reproductive success, MSA groups could have buffered against food shortages in terrestrial resources by relocating to coastlines and consuming marine foods. They would thereby reduce mortality rates in the entire population in the long run relative to groups without access to marine resources or the ability to efficiently exploit them. This is in accordance with the archaeological record, which shows that coasts and their resources were an integral part of the overall settlement and foraging system for some MSA populations, which could shift occupation locales from interior to coastal areas. Moreover, our summary showed that MSA people consumed marine resource on a stable and regular basis over many generations, but did not shift their overall subsistence to marine prey. Rather, they added them to a diet that mostly consisted of terrestrial taxa, such as bovines and ungulates (e.g., Jerardino, 2010c), a pattern consistent with them serving as potential fallback foods.

Combining both models, the consumption of marine foods by modern humans resulted in an increase in diet breadth – an active choice by MSA people – as well as a higher intake of nutrients essential for normal brain development – a passive consequence of the biochemical food composition. Coastal adaptations could thus act both as a buffer against terrestrial food shortages and maintain large brains more securely in a larger proportion of the population by preventing against deficiency diseases. In this way, coastal adaptation provided MSA populations with selective advantages as they decreased population-level mortality rates and increased the average number of viable offspring with healthy brain development per generation. As a larger number of offspring survived for a longer time, their propensity for reproducing increased, resulting in higher average fecundity. Importantly, even low proportions of marine foods in the diet of MSA people would confer these selective advantages compared to competing populations lacking these adaptations (cf. Janssen and Kiliaan, 2014; Stonehouse, 2014; Witte et al., 2014), although we currently lack precise knowledge on the critical amounts (or threshold values) of brain-selective nutrients.

Apart from these dietary, cognitive and health implications, the reviewed data demonstrate that coastal adaptations had a strong influence on the mobility and settlement systems of MSA hunter–gatherers, carrying their own selective advantages. Moving firmly into the ecological niche of coasts opened new landforms as options for occupation and thus demographic expansion. The settlement of coastal environments has consequently been interpreted as an exaptation for modern humans to successfully colonize the rest of the world along a coastal route (Sauer, 1963; Stringer, 2000; Walter et al., 2000; Field and Lahr, 2006; Bulbeck, 2007; Oppenheimer, 2009; Mellars et al., 2013; Erlandson and Braje, 2015). MSA populations were accustomed to the geographic and ecological features of coasts and possessed the knowledge and abilities to acquire food resources efficiently from the surrounding ocean. This increase in behavioral flexibility (Kandel et al., 2015) might have allowed MSA people to adapt successfully to various ecological circumstances and spread quickly along a combination of inland and coastal routes from Africa to the rest of the world (see also Reyes-Centeno et al., 2014; Erlandson and Braje, 2015; Groucutt et al., 2015).

Marean (2014) recently developed a model that emphasizes the impact of coastal adaptations on the social and economic behavior of MSA people. Studies on modern hunter–gatherers show that a consistent use of marine resources is frequently associated with lower mobility, larger group sizes, complex technology, and social differentiation, as marine resources represent a spatiotemporally predictable and dense food (Fitzhugh, 1975; Oswalt, 1976; Yesner, 1980; Keeley, 1988; Kelly, 1995; Binford, 2001; Sealy, 2006). On this basis, Marean (2014) hypothesizes that the commitment of MSA people to coastal landscapes in southern Africa led to increased investment in boundary defense, resulting in an increase of intergroup conflicts, and thus a situation providing an ideal context for the proliferation of cooperative behaviors within populations (*sensu* Bowles, 2009; Bowles and Gintis, 2011).

While this model is largely speculative and consists of a long chain of inferences based strongly on ethnographic analogy, some of these elements can be seen in the MSA record of the southern Cape. Coastal sites such as Blombos, Klasies, Pinnacle Point and Klipdrift, demonstrate intense and potentially year-round occupation, including abstract engravings and shell beads that could have acted as personal or group identity markers (e.g., Henshilwood et al., 2004; d'Errico et al., 2009; Henshilwood et al., 2014). This model does not seem to apply to the MSA archaeological record of the Atlantic, Red Sea and Mediterranean coasts. The evidence for other use, bone tools, abstract engravings, and shell beads from MSA coastal sites from northern and southern Africa agrees, however, with recent hunter–gatherers adapted to coastal ecosystems, showing that they have a complex repertoire of material culture, and a multi-layered connection with coasts and oceans (Oswalt, 1976; Beaton, 1995; Thomas, 2015). Addressing selective advantages, scholars proposed that the emergence of ultra-social behavior in individuals as part of a group selection process could have increased reproductive success over populations not possessing this particular trait (e.g., Richerson and Boyd, 2005).

In conclusion, the archaeological record, combined with data from nutritional, medical and ethnographic studies, shows that the specific nature of MSA coastal adaptations – with their long duration, systematic and consistent character and spatial extension – had ample potential to increase the reproductive fitness of modern human populations via several evolutionary pathways. While we can only infer that coastal adaptations *might* have increased reproductive success of early modern humans in the absence of direct fitness data (or *potential* fitness instead of *realized* fitness after O'Brien and Holland, 1992), the archaeological pattern in space and time strongly supports this: once it originated in one or several independent populations, this set of behavioral traits increased in frequency and persisted consistently over many generations and regions of the African continent. These behaviors likely constituted an important part of the early demographic success and intercontinental migrations of *Homo sapiens*. Coastal adaptations also demonstrably influenced the overall adaptive suite of modern humans during the MSA, including not only their subsistence and diet, but also land use strategies and the socio-cultural organization of groups.

6.3. Bias, limitations and avenues of future research

There are several biases that impact the archaeological record of MSA coastal adaptations. The most important bias derives from the differential preservation of coastal sites. Archaeologists need to acknowledge the loss of potential coastal sites due to global sea-level fluctuations during the Pleistocene (Hendey and Volman, 1986; Van Andel, 1989; Erlandson, 2001; Bailey et al., 2007; Bailey and Flemming, 2008; Bicho and Haws, 2008; Bailey, 2009; Fisher et al., 2010; Gusick and Faught, 2011; Bailey et al., 2015).

As a result, the geographical and chronological pattern of MSA sites with evidence for coastal adaptations that we have discussed here is biased to a certain extent. In order to evaluate coastal adaptations by hominins, it is also of paramount importance to first establish the anthropogenic nature of the collection of the marine remains by analyzing site formation processes and the shellfish assemblages.

Acknowledgment of these biases and other shortcomings helps in contextualizing interpretations (e.g., Erlandson and Braje, 2015), but also reveals and shapes avenues of future research. We identify five areas for future work into early coastal adaptations by modern humans: chronology, geography, environment, species and method. In terms of chronology, research should focus on what happened before MIS 5 and between 50 and 12 ka (MIS 3–2). These temporal gaps in our current knowledge might be partially due to sea-level changes, and could harbor further evidence of systematic coastal adaptations. Regarding geography, the majority of coastlines on the eastern and western side of the African continent remain largely unexplored (Fig. 1). Additionally, research on the behavioral relation between coastal and inland sites should be intensified (cf. Creamer et al., 2011).

In order to correct for chronological and geographical bias in the MSA record, archaeologists will need to focus on the large strips of African coastline that remain *terra incognita* and examine sites that have escaped the global high stands due to their elevation on the modern coastline. Furthermore, researchers can explore coastlines with a steep offshore bathymetric profile and narrow continental shelves or engage in underwater archaeology to search for submerged evidence (Erlandson, 2001; Bailey and Flemming, 2008; Gusick and Faught, 2011; Fisher et al., 2013; Bailey et al., 2015; Erlandson and Braje, 2015).

We have deliberately refrained from including the long and ongoing debate about differences in marine subsistence between MSA and LSA people and its implications (e.g., Klein and Cruz-Uribe, 1996; Parkington, 2003; Jerardino, 2010a; Klein and Steele, 2013; Kyriacou et al., 2015). Many of these studies have inferred that coastal adaptations during the LSA are characterized by more people regularly using a larger variety of marine resources compared to MSA populations, which suggests a different adaptability to coastal ecosystems. That being said, faunal remains of marine birds, fish or crustaceans have not been studied in detail for many MSA sites (Steele and Klein, 2009; Steele and Álvarez-Fernández, 2011), impeding final conclusions. Contextualizing the differences between MSA and LSA coastal adaptations and looking for potential continuities will thus require future work on relevant assemblages with a temporal focus on filling the gap between 50 and 12 ka.

The coastlines of the African continent vary strongly in environmental parameters and bio-productivity. Research should thus pay more attention to the impact of different marine ecosystems on hominin patterns of coastal adaptations – such as species diversity, shore topography, sea surface temperature or tidal amplitude (e.g., Bustamante and Branch, 1996, 1997; Fa, 2008; Kappelman et al., 2014) – in both time and space, as well as the overall environmental underpinnings that shaped past selection forces (cf. Bock, 1980). A full evolutionary account of coastal adaptations will also need to consider interspecies comparisons. As both *Homo sapiens* and *Homo neanderthalensis* made use of marine resources and coastal landscapes, this array of adaptive behavioral traits might either be shared from the most recent common ancestor or reflect independent convergent innovations in each lineage. Detailed comparisons of the specific nature of these coastal adaptations are required to answer this and related questions (e.g. Cortés-Sánchez et al., 2011; Marean, 2014).

Finally, there are methodical issues with regard to coastal adaptations. More formal evolutionary models that encompass quantitative approaches linked to population genetics could be constructed to assess coastal adaptations more thoroughly with regards to reproductive success. Applying such rigorous models decreases the danger of producing a myriad of “just-so” stories (Gould and Lewontin, 1979) regarding the origin, persistence and consequences of coastal adaptations for modern humans. Quantitative evolutionary models combined with nutritional studies could consider what causal effects various additional amounts of certain brain-selective nutrients could have had on brain development, demography, and other aspects of mobile hunter-gatherer groups during the Pleistocene.

We have taken first steps in this direction by providing an evolutionary definition of coastal adaptations, assessing their specific nature during the MSA and proposing falsifiable evolutionary scenarios on this empirical basis. In order to test our hypotheses about the impact of coastal adaptations on the evolution of *Homo sapiens*, more data deriving from an expanded spatiotemporal archaeological and environmental record are needed, just as much as more formal evolutionary models and the integration of nutritional and medical data.

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Characterizing the Late Pleistocene MSA Lithic Technology of Sibudu, KwaZulu-Natal, South Africa

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Abstract

Studies of the African Middle Stone Age (MSA) have become central for defining the cultural adaptations that accompanied the evolution of modern humans. While much of recent research in South Africa has focused on the Still Bay and Howiesons Poort (HP), periods following these technocomplexes were often neglected. Here we examine lithic assemblages from Sibudu that post-date the HP to further the understanding of MSA cultural variability during the Late Pleistocene. Sibudu preserves an exceptionally thick, rich, and high-resolution archaeological sequence that dates to ~58 ka, which has recently been proposed as type assemblage for the “Sibudan”. This study presents a detailed analysis of the six uppermost lithic assemblages from these deposits (BM-BSP) that we excavated from 2011–2013. We define the key elements of the lithic technology and compare our findings to other assemblages post-dating the HP. The six lithic assemblages provide a distinct and robust cultural signal, closely resembling each other in various technological, techno-functional, techno-economic, and typological characteristics. These results refute assertions that modern humans living after the HP possessed an unstructured and unsophisticated MSA lithic technology. While we observed several parallels with other contemporaneous MSA sites, particularly in the eastern part of southern Africa, the lithic assemblages at Sibudu demonstrate a distinct and so far unique combination of techno-typological traits. Our findings support the use of the Sibudan to help structuring this part of the southern African MSA and emphasize the need for further research to identify the spatial and temporal extent of this proposed cultural unit.

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Introduction

Recent archaeological, palaeoanthropological and genetic research demonstrates that modern humans evolved on the African continent. Fossils of modern humans date back as far as 200,000 years ago (= 200 ka), and starting from Africa *Homo sapiens* dispersed to the rest of the world [1–6]. Studies in the African Middle Stone Age (MSA), which dates between ca. 300 and 30 ka, have focused on the biological and behavioral evolution of our species, as well as the geographic expansion of modern humans. The MSA of southern Africa plays a central role in these questions due to its long research history and the wealth of excavated sites [7–9]. Most importantly, southern African MSA sites including Klasies River [10,11], Blombos [12,13], Pinnacle Point 13B [14,15], Sibudu [16,17], and Diepkloof [18–20] provide a long and well-dated chrono-cultural framework.

With documentation of the biological origin of *Homo sapiens* in Africa [1–4], researchers shifted their focus to the MSA, which had been previously neglected, to examine the nature and tempo of cultural change in early modern humans. Since the late 1990s, archaeological finds in the southern African MSA with unexpectedly early dates led researchers to rethink the evolution of modern human behavior. These finds include among others: abstract

depictions on ochre and ostrich eggshell [21–24], ochre processing kits [13], personal ornaments [25,26], bone artifacts [27,28], heat treated artifacts [29], and potentially bow and arrow technology [30]. Due to these discoveries, the African continent and particularly southern Africa has become the center of attention for studying the cultural evolution of *Homo sapiens* [1,5,31] (but see [32–34]).

Many of these early complex elements of the material culture were observed in two sub-stages of the southern African MSA, the Still Bay (SB) and Howiesons Poort (HP). Backed tools and laminar technology characterize the HP, whereas bifacial technology with foliate points mark the SB [35–39]. Scholars often consider these cultural units as indicating advanced cognition and sophisticated socio-economic behaviors of their makers. This view has resulted in a strong research emphasis on the SB and HP [5,40–45]. Some researchers even associate the innovative technological and socio-economic aspects of the SB and HP with subsequent dispersals of modern humans to Eurasia (e.g. [5,46]).

While research has focused on the supposedly unique aspects of the SB and HP, earlier and later periods of the MSA were often considered as unsophisticated, less innovative or conventional in their technology. In this view, the SB and HP represent two short-lived but culturally advanced episodes preceded and followed by

less behaviorally sophisticated phases. Based on this reasoning, some scholars invoke a model of discontinuous cultural evolution in modern humans in which complex material culture appears and disappears abruptly in the South African MSA [41,43,47–51]. Although ecological causes are sometimes cited (e.g. [47,51]), most of the proponents of these ideas call upon demographic collapses to explain their model. As a consequence of this purported depopulation, smaller isolated groups of people lost traditions that were previously shared with other groups over large areas (e.g. [41,50]).

These views have increasingly attracted criticism. Some scholars argue that the proposed model of cultural evolution is overly simplistic [52,53]. Moreover, the current archaeological evidence contradicts this theory: many SB and HP localities such as Diepkloof, Sibudu or Klasies River were not abandoned by the inhabitants afterwards. Instead, people occupied these sites continuously without evidence for stratigraphic hiatuses. Phases of occupation that follow the HP sometimes even exhibit higher intensities of settlement, such as at Sibudu. Additionally, recent synthetic research has found that more sites existed at ~58 ka than during the SB phase [54–57], although differences in settlement systems, taphonomy and discovery biases might influence this measure. Current studies on lithic assemblages from the SB and HP have also documented a higher degree of temporal and regional variability than acknowledged before [35,39,58–62]. At Diepkloof, researchers have argued that both SB and HP occupations date earlier and last longer than at other MSA localities in southern Africa [20]. Based on current evidence, regional and temporal variation occur in all periods of the MSA and the number and occupation intensities of sites post-dating the HP appear to refute hypotheses favoring demographic collapses following this technocomplex.

The focus on the SB and HP remains a problem facing current research on technological variability during the southern African MSA. This emphasis has resulted in a lack of detailed studies for other phases of the MSA in an otherwise well-studied region (see [19,35,39,52,54,60,63,64]). Hence, assemblages from these periods are frequently attributed to informal stages such as “post-HP” or “pre-SB”. Considering this research bias, it comes as no surprise that some scholars consider lithic assemblages after the SB and HP as technologically rudimentary, unsophisticated, or a return to a conventional “pre-SB” MSA [41,47,50,65–67]. Yet, in order to track technological change in the southern African MSA, all of its phases must be studied with the same intensity.

The “post-HP” of Southern Africa and at Sibudu

Regarding the later part of the southern African MSA, lithic assemblages that succeed the HP and fall within MIS 3 comprise the so-called “post-HP” [11,68], “MSA 3” [8] or “MSA III” [10]. At present, these labels act as catch-all categories with little scientific value [54,63,69,70]. For instance, Wadley ([69], p. 2404) summarizes the current view of the “post-HP” as being poorly understood while at the same time regarded as “dark ages” that followed the HP. Even so, many sites from this time period exist in southern Africa, such as Apollo 11, Border Cave, Diepkloof, Klasies River, Klein Kliphuis, Melikane, Sibudu, Sehonghong and Umhlatuzana (see [9,54,71]). They include localities with ephemeral settlements but also with thick occupation sequences (e.g. Sibudu, ca. 1.5 m from ~58–38 ka [68], Klasies River, ca. 1.2 m at ~58 ka [60]).

Finer subdivision of the MSA that follows the HP, covering a period of approximately 30 ka, have been made primarily at sites that feature long sequences from this time span. At Sibudu, for instance, Wadley and Jacobs [68] distinguish the informal phases

“post-HP” (~58 ka), “late MSA” (~48 ka), and “final MSA” (~38 ka). These informal terms, however, have not been applied by other researchers in a uniform manner. In most recent publications, the term “post-HP” is used to address the earlier phases of MIS 3 (ca. 58–40 ka; including “late MSA” assemblages) and “final MSA” – with hollow-based points as characteristic tool forms in KwaZulu-Natal – to denote the following period that ends with the onset of the LSA [9,39,57,64,71].

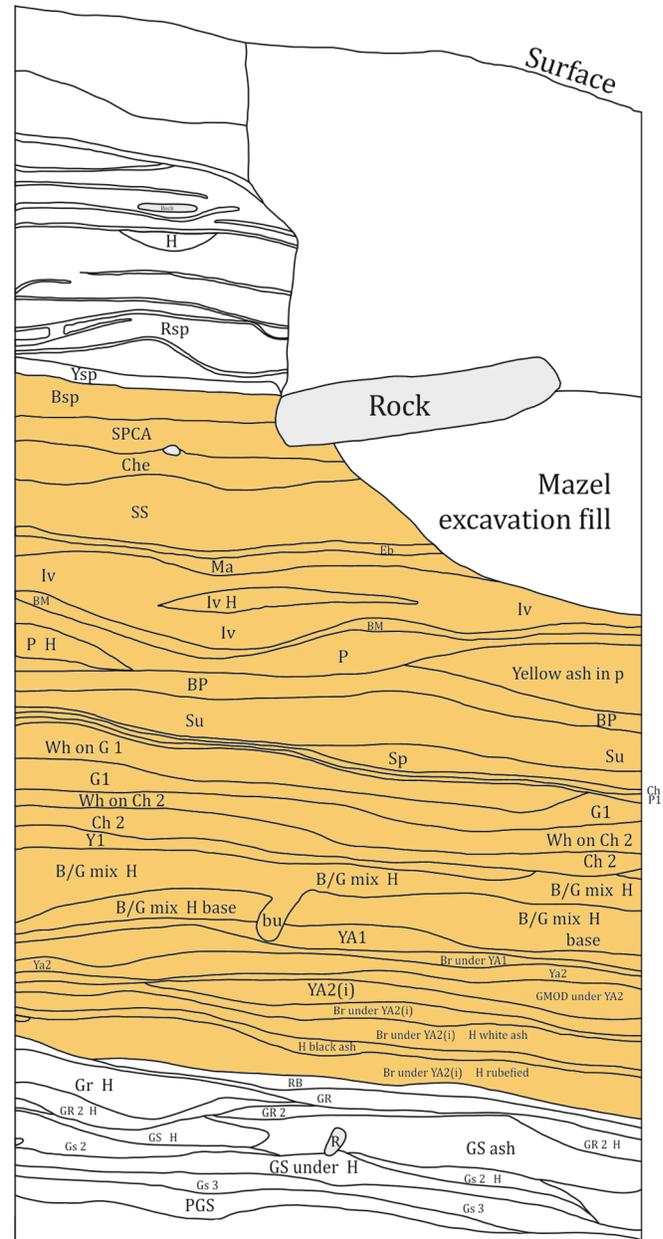
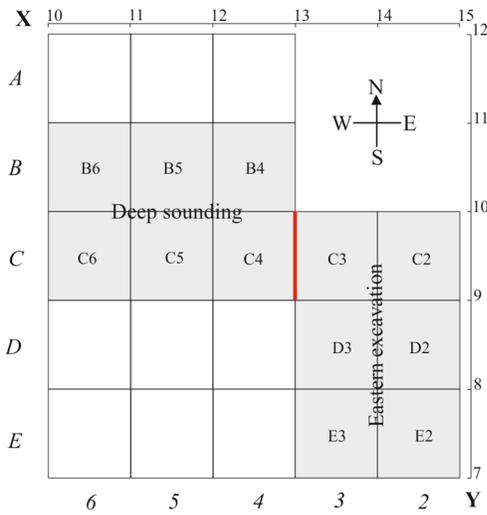
In terms of their geographical distribution, MSA sites postdating the HP occur throughout southern Africa and can be found in various climatic and environmental contexts (see [9,54,71]). A decline in the number and intensity of occupations after the HP in the Western Cape, especially between 50–25 ka (e.g. [19,59,71]), has sometimes been interpreted as indicating low population densities during MIS 3 in southern Africa (e.g. [41,46,48,72], but see [54]). These observations, however, do not correspond to the pattern in the eastern part of southern Africa. Here, the number of sites increases and several localities with thick and rich occupation sequences, such as Umhlatuzana [73,74] or Sibudu [57,63,68], occur during this period (see also [54,71] for discussion and references).

Scholars defined the MSA lithic assemblages that follow the HP for the most part on the basis of what they lack, such as bifacial points or backed pieces, instead of what they contain (see [57,63]). The only unifying characteristics frequently cited for the “post-HP” are a greater variety of flake tools and numerous unifacial points that replace backed artifacts as the principal tool category (e.g. [9,39,60,71]). In our view, the “informal” or “conventional” MSA character that is often attributed to assemblages following the HP derives from a combination of several factors. First, they reflect a wide range of assemblages from different chronological, environmental and techno-economic contexts. Second, the lithic assemblages are often poorly studied and poorly published. Additionally, scholars have frequently mentioned the (near-) absence of engravings, ornaments or worked bone for this period (e.g. [5,39,40,54]). While some of these elements of the material culture occur exclusively in the HP (e.g. engraved ostrich eggshell [23,75]) and their quantity is much higher, assemblages of the “post-HP” in southern Africa have also provided worked bone [28,76], potential engravings on ochre [77] and other elements of complex behaviour (see below).

It is the main objective of this paper to help correct the research bias toward the HP and SB by providing new, detailed data on lithic assemblages that follow these technocomplexes. Our work concentrates on the archaeological site of Sibudu as it constitutes a promising candidate to study the period following the HP. The “post-HP” sequence at Sibudu is approximately one meter thick with more than 30 individual archaeological layers [68]. These finely laminated horizons provide the best stratigraphic record of this period known anywhere on the sub-continent (Figure 1). Archaeological layers at the top and base of this thick sequence have been dated to ~58 ka, providing an exceptionally high temporal resolution. The whole “post-HP” sequence might have accumulated over only a few centuries or millennia [40,57,68].

Recent research on the “post-HP” sequence of Sibudu contradicts notions of large-scale population collapses after the HP. These studies also provide ample evidence for advanced technological behaviors of modern human populations living at Sibudu during this period. The sequence that follows the HP (< 60 ka) exhibits burning events that are frequently stacked, indicating that people made repeated use of hearths and settled more intensively at the site after the HP [70,78–82]. Results from dating and sediment micromorphology support this assertion in showing a higher rate of anthropogenic sedimentation and find

Sibudu, C4 east profile



Sibudu, C3 north profile

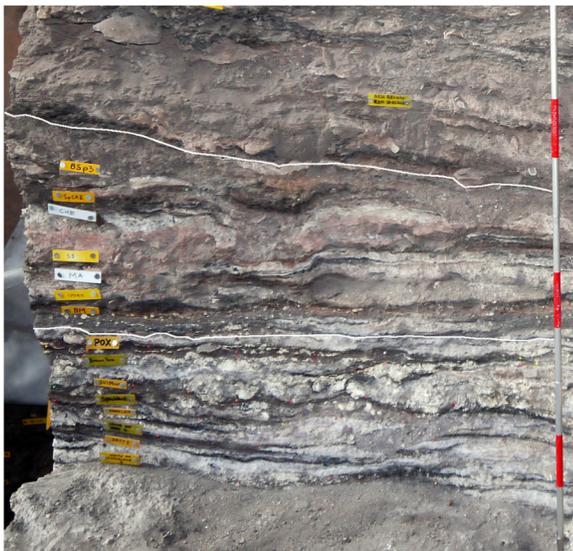


Figure 1. Excavation area and stratigraphic sections of the “post-HP” sequence from Sibudu. Upper left: Excavation grid. The lithic assemblages from the Sibudan come from the “Eastern Excavation”. Right: Sketch of the stratigraphic section of the eastern profile (C4, after Wadley). The complete “post-HP” sequence is highlighted in orange (layers BSP-BR Under YA2). Bottom left: Photograph depicting the stratigraphic section of the northern profile (C3) during excavations in 2013. The white lines mark the seven uppermost layers of the “post-HP”, or Sibudan, sequence from the top of BSP until the bottom of BM. Note the very fine lamination of archaeological layers in different colors caused by frequent combustion features (photograph by M. Will).
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densities in the these layers [63,68,83]. Geoarchaeological analyses document that the inhabitants constructed bedding made from sedges in the “pre-SB”, HP, “final MSA” and “post-HP” layers [80,83,84]. The more frequent occurrence of bedding constructions, burning and other forms of site use and maintenance during the “post-HP” suggests intensified occupations and a change in domestic organization [80,83]. Just as during the SB and HP, people produced ochre powder on-site during the “post-HP”

[69,77] and used it as part of a compound adhesive for hafting stone tools, indicating advanced mental capacities and technical skill [85–90]. A particular phenomenon of the “post-HP” layers are large patches of ground ochre on the cemented ashes of burnt hearths. Wadley [69] argues that these cemented ashes served as work surfaces for the production of ochre powder, suggesting an especially extensive use of this raw material. Bone tools, often cited as markers of cultural complexity [27,91,92], occur in the “Pre-

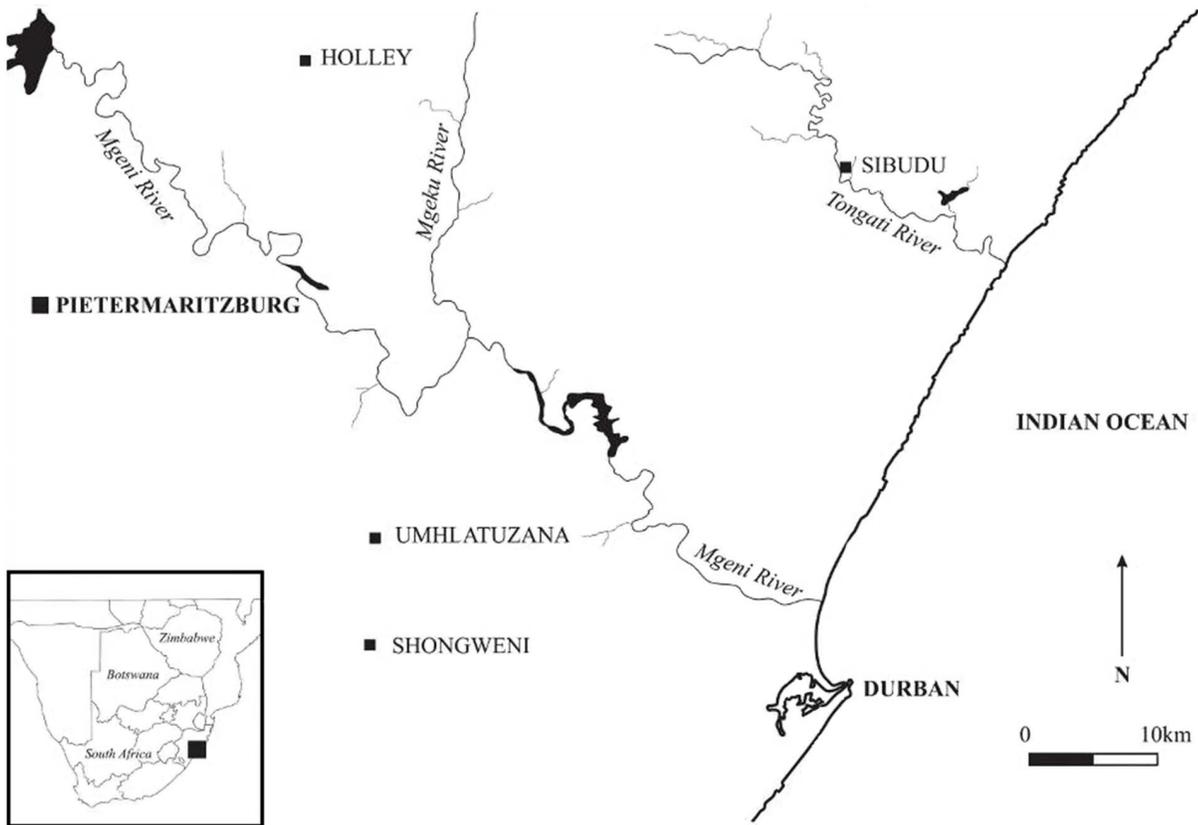


Figure 2. The archaeological site of Sibudu. Geographic location of Sibudu in KwaZulu-Natal (top, after [68]) and view on the excavation area within the rock shelter (bottom; photograph by M. Ecker).
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SB”, SB, HP and “post-HP” assemblages. The “post-HP” yielded two notched pieces, one smoother, one splintered piece, and one pressure flaker [28,76].

On the basis of these features and an analysis of the highly structured and characteristic tool assemblages, Conard, Porraz and Wadley [63] recently proposed Sibudu as the type locality of a new sub-unit of the MSA, the “Sibudan” [63] which is not identical with the “Sibudu technocomplex” proposed by Lombard *et al.* [9]. They ([63], p. 181) justified the naming of a new sub-unit of the MSA on the basis that “informal terminology is untenable, because it implies that material cultural remains can be characterized by what they are not, rather than by their positive characteristics”. Conard *et al.* [63] distanced themselves from the informal “post-HP” and proposed the term Sibudan for the assemblages they studied, based on positive features. They stress that the Sibudan is not intended as a one-to-one equivalent of the “post-HP” of southern Africa, which would simply be replacing one label with another. Instead, the term is used to organize the many excavated assemblages from Sibudu, with these high-quality lithic data providing a point of comparison for further research. Conard *et al.* ([63], p. 181) also emphasize “that defining a new cultural taxonomic unit is a process” and they recommend conducting additional research to evaluate the viability of this term. In conclusion, they proposed the Sibudan as an organizational unit that constitutes a first step towards the nomenclature for the cultural sequence after the HP. We thus regard the Sibudan as a cultural-taxonomic unit that needs better characterization and contextualization in order to test its utility.

While Conard *et al.* [63] studied the tool assemblages and proposed a working model to characterize them, complete data was not then available on other technological aspects of these lithic assemblages. Here, we present our findings from a detailed technological analysis which are crucial to define the key elements of the Sibudan lithic technology and evaluate its short-term diachronic variability. With this approach we intend to further the understanding of technological variation during the Late Pleistocene MSA of southern Africa and provide a high-resolution empirical basis for comparative work. We also investigate the utility of the Sibudan as a possible cultural-taxonomic unit to help organize the sequence after the HP, by comparing our findings with lithic assemblages from other localities of this time period.

Materials and Methods

The archaeological site of Sibudu is a large rock shelter situated above the Tongati River (also spelled “uThongathi”) in KwaZulu-Natal approximately 40 km north of Durban and 15 km from the Indian Ocean (Figure 2). The locality has yielded a rich archaeological sequence with deposits that span a time range of >75–37 ka [17,68,70,78]. Sibudu is one of the few sites in South Africa that has yielded evidence for both SB and HP occupations, as well as the periods before and after [40,63,78]. The long-term excavations by L. Wadley provide a sound stratigraphic framework [17,68]. The archaeological layers discussed here are almost completely anthropogenic, show little post-depositional disturbance and feature good organic preservation [70,79,80]. New field work at Sibudu has been carried out by a team of the University of Tübingen under the direction of N. Conard since 2011, building on the previous excavations by L. Wadley. The research permit to conduct archaeological excavations at Sibudu is issued under the KwaZulu-Natal heritage Act No. 4 of 2008 by Amafa AkwaZulu-Natali and is valid until December 2017. The permit holder is Nicholas Conard of the University of Tübingen (permit number: REF: 0011/14; 2031CA 070). All recovered archaeological

specimens are permanently stored at the KwaZulu-Natal Museum in Pietermaritzburg (South Africa, 237 Jabu Ndlovu Street).

During the excavations we adopted Wadleys stratigraphic system and layer designations (see [68] Tab. 2) and added systematic 3D piece plots of all classes of archaeological materials with a total station to the field methods. In each quarter meter, excavation proceeded in 2–3 cm thick *Abträge* that followed the slope of the sediments and never crosscut geological strata. The maximum volume of one *Abtrag* was a 10-liter bucket of sediment. These *Abträge* constitute the smallest time unit we discern at Sibudu and sometimes equal defined archaeological strata. We chose archaeological layers as the units to analyze the lithic assemblages as they constitute the best basis for inter-assemblage comparisons.

For this study, we analyzed the lithic assemblages from the 7 uppermost layers BM-BSP of the “post-HP” sequence from an area of 6 m² (ca. 1.5 m³ of sediment; Figure 1), that we excavated in three seasons between 2011–2013. The results for six of these assemblages are presented in the following, with one layer (SS) being excluded due to the low number of lithic artifacts (n<100). The assemblages contain a total of 59,390 stone artifacts, with 2,649 pieces >25 mm and 56,741 small debitage products < 25 mm (Table 1). For a detailed characterization of the technology of these assemblages, we examined the procurement and use of lithic raw materials, investigated reduction sequences, evaluated the methods and techniques of reduction and performed typological and techno-functional analyses of tools.

We examined all stone artifacts >25 mm individually, combining attribute analysis and reduction sequence approaches. Attribute analysis quantifies the various traces on lithic artifacts that result from the knapping process and records metric traits in order to reconstruct technological behavior [93–97]. In addition to observations by hand lenses we sometimes used light microscopy. Our qualitative investigation follows the concept of *chaîne opératoires* [99–100] or reduction sequences [101–103]. This approach studies the methods of core reduction and the stages of lithic manufacture that people performed at the site. We also conducted quantitative analyses on samples of the small debitage products to calculate raw material proportions and frequencies of retouching activities.

As the method of core reduction constitutes an essential point in characterizing the technology of MSA people, and description of core types should be comparable between sites, we employed the unified taxonomy by Conard *et al.* [104]. We analyzed the tool inventories of the lithic assemblages with regards to typological, technological and techno-functional aspects. Although researchers have legitimately criticized the traditional typological approach to retouched artifacts [105–108], a list of defined tool types still provides a broad means of comparison between different sites and technocomplexes. We recorded tool types with a special recognition of the typology of the southern African MSA (*cf.* [109–112]). Most importantly, scholars in South Africa have defined “unifacial points” in a very broad sense which include a wide range of convergent and pointed forms with both marginal and invasive retouch. A unifacial point in this definition may be the equivalent of a convergent scraper, a marginally retouched Levallois point, or a triangular flake that was modified at the distal tip only [63,111,112].

Conard *et al.* [63] recently published a novel classification scheme for tools in the Sibudan based on a techno-functional method that differs from traditional typological (“type fossil”) approaches. This new procedure was devised, among other reasons, to organize assemblages rich in unifacial points, as the very broad definitions of unifacial points in South Africa obscure subtle morphological and metric differences. The new classifica-

Table 1. Distribution of single finds (>25 mm) and small debitage (<25 mm).

Layer	Single finds	Small debitage	Total lithics
BSP	822	13644	14466
SPCA	578	10019	10597
CHE	133	2792	2925
MA	178	4421	4599
IV	676	20389	21065
BM	262	5476	5738
Total	2649	56741	59390

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tion scheme rests mainly on an emphasis of the reduction and transformation of tool types that are usually treated as static entities [105,107,113]. In addition, they [63] employed a techno-functional approach (*sensu* [114–117]), which divides tools into a transformative, prehensile and intermediate part and studies the treatment of these portions separately. Upon these methods, Conard *et al.* [63] classified tools based on the identification of specific patterns of repetitive retouch on different parts of the tool which indicate formal and distinct retouching cycles. On these grounds, several tool classes and tool cycles were defined, including two categories that would usually be subsumed under the label unifacial points: “Tongatis” (Figure 3) and “Ndwedwes” (Figure 4). Conard *et al.* ([63]) provide further descriptions and depictions of these tool classes and their retouch cycles, including naturally backed tools (NBTs; Figure 5: 1–6). This new tool taxonomy presents a working model that needs to undergo critical appraisal with additional techno-functional, use wear and residue analyses.

In 2013, we recognized asymmetric convergent tools (ACT) as an independent tool class and retouch cycle among our enlarged sample of unifacial points of which the majority was originally classified as Tongatis. The main characteristic of ACTs is the eponym asymmetric and convergent distal end. It is formed by one convex retouched edge and one opposing straight edge which is frequently not retouched (Figure 5: 7–10). Additionally, most ACTs exhibit steeper retouch on the convex lateral, creating a blunt edge. The opposite straight edge features a sharp feathered termination. The cross-sections of ACTs are mostly asymmetric and often exhibit a thick ridge near the convexly retouched lateral edge. From our preliminary observations of the different varieties of these specimens and their reduction stages ($n = 38$), ACTs appears to change only at their initially unretouched working edge, where use-wear and edge damage accumulate continuously, thus decreasing the width of the piece during their tool cycle.

We analyzed flaking efficiency and reduction intensities for assemblages and individual raw materials as additional technological and techno-economic measures. Flaking efficiency measures the efficiency by which a knapping strategy converts a mass of stone into flake edge [118–120]. It is calculated for complete blanks by dividing edge length by mass. Higher values indicate a more efficient use of raw materials within assemblages. We use this measurement as it provides “an effective means of tracking technological change” ([120] p. 620). The reduction intensity of assemblages can have a strong influence on their technological and typological parameters. We thus examined it in two separate ways. For one, the ratio of blanks to cores provides a rough approximation. The higher the ratio, the more intense has an assemblage been reduced (e.g. [121]). Secondly, the intensity of

core reduction can be measured by average core and flake length or thickness. Assemblages with shorter or thinner flakes and cores are more heavily reduced, assuming that knappers used nodules with consistent starting size [121,122].

Results

Raw Material Procurement

Knappers at Sibudu used a variety of lithic raw materials. Results of previous studies [58,123] suggest that they can be divided into two categories. The majority consists of local raw materials, including dolerite, quartzite, milky white quartz and sandstone. Non-local raw materials are mainly represented by hornfels, with rare pieces of jasper and crypto-crystalline silicates (CCS; Figure 6).

The local dolerite is an igneous granular-appearing rock that varies significantly in grain-size and mineral composition. In general, it is a hard, rough and homogeneous raw material. Dolerite occurs mainly as tabular slabs in sills and dykes. A dolerite intrusion into the sandstone cliff is located only a few hundred meters away from Sibudu. Further potential sources are a large number of dolerite dykes and sills in the near-by Dwyka tillite and the Pietermaritzburg Formation [123,124]. The sandstone presumably derives from local resources, as the shelter itself is part of the Natal Group sandstones. However, people during the MSA also used sandstones that appear to be finer-grained than the shelter wall. The inhabitants of Sibudu collected most of the milky white quartz and quartzite from the Tongaati River where these raw materials still occur today [123]. Our own observations of frequent smoothed and rounded pebble cortex on these materials support this assertion.

Hornfels (metamorphosed shale) constitutes the finest-grained material used at Sibudu. It is dark-grey to black, dense, massive and has a high silica content. The hornfels shows favourable knapping characteristics and produces sharp but potentially fragile edges. Hornfels of the quality found in the MSA assemblages is not present in the direct vicinity of Sibudu today. The closest known outcrop of hornfels occurs in the Verulum area ~15–20 km south of the site [123].

Knappers mainly used dolerite and hornfels for producing stone artifacts throughout BM-BSP, with a combined frequency of > 93% for each assemblage (Table 2). Out of these two, dolerite dominates in all layers. Other raw materials like quartzite, quartz or sandstone never reach more than 5% abundance. CCS and jasper occur only in a few assemblages (CCS: BSP, SPCA; jasper: MA, IV) and in very small amounts (<1%). The inhabitants used principally the same range of raw materials throughout the sequence, and there is little diachronic variability in their

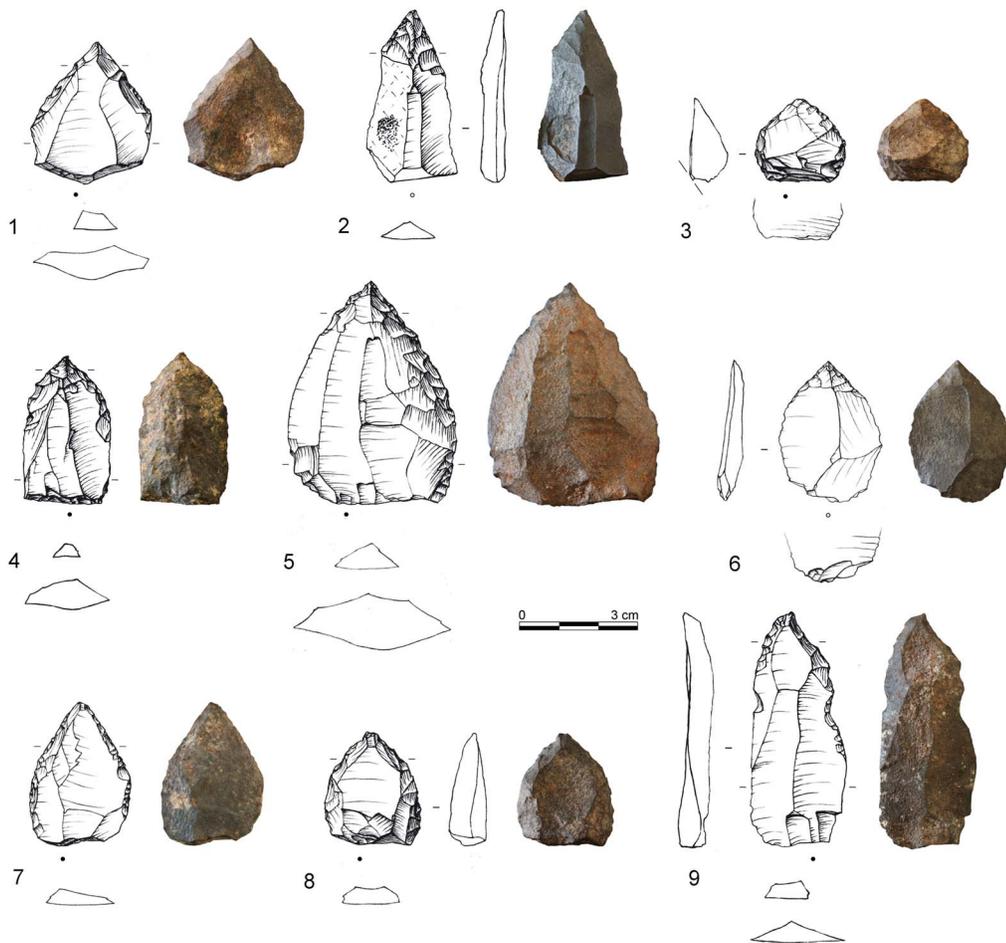


Figure 3. Examples of Tongatis from BM-BSP. 1: IV, dolerite, D3-532.1; 2: BSP, hornfels, E3-8.6; 3: IV, dolerite, C3-631.2; 4: BM, dolerite, E2-444; 5: IV, dolerite, E3-665; 6: BM, hornfels, E3-737; 7: IV, dolerite, D3-435; 8: IV, dolerite, E3-584; 9: BM, dolerite, D2-434. Drawings by F. Brodbeck and G. Porraz; photographs by G. Porraz. After [63] Fig. 7. doi:10.1371/journal.pone.0098359.g003

abundance (Figure 7). The amount of dolerite as dominating raw material ranges between 58% (SPCA) and 69% (BM). The percentage of non-local hornfels varies between 25–38% and correlates negatively with the proportions for dolerite. The successive layers BM and IV exemplify this pattern, in which an increase in hornfels leads to a drop in dolerite and *vice versa*. Local raw materials always outnumber non-local ones, with the later accounting for roughly a third of the assemblages. In sum, we observe consistency in the choice and range of raw materials, including abundant import of non-local tool stones, with some temporal differences in the frequency of their use.

Technological Aspects

Debitage analysis. A quantitative analysis of debitage products demonstrates that unretouched blanks constitute the main category of stone artifacts in all layers (>69%; Table 3). Angular debris and especially cores (~2%) are rare. The most remarkable feature of the assemblages is their extraordinarily high proportion of retouched lithics compared to other MSA sites which are often characterized by less than 2% tools (e.g. [11,109]). Tools account for an average of 21% of the analyzed stone artifacts >25 mm. The percentage of retouched specimens ranges between 17% (BSP) and up to 27% (MA), showing a consistent signal of abundant retouching activities (Figure 8).

Blank production. Flakes constitute the most frequent type of blanks produced (~70%; Table 4). At the same time, blades and convergent flakes mark an important and persistent aspect of all assemblages (Figure 8). The proportion of blades varies between 11–20%, with convergent flakes being slightly less abundant (9–16%). There are clear sequences for the production of flakes, convergent flakes and blades, but not for bladelets. Most of the bladelets ($n=9$; 0.4%) appear to be by-products of the laminar system that focussed on the manufacture of blades. The unimodal distribution of blade widths in all assemblages (Figure 9) and the lack of bladelet cores, with the exception of BSP and SPCA, support this interpretation (see *core reduction*). Throughout the sequence, a consistent proportion of about a third of the blanks is complete. Among the blank fragments, we found a particularly high proportion of longitudinal breaks (20–30%).

Knappers manufactured blanks that are relatively large. On average, (convergent) flakes are ~40–42 mm long, occasionally exceeding 70 mm. The average length of blades is 48 mm with a width of 19 mm. Throughout the sequence, (convergent) flakes become increasingly larger. The oldest assemblage BM yields the smallest pieces, while the uppermost units SPCA and BSP demonstrate the largest ones. There is, however, no strong difference in their width or shape (length/width ratio). In contrast to these blank types, blades from all layers exhibit similar metric

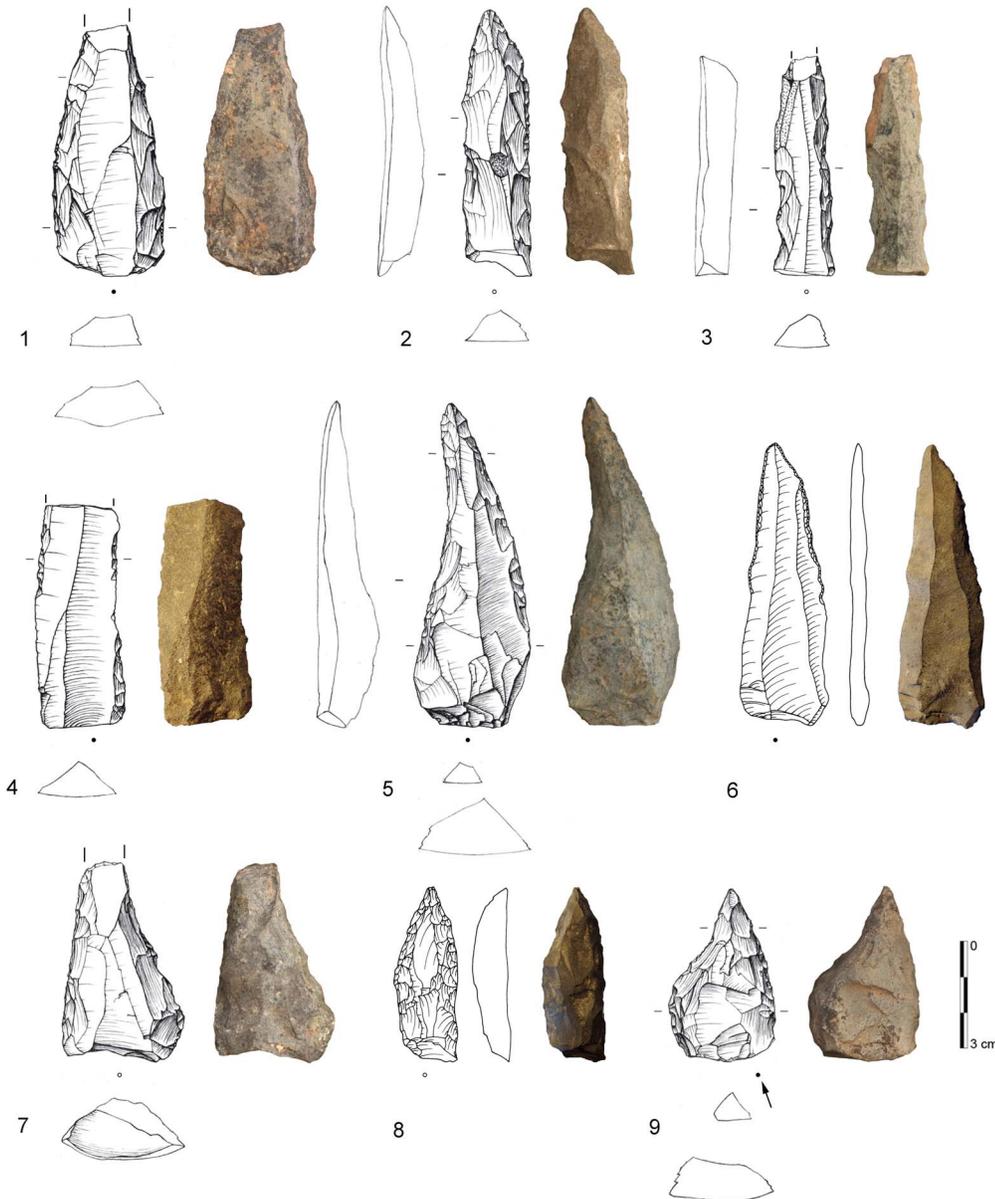


Figure 4. Examples of Ndwedwes from BM-BSP. 1: IV, dolerite, D3-460; 2: IV, dolerite, E2-322; 3: IV, dolerite, E3-521; 4: BSP, dolerite, D3-51; 5: IV, dolerite, D3-546; 6: BSP, hornfels, D2-77; 7: MA, dolerite, D2-293; 8: BSP, hornfels, D3-114; 9: SPCA, dolerite, E3-409. Drawings 1–5, 7, 9 by F. Brodbeck and G. Porraz; drawings 6 & 8 by M. Malina; photographs by G. Porraz. 1–3, 5, 7, 9 after [63] Fig. 11. doi:10.1371/journal.pone.0098359.g004

dimensions and length/width ratios of 2.5:1. These observations suggest that the inhabitants followed a uniform approach to produce blades with standardized dimensions and shapes. The unimodal distribution of blade widths, clustering around 18–20 mm, supports this assertion (Figure 9).

Core reduction. The most frequent core types are parallel ($n=23$) and platform ($n=19$) variants (Table 5). Among the remaining specimens there are three inclined, three bipolar, and four indeterminate broken cores. In total, the sample of cores is small for most assemblages. The uppermost layers BSP and SPCA show a strong dominance of parallel and platform cores, as does layer IV (Figure 10: 1–6; 8–11). All assemblages but MA feature parallel cores, many of which can be attributed to a Levallois system of reduction (*sensu* [98,125,126]). Inclined core variants, for the most part showing a discoid reduction method (*sensu*

[125,127]), occur exclusively in BSP and IV (Figure 10: 7). Only BSP features bipolar cores ($n=3$). Most of the cores show traces from the production of flakes ($n=31$), followed by blades ($n=14$), bladelets ($n=5$) and convergent flakes ($n=2$). All bladelet cores are derived from the two uppermost layers BSP and SPCA (Figure 11). However, the majority of cores is heavily reduced and thus provides only limited information from the final stages of core reduction. In order to overcome these shortcomings and gain a better understanding of the core reduction systems in layers BM-BSP, we studied the geometry and configuration of dorsal negatives on debitage products and cores in more detail. Three coexisting strategies of core reduction characterize the assemblages: Parallel (mostly Levallois), platform, and inclined (discoid).

Parallel cores occur frequently. They are characterized by two hierarchical, asymmetric and non-interchangeable surfaces, some-

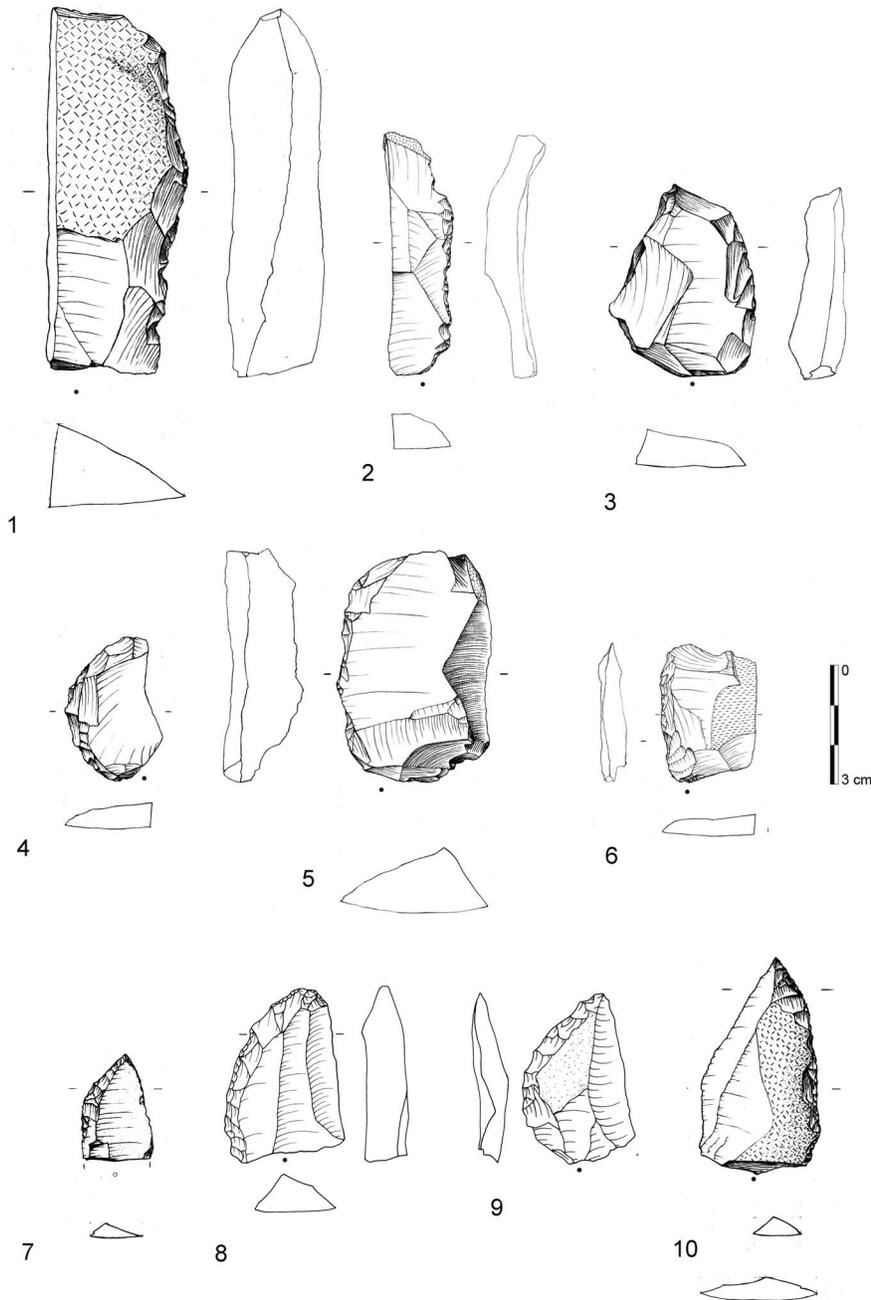


Figure 5. Naturally backed tools (1–6) and asymmetric convergent tools (7–10) from BM-BSP. 1: IV, dolerite, C3-392; 2: BSP, hornfels, C3-21; 3: IV, dolerite, E2-310; 4: IV, dolerite, E2-392; 5: BSP dolerite, D3-113; 6: SPCA, hornfels, E3-664; 7: BSP, hornfels, E3-38.2; 8: SPCA, dolerite, C2-237; 9: IV, dolerite, D3-371; 10: BSP, dolerite, E3-44. Drawings 1–7, 10 by F. Brodbeck and G. Porraz; drawings 8 & 9 by M. Malina. 1–5 after [63] Fig. 12. doi:10.1371/journal.pone.0098359.g005

times with intense preparation of the striking platform (Figure 10: 1–6). The side of the core opposite to the removal surface is either steeply prepared or covered with cortex. Knappers prepared the lateral and distal edges of the core with centripetal removals to create a convex removal surface. Both end products and core rejuvenation flakes occur for this reduction strategy. The products of this system include (convergent) flakes which are longer than wide but also blades. Platforms of these products are often faceted. The (convergent) flakes are mostly flat, have feathered terminations, and exhibit exterior platform angles (EPA) that are typically $>80^\circ$. The majority of the parallel cores, flakes and

maintenance products demonstrates unidirectional recurrent (Figure 10: 1, 2) or centripetal removals (Figure 10: 3, 5, 6). Knappers also removed blades in a unidirectional and recurrent manner from the parallel cores. These products are mostly flat and frequently exhibit faceted striking platforms.

The second strategy of core reduction that we observed is a platform method aimed at the production of blades (Figure 10: 8, 9), flakes (Figure 10: 10, 11) and bladelets (Figure 11). Knappers often set up multiple striking platforms with several removal surfaces and rotated the core during reduction. They reduced the platform cores from both broad and narrow surfaces. The blades

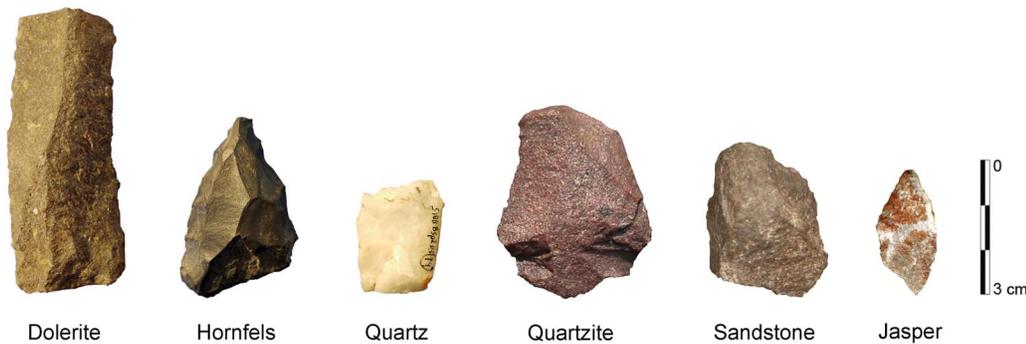


Figure 6. Selection of raw materials used by knappers in BM-BSP. Photographs by G.D. Bader.
doi:10.1371/journal.pone.0098359.g006

from these cores are characterized by plain striking platforms, an average width of ca. 19 mm and regular parallel edges. Most of the blades show recurrent unidirectional removals on the dorsal surface, but bidirectional patterns occur in lower numbers as well. From the six studied assemblages, only BSP ($n = 4$) and SPCA ($n = 1$) yielded cores for the production of bladelets (Figure 11). These cores demonstrate plain striking platform from which several bladelets are struck in a recurrent manner from one removal surface. The bladelet products are largely missing in BSP and SPCA.

A small number of cores and blanks also attests to the existence of an inclined reduction strategy with non-hierarchical and interchangeable surfaces without platform preparation, which appears to be confined to dolerite. Knappers reduced these cores by alternating removals from both surfaces around the entire circumference (Figure 10: 7). Products of this reduction sequence include the characteristic and frequent core edge flakes, in which the roughly triangular blank preserves part of the steep circumference of the discoid core on one lateral edge. The other main products of this method are short quadrangular flakes with inclined dorsal negatives and low EPAs ($< 80^\circ$).

In addition to these three main systems, we observed bipolar knapping on a few cores and flakes. This system of core reduction, however, occurs in very low frequencies and does not appear to be as structured and frequent as the other three methods. Furthermore, a total of 13 splintered pieces indicate a bipolar use of these specimens (*cf.* [128]).

Knapping technique. The inhabitants at Sibudu employed different knapping techniques depending on the blank type they produced. In all assemblages, flakes and convergent flakes were predominantly knapped using a hard stone hammer with direct and internal percussion. These products demonstrate an average platform thickness of around 6 mm in each assemblage ($n = 1241$) with very few butts thinner than 2 mm (4%). Bulbs are very frequent (72%) and often strongly developed with visible contact points or cones of percussion. Lips occur in low frequency (10%) and EPAs cluster around $85\text{--}90^\circ$. The high frequency of longitudinal breaks on flakes is also consistent with strong forces exerted by hard stone hammers that had direct contact with the core.

The knappers used a different approach to the production of laminar products. Based on approaches of previous studies [35,129], we recorded a list of attributes and measurements on blades for each assemblage (Table 6). The analyzed sample amounts to 393 blades. The results show that bulbs are abundant (60%) but poorly developed. Proximal lips occur frequently (24%) and shattered bulbs constitute an even more common feature (31%). The blades feature prepared platforms (faceted 17%,

dihedral 5%), but the majority of butts are plain (44%) or crushed (26%). Blade platforms are relatively thick with an average of 5.0 mm and a modal value of 3.0 mm. The EPAs cluster around 80° . We frequently observed contact points on the blades but almost no platform abrasion. Knappers often trimmed the proximal edges by small overhang removals prior to the production of a blade.

In summary, the discrete and metric attributes indicate that knappers predominantly used a soft stone hammer with direct internal percussion to produce blades. The abundance of shattered bulbs and contact points, the frequent occurrence of poorly developed bulbs and proximal lips, and the range of EPAs are consistent with results from experimental knapping with soft stone hammers [129,130], although these experiments were performed on flint. A marginal percussion movement can be ruled out by the low frequency of platforms < 2 mm (6%) and the lack of platform abrasion prior to blade removal. The fact that all four hammerstones found in BM-BSP are out of sandstone supports our findings.

Flaking efficiency and reduction intensity. We found a strong temporal trend in the diachronic comparison of flaking efficiencies (Figure 12). The oldest layers BM and IV yield the highest values for flaking efficiencies. In contrast, the minimum values come from the youngest levels BSP and SPCA, suggesting that knappers made less efficient use of stone materials in these assemblages.

Concerning the reduction intensity of the assemblages, there is a clear separation between two groups for the ratios of blanks to cores. Highly reduced assemblages include BM and MA with values of 123:1 and 66:1. In contrast, BSP, SPCA, CHE and IV yield consistent blank to core ratios that are far lower (33–38:1). Due to the low number of cores in some of the assemblages, these results need to be considered with caution. We thus also analyzed the sizes of flakes and cores, finding a consistent increase through time. The oldest assemblages BM and IV yield the smallest and thinnest blanks and cores, while the youngest assemblages (e.g. BSP, SPCA) demonstrate larger and thicker specimens. Blanks > 80 mm occur only in the uppermost assemblages. Hence, the inhabitants at Sibudu reduced their lithic raw material more intensively in the earlier assemblages compared to the younger ones.

Tool Assemblages

From a traditional typological point of view, unifacially retouched points characterize the six studied Sibudan assemblages (Figure 13). Unifacial points ($n = 277$) make up half of all modified pieces ($n = 555$) and constitute the most frequent tool type in each

Table 2. Distribution of raw materials.

Layer	Dolerite	Hornfels	Sandstone	Quartzite	Quartz	Jasper	CCS	TOTAL
BSP	535 (65%)	262 (32%)	11 (1%)	8 (1%)	5 (1%)	-	1 (0%)	822
SPCA	333 (58%)	222 (38%)	11 (2%)	9 (2%)	2 (0%)	-	1 (0%)	578
CHE	79 (59%)	50 (38%)	4 (3%)	-	-	-	-	133
MA	111 (62%)	58 (33%)	4 (2%)	3 (2%)	1 (1%)	1 (0%)	-	178
IV	406 (60%)	235 (35%)	21 (3%)	6 (1%)	-	8 (1%)	-	676
BM	181 (69%)	66 (25%)	12 (5%)	2 (1%)	1 (0%)	-	-	262
Total	1645 (62%)	893 (34%)	63 (3%)	28 (1%)	9 (0%)	9 (0%)	2 (0%)	2649

Rounded percentages are given in brackets.
doi:10.1371/journal.pone.0098359.t002

assemblage ranging between 38–54% (Figure 14; Table 7). They are followed by far fewer scrapers (17%) and lateral retouch on blades (8%). Other tool types that are usually frequent in MSA assemblages, like notches, denticulates, or splintered pieces, occur rarely (<3%). In some layers, these implements are absent (e.g. BM and CHE). Layers BM-BSP yield only 4 backed tools or segments (Figure 13: 1, 2) and 3 bifacial points. There is a marked increase of scrapers in the upper layers BSP-MA (17–24%) compared to the oldest assemblages IV (13%) and BM (12%). In general though, the range and frequency of tool types is homogenous.

From a techno-functional point of view, four formal tool classes and tool cycles characterize BM-BSP (see Figures 3–5): Tongatis, Ndwedwes, naturally backed tools (NBT), and asymmetric convergent tools (ACT). The four formal tool classes make up more than two thirds in each assemblage (67–77%; Table 8). Throughout the sequence, Tongatis are the most abundant tool class (27–42%), followed by Ndwedwes (16–25%). Tongatis and Ndwedwes thus constitute the hallmark of formal tools in BM-BSP, representing >50% of each assemblage with a combined total of 301 pieces (Figure 14). NBTs (Figure 5: 1–6) and ACTs (Figure 5: 7–10) occur in low but stable frequencies throughout the sequence (NBTs: 6–14%; ACTs: 3–9%). Other formal tools, comprising various forms of scrapers, denticulates and notches, play a minor role (3–13%).

We also examined technological aspects to assess the approach of knappers to execute retouch. The inhabitants preferentially selected elongated (18.5%) and convergent forms (33.5%) for secondary modification (Table 9). Still, most tools are made on regular flakes (48%). The knappers applied retouch predominantly to the dorsal side of the blanks (93%) and only in rare instances on the ventral side (3%) or bifacially (4%). Small stepped negatives are the most abundant type of modification on tool edges. Many times the retouch on tools is intense and invasive, with several layers of small overlapping negatives. The modification often covers long parts of the artifact edges, indicating abundant retouch and recycling activities taking place on-site. Concerning the preservation of tools, only a third is in complete state.

Reduction Sequences

We characterized reduction sequences for the different raw materials within each assemblage. In general, both the local dolerite and the non-local hornfels show complete reduction sequences, with products of all manufacturing phases present, indicating their on-site production. Having said this, hornfels exhibits a strong emphasis on the production, resharpening and curation of tools. In contrast to dolerite and hornfels, quartzite, jasper and CCS typically occur in the form of isolated blanks and tools. Sandstone and quartz are only represented by the early stages of knapping. For the latter, there are many cores (n = 3) compared to the few debitage products, suggesting that people exported quartz artifacts to other places in the landscape.

We analyzed the reduction sequences in more detail for the largest assemblage BSP including all artifacts >25 mm (n = 822). BSP mirrors the general observations previously discussed very closely. Dolerite exhibits all stages of the knapping process in relatively large numbers (84% blanks, 2% cores, 11% tools) with some highly cortical products from the earliest phases of reduction. Hornfels displays an emphasis on the distal reduction phases (66% blanks; 29% tools) and an underrepresentation of early manufacturing stages. Quartzite, sandstone and CCS appear in very low numbers and exclusively as finished blanks and tools. The early stages of production for these raw materials presumably occurred off-site during their procurement and previous use. The five quartz

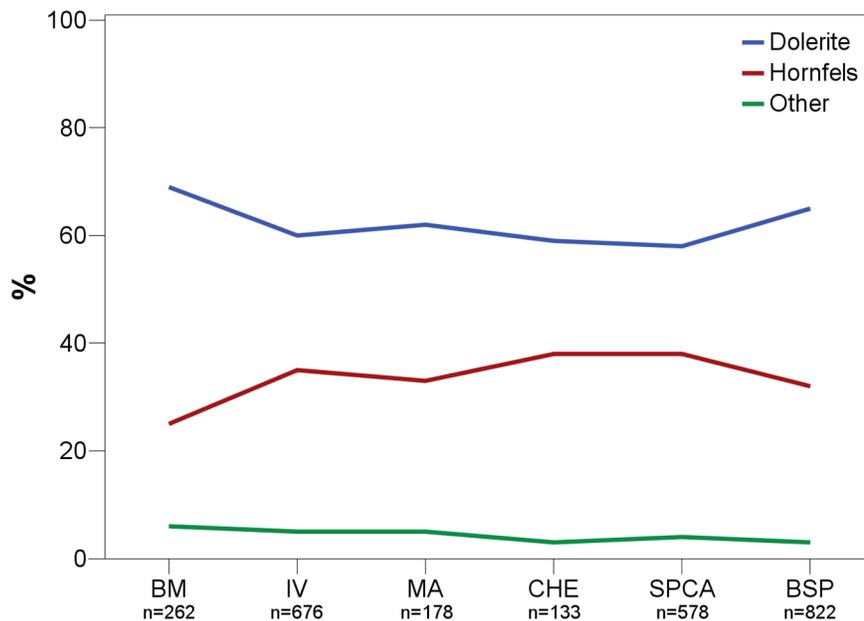


Figure 7. Percentual abundance of raw materials throughout BM-BSP. BM = oldest layer; BSP = youngest layer.
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artifacts from BSP include three cores but only two unmodified flakes, demonstrating an apparent lack of debitage products. The existence of a quartz bladelet core (Fig. 10: 1) and the absence of the corresponding bladelets in BSP support the observation that the inhabitants of Sibudu transported quartz artifacts outside the area of excavation.

Quantitative data support the qualitative observations of reduction stages taking place at Sibudu. The proportion of cortex on an artifact, whether from an outcrop or pebble source, can inform on its position in a reduction sequence as cortex cover decreases in a more or less continuous manner during the knapping process [93,131,132]. We assessed cortex on each artifact in increments of 20% from completely non-cortical (0%) to fully cortical (100%) and compared the results between layers and raw materials. In general, all Sibudan assemblages show a similar pattern in which all classes of cortex cover occur (Table 10). Non-cortical specimens amount to ~60–65%. The number of artifacts per increment class decreases gradually with higher cortex proportions. While there are many cortical specimens (>50%), fully cortical artifacts are rare (0–2%), suggesting that the initial

stages of decortification took place off-site. There are some assemblages with more cortical pieces (e.g. CHE, MA) than others (e.g. BSP, BM), but there is no consistent diachronic trend.

We also compared the cortex cover of artifacts made from dolerite and hornfels (Table 10). In general, both dolerite and hornfels show all proportions of cortex in each assemblage, indicating complete reduction sequences that took place on-site. For hornfels, however, there are more non-cortical specimens whereas dolerite exhibits more highly cortical artifacts (>50%). Only BSP and SPCA yielded enough quartzite specimens to roughly assess its cortex frequencies. In BSP and SPCA combined, only 1 out of 19 specimens show any amount of (pebble) cortex, indicating that knappers reduced quartzite mostly off-site.

In order to study the retouch and curation activities of the inhabitants, we quantified the retouch debitage among the small debitage for each raw material (<25 mm; see [63,133]). We analyzed a sample of small debitage from each assemblage (total $n=8193$). On average, retouch flakes amount to ~16% ([63], Tab. 3). The percentages fluctuate between 10–25%, suggesting extensive retouch and curation activities performed on-site

Table 3. Quantitative debitage analyses of the main lithic categories.

Layer	Blank	Tool	Core	Angular debris	TOTAL
BSP	640 (78%)	139 (17%)	19 (2%)	24 (3%)	822
SPCA	453 (78%)	104 (18%)	12 (2%)	9 (2%)	578
CHE	99 (74%)	29 (22%)	3 (2%)	2 (2%)	133
MA	123 (69%)	48 (27%)	1 (1%)	6 (3%)	178
IV	473 (70%)	179 (26%)	14 (2%)	10 (2%)	676
BM	196 (75%)	57 (22%)	3 (1%)	6 (2%)	262
Total	1984 (75%)	556 (21%)	52 (2%)	57 (2%)	2649

Rounded percentages are given in brackets.
doi:10.1371/journal.pone.0098359.t003

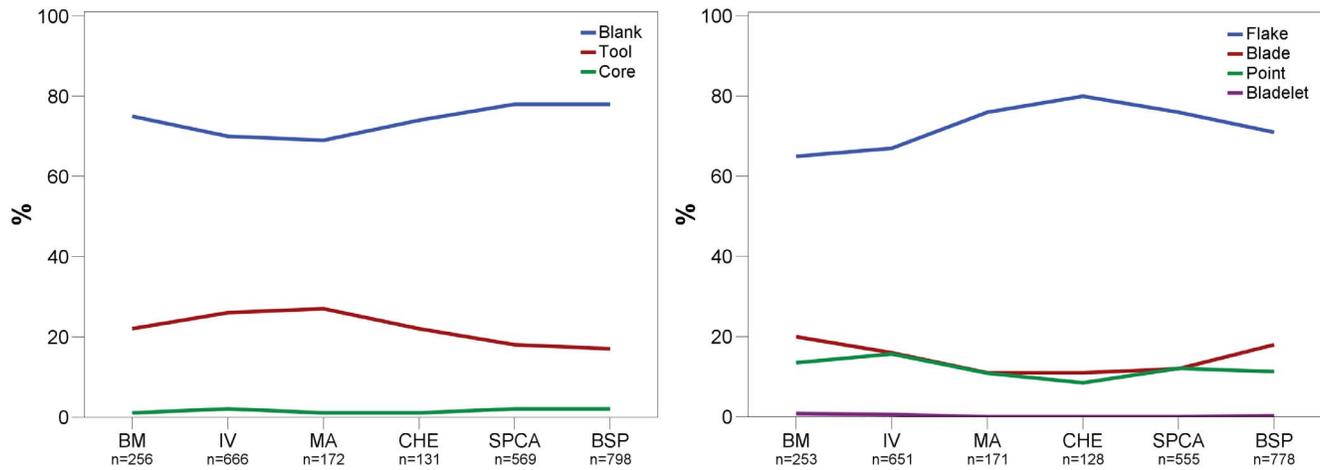


Figure 8. Frequencies of the main debitage categories (left) and blank types (right) produced throughout BM-BSP. BM = oldest layer; BSP = youngest layer. doi:10.1371/journal.pone.0098359.g008

throughout the sequence. This observation corresponds to the very high proportion of tools in these layers compared to many other MSA assemblages. The characteristics of the retouch flakes such as very low EPAs, the presence of a lip and diffuse bulbs of percussion attest to soft hammer percussion with a tangential knapping motion.

The density of lithic artifacts (>25 mm) and small debitage (< 25 mm) can help to assess the intensity of on-site reduction and site use. Figure 15 illustrates the densities of stone artifacts in layers BM-BSP, ranging between 30,000–50,000 n/m³ for lithic products <25 mm. Compared to values of South African MSA sites like Pinnacle Point 13BB (<5000 n/m³ for all occupation horizons; [134]) and our own excavations at Hoedjiespunt 1 ([135], ~600–3000 n/m³, unpublished data) the small debitage values are very high, suggesting repeated and intense occupations with widespread knapping activities taking place. There are, however, strong temporal fluctuations in the lithic densities, suggesting differing intensities of on-site stone knapping. The higher small debitage densities in BM and especially IV are roughly consistent with the observations that these assemblages are more intensively reduced.

Raw Material Economy

The knappers at Sibudu used their main raw materials in a different manner. Observations from the reduction sequences demonstrated that the non-local hornfels shows an emphasis on the production and curation of tools. The Raw Material Retouch Index (RMRI; [136]) supports this interpretation. Blanks made from hornfels (RMRI = 1.43) were more likely to be retouched than dolerite (RMRI = 0.81). The results from the debitage analyses by raw materials are also consistent with these observations. We found an overrepresentation of hornfels tools (48%) compared to the overall proportion of this raw material in the entire assemblage (34%). The ratio of tools to blanks is on average two times higher for hornfels compared to dolerite. In contrast, dolerite occurs most often in the form of unmodified blanks, with a marked underrepresentation of retouched pieces.

An independent t-test comparison of the weight, maximum dimensions and thickness of all complete tools (Table 11) shows that retouched artifacts from hornfels are significantly lighter, smaller and thinner than those from dolerite (p<0.002). Principally the same statistical results are obtained for the differences in maximum core dimension, weight and thickness between the two raw materials, with dolerite cores being significantly heavier, larger and thicker (p<0.031). Hornfels also exhibits by far the smallest,

Table 4. Distribution of blank types.

Layer	Flake	Convergent flake	Blade	Bladelet
BSP	552 (71%)	88 (11%)	136 (18%)	2 (0%)
SPCA	418 (76%)	69 (12%)	68 (12%)	-
CHE	102 (80%)	12 (9%)	14 (11%)	-
MA	130 (76%)	22 (13%)	19 (11%)	-
IV	435 (67%)	105 (16%)	106 (16%)	5 (1%)
BM	165 (65%)	36 (14%)	50 (20%)	2 (1%)
Total ¹	1802 (71%)	332 (13%)	393 (16%)	9 (0%)

¹Including blank types of retouched artifacts. Rounded percentages are given in brackets. doi:10.1371/journal.pone.0098359.t004

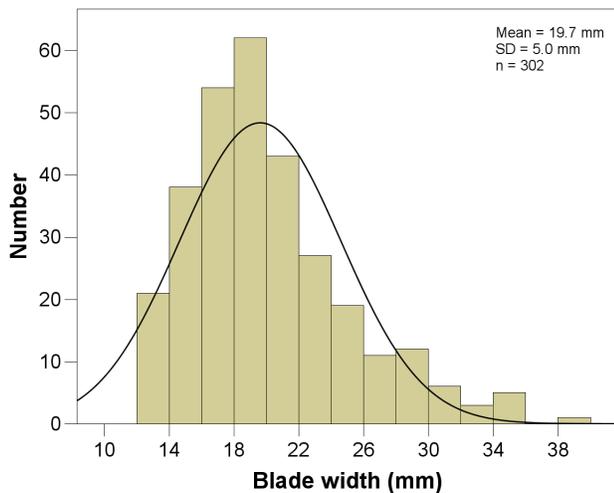


Figure 9. Distribution of blade widths (mm) from BM-BSP.
doi:10.1371/journal.pone.0098359.g009

lightest and thinnest blanks of all raw materials. The difference to unretouched dolerite blanks is highly significant ($p < 0.001$).

The knappers also varied their approach to core preparation with regards to raw materials as can be deduced from the types of platforms. Hornfels has the highest proportion of prepared platforms (29%), followed by dolerite (24%), and sandstone (19%). Very fine platform preparation with >5 small facets occurs most often on hornfels artifacts. In correspondence with this pattern, plain butts are far more frequent for dolerite than hornfels. In contrast, platform crushing and shattering is mostly associated with hornfels and quartzite, probably due to their more delicate nature. Regarding blank types, knappers produced flakes predominantly from dolerite, quartzite and sandstone. Quartz, jasper and CCS occur only in the form of flakes. The relative frequency of blades and convergent flakes is highest for hornfels, with dolerite being second. For hornfels, there are some very long blades and elongated convergent flakes with intense proximal overhang removals and abundant facettation of platforms. Some tool types also show a favored use of raw materials. Knappers made splintered pieces predominantly from hornfels while dolerite was preferentially used to manufacture notches and denticulates. In terms of techno-functional tool classes, knappers at Sibudu preferred hornfels for producing Ndwedwes and dolerite for the manufacture of NBTs.

The amount of small debitage products can provide information on the reduction of raw materials on-site [137–139]. We quantified a sample of small debitage products by raw materials in BSP ($n = 2324$). The resulting frequencies for hornfels and dolerite compare well with the abundances of artifacts >25 mm (Figure 16), demonstrating that knappers reduced both materials on-site. Consistent with their incomplete reduction sequences, small debitage products of quartzite, other raw materials and especially quartz are rare. Preliminary observations on the very large assemblage of small debitage products from the other layers ($n = 43097$) are consistent with these results. In each layer, there is abundant small debitage for dolerite and to a lesser degree for hornfels. In contrast, small knapping products for quartzite, quartz and other raw materials occur rarely. In terms of flaking efficiency, hornfels demonstrates the highest value among all raw materials, followed by dolerite with markedly lower values (Table 12). Sandstone and quartzite show the lowest edge length to mass ratios. These results suggest that among all raw materials, knappers used hornfels in the most efficient way, presumably to conserve this high-quality and non-local raw material.

The observed patterns of raw material economy occur alike throughout BM-BSP. Analyses of reduction sequences, frequencies of retouched forms, RMRI values, small debitage products, and flaking efficiencies suggest a stronger emphasis on retouch and curation for hornfels, with knappers investing more energy and time in the treatment of this non-local high-quality raw material compared to dolerite. An additional factor probably influenced these differences. While hornfels is fine-grained and easy to knap, its sharp edges are often fragile and have a tendency to break. Thus, they require more resharpening than the more durable tool edges of the coarser-grained dolerite (see [123]).

Discussion

Key Elements and Technological Variability of the Sibudan Lithic Assemblages BM-BSP

The period of the MSA following the HP in southern Africa (“post-HP”) has not been studied in great detail, particularly in comparison with the HP and SB technocomplexes (see [19,35,39,52,54,60,63,64]). We examined six lithic assemblages from Sibudu that post-date the HP, from the so-called Sibudan (*sensu* [63]), as part of the process of correcting this research bias.

The lithic assemblages of the Late Pleistocene sequence at Sibudu that we have analyzed here yield a robust technological signal. The key elements of BM-BSP include technological, techno-economic, techno-functional and typological aspects. These characteristics occur in a homogenous manner in each

Table 5. Distribution of core categories¹.

Layer	Parallel	Platform	Inclined	Bipolar	Indeterminate broken
BSP	6	5	2	3	3
SPCA	8	4	-	-	-
CHE	2	1	-	-	-
MA	-	1	-	-	-
IV	5	7	1	-	1
BM	2	1	-	-	-
Total	23	19	3	3	4

¹Core classification follows the taxonomy of Conard *et al.* [104].
doi:10.1371/journal.pone.0098359.t005

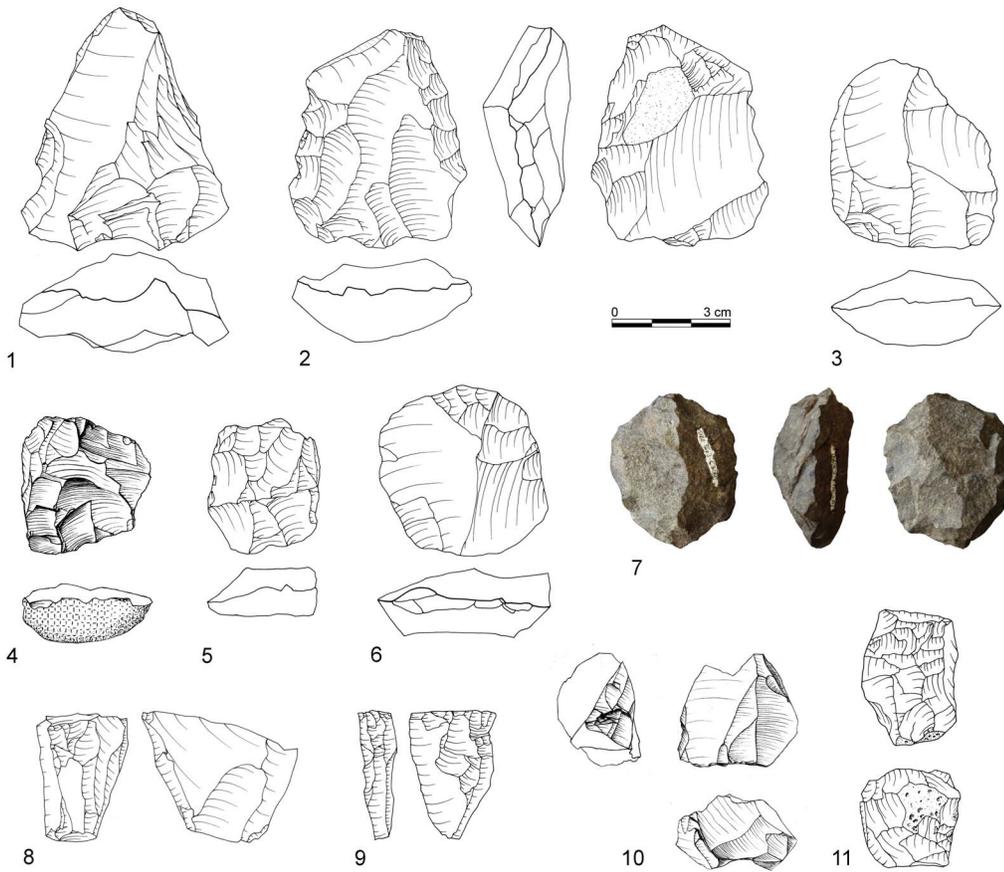


Figure 10. Core types from BM-BSP. 1: Parallel core (BSP, dolerite, E3-122); 2: Parallel core (BSP, hornfels, E3-206); 3: Parallel core (BSP, dolerite, C2-9); 4: Parallel core (BM, dolerite, D3-761); 5: Parallel core (SPCA, hornfels, E3, 550); 6: Parallel core (SPCA, dolerite, D2-243); 7: Inclined core (BSP, dolerite, C3-79); 8: Platform core, laminar products (SPCA, dolerite, E2-208); 9: Platform core, laminar products (SPCA, hornfels, C3-257); 10: Platform core (SPCA, dolerite, C3-149); 11: Platform core (BSP, hornfels, E2-16.1). Drawings 4 & 10 by F. Brodbeck; drawings 1–3, 5, 6, 8, 9, 11 by M. Malina; photograph 7 by M. Will. 4 & 10 after [63] Fig. 4. doi:10.1371/journal.pone.0098359.g010

assemblage and can thus help to define features of the Sibudan (*sensu* [63]). The lithic assemblages demonstrate that the inhabitants followed a consistent pattern of raw material procurement in the brief period we have studied so far, both in terms of their variety and abundance. Knappers used tool stones of local (dolerite, sandstone, quartzite) and non-local (e.g. hornfels) origin.

We also observed a uniform approach to the use of the two main raw materials dolerite and hornfels in terms of reduction sequences and the production of blanks. In accordance with its transport

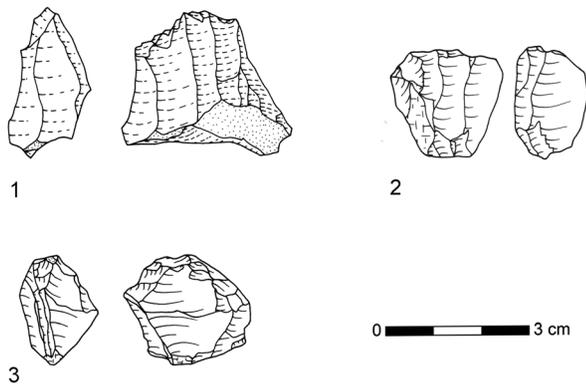


Figure 11. Selection of bladelet cores from BSP (1–2) and SPCA (3). 1: BSP, quartz, E3-273; 2: SPCA, hornfels, C3-149; 3: BSP, hornfels, D3-64.10. Drawings by M. Malina. doi:10.1371/journal.pone.0098359.g011

Table 6. List of attributes and measurements recorded on blades to diagnose the knapping technique.

Discrete attributes	
- Presence of bulb of percussion	(Y/N)
- Presence of proximal lip	(Y/N)
- Presence of shattered bulb	(Y/N)
- Presence of proximal trimming negatives	(Y/N)
- Presence of abrasion on platform	(Y/N)
- Presence of contact point of hammerstone	(Y/N)
- Presence of (partial) Hertzian cone	(Y/N)
- Type of platform	(plain, faceted, dihedral, cortical, crushed)
Measurements	
- Platform thickness	(in mm)
- Platform width	(in mm)
- Exterior platform angle	(in degrees)

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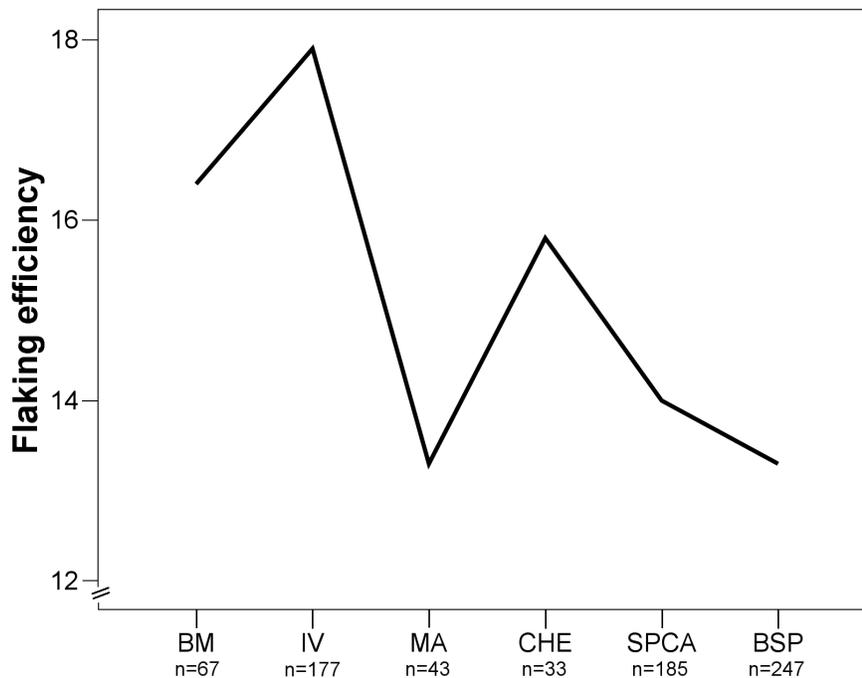


Figure 12. Mean values of flaking efficiency for BM-BSP. Flaking efficiency = edge length/mass. BM = oldest layer; BSP = youngest layer. doi:10.1371/journal.pone.0098359.g012

distance and high quality, people curated artifacts of hornfels more intensively than those of dolerite (*cf.* [121,122]). Our results are in agreement with observations from other research [58,123] suggesting that knappers had ready access to dolerite.

All the Sibudan assemblages we have studied so far are based on various blank types of large size (40–48 mm on average). Throughout BM-BSP, knappers produced blades with principally the same dimensions and shapes. Elongated and convergent products were preferentially selected for retouch and exhibit higher frequencies of prepared platforms. Furthermore, the co-existence of several reduction methods characterizes the layers of this study. Parallel and platform systems are frequent, with inclined cores playing a minor role. Only the parallel cores show extensive core preparation, with one quarter of all blanks exhibiting faceted platforms.

Knappers typically employed hard stone hammers to produce (convergent) flakes but soft stone hammers for blades in all assemblages. The proportion of retouched artifacts is exceptionally high among pieces >25 mm (17–27%), with a diverse and distinct inventory of formal tools. From a traditional point of view, unifacial points constitute the hallmark of implements in BM-BSP, while other typical MSA tools like denticulates and notches occur rarely. From a techno-functional perspective, four tool classes which amount to more than two thirds of all retouched specimens characterize the assemblages. The large number of Tongatis, Ndwedwes, NBTs and ACTs is a characteristic feature of the assemblages BM-BSP. The highly repetitive pattern of organizing the working edges for these implements also indicates a structured approach to tool manufacture, providing distinctive and well-defined tool cycles (see also [63]). We do not consider these tool classes as type fossils but as organizational elements within the Sibudan. They also occur in other periods at Sibudu, and their abundance will likely vary in other parts of the sequence pre- and post-dating the HP. We are currently working to refine this approach using a longer sequence of the Sibudan.

Finally, the six Sibudan assemblages document that similar knapping activities have been performed at the site. Throughout this part of the sequence, we found that the same stages of reduction taking place for each raw material. While dolerite and hornfels show mostly complete reduction sequences, quartzite, quartz, sandstone, jasper and CCS exhibit truncated manufacture sequences. The most prominent feature of the assemblages BM-BSP is their strong emphasis on the distal part of the reduction sequence. Compared to many other assemblages from the MSA, these layers exhibit a very high abundance of tools with intensively retouched and curated pieces as well as a large amount of retouching debitage. This observation is related to the intensive production and curation of tools in these layers. Of course, it is possible that other facies of the Sibudan show different features including lower proportions of tools and distal elements in the lithic technology.

While the Sibudan assemblages studied so far provide a strong and consistent technological signal, the high-resolution stratigraphy allowed for the recognition and evaluation of small-scale technological variation throughout the archaeological deposits. This behavioral variability is to be expected since the technological behavior of mobile hunter-gatherer groups is influenced by many ecological, social and functional parameters that change within short periods of time at the same locality (e.g. [140–142]).

We observed slight differences in the choice of raw materials. While the main types of tool stones remain the same, rare variants such as CCS and jasper occur only in a few assemblages. The abundance of non-local raw materials ranges between 25–38%. These variations might reflect differential access to the sources of raw materials or changes in the mobility system of the inhabitants such as smaller or larger home ranges and foraging trips. There is also some variation in the forms of tools produced, although there are no clear temporal trends in this part of the sequence. This variability could be an outcome of different activities performed at the site. Future studies will investigate site function and tool use in more detail. Finally, the difference in the reduction intensities of

Table 7. Distribution of traditional tool types.

Layer	Unifacial Point	Side Scraper	Lateral Retouch	Denticulate & Notch	End Scraper	Backed tool	Bifacial Point	Hammer-stone	Minimal retouch	Other
BSP	66 (48%)	24 (17%)	13 (9%)	4 (3%)	2 (1%)	2 (1%)	2 (1%)	1 (1%)	19 (14%)	6 (4%)
SPCA	48 (46%)	24 (23%)	6 (6%)	4 (4%)	3 (3%)	-	-	2 (1%)	9 (9%)	8 (8%)
CHE	11 (38%)	7 (24%)	3 (10%)	-	-	-	-	-	8 (28%)	-
MA	26 (54%)	10 (21%)	3 (6%)	-	1 (2%)	-	-	-	5 (11%)	3 (6%)
IV	97 (54%)	23 (13%)	15 (8%)	11 (6%)	1 (1%)	2 (1%)	1 (1%)	1 (1%)	20 (11%)	8 (4%)
BM	29 (52%)	7 (12%)	6 (11%)	-	1 (2%)	-	-	-	10 (18%)	3 (5%)
Total	277 (50%)	95 (17%)	46 (8%)	19 (3%)	8 (1%)	4 (1%)	3 (1%)	4 (1%)	71 (13%)	28 (5%)

Rounded percentages are given in brackets.
doi:10.1371/journal.pone.0098359.t007

the assemblages constitutes the most conspicuous technological variation in the studied sequence. The older assemblages (BM, IV) are more intensively reduced, with higher blank to core ratios and smaller debitage products. Consistent with this observation, these layers also feature the highest densities of small debitage. Interestingly, the density for ochre and faunal remains >25 mm that people left behind at the site does not follow the patterns of the lithics (Figure 17). These subtle distinctions between the upper and lower assemblages are most likely the result of differences in the use of the site, the access to raw materials and the system of mobility.

In contrast to studies which consider the “post-HP” as a phase of unstructured or unsophisticated lithic technologies during the MSA (e.g. [41,50,65,67]), we found clear cultural signals that unite the assemblages studied at Sibudu so far. These key elements occur homogeneously in many independent aspects of the lithic technology in six successively stratified assemblages of different sample sizes and reduction intensities, attesting to a structured lithic technology. Many of these characteristics, such as the well-recognizable tool assemblages with repetitive forms and distinctive reduction cycles, or the production of morphometrically standardized blades by soft stone hammers, demonstrate that the people at Sibudu did not possess a rudimentary or unsophisticated approach to stone knapping (*contra* [41,50], see also [63]).

Comparing the Sibudan to MSA Assemblages following the HP in Southern Africa

In order to move forward with the process of characterizing the Sibudan, it is essential to compare its lithic assemblages with those from other sites of this time period. Only then will it be possible to assess the spatial and temporal variation of the material culture following the HP and to consider where the Sibudan fits in the African taxonomy with its hierarchy of phases defined at the Burg Wartenstein meeting of 1965 ([143,144], see also [9]).

Recently, Lombard *et al.* [9] proposed the “Sibudu Industry” or “Sibudu technocomplex” to describe lithic assemblages at Sibudu that derive from both the “post-HP” (~58 ka) and “late MSA” (~48 ka) layers. They [9] view the Sibudu technocomplex as a pan-southern African phenomenon including assemblages from a list of ten sites that are characterized by the following typo/technological characteristics: most formal retouched is aimed at producing unifacial points which are predominantly produced by Levallois methods, with a tendency towards elongated forms with faceted platforms (*Sibudu point* as type fossil). Some plain butts occur as well. Side scrapers are present and there are rare bifacially retouched points and backed pieces [9,145]. While our results from the lithic assemblages BM-BSP are broadly consistent with these characteristics, many important technological elements that we have found do not feature in this list. Detailed information on the methods of core reduction, the types of blanks produced, the knapping techniques and the reduction sequences will need to be provided for a conclusive comparison.

The most straightforward approach to evaluate the place of the studied Sibudan assemblages within the cultural sequence of the Late Pleistocene MSA are site by site comparisons. We chose assemblages based on the availability of technological data, reliable stratigraphy and secure dating. We also selected localities that are broadly comparable in their age, geographical and environmental parameters, and patterns of site-use, although this was not always possible. Lithic assemblages from the eastern part of South Africa constitute the most promising comparisons due to the short geographical distances and similar environmental circumstances. The southern African summer rainfall zone has provided several MSA sites that follow the HP (see [9,54,71]).

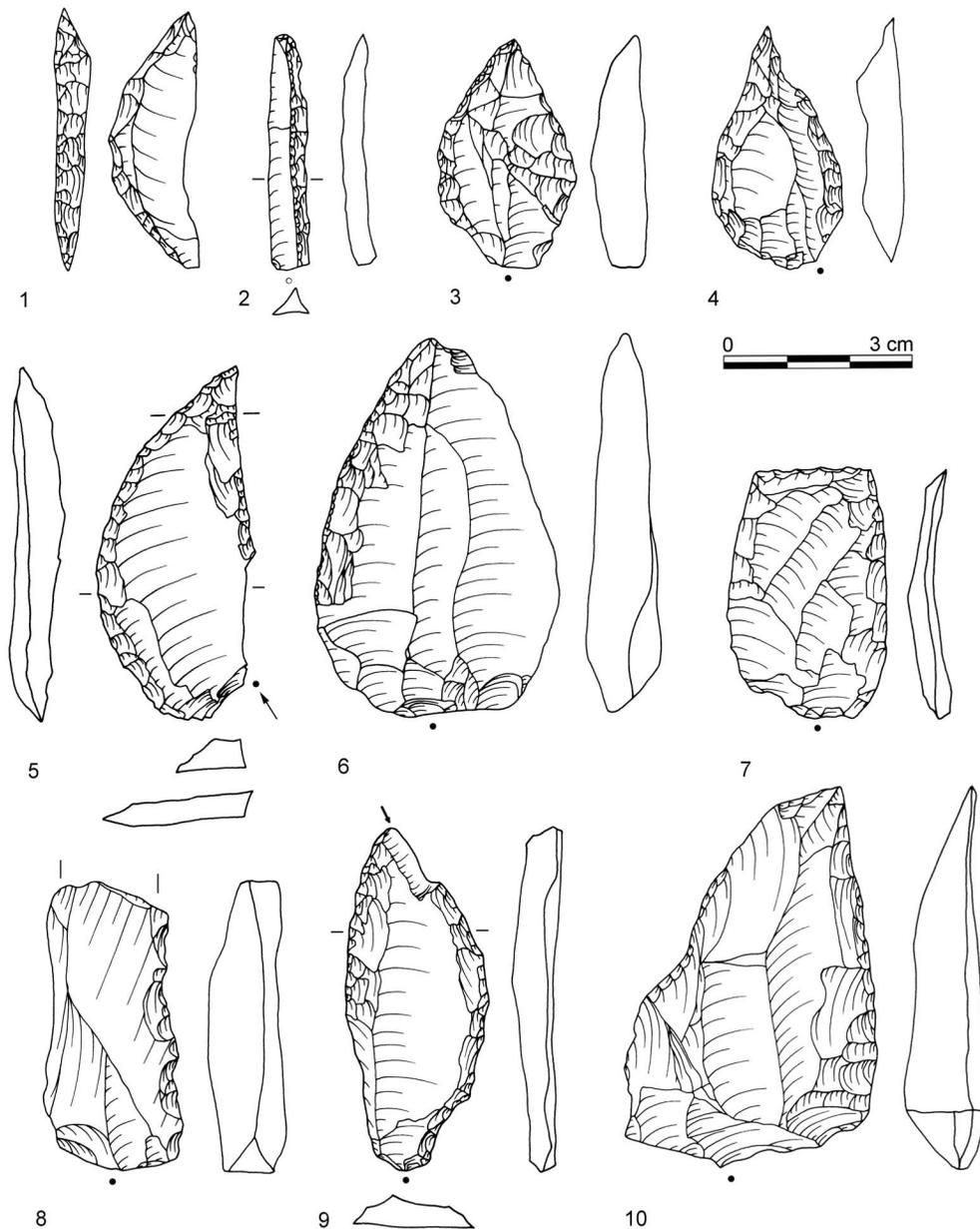


Figure 13. Selection of traditional tool types from BM-BSP. 1: Backed tool/segment (BSP, hornfels, D3-42.1); 2: Backed tool (BSP, hornfels, D3-17); 3: Unifacial point (BSP, hornfels, C3-42); 4: Unifacial point (BSP, hornfels, E3-40); 5: Unifacial point (BSP, hornfels, D3-18); 6: Unifacial point (BSP, hornfels, C2-8); 7: Biseau (IV, hornfels, E3-542); 8: Denticulate (IV, hornfels, D2-374); 9: burin (SPCA, hornfels, C3-273); 10: Side scraper (BSP, hornfels, C2-186). Drawings by M. Malina.

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Umhlatuzana Rock Shelter (URS) lies in KwaZulu-Natal only 90 km south-west from Sibudu and ~35 km from the Indian Ocean [73,145]. The earliest layers that follow the HP (“late MSA”, Levels 19–21) date to around 40–44 ka [74]. While there are some problems with the stratigraphy [73,145], recent OSL dating supports the integrity of the sediments [74]. In the following we describe the “late MSA” assemblages from URS (after [73,145]) and also include detailed descriptions of the unifacial points [64,74].

The lithic assemblages are large (17,000–70,000 pieces), suggesting intensive occupations and on-site knapping. Hornfels dominates the assemblages (60–90%), followed by quartzite (11–35%) and few other raw materials. Flakes with plain platforms

constitute the most frequent blank type, but faceted butts occur as well. Bladelets are more frequent than blades, with the latter being rare ($n=36$). Knappers manufactured bladelets from both platform and bipolar cores, with an average width of 6 mm. The most frequent core forms are irregular and platform types, with bipolar cores being less abundant. Kaplan [73] mentions prepared core technology but provides no further descriptions. The majority of cores is very small with mean lengths of ~20 mm. Formal tools account for only 0.2%, but no size cut-off point was used for artifact counts [73,145]. Unifacial points (37–40%) dominate the tool assemblages, followed by bifacial points (4–11%) and scrapers (3–15%). Rare miscellaneous backed pieces, backed points and small segments complete the tool spectrum. Knappers

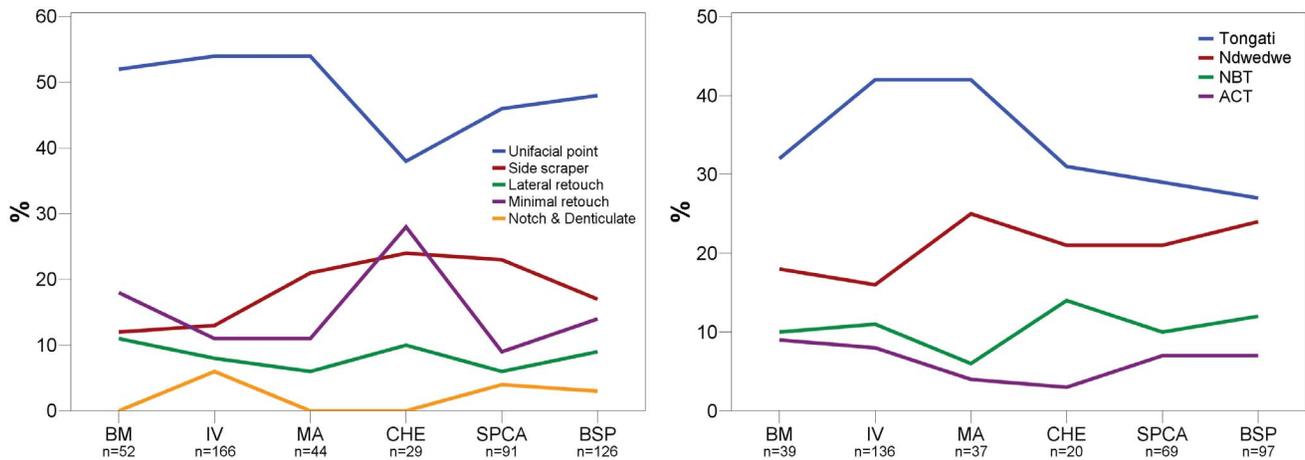


Figure 14. Percentual abundance of classic typological categories (left) and techno-functional tool classes (right). BM = oldest layer; BSP = youngest layer. doi:10.1371/journal.pone.0098359.g014

preferentially selected hornfels and elongated flakes to manufacture unifacial points [64,74]. The points are generally of large size (~48 mm) and feature faceted platforms (22%). URS displays a variety of unifacial point forms, often with invasive retouch. The majority of the depicted unifacial points resembles Tongatis (see in [64], Fig. 5a: c, f, g, i, l), but there are also three potentials Ndwedwes (see in [64], Fig. 5a: e, h) and one ACT (see in [64]; Fig. 5a: k).

Overall, the “late MSA” at URS conforms to the Sibudan assemblages BM-BSP in several typo-technological aspects. The core reduction methods are broadly similar and the unifacial points at URS match the variety in forms, the size, the intensive retouch and the blank types of those manufactured at Sibudu (*cf.* [64,146]). Having said this, there are also differences. In contrast to the assemblages we have studied, URS features finely made bifacial points and very small backed segments. Additionally, the absolute number of retouched pieces ($n = 217$) in relation to the total assemblage ($n = 130,000$) is around five times lower for URS compared to Sibudu (tools $n = 555$; total assemblage $n = 60,000$). Discoid technology has not been reported at URS and it is unclear whether knappers produced convergent flakes. The abundance and small size of bladelets as well as the scarcity of blades also distinguishes URS. There are no information on rock type availability, raw material economy or knapping technique.

Rose Cottage Cave constitutes one of the few well-excavated, well-stratified and well-dated sites of eastern part of southern Africa [35,147,148]. The large cave lies in the Orange Free State ca. 350 km west of Sibudu. The early “post-HP” assemblages (THO, BYR) are dated to around ~50 ka by TL or ~57 ka by OSL [35]. We summarize the recent description of the lithic assemblages [35] with additional information from Harper [148].

The knappers at RCC used mostly local rocks, with more than 80% being opaline of high knapping quality, 10% tuff and few other raw materials. The inhabitants frequently produced blades (BYR 57%, THO 30%) but flakes are reported to be the primary objective of core reduction. The blades are mostly irregular, showing a low degree of standardization. Knappers produced blades by unidirectional reduction from the narrow face of the core. Cores make up 9–13% of the assemblages, with frequent bipolar cores in THO ($n = 25$) but not in BYR ($n = 1$). Flake cores dominate and Levallois flakes are common. The inhabitants used hard stone hammers with internal percussion to produce blades, often with faceted platforms (25%). Tool frequencies are high for

both BYR (14.6%) and THO (26.5%). Various scraper forms dominate the tool assemblages (55%), followed by unifacial and partly bifacial points (12%), some scaled pieces and rare backed pieces, notches and denticulates. The tool types show little standardization. Flakes form 55–72% of blanks used for retouched pieces, with blades amounting to 28–45%. Unifacial points were predominantly made on flakes. Knappers manufactured most of their tools on opaline, corresponding to its overall abundance. The large number of small debitage pieces indicates frequent on-site tool manufacture.

There are several parallels to the Sibudan assemblages BM-BSP, including the production of both blades and flakes, Levallois and platform reduction methods, the high number of retouched specimens, the variety of tool forms and the manufacture of tools on-site. The abundance of fine-grained raw materials around the site explains the lack of non-local raw materials. In contrast to RCC, however, knappers at Sibudu produced blades from both narrow and broad surfaces of cores with higher degrees of morphometric standardization. They also employed a soft stone hammer for the production of blades. There is no information on the existence and role of convergent flakes as desired blanks at RCC. In opposition to Sibudu, cores are frequent in the early “post-HP” at RCC but without discoid reduction. The relatively low frequency of unifacial points at RCC might be partially explained by the separation of convergent scrapers and unifacial points [35]. Of the three depicted unifacial points, two compare well to Tongatis (see in [35], Fig. 16: 7–8) but none to Ndwedwes or asymmetric points. This observation matches with Harpers [148] description that most unifacial points are thin and show symmetric triangular distal ends.

In a next step, we compared the six Sibudan lithic assemblages with geographically more distant areas of South Africa. Both the Southern (e.g. [10,11,149]) and Western Cape (e.g. [56,59,62,150]) have provided several localities with lithic assemblages post-dating the HP. Klasies River (KR) is a complex of caves and shelters located on the southern coast of South Africa about 200 km east of Mossel Bay. The locality is famous for its almost 20 m thick sequence which long served as the type site for the cultural stratigraphy of the South African MSA [10,11,151]. Most recently, Wurz [11] and Villa *et al.* [60] studied the “MSA III” lithic assemblages of Cave 1A that date to around ~58–60 ka [40,152].

Table 8. Distribution of techno-functional tool classes.

Layer	Tongati	Ndwedwe	NBT	ACT	Biseau	Splintered piece	Formal tool	Broken tool	Other
BSP	37 (27%)	34 (24%)	17 (12%)	9 (7%)	2 (1%)	4 (3%)	18 (13%)	15 (11%)	3 (2%)
SPCA	30 (29%)	22 (21%)	10 (10%)	7 (7%)	-	4 (4%)	13 (12%)	16 (15%)	2 (2%)
CHE	9 (31%)	6 (21%)	4 (14%)	1 (3%)	-	-	2 (7%)	7 (24%)	-
MA	20 (42%)	12 (25%)	3 (6%)	2 (4%)	-	1 (2%)	4 (8%)	6 (13%)	-
IV	74 (42%)	29 (16%)	19 (11%)	14 (8%)	2 (1%)	3 (2%)	13 (7%)	22 (12%)	2 (1%)
BM	18 (32%)	10 (18%)	6 (10%)	5 (9%)	-	1 (2%)	2 (3%)	13 (23%)	2 (3%)
Total	188 (34%)	113 (20%)	59 (11%)	38 (7%)	4 (1%)	13 (2%)	52 (9%)	79 (14%)	9 (2%)

Rounded percentages are given in brackets.
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The majority of raw materials is local, including quartzite, quartz, hornfels and chalcedony. Silcrete constitute the only potential non-local tool stone and occurs in low frequencies (but see [153]). Knappers primarily manufactured blades (>50%), with convergent flakes being rare. According to Wurz [11] there are also no cores for convergent flakes. The main core reduction method is unidirectional blade removals from semi-prismatic cores, beginning on the narrow face of the core and using symmetrical crested blades (see in [60]; Fig. 16). Blade widths range widely between 10–30 mm and do not show a normal distribution around one peak (in [60]; S. Fig. 21). Knappers employed direct internal percussion with a hard stone hammer to produce blades. About 10% of the artifacts are retouched. Side scrapers, denticulates and notches dominate the tool assemblages, but truncated faceted pieces occur as well. Unifacial points are rare (7%; [60]), but Singer and Wymer [10] report ~24%. Knappers preferentially selected blades (85%) over flakes (15%) for retouch. Almost all of the modified pieces are from the local quartzite, with few specimens from the potentially non-local silcrete.

Overall, the “MSA III” lithic assemblages at KR differ markedly from the Sibudan assemblages we have studied so far. While the existence of a blade production strategy with a comparable method of core reduction unites the assemblages, there are several major technological and typological differences. In BM-BSP flakes and not blades are the principal types of blanks produced, and disoid and Levallois core reduction method occur as well. The blades at Sibudu show higher standardization in size and shape, with a width distribution around a single peak. Furthermore, knappers usually manufactured blades with soft stone hammers and not hard stone hammers. While retouched specimens are relatively frequent at KR, the tool assemblages appear to be distinct. There is also a difference in the raw material economy at Sibudu, where knappers preferentially retouched and curated non-local tool stones.

Klein Kliphuis rockshelter (KKH) lies in the Western Cape of South Africa, approximately 200 km north of Cape Town and 70 km inland of the current coastline. The relevant assemblages of the “Early post-HP” derive from spits Dv and Dvi1-7 and date to ~58 ka [40,59]. We summarize the descriptions of these lithic assemblages by Mackay [56,59].

Silcrete, quartz and quartzite are local raw materials and account for almost all artifacts, with rare non-local hornfels (< 1%). Quartzite constitute the most common raw material overall, but there are marked changes in the procurement of tool stones. Blades amount to 10–20% of blanks with the rest being flakes of around 30–40 mm length (see in [56]; Fig. 8). Faceted platforms are frequent (16–41%) and the knappers employed Levallois, radial, platform and bipolar core reduction methods. KKH features many large cores (14–259 g), with few intensively reduced or exhausted specimens. The blades have a mean platform thickness of ~5 mm, EPAs of 82° and are often faceted (33%). Retouched specimens constitute 6% of all artifacts >25 mm (A. Mackay, pers. comment). Unifacial points are the most common formal implements, followed by scrapers. The actual number of unifacial points numbers, however, is low (*cf.* [56], Fig. 5): no units yielded more than five unifacial points and five spits exhibit only one or none. Backed tools occur in the earliest layers of the “post-HP” (Dvi6-7) as well as six bilaterally backed points. The high number of lithic products suggest intensive occupations and knapping activities. Mackay [120] also provides mean edge length to mass ratios of 28.65 for layers DV-Dvi7, fluctuating between 20–40.

Table 9. Number of blank types used for the manufacture of tools for the combined assemblages BM-BSP.

Blank	Tools (n)	Tools (%) ¹	Blanks (%) ²	%diff ³
Flake	262	47.5	71.0	-23.5
Convergent Flake	184	33.5	13.1	+20.4
Blade	102	18.5	15.5	+3.0
Bladelet	3	0.5	0.4	+0.1

¹Proportion of tools made on this blank type in all assemblages.

²Proportion of blanks in all assemblages.

³Tools (%) – Blanks (%).

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The “Early post-HP” at KKH resembles the Sibudan assemblages BM-BSP in terms of blank production, core reduction and core preparation. While there is no information on the production of convergent flakes, the size of the flakes and the proportions of blades to flakes are also similar. Unifacial points constitute the most frequent formal tool type at KKH, but their absolute number is very low with a diminished diversity in forms compared to the six Sibudan assemblages. The unifacial points depicted (see in [59], Fig. 8) resemble Tongatis. Comparable pieces to NBTs, Ndwedwes or ACTs are not presented. Average values of flaking efficiency at Sibudu fall below the range of KKH, indicating a less efficient use of raw materials. Interestingly, the majority of cores at Sibudu is heavily reduced, which is not the case for KKH. The lack of non-local artifacts at KKH can best be explained by the local availability of high-quality lithic raw material. Based on the values for platform thickness, blade production proceeded by internal percussion, but the kind of hammer used remains unclear. A conclusive evaluation will need to include a more detailed assessment of the knapping technique for blades and flakes, a technological analysis of the blanks produced, and the economy and reduction sequences of raw materials.

Diepkloof Rock Shelter (DRS) lies around 15 km inland from the Atlantic Ocean and yielded a thick stratigraphic sequence with frequent and intense occupations during the “post-HP” that compare well with Sibudu [18]. Porraz *et al.* [62] provide a short characterization of the lithic assemblages Danny to Claude (n = 1289, >20 mm), which are dated to 52+/-5 ka [20] and 55.4+/-2.0 ka [40].

The knappers used mainly silcrete, quartzite and quartz, with non-local raw materials amounting to ca. 50% of the assemblages. The majority of blanks are flakes (66%), followed by blades (19%), bladelets (8%) and few convergent flakes (3%). Core reduction is characterized by blade products, including HP-type debitage. Knappers produced blades with irregular forms by internal percussion using hard stone hammers. Flakes are morphologically variable and show unidirectional and centripetal dorsal negatives with little platform preparation. Retouched forms are frequent (14%). Scrapers in various reduction degrees constitute the most frequent tool form (27%), followed by unifacial points (14%). Some of the points show short triangular ends that are comparable to the Tongatis of the Sibudan (see in [62], Fig. 11: 7–9). Other tool forms include denticulates and notches (15%), burins (6%), truncated pieces (5%), backed pieces (4%) and splintered pieces (4%), and end scrapers (2%).

The provisioning with local and non-local raw materials, the production of flakes and blades, the coexistence of different core reduction methods and an emphasis on the distal reduction sequence reflect similarities between the “post-HP” at Sibudu and

DRS. However, Porraz *et al.* [62] note that there are important typological and technological differences between these assemblages, such as the lack of unifacial point categories other than the Tongatis and the absence of NBTs. They conclude that the “post-HP” at DRS should thus not be subsumed under the “Sibudu technocomplex” (*sensu* [9]). To these observations, we add that the production of convergent flakes only plays a negligible role at DRS and blades in the Sibudan assemblages BM-BSP are more regular and produced by soft stone hammers. Discoid technology and more frequent core preparation also distinguish these layers from Danny to Claude at DRS.

Our site by site comparisons demonstrate that the Sibudan assemblages that we have studied so far show several parallels in terms of technology, techno-economy and typology to other sites dating to early MIS 3. But there are also important differences in these domains. In particular, the abundance of unifacial points – and tools in general –, the clear patterning of production cycles and reduction histories for specific tool classes (e.g. Tongatis, *sensu* [63]), the use of a soft stone hammer to produce blades, the frequent manufacture of convergent flakes and the co-existence of several core reduction methods, including the discoid method, distinguish the Sibudan from most of these assemblages. We see two potential explanations for the observed patterns. First, the lithic assemblages BM-BSP could be interpreted as a special, site-specific case of the “post-HP” due to particular environmental circumstances, patterns of site use, mobility patterns or raw material availability. As an alternative explanation, our findings can be interpreted as supporting the working hypothesis by Conard *et al.* [63] that the lithic assemblages dated to ~58 ka at Sibudu yield a new signal of the early “post-HP” that can be attributed to a novel cultural-technological unit, the Sibudan.

We support the latter interpretation, as we made great efforts to compare the assemblages at Sibudu to sites that are as similar as possible in terms of dating, type of site occupation, raw materials, geographical and environmental parameters. Sibudu and its occupation sequence after the HP are not exceptional with regards to these characteristics. All assemblages that we have compared derive from similar timeframes, feature raw materials of high and low flaking quality, show all stages of the lithic reduction sequence and derive from sites with repeated and intensive occupations similar to residential camps. Furthermore, the six studied Sibudan assemblages share several features with other “post-HP” assemblages, especially with the nearby sites URS and RCC, and are thus not an entirely isolated phenomenon. The perceived uniqueness of the techno-typological signal could also be attributed to the fact, that the Late Pleistocene MSA lithic technology of eastern South Africa is poorly documented, with few sites available for comparison. More detailed information on the lithic technology of URS and RCC, especially for aspects that we

Table 10. Cortex cover on artifacts for each assemblage and for the total sample of dolerite and hornfels.

% cortex	Layer	Raw material						
		BSP	SPCA	CHE	MA	IV	BM	Dolerite
0	525 (64%)	368 (64%)	74 (56%)	109 (61%)	410 (61%)	174 (66%)	963 (58%)	626 (70%)
1–20	124 (15%)	73 (13%)	20 (15%)	20 (11%)	94 (14%)	30 (11%)	232 (14%)	115 (13%)
21–40	88 (11%)	65 (11%)	18 (14%)	22 (12%)	75 (11%)	26 (10%)	200 (12%)	81 (9%)
41–60	31 (4%)	23 (4%)	8 (6%)	10 (6%)	45 (7%)	16 (6%)	92 (6%)	34 (4%)
61–80	34 (4%)	35 (6%)	6 (4%)	12 (7%)	36 (5%)	10 (4%)	99 (6%)	30 (3%)
81–99	15 (2%)	8 (1%)	5 (4%)	2 (1%)	14 (2%)	4 (2%)	42 (3%)	4 (1%)
100	5 (0%)	6 (1%)	2 (1%)	3 (2%)	2 (0%)	2 (1%)	17 (1%)	3 (0%)
Total	822	578	133	178	676	262	1645	893

Rounded percentages are given in brackets.
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could not yet compare, might reveal that they should be included within the Sibudan. In conclusion, we view the Sibudan as a working model that can help to organize part of the cultural sequence of the MSA during MIS 3. Based on the long excavation history, the thick and high-resolution stratigraphy and the outstanding preservation of materials, Sibudu is ideally suited to serve as a type site and reference point for further comparisons (see also [9,63]).

In view of the current data basis, the Sibudan appears to be a phenomenon during early MIS 3 which does not cover the entire period following the HP in terms of geography and chronology. Our comparisons have revealed several techno-typological parallels to sites from the eastern part of southern Africa but more pronounced differences to localities from the Southern and Western Cape. We want to emphasize, however, that the results and comparisons described here reflect work in progress. For now, we presented technological, techno-functional, techno-economic and typological data for six Sibudan lithic assemblages (BM-BSP) that date to ~58 ka and provided preliminary comparisons with other sites. Using these data, researchers can perform additional comparisons with assemblages post-dating the HP, test the utility of the Sibudan as a cultural-taxonomic unit and critically examine its spatio-temporal range. Regarding our own work at Sibudu, there are still many layers of the depositional sequence following the HP that need to be analyzed. The Tübingen fieldwork at Sibudu is ongoing with the aim to excavate the entire sequence that follows the HP in the coming years (see Figure 1). We expect to observe still greater variation in the strata dated to ~58 ka that have not yet been excavated by our team. The study of this variability can document patterns of short-term cultural behavior within the Sibudan. Characterizing the full range of variation will also represent an essential next step in testing and refining the ideas presented here.

Conclusion

The Late Pleistocene cultural sequence at Sibudu that we have studied here exhibits a distinct technological signal of modern humans living during the later MSA in the eastern part of South Africa. We were able to define key elements that characterize the lithic assemblages and document technological variability within a high-resolution stratigraphy. The markers that unite these assemblages occur in several independent technological and typological domains even though they differ in sample size and reduction intensity. Comparisons with other assemblages from southern Africa that post-date the HP demonstrate several techno-typological parallels, particularly with the geographically closest sites Rose Cottage Cave and Umhlatuzana. Having said that, the Sibudan assemblages BM-BSP yield a so-far unique combination of technological, typological and techno-economic characteristics. These results support the use of the Sibudan (*sensu* [63]) as a concept that can serve as a starting point for comparisons with other MSA assemblages of this timeframe. Further research on local, regional and sub-continental scales is necessary and will help to assess the spatio-temporal distribution of the Sibudan. This work should evaluate whether the Sibudan is confined to the eastern part of southern Africa during early MIS 3 or covers a broader geographical and chronological range. These studies will also help to define the place of the Sibudan in the taxonomic hierarchy (e.g. [9,143,144]).

The findings that we have presented here, alongside recent studies by other researchers [54,56,57,59,60,62], demonstrate the need to intensify research on periods that follow the SB and HP. From our analysis, we conclude that there is no reason to denote

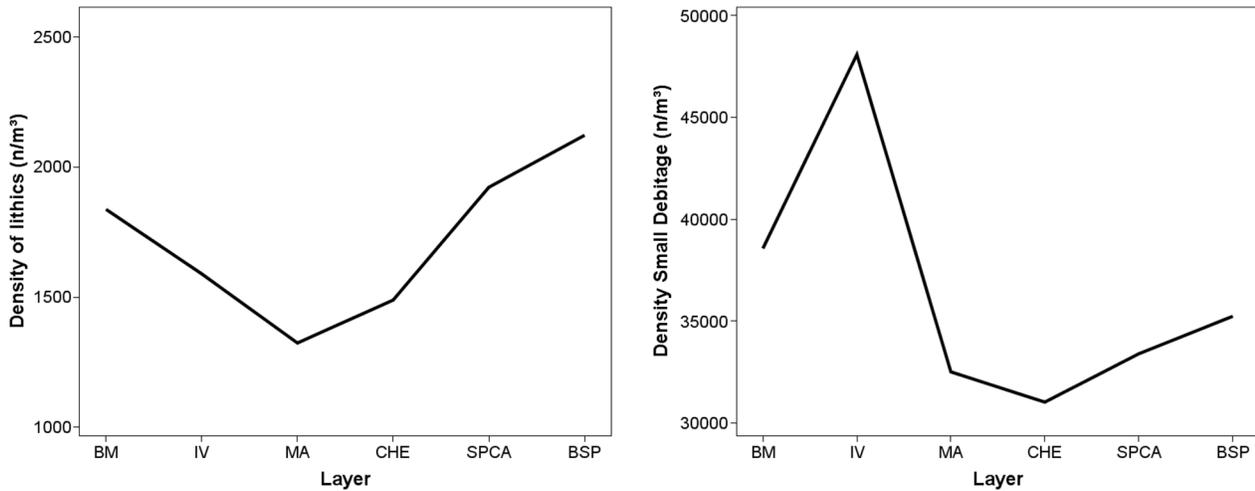


Figure 15. Density of lithic remains throughout BM-BSP. Lithics >25 mm (n/m³, left) and lithic remains <25 mm (n/m³, right). BM = oldest layer; BSP = youngest layer.
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the technology of people living after the HP as “unsophisticated”, “conventional” or a “dark age”. Rather it seems to us that the lack of attention and detailed analyses devoted to this phase of the MSA resulted in a distorted picture. The results from the Sibudan assemblages BM-BSP refute these assertions by demonstrating that the knappers possessed a highly structured and sophisticated lithic technology. These findings are consistent with recent lithic studies at Diepkloof [62], Klasies River [60], Rose Cottage Cave [35] and Klein Kliphuis [56], suggesting that with an increased knowledge of this time frame, we gain a more realistic picture of spatial and temporal patterning of technological variability and cultural evolution of modern humans during the MSA of southern Africa.

Finally we stress that we do not see defining the Sibudan as a movement toward creating a rigid cultural taxon, but as part of a

process of inquiry and a step toward gaining a better understanding of the cultural dynamics of the MSA. Here we follow the arguments made by Brew [154] decades ago and view cultural taxonomy as a tool to help archaeologists answer questions about the past and as a means of organizing our ideas about the past. Like Brew, we are not striving to create a single, ideal taxonomy that is universally valid, for such a goal is illusory and ultimately futile. Instead we are working to identify the cultural variability at Sibudu as part of the process of characterizing the behavioral patterning within the MSA. The critical assessment of the Sibudan may or may not confirm the usefulness of this approach, but, by presenting these results, we intend to further our understanding of the cultural dynamics of the MSA and thereby provide new insights into the behavioral patterns of modern humans in

Table 11. Independent t-test comparison of metric attributes between complete artifacts made from dolerite and hornfels.

	Ø MD (mm) ¹	Ø Thickness (mm)	Ø Weight (g)
Tools			
Dolerite	46.4	9.6	14.4
Hornfels	42.5	8.1	7.4
<i>df</i> ²	430	430	430
<i>p</i> ³	0.002	<0.001	<0.001
Cores			
Dolerite	54.8	22.6	66.8
Hornfels	44.6	17.7	29.1
<i>df</i>	39	39	39
<i>p</i>	0.031	0.028	0.005
Blanks			
Dolerite	45.0	8.8	13.4
Hornfels	40.2	6.7	6.9
<i>df</i>	1459	1459	1459
<i>p</i>	<0.001	<0.001	<0.001

¹Maximum dimension of the artifact.

²Degrees of freedom.

³Significance value of the two-sided t-test ($\alpha=0.05$).

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Table 12. Flaking efficiency by raw material for the combined assemblages BM-BSP.

Raw material	n	Flaking efficiency $\bar{\phi}^1$	Max.	Min.	SD
Dolerite	734	14.3	60	2	9.2
Hornfels	283	19.6	89.9	3.9	11.1
Quartzite	10	11.9	30.9	3.3	9.5
Sandstone	11	12.7	30.2	1.9	8

¹Flaking efficiency is calculated after [120].
doi:10.1371/journal.pone.0098359.t012

southern Africa shortly before the main expansion of our species across the Old World. Since the study of this phase of the MSA has been neglected in the past, we hope to have shown that the period following the HP does warrant our close attention. The intense research in recent decades in southern Africa makes the subcontinent a suitable region for developing more precise models of cultural evolution during the MSA. Only through detailed studies of multiple regions within southern Africa and Africa as a whole will we have any chance of determining what role, if any, the cultural evolution in southern Africa played in the successful expansion of our species around the globe.

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Author Contributions

Conceived and designed the experiments: MW NJC. Performed the experiments: MW GDB. Analyzed the data: MW GDB NJC. Contributed reagents/materials/analysis tools: NJC. Wrote the paper: MW NJC.

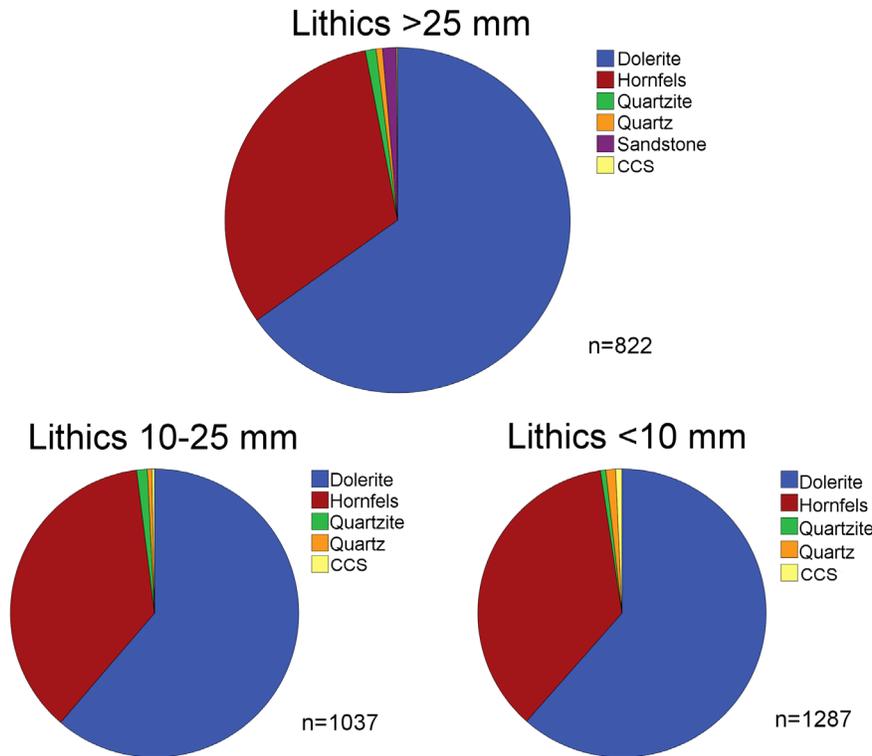


Figure 16. Proportions of raw materials in assemblage BSP. Lithics >25 mm (top), lithics 10–25 mm (bottom left) and lithics <10 mm (bottom right).
doi:10.1371/journal.pone.0098359.g016

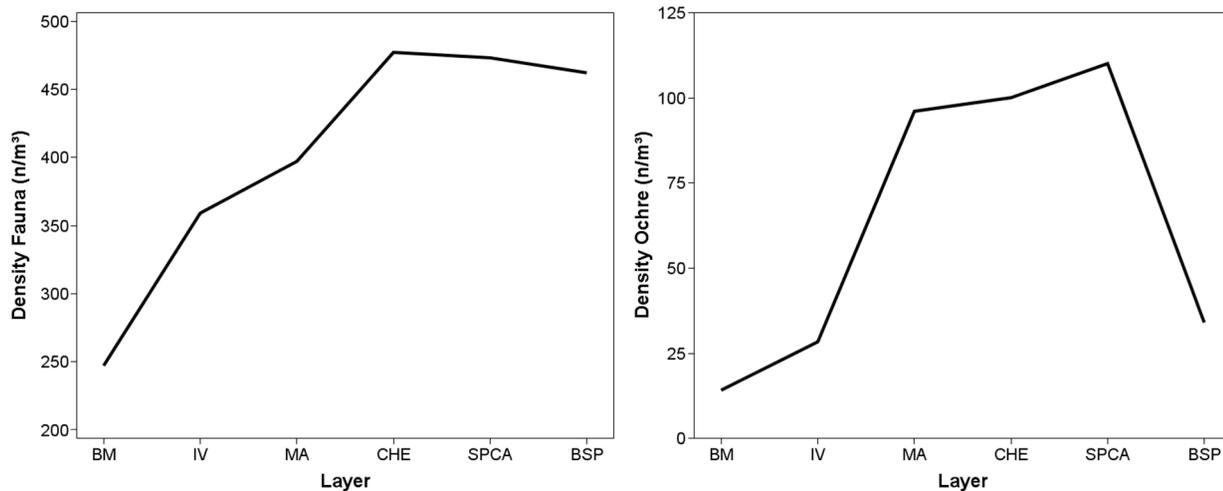


Figure 17. Density of faunal remains and ochre throughout BM-BSP. Faunal remains >25 mm (n/m^3 , left) and ochre >25 mm (n/m^3 , right). BM = oldest layer; BSP = youngest layer. doi:10.1371/journal.pone.0098359.g017

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RESEARCH ARTICLE

Examining the Causes and Consequences of Short-Term Behavioral Change during the Middle Stone Age at Sibudu, South Africa

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Data Availability Statement: All recovered archaeological specimens are permanently stored at the KwaZulu-Natal Museum in Pietermaritzburg (South Africa, 237 Jabu Ndlovu Street). The specimen numbers of this study are C2.6-1439; C3.2-1141; D2.2-1028; D3.1-1364; E2.4-1151; E3.2-1457 (including sub-numbers).

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Abstract

Sibudu in KwaZulu-Natal (South Africa) with its rich and high-resolution archaeological sequence provides an ideal case study to examine the causes and consequences of short-term variation in the behavior of modern humans during the Middle Stone Age (MSA). We present the results from a technological analysis of 11 stratified lithic assemblages which overlie the Howiesons Poort deposits and all date to ~58 ka. Based on technological and typological attributes, we conducted inter-assemblage comparisons to characterize the nature and tempo of cultural change in successive occupations. This work identified considerable short-term variation with clear temporal trends throughout the sequence, demonstrating that knappers at Sibudu varied their technology over short time spans. The lithic assemblages can be grouped into three cohesive units which differ from each other in the procurement of raw materials, the frequency in the methods of core reduction, the kind of blanks produced, and in the nature of tools the inhabitants of Sibudu made and used. These groups of assemblages represent different strategies of lithic technology, which build upon each other in a gradual, cumulative manner. We also identify a clear pattern of development toward what we have previously defined as the Sibudan cultural taxonomic unit. Contextualizing these results on larger geographical scales shows that the later phase of the MSA during MIS 3 in KwaZulu-Natal and southern Africa is one of dynamic cultural change rather than of stasis or stagnation as has at times been claimed. In combination with environmental, subsistence and contextual information, our high-resolution data on lithic technology suggest that short-term behavioral variability at Sibudu can be best explained by changes in technological organization and socio-economic dynamics instead of environmental forcing.

Introduction

Researchers studying the cultural evolution and Paleolithic lifeways of hominins conduct their work at multiple scales of analysis, including temporal, spatial, demographic and behavioral

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dimensions [1–3]. Archaeologists can consider actions of hominins on the scales of seconds or many hundreds of thousands of years. Spatial scales can range from microscopic to continental. When examining the demographic dimension, the individual is the smallest unit of analysis, while studies can also address the population dynamics of entire species. Finally, the behavior scale spans the range of hominin experience from the fulfillment of essential biological needs for food, drink and sleep to a wide range of practical activities as well as abstract thoughts and beliefs.

Studies of the Middle Stone Age (MSA) and Middle Paleolithic, which span the period from roughly 300 ka to 30 ka, have addressed all these scales with mixed results. Each area of research and multiple schools of thought approach these issues from different perspectives with specific goals and methods [2, 4–8]. For example, Middle Paleolithic research in Europe has often addressed scales of high spatial and temporal resolution at the level of individuals and small social units. Work at sites including Maastricht-Belvédère [9], Tönchesberg [10, 11], Wallertheim [12, 13], and Abric Romani (articles in [8, 14]) reflect examples of high-resolution archaeology, often based on refitting studies of lithic artifacts and faunal material. Such approaches have generally not been the emphasis of researchers working in the MSA, with few notable exceptions such as Van Peer *et al.*'s [15] work at Taramsa I in Egypt, although Wadley [16, 17] has advocated similar strategies.

Here we aim to examine the high-resolution cultural stratigraphic sequence of Sibudu in KwaZulu-Natal, South Africa, to consider the nature and potential explanations for short-term changes in behavior during the MSA. In the case study presented here, we are less concerned with the paleo-ethnographic scale (e.g. [18–20]) which focuses on the actions of individuals and small social units over periods of seconds, hours, days, months or years and their implications for the material record of the past. Instead, we consider how the rich archaeological record from Sibudu preserves a record of short-term cultural change over what likely spans the temporal scale of individual lives, decades and centuries.

Based on the available OSL dates, the eleven archaeological strata from Sibudu that we analyze here are indistinguishable in age and date to around 58,000 years ago (= 58 ka), ca. 4,000 years younger than the underlying Howiesons Poort (HP) occupations [21, 22]. The focus of this paper is to examine how we can use these high-resolution signatures of changing lithic assemblages to gain new insights into the nature and potential causes of changes in behavior and technology in a sequence of multiple find horizons that all fall within the uncertainty of the resolution of radiometric dating. Generally research in the MSA has not addressed this scale of variation, although previous research at Sibudu (e.g. [17]) or Diepkloof [23, 24] used similar approaches. Here we look at short-term technological change during the early phase of MIS 3 to illuminate potential factors that shape cultural evolution. These observations have implications for ongoing debates about the rates and causes of cultural change during the MSA and the reasons why some innovations come and go, while others spread and shape technological systems in the long-term [22, 23, 25–30].

More specifically, we examine 11 find horizons in the period that we elsewhere have defined as the Sibudan [31, 32]. While the upper part of the sequence, find horizons BM-BSP, reflects the type assemblages for this cultural entity, we here report different technological signature for the lower stratigraphic units. This variability raises fundamental questions about the causes and scope of technological changes and begs the question of how much variation can be included in any cultural taxonomic unit. Following J. Brew [33], we are very much aware that there are no universally valid answers to these questions, since any taxonomy has meaning only within the contexts of specific questions researchers pose. Nonetheless, in the case of the Sibudan and the cultural stratigraphy of the MSA, researchers need to be explicit about these questions, since often we have simply continued to use the cultural taxa defined by Goodwin

and van Riet Lowe [34] over 85 years ago based on the poor data that were available at that time.

We also consider what approaches will likely provide insight into the causes and implications of cultural change during early MIS 3. We draw on organization of technology of and evolutionary approaches to cultural change to see if they can help us assess why innovations occur, persist or disappear and to examine what selective pressures shape MSA technology. More specifically, we investigate whether changes in demography, environment, subsistence and other socio-cultural dynamics were causal mechanisms of behavioral change at Sibudu.

Materials and Methods

Sibudu and its high-resolution MIS 3 deposits

Sibudu is a large rock shelter located above the Tongati River (also spelled "uThongathi") about 40 km north of Durban and 15 km from the Indian Ocean in the KwaZulu-Natal region (Fig 1). The site hosts a rich and thick archaeological sequence with deposits that have been dated to >77–37 ka, preserving more than 40,000 years of MSA occupations. In terms of cultural chronology, Sibudu has yielded evidence for Still Bay (SB) and Howiesons Poort (HP) occupations, but also for the periods before and after. The record from MIS 3 is particularly rich, consisting of pulses of occupation at ~58 ka, ~48 ka and ~38 ka [21, 22, 31, 35].

The stratigraphic framework of the site results from long-term excavations by L. Wadley that began in 1998 and continued until 2011. The MSA sequence at Sibudu is over 3 meters thick and is characterized by largely anthropogenic sediments, features good organic preservation and little post-depositional disturbance [36–40]. The 11 lithic assemblages of this study derive from the upper portion of the ~1.5 meter thick sediments that overly the HP. This "post-HP" sequence at Sibudu contains over 20 archaeological horizons consisting of finely laminated strata [21, 32] (see also [35]: Fig 1). Occupations at the top and base of this thick sequence have been dated indistinguishably to ~58 ka by OSL, providing an exceptionally high temporal resolution for an MSA site [21, 22]. These layers likely accumulated over a period of centuries and constitute one of the best and thickest stratigraphic records of this period known anywhere. They present an ideal case study for analyzing high resolution MSA behavioral variability. Based on detailed lithic analyses, we recently proposed that the uppermost 6 layers of these deposits form part of the "Sibudan", a new cultural taxonomic unit of the later MSA [31, 32].

The excavations by Wadley and our own team have documented very high densities of archaeological finds in these Sibudan strata. Additionally, both absolute dating and

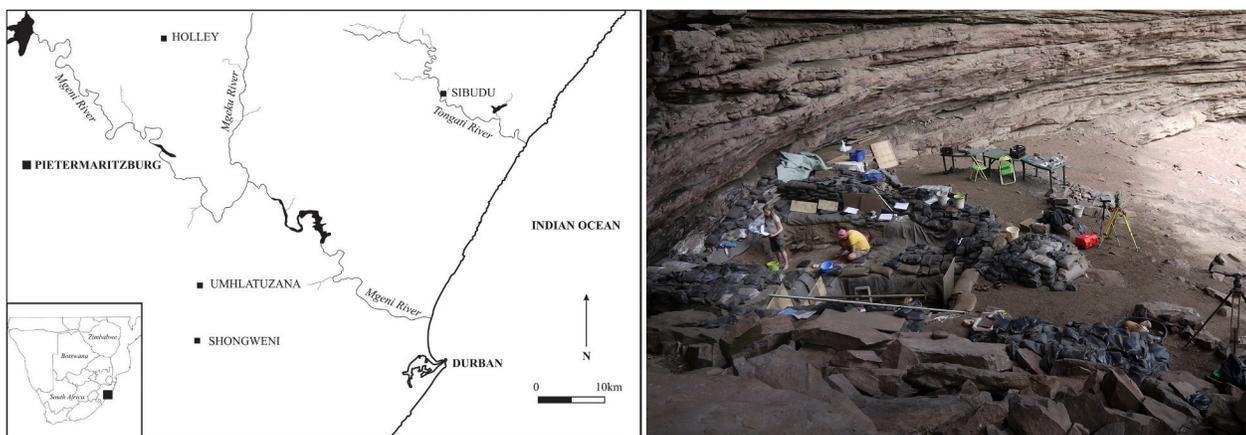


Fig 1. Geographical location of Sibudu in KwaZulu-Natal and view on the excavation area within the rock shelter.

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geoarchaeological analyses suggest high rates of anthropogenic sedimentation. The sequence exhibits multiple hearths, bedding and other indications of site use and maintenance. These observations document that modern humans made very intense use of the site around ~58 ka [21, 31, 32, 38–41].

Methods of excavation

New field work at Sibudu has been carried out by a team of the University of Tübingen under the direction of N. Conard since 2011. The research permit to conduct archaeological excavations at Sibudu is issued under the KwaZulu-Natal heritage Act No. 4 (permit number: REF: 0011/14; 2031CA 070). All recovered archaeological specimens are housed in the KwaZulu-Natal Museum in Pietermaritzburg. The specimen numbers of this study are C2.6–1439; C3.2–1141; D2.2–1028; D3.1–1364; E2.4–1151; E3.2–1457 (including sub-numbers).

The current research team adopted Wadley’s stratigraphic system and designations (see [21] Table 2). The find horizons have been excavated with careful piece-plotting of artifacts, using a Leica total station and the EDM program [42], with great attention being paid to establish reliable high-resolution cultural chronological units. We do this by following the concept of excavating *Abträge* (singular *Abtrag*) that follow the contours of the stratigraphic sequence. In keeping with this approach, our excavations proceeded carefully in 1–3 cm thick *Abträge* in each quarter meter, following the slope of the sediments without crosscutting geological strata. We group these *Abträge* in larger units that we call find horizons. Given the rapid rate of sedimentation and the high occupation intensity at Sibudu, this excavation method allows us to examine patterns of change in the material culture of the site’s inhabitants in great detail. Due to this careful strategy, we are confident in assessing the provenience of each artifact and thus in the integrity of the lithic assemblages of this study. We recorded the volume of all excavated sediments and sieved every buckets of sediment through nested screens with 5 mm and 1 mm mesh in order to recover small finds.

Materials and methods of lithic analysis

This study includes all lithic finds from layers WOG1-BSP from the 2011–2014 Tübingen excavations, which reflects an area of excavation of 6 m² and a volume of excavation of about 3 m³ (Fig 2). We analyzed a total of eleven assemblages, with one layer (SS) being excluded due to the low number of artifacts (n<100). Due to the high density of lithic artefacts, we used 30 mm

Table 1. Distribution of lithic single finds (>30 mm) and small debitage (<30 mm).

Layer	Single finds	Small debitage	Total lithics
BSP	822	13644	14466
SPCA	578	10019	10597
CHE	133	2792	2925
MA	178	4421	4599
IV	676	20389	21065
BM	262	5694	5956
POX	2192	43418	45610
BP	261	4039	4300
SU	1624	26816	28440
SP	705	5060	5765
WOG1	368	2210	2578
Total	7799	138502	146301

doi:10.1371/journal.pone.0130001.t001

Table 2. Distribution of raw materials (>30 mm).

Layer	Dolerite	Hornfels	Sandstone	Quartzite	Quartz	Jasper	CCS/Other	TOTAL
BSP	535 (65%)	262 (32%)	11 (1%)	8 (1%)	5 (1%)	-	1 (0%)	822
SPCA	333 (58%)	222 (38%)	11 (2%)	9 (2%)	2 (0%)	-	1 (0%)	578
CHE	79 (59%)	50 (38%)	4 (3%)	-	-	-	-	133
MA	111 (62%)	58 (33%)	4 (2%)	3 (2%)	1 (1%)	1 (0%)	-	178
IV	406 (60%)	235 (35%)	21 (3%)	6 (1%)	-	8 (1%)	-	676
BM	181 (69%)	66 (25%)	12 (5%)	2 (1%)	1 (0%)	-	-	262
POX	1919 (88%)	134 (6%)	93 (4%)	42 (2%)	1 (0%)	-	3 (0%)	2192
BP	245 (94%)	7 (3%)	5 (2%)	4 (1%)	-	-	-	261
SU	1479 (91%)	22 (1%)	80 (5%)	41 (3%)	1 (0%)	-	1 (0%)	1624
SP	567 (80%)	7 (1%)	100 (14%)	26 (4%)	4 (1%)	-	1 (0%)	705
WOG1	270 (74%)	-	74 (20%)	15 (4%)	9 (2%)	-	-	368
Total	6125 (79%)	1063 (14%)	415 (5%)	156 (2%)	24 (0%)	9 (0%)	7 (0%)	7799

Rounded percentages are given in brackets.

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as the cut off for single finds. The eleven assemblages include a total of 146,301 stone artifacts, with 7,799 pieces >30 mm and 138,502 small debitage products <30 mm (Table 1). The large number of successive layers and lithic finds allows for an excellent assessment of diachronic variability throughout this part of the sequence. The very high ratio of small debitage to single finds (95:5%) is indicative of intense stone knapping with little post-depositional disturbance or sorting based on size (S1 Fig).

The aim of this study is to document and interpret short-term behavioral change in a high-resolution sequence. In order to achieve this goal and maximize the amount of pertinent information, we follow an approach to lithic analysis that combines the virtues of several complementary methods:

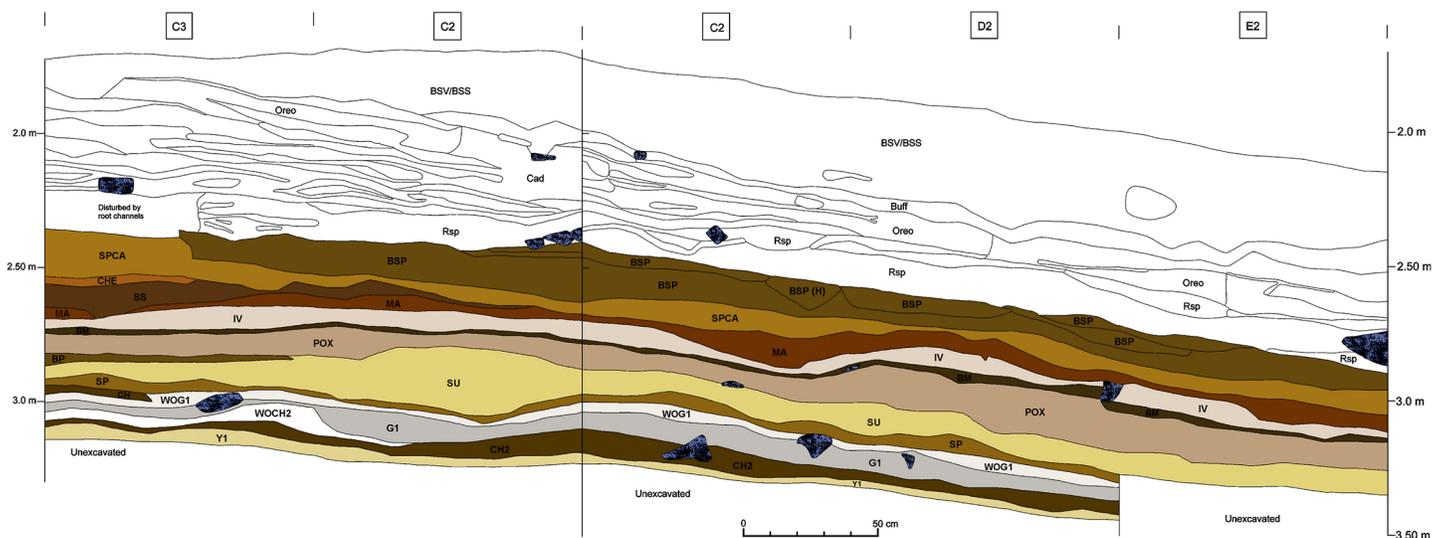


Fig 2. Stratigraphic section of the Eastern Excavation (combined north and east profile) of Sibudu. Colored layers, beginning with BSP, were excavated by the Tübingen team between 2011–2014 and are located in the upper part of the sequence dated to ~58 ka.

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- Reduction sequence analysis [12, 43–47] evaluates the methods of core reduction and the stages of knapping, use and discard of stone artifacts that people performed at the site. We include only lithic artifacts larger than 30 mm.
- Attribute analysis [48–53] informs on technological behaviors by providing quantitative data of the numerous discrete and metric traces on individual artefacts that result from the knapping process. As part of this method, techno-economic approaches measure reduction intensities [54–56], calculate flaking efficiencies [57, 58] and assess raw material economy [59–63]. Only stone artifacts >30 mm were included.
- Typological [64, 65] and techno-functional analyses [66–70] provide comparable data on tool types across sites and regions and study the technological approach of knappers towards producing, using and recycling tools.
- Quantifying small lithic artifacts (30–5 mm) according to raw material aids in calculating find densities and patterns in the raw material economy. Identifying retouch debitage quantifies the level of on-site tool production and recycling.

Combing these methods, we reconstruct technological strategies of the individual assemblages by providing information on procurement and use of raw materials, reduction sequences, techniques of blank production and the approach used for tool manufacture and maintenance.

In order to help quantify the amount of retouching conducted on-site for each assemblage, we analyzed a representative sample of small debitage products (<30mm) for retouch flakes. Retouch flakes among the small debitage were identified using the following characteristics: 1) a plain striking platform with a lip; 2) an obtuse angle between striking platform and ventral surface; 3) the existence of dorsal negatives that originate from the previously retouched edge; 4) an overall divergent fan-like morphology; 5) an abrupt, hinge or plunge termination (see [31]: Fig 14). We classified the piece as retouch debitage if at least three of five characteristics were present, yielding conservative estimates for on-site retouching.

Our analyses of core reduction methods follow the unified taxonomy by Conard *et al.* [71] in order to provide a classification which is applicable to all periods without temporal or spatial restrictions. In this taxonomy, “parallel”, “inclined” and “platform” constitute three main types of core reduction. Conard *et al.* ([71]: 15–16) define their core categories as follows. Parallel cores “have two surfaces whose main removal surface must include one or more major removals parallel to the plane that intersects the two surfaces [. . .] These cores are usually asymmetrical in cross-section with a slightly convex main removal surface and a more inclined ‘underside’. All significant removals originate from the intersection of the two surfaces”. Inclined cores on the other hand “have two surfaces with removals inclined relative to the plane defined by the intersection of the surfaces. Either or both surfaces may be used for the main removals. The removals have an angle of roughly 45° relative to the plane of intersection. All significant removals originate from the intersection of the two surfaces”. Finally, platform cores “have more than two faces and are not defined by the plane of intersection of two surfaces as in the above two approaches. Removals do not need to be on the broad surface of the core and are often on narrow surfaces. One or more well organized and well developed striking platforms with three or more contiguous, successful removals from the corresponding knapping surfaces must be recognizable”. This category encompasses what is elsewhere referred to as single and multi-platform as well as so-called rotated cores for the production of flakes, blades or bladelets.

In order to overcome limitations of a typological approach [53, 72, 73], we also employed a techno-functional method for the analysis of retouched specimens which divides tools into a

transformative, prehensile and intermediate part and studies the treatment of these portions separately [66–70]. In combination with this concept, we also focused on the reduction and transformation of tools (e.g. [74–77]), emphasizing their dynamic nature instead of considering only their final state of modification and discard. Using these methods, we previously classified tools based on the identification of specific patterns of repetitive retouch on different parts of the tool which indicate formal and distinct retouching sequences [31, 32]. The four main techno-functional tool classes and reduction sequences at Sibudu comprise Tongatis, Ndwedwes, naturally backed tools (NBTs), and asymmetric convergent tools (ACTs). Although these tool classes do not function as type fossils, their frequent and joint occurrence is part of the original definition of the “Sibudan” [31].

The hallmark of Tongati tools is their short triangular distal end, which is usually retouched in a symmetric manner on both working edges of the point. Tongatis are continuously reduced from the distal to the proximal end—becoming shorter as retouch progresses—but they always retain their convergent distal configuration (see [31]: Fig 5–8). ACTs are similar to Tongatis, but the distal tip is always asymmetrical. Most specimens have steeper, retouched edges opposed to a sharp non- or only marginally retouched edge (see [32]: Fig 5). ACTs typically change at their initially unretouched working edge, as use-wear and edge damage accumulate, decreasing the width of the piece during their use life. “Ndwedwe” tools comprise retouched forms that are elongated, thick pieces with modifications along the lateral edges. They are characterized by their steep and invasive lateral retouch that usually runs the entire length of both sides of the tool. In contrast to Tongati tools, Ndwedwes begin with relatively broad forms and become narrower and narrower with progressive retouch, while the length remains nearly constant over the course of reduction (see [31]: Fig 11). Finally, NBTs are characterized by a natural back—including Siret fractures, other kinds of breaks and cortical edges—opposite to the retouched edge of the piece (see [31]: Fig 12). Due to the existence of a thick back, NBTs usually possess an asymmetric cross-section. More detailed descriptions, discussion of their function and additional drawings of these tool concepts and reduction sequences can be found in Conard *et al.* [31] and Will *et al.* [32].

Results

Procurement and use of lithic raw materials

Knappers at Sibudu procured both local and non-local (>10 km distant) lithic raw materials. Local materials include dolerite, quartz, quartzite and sandstone, with non-local variants represented by hornfels, jasper and crypto-crystalline silicates (CCS). The local materials occur either directly at the shelter and its surroundings (dolerite, sandstone) or as pebbles in the Tongati River (quartz, quartzite). There are no known outcrops of hornfels, jasper and CCS in the direct area (10 km radius) around Sibudu. While their precise origins remain to be determined, the inhabitants of the site had to import these raw materials from some distance to the site [78, 79].

Accessibility, form of occurrence and knapping quality of raw materials, as well as social parameters influenced the choice of raw materials used by MSA hunter gatherers. From the point of view of fracture mechanics [80, 81], hornfels, CCS and jasper constitute the best materials at Sibudu. While these raw materials provide sharp edges, they are often fragile and prone to break (e.g. [79]). The local dolerite from Sibudu is a homogenous but hard and rough raw material. Knapping of dolerite requires considerable force and skill, but yields durable edges which do not break as easily as those of hornfels [79]. Quartzite and sandstone share similar qualities, with the latter being very coarse-grained. Due to its internal structure, quartz tends to

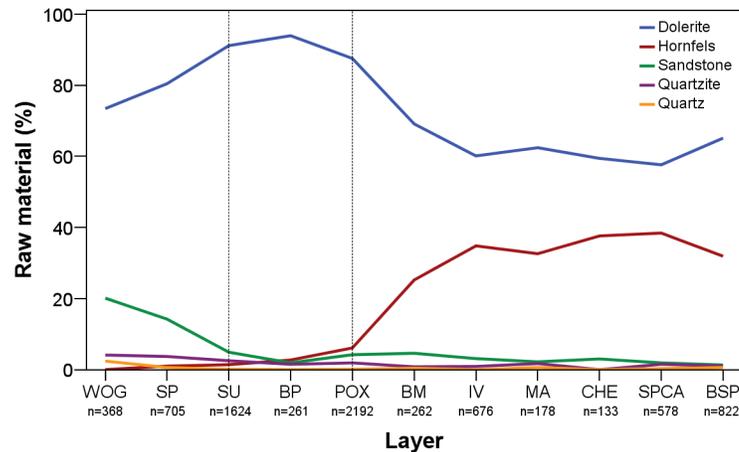


Fig 3. Percentual abundance of raw materials throughout WOG1-BSP. WOG1 = oldest layer; BSP = youngest layer.

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break along crystal boundaries and not conchoidally but provides extremely sharp and durable edges [82–84].

Throughout the studied sequence, knappers gradually changed their selection of raw materials (Fig 3; Table 2). Dolerite constitutes the dominant tool stone in all layers, but varies in abundance. The two lowest assemblages WOG1 and SP yield values between 75–80%, followed by an almost exclusive use of dolerite in SU-POX (90–95%) and finally a drop in frequency to between 60–70% in the uppermost layers BM-BSP. In contrast to dolerite, we found unidirectional temporal changes for the selection of non-local hornfels and local sandstone. Hornfels is absent in the lowest assemblage WOG1 and increases gradually from SP (1%) to POX (6%). Layer BM marks a distinct break in the sequence with hornfels shooting up to 25%, reaching almost 40% in CHE and SPCA (Fig 3). From SU-BSP, decreases in dolerite correlate strongly with increases in hornfels ($r = 0.87$; $p = 0.002$). While sandstone is well-represented in the lower assemblages WOG1 and SP (14–20%), layers SU and above demonstrate only <5% of this raw material. Other local (quartz, quartzite) and non-local raw materials (jasper, CCS) played a negligible role for the inhabitants. In terms of raw material origins, all assemblages from the base of the studied sequence up to POX yield less than 6% raw materials from non-local sources—or none at all—whereas the upper layers BM-BSP exhibit a four- to six-fold increase in tool stones from further away to between 25–38%.

In conclusion, knappers pursued three different strategies of raw material procurement (Fig 3). The lowest layers WOG1 and SP are characterized by the near absence of non-local raw materials, with the strongest focus on sandstone. Throughout SU-POX, the inhabitants of Sibudu almost exclusively used the local dolerite, with a small but gradually increasing amount of non-local hornfels. The upper layers BM-BSP exhibit an emphasis on the procurement of non-local hornfels associated with a decrease in dolerite and little use of other raw materials.

Technological and techno-economic behavior

Analysis of debitage. The quantitative analysis of debitage for assemblages WOG1-BSP demonstrates marked diachronic changes (Table 3). Tools increase gradually throughout the sequence, with the transition from POX (6%) to BM (22%) being the most pronounced break (Fig 4). In general, WOG1-POX yield only few retouched specimens (1–6%), a standard value for most MSA assemblages (e.g. [85–87]). These figures stand in marked contrast to the upper

Table 3. Quantitative debitage analyses of the main lithic categories (>30 mm).

Layer	Blank	Tool	Core	Angular debris	TOTAL
BSP	637 (78%)	142 (17%)	19 (2%)	24 (3%)	822
SPCA	453 (78%)	104 (18%)	12 (2%)	9 (2%)	578
CHE	99 (74%)	29 (22%)	3 (2%)	2 (2%)	133
MA	123 (69%)	48 (27%)	1 (1%)	6 (3%)	178
IV	473 (70%)	179 (26%)	14 (2%)	10 (2%)	676
BM	196 (75%)	57 (22%)	3 (1%)	6 (2%)	262
POX	2018 (92%)	133 (6%)	12 (1%)	29 (1%)	2192
BP	251 (96%)	8 (3%)	1 (0.5%)	1 (0.5%)	261
SU	1539 (95%)	52 (3%)	11 (1%)	22 (1%)	1624
SP	680 (97%)	9 (1%)	6 (1%)	10 (1%)	705
WOG1	352 (96%)	5 (1%)	5 (1%)	6 (2%)	368
Total	6821 (87%)	766 (10%)	87 (1%)	125 (2%)	7799

Rounded percentages are given in brackets.

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assemblages BM-BSP for which the retouched lithic component is exceptionally high (17–27%). Not surprisingly, the number of unretouched blanks covaries with the frequency of tools. Cores and angular debris remain at low values throughout the studied sequence. The paucity of cores (n = 57; 1–2%) suggests that knappers reduced their raw materials intensely on-site and often exported non-exhausted cores.

For each assemblage, we analyzed retouch flakes in a representative sample of small debitage products (<30mm) to quantify the amount of on-site retouching. Based on the proportions of small retouch flakes in WOG1-BSP (total small debitage n = 22686; total retouch debitage n = 1645; [S1 Table](#)), the frequency of tools appears to be associated with their on-site production and curation. Just as in the overall tool proportions, there is a gradual increase of retouch flakes in the lowest layers WOG1-POX (~1–4%), followed by a distinct break from assemblage BM onwards (~11–24%). A statistical test of correlation confirms the strong co-variation between the proportion of retouch flakes (<30mm) and tool frequencies (>30mm) in the assemblages ($r = 0.869$; $p = 0.001$).

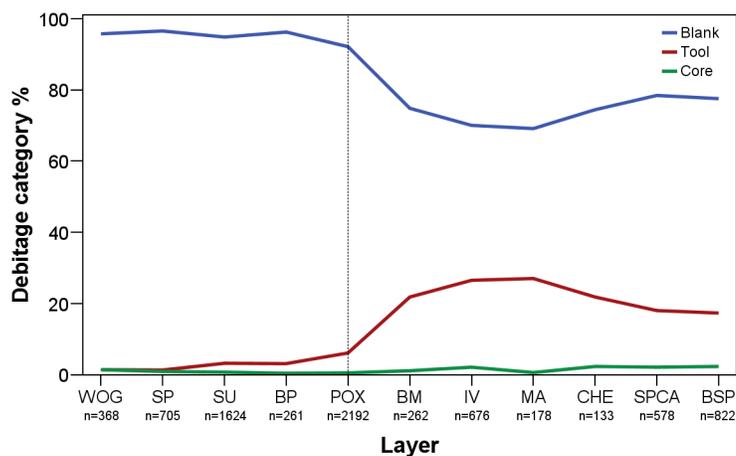


Fig 4. Frequencies of the main debitage category produced throughout WOG1-BSP. WOG1 = oldest layer; BSP = youngest layer.

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Table 4. Distribution of blank types¹ (>30 mm).

Layer	Flake	Convergent flake	Blade	Bladelet
BSP	552 (71%)	88 (11%)	136 (18%)	2 (0%)
SPCA	418 (76%)	69 (12%)	68 (12%)	-
CHE	102 (80%)	12 (9%)	14 (11%)	-
MA	130 (76%)	22 (13%)	19 (11%)	-
IV	435 (67%)	105 (16%)	106 (16%)	5 (1%)
BM	165 (65%)	36 (14%)	50 (20%)	2 (1%)
POX	1591 (74%)	203 (9%)	185 (16%)	14 (1%)
BP	187 (72%)	40 (16%)	29 (11%)	3 (1%)
SU	1198 (75%)	193 (12%)	185 (12%)	14 (1%)
SP	569 (83%)	83 (12%)	36 (5%)	1 (0%)
WOG1	294 (83%)	43 (12%)	18 (5%)	-
Total ¹	5640 (74%)	894 (12%)	1001 (13%)	44 (1%)

¹Including blank types of retouched artifacts. Rounded percentages are given in brackets.

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Production of blanks. Knappers at Sibudu produced a variety of types of blanks including flakes, convergent flakes, and blades, as documented from the blanks themselves and the cores used to produce them (Table 4). Flakes of various morphologies and sizes make up the majority of blanks in all layers. Although in lower numbers, the manufacture of convergent flakes and blades constitutes important elements throughout the sequence, an observation backed by frequent retouching of these blank types (see below). The only temporal difference in blank manufacture concerns the lowest layers WOG1 and SP. Not only is the blade component by far the lowest (5%), but many of these specimens also appear to be by-products. Hence, it is unclear whether an independent strategy of blade production exists in these assemblages. Although there are cores for the production of bladelets (n = 11), we found little evidence for the products themselves. A scatter plot of length and widths of all laminar products and a histogram of widths only (Fig 5) support this observation. Both diagrams exhibit normal distributions around one peak, with the recovered bladelets rather as by-products of the continuous reduction of blade cores. We will further investigate whether or not this observation is an artifact of the size cut-off point of 30 mm used in this study.]

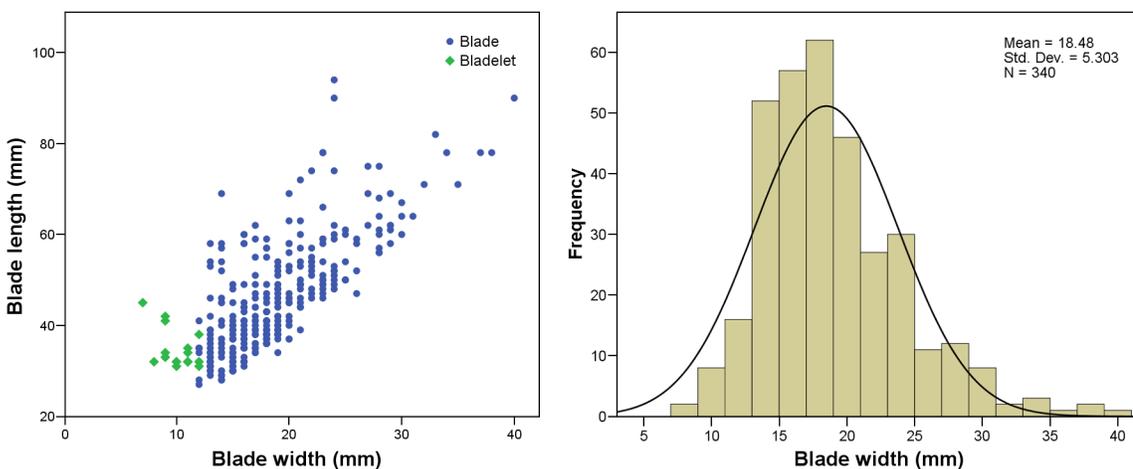


Fig 5. Scatter plot of blade widths and lengths (left) and histogram of blade widths (right) for the combined sequence WOG1-BSP.

doi:10.1371/journal.pone.0130001.g005

Table 5. Distribution of core categories¹.

Layer	Parallel	Platform	Inclined	Bipolar	IBR ¹
BSP	6	5	2	3	3
SPCA	8	4	-	-	-
CHE	2	1	-	-	-
MA	-	1	-	-	-
IV	5	7	1	-	1
BM	2	1	-	-	-
POX	1	4	3	-	4
BP	-	-	1	-	-
SU	5	3	1	-	2
SP	3	2	-	1	-
WOG1	1	1	-	3	-
Total	33	29	8	7	10

¹Core classification follows the taxonomy of Conard *et al.* [71]; IBR = indeterminate broken.

doi:10.1371/journal.pone.0130001.t005

Reduction of cores. The methods of core reduction constitute an integral part of the technological system of MSA knappers. We chose the unified taxonomy by Conard *et al.* [71] to provide a comparable framework of core classification. We focus on the differential frequency and thus variation in use of reduction strategies, since one can commonly identify multiple knapping strategies in a single assemblage (e.g. [53] p.120). Due to the scarcity of cores in each assemblage (Table 5) and their intense degree of exploitation, the discussion of reduction strategies also draws heavily on information gained from the morphology, geometry and dorsal scar configuration of debitage products. Due to the problem of equifinality in lithic reduction, many debitage products cannot be unambiguously attributed to a specific reduction system. We thus base the following discussion on specific forms that could be directly and repeatedly associated with a particular core reduction system. While these observations cannot provide precise quantitative data, they do inform on the absence or presence of certain core reduction systems as well as their relative abundance within the studied sequence. Table 6 summarizes

Table 6. Relative prevalence of the main methods of core reduction within the sequence¹.

Layer	Parallel (Levallois)	Platform (Laminar)	Inclined (Discoid)
BSP	++ ²	++	+
SPCA	++	++	-
CHE	+	+	-
MA	+	+	-
IV	++	++	-
BM	++	++	+
POX	-	++	++
BP	-	++	++
SU	+	++	++
SP	++	-	+
WOG1	++	-	+

¹Summary based on observations from the entire lithic assemblage, including the frequency of both cores and debitage products typical for one of the reduction systems

²Code of prevalence: ++ = frequent; + = common; - = rare.

doi:10.1371/journal.pone.0130001.t006

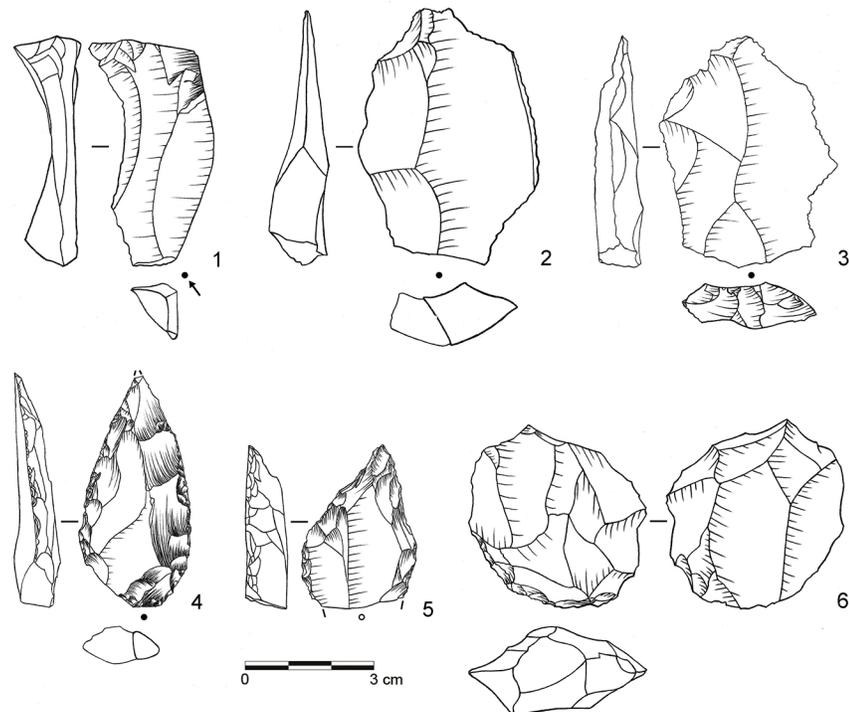


Fig 6. Selection of stone artifacts from assemblage BP. 1: Overshot flake from unidirectional platform blade core (dolerite, D3-955); 2: Levallois flake with partial core edge (dolerite, D3-922); 3: Levallois flake (dolerite, C3-896); 4: Unifacial point, Ndwedwe (hornfels, C3-951); 5: Asymmetric unifacial point, ACT (dolerite, C3-891); 6: Inclined core (dolerite, C3-929). (Drawings by L. Brandt and M. Lajmiri)

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these observations. There are three principle methods of core reduction which vary in abundance: Parallel, platform and inclined. Figs 6–11 provide an overview for the cores and products of these systems for the newly described assemblages WOG1-POX (see [32]: Figs 10 and 11 for cores from BM-BSP).

Parallel methods at Sibudu mostly follow a Levallois system of reduction (*sensu* [43, 88]). The cores exhibit two hierarchical and non-interchangeable surfaces and the major removals are executed parallel to the plane that intersects the two surfaces from prepared striking platforms (Fig 10: 1–3; Fig 11: 1–2). Using this method, knappers produced large rectangular, oval or convergent flakes often with faceted platforms, flat longitudinal profiles and exterior platform angles (EPA) around 90° (Fig 6: 2–3; Fig 7: 13–16; Fig 9: 13–15). In most cases, the reduction of parallel cores proceeded by unidirectional or centripetal removals with a few cores showing preferential or bidirectional modalities. Based on the number of cores and specific products, knappers used parallel production predominantly in BM-BSP and WOG1-SP (Table 6). The assemblages that lie in between (SU-POX) show a low prevalence of this method, but with some diagnostic Levallois flakes.

The second reduction system comprises various platform approaches [71, 89–91]. At Sibudu, knappers set up one or multiple platforms and removal surfaces to produce either blades or flakes (Fig 8: 3; Fig 10: 5; Fig 11: 3). The organization of multi-platform cores encompasses 2–3 platforms either positioned adjacent or opposed to one another. The platforms themselves are mostly plain, sometimes prepared and rarely cortical. Knappers mainly detached blanks from one removal surface, but cores with two or three removal surfaces also occur. The removal surfaces were located on both the broad and the narrow faces of the cores.

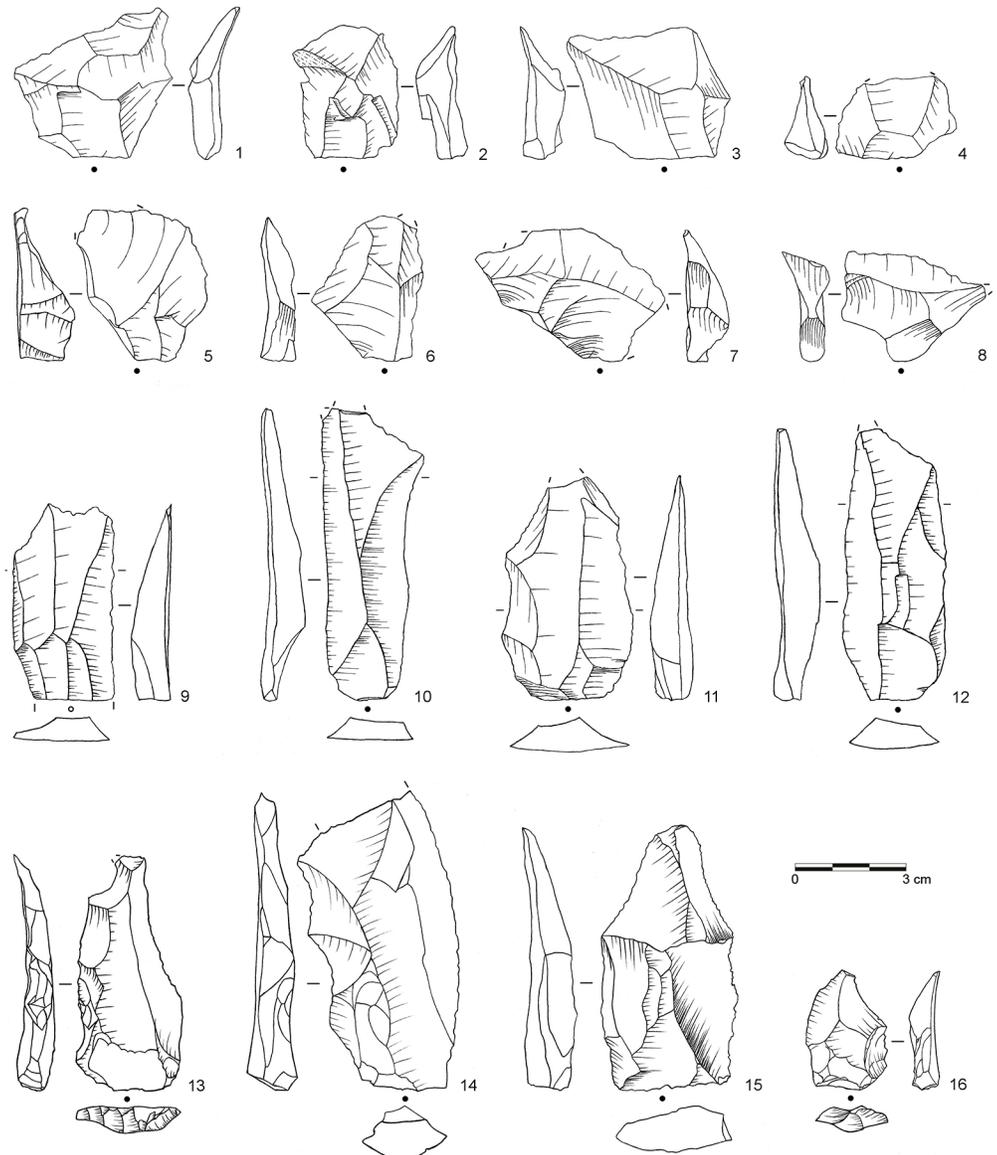


Fig 7. Selection of blanks from assemblage POX. 1–2: Inclined flake, invasive (both dolerite, E3-824, D3-599.4); 3–4: Inclined flake, central (both dolerite, E2-555, E2-638); 5–8: Inclined flake, partial core edge (all dolerite, E3-939, E3-973, D2-450, E3-909); 9: Blade, bidirectional (hornfels, D2-592); 10–11: Blade, bidirectional (dolerite, D3-600, E3-871); 12: Blade, orthogonal (E2-485); 13–16: Levallois flake (all dolerite, C2-934, D2-627, D2-646, D2-610.10). (Drawings by L. Brandt and M. Lajmiri)

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Platform methods were particularly used for the manufacture of blades. Most of the blades from the optimal phase of debitage show plain or faceted platforms with recurrent unidirectional removals on their dorsal surfaces (Fig 6: 1; Fig 9: 10, 12), but bidirectional patterns also occur in low numbers (Fig 7: 9–12; Fig 9: 11). There are total of 7 platform bladelet cores throughout the sequence, typically with one or two plain striking platforms and one removal surface (Fig 10: 6; see also [32]: Fig 11). Blades and platform cores are most common throughout BM-BSP and are still frequent in the underlying assemblages SU-POX (Table 6). The deepest assemblages SP and WOG1 yield little evidence for this core reduction strategy.

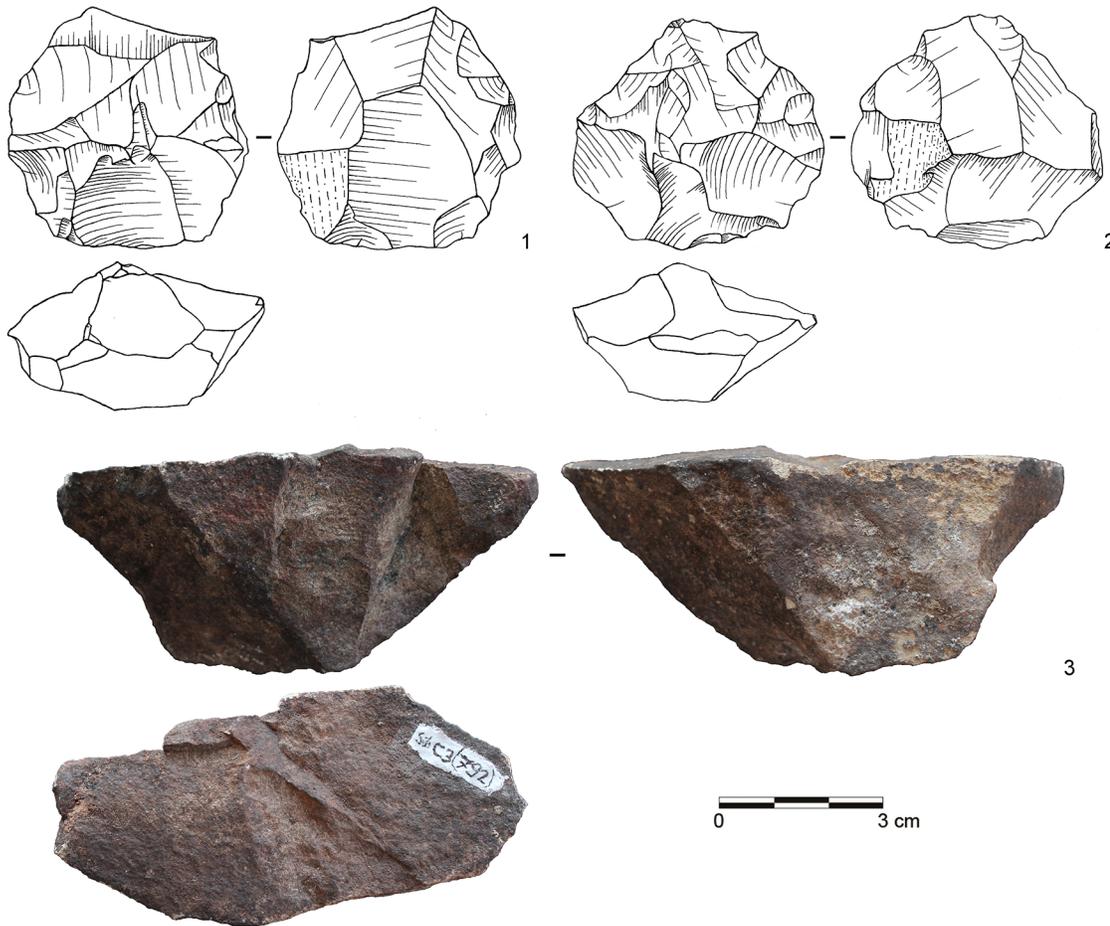


Fig 8. Selection of cores from assemblage POX. 1–2: Inclined core, bifacial (both dolerite, E2-700; E2-708); 3: Single-platform core, blades (dolerite, C3-792). (Drawings by L. Brandt and M. Lajmiri; photograph by J. Becher)

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Knappers used an inclined approach to produce flakes of various morphologies, similar to a discoid method (*sensu* [88, 92, 93]) in which removals are inclined relative to the plane defined by the intersection of the two non-hierarchical core surfaces. Two cores from layer POX exemplify this strategy at Sibudu (Fig 8: 1–2; see also Fig 6: 6; Fig 10: 4): Knappers detached flakes with an inclined angle in an alternating bifacial manner from two interchangeable surfaces of the core. This strategy lead to conically shaped surfaces and involved no preparation of platforms, as suitable angles are created by the previous inclined removals. Unifacial inclined cores with only one removal surface occur rarely. Knappers removed flakes either along the lateral edges of the core or in centripetal pattern. The diagnostic products from the edges include core edge flakes (or *éclat débordant*; Fig 7: 5, 8; Fig 9: 8) and partial core edge flakes (or *dos limité*; Fig 7: 6–7; Fig 9: 3–7). Thick central flakes with triangular or quadrangular shape and EPAs <80° (Fig 7: 3–4; Fig 9: 2) and invasive flakes with centripetal negatives removing the conical surface of the core (Fig 7: 1–2; Fig 9: 1), derive from the central centripetal reduction. The blanks detached by this strategy are smaller and lighter, but often thicker and with lower EPAs, than those of the parallel production. Specific products and cores of the inclined strategy are most frequent in the middle of the studied sequence (POX-SU; Table 6). Knappers employed discoid reduction less often in the layers below (WOG1-SP) and only rarely or not at all in the upper part of the sequence (BM-BSP).

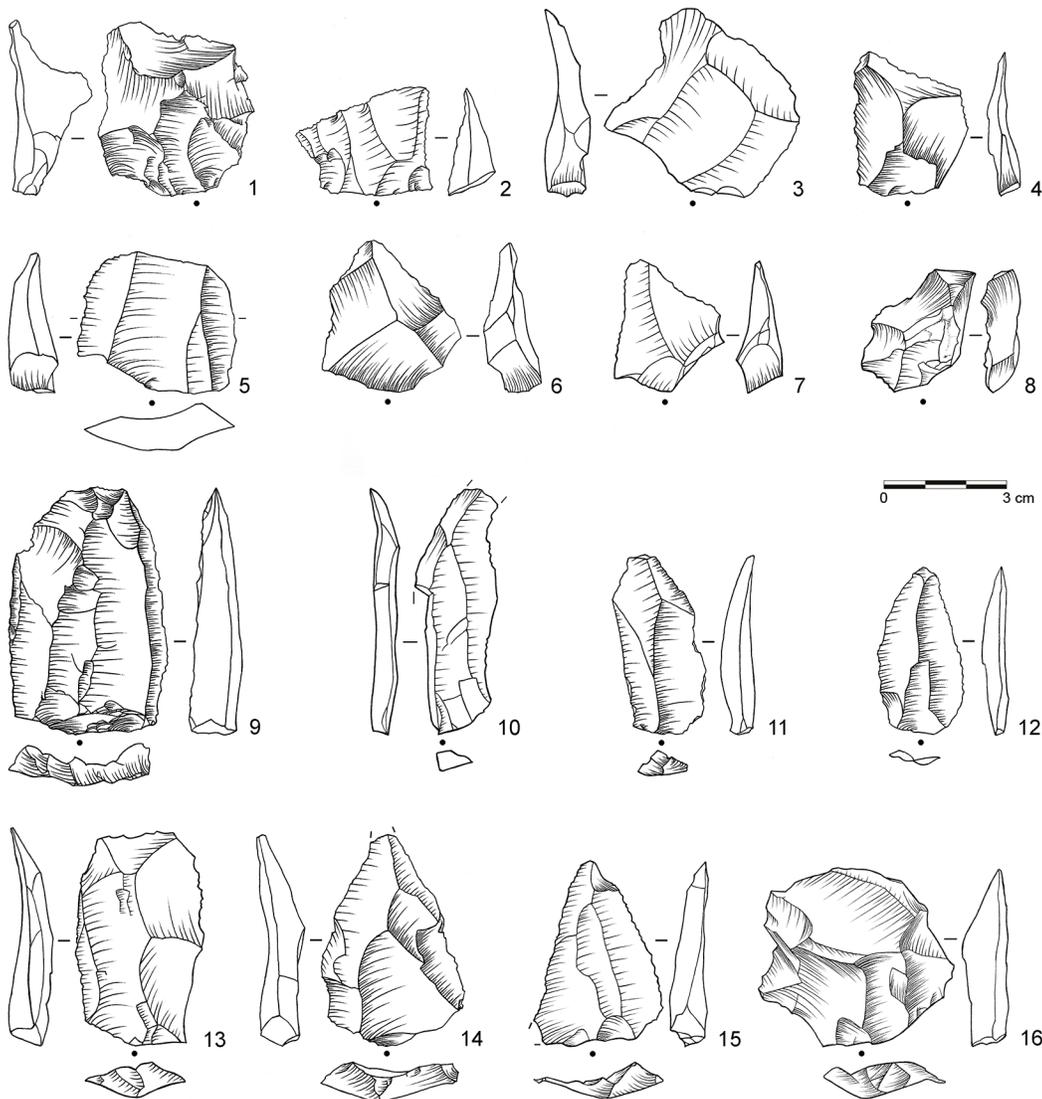


Fig 9. Selection of blanks from assemblage SU. 1: Inclined flake, invasive (dolerite, D3-1111); 2: Inclined flake, central (dolerite, E2-852); 3–4: Inclined flake, partial core edge (both dolerite, C3-1022, E2-947); 5–8: Inclined flake, partial core edge (all dolerite, C2-1236, D3-1222.5, D2-791, D2-838); 9: Laminar flake, bidirectional (dolerite, D3-1184); 10: Blade, unidirectional (dolerite, C2-1091); 11–12: Blade, bidirectional (both dolerite; C2-1005.3, C2-1183); 13: Levallois flake, unidirectional (dolerite, C3-982); 14–15 Levallois point (both dolerite, C2-1234, E2-934); 16: Levallois flake, centripetal (dolerite, C2-1220). (Drawings by M. Lajmiri)

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Throughout the sequence we found only circumstantial and discontinuous evidence for cores on flakes, the use of burins for the production of bladelets (Fig 10: 6–7; $n = 5$; in SPCA, BM, POX and SU) and bipolar technology. Bipolar cores occur at the top (BSP; $n = 3$) and bottom of the sequence (SP and WOG1; $n = 4$), most often on quartz (5/7). It is also the quartz blanks that show most frequent traces of bipolar percussion.

Knapping technique. The technical act of detaching a flake from a core constitutes another major variable in technological behavior [94]. We previously described a dichotomy in knapping techniques in layers BM-BSP [32]. Knappers often produced convergent flakes with internal percussion using hard stone hammers, whereas they tended to detach blades with a soft stone hammer. We followed the same analytical procedure to examine assemblages

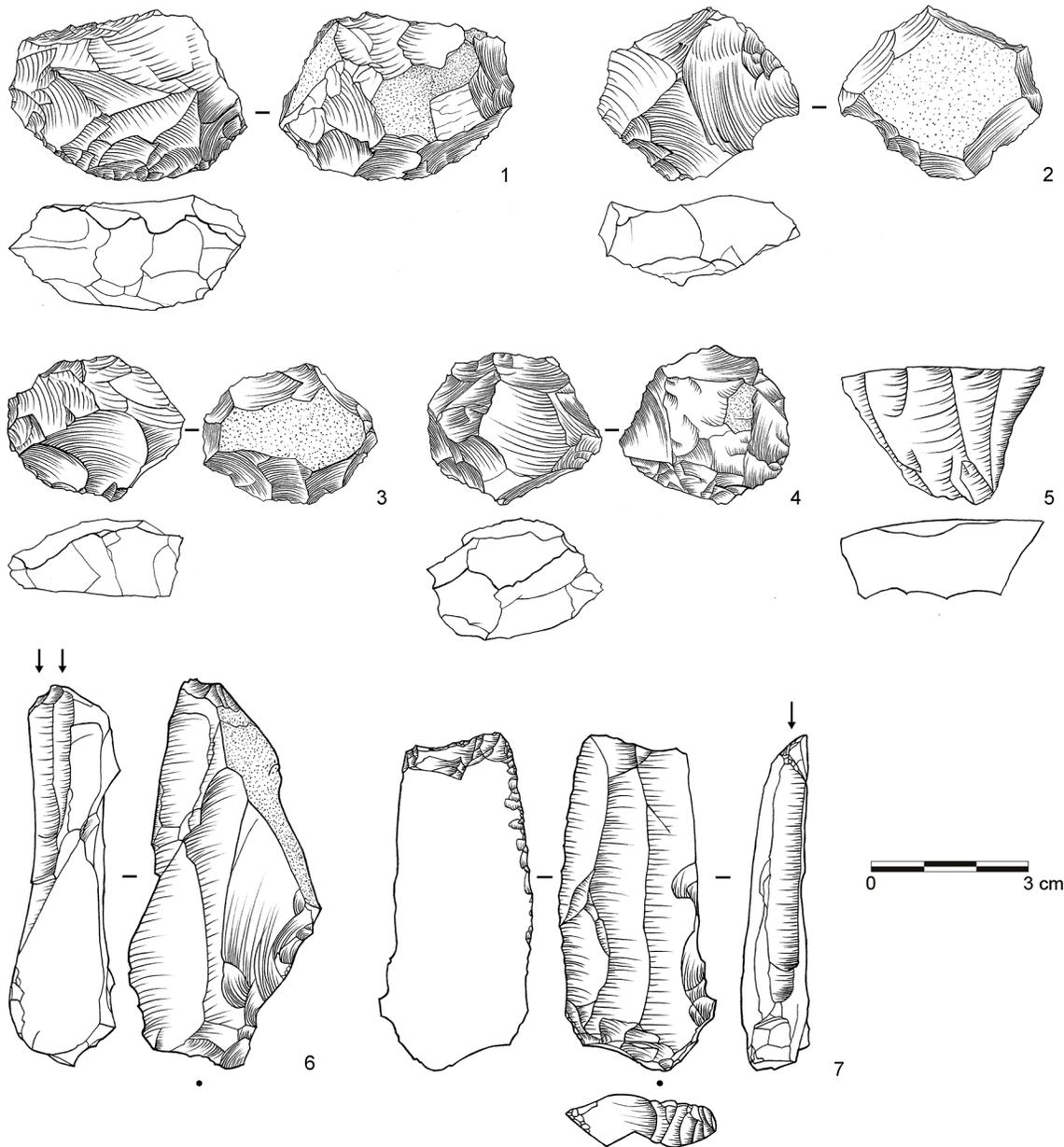


Fig 10. Selection of cores from assemblages SU. 1: Parallel core, bidirectional (dolerite, E2-854); 2: Parallel core, centripetal (dolerite, D3-1082); 3: Parallel core, unidirectional (dolerite, E3-1246.1); 4: Inclined core, bifacial (E3-1214); 5: Single-platform core, blades (dolerite, C2-1192); 6: Single-platform core on flake, bladelets (hornfels, C2-1127); 7: Burin on tool, bladelets (hornfels, C2-1026). (Drawings by M. Lajmiri).

doi:10.1371/journal.pone.0130001.g010

WOG1-POX (see [32] Tab. 6). Our results suggest that the inhabitants followed similar approaches throughout the entire sequence. Flakes and convergent flakes in WOG1-POX exhibit frequent and well-developed bulbs, few proximal lips and shattered bulbs, thick platforms (average = 6.0 mm, mode = 4.0 mm; n = 2927), abundant longitudinal breaks and EPAs clustering around a modal value of 90°. These observations are consistent with percussion by a hard stone hammer a couple of millimeters away from the core edge (internal percussion; *sensu* [94]). Blades, on the other hand, exhibit fewer and generally less-developed bulbs, moderate occurrence of lips (10–25%), abundant shattered bulbs (>40%), EPAs with modal values

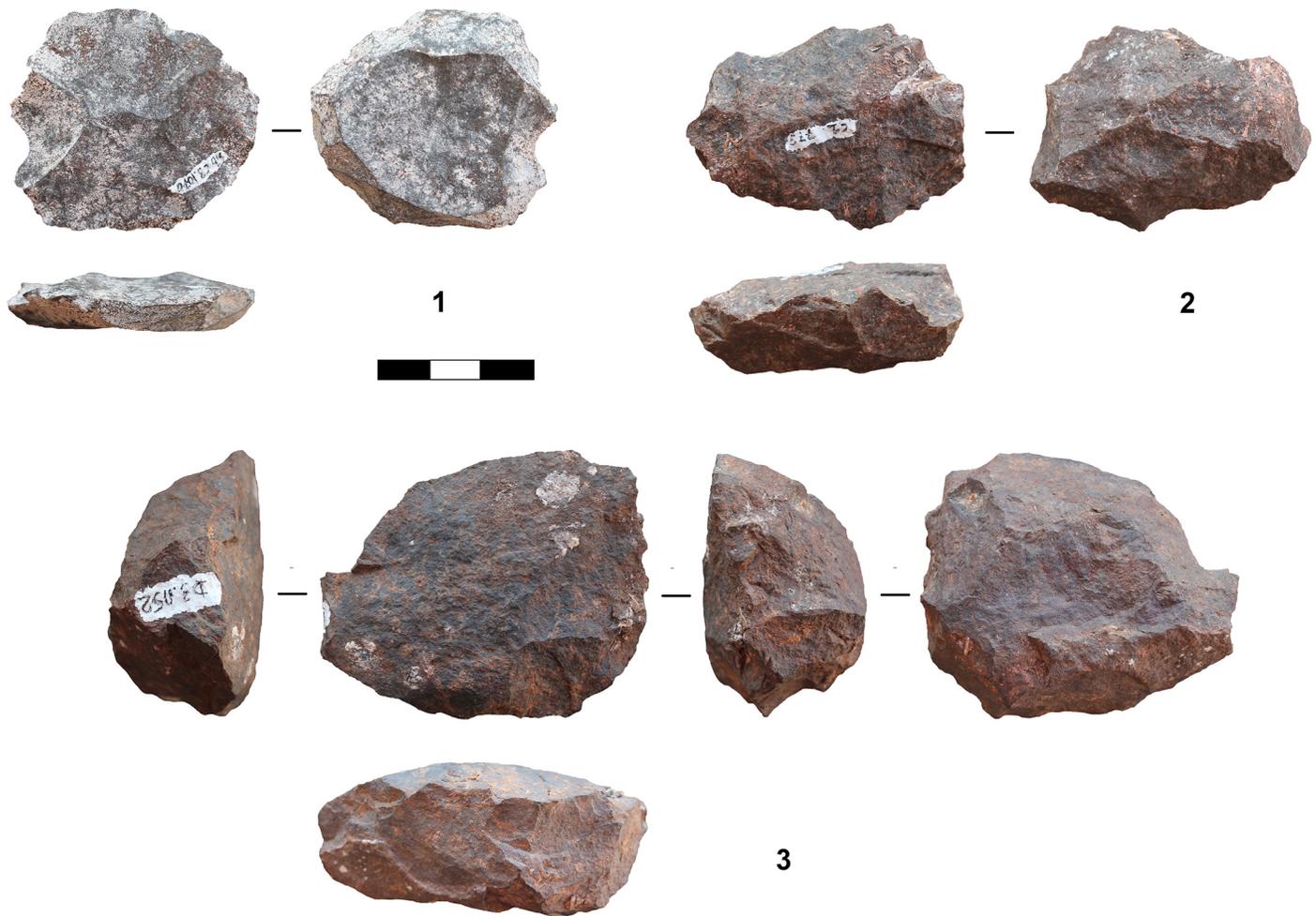


Fig 11. Selection of cores from assemblage SP. 1: Parallel core, centripetal (dolerite, C3-1070); 2: Parallel core, centripetal (dolerite, C2-773); 3: Single platform core, flakes (dolerite, D3-1152.3). (Photographs by J. Becher)

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close to 85° and thick platforms (average = 4.6 mm, mode = 3.0 mm, n = 394). We also found frequent contact points of the hammer on the striking platform, identifiable by a semi-circular break of the internal delineation of the platform and crushing in this circumscribed area. These observations suggest that knappers predominantly used soft stone hammers with internal percussion for blade production [94–96].

While the inhabitants employed consistent knapping techniques, they varied their approach to platform preparation. WOG1 and SP show comparably high values of platform faceting (23%) similar to the uppermost layers BM-BSP (22–29%), with many platforms having several facets. In between these assemblages, SU-POX show consistently less platform preparation (12–16%) and most platforms exhibit three or fewer facets. This difference can be related to the less frequent use of parallel core reduction methods in SU-POX, which involve a larger degree of core preparation compared to platform or inclined strategies.

Techno-economic measures. Diachronic comparisons of three independent measures regarding reduction intensities converge to the same picture. In terms of blank to tool ratio [55], total core mass to total assemblage mass ratio [56] and average thickness and length of blanks and cores [54, 55], SU-POX produce the most reduced signature (S2 Table). The

uppermost layers BM-BSP exhibit far lower reduction intensities, with MA being an outlier due to low sample size. The deepest assemblages WOG1 and SP lie in between these broad patterns. Studying the flaking efficiency of an assemblage can corroborate analyses of reduction intensities as it measures the efficiency by which knapping strategies convert a mass of stone into flake edge [58, 97]. To eliminate the potential impact of different raw materials on this measure, we analyzed flaking efficiency for dolerite only in each assemblage. The results mirror the findings from the reduction intensities. Knappers used dolerite during SU-POX in the most efficient manner, followed by WOG1-SP. Above POX, there is a consistent decrease in flaking efficiency (S3 Table).

Calculation of lithic find densities (n/m^3) provides a third independent line of evidence to reconstruct techno-economic behavior, with the assumption that higher values reflect more knapping activities and artifact discard taking place on site. Total lithic densities at Sibudu range between ca. 14,000–90,000 n/m^3 , very high values compared to the few other published figures for MSA occupations (see [98, 99]). There are, however, no published density values from sites with comparable environmental setting, taphonomic context or site type which complicates a comparative assessment of settlement intensity between MSA localities based on this measure alone. In terms of intra-site patterns (Fig 12), SU-POX demonstrate by far the highest densities for small lithic finds (<30 mm; 67,000–84,000 n/m^3). The upper six layers BM-BSP (31,000–48,000 n/m^3) come in second, followed by the bottom strata WOG1-SP (12,000–22,000 n/m^3). Combining all independent observations, the inhabitants of Sibudu reduced their tool stones most intensely and most efficiently during the formation of the layers SU-POX. This techno-economic behavior resulted in the highest density of lithic finds from these layers within the occupation sequence.

Tool assemblages: Typological, technological and techno-functional analysis

Retouched artifacts from the newly described assemblages BP, POX and SU are illustrated in Figs 6, 13 and 14 (for BSP-BM, see [32]: Fig 3–5 and 13). From a traditional typological point of view [64, 65], and taking southern African MSA taxonomy into consideration [85, 86, 100], several varieties of unifacial points constitute the most abundant tool type in the studied sequence ($n = 347$; 45%; Fig 6: 4–5; Fig 13: 1–6; Fig 14: 1–7). They are followed by side scrapers ($n = 118$; 16%; Fig 14: 8), lateral retouch on blades ($n = 62$; 8%; Fig 14: 9–10) and denticulates

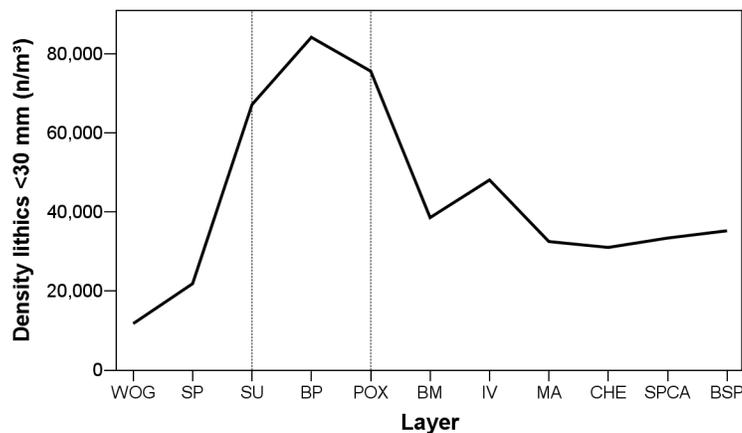


Fig 12. Lithic density (n/m^3) of stone artefacts (<30 mm) throughout WOG1-BSP. Sample sizes for each assemblage can be found in Table 1. WOG1 = oldest layer; BSP = youngest layer.

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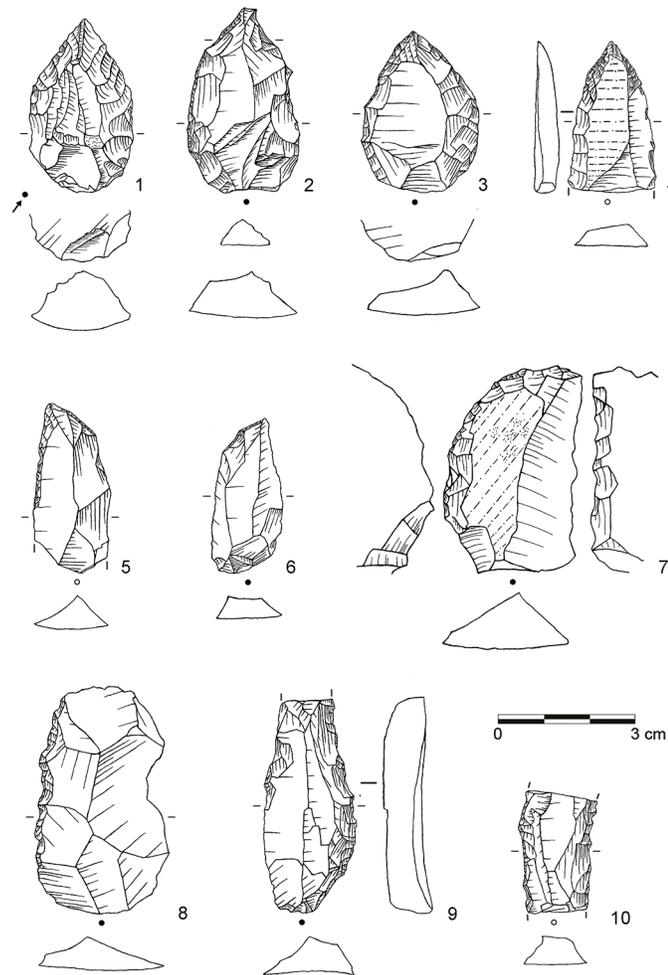


Fig 13. Selection of tools from assemblage POX. 1–3: Unifacial point, Tongati (all dolerite, C3-868, D2-596, C2-763.7); 4: Unifacial point, Tongati (hornfels, E3-977); 5: Unifacial point, ACT (hornfels, C2-717); 6–7: Unifacial point, ACT (both dolerite, D3-856; D3-615); 8) Denticulate (dolerite, D2-446); 9: Lateral retouch, Ndwedwe (dolerite, D3-619); 10: Lateral retouch, Ndwedwe (hornfels, D3-608). (Drawings by L. Brandt)

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and notches ($n = 55$, 6%; [Table 7](#), [Fig 13](#): 9–10). Backed pieces and bifacial points occur rarely. There are consistent diachronic changes within WOG1-BSP in overall retouch frequencies (see above) and tool composition ([Table 7](#)). In the bottom layers WOG1 and SP, unifacial points and side scrapers occur only in low numbers or not at all, whereas denticulates and notches constitute the most abundant tool type (40–78%). In the following assemblages SU and POX, unifacial points (27–37%) and side scrapers (7–23%) become more frequent and notched retouch decreases (13–19%). The youngest assemblages BM-BSP are characterized by very high proportions of unifacial points (38–54%), many side scrapers (7–23%) and few if any denticulates and notches (0–6%).

Notwithstanding the low sample sizes of tools in some layers (WOG1, SP and BP), knappers reorganized their approach towards transforming blanks throughout the sequence. Whereas single-layered notched and marginal retouch prevails in the lower assemblages, multi-layered and invasive retouch that frequently reshaped the original morphology of the blanks characterizes the upper layers. Together with the overall proportion of tools and retouch debitage, as well as the diminished diversity in tool forms, these data suggest

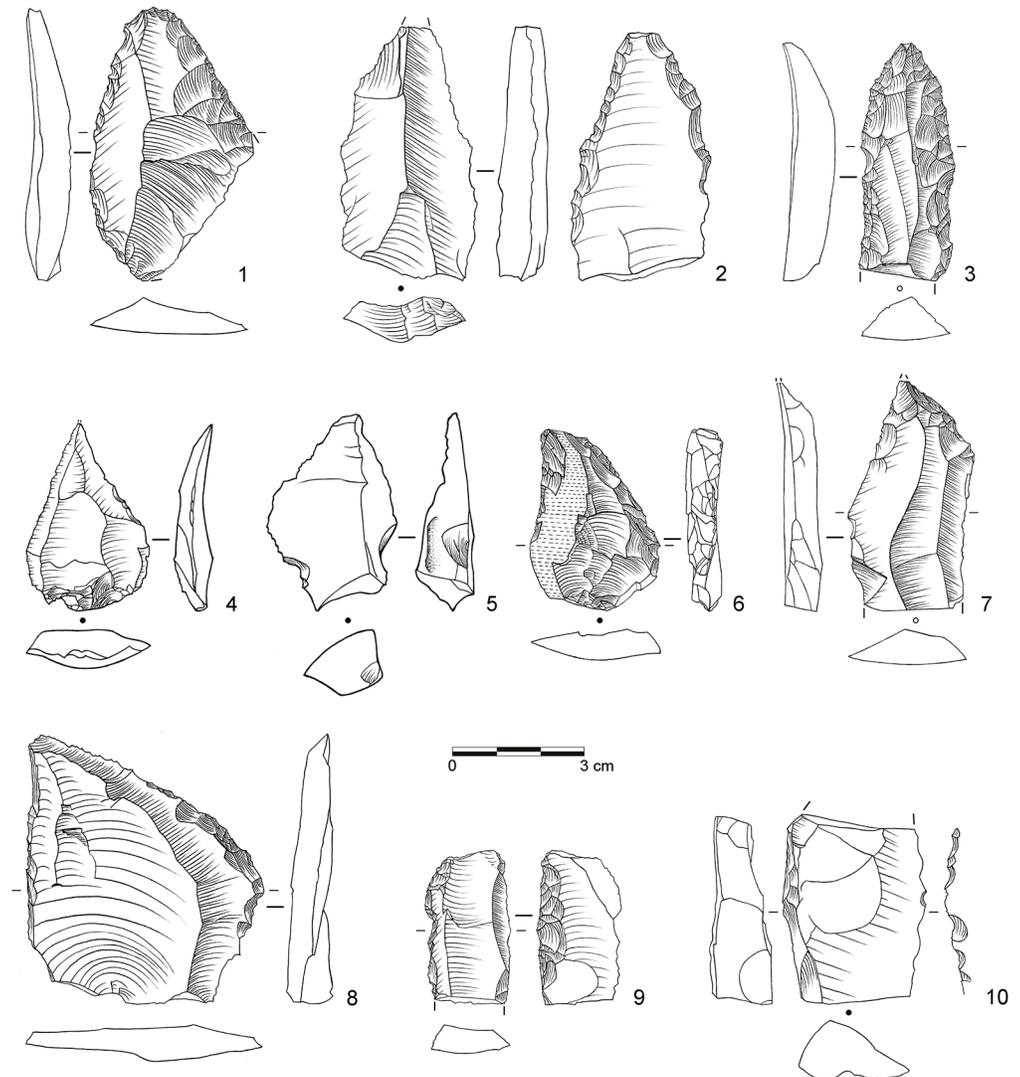


Fig 14. Selection of tools from assemblage SU. 1–2: Unifacial point, Tongati (both dolerite, C3-999, C3-991); 3: Unifacial point, Ndwedwe (dolerite, D3-1036); 4: Unifacial point (dolerite, E3-1092); 5: Unifacial point, notched (dolerite, E2-922); 6–7: Unifacial point, ACT (both dolerite, C3-1032, C2-1012.18); 8: Transverse scraper, NBT (dolerite, C3-996); 9: Lateral retouch (dolerite, D3-1078); 10: Denticulate, NBT (dolerite, C3-979.1). (Drawings by L. Brandt and M. Lajmiri)

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that inhabitants at Sibudu put less effort and time into on-site tool production and recycling during the lower part of the studied sequence. Regarding their different compositions, it is likely that the tool kits served different functional needs. This hypothesis will be further investigated by diachronic residue and micro-wear studies currently underway by V. Rots.

In order to examine the inhabitant's preference for retouching certain blank types, we devised a "Blank Retouch Index" (BRI) which is computed analogous to the "Raw material Retouch Index" by Orton [101]. The index is calculated by dividing the proportion of a raw material (or blank type) among all tools by the overall proportion of the same raw material (or blank type) for all assemblages. Higher values indicate a stronger retouch preference for a particular raw material (or blank type). According to the BRI, knappers preferentially selected convergent flakes and blades to manufacture tools (S4 Table). Flakes and bladelets were less likely

Table 7. Distribution of traditional tool types.

Layer	Unifacial Point	Side Scraper	Lateral Retouch	Denticulate & Notch	End Scraper	Backed tool	Bifacial Point	Hammer-stone	Minimal retouch	Other
BSP	67 (47%)	24 (18%)	14 (10%)	4 (3%)	2 (1%)	2 (1%)	2 (1%)	2 (1%)	19 (13%)	7 (5%)
SPCA	48 (46%)	24 (23%)	6 (6%)	4 (4%)	3 (3%)	-	-	2 (1%)	9 (9%)	8 (8%)
CHE	11 (38%)	7 (24%)	3 (10%)	-	-	-	-	-	8 (28%)	-
MA	26 (54%)	10 (21%)	3 (6%)	-	1 (2%)	-	-	-	5 (11%)	3 (6%)
IV	97 (54%)	23 (13%)	15 (8%)	11 (6%)	1 (1%)	2 (1%)	1 (1%)	1 (1%)	20 (11%)	8 (4%)
BM	29 (52%)	7 (12%)	6 (11%)	-	1 (2%)	-	-	-	10 (18%)	3 (5%)
POX	49 (37%)	9 (7%)	9 (7%)	17 (13%)	1 (1%)	2 (1%)	-	-	42 (31%)	4 (3%)
BP	5 (62%)	1 (13%)	-	-	-	-	-	-	2 (25%)	-
SU	14 (27%)	12 (23%)	4 (8%)	10 (19%)	-	-	-	-	11 (21%)	1 (2%)
SP	-	-	2 (22%)	7 (78%)	-	-	-	-	-	-
WOG1	1 (20%)	1 (20%)	-	2 (40%)	-	-	-	-	1 (20%)	-
Total	347 (45%)	118 (16%)	62 (8%)	55 (6%)	9 (1%)	6 (1%)	3 (0%)	5 (1%)	127 (17%)	34 (5%)

Rounded percentages are given in brackets.

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to be retouched. The inhabitants applied retouch almost exclusively to the dorsal side of blanks (91%) and rarely to the ventral (4%) or both (5%) faces.

The main techno-functional tool classes and reduction chains at Sibudu comprise Tongatis, Ndwedwes, naturally backed tools (NBTs), and asymmetric convergent tools (ACTs). We found an initially slow and gradual appearance of the four main tool classes throughout the sequence, followed by a more rapid increase (Table 8; S2 Fig). The oldest assemblages WOG1-SP exhibit only NBTs, whereas SU-POX features all four tool classes with combined frequencies of 33–55% (Figs 6, 13 and 14). Layer SU, the first assemblage featuring Tongatis, Ndwedwes and ACTs, provides only low frequencies of these tools (4–6%). The four main tool classes continue to appear in the upper layers BM-BSP, but with much higher combined frequencies (67–77%), particularly for Tongatis and Ndwedwes (50–67%; see [32]: Figs 3–5). These results again demonstrate that the lowest layers WOG1-SP yield a very different

Table 8. Distribution of techno-functional tool classes.

Layer	Tongati	Ndwedwe	NBT	ACT	Splintered piece	Formal tool	Broken tool	Other
BSP	37 (26%)	34 (24%)	18 (13%)	9 (6%)	4 (3%)	20 (14%)	15 (11%)	5 (3%)
SPCA	30 (29%)	22 (21%)	10 (10%)	7 (7%)	4 (4%)	13 (12%)	16 (15%)	2 (2%)
CHE	9 (31%)	6 (21%)	4 (14%)	1 (3%)	-	2 (7%)	7 (24%)	-
MA	20 (42%)	12 (25%)	3 (6%)	2 (4%)	1 (2%)	4 (8%)	6 (13%)	-
IV	74 (42%)	29 (16%)	19 (11%)	14 (8%)	3 (2%)	13 (7%)	22 (12%)	4 (2%)
BM	18 (32%)	10 (18%)	6 (10%)	5 (9%)	1 (2%)	2 (3%)	13 (23%)	2 (3%)
POX	29 (22%)	8 (6%)	10 (7%)	11 (8%)	1 (1%)	30 (23%)	43 (32%)	1 (1%)
BP	3 (34%)	1 (11%)	-	1 (11%)	-	1 (11%)	2 (22%)	1 (11%)
SU	3 (6%)	2 (4%)	10 (20%)	2 (4%)	-	20 (39%)	14 (27%)	-
SP	-	-	5 (56%)	-	-	3 (33%)	1 (11%)	-
WOG1	-	-	1 (20%)	-	-	1 (20%)	3 (60%)	-
Total	223 (29%)	124 (16%)	86 (11%)	52 (7%)	14 (2%)	110 (14%)	142 (19%)	15 (2%)

Rounded percentages are given in brackets.

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signature regarding the composition of tool kits. The absence of three main techno-functional tool classes, and thus the lack of the deliberate construction of certain edge modifications of the later assemblages indicates differences in functional needs and potentially site use.

Reduction sequences and use of raw materials

In previous work we observed a consistent pattern of differential raw material use between the two main tool stones of layers BSP-BM at Sibudu [32]. While both raw materials exhibit complete reduction sequences, the non-local, high-quality hornfels shows a stronger emphasis on retouch and curation, with knappers investing more energy and time in its treatment compared to the local, coarser-grained dolerite. For the layers below (WOG1-POX), we found similar trends but also differences. The strong decrease in the use of hornfels in layers SP-POX (1–6%) compared to assemblages BM-BSP, results in difficulties documenting the entire reduction sequence, in part due to the small size of these samples. Although the number of hornfels pieces is low in SU-POX, still 21–29% of this raw material are retouched, a very high percentage compared to dolerite (2–5%). Cores made from hornfels are missing (SP and BP) or very rare (n = 1; SU and POX) and hornfels blanks are predominantly non-cortical. These data suggest that the early knapping stages of hornfels took place elsewhere for assemblages SP-POX, with knappers mainly importing finished blanks and tools to the site. Dolerite, on the other hand, exhibits complete reduction sequences throughout the entire sequence WOG1-BSP. Consistent with this qualitative observation, all cortex values (0–100%) occur for dolerite in each assemblage in a gradually declining fashion (S5 Table). In contrast to the rest of the sequence, knappers reduced sandstone completely on-site in the oldest layers WOG1 and SP, including initialization, reduction of cores and tool manufacture. Quartz and quartzite exhibit mostly incomplete reduction chains, with the initial stages of knapping far better represented than the distal phases. Quartz in particular shows a high ratio of cores to blanks and tools.

We sampled a total of 15,605 small lithic products (<30 mm) from six layers by raw material, dividing the sample into 5–10 mm and 10–30 mm size classes (S6 Table). These data provide a proxy for the intensity of on-site knapping for a particular raw material. The results for both size classes mirror the observations for raw material proportions of artifacts >30 mm. There is ample evidence for on-site knapping of hornfels in the upper part of the sequence, but not in layers WOG1-BP. In contrast, knappers reduced dolerite in all assemblages, though to varying degrees, with sandstone showing a peak in the two oldest layers.

The Raw Material Retouch Index shows that knappers strongly favored hornfels for the production of tools when it was in use, with blanks of this raw material being four times more likely to be retouched than those of dolerite (Table 9). The inhabitants rarely modified

Table 9. Raw material retouch index (RMRI) for the combined assemblages WOG1-BSP.

Raw material	Tools (n)	Tools (%) ¹	RMU (%) ²	RMRI ³
Dolerite	440	57.4	78.5	0.73
Hornfels	305	39.7	13.6	2.91
Quartzite	7	0.9	2.0	0.46
Sandstone	10	1.3	5.3	0.25

¹Proportion of tools made on this raw material in all assemblages combined.

²Overall proportion of raw material in all assemblages combined.

³RMRI = Raw Material Retouch Index: Tools (%) / RMU (%) (after [101])

quartzite and sandstone. We also found a very strong and highly significant correlation between the proportion of hornfels and retouched pieces in the studied sequence ($r = 0.934$; $p < 0.001$). Fig 15 demonstrates a clear separation between the upper assemblages with intense hornfels use and very frequent manufacture of tools (BM-BSP) and the lower layers characterized by low degrees of retouch and little procurement of hornfels (WOG1-POX).

Discussion

Short-term cultural change in the high-resolution MIS 3 sequence of Sibudu

We analyzed eleven successive lithic assemblages (WOG1-BSP) from early MIS 3 deposits at Sibudu. This sequence demonstrates considerable diachronic variation in technological behavior within a high-resolution stratigraphy. The studied assemblages all date to ~58 ka [21, 22], suggesting that the behavioral changes likely took place over a period of centuries. Our study thus documents an exceptional case of short-term cultural variability during the MSA. The findings reported here stand in contrast to our results from the six uppermost layers of these deposits (BM-BSP), which yielded a homogeneous cultural signature [31, 32]. Based on the results of this study, however, we can now distinguish between three phases (S7 Table). From bottom to top these are:

- WOG1 and SP: The lithic technology is characterized by the procurement of local raw materials with the most frequent use of sandstone and an absence of non-local tool stones. Knappers invested little effort and time in making tools, but they produced predetermined convergent flakes with the dominant use of parallel methods. Platform preparation and the manufacture of blades played only a minor role. The tool assemblages exhibit little diversity in implements and consist mostly of notches and denticulates, with a near-absence of unifacial points. Only NBTs occur as techno-functional tool class characteristic of the Sibudan. Lithic find densities are comparably low and knappers did not reduce their raw materials in a particularly intense manner.

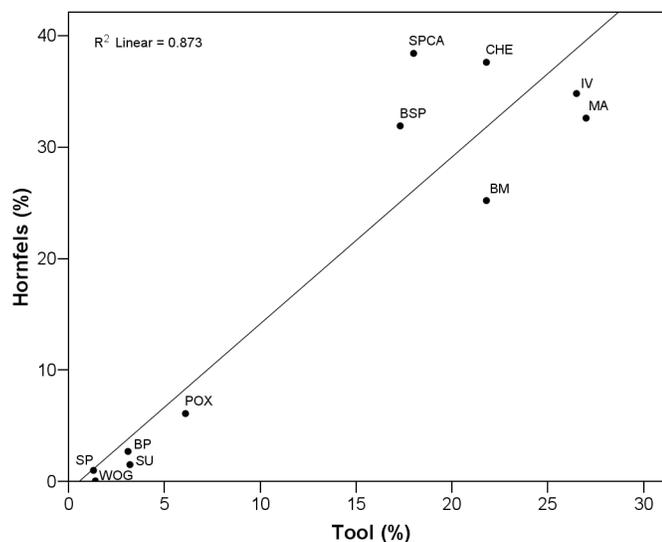


Fig 15. Linear regression of tool percentage and hornfels percentage of assemblages WOG1-BSP ($R^2 = 0.873$; $p < 0.01$).

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- SU-POX: The occupants of Sibudu predominantly collected and reduced the local dolerite in these assemblages, with low but gradually increasing proportions of non-local hornfels. Core reduction proceeds most often by an inclined method with little core preparation but high output of small blanks. Blades become an important blank type, produced by various platform methods. Tool frequencies are low but increase gradually, with more frequent unifacial points and a decrease in notched and denticulated implements. Tongatis, Ndwedwes and ACTs appear for the first time. They begin in low frequencies and increase considerably through this part of the sequence. Knappers reduced their raw materials in the most intense way, associated with inclined reduction strategies which produce a larger number of small flakes per core, a behavior that also resulted in the highest lithic densities within the sequence.
- BM-BSP: The assemblages exhibit a strong emphasis on the use of non-local hornfels combined with continued exploitation of dolerite. The inhabitants of Sibudu invested more time and energy in the production and curation of tools, with high retouch proportions and a diverse tool kit, as well as in the preparation of cores. Platform methods for the production of blades dominate, followed by the use of parallel systems, with little reduction by inclined strategies. Various forms of unifacial points constitute the main typological signature, whereas notches and denticulates are rare or absent. The four main techno-functional tool classes occur frequently and in all assemblages. Knappers used their raw materials in a less efficient manner and produced the largest products within the studied sequence (see also [32]).

The phases represent different strategies of lithic technology, which build upon each other in a gradual, cumulative manner. The gradual trajectory of this change encompasses a continuous increase in non-local hornfels, a stronger emphasis on the manufacture of tools, as well as a rise in the abundance of unifacial points and the four main tool classes of the Sibudan throughout the entire sequence (S7 Table). Sometimes change follows a U-shaped trajectory, as is the case for lithic density, the abundance of faceted platforms, and the abundance of dolerite in the assemblages. Having said this, variation in these aspects is never discontinuous or erratic. Shifts in important elements of lithic technology most often occur between the groups WOG1-SP/SU-POX or SU-POX/BM-BSP (see S7 Table), supporting the notion of gradual and cumulative changes over time.

While the three assemblage groups were identified based on similar frequencies as well as absence or presence of traits (S7 Table), they can also be discriminated based on statistical analyses. Chi square tests for homogeneity find significant ($p < 0.05$) differences between the assemblage groups for traits pertaining to raw material selection, debitage distribution, blank production and tool manufacture (see S1 Text). Combined with observations on qualitative differences in core reduction methods and quantitative variations in lithic density, the tripartite division provides a robust diachronic framework for the technological sequence studied here.

Examining the causes of short-term behavioral change at Sibudu

In the following, we employ an organization of technology approach [102–107], apply evolutionary theory and draw from models of cultural transmission theory [53, 108–110] to examine the causes of the observed short-term behavioral changes. We assess the limits of these explanatory models and point to alternatives that may help to clarify the picture of cultural change during the MSA sequence of Sibudu and other nearby sites dating to early MIS 3. More specifically, we investigate whether changes in environment, subsistence, demography or other socio-cultural dynamics can be invoked as causal mechanisms for behavioral change at Sibudu.

Organization of technology. An organization of technology approach seems a promising explanatory model as much of the variation in lithic technology at Sibudu could be related to changes in raw material procurement and mobility strategies [59–63, 81, 103, 104, 111–113], as well as site use and reduction intensities of assemblages [54–56, 97, 114, 115]. Both access to raw material and its internal properties influence the choice of knappers and the composition of lithic assemblages [55, 59, 61, 63, 116]. The frequency of the procured raw materials, and the degree of their reduction, certainly had a strong influence on the assemblage compositions at Sibudu. The extremely high correlation between the proportion of hornfels and retouched artifacts constitutes a prime example (Fig 15). Theoretical considerations from behavioral ecology [55, 59, 63, 105, 116] predict that the degree of time and energy invested in the knapping, use and curation of this material will be higher than those for local raw materials of lower quality such as dolerite or sandstone. Exactly this pattern is reflected in the higher retouch rates and smaller artifacts made from hornfels. Furthermore, and in agreement with theoretical predictions, hornfels that travelled from further away entered the site more often as finished products and tools, with an under-representation of early products of the reduction sequence.

Knappers at Sibudu had access to a constantly high supply of dolerite and other local raw materials in the direct vicinity of the site. In theory, abundance of raw material should allow hunter gatherers to discard dulled artifacts without resharpening them and simply make new ones as needed [63, 81, 116–118]. The assemblages at Sibudu should thus on average have relatively low frequencies of retouched exhausted artifacts if scheduling of movements remained constant. Interestingly, only assemblages WOG1-POX are in accordance with the theoretical models for expedient technologies. In the upper part of the sequence, and even though raw materials were constantly abundant around Sibudu, the occupants of the site increasingly chose to use non-local hornfels. This pattern stands in contrast to theoretical predictions that claim that local resources will always be used when available (cf. [119]), but does none the less help to explain high retouch frequencies in these layers with abundant hornfels. While factors such as predictability of resources and scheduling of movements in the subsistence round constitute additional behavioral dimensions driving variable use of local vs. non-local raw materials in these models [81, 104, 116–119], Sibudu so far constitutes a single data point in the landscape, and we thus lack the necessary contextual information to evaluate these variables. We can only speculate on whether or not low predictability in access to resources and scheduling of movements in the lower part of the sequence could have led to an increased reliance on local rocks with higher reduction intensity, whereas increased predictability in the upper layers resulted in the opposite behavior. That being said, paleoenvironmental indicators, hunting behavior and principal site function remain more or less constant throughout the studied sequence (see below).

Raw material properties constitute an additional dimension that warrants consideration when comparing the techno-economic use of dolerite vs. hornfels (cf. [120]). Hornfels is easy to knap, but its sharp edges are fragile and have a higher tendency to break, rendering frequent resharpening necessary. In contrast, dolerite yields more durable edges that remain sharp for a long time, decreasing the need for retouch and resharpening [79]. We have previously hypothesized that this observation helps to explain the high percentage of tools in layers BM-BSP [32], and subsequently we have found a similar pattern at the MSA locality Holley Shelter [121]. In support of this, the abundance of tools decreases sharply in the lower occupation horizons where knappers used more durable local raw materials, such as dolerite, sandstone and quartzite.

Land-use strategies describe the pattern in which hunter gatherers move across the landscape over time, encompassing the selection of occupations, task specific locations, how they acquired resources and implemented lithic technology [103, 104, 122, 123]. The assemblages at

Sibudu can be divided into those with a strong predominance of local raw materials (WOG1--POX) and those with a high percentage of non-local hornfels (BM-BSP). Examining this criterion, mobility increases during the younger assemblages, either by larger range for activities related to subsistence or more frequent relocation of camps. As explained above, shortage in local raw materials cannot explain the archaeological signatures at Sibudu and changes in the scheduling of movements in the subsistence round are difficult to assess at the site level. The change in raw material selection could, however, indicate that subsistence activities were generally carried out over larger distances during the later phases of the studied sequence. If, due to their intense exploitation, food resources around the site became depleted or less predictable, a strategy of embedded procurement during further-reaching subsistence rounds would likely lead to the greater use of non-local lithic resources, all else being equal (e.g. [103, 104, 123, 124]). While the faunal assemblages of the studied sequence show that the inhabitants generally hunted the same type and frequency of animals, there a slight increase in large-sized bovids in the topmost assemblages [125, 126]. The intentional choice of hornfels from further away via direct or special purpose procurement [124, 127] to produce specific kinds of tools, or due to other socio-cultural factors [119], may also help to explain the high frequency of non-local raw material in BM-BSP.

Based on the high density of lithic remains, the frequent occurrence of combustion features, evidence for site maintenance, numerous faunal remains, the use of ochre and the construction of bedding, Sibudu functioned as a base camp throughout the entire period under study (cf. [103, 104]). Thus, simple predictions about land-use strategies from retouch frequency and artifact density [118, 128] do not apply to Sibudu where these variables fluctuate throughout the sequence. The changing composition of tool kits—notched implements vs. unifacial points—certainly played a role in subsistence tasks, such as a higher reliance on plant or wood processing for occupations rich in denticulates [129]. While the general function of the site remained the same, these variations likely reflect task-specific changes in the frequency of various activities of daily life.

The intensity of stone artifact knapping at a site and the reduction intensity of raw materials constitute further important factors influencing the size, composition and morphology of lithic assemblages [54–56, 58, 76, 103]. The highest reduction intensities (S2 Table) and lithic densities (Fig 12) are associated with the most frequent use of dolerite (Fig 3) and inclined core methods (Table 6) in the middle of the sequence (SU-POX). The intense on-site reduction of dolerite by means of inclined reduction, with the production of large numbers of small flakes, helps to explain the highest lithic density in this part of the sequence. The more frequent use of hornfels in BM-BSP, for which part of the reduction sequence took place elsewhere, and the dominant use of prepared core strategies in WOG1-SP could explain the comparatively lower lithic densities in these groups.

From a techno-economic viewpoint, scholars have proposed that the frequent application of inclined reduction strategies, such as the discoid method, constitutes an economizing behavior as the number of usable flakes is higher in relation to prepared core strategies such as Levallois [88, 90, 130–132]. Inclined systems exploit the volume of the core through a continuous series of flakes that can be knapped without preparation, thus conserving raw material. Recent experimental studies also demonstrate that inclined concepts are less vulnerable to raw material constraints and provide a steadier output of usable cutting edge compared to some platform core technologies [131]. Values for the flaking efficiency of dolerite (S3 Table) show that knappers at Sibudu used this raw material economically during the formation of layers SU-POX. They did this presumably because other high-quality raw materials were not available in the reduced area in which they gathered and hunted. This interpretation is consistent with the fact that whereas hornfels is intensely retouched in layers BM-BSP, knappers exploited dolerite in a less

efficient manner and made less use of inclined technology. These observations are in agreement with theoretical models predicting that lithic assemblages used by hunter gatherers with lower mobility will contain fewer formal tools and prepared cores [63, 116, 133–135].

In conclusion, changing patterns of mobility coupled with a different selection and use of raw materials can explain a portion of the variation in lithic technology observed at Sibudu. While Sibudu always served as base camp during the period under study, variations in retouch intensity and marked differences in the composition of tool kits document a dynamic economic context in which innovations and directed cultural change occurred.

Evolutionary theory and environmental forcing. Evolutionary models of cultural change constitute another candidate to interpret the data from Sibudu. In a classic evolutionary model, changes in populations of organisms are explained either by biotic or abiotic mechanisms of natural selection working on individuals and populations on various spatiotemporal scales. The interplay between abiotic and biotic ecological factors drives evolutionary change, with historical contingency determining the importance of different selective agents [136–139].

In Paleolithic archaeology and paleoanthropology, researchers often favor abiotic factors of selection to explain cultural change. Long-term changes in the environment put novel selection pressures on hominins to which they have to react by modifying their behavior and material culture in order to prosper and reproduce. Temporal correlations between environmental data and cultural change on large scales usually form the explanatory link in these models (e.g. [140–148]). Within the southern African MSA such approaches have been put forward to explain the appearance and disappearance of the SB and HP [29, 149–151] (but see [152]).

In order to apply this theoretical framework, we combined local paleoenvironmental ([37, 125, 126, 153–164]; summary in [S2 Text](#)) and subsistence data [125, 126, 161, 162] for layers WOG1-BSP at Sibudu with our own observations on lithic technology. The results show a remarkable disconnect between environmental and cultural change. Various indicators of climate and vegetation, suggesting drier and warmer conditions with more open grassland habitats than today, remain constant throughout the period of study (see [17, 126, 157–159]) with minor random fluctuations (see [160]), while the lithic technology undergoes marked and unidirectional changes. Behavioral change thus occurred independent of environmental change, suggesting that the observed alterations in technology do not constitute adaptive responses to variable natural environments. Some of the paleoenvironmental proxies, however, are not as finely resolved as the lithic data ([S2 Text](#)). While we work on achieving the same resolution for all datasets in the future, the difference in scale for some environmental proxies is a potential confounding factor of this interpretation.

Regarding subsistence, the inhabitants of Sibudu constantly hunted the same types and range of animals in each occupation horizon of the sequence WOG1-BSP, particularly large-sized bovids (ungulates). Subsistence activities, at least in terms of hunting, are thus not the main driver of different knapping strategies and the manufacture of different kinds of tools (cf. [126]). In contrast, the largest shifts in terms of environmental indicators and hunting strategies occur between layers YA2-G1 (“post-HP MSA 2”) and G1-BSP (“post-HP MSA 1”) [17, 125, 126, 156, 158, 162]) and above BSP in the final MSA [159].

Cultural transmission theory. Due to the gradual and cumulative changes observed in the sequence at Sibudu, and the mismatch between environmental, subsistence and lithic technological data, we viewed our results from the perspective of cultural transmission theory [108–110, 165–167]. The frequencies of Tongatis, Ndwedwes, NBTs, and ACTs serve as a good example for the observed gradual and cumulative changes. As these artefacts reflect repetitive actions of knappers with the goal of producing a particular functional edge morphology by means of retouch, their reproduction by other individuals required high-fidelity social transmission of technological information. The four main tool classes start off in very low numbers

(WOG1 and SU) followed by a rapid increase (BP-POX), and then a slowdown at high values (BM-BSP). This unidirectional trajectory resembles the S-shaped cumulative distribution curve that was found typical for the spread and adoption of many new technologies, practices and beliefs [108, 109, 166, 168], admittedly over much shorter timescales [169].

According to Rogers [168] and Henrich [166], such an S-shaped uptake curve usually indicates local innovations with a subsequent increase in frequency by means of biased cultural transmission via social learning instead of random drift of a neutral trait (see also [170]). Biased transmission denotes the circumstance in which populations favor certain cultural variants over others during the process of information transmission. In other words, certain cultural elements were preferably maintained and passed on to next generation due to reasons of their function, popularity, prestige, association with important individuals or ease of imitation [108, 169, 171]. In contrast to such a directed positive selection, drift of a neutral trait most often follows the pattern of an erratic stochastic process, rarely creating a unidirectional or S-shaped cumulative distribution curve [108, 109, 166, 170, 172, 173]. We also consider it highly unlikely that the specific and functionally relevant configuration of edge modifications of the techno-functional tool classes represent repeated random errors during information transmission, which would be the basis of random drift particularly in small populations (e.g. [164, 172–174]). For other traits in the studied sequence, such as non-functional or single-component elements that exhibit non-directional temporal changes in frequency, random drift remains a plausible explanation that we will examine once the entire ~58 ka lithic sequence is available.

For now, we do not know exactly why these techno-functional tool classes were transmitted to successive generations (cf. [169, 171, 175]), but we emphasize the importance of socio-economic over environmental selection factors in their appearance and distribution. Presumably these tools worked well for the purposes for which they were used and thus experienced positive selection that led to the increase in the frequency of their manufacture and use. V. Rots is currently conducting functional studies and residue analysis at Sibudu which should provide us with more specific explanatory hypotheses in the near future.

While the sequence at Sibudu shows directed behavioral change, this takes place against a backdrop of relatively stable technological adaptations. These unifying characteristics include 1) the regular collection of dolerite and its complete reduction on site, 2) the use of the same variants of quartzite, 3) the consistent application of knapping techniques and 4) the use of similar reduction methods. These observations together with the nearly continuous occupation of the site during the period of study reflect successful transmission of information between successive generations living in the region of Sibudu.

Demography. Changes in demography, such as migrations of people, fluctuations in population size, population composition, or general population pressure, might play a role in the observed cultural change at Sibudu, and these variables have been popular themes in research on the MSA [25–27, 176–178]. The gradual, cumulative and often unidirectional change in the lithic technology at Sibudu is consistent with cultural transmission within a shared information system. Hence, our technological observations do not require any radical changes in human populations or migrations, and we favor a model of demographic continuity over the course of the sequence under study. This being said, it is plausible that innovations from neighboring groups may have spread to the occupants of Sibudu via social and economic interaction.

In terms of population size, the available archaeological evidence suggests that all assemblages that follow the HP at Sibudu derive from intense occupations, which may reflect high local population densities [17, 21, 38, 39]. This intensification at ~58 ka may have resulted from longer visits, more visits, or larger groups than during earlier phases of occupation, but we cannot easily distinguish between these possibilities.

Summary. The short-term cultural variation that we have observed in the late MSA lithic sequence at Sibudu can be interpreted using both an organization of technology approach and cultural transmission theory. Standard evolutionary models based on climatic or environmental forcing are not required to explain our observations. Similarly, while the spread of ideas between neighboring groups is possible, such a diffusion of ideas is not needed to generate the changes during this phase of occupation at Sibudu. This is of considerable interest since most explanatory models for the MSA have invoked environmental or demographical causality to explain behavioral change. Unlike most other studies, however, we have presented behavioral variation during the MSA with a very fine temporal resolution. These data bring us closer to a paleo-ethnographic time scale. On such a scale, other factors become plausible causes of technological change. Here we are tracing social interaction and human behavior across life spans and generations rather than millennia, which is the more typical temporal scale of research in the MSA (see also [2, 23, 126, 179]).

Conclusions

What are the implications of our findings for the MSA culture-stratigraphic sequence of KwaZulu-Natal and South Africa during MIS 3? While trying to answer this question, we also evaluate the role of short-term cultural change for the definition of the Sibudan [31, 32] and discuss methodological considerations from our approach.

Lithic assemblages that succeed the HP and fall within MIS 3 comprise the so-called “post-HP” [86], “MSA 3” [180] or “MSA III” [176]. We have recently criticized these units as catch-all categories that have done more to hinder rather than to stimulate research ([31, 32]; see also [181–184]). Here, we emphasize trends emerging from recent analyses of lithic technologies in eastern South Africa during MIS 3. As more and more sites are studied with comparable methods [31, 121, 179, 185, 186], technological and typological variability, rather than stasis, appears to be the main cultural signal within KwaZulu-Natal during MIS 3.

In this article, we demonstrated cultural change at one site within a narrow time frame during early MIS 3. As an example of cultural variability on the regional scale, broadly contemporary lithic assemblages from Umhlatuzana, 90 km southwest of Sibudu, feature finely made bifacial points and small backed segments [186, 187]. These tool assemblages are more similar to the HP at Sibudu [188] than to those of WOG1-BSP that we presented here. Our reanalysis of the broadly contemporaneous MSA sequence at Holley Shelter [121], located only 40 km west of Sibudu, provides some parallels but also marked differences to Sibudu. Whereas the middle of the sequence conforms to the Sibudan as characterized in Will *et al.* [32], the upper and lower parts do not match with any of the three technological groupings that we have presented here. Particularly the upper occupation horizons at Holley Shelter, characterized by a strong dominance of splintered pieces, mark a distinctive pattern of lithic technology. Slightly later in the sequence, the final MSA assemblages at Sibudu (~38 ka) and Umhlatuzana (~35 ka) feature hollow-based points as characteristic tool form that occurs exclusively in KwaZulu-Natal during late MIS 3 [181, 185, 187]. To conclude, apart from the unifying characteristic of frequent unifacial points [179, 185], assemblages following the HP in this region encompass much more diachronic and spatial variability than has been previously recognized.

The Sibudan, a techno-complex we originally defined at Sibudu based on the six assemblages BM-BSP [31, 32], constitutes a case in point. As discussed above, the two assemblage groups SU-POX and WOG1-SP show both similarities and differences to the original definition. SU-POX conform to all principle techno-typological criteria of the Sibudan with differences being gradual and quantitative, such as a lower abundance of tools in general and more specifically Tongatis and Ndwedwes. In contrast, the oldest assemblages in our study

(WOG1-SP) exhibit stronger differences, such as the absence of unifacial points and three techno-functional tool classes, a lack of blade production and the exclusive use of local raw materials. Thus, while the assemblages SU-POX can be included within the existing concept of the Sibudan techno-complex without transcending its previously defined techno-typological boundaries, the lower part of the sequence raises several new questions and challenges the concept of the Sibudan. This problem is to a large extent an issue of perspective. When looking at the entire sequence, gradual and cumulative change stands out. When focusing only on the youngest and oldest assemblage of the studied sequence, techno-typological differences are the prominent pattern.

The central issue is how we can best view short-term cultural change over narrow time spans (Fig 16). Considering that all of these horizons are of indistinguishable OSL ages of ca. 58 ka and reflect a nearly continuous sequence of occupations, we ideally would like to place them within the same cultural taxonomic unit. Indeed, if we view time as the leading variable for defining analytical units, we must place them in the same unit. Alternatively, if we grant technology and the nature of the material culture primacy, at some point this variation goes beyond the spectrum of what we can comfortably place within the Sibudan. To complicate this situation, changes in the procurement and use of raw materials as well as site function demonstrably influenced the techno-typological characteristics of the assemblages. These and similar issues were at the heart of the various scenarios that characterized the Mousterian debate of the late decades of the 20th century.

A narrow definition of the Sibudan would render comparisons with other sites easier, but may ultimately lead to complex terminology if researchers follow the approach of “splitters” to its logical conclusion. This approach would also impose arbitrary boundaries in an essentially contemporaneous sequence characterized by cumulative changes. We propose several hypotheses in Fig 16, favoring those that emphasize gradual change and continuity, but refrain from providing a final answer to this question as there are still about 0.5 m of sediments dated to ~58 ka left to study. Referring to Brew [33], there is no universally valid answer to the question of how much variability can be incorporated into one techno-complex. Answers to such questions can only be found in the context of well-defined research questions, and the utility of any cultural taxonomy can only be assessed in terms of how it helps us gain insight into past human lifeways or for testing specific hypotheses. For now, we are in the midst of a phase of more inductive research in which it is essential to establish reliable technological observations from within well controlled chronostratigraphic contexts. Future synchronic and diachronic studies on various scales will test the definition and value of the “Sibudan” as a concept for structuring the MSA record of MIS 3.

Turning back to the larger geographical scale, there are interesting technological differences between the western, southern and eastern parts of southern Africa during MIS 3. The decline in the number and intensity of occupations after the HP in the Western Cape, especially between 50–25 ka (e.g. [23, 30, 189]), finds no equivalent in the eastern part of southern Africa. Here, the number of sites appears to increase, characterized by several localities with thick and rich occupation sequences, such as Umhlatuzana [187] or Sibudu [17, 21, 38, 40]. There are also spatial differences in terms of dominant techno-typological signatures (see [30, 32, 190]). Combining geographical with chronological information, our results from Sibudu and Holley Shelter, as well as other recent studies [23, 30, 31, 179, 182, 185, 191], demonstrate that MSA lithic technology during MIS 3 in southern Africa may well be characterized by an increase in variability and regionalization compared to the previous HP and SB. At least in KwaZulu-Natal, this pattern cannot be explained by demographic collapses or technological regression (*sensu* [26, 27, 178, 192, 193]) and it might in part be a reflection of the higher primary productivity of KwaZulu-Natal compared to more marginal environmental zones of southern Africa

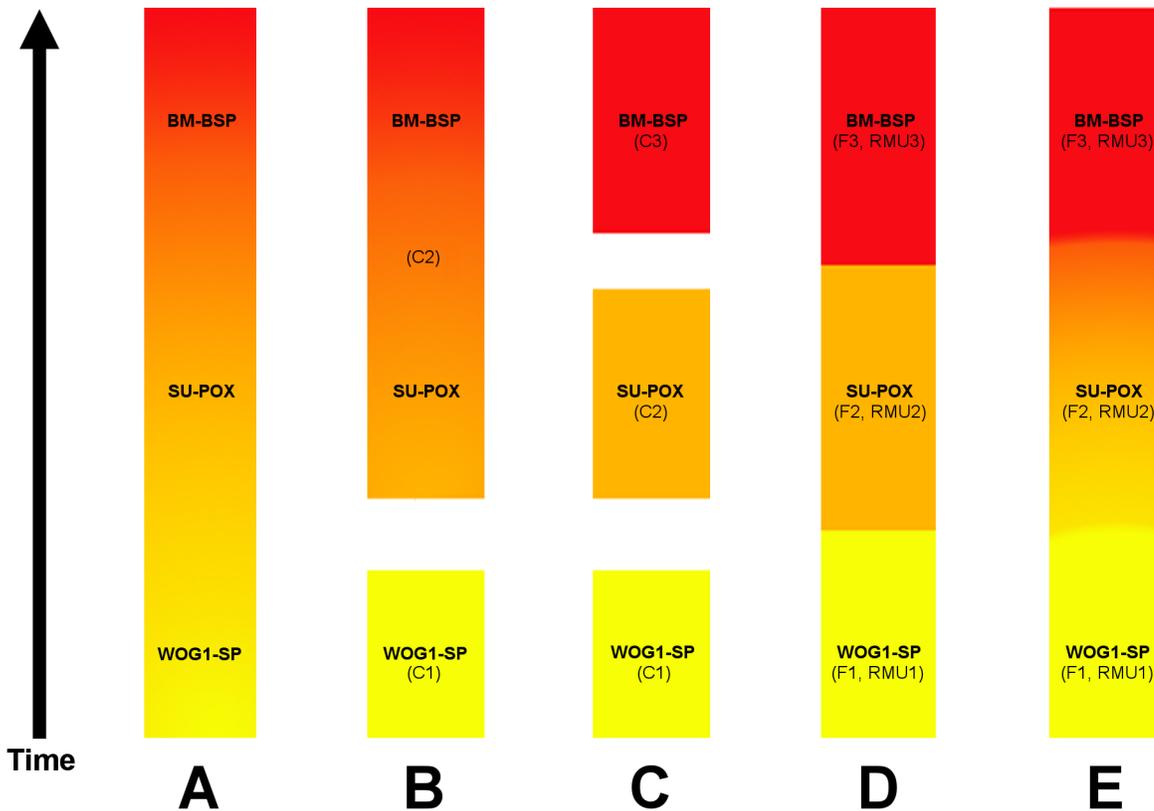


Fig 16. Schematic representation of hypotheses to conceptualize the short-term cultural changes at Sibudu throughout WOG1-BSP. A) Gradual change with continuous cultural transmission among local populations throughout the entire sequence (broad Sibudan definition). B) Discontinuous change with two distinct units (C_x)—one encompassing internal gradual change—separated through disruption of information transmission or occupation hiatuses. This could either reflect two independent populations or cultural taxonomic units (SU-BSP as a narrow Sibudan definition). C) Discontinuous change with three distinct units (C_x), separated through disruption of information transmission or occupation hiatuses. This could either reflect three independent populations or cultural taxonomic units (“splitter” taxonomy with BM-BSP as originally defined Sibudan). D) Discontinuous change with three groupings reflecting different site function (F_x), technological organization, or raw material use (RMU $_x$) at different time periods during the occupation of the locality. This hypothesis does not include statements about information transmission or population displacement. E) Gradual change with continuous cultural transmission among local populations in the region around Sibudu. Within this continuum, three groupings can be concerned based on differences in site function (F_x), technological organization, or raw material use (RMU $_x$) at different time periods during the occupation of the locality.

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(cf. [3, 194]). Sibudu in particular exhibits a long and intense occupation sequence with clear techno-typological markers after the HP, showing that knappers continued to use a highly structured and sophisticated lithic technology. We thus interpret the MIS 3 record as showing the evolution of new and divergent technological trajectories with equal or perhaps still greater complexity as those of the earlier SB and HP of southern Africa.

The fine-grained scale of this analysis also shows that we should not underestimate temporal variation below the level of the techno-complex (see also [23, 58, 195, 196] and [2] in particular). Often, MSA site reports treat techno-complexes as monolithic entities, without discussing potential variability within these units. This is ultimately a question of analytical scale reflected in whether researchers combine various find horizons together because they superficially belong to the same techno-complex, or analysis proceeds by the examination of individual find horizons. Unlike other parts of Africa, many archaeological localities of the MSA in southern Africa do provide the necessary resolution, preservation and find density to conduct analyses on very fine temporal and behavioral scales. In our view, this potential has so far not been fully exploited. However, the questions researchers ask and answer with the

archaeological record depend largely on the scale of the analysis [1–3]. In order to explain the nature and tempo of cultural evolution among modern humans in Africa, as well as its causes and consequences, we should embrace all scales of analysis.

Finally, our findings suggest that external factors such as climate and environment should be used more prudently as causal explanations for cultural and behavioral change in the MSA (see also [23, 126, 179, 197]). While we do not want to downplay the importance of adaptive responses to variable environments, modern humans in the Pleistocene were able to vary their behavior independent of changes in the natural surroundings. In such cases, internal causality emerging from the social and cultural dynamics within and between groups play a larger role than previously acknowledged, particularly on a fine temporal and spatial scale. These factors include changes in settlement dynamics and social relations, loss and exchange of cultural information, but also independent innovations along with the complex pathways of their subsequent transmission.

Supporting Information

S1 Fig. Distribution of lithic size classes throughout the studied sequence at Sibudu.

WOG1 = oldest layer; BSP = youngest layer.

(TIF)

S2 Fig. Percentual abundance of techno-functional tool classes. WOG1 = oldest layer;

BSP = youngest layer.

(TIF)

S1 Table. Frequencies of retouch debitage (<30 mm) for each assemblage at Sibudu. The samples of small debitage combine size classes 5–10 mm and 10–30 mm.

(DOCX)

S2 Table. Three measures of reduction intensity for lithic assemblages at Sibudu. A) Blank to core ratio (after [55]). The higher the ratio is, the more intensely reduced are the assemblage. B) Total core mass relative to total assemblage mass (after [56]). The lower the values are, the more intensely reduced were the cores of this assemblage. C) Average core and flake length or thickness (after [54, 55]) Assemblages showing shorter or thinner flakes and cores are more heavily reduced.

(DOCX)

S3 Table. Flaking efficiency by layer for all raw materials and for dolerite only at Sibudu.

Higher values indicate higher efficiency of converting a mass of stone into flake edge.

(DOCX)

S4 Table. Number of blank types used for the manufacture of tools for the combined assemblages WOG1-BSP.

(DOCX)

S5 Table. Number (n) and proportion (%) of cortex cover on artifacts made on dolerite per assemblage at Sibudu.

(DOCX)

S6 Table. Number (n) and proportion (%) of small debitage (<30 mm) by raw materials per assemblage at Sibudu.

(DOCX)

S7 Table. Summary of the most important diachronic changes in lithic technology within WOG1-BSP, highlighting variation in several main technological domains. Domains

include raw material procurement, core reduction and preparation, blank production, tool manufacture and lithic density (cf. [53]: 98–137). The color codes indicate homogeneity in frequency or absence/presence of traits. See [S2 Text](#) for a statistical comparison of the groupings. (DOCX)

S1 Text. Statistical comparisons of assemblage groups BM-BSP, SU-POX and WOG1-SP.

(DOCX)

S2 Text. Summary of paleoenvironmental data from Sibudu.

(DOCX)

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Author Contributions

Conceived and designed the experiments: NJC MW. Performed the experiments: NJC MW. Analyzed the data: NJC MW. Contributed reagents/materials/analysis tools: NJC MW. Wrote the paper: NJC MW.

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Research Article

THE LITHIC TECHNOLOGY OF HOLLEY SHELTER, KWAZULU-NATAL, AND ITS PLACE WITHIN THE MSA OF SOUTHERN AFRICA

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ABSTRACT

While the majority of research on the Middle Stone Age (MSA) in southern Africa has been conducted in the southern and western Cape, studies of the east coast of South Africa have become increasingly important due to the existence of well-stratified sites such as Sibudu. Because of the scarcity of comparable localities, however, we still know little about the spatial and temporal variability of MSA lithic technology in this region. We therefore chose to expand our research focus to other, lesser-known sites in the eastern part of South Africa. One such site is Holley Shelter which was excavated by Gordon Cramb between 1950 and 1960. Since its archaeological material was only studied in a cursory manner, we conducted a detailed technological study of the MSA lithic artefacts from Cramb's excavations, including attribute analysis and examination of reduction sequences. Our first aim was to assess the degree of potential mixing and recovery bias among the lithic material. We then characterised the different assemblages and investigated their diachronic variation throughout the occupation sequence. In order to obtain a rough age estimate of the so far undated sequence of Holley Shelter, we compared its lithic technology to other MSA sites in the eastern part of South Africa. Our results indicate three different phases of MSA occupation that vary in terms of raw material composition, core reduction, and tool manufacture. The assemblages are characterised by a blade and point technology that mostly derives from platform cores as well the highest proportions of splintered pieces reported from a southern African MSA site. The sequence does not feature Later Stone Age (LSA), Howieson's Poort, Still Bay or final MSA industries. Compared to other sites in the general region, the assemblages are most similar to lithic technology post-dating the Howieson's Poort, suggesting that the occupations fall broadly into the earlier part of MIS 3.

Keywords: lithic technology, Middle Stone Age, South Africa, KwaZulu-Natal, Holley Shelter.

INTRODUCTION

The discovery of an African origin of anatomically modern humans during the 1980s (Bräuer 1984; Smith *et al.* 1989; Stringer 1989; White *et al.* 2003; McDougall *et al.* 2005) led to an increased research interest in the archaeology of the Middle Stone Age (MSA, c. 300–35 ka) in the following decades. Scholars have paid special attention to indices of 'cultural modernity' that appear first during the MSA, including manifold applications of pigments as hafting element or base for symbolic engravings (Wadley 2005a; Henshilwood *et al.* 2009, 2011), heat-treatment of fine-grained raw material (Brown *et al.* 2009, Schmidt *et al.* 2013), the manufacturing of bone tools (Henshilwood *et al.* 2001, Backwell *et al.* 2008), personal ornaments like shell beads (Henshilwood *et al.* 2004; D'Errico *et al.* 2005), engravings on ostrich eggshell (Texier *et al.* 2010), and

the consumption of marine resources (Parkington *et al.* 2004; Conard 2005; Marean *et al.* 2007; Will *et al.* 2013). However, apart from these features, the analysis of stone artefacts, encompassing their production, reduction and use, represent an indispensable tool for prehistoric archaeologists to reconstruct past human behaviour and build comparative cultural-technological sequences.

During the last four decades, research on the MSA has focused on specific geographic regions rich in archaeological records. The western and southern coast as well as the Cape region of South Africa have been studied extensively owing to the existence of several sites with long and well-preserved stratigraphic sequences such as Klasies River Mouth (Singer & Whymer 1982; Wurz 2000, 2002), Blombos Cave (Henshilwood *et al.* 2001), Diepkloof (Texier *et al.* 2010; Porraz *et al.* 2013) or Pinnacle Point (Marean *et al.* 2010). Although there are some comparable sites in KwaZulu-Natal, namely Border Cave (Cooke *et al.* 1945; Beaumont 1978; Villa *et al.* 2012), Umhlatuzana (Kaplan 1989, 1990; Lombard *et al.* 2010; Mohapi 2013) and particularly Sibudu (Wadley & Jacobs 2004; Wadley 2005b, 2007; Conard *et al.* 2012; Will *et al.* 2014; Conard & Will 2015), the last is the only locality with detailed technological data from lithic assemblages, including information on core reduction methods, reduction sequences and knapping techniques.

In order to move forward in our understanding of the geographic and diachronic variation within MSA lithic technology of southern Africa, it is important to shift the focus of research to less investigated regions like KwaZulu-Natal. As a starting point for this project, we chose Holley Shelter and reanalysed its lithic material using state-of-the-art analytical methods.

THE MSA SEQUENCE OF KWAZULU-NATAL

In order to place the lithic technology of Holley Shelter within the MSA sequence of South Africa, it is necessary to provide a general outline of the characteristics of this period in KwaZulu-Natal. As this region is generally understudied, compared to the western and southern Cape, the best candidate to provide an overview for this region is the archaeological site of Sibudu. This locality provides the most complete and well-published MSA sequence of stone artefact assemblages in KwaZulu-Natal. We further include Umhlatuzana in this brief outline because of its proximity to both Sibudu and Holley Shelter. The MSA sequence of Border Cave at the very northern border of KwaZulu-Natal will also be analysed in the discussion section.

In contrast to the southern and western Cape, no stratified early MSA assemblages dating to >80 ka have been found in KwaZulu-Natal. Starting from bottom to top, the lowermost layers at Sibudu published so far date to 77.2 ka and are

informally designated as pre-Still Bay (Wadley 2012). Work on these layers is still in progress with little information available as of now. That being said, Wadley (2012) mentions large blades and flakes, as well as thin bifacial points.

The overlying layers date to 70.5 ka (Jacobs & Roberts 2008) and are described to be of Still Bay (SB) character, marked by the frequent occurrence of bifacial points (Lombard 2006; Wadley 2007). According to Wadley (2007), bifacial points and bifacial tools (including broken pieces) represent around 40% of the retouched tools in layers RGS and RGS2. Double pointed forms appear to be typical for the Still Bay. By comparison, unifacial points, backed tools and other formal tools like scrapers occur in very low proportions (10% and below). The distribution of blanks shows a flake- rather than blade-based industry (Wadley 2007: table 4). There is little information on core reduction methods. Wadley (2007) describes two radial, one cylindrical and one opposed platform core. At Umhlatuzana, Layers 25 to 27 have originally been attributed to the pre-Howieson's Poort. According to Lombard *et al.* (2010), however, they are most similar to a Still Bay industry. The assemblages are characterised by a flake-based technology with unifacial and bifacial points, but also segments (Kaplan 1989, 1990). What makes these layers unique so far is the existence of both unifacial and bifacial serrated points (Lombard *et al.* 2010). These pieces occur more frequently in the lower layers of the Still Bay at Umhlatuzana.

As in other parts of South Africa, Still Bay assemblages are followed by Howieson's Poort (HP) industries at both Sibudu and Umhlatuzana. The HP lithic assemblages of Sibudu have recently been described by de la Peña *et al.* (2013) and de la Peña and Wadley (2014a,b) and date to 63.8 ka (Jacobs & Roberts 2008). The HP at Sibudu shows many characteristics apart from backed tools, like small bifacial points from quartz (de la Peña *et al.* 2013), the production of very small quartz bladelets, and the frequent use of bipolar technology (de la Peña & Wadley 2014a). Different kinds of cores on flakes also play an important role during the HP occupations of Sibudu (de la Peña & Wadley 2014b). Apart from these features, the defining characteristics of the HP are the frequent occurrence of segments made on blades as well as a blade-based technology in general (Wadley & Mohapi 2008). The HP occupations at Umhlatuzana (Layers 22–26) are similar in this regard, showing a high amount of backed pieces and segments, a higher percentage of blades compared to the underlying layers, but unifacial and bifacial points are also present (Kaplan 1990).

The so-called post-Howieson's Poort (post-HP) period will only be summarised briefly here (see discussion for a more detailed description). Post-HP occupations at Sibudu follow the HP and date to *c.* 58 ka, thus falling into early MIS 3 (Wadley & Jacobs 2006; Jacobs *et al.* 2008). They reflect a much higher variability in lithic technology and are based on different methods of core reduction, proportions of raw materials, and blank production, that all change over time. The assemblages at Sibudu from this period are flake- rather than blade-based, without evidence of significant bladelet production (Conard *et al.* 2012; Will *et al.* 2014; Conard & Will 2015). Backed artefacts and segments are few in numbers and absent in most assemblages. They are replaced by unifacial points as the overall most frequent category of retouched pieces. The unifacial points encompass three different categories (Tongati, Ndwedwe, ACT), defined on techno-functional aspects and an emphasis on tool reduction and re-sharpening (Conard *et al.* 2012; Will *et al.* 2014). While unifacial points constitute the most important tool component in the upper layers of the post-HP (or Sibudan), there are marked differences throughout the

sequence, with some of the older assemblages showing more notched and denticulated implements, and only few or no unifacial points (Conard & Will 2015).

Layer RSP overlies the post-HP assemblages at Sibudu and is informally denoted as late MSA by Villa *et al.* (2005). The late MSA dates to approximately 48 ka (Wadley & Jacobs 2006; Jacobs *et al.* 2008). Uni- and bidirectional platform cores with simply prepared platforms dominate – including bladelet cores – whereas Levallois technology is not common (Villa *et al.* 2005: 405). While flakes are the most common end products, blades make up a considerable portion of up to 37%. Almost all of the pieces have been knapped using direct hard hammer percussion. The most common tool types are pointed forms (most of them unifacial) and side scrapers. In general, the tool component is high at 15%. According to Villa *et al.* (2005), few of the retouched pieces were made on blades. A late MSA industry also exists at Umhlatuzana and will be discussed in more detail later.

The youngest stage of the MSA in KwaZulu-Natal is informally named as the final MSA. At Sibudu it dates to *c.* 38 ka (Wadley & Jacobs 2006; Jacobs *et al.* 2008) and is characterised by a variety of scrapers, unifacial and bifacial points in comparable amounts. Most importantly, these assemblages feature hollow-based points. Although they are not very frequent, Wadley (2005b) emphasises that hollow-based points do not occur in any other layers at Sibudu and thus mark a distinct feature of this part of the occupation sequence. The cores are mostly minimal (“chunk with two or three randomly placed removals”) (Wadley 2005b: 54) or bipolar cores. However, a few examples of platform, radial and Levallois cores occur (Wadley 2005b). Knappers predominantly manufactured flakes (96%) rather than blades. Importantly, hollow-based and bifacial points are also an important feature of the uppermost three MSA/LSA-transitional layers at Umhlatuzana dated to ~36 ka, and single-platform cores are the most common core type (Kaplan 1989, 1990).

HOLLEY SHELTER

Holley Shelter is an elongated rock shelter on the eastern exposure of a large canyon, completely surrounded by dense vegetation. The site lies in a sandstone area that is drained by small streams that flow west to the Umgeni River (Cramb 1952) about 25 km northeast of Pietermaritzburg in KwaZulu-Natal. Holley Shelter is located around 60 km inland from the Indian Ocean (Fig. 1) and approximately 780 m above the current sea level. A waterfall runs from the top of the shelter into a small river about 20 m down the cliff, flowing in western direction through the canyon. During the time of excavation, the area was owned by Mr. J. Hunt Holley (Cramb 1952) and the site was subsequently named after him. As Holley Shelter constitutes an inland site, fluctuations of sea level had no direct influence in terms of resource availability over time, distinguishing the site from the majority of MSA localities in South Africa that are often scattered along the modern coastlines. Having said this, little Stone Age research has been conducted in the region around Holley Shelter in the last decades.

During the 1950s, Gordon Cramb excavated Holley Shelter in five short campaigns (Cramb 1952, 1961). He excavated in three different areas of the shelter, a smaller, a larger and a trial trench. The smaller area was excavated first and without using a grid system in order to “conserve the limited space” of the area (Cramb 1952: 181). Before he started excavating the larger area, Cramb dug a trial trench close-by in order to probe the stratigraphic situation. This line of action was based on his experience from the smaller section, that the sediments are “of

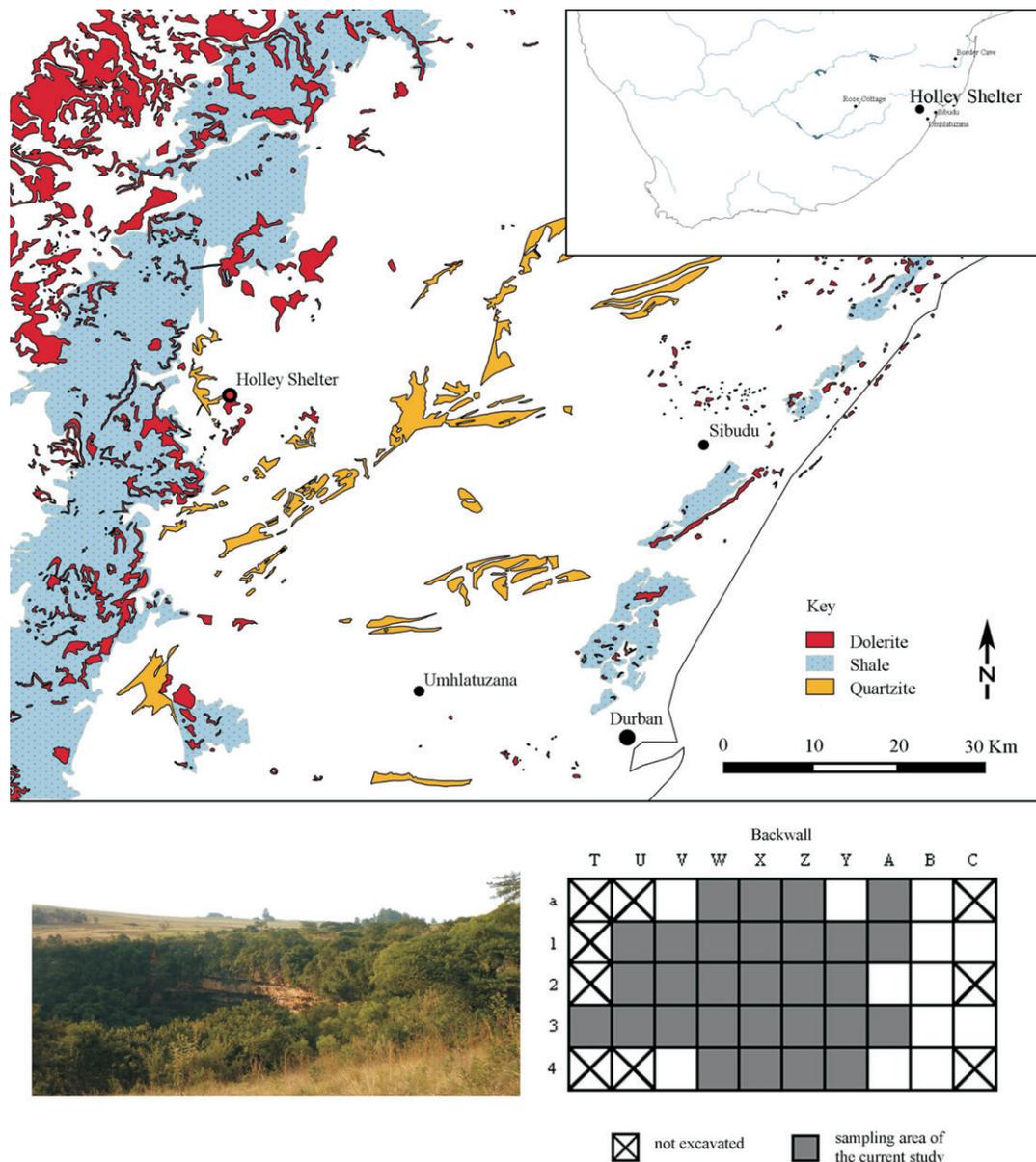


FIG. 1. Top: location of Holley Shelter, Umhlatuzana and Sibudu within the geological context of the region. Map is designed based on 1:250000 geological map by the Department of Mineral and Energy Affairs. **Bottom left:** view to the shelter. **Bottom right:** sampling area of the current study.

dustlike consistency” (Cramb 1961: 45) and too homogenous to identify separate layers. Due to these circumstances, Cramb excavated the bigger area in artificial inch spits and also used a grid system that he painted directly on the rock wall (Fig. 1). Unfortunately, there is no detailed information on the precise locality of the different trenches. Nevertheless, we were able to identify the larger excavation area in the northwestern corner of the shelter during a short visit to the site as the painted grid system was still preserved on the rock wall. In total, Cramb excavated this larger area within 38 square yards (~34.7 m²). He reached a maximum depth of 48 inches (1.22 metres), but not in all squares.

Cramb proposed that the uppermost 6 inches contain a mixture of LSA and MSA artefacts, marked by the appearance of thumbnail- and duckbill endscrapers as well as backed blades, whereas the lower levels comprise only MSA occupations. Cramb (1952) also mentioned the presence of beads of different colours in the first 3 to 9 inches. He also published two radiocarbon dates from the MSA part of the larger trench that date to 4400 ± 150 and 18.200 ± 500 bp. We, however, reject these dates because of the clear MSA character of the assem-

blages. Wadley (2001: 4) also argues that the previous dating “is not representative of any of the MSA occupations, which are probably too old for dating by the radiocarbon method”. As a result, the exact age of the MSA occupations at Holley Shelter remains unknown. Although Cramb’s original publications (1952, 1961) point towards an MIS 3 occupation of the shelter based on the frequent manufacture of unifacial points, this assessment lacks comparable technological and quantitative data for validation. We therefore decided to re-analyse the lithic assemblages from Holley Shelter with modern methods. We also plan to obtain new absolute age estimates from the site in the future, but the locality is currently not accessible owing to legal issues regarding land ownership.

MATERIALS AND METHODS

The archaeological material from Cramb’s excavation is stored in the KwaZulu-Natal Museum in Pietermaritzburg. The assemblages contain c. 4000 lithic artefacts in total. This study deals only with the artefacts deriving from the larger trench since it was excavated in coherent squares and therefore provides consistent horizontal and vertical distribution

patterns. During excavations, Cramb sometimes changed the depth of spits and, as a consequence, the connection between distinct spit-depths varies (e.g. Inch 0–6 and Inch 3–12). Therefore, we could not include all stone artefacts in a reasonable way into our analysis. We selected those lithic artefacts which could be clearly attributed to successive 6 inch thick spits (approximately 15 cm) throughout the entire sequence. These standardised spits serve as analytical units to group assemblages in the absence of defined archaeological layers (Inch 0–6, Inch 6–12). All these groups derive from a coherent area of grid squares as shown in Fig. 1. Based on this sampling procedure, we analysed 1980 pieces individually, including blanks >3 cm and all retouched artefacts and cores regardless of size (Table 1). In addition, we quantified the type of raw material for 493 artefacts <3 cm. Because of the small number of artefacts ($n = 5$) in the lowermost spit (42–48 inches), we excluded this unit from our analyses. Further, we counted artefacts from spits 30–36 and 36–42 together since they contain only 87 pieces and show comparable technological features. The uppermost unit (Inch 0–6) contains a total of about 600 pieces but due to time constraints, we could only include 388 pieces in our sample.

As a first step, we aimed to establish whether the assemblages provide reliable features that can help to answer the question of potential mixing. With mixing, we mean significant exchange of artefacts between lithic assemblages by means of vertical movement that occurred throughout the sequence (e.g. intrusive LSA elements in an MSA assemblage). In order to resolve this problem – in absence of any geomorphological or taphonomic data – we defined several criteria the assemblages should meet. First, the technological criteria of both cores and end products within a defined layer (in this case inch spits) should fit to one another. Specific types of core reduction also frequently produce characteristic technological elements and should thus be associated with them in unmixed assemblages. Second, one would not expect numerous distinct guide fossils of a specific techno-complex in an assemblage that otherwise do not belong to it. For example, bifacial Still Bay points do not usually occur within an LSA Robberg assemblage. Finally, refits or conjoins of artefacts indicate a certain degree of stratigraphic integrity if found in the same spit. In combination, the existence of these features in an assemblage render a large degree of mixing unlikely, but cannot ultimately exclude post-depositional vertical movement of artefacts between layers.

Another problem arising from the early excavation at Holley Shelter is the likely scenario that the original excavators operated in a selective way and preferentially collected eye-catching pieces – such as large retouched artefacts – rather than unmodified blanks, cortical or technological items. The nature of the lithic assemblages provides the best evidence against such an excavation and collection bias. If specimens of many different artefact categories – blanks, cores, tools, techno-

logical pieces – occur in different sizes and frequencies in each individual layer, it is likely that there was either no or only minimal selection. The existence of small or informal artefacts would thus testify against a strong collection bias. Furthermore, one would expect a continuously high proportion of eye-catching pieces in each layer if a systematic bias applies, rather than gradual changes in their frequencies compared to cores or unmodified blanks. These criteria, combined with information on the actual field methods, can mount evidence against a strong collection and excavation bias.

Our next aim was to characterise the different assemblages of the site and investigate their variation over time. In order to achieve these goals, we collected data on raw material composition and economy (Andrefsky 1994; Floss 1994; Brantingham *et al.* 2000; MacDonald & Andrefsky 2008), discrete and metric attributes resulting from the knapping process (Dibble 1997; Wurz 2000; Odell 2004; Dibble & Rezek 2009) and the variation of core reduction methods over time (Boëda 1994; Conard *et al.* 2004, Delagnes *et al.* 2012). For characterising blank production, we employed four categories: (i) Blades denote pieces that are at least twice as long as wide with parallel edges and a width of >10mm (Hahn 1991); (ii) Bladelets fall under the same definition, but are narrower than 10 mm; (iii) Flakes are blanks with variable edge morphologies and less than twice as long as wide; whereas (iv) Points refer only to flakes with a convergent distal end (Hahn 1991).

Although our approach is of technological nature, we point to the need of using uniform typological taxonomies in order to convey a coherent picture of tool assemblages that renders them comparable to other sites and regions. To this end, we followed South African tool taxonomies which are commonly used in this part of the world to classify retouched artefacts (Volman 1981; Wurz 2000; Villa *et al.* 2005). Owing to the very high percentage of retouched artefacts in Holley Shelter, we also employed a techno-functional approach (Lepot 1993; Boëda 2001; Soriano 2001; Bonilauri 2010) similar to a recent analysis by Conard *et al.* (2012) for the post-HP, or Sibudan, layers of Sibudu. This approach provides more detailed data on retouch patterns and morphologies of modified edges. It also increases the number of comparable technological attributes of retouched artefacts between different sites. In addition, we conducted morphometric studies similar to Mohapi (2013) for the unifacial points.

A CLASSIFICATORY SYSTEM FOR SPLINTERED PIECES

Owing to the high frequency of splintered pieces at Holley Shelter (see results), as well as their morphological and diachronic variability, we developed a new classificatory system for these artefacts. Most of the splintered pieces at Holley Shelter resemble specimens from the late MSA at Sibudu (Layer RSP), published by Villa *et al.* (2005) (Fig. 8, Nos. 7–9). While discussions on the function of these pieces as either bipolar cores or

TABLE 1. Distribution of artefact types throughout the sequence of Holley Shelter.

Unit	Depth below datum (cm)	Blank n (%)	Tool n (%)	Core n (%)	Pebble n (%)	Angular debris n (%)	Total
Inch 0–6	15.0	279 (71.9)	91 (23.5)	10 (2.6)	0 (0)	8 (2.1)	388
Inch 6–12	30.0	405 (69.7)	142 (24.4)	17 (2.9)	4 (0.7)	13 (2.2)	581
Inch 12–18	45.0	217 (57.4)	150 (39.7)	5 (1.3)	0 (0)	6 (1.6)	378
Inch 18–24	60.0	128 (50.0)	111 (43.4)	12 (4.7)	0 (0)	5 (2.0)	256
Inch 24–30	75.0	209 (72.1)	56 (19.3)	6 (2.1)	2 (0.7)	17 (5.9)	290
Inch 30–42	105.0	48 (55.2)	13 (14.9)	9 (10.3)	4 (4.6)	13 (14.9)	87
Total %		64.9	28.2	3.0	0.5	3.1	1980

wedges/chisels are still ongoing (Hayden 1980; Barham 1987; LeBlanc 1992; Shott 1999; Brun-Ricalens 2006; De la Peña & Wadley, 2014), recent residue analyses by Langejans (2012) provide additional support for the assumption that at least some of these pieces have been used as tools in a chisel-like manner in the HP layers at Sibudu. Here, we present a morphological model for a more detailed classification of splintered pieces. Our approach is comparable to the work of Hays and Lucas (2007) for Le Flagelot I in southern France. That being said, our approach is only macroscopic and based on the following criteria:

1. The overall morphology of the pieces.
2. The location of the splintered edges and their orientation to each other.
3. The direction of the splintered negatives on the dorsal and ventral sides, as well as their orientation to one another.

The results of this analysis are presented below (*Tool assemblages*).

RESULTS

RAW MATERIAL PROCUREMENT

The procurement of raw materials constitutes the first step in the operational sequence of producing stone tools and plays an important role in the technological organisation of mobile hunter and gatherer groups. The knappers at Holley Shelter used four different raw materials: hornfels, quartz, dolerite and quartzite (see Fig. 1). While there is a small number of artefacts made on unknown raw materials for which we do not know the source, there are no signs for long distance transportation (>20 km) of raw materials to Holley Shelter.

Among pieces >3 cm, the most common raw material is hornfels (Table 2), a relatively fine-grained black or grey stone of contact metamorphic origin (Cairncross, 2004). Hornfels commonly originate in areas where sedimentary rocks, like shale, and intrusive rocks, like dolerite or granite, come into contact. As shown in Fig. 1, such contact zones occur in numerous areas around Holley Shelter. Between inches 0 to 30, hornfels constitutes the dominant raw material with over 90% abundance in the uppermost spits 0–6 and 6–12 inches. Below these levels, the number of hornfels decline constantly until quartz becomes

the most frequent raw material used in lowermost inches 30 to 42. While its exact source remains unknown, quartz pebbles occur in the nearby river (Cramb 1952) and rounded, pebble-like cortex is frequently preserved on quartz artefacts from Holley Shelter. Besides hornfels and quartz, the inhabitants sometimes reduced quartzite and dolerite, but their frequency never exceeds 8%. Among pieces <3 cm, quartz has a disproportionately high abundance in all spits. This observation corresponds to the use of pebbles of small dimensions and the inherent fracturing tendencies of quartz, resulting in more (small) flakes per percussion event for quartz compared to other raw materials (Barham 1987; Conard 1992; Driscoll 2010). The proportion of close to 100% quartz for small debitage (<3 cm) in the two lowermost spits (inches 30–36 and 36–42), however, confirms a different provisioning of raw material in the earliest occupations at Holley Shelter.

CORE REDUCTION

At least three different strategies of core reduction characterise the MSA assemblages at Holley Shelter, following the unified core taxonomy proposed by Conard *et al.* (2004). First, platform cores occur in high frequencies in the upper five spits (inches 0–6, 6–12, 12–18, 18–24, 24–30) (Table 3). Second, most of the platform cores exhibit only one striking platform, mostly prepared but sometimes plain, associated with a unidirectional pattern of reduction. Rotated or multi-directional platform cores are rare. Third, cores often show flat cortical faces, suggesting the exploitation of slab-like raw materials, especially for hornfels. The majority of platform cores bear removal scars of blades, with a mean length of 35 mm.

We identified two different reduction strategies among the platform cores. The first and most common method can be described as ‘semi-circumferential platform core reduction’. In this system, knappers exploited one striking platform of the cores around several available edges by turning the core during the reduction process (Fig. 2, Nos. 3–4). The second and less common method is a narrow-sided core reduction. Here, platform cores are reduced exclusively along their narrow edge (Fig. 2, No. 5), explaining their identification as narrow-sided cores (Monigal 2001; Delagnes *et al.* 2012). In general, the semi-circumferential cores exhibit platform preparation more

TABLE 2. *Distribution of raw materials used at Holley Shelter throughout the sequence.*

Unit	Depth below datum (cm)	Hornfels n (%)	Dolerite n (%)	Quartz n (%)	Quartzite n (%)	Sandstone n (%)	Other n (%)
0–6	15.0	369 (95.1)	8 (2.1)	7 (1.8)	1 (0.3)	2 (0.5)	1 (0.3)
6–12	30.0	539 (92.8)	6 (1.0)	32 (5.5)	2 (0.3)	1 (0.2)	1 (0.2)
12–18	45.0	328 (86.8)	21 (5.6)	17 (4.5)	8 (1.9)	3 (0.8)	2 (0.5)
18–24	60.0	217 (84.8)	15 (5.9)	8 (3.1)	11 (4.3)	2 (0.8)	3 (1.2)
24–30	75.0	217 (74.8)	22 (7.6)	35 (12.1)	5 (1.7)	7 (2.4)	4 (1.4)
30–42	105.0	37 (42.5)	3 (3.4)	40 (46.0)	5 (5.7)	0 (0.0)	2 (2.3)

TABLE 3. *Distribution of core types at Holley Shelter for each inch spit.*

Unit	Depth below datum (cm)	Platform core circumferential	Platform core narrow-sided	Parallel core	Bipolar core	IBC
Inch 0–6	15.0	8	0	1	1	0
Inch 6–12	30.0	6	8	2	1	0
Inch 12–18	45.0	2	2	0	1	0
Inch 18–24	60.0	5	0	3	2	1
Inch 24–30	75.0	3	1	1	2	0
Inch 30–42	105.0	0	1	0	7	1

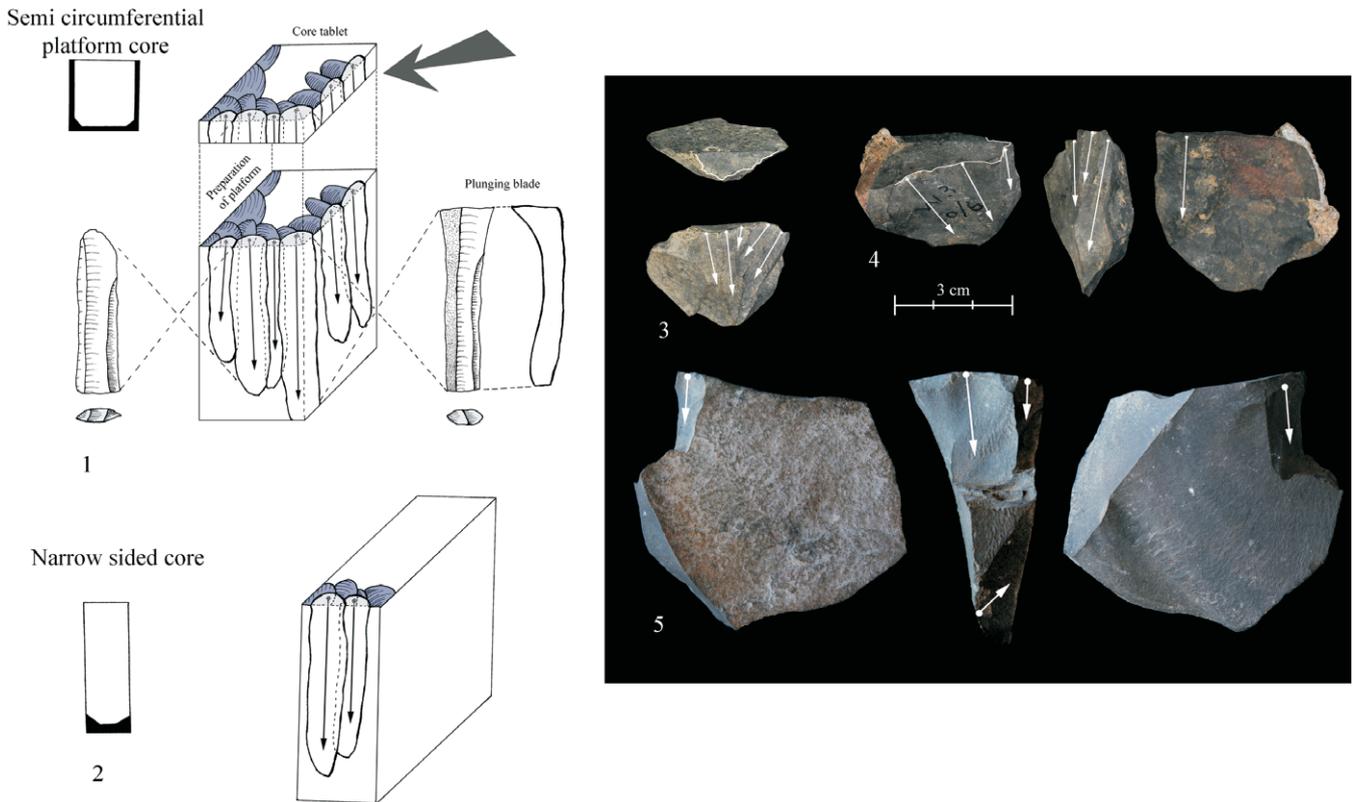


FIG. 2. (1–2) Schematic model of the two kinds of platform core reduction at Holley Shelter; (3–4) semi-circumferential platform core (hornfels); (5) narrow-sided core (hornfels).

often than the narrow-sided cores, but both core types frequently exhibit preparation of platforms. The primary products of both core types are thick elongated blades with unidirectional scar patterns and faceted platforms. We also found many products of core rejuvenation consistent with this strategy, such as core tablets with centripetal preparation and parallel negatives around the edge of the previous core, plunging blades and partially crested blades. Based on these observations, we can reconstruct the strategy of platform core reduction during the MSA at Holley Shelter as shown in Fig. 2, Nos. 1–2.

In contrast to platform cores, parallel reduction methods (Conard *et al.* 2004), which are similar to the concept of Levallois, play a minor role at the site. Nevertheless, the few ($n = 7$) but distinct examples demonstrate the application of this method by the inhabitants of Holley Shelter during the MSA. The scar patterns of these cores suggest end products with flake or point morphology. This observation is substantiated by a quartzite point, refitted to a parallel core. Both, core and point derive from the same spit (inches 18–24) and square.

Knappers predominantly applied bipolar reduction to small quartz pebbles, particularly in the two lowermost spits 30–36 and 36–42. Compared to the overlying occupation

levels, there is an overrepresentation of bipolar cores on quartz in the lowest two spits (inches 30–42). In contrast to the upper occupation sequence, only one platform core occurs in these spits.

In summary, knappers at Holley Shelter predominantly employed two different modalities of platform core reduction with intense preparation of platforms to produce blades in the upper and middle part of the sequence (inches 0–30). The majority of blades with faceted striking platforms derive from these highly prepared cores. Parallel core reduction plays only a secondary role in this technological system, whereas inclined (or formally discoid) cores (Boëda 1993; Peresani 2003; Conard *et al.* 2004) and their respective products are absent in the MSA sequence of Holley Shelter. In the lowermost spits, bipolar cores appear in higher frequencies, a technological change that is closely associated with a raw material procurement geared towards an intense use of quartz.

BLANK PRODUCTION

Blades constitute the main blank type produced during the MSA occupations of Holley Shelter. In the lowermost two spits (inches 30–36 and 36–42), the frequency of blades (24%) is

TABLE 4. Distribution of blank types throughout the sequence of Holley Shelter.

Unit	Depth below datum (cm)	Blade n (%)	Flake n (%)	Point n (%)	Bladelet n (%)	Total n
Inch 0–6	15.0	129 (35.0)	202 (54.7)	32 (8.7)	6 (1.6)	369
Inch 6–12	30.0	209 (38.1)	287 (52.3)	50 (9.1)	3 (0.5)	549
Inch 12–18	45.0	115 (31.3)	206 (56.0)	45 (12.2)	2 (0.5)	368
Inch 18–24	60.0	99 (41.4)	82 (34.3)	57 (23.8)	1 (0.4)	239
Inch 24–30	75.0	92 (35.1)	143 (54.6)	24 (9.2)	3 (1.1)	262
Inch 30–42	105.0	16 (26.2)	39 (63.9)	4 (6.6)	2 (3.3)	61

comparatively low for the site. The blade component increases particularly in the upper five spits (inches 0–6, 6–12, 12–18, 18–24, 24–30) with a minimum of 31% in spit 12–18 and a maximum of 41% in spit 18–24 (Table 4). Bladelets constitute only a minor part of the assemblages (including pieces <3 cm) ranging between 0.4 and 1.6%. Points occur in lower frequencies than blades. In the lowermost spits, between 24 and 42 inches, they represent only 7–9% of the blanks. In the middle part of the sequence (inches 18–24) points reach a maximum of 24% and the younger occupation levels (inches 0–6) feature 9%.

Apart from blades and points, flakes are the most numerous blank types within the individual spits with the exception of spit 18–24, where blades occur in higher frequencies than flakes. Most of these flakes, however, are probably the by-product of the unidirectional platform reduction system. The aim of the knappers to produce blades is supported by the fact that most pieces that have been transformed into tools by retouch in all levels exhibit blade dimensions (between 63.6 and 47.3%). In accordance with the decreasing number of points from inch 24 to 0, the proportion of tools made on points decreases from 34% to 15%. In parallel, the importance of flakes as blanks for tool production increases from inch spit 24 to 0.

The artefacts in the lowermost spits 24–30, 30–36 and 36–42 demonstrate primarily plain platforms (Table 5). By contrast, knappers prepared around 50% of the blank platforms in the four uppermost spits (inches 0–6, 6–12, 12–18, 18–24). The blanks exhibit a high frequency of shattered bulbs (44–71%) as well as (strongly) developed bulbs in all spits (Table 6). Proximal lips, on the other hand, are almost absent. A high frequency of

shattered bulbs is primarily associated with direct percussion by soft stone hammers (e.g. sandstone or limestone) (Pelegrin 2000; Soriano *et al.* 2007; Floss & Weber 2012). Contact points (or ring cracks) on the striking surfaces and ripple lines on the ventral faces are very common and associated with the application of a soft stone hammer. Although we are aware that most of these experiments have not been conducted with South African raw materials, our interpretation is supported by the fact that all hammer stones at Holley Shelter are of sandstone.

The striking platforms of the blanks are thick and wide for all spits (Table 6). The mean values for platform width varies between 15.2 and 19 mm with gradual changes. The platforms are also constant in their thickness that varies between a mean value for each assemblage of 5.3–6.5 mm. For all levels, the exterior platform angle (EPA), as described by Dibble and Rezek (2009), varies between a mean value of 82° and 84° (Table 6). Based on these observations, knappers predominantly employed soft stone hammers with a direct internal percussion movement, regardless of the type of blank they produced. The thick platforms in combination with the relatively high EPAs between 80° and 85° also explain the large dimensions of most blanks and tools at Holley Shelter (Dibble 1997; Pelcin 1997; Lin *et al.* 2013).

Regarding the dimension of blanks, blade length varies between 57 and 65 mm (mean value) with a maximum length of 134 mm. Flakes are markedly shorter, ranging between 38 and 44 mm mean length. They are also broader and thicker than blades in all spits. The number of completely preserved points and bladelets is too low to provide meaningful comparisons.

TABLE 5. Platform characteristics for all artefacts throughout the sequence of Holley Shelter.

Unit	Depth below datum (cm)	Faceted coarse n (%)	Faceted fine n (%)	Step flaking n (%)	Dihedral n (%)	Plain n (%)	Cortical n (%)	Crushed n (%)
Inch 0–6	15.0	39 (16.4)	49 (20.6)	11 (4.6)	12 (5.0)	98 (41.2)	4 (1.7)	25 (10.5)
Inch 6–12	30.0	68 (19.8)	53 (15.4)	20 (5.8)	22 (6.4)	127(36.9)	12 (3.5)	42 (12.2)
Inch 12–18	45.0	57 (23.0)	32 (12.9)	19 (7.7)	22 (6.4)	92 (37.1)	8 (3.2)	18 (7.3)
Inch 18–24	60.0	40 (23.7)	28 (16.6)	3 (1.8)	11 (6.5)	71 (42.0)	5 (3.0)	11(6.5)
Inch 24–30	75.0	30 (18.1)	6 (3.6)	9 (5.4)	12 (7.2)	80 (48.2)	4 (2.4)	25 (15.1)
Inch 30–42	105.0	2 (6.1)	2 (6.1)	0 (0)	3 (9.1)	20 (60.6)	0 (0)	6 (18.2)

TABLE 6. Knapping characteristics for all artefacts throughout the sequence of Holley Shelter.

Percussion marks	Unit	Unit					
		0–6	6–12	12–18	18–24	24–30	30–42
Bulb (%)	Shattered	69.7	71.3	64.2	55.2	43.5	61.8
	Well developed	10.3	9.2	13.2	16.4	14.3	11.8
	Developed	14.5	13.9	18.1	19.4	30.4	11.8
	Poorly developed	5.1	4.1	2.5	7.3	10.6	11.8
	na	0.4	1.5	2.1	1.8	1.2	2.9
Point of contact (%)		21.2	21.1	25.7	38.5	17.0	20.0
Ripple lines (%)		1.1	2.6	3.5	4.6	1.2	3.3
Hertzian cone (%)		2.5	0.4	1.4	4.1	2.8	8
Lip (%)		1.5	1.8	2.4	3.4	4.3	4.0
Platform thickness (mm)	Max	15	19	25	13	16	18
	Min	1	1	1	1	1	1
	Mean	5.3	5.7	6.5	5.9	5.3	5.8
Platform width (mm)	Max	35	37	58	42	46	44
	Min	1	4	4	1	1	5
	Mean	15.8	15.9	18.6	18	15.2	19
EPA (°)	Max	90	90	90	95	100	90
	Min	55	65	50	65	40	60
	Mean	83.5	84	81.8	83.3	81.7	82.9

TOOL ASSEMBLAGES

Holley Shelter features a comparatively low component of tools in the lowermost spits (30–36 and 36–42 inches), between 13.5 and 16%, which is still high for MSA assemblages. We observed an extremely high tool proportion in the upper and middle spits (inches 0 to 30). The frequency decreases from the middle part of the sequence (inches 18–24) where the assemblage contains a maximum of 43% retouched pieces (Table 1) to the uppermost spit (23.5% in inch 0–6). As a comparative value, the Sibudan at the nearby site of Sibudu has a maximum of 27% modified blanks >3 cm (Will *et al.* 2014). We are aware that the tool proportions from Holley Shelter have to be treated very carefully, keeping in mind the potential recovery bias associated with the old excavations as discussed above. Having said this, Cramb reports on the sieving of sediments (Cramb 1961), which is supported by the presence of small debitage products (<3 cm). While the frequencies of retouched specimens are probably overestimates, Cramb's application of relatively fine-grained field methods supports the observation that people frequently manufactured and curated tools at Holley Shelter.

The majority of retouched artefacts do not correspond to formally defined tool forms such as scrapers, but can be best described as minimally retouched blades, flakes or points (Table 7). There are only two tool categories that occur in significant numbers. Splintered pieces of different forms amount to between 26 and 61% of the tools (Table 7), making them the most frequent tool type in almost all spits. Most of these pieces (93.5%) are on hornfels. In the middle part of the sequence, unifacial points, that were also made on hornfels, occur frequently in proportions up to between 23 and 41% (Table 7).

By employing the morphological approach described above, we could identify three main categories of splintered pieces. **Single edge splintered pieces** (Fig. 3, Nos. 1–4) are characterised by splintering only on the distal edge, while the proximal part is well-preserved and thick, often with a developed bulb. There are either no or few splintered negatives on the proximal part. Although residue- and use-wear analyses are required to clarify the exact function and manner of use for these pieces, we suggest that this one-sided damage pattern might be an indication of hafting. **Opposed edge splintered**

pieces (Fig. 3, Nos. 5–10) show splintered negatives on a minimum of two straight and opposed edges. In some cases, all four edges are splintered. The orientation of the damage scars is parallel. As Hays and Lucas (2007) demonstrated, their experimental pieces showed splintering only on the actively knapped edge, while the opposed edge showed blunting only. They pointed out that splintered pieces with damage scars on two opposed edges might have been rotated during their use life. This could be an indication of rotating the opposed edge pieces from Holley Shelter during use as well. However, we recently conducted small-scale experiments using dolerite and quartzite flakes as chisels in order to split bone: during this experiment, both ends of the piece splintered without rotation. Finally, **diagonal splintered** pieces (Fig. 4) denote specimens with one straight and one opposed asymmetric edge, both with splintered negatives. Considering the orientation of the dorsal and ventral scars of these pieces, they have been most likely used obliquely to their main axis. The remaining pieces are mostly broken and do not fit in any of the three categories.

We are aware that we cannot exclude the possibility that splintered pieces from Holley Shelter have been bipolar cores, especially since no residue- or use-wear analyses have been conducted so far. We likewise admit that we cannot ultimately solve this problem here. However, based on the following criteria, we consider it unlikely that the splintered pieces from Holley Shelter functioned as cores. First, we observed many pieces that are made on blades and bear only marginal splintered negatives along the proximal and distal edges (Fig. 3, No. 7). These pieces produced tiny shatters, instead of useful flakes that could be seen as end products. We interpret this kind of splintered pieces as being in an early stage of their use cycle. Other specimens show complete coverage with negatives resulting from bipolar impact on both faces and exhibit intensely splintered edges (Fig. 3, Nos. 5–6). Interpreting those pieces as cores might be more comprehensible but in our view they reflect a final stage of their use life. This is mostly based on the observation that there is no evidence for bipolar knapping on any of the hornfels blanks at Holley Shelter, regardless of size. Furthermore, comparable pieces appeared during our

TABLE 7. Distribution of tool types throughout the sequence of Holley Shelter (including retouched tools and splintered pieces).

Tool type	Unit							Total
	0–6	6–12	12–18	18–24	24–30	30–36	36–42	
Backed piece	2	2	1	3	0	0	0	9
Burin	2	3	2	1	0	0	0	8
Denticulate	2	4	3	1	3	0	0	13
Stone hammer	1	1	1	0	3	0	0	6
Notch	8	6	3	0	2	0	0	19
Retouch on Blade	15	13	17	13	10	1	0	69
Retouch on Flake	9	6	10	5	4	0	0	34
Retouch on Point	6	6	4	2	2	0	0	20
Retouch on Bladelet	0	0	0	0	1	1	0	2
Scraper end	1	2	1	1	1	0	0	6
Scraper side	0	0	10	7	2	1	2	22
Splintered piece	42	86	61	29	20	4	1	243
Unifacial point	2	9	35	46	3	1	2	98
Unifacial tool	0	4	2	3	5	0	0	14
Strangled piece	1	0	0	0	0	0	0	1
Tools total N	91	142	150	111	56	8	5	563
Artefacts total N	388	581	378	256	290	50	37	1980
Tools total % per inch	23.5	24.4	39.7	43.4	19.3	16	13.5	

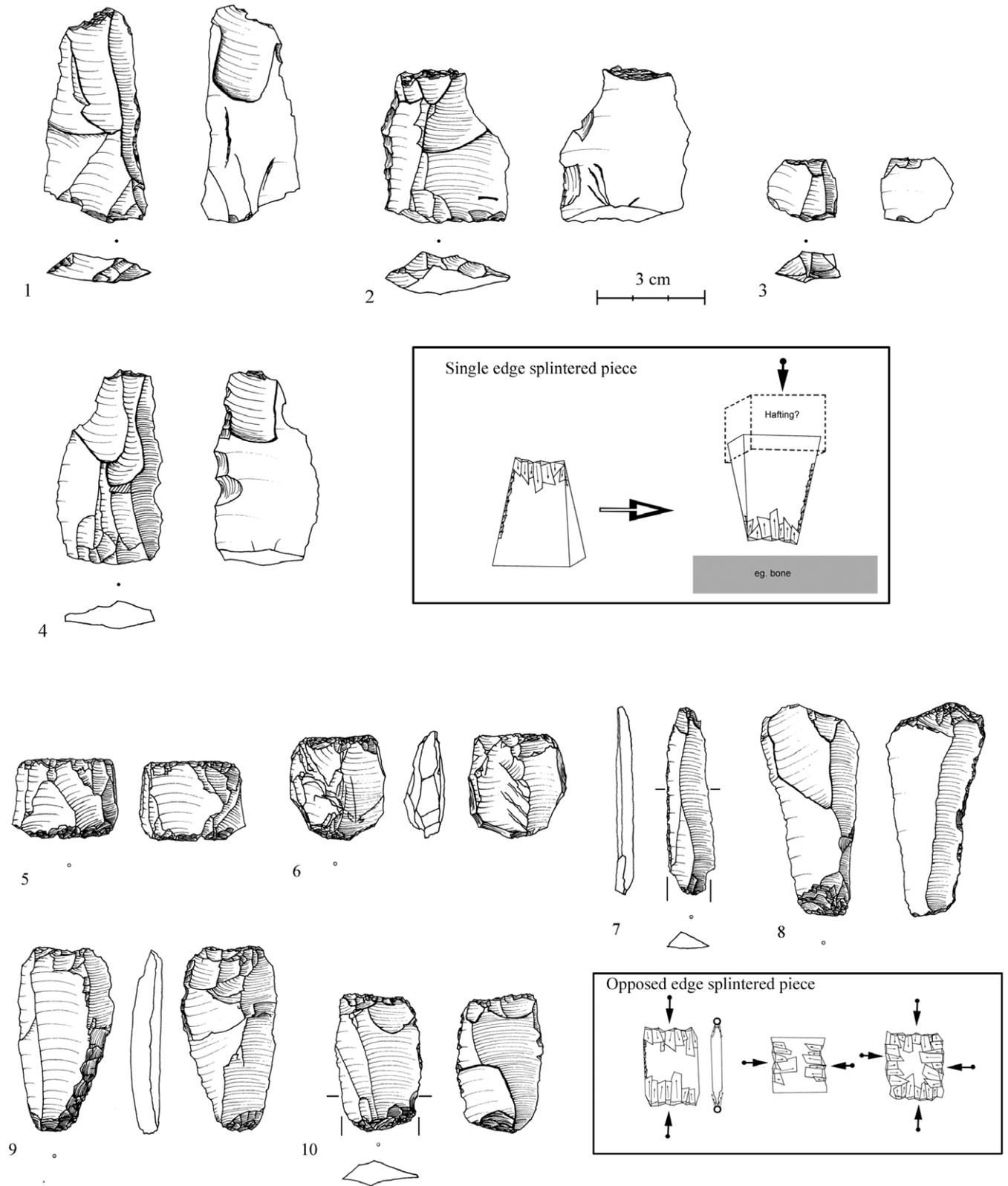


FIG. 3. (1–4) Single-edge splintered pieces; (5–10) opposed-edge splintered pieces (all hornfels) from Holley Shelter.

small-scale experiments mentioned above when we used unretouched dolerite flakes as chisels in order to split bone.

As Hiscock (2015) pointed out, bipolar reduction provides the possibility to reduce cores to very small sizes, which is an advantageous strategy especially when raw materials are scarce. This does not fit the circumstances at Holley Shelter, a site located in an environment very rich in raw material (Fig. 1). In addition, we recognised that many of the splintered pieces

have intentional retouch on their lateral edges (Fig. 3, No. 2, Nos. 7–9). This likely indicates a recycling process for exhausted tools. The majority of the splintered pieces are elongated and also quite thin (between 8 and 9 mm on average) with regards to their length (see Fig. 3, Nos. 7–9), making their use as cores difficult. Apart from the problems and discordances above, we tried to shed light on this special kind of artefact and its variability over time with the categories provided here. While we

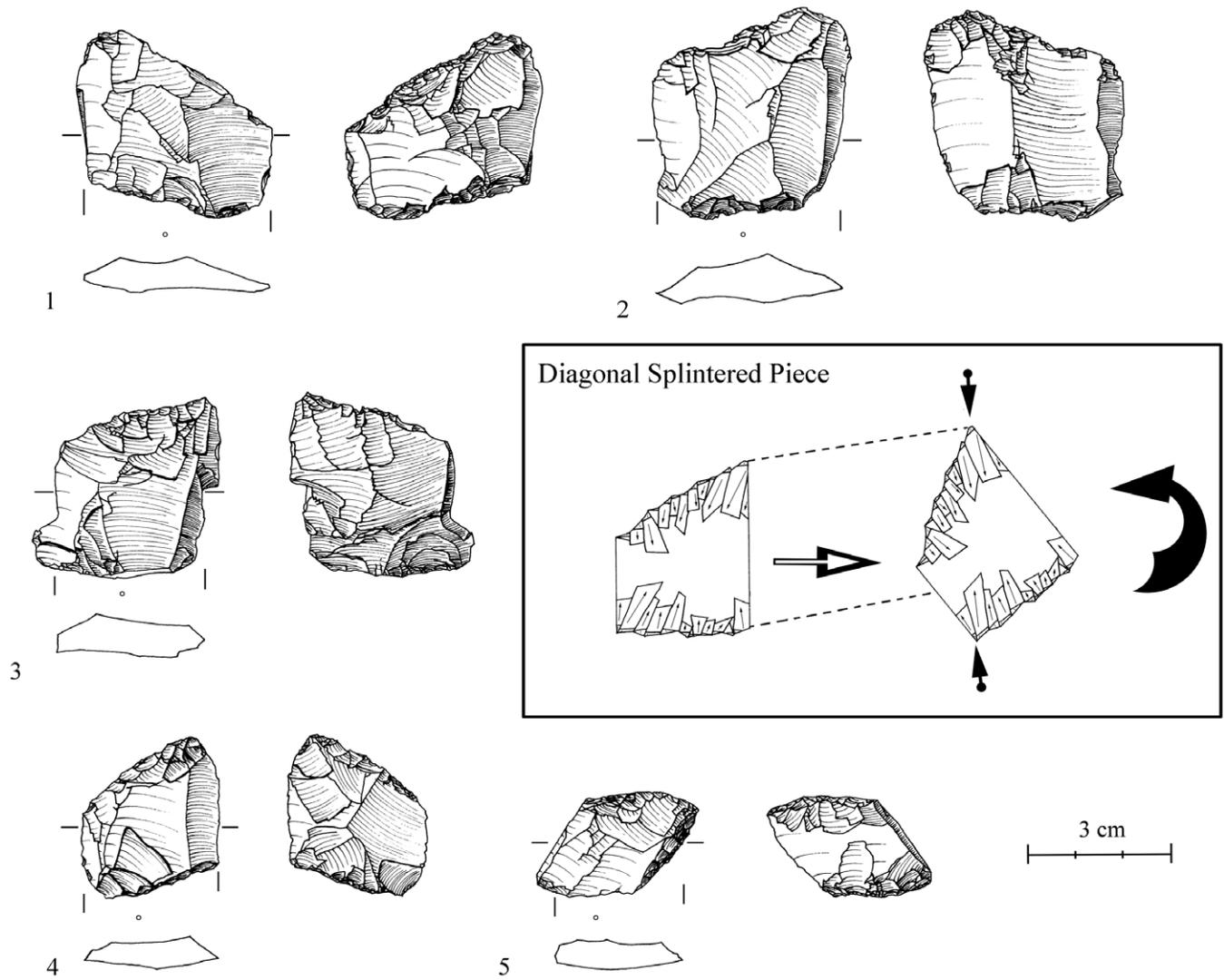


FIG. 4. (1–5) Diagonal splintered pieces (all hornfels) from Holley Shelter.

subsume splintered pieces as formal tools for the above reasons, Holley Shelter’s tool assemblage can easily be calculated without them (Tables 1, 3, 7).

Regarding their frequencies, **opposed-edge splintered pieces** (see Table 8) are the most common representatives in all spits, ranging between 40 and 76%. **Single-edge splintered**

pieces amount to between 14 and 18% in the uppermost three spits (inches 0–18). In the lower spits, they occur only in marginal frequencies. **Diagonal splintered pieces** only occur in the upper part of the sequence. In the 12–18 inch spit, they amount to 10%. In the overlying spits, the number declines to only 2%. Based on this new classification of splintered pieces,

TABLE 8. Classification of splintered pieces at Holley Shelter: *On tool* describes the number of pieces that bear retouch modifications in addition to their splintered edges.

Unit	Depth below datum (cm)	Single edge		Opposed edge		Diagonal		Broken		Total <i>n</i>	Total on tool (%)
		Total	On tool	Total	On tool	Total	On tool	Total	On tool		
Inch 0–6	15.0	7 (14.3%)	4	31 (63.3%)	8	1 (2%)	0	3 (6.1%)	2	49	28.6
Inch 6–12	30.0	15 (18.1%)	4	49 (59.0%)	7	6 (7.2%)	0	13 (15.7%)	4	83	18.1
Inch 12–18	45.0	10 (6.9%)	6	37 (62.7%)	7	6 (10.2%)	2	6 (10.2%)	2	59	28.8
Inch 18–24	60.0	2 (6.9%)	0	22 (75.9%)	10	0 (0%)	0	5 (17.2%)	4	29	48.3
Inch 24–30	75.0	1 (5%)	0	11 (55%)	2	0 (0%)	0	8 (40%)	3	20	25
Inch 30–42	105.0	0 (0%)	0	2 (40%)	0	0 (0%)	0	3 (60%)	2	5	40
Total <i>n</i>		20	14	152	34	13	2	38	17	245	

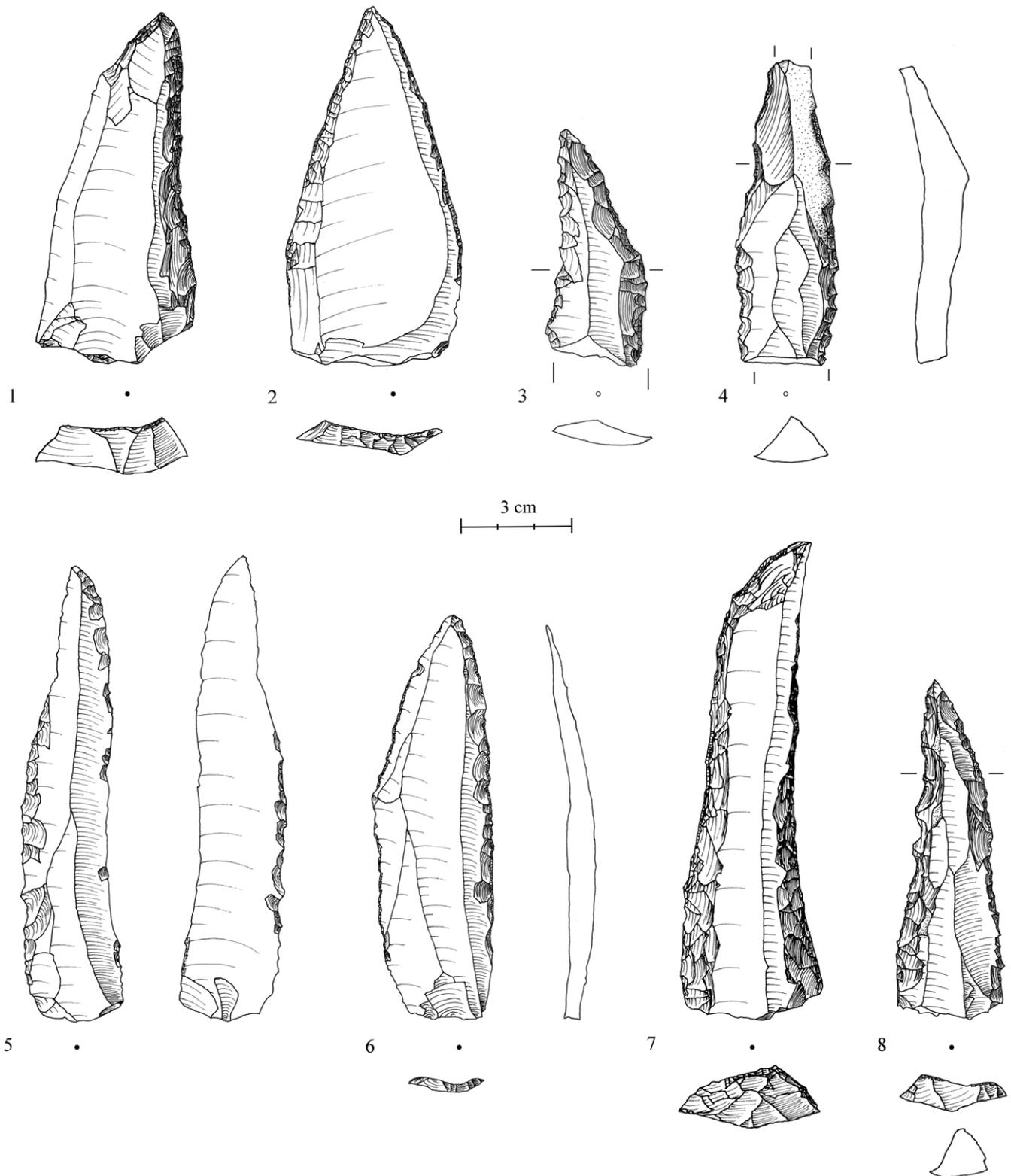


FIG. 5. (1–8) Unifacial points (all hornfels) from Holley Shelter.

we see clear temporal changes during the sequence of Holley Shelter.

Unifacial points constitute the second important tool type at Holley Shelter. They occur in significant numbers only in the middle of the sequence (inches 12–18 and 18–24). In these spits they are the most common tool type. Owing to the similarities between the unifacial points from Holley Shelter and Sibudu (especially layers BSP–BM) (Conard *et al.* 2012; Will *et al.* 2014) we decided to adopt the techno-functional system of analysis

for these tool classes proposed by Conard *et al.* (2012). Using this conceptual framework, most of the unifacial points from Holley Shelter can be classified as Ndwedwe tools (Fig. 5). Following the definition of Conard *et al.* (2012), Ndwedwe tools are “characterised by distinctive, strong, lateral retouch that usually runs the entire length of both sides of the tool. [...] With progressive retouch the pieces become narrower and narrower, while the length remains nearly constant over the course of reduction and modification” (Conard *et al.* 2012: 192).

TABLE 9. Morphometric comparison between Holley Shelter, Sibudu and Umhlatuzana (following Mohapi 2013). All metrics are in mm, mass is in grams. TCOSA is calculated following Hughes (1998) and Shea (2006).

Metrics (mm)	Statistics	Holley Shelter Inch 18–30	Sibudu Post-HP	Umhlatuzana Level 18–16	Umhlatuzana Level 23–19
Length	Mean	67	41.2	46	47.7
	Range	37–130	13–90	33–69	34–74
	<i>n</i>	45	169	13	18
Breadth	Mean	29.0	26.7	26.3	28
	Range	18–45	7–54	18–39	20–39
	<i>n</i>	46	226	16	20
Thickness	Mean	9.1	8.4	9	10.7
	Range	5–15	3–19	6–15	5–17
	<i>n</i>	46	275	17	20
Platform breadth	Mean	22.3	18.8	22.7	19.2
	Range	7–42	3–37	9–35	11–33
	<i>n</i>	45	145	23	19
Platform thickness	Mean	7.4	6.8	5.4	5.3
	Range	2–15	1–17	2–11	2–10
	<i>n</i>	45	153	23	19
Length/breadth ratio	Mean	2.3	1.6	1.8	1.8
	Range	1.3–4.8	0.5–5.0	1.2–2.6	1.3–2.7
	<i>n</i>	46	157	12	18
Mass	Mean	19.3	12.0	10.6	13.5
	Range	4.8–64.47	1.5–64.4	4.7–18.4	4.9–37.2
	<i>n</i>	46	148	10	18
TCOSA	Mean	135.3	119.0	122.8	153.9
	Range	60–280	13.5–465.5	54–234	60–297.5
	<i>n</i>	46	222	16	20

In inch spits 12–18 and 18–24, more than 60% of the unifacial points constitute Ndwedwe tools. Among the unifacial points, we also found some Tongati tools (Conard *et al.* 2012) and asymmetric convergent tools (ACTs) (Will *et al.* 2014). In contrast to Ndwedwe tools, Tongati tools are continuously reduced from the distal to the proximal end, but always retain their convergent distal configuration. ACTs are similar to Tongati tools, but the distal tip is always asymmetrical. Most specimens have steeper, retouched edges opposed to a sharp non- or only marginally retouched edge. These two tool classes appear in much lower frequencies than the Ndwedwe points at Holley Shelter. Additional techno-functional tool classes, such as naturally backed tools (NBTs), occur at Holley Shelter, but only in low frequencies. Table 9 compares several metrics of the unifacial points from Holley Shelter, Sibudu and Umhlatuzana. These comparisons show that the points from Holley Shelter are by far the longest and possess the highest length/breadth ratio. They are also characterised by very thick platforms and a high tip cross-sectional area (TCOSA; after Hughes 1998; Shea 2006; Sisk & Shea 2011).

DISCUSSION

STRATIGRAPHIC INTEGRITY OF THE LITHIC ASSEMBLAGES FROM HOLLEY SHELTER

As many stratigraphic and taphonomic studies have shown (e.g. Cahen & Moeyersons 1977; Hofman 1986; Eren *et al.* 2010; Staurset & Coulson 2014) archaeologists need to be particularly careful when interpreting assemblages without having detailed knowledge about the depositional and post-depositional situation of the site. Based on the results presented above, we can conclude that the stratigraphic situation at Holley Shelter is more reliable than appears from first sight. Within individual spit levels, we observed homogeneous technological signals from cores and blanks. There are also no diagnostic artefacts or tool types (e.g. LSA material such as small segments, microliths or microlithic cores) that do not fit

with the rest of the assemblages (Table 7). The high proportion of splintered pieces might be an exception, but this is discussed in detail below.

Although we found only one refit, both the core and its refitted product belong to the same spit and even to the same square. Further, the nature of the lithic assemblages suggests that we can exclude a strong selection of eye-catching pieces by Gordon Cramb, though there is a minor degree of recovery bias. This observation is based on the original excavator's report on sieving sediments and the concomitant existence of numerous pieces in the assemblage that are smaller than 1 cm without showing any outstanding feature. While the extraordinarily high amount of retouched artefacts may be exaggerated by recovery bias, unmodified blanks still constitute the most abundant category of lithic specimens throughout the sequence. In comparison with sites like Sibudu, which was excavated by state-of-the-art field methods, the high number of retouched artefacts is also not extraordinary. In conclusion, the MSA sequence of Holley Shelter features no obvious extent of mixing to a degree larger than at any modern site. The minor collection bias stemming from the old excavations does not ultimately compromise the nature and completeness of the lithic assemblages. We are thus confident in deriving further-reaching interpretations based upon the MSA material from Holley Shelter.

OCCUPATIONAL PHASES AT HOLLEY SHELTER BASED ON TECHNO-TYOLOGICAL ANALYSES

Based on the techno-typological analyses of the lithic assemblages, we distinguish three different occupational phases. The first comprises the lithic assemblages of the lowermost two spits (inches 30–36 and 36–42), primarily characterised by a different strategy of raw material procurement compared to the overlying inch spits. Here, knappers predominantly collected and used quartz, with hornfels being second in abundance. The number of tools is comparably low and bipolar percussion is the most prevalent core reduction strategy. The

abundance of quartz is associated with the organisation of the lithic technological system towards bipolar percussion. There are only few unifacial points ($n = 3$) and splintered pieces ($n = 5$). The latter occur exclusively as opposed-edge splintered pieces or broken specimens. The near absence of prepared platform cores results in a relatively low number (21.3%) of faceted butts, with most platforms being plain or crushed. The composition of blanks shows the highest abundance of flakes in the Holley Shelter sequence (63.9%). Finally, the number of artefacts >3 cm is the lowest for the entire sequence with only 50 pieces in the inch spit 30–36 and 37 specimens in inch spit 36–42.

The middle part of the sequence, inches 12–18, 18–24, and 24–30, comprise the second coherent technological system during the MSA occupations at Holley Shelter. The abundance of tools increases in these layers as well as the frequency of hornfels from bottom to top. From a metrical perspective, blanks and tools are larger compared to the underlying spits and artefact density is much higher. Knappers preferentially produced blades with faceted platforms but points are also frequent, especially in inches 18–24. In the same spit, 34% of the retouched tools are made on points confirming an increasing importance of this blank type. Different to the underlying spits, platform cores constitute the most important reduction strategy. People adopted soft stone hammer techniques for producing the majority of all blanks. Splintered pieces of all three categories occur and opposed-edge splintered pieces constitute the most common subtype. Single-edge splintered pieces increase towards the top of the sequence while diagonal splintered pieces occur the first time in the inch spit 12–18 of about 10%. Unifacial points appear in the highest frequencies in this part of the sequence. Based on direct comparison with unifacial points from the Sibudan (Conard *et al.* 2012; Will *et al.* 2014), most of these pieces are comparable to Ndwedwe tools.

The two uppermost spits (inch 0–6 and 6–12) correspond to a third coherent occupation phase. Although Cramb noted that the first six inches represent a mixture of LSA and MSA artefacts (Cramb 1961), we did not find any LSA signature in the lithic technology at Holley Shelter. Apart from a single strangled endscraper that could be of LSA character (see Goodwin 1930), the assemblage from the first spit conforms in all techno-typological aspects to a typical MSA technology without evidence for microlithic reduction systems (Deacon 1984; Opperman 1987; Carter *et al.* 1988). The assemblages from spits 0–6 and 6–12 are characterised by the almost exclusive use of hornfels, the preferential production of blades with faceted butts made on unidirectional platform cores, a low tool component compared to the underlying spits and the use of soft stone hammer percussion. Splintered pieces constitute the most abundant tool type, which are almost exclusively made on hornfels. All categories of splintered pieces, as defined above, occur with a dominance of opposed-edge splintered pieces. Single-edge and diagonal splintered pieces increase from top to bottom.

THE PLACE OF HOLLEY SHELTER WITHIN THE MSA OF SOUTHERN AFRICA

As stated above, the absolute age of the occupations at Holley Shelter remains unknown to date. Owing to the described problems of obtaining access to the site, we had no opportunity to extract datable material. We thus tried to narrow down the potential age of the MSA occupation at Holley Shelter by a techno-typological and morphometric comparison with other sites in South Africa, particularly its eastern part in the region of KwaZulu-Natal.

Owing to the absence of bifacial technology and small backed segments at Holley Shelter, we can exclude the existence of Howieson's Poort and Still Bay occupations at the site from our comparative analyses. The lack of bifacial cutting tools and hollow-based points also rules out a final MSA comparable to those at Sibudu or Umhlatuzana. These observations are important for chronological interpretations of the thick sequence at Holley Shelter, as the SB and HP are commonly found in various regions of southern Africa – including KwaZulu-Natal – and can serve as marker horizons for MIS 4 technology (Wadley 2007; Jacobs & Roberts 2008; Lombard *et al.* 2010; Mackay 2011; Henshilwood *et al.* 2014; but see Tribolo *et al.* 2013). Furthermore, the absence of final MSA markers at Holley Shelter helps to further narrow down the potential age of the site to before 35 ka.

There are two well-published sites in the vicinity of Holley Shelter: (i) Sibudu (Wadley & Jacobs 2004, 2006; Wadley 2005b, 2007; Wadley & Mohapi 2008; Conard *et al.* 2012, Will *et al.* 2014; Conard & Will 2015) located about 40 km away; and (ii) Umhlatuzana (Kaplan 1989, 1990; McCall & Thomas 2009; Mohapi 2008, 2013; Lombard *et al.* 2010) at about 60 km distant. In order to obtain more comparable data, we also included Border Cave (Cooke *et al.* 1945; Beaumont 1978; Villa *et al.* 2012) and Rose Cottage Cave (Wadley & Harper 1989; Clark 1997a; Harper 1997; Wadley 1997; Soriano *et al.* 2007) in our comparative analyses, which are both about 300 km away from Holley Shelter.

The only assemblages that compare well from the four sites mentioned above are those post-dating the HP. Most of these assemblages feature frequent unifacial points and all belong to MIS 3 (~58–24 ka). In the late MSA of Umhlatuzana, between 37 and 40% of the tools are unifacial points (Kaplan 1989, 1990). In the post-HP, or Sibudan, of Sibudu (layers BSP-BM) this tool form even comprises between 38 and 54% of all retouched artefacts (Will *et al.* 2014). Unifacial points with faceted butts are also characteristic for the post-HP or MSA3 at Border Cave (layer 2WA – 2BSUP) (Beaumont 1978; Volman 1981; Villa *et al.* 2012). At Rose Cottage Cave, unifacial points occur in both the pre-HP and the post-HP layers. Based on published drawings by Harper (1997), specimens from the pre-HP layers show a more leaf-shaped morphology with reduced butts that do not correspond to the morphology of unifacial points from Holley Shelter. Similarly to Holley Shelter, unifacial points occur predominantly in the middle part of the post-HP sequence at Rose Cottage Cave and their number decreases towards the underlying HP (Soriano *et al.* 2007). In contrast to Holley Shelter, however, the unifacial points from all four comparative sites exhibit flake or point proportions and not elongated blade shapes. While most unifacial points at Holley Shelter are best comparable to Ndwedwe tools from Sibudu (Conard *et al.* 2012), most other sites yield points that are more comparable with Tongati tools. As an additional point regarding tool kits, all comparative sites exhibit higher proportions of retouched artefacts during the post-HP/late MSA occupations compared to both under- and overlying layers.

In order to enlarge the possibilities of comparing assemblages we also conducted a morphometric analysis. Umhlatuzana and Sibudu constitute the best sites for such an analysis since they have detailed morphometric data. Table 5 directly compares various measurements between the unifacial points from the middle sequence of Holley Shelter with those from the late MSA at Umhlatuzana, based on work by Mohapi (2013) as well as the unifacial points from layers directly post-dating the HP at Sibudu based on our own data. The unifacial points from the different sites bear more similarities than differences. Most

measurements show only little variation of a few millimetres for mean values. Having said that, the Holley Shelter points are markedly longer and heavier and also have a higher length to width ratio than those from Umhlatuzana (both sections) and Sibudu. While there might be several reasons for this pattern, one simple explanation derives from the geographic position of Holley Shelter nearby many potential occurrences of hornfels (Fig. 1). The inhabitants of Holley Shelter thus had better access to larger amounts of hornfels compared to those at Sibudu or Umhlatuzana, an interpretation consistent with the existence of large blocks of this raw material in the MSA assemblages.

In terms of blank production, the post-HP at Border Cave is characterised by a higher percentage of blades which declines from the oldest post-HP layer 2WA with 80% to the youngest 2BSUP with 40% (Villa *et al.* 2012). Rose Cottage Cave also shows a strong signal of blade production in the occupations following the HP (Soriano *et al.* 2007). In the layers that follow the HP at Sibudu, blades never exceed 20% (Will *et al.* 2014; Conard & Will, 2015) and Umhlatuzana does not feature blades in significant frequencies during the late MSA (Kaplan 1990). Turning to core reduction strategies, the Sibudan at Sibudu also yielded many platform cores (Will *et al.* 2014: fig. 10, 8–9) which show technological similarities to Holley Shelter. At Holley Shelter, however, platform cores occur in much higher frequencies and play a more important role compared to Sibudu. While there is little published information on core reduction at Umhlatuzana, Kaplan (1989, 1990) mentioned single platform and bipolar cores. In the post-HP of Border Cave, narrow-sided cores occur as well as parallel cores (based on figures SI4, SI6 and SI8 in Villa *et al.* 2012). Finally, Rose Cottage Cave also yielded both laminar platform and parallel cores in the post-HP (Soriano *et al.* 2007: fig. 13).

Based on raw material proportions, Holley Shelter, Sibudu and Umhlatuzana share many similarities. The late MSA at Umhlatuzana features up to 80% of hornfels. In the older and younger strata, the number of hornfels artefacts declines and quartz becomes the most common raw material (Kaplan 1989, 1990). There is a similar trend in the Sibudan at Sibudu. Here dolerite followed by hornfels are the dominant raw materials (Will *et al.* 2014; Conard & Will 2015) while quartz is the more common raw material around the immediate transition between the HP and post-HP (Cochrane 2006; our own observations). These observations match well with the raw material shift at Holley Shelter from quartz, which dominates the bottom of the sequence, to hornfels in the middle and upper occupation horizons. Considering the short distances between Holley Shelter, Sibudu and Umhlatuzana, changes in environmental, demographic and socio-cultural variables probably affected the organisation of lithic technologies in similar ways at all three sites.

Apart from many similarities with stone artefact assemblages postdating the HP, there are differences in lithic technology of this period between the comparative sites and Holley Shelter. The extremely high proportions of retouched artefacts remain unique. This might be in part explained by the dominant use of hornfels in the upper and middle part of the sequence at Holley Shelter in combination with a minor recovery bias. Wadley and Kempson (2011) showed that hornfels is a relatively soft and fragile material, meaning that edges need to be resharpened more often compared to other raw materials. This could be one reason why knappers retouched hornfels more intensely than, for example, dolerite. It is conspicuous that the same over-representation of tools made on hornfels compared to other materials appears at Sibudu (Will *et al.* 2014; Conard & Will 2015). Having said that, we point to the fact that Umhlatuzana

shows low proportions of retouched artefacts although hornfels is the preferred raw material here (Kaplan 1989, 1990). The high proportion of retouched blanks at Holley Shelter in the middle and upper part of the sequence cannot be explained by the scarcity of raw material or long distance import. Under such conditions we would expect a higher variability in raw material composition and a higher proportion of retouched tools made on non-local raw materials compared to local raw material (*cf.* Bamforth 1986; Andrefsky 1994; Floss 1994; Auffermann 1998; MacDonald & Andrefsky 2008). However, this is not the case in the upper and middle part of the sequence at Holley Shelter where knappers almost exclusively used hornfels to produce both tools and unretouched blanks. Furthermore, many potential outcrops of hornfels occur within a 10 km radius around Holley Shelter and the inhabitants introduced large blocks of this raw material to the site. We have identified only a few pieces of potentially non-local raw materials and they exhibit less frequent modifications than hornfels. The situation might be different for the lowest phase of occupation, during which people preferentially collected and knapped quartz but continued to manufacture most tools on hornfels (10 out of 13).

Another feature that distinguishes Holley Shelter from most MSA sites in the eastern part of southern Africa is the high percentage of blades (on hornfels). Most of the comparative sites show much lower percentages of blades and tools are usually made on flakes and points (Kaplan 1989, 1990; Villa *et al.* 2012; Will *et al.* 2014). Only the blade-based post-HP assemblage from Rose Cottage Cave shows high percentages of retouched blades similar to Holley Shelter (Soriano *et al.* 2007). In part, this might again be associated with the natural proportions of hornfels and its abundant occurrence near Holley Shelter. Based on the frequent preservation of slab-like cortex on hornfels artefacts, we suggest that knappers intentionally chose large slabs from around Holley Shelter. Various authors have proposed that slabs often provide favourable conditions for producing blades (Moncel 2005; Carmignani 2010; Shimelmitz *et al.* 2011; Delagnes *et al.* 2012).

Turning to one of the main characteristics of Holley Shelter, the splintered pieces, in the uppermost part of the sequence with up to 61% of this tool category, show strong similarities to the Early LSA (ELSA) occupation at Border Cave (Villa *et al.* 2012) and Rose Cottage Cave (Wadley 1996; Clark 1997b). This observation, however, is the only similarity. In the ELSA at Border Cave, (i) the core technology becomes “unorganised” and “wasteful” (Villa *et al.* 2012: 13210) compared to the underlying post-HP, (ii) the percentage of blades strongly decreases, (iii) bipolar knapping becomes more important, and (iv) a systematic production of microliths is evident (Villa *et al.* 2012). The ELSA at Rose Cottage Cave is marked by irregular cores, bipolar knapping and bladelet production (Wadley 1996; Clark 1997b). We observed none of the above cited changes at Holley Shelter. By contrast, there is clear continuity in technology during the upper and middle part of the sequence. The frequent occurrence of splintered pieces at Holley Shelter is strongly associated with MSA technology, rendering this a unique feature of the site. In fact, we know of no other MSA assemblage in Africa with such a high proportion of splintered pieces.

In summary, the stone artefact assemblages from Holley Shelter share most similarities with lithic industries that post-date the HP in southern Africa. Furthermore, they are clearly distinguished from the Still Bay and Howieson’s Poort technologies which mostly date to MIS 4. The most parsimonious explanation is that the entire MSA occupation of Holley Shelter took place during MIS 3 and before ~35 ka. Based on

our data, we cannot completely reject Cramb's original observation of a short LSA occupation at the top of the sequence as most of his examples derive from excavation of the smaller area of the shelter which is not included in our analysis. This might be an indication of different activity areas during different times. Such an interpretation is also supported by Cramb's notion that "the paucity of split quartz pebble scrapers in the larger section – as compared with the smaller section – is puzzling." (Cramb 1961: 45).

CONCLUSION

We concur with Cramb's statement that "the entire assemblage can best be described as a point and blade industry in a perfect state of preservation" (Cramb 1952: 183). With our re-analysis of the original material, however, we could distinguish different technological phases and were able to show that the structure in lithic technology of Holley Shelter is much more complex. The three phases of occupation that we define most likely belong to settlements during MIS 3 following the Howieson's Poort. The uppermost part of the sequence comprises typical MSA technology together with an extremely high proportion of splintered pieces that is elsewhere only known from ELSA occupations (Clark 1997b; Villa *et al.* 2012). The middle part of the sequence resembles in many ways the Sibudan as defined by Conard *et al.* (2012) and Will *et al.* (2014). We base this assessment on similarities in core reduction, knapping strategies, morphometrics of unifacial points and provisioning of raw material, but also on the appearance of distinct techno-functional markers, namely the Ndwedwe and Tongati tools.

To the best of our knowledge, the frequency of splintered pieces at Holley Shelter is higher than for any other African MSA site. Based on this observation, we used a morphological classification system for this type of artefact. Apart from the still ongoing 'tool vs core'–debate, our results show that splintered pieces have a much higher morphological and temporal variability than recognised so far. These observations can serve as a starting point for more technological and functional studies of splintered pieces deriving from MSA contexts.

Our analyses of the techno-typological markers of Holley Shelter show that knappers possessed a highly structured lithic technology with many diagnostic features, outside of a Howieson's Poort or Still Bay context. If our temporal placement of the settlement within MIS 3 is correct, these results support recent arguments that the MSA after the HP in southern Africa is characterised by increased regionalisation and divergent cultural evolutionary trajectories, but does not show evidence for cultural regression (Mitchell 2008; Lombard & Parsons 2010, 2011; Mackay 2011; McCall 2011; Conard *et al.* 2012; Lombard *et al.* 2012; Villa *et al.* 2012; Porraz *et al.* 2013; Mackay *et al.* 2014; Will *et al.* 2014; Conard & Will 2015). At Holley Shelter, this hypothesis will need to be tested by absolute dates deriving from modern chronometric methods.

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RESEARCH ARTICLE

Implications of Nubian-Like Core Reduction Systems in Southern Africa for the Identification of Early Modern Human Dispersals

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Abstract

Lithic technologies have been used to trace dispersals of early human populations within and beyond Africa. Convergence in lithic systems has the potential to confound such interpretations, implying connections between unrelated groups. Due to their reductive nature, stone artefacts are unusually prone to this chance appearance of similar forms in unrelated populations. Here we present data from the South African Middle Stone Age sites Uitpanskraal 7 and Mertenhof suggesting that Nubian core reduction systems associated with Late Pleistocene populations in North Africa and potentially with early human migrations out of Africa in MIS 5 also occur in southern Africa during early MIS 3 and with no clear connection to the North African occurrence. The timing and spatial distribution of their appearance in southern and northern Africa implies technological convergence, rather than diffusion or dispersal. While lithic technologies can be a critical guide to human population flux, their utility in tracing early human dispersals at large spatial and temporal scales with stone artefact types remains questionable.

Introduction

Similarities in material culture among populations can arise by three pathways: convergence (independent innovation), dispersal (movement of people) or diffusion (movement of ideas/objects or cultural exchange). Historically, most similarities in material culture between two or more samples have been explained through the latter two mechanisms [1–10], though the problem of convergence has long been appreciated [11–13]. Dispersal denotes the physical movement, migration or relocation of a group of people from one area to another together carrying with them (parts of) their material culture, while cultural diffusion involves the movement of ideas or objects from their place of origin to another population in a different area via

analysis, decision to publish, or preparation of the manuscript.

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information transmission (e.g. cultural exchange, stimulus diffusion, trade etc.) without associated movement of people [3,6,14–17].

In contrast to diffusion and dispersal, convergence describes similar ideas or objects arising from independent innovation, analogous to homoplasy of character states in evolutionary biology [18–25]. Such ideas and objects cannot be used to resolve historical relationships between populations and cultures, just as homoplasies do not provide phylogenetic information on organisms [18–25]. The problem of convergence in material culture is particularly acute in lithic technologies, an essentially reductive method of tool manufacture bound by functional requirements of edge production, and by the physics of fracture mechanics [26–28]. These parameters constrain the potential effective morphological space and increase the likelihood of reaching the same form independently (cf. [24,25] for an analogous argument regarding homoplasies in biological systems). From an empirical point of view, convergence can be demonstrated by the fact that similar kinds of lithic artefacts, such as Levallois cores, bifacial lanceolate points, tanged tools or backed microliths, were independently developed by populations widely spread in space and time, precluding *a priori* assumptions of shared information systems [29–32]. Nevertheless, the unique durability of lithic artefacts and their tendency to pattern in space and time means that they remain the basis for most assessments of population flux in the Palaeolithic. This is particularly the case where ancient human DNA is as yet unavailable and given that modern DNA alone can more easily isolate population changes in time than in space [33,34]. More specifically, the identification of past populations with certain lithic assemblages has been consistently employed in the interpretation of human dispersals within, out of, and beyond Africa (e.g., [8,10,35,36–43]).

Dispersal, diffusion and convergence are likely to produce different signals in the archaeological record. Because they involve the retention and movement of information, dispersal and diffusion are consistent with an archaeological pattern of continuity in the occurrence of technological elements through contiguous ranges of space and time. Dispersals should leave an additional genetic signature in the populations involved (cf. models of the spread of farming to Europe [6,14,15,44–46]). The technological element under study itself offers another dimension to distinguish between diffusion and dispersal: cultural diffusion likely operates through product copying and thus the lower-fidelity transmission of more simple assemblage elements, while dispersal would involve process copying and the relatively high-fidelity transmission of more derived systems [41,47–51].

Technological convergence produces different archaeological expectations to diffusion and dispersal. Independent innovation in two unrelated populations is implied by a) a large gap in the spatio-temporal distribution of the technological elements under consideration, and b) replication of only a limited subset of the technological repertoire in the two separated assemblages. Furthermore, as the range of space and time considered increases, so does the probability of convergence, particularly where the technologies are nested in a shared ancestral system [30]. Convergence is a parsimonious explanation where a single assemblage element replicates between spatio-temporally separated samples across a large spatial range—a problem that in particular has plagued the search for inter-continental transmission [40].

In order to limit the confounding potential of convergence, research in the Palaeolithic has usually focused on the most derived components of lithic assemblages, where elaborate, multi-step flaking systems reduce the probability of chance morphological similarities. In more basic elements of lithic technology, such as retouched flakes, equifinality of form is almost inevitable [32,52]. In this respect, systems of core reduction, which include long sequences of interdependent actions, have been a particular focus (e.g. [36,41,53,54]).

The Nubian Techno-Complex and Early Modern Human Dispersals

The Nubian techno-complex provides a significant recent example of attempts to trace broad-scale movements of populations and ideas through a specific core reduction system and its associated products. The Nubian system is a tightly-defined subset of the preferential Levallois core reduction method, in which flakes and points of predetermined size and form are manufactured [55]. Due to its elaborate and specific method of core preparation, the Nubian techno-complex has been equated both with an information sharing network [56] and a group of people [37,57,58] (though note [59]).

Other than the presence of Nubian core technology and the concomitant production of points, proponents have not reached consensus on what additional technological and typological criteria define this cultural unit or how frequent Nubian cores need to be for an assemblage to be characterised as Nubian [56–58,60–64]. This disagreement foregrounds the presence of cores as the principal binding element of Nubian assemblages, but inhibits more complex comparisons between regions [59,65–71].

Based primarily on the presence of Nubian cores, the spatial distribution of the Nubian techno-complex was initially limited to north-east Africa, and age-constrained to MIS 5 (130–74 ka). While proportionally few Nubian sites have been well-dated (cf. [63,66,71]), researchers have distinguished an ‘early Nubian techno-complex’ dating to early MIS 5 (i.e. MIS 5e, ~120 ka), characterized by an emphasis on bilaterally prepared Nubian type 2 cores and a bifacial *façonnage* component (see further discussion below). In contrast, a ‘late Nubian techno-complex’ is said to feature a higher a proportion of Nubian Type 1 cores with distal divergent preparation but without bifacial elements, dating to the second half of MIS 5 [37,39,57,58,64,72,73]. This ‘late Nubian techno-complex’ or N-group [56,61]—has sometimes been seen as the Nubian techno-complex *sensu stricto*, belonging mainly to MIS 5a [39,64,73].

Various usage sees the distribution of the Nubian techno-complex range from specific parts of Northeast Africa, to the combined regions of northern Sudan, the middle and lower Nile Valley, the Eastern Sahara and the Red Sea Mountains and through to “Northeast Africa” more generally [37,39,56,64,73]. Occasional cores with Nubian characteristics have also been reported from Ethiopia [74–77], Kenya [78], Somalia [75], Libya [69], Algeria [70] and as far west as Mauritania [79]. While the majority of reports place the Nubian techno-complex into MIS 5 and thus older than 74 ka [37], the chronological range of Nubian cores extends into MIS 4 and potentially early MIS 3 at the site of Taramsa 1 [73]. That being said, this single MIS 3 occurrence has been referred to the Taramsan rather than the Nubian techno-complex [64,72,73], with volumetric blade debitage replacing Nubian point core reduction.

Recently, documentation of Nubian cores in southern and central Arabia has been used to infer ‘demographic exchange across the Red Sea’, and the concerted presence of anatomically modern humans in the region before 100 ka [37,57,58]. This would represent one of the earliest identified populations of African-derived modern humans outside of Africa, and has been used to support arguments for the southern migration route of modern humans into Asia and Oceania [57]. This hypothesis maintains that the “Afro-Arabian Nubian techno-complex” in both North-East Africa and the Arabian Peninsula, defined on the presence of Nubian cores, reflects the same group of people using this specific reduction technology [37,57,58]. While the chronological control over many sites is weak—particularly on the Arabian Peninsula where they occur almost exclusively as surface assemblages [66]—the slightly later presence of Nubian cores in Arabia is interpreted as evidence for modern human dispersals from their source area in northeast Africa. Two cores with Nubian characteristics have also been reported from the Thar Desert in India and are tentatively associated with early modern human dispersals [80].

Our interest in this paper is whether current definitions preclude the classification of cores from distant parts of Africa as Nubian, and whether any identified similarities more likely arise from dispersal, diffusion or convergence. This has a bearing on the certainty with which the Afro-Arabian Nubian techno-complex can be used to support arguments for anatomically modern humans outside of Africa by 100 ka, for the support that the Afro-Arabian Nubian techno-complex offers the identification of dispersal routes, and also for a number of other arguments concerning early dispersals of modern humans within and beyond Africa [8,36,40,41,81].

Defining the Nubian core reduction system

Formal definitions of the Nubian core reduction system are provided by [55,57,58,60]. Initial definitions delimited two distinct Nubian methods [55,60], though the discreteness of those classes is disputed [82]. Recent definitions [57,58] recognise three Nubian core types (Fig 1), with the potential for transformation between them during the reduction of a single core [82]. Nubian type 1 cores involve the production of a distal ridge by two divergent debordant removals from the distal platform. Type 2 cores involve production of a distal ridge by a series of centripetal removals from the lateral margins of the core. Type 1/2 cores involve a combination of distal and lateral removals to establish the distal ridge that controls final flake form. For all of these core forms, convergent flakes (or points) constitute the main end products.

Usik et al. [58] present four necessary technological attributes for a core to be classified as Nubian: a steeply angled median distal ridge $<120^\circ$ and generally $>60^\circ$; an opposed striking platform with angle of intersection to the exploitation surface varying from $50\text{--}90^\circ$; a triangular core shape (including triangular, cordiform, and pitched); and a prepared main striking platform. They state that “such a rigid definition is necessary to prevent any unwarranted broadening of this particular reduction strategy” (p. 249). As a further criterion, one can add the existence of one or more main convergent removals on the core’s primary working surface indicating the exploitation of Nubian cores for desired end products. While size does not form part of any definitions of the Nubian system, Usik et al. [58] distinguish cores less than 80 mm in length as ‘micro-Nubian’. Their data suggest a continuous, if not evenly distributed, set of cores lengths from 40 mm to 180 mm.

Material and Methods

Uitspankraal 7

Our principal data for this paper derive from the open air site Uitspankraal 7 (UPK7), situated at the confluence of the Doring and Biedouw rivers in south-western South Africa (Figs 2 and

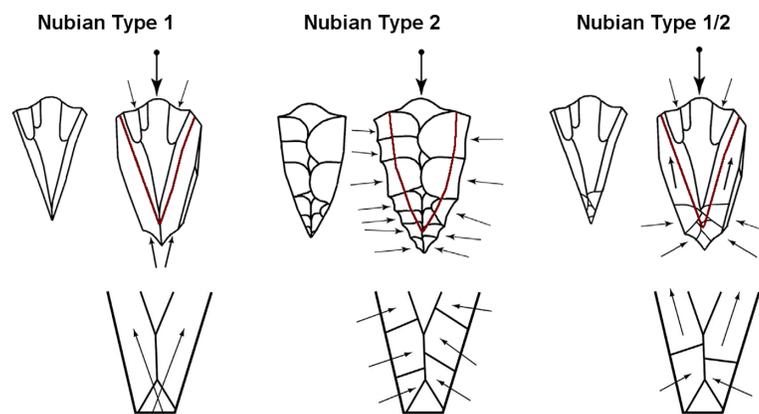


Fig 1. Schematic depiction of the three Nubian core types following [58].

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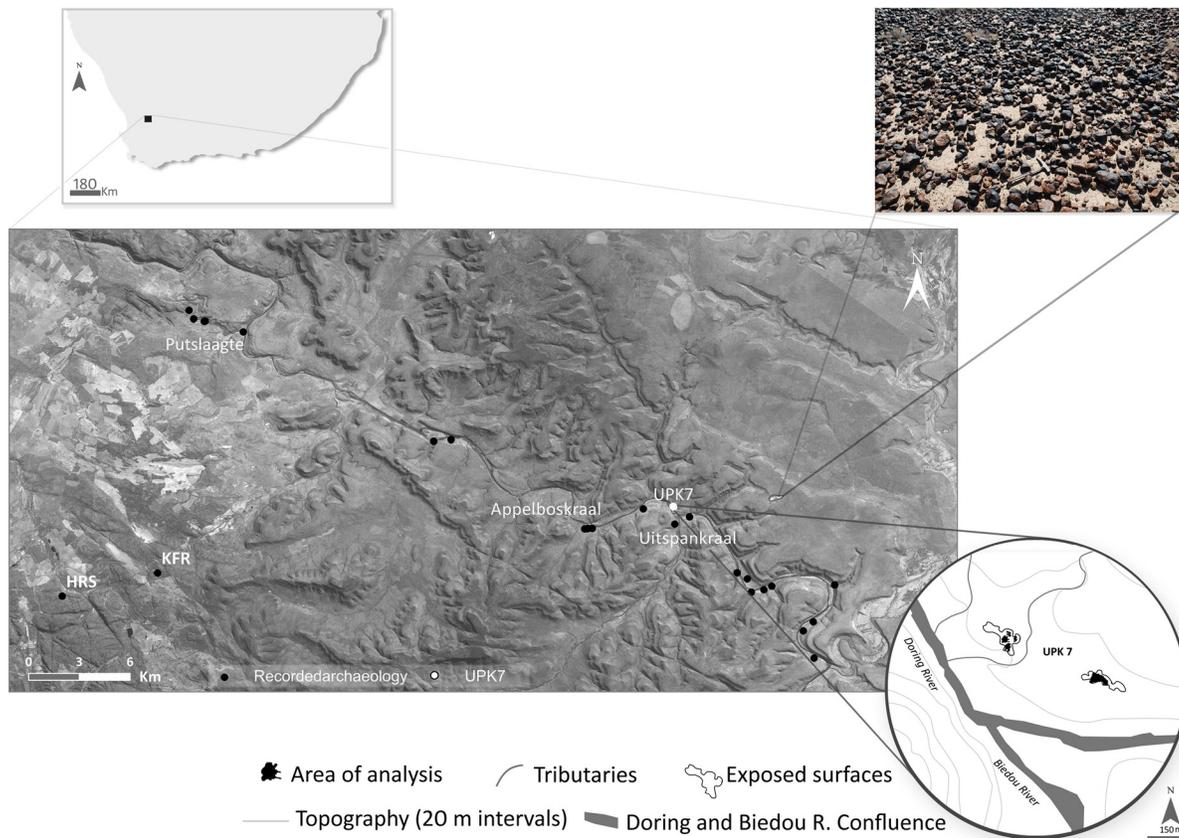


Fig 2. Location of UPK7 and nearby sites in southern Africa, including Mertenhof (MRS), Hollow Rock Shelter (HRS) and Klipfonteinrand (KFR). Inset (top right) are silcrete cobbles from Swartvlei. Landsat panchromatic EDM+ scene downloaded from Global Land Cover Facility (University of Maryland) at <http://glcf.umiacs.umd.edu/index.shtml>. Original scene sourced and modified from [125].

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3). Unlike many parts of Africa, the regional sequence of lithic technological changes in southern Africa is reasonably well-documented, and generally well-dated [41,83,84]. We concentrate here on the Middle Stone Age (MSA) parts of that sequence (Table 1), as it is during the MSA that the Afro-Arabian Nubian techno-complex occurs. Though the MSA of southern Africa shares characteristics with that of north-eastern Africa, including the use of Levallois and discoidal modalities, no Nubian Levallois has previously been identified (though note [85] figs 29 & 30), consistent with the spatially circumscribed notion of the Nubian techno-complex.

UPK7 is a dense scatter of flaked, ground and battered stone artefacts situated ~7 m above the Doring River (Fig 3). The site is actively eroding, with artefacts from multiple palaeosols deflated onto and migrating across the present surface. In spite of this, the site retains spatial structure in many of its time-sensitive elements, with distinct clustering of late Holocene (pottery), early Holocene (naturally backed knives), early Later Stone Age (small blades and platform cores), Still Bay (bifacial points), other MSA (discoidal and Levallois cores; denticulates) and Acheulean (handaxes) markers (Fig 4).

In total we analysed and mapped 9350 artefacts from UPK7 during the field season conducted in 2014. All artefacts were assigned unique identification numbers, analysed in situ and plotted individually in the WGS 84 coordinate system with a total station, using local control points established with a Trimble RTK base and rover DGPS. As we performed in-field analyses on the UPK7 materials only, without collecting or displacing any artefacts, no permits were



Fig 3. Panoramic view of UPK7 (black circle) adjacent to the Biedouw River.

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required. Heritage Western Cape (HWC) requires permits only for the collection and destruction of archaeological material. For the present study, all artefacts had their spatial location recorded to within 1 mm, were analysed in-field by non-destructive methods, and were then returned to their original location. Permission to access the farm Uitspankraal was obtained through Manus and Lillie Hough, owners of Uitspankraal farm.

The sampling included analysis of time-sensitive artefacts identified across the site during repeated non-systematic sampling over one month, and a complete sample of artefacts >20 mm in two areas comprising 299 m², or 3.9% of the total site area. One of these areas comprising 21 m² appeared to consist principally of an early Later Stone Age (LSA) variant [86], the other contained of a mix of MSA components including an accumulation of what we believed to be post-Howiesons Poort artefacts (278 m²). This area and its immediate buffer were the main focus of our seasons' work.

Main area methods and sample

The following methods of lithic analysis were employed in the systematic sampling of the main area of UPK7. Key data captured for all artefacts >20 mm were: raw material, artefact class (flake, retouched flake, core, flaked piece), completeness, artefact type (including tool type or core type), reduction system, weight, maximum dimension, cortex %, cortex type, weathering and reworking. We collected metric data of lithic artefacts using analogue callipers accurate to 1 mm and electronic scales with minimum 1 g precision. All data were entered into Lenovo tablets by a recorder working with an analyst.

Table 1. Characteristics of major Middle Stone Age industries in southern Africa, following [41, 83, 84, 92–94].

Industry	Age (ka) (approx.)	Major implements	Blank types	Raw material selection
Late MSA	30–50	None known	Points, flakes	Local
Post-Howiesons Poort	50–60	Unifacial points, scrapers	Levallois points, blades	Some preferential selection for silcrete
Howiesons Poort	60–65 (60–110)	Backed artefacts, notched blades	Blades	Heavy preferential selection for silcrete
Still Bay	70–80 (70–110)	Bifacial points	Bifacial thinning flakes	Some preferential selection for silcrete
Early MSA	>80	Denticulates	Levallois points, long blades	Local

We restrict the industries described to those occurring in the modern winter and year-round rainfall zones, given potential issues of comparability with industries from further away [41]. Ages in brackets are based on the sequence of Diepkloof Rockshelter [95], which has so-far yielded a uniquely older signal (but see [92, 96]).

doi:10.1371/journal.pone.0131824.t001

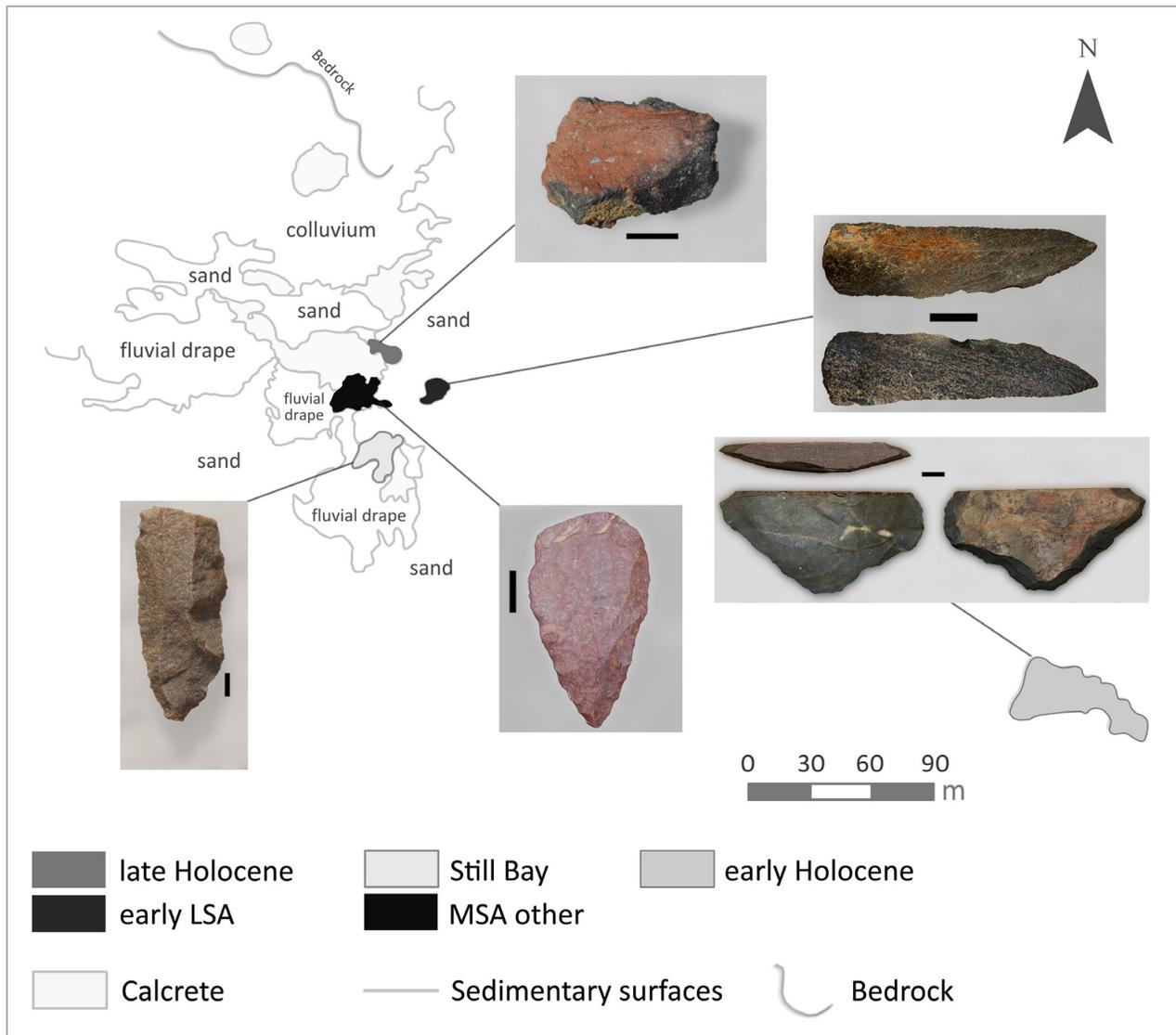


Fig 4. Overview of the UPK7 surface scatter indicating the distinct spatial patterning of time-sensitive cultural elements.

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Additional attributes were recorded on all Levallois cores with Nubian-like characteristics following the definitions and recommendations of [58]. All attributes and measurements were taken by AM and MW and cross-checked to ensure replicability. We measured angles with a goniometer to the nearest degree (°) and dimensions with analogue callipers to the nearest millimetre (mm). In addition to the attribute analysis, each core was photographed and schematically sketched on a spread sheet in the field to record the configuration and sequence of removals on the main working surface (S1 Text).

While we made no systematic attempt at refits during our analysis, we nevertheless identified three refit sets variously comprising three complete flakes, two complete flakes, and one flake and core set. We also conjoined broken artefacts in a further four locations. These observations reaffirm the spatial integrity of the site suggested by the distinct clustering of time-sensitive cultural elements.

Non-systematic samples

Over the course of October 2014 we repeatedly walked the erosional area surrounding the main analytic area at UPK7. During this time we flagged any observed artefacts with potential time-sensitive characteristics. These included backed microliths ($n = 2$), bifacial points ($n = 9$), unifacial points ($n = 3$), denticulates ($n = 7$) and pieces of pottery ($n = 15$), as well as Levallois cores with Nubian-like characteristics. These artefacts were all mapped and analysed at the end of the season. Necessarily these results are not exhaustive but serve to contextualise and in some cases supplement the main analytic sample.

Mertenhof

In addition to UPK7, we present data from ~11800 piece plotted artefacts from the site of Mertenhof (MRS), a rock shelter located 25 km away on the Biedouw River. Three seasons of excavation have been undertaken at MRS so far under the direction of AM and Aara Welz (Fig 5; see S2 Text). The research permit to conduct archaeological excavations at Mertenhof is issued under the National Heritage Resources Act (Act 25 of 1999) and the Western Cape Provincial Gazette 6061, Notice 298 of 2003 and valid from April 2013–2016. AM is the permit holder (permit number: 130306TS13).

All recovered lithic artefacts are temporarily housed in the Department of Archaeology at the University of Cape Town pending accessioning at Iziko South Africa Museum, 25 Queen Victoria Street, Cape Town, 8001, South Africa, where they will be available for further analysis. Mertenhof specimen numbers range from 1–12923 (season 1), 20000–29429 (season 2) and 30000–42600 (season 3).



Fig 5. View of the Mertenhof archaeological site with focus on the rock shelter entrance.

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Mertenhof is one of seven MSA sites excavated within 100 km of UPK7: Elands Bay Cave, Diepkloof, Varsche Rivier 3, Klein Kliphuis, Putslaagte 1, Putslaagte 8 and Klipfonteinrand being the others [86–91]. These assemblages allow the UPK7 finds to be situated in the regional technological and chronological sequence.

Results

The distribution of artefacts at UPK7 reveals distinct high density clustering in the south east quadrant of the analysed area (Fig 6). This high density area is notably silcrete-rich. Fourteen unifacial points were recorded in this area, while a further four were identified in the lower density fringes of the main concentration. Here and below, we refer to all convergent flakes (or point blanks) with dorsal-only retouch as unifacial points, as is common in southern African nomenclature. We mapped and analysed 31 preferential Levallois cores with possible Nubian characteristics in this main sample area (Figs 6 and 7), with a further five such cores being identified in surrounding parts of the site.

We analyzed the 36 potential Nubian cores in terms of the stringent technological definition provided above by [58] to preclude misidentifications. These cores conform either to type 1/2 (58%) or type 2 (36%) variants of the Nubian system (Fig 7), with only one specimen exhibiting type 1 preparation. Knappers manufactured these cores on all principal raw materials at UPK7, including silcrete, quartzite, hornfels and chert. Most of the cores are on silcrete (56%), consistent with their presence in the silcrete-rich area of the site.



Fig 6. Distribution of artefacts in the main area at UPK7, with a focus on silcrete (white circles), unifacial points (nested triangles), and cores with Nubian characteristics (nested circles).

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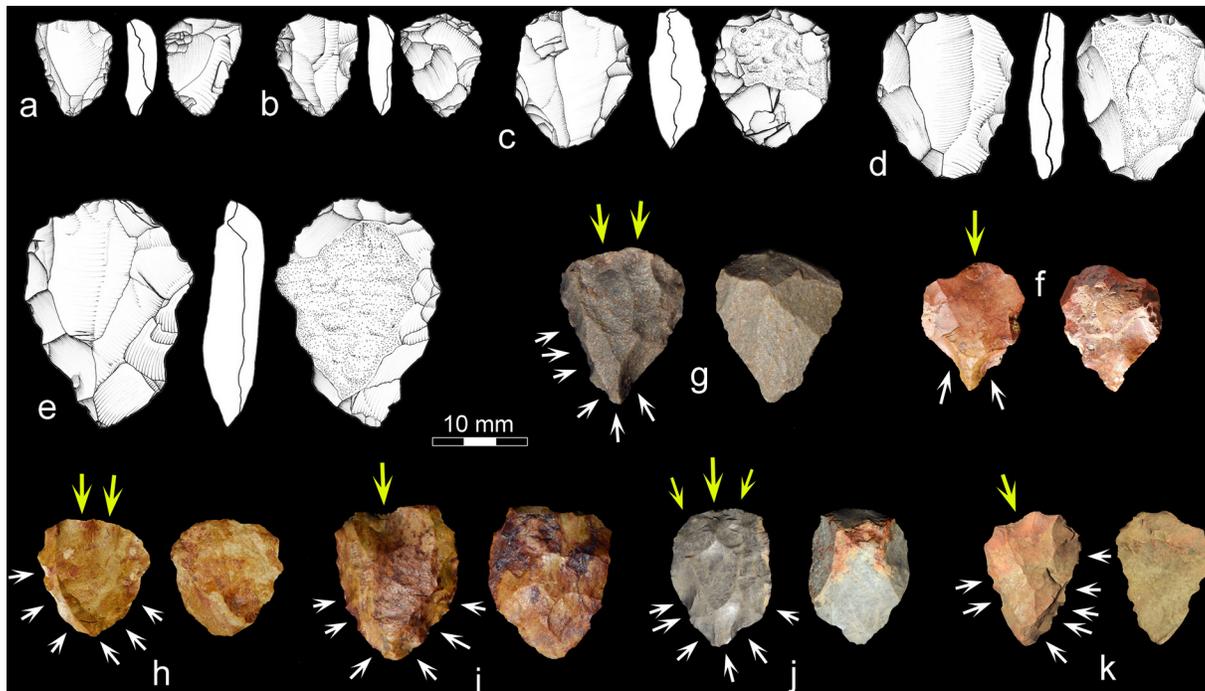


Fig 7. Cores with Nubian characteristics from UPK7 and Mertenhof. UPK7: a, c, h, f & i, silcrete; b & j, chert; d, hornfels; e & g, quartzite. Mertenhof: k, silcrete. White arrows on photos show direction of lateral and distal preparation; yellow arrows show direction(s) of preferential blows.

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The characteristics of the Nubian-like cores at UPK7 conform to the strict technological taxonomic classification by [58] (Table 2). More than 97% of cores (35 of 36) show a steeply angled median distal ridge that serves to control the distal lateral convexity of the core’s primary working surface (mean = 87.2°; range = 59°-135°). Most cores (61%) fall into the “semi-steep” category of [58]. In all cases, knappers set up an opposed secondary striking platform for the preparation of the distal ridge, with a narrow distribution of distal platform angles (mean = 68.7°, range = 53–82°; 82% “semi-acute”). The main and distal striking platforms were treated differently and independently. Knappers always prepared the lateral core margins before installing the distal striking platform.

The Nubian-like cores at UPK7 correspond in 91% to a triangular core morphology, which is most often cordiform (48%). The main striking platform is always prepared, with a dominance of faceted (60%) over dihedral (40%) butts. In terms of end products, most of the cores in our sample exhibit one or more convergent removals on the core’s primary work surface (91%), with flake and blade negatives being rare.

Table 2. Summary statistics of metrics taken on the Nubian cores from UPK7.

	Median distal ridge angle (°)	Distal platform angle (°)	Weight (g)	Maximum dimension (mm)	Length (mm)	Width (mm)	Thickness (mm)	Last removal length (mm)
Mean	87.2	68.7	31.2	45.8	44.4	36.7	16.5	35.4
Min.-Max.	59–135	53–82	8.3–123.1	35–88	33–86	27–66	8–32	10–69
SD	15.0	7.9	28.3	11.6	11.6	9.0	5.7	12.1
n	32	33	34	34	33	33	33	31

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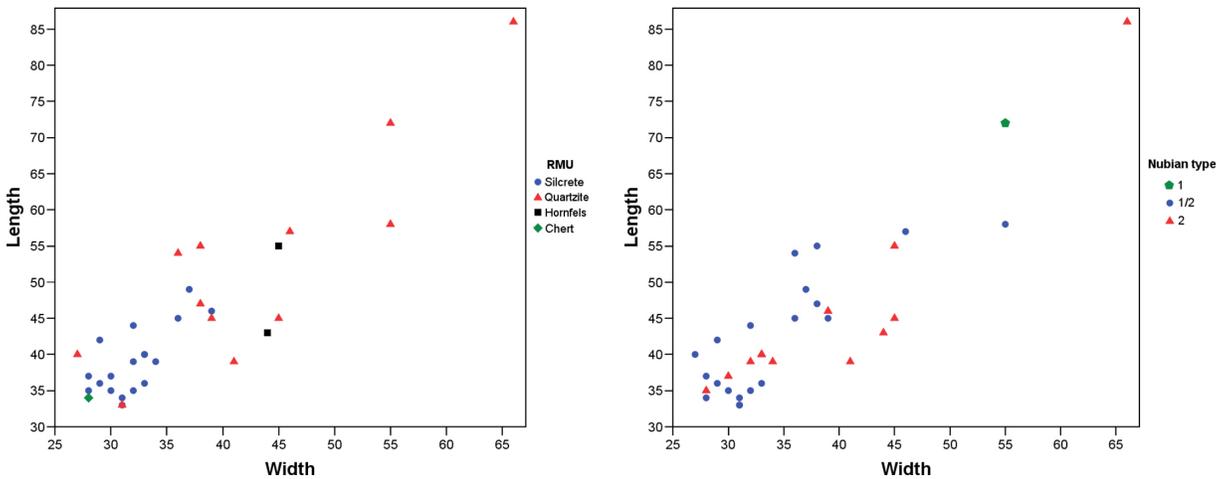


Fig 8. Scatter plots showing length by width (in mm) for Nubian-like cores from UPK7 with indication of raw material (left) and Nubian core type (right).

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The Nubian-like cores at UPK7 are small relative to those from north-eastern African and Arabia (mean length = 44.4 mm, range: 33–86 mm; Fig 8; Table 2), but generally fall in the lower end of the size spectrum of Nubian cores in [58]. The difference in size is likely driven by available raw materials. The silcrete in the sample probably derives from Swartvlei, 5 km SE of the site, where the rock occurs in the form of small nodules <100 mm (Fig 2).

In addition to the Nubian cores, products deriving from this reduction system occur at UPK7 (n = 14; Fig 9). These convergent flakes show negatives from type 2 or type 1/2 Nubian preparation with faceted platforms, exterior platform angles close to 90° and feathered terminations on all edges. The mean length of the last removals on the cores' working surfaces (35.4

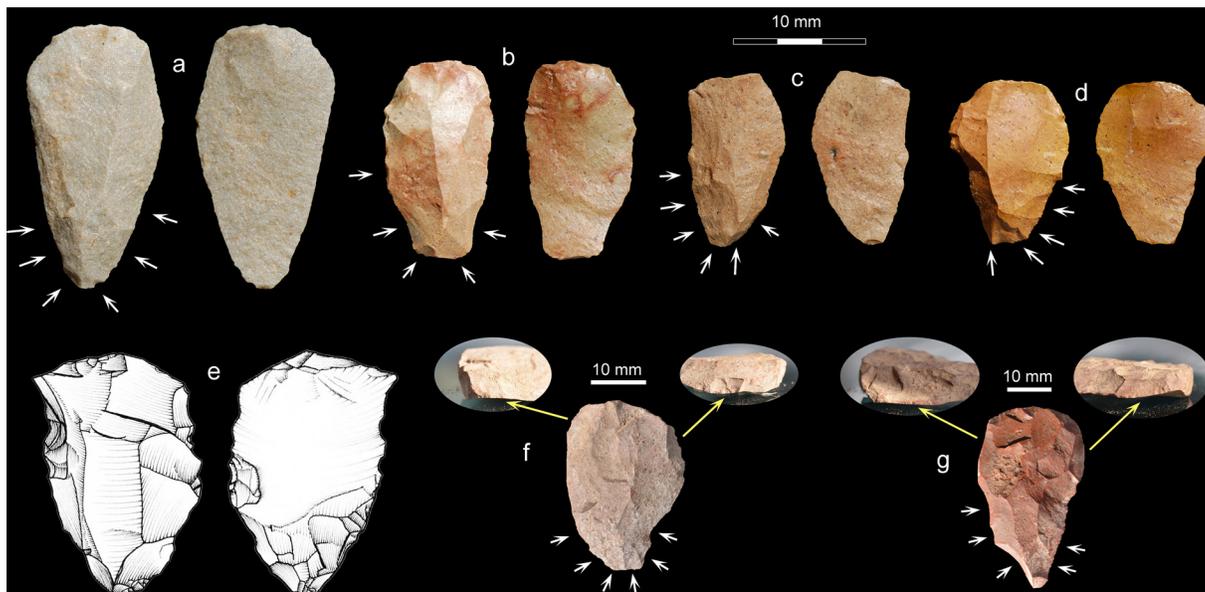


Fig 9. Levallois points with Nubian characteristic from UPK7 and Mertenhof. UPK7: a, quartzite; b-d, silcrete; Mertenhof: f & g, both silcrete. White arrows show directions of preparation removals. Overshot flake from Nubian-like core (e, silcrete). Inset images for Mertenhof points show damage immediately below flake platforms.

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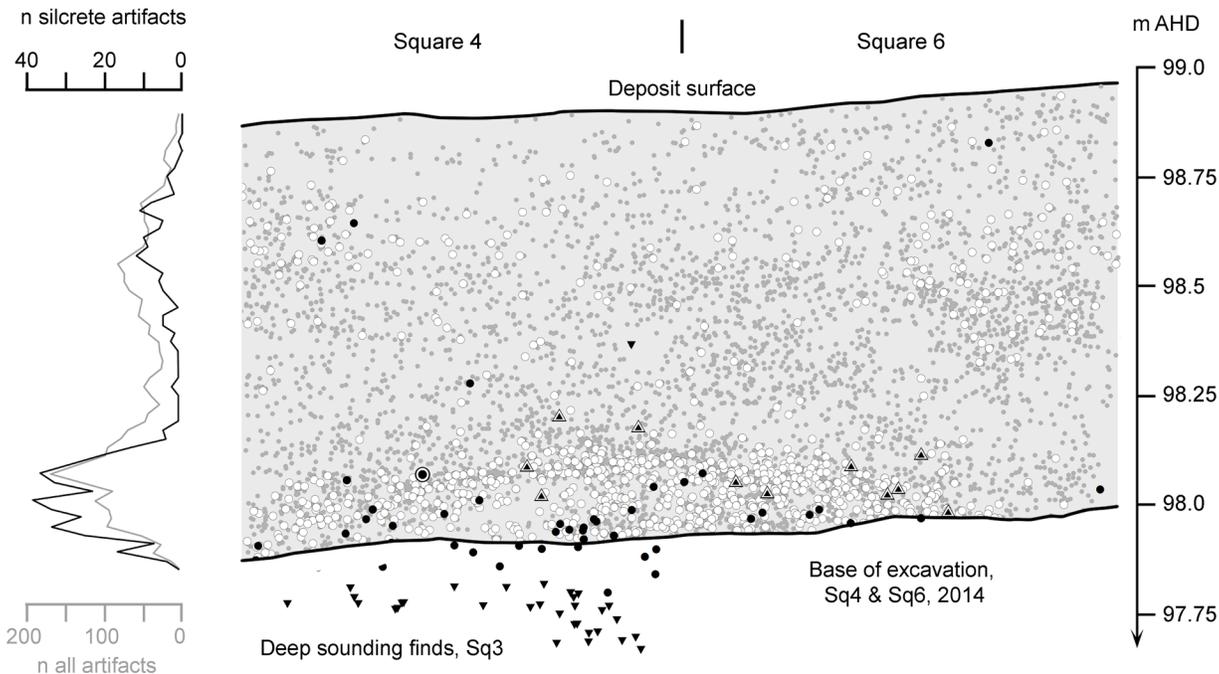


Fig 10. Distribution of artefacts in the Mertenhof sequence. Non-silcrete artefacts (filled grey circles) and silcrete artefacts (white circles) are shown from squares 4 and 6 only (see [S2 Text](#) for square locations). Unifacial points (nested triangles), backed artefacts (black circles), bifacial points and thinning flakes (inverted black triangles) are shown from all excavated squares, including the deep sounding square 3. The single nested circle represents a core with Nubian characteristics. Frequency histograms for all artefacts (grey line and scale) and silcrete artefacts (black line and scale) are generated using arbitrary 20 mm horizontal bins.

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mm) attests to the production of predominantly small convergent flakes at UPK7, particularly for silcrete and chert. Furthermore, three overshoot flakes preserve the distal and lateral core preparation matching the existence of overshoot removal negatives on two of the cores in our sample ([Fig 7c](#)). These products confirm the in situ exploitation and subsequent discard of Nubian-like cores.

Situated 25 km south west of UPK 7, Mertenhof Rock Shelter preserves a long sequence of late Pleistocene lithic industries (see [S2 Text](#); [S1 Fig](#)). Artefact density shows a distinct peak between 98.14 m and 97.9 m above arbitrary height datum coincident with the shift to stratigraphic unit BGG/WS ([Fig 10](#)). The proportion of silcrete also peaks in this range ([Table 3](#)). Unifacial points are common through the upper part of BGG/WS and the immediately overlying unit DGS. In contrast, backed microliths are frequent in lower BGG/WS ([Table 4](#); [S2 Fig](#); see [S2 Text](#) for further discussion).

The assemblages in the upper parts of BGG/WS—dense, silcrete-rich and containing unifacial points—conform to the characteristics of the very earliest “post-Howiesons Poort” at nearby Klein Kliphuis and Diepkloof, dated 60–50 ka [[87,88,90,92](#)]. The so-called “post-Howiesons Poort” is widespread across southern Africa, exhibits a consistent stratigraphic position relative to other industries, and without exception dates to early MIS 3 [[93,94](#)] (see also [Table 1](#)). The immediately underlying assemblages at Mertenhof are typical of the Howiesons Poort, dating >60 ka [[92,95–97](#)]. Bifacial points and associated thinning flakes underlie the distribution of backed microliths and are associated with the Still Bay industry dating >70 ka [[92,95,96,98,99](#)].

That the putative post-Howiesons Poort at Mertenhof is situated in an unusually complete late Pleistocene sequence makes it unlikely that it is in fact some other industry. In the sample recovered so far, the post-Howiesons Poort component of Mertenhof has produced one core

Table 3. Number of artifacts and percentages of major raw material types by stratigraphic unit from Mertenhof (pit and burial units excluded).

Unit	n	Hornfels	Quartz	Quartzite	Silcrete	Chert	DWS*
ULBD	572	31.6	19.9	36.5	4.4	4.4	0.2
R/GBS	1043	27.6	16.9	35.0	13.1	5.2	0.0
LGS	782	17.1	26.3	35.9	6.1	7.7	4.1
LRS	702	12.5	23.4	37.5	2.4	5.0	14.2
DGS	876	4.5	10.7	44.6	4.7	1.5	29.1
Upper BGG/WS	3227	2.2	4.0	43.9	27.3	3.6	14.6
Lower BGG/WS	2561	3.1	6.1	17.9	32.2	15.2	19.0
RGS	444	3.4	8.3	41.9	15.1	2.3	17.3
DBS	339	4.7	5.9	66.1	1.2	0.0	10.0
Total (n)	10546	911	1097	3795	2045	701	1455

*DWS = degraded white stone.

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similar in form to those classified as Nubian, though this lacks installation of a distal platform (Fig 7k). Mertenhof has also produced two unretouched Levallois points that were manufactured from Nubian-like cores, both of which have damage immediately below the platform that may relate to hafting (Fig 9). All three of these artifacts derive from the upper BGG/WS unit.

Discussion

A total sample of 36 preferential Levallois cores from UPK7, mostly deriving from an area of only 278 m², match the stringent definition of the Nubian as outlined in [58]. The contextual data from Mertenhof and regional sites associate these cores with the early post-Howiesons Poort, confidently age bracketed ~60–50 ka. Several lines of evidence suggest that appearance of Nubian core reduction systems in southern Africa reflects convergence on the systems of north-east Africa and Arabia based on the criteria we outlined at the start of this paper.

The first is the large spatial gap between the northern and southern occurrences of Nubian systems. While such systems are widespread in north Africa and occur as far south as Kenya, we could find no published accounts or artefact drawings of Nubian cores from central Africa [100–104], south-central Africa [105–109], or eastern Africa south of Kenya [75,108,110,111]. Particularly important is the lack of Nubian-like cores from well-excavated and stratified sites

Table 4. Frequency of major artefact types by stratigraphic unit from Mertenhof (pit and burial units excluded).

Unit	Scrapers	Notched flakes	Backed microliths	Levallois points	Unifacial points	Bifacial points	BTF*
ULBD	7	0	0	0	0	0	0
R/GBS	3	0	1	0	0	0	0
LGS	2	0	0	0	0	0	1
LRS	1	2	1	5	0	0	0
DGS	4	3	0	13	3	0	0
Upper BGG/WS	6	3	5	31	9	0	0
Lower BGG/WS	2	6	36	5	2	0	0
RGS	0	1	2	2	0	5	26
DBS	0	0	0	3	0	0	0
Total	25	15	46	59	14	5	26

*BTF = bifacial thinning flakes.

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with large lithic assemblages such as Kalambo Falls [112], Mumba Cave [111,113], Apollo 11 [114] and Twin Rivers [115]. While this absence of evidence between southern and north-east Africa could in part be due to discovery or sampling bias, a complete lack of reported Nubian cores from a multitude of variable MSA occurrences is striking considering their high recognition value [57] and long research tradition [60].

Second is the temporal gap between the Nubian occurrences. As noted earlier, most available ages place the occurrence of Nubian core reduction systems in north Africa within MIS 5, with examples of isolated cores in non-Nubian assemblages in MIS 4 and early MIS 3. In contrast to the Nubian techno-complex, the post-Howiesons Poort of southern Africa is well-dated and consistently placed in early MIS 3 only. While there is thus potential for very limited overlap with the occurrence of such core types in North Africa, we note that the vast majority of Nubian-like cores at UPK7 are type 2 and type 1/2. Such cores are common in North Africa during the 'early Nubian techno-complex', and thus in early MIS 5. The 'late Nubian techno-complex' of North Africa is dominated by type 1 cores, which are all but absent from our sample.

Given these points, in order to constitute dispersal or diffusion of the early Nubian from North Africa, our assemblages must reflect transmission of technological information across between 700–3000 generations (allowing for an origin from the late Nubian techno-complex in MIS 5a to the early Nubian techno-complex in MIS 5e), and sustained over 6000 km of diverse environments from the northern deserts through the tropics to the arid and semi-arid regions of the southern temperate zone without leaving an intervening technological signal. If diffusion, this explanation requires high fidelity transmission of that technological system through product copying over 14 000–60 000 years to the exclusion of other technological variants associated with populations encountered en route from south Sudan to the south-western tip of Africa. In order to represent dispersal, this needs to have occurred without leaving a genetic signature, given that "African populations have maintained a large and subdivided population structure throughout much of their evolutionary history" [116], and that genetic studies indicate that north-south dispersals across the various climatic zones and biomes of Africa have been limited during the Pleistocene [116–120]. To that end we note that, while technological industries have occasionally been documented at the continental scale (e.g., Clovis), we are unaware of any industry associated with anatomically modern humans that extends from the temperate zones of the northern hemisphere to those of the southern hemisphere across the tropics. Within Africa, major industries such as the Lupemban, Aterian, Howiesons Poort and Still Bay are restricted to either one temperate zone or to the tropics.

Third, while Nubian-like cores occur in our samples, they are accompanied by unifacial points that are otherwise typical of the post-Howiesons Poort in the region. Thus, our samples and those in the north east of Africa are linked solely by a specific core form.

Overall, given that we have replication of a single technological element between spatially and temporally isolated assemblages, and allowing that the potential sampling interval covers up to 60 000 years across the breadth of Africa, convergence necessarily constitutes the most parsimonious explanation for the Nubian cores found at UPK7 in southern Africa.

Interpreting the UPK7 assemblage as including an instance of technological convergence on the Nubian core reduction system carries several implications. Foremost, the distribution of Nubian cores cannot be assumed to reflect information sharing networks. This does not fundamentally confound the interpretations of [37,57,58] but it does complicate them. In cases where similar lithic systems occur in the same restricted time interval in contiguous areas, information transmission with or without attendant population movement remains a relatively parsimonious explanation. The validity of this hypothesis, however, is contingent on establishing chronological controls for relevant samples, as well as more detailed technological and quantitative comparisons of entire lithic assemblages rather than a single core reduction

method. At the moment, such assessments are complicated by a lack of consent regarding different elements of the Nubian or Afro-Arabian Nubian techno-complex and the equation of this unit with a particular group of people [38,59]. In this regard, the recent demonstration of technological convergence of tanged artefacts between North Africa and Arabia—with the latter probably dating to the Holocene—serves as a note of warning [67,68].

More generally, arguments that rely on lithic technologies to track the dispersal of modern human populations across Africa and beyond (e.g., [40]) are necessarily problematic where they assume that the degree of similarity in lithic reduction system informs on the degree of population relatedness in assemblages that are widely separated in space and time [36]. Unrelated populations made similar artefacts [121], and related populations made quite different artefacts given the passage of relatively brief amounts of time [122]. Most problematic in this regard are hypotheses that are based on single core or tool types [37,40,57] which not only mask assemblage variability but also increase the chance of convergence [66,123]. More robust hypotheses may be built using approaches that characterize variability across several lithic domains with a focus on quantitative data and multivariate statistical analyses [35,50,66,123,124]. With presently available data, however, our confidence in lithics as a proxy for the dispersal routes taken by early modern human within and out of Africa must remain weak [34].

Supporting Information

S1 Fig. Mertenhof Rock Shelter. Left panel (a) plan view of topo points on shelter walls and immediate talus (green point), with shelter walls and excavation squares shown in white; b) section view of topo points with plotted finds (blue circles); (c) layout of squares. Right panel shows excavation at the end of season 3.

(TIF)

S2 Fig. Sample of artefacts from Mertenhof Rock Shelter. (a-d) platform (bladelet) cores, Robberg layers; (e) truncated quartz blade, (f) chert segment, (g) chert truncated notched blade, Howiesons Poort layers; (h) silcrete unifacial point tip, (i) hornfels unifacial point, post-Howiesons Poort layers; (j) silcrete bifacial point, (k) quartzite bifacial point, Still Bay layers; (l) quartzite denticulate, (m) quartzite blade, early MSA layers. White dots show location of retouch on backed artefacts and denticulates.

(TIF)

S1 Text. Nubian core spreadsheet. Example of a filled-in Nubian core spreadsheet with a schematic sketch of the configuration and sequence of removals on the main working surface.

(DOCX)

S2 Text. Archaeology of Mertenhof Rock Shelter, Western Cape, South Africa.

(DOCX)

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Author Contributions

Conceived and designed the experiments: MW AM. Performed the experiments: MW AM NP. Analyzed the data: MW AM NP. Contributed reagents/materials/analysis tools: MW AM NP. Wrote the paper: MW AM.

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Bringing the Middle Stone Age into Clearer Focus

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Abstract: *Prior to the 1990s, archaeologists often viewed the Middle Stone Age (MSA) as a period less important for research than the Earlier Stone Age in which early Homo evolved and the Later Stone Age in which scholars envisioned a high degree of archaeological continuity with recent hunters and gatherers. With the realization that modern humans evolved in Africa during the MSA around 200 ka BP, this period became a central topic of international research. Subsequently, new excavations and research projects made southern Africa the leading region for research on the MSA. Based on the results of an international workshop held in Tübingen in September 2014, we summarize the state of this research and demonstrate that current models advocating a clear cultural sequence across the entire subcontinent with well-defined and largely homogeneous cultural-chronological units are too simplistic. Here we stress that the archaeological record of the MSA is more complex and regionally variable than has been recognized in current publications, including what we refer to as the Synthetic Model proposed by Jacobs, Henshilwood and other colleagues. Based on high-resolution observations presented at the workshop in Tübingen, we argue that research is entering a phase in which a more complex record of the MSA will come into clearer focus and improved models of behavioral change and spatial-temporal variation will emerge to examine the dynamics of cultural evolution during the MSA.*

Keywords: *Middle Stone Age, southern Africa, lithic technology, cultural sequence, behavioral variability*

Das Middle Stone Age besser in den Brennpunkt bringen

Zusammenfassung: Bis in die 1990er Jahre beschäftigte sich die Steinzeitforschung in Afrika hauptsächlich mit dem Earlier Stone Age, welches die Entwicklung der ersten Vertreter der Gattung *Homo* umfasst, sowie dem Later Stone Age, welches durch seine zeitliche Stellung mögliche Anknüpfungspunkte an rezente Jäger- und Sammlergruppen aufweist. Erst mit der Erkenntnis, dass moderne Menschen um ca. 200.000 vor heute in Afrika entstanden, begann die Archäologie sich auf das zwischen diesen Perioden liegende Middle Stone Age (MSA) zu konzentrieren. Seit den späten 1990er Jahren bezog sich die Forschung vor allem auf das östliche und südliche Afrika, um die frühe kulturelle Entwicklung von *Homo sapiens* nachzuvollziehen. Infolgedessen wurde das heutige Südafrika aufgrund der Vielzahl an neuen Grabungen und internationalen Forschungsprojekten zur archäologisch am besten erfassten Region für das MSA in Afrika. Im September 2014 veranstalteten wir einen Workshop in Tübingen, zu welchem internationale Teams geladen wurden, um die neuesten Forschungsergebnisse aus Südafrika und anderen afrikanischen Regionen zusammenzufassen, zu diskutieren und in den weiteren Kontext der frühen kulturellen Evolution des modernen Menschen zu stellen. Hierbei sollten vor allem Fragen nach deren Art und Verlauf gestellt und kritisch beleuchtet werden. Die kritische Evaluation dieser Ergebnisse zeigte, dass derzeitige vorherrschende Modelle zu stark vereinfachend strukturiert sind, um

die komplexe archäologische Realität des MSA zu erklären. Das gegenwärtig in der Diskussion dominierende „Synthetische Modell“ von Jacobs, Henshilwood und Kollegen besagt, dass die kulturelle Abfolge des MSA im südlichen Afrika durch zwei klar definierte, einheitliche und zeitlich eng begrenzte Technokomplexe, das Still Bay und das Howiesons Poort, charakterisiert ist. Diese beiden Einheiten sollen demzufolge zwei kulturell hochentwickelte Phasen widerspiegeln, die sich klar in ihrer materiellen Kultur von den Perioden davor und danach unterscheiden. Wir zeigen hier, dass die chrono-kulturelle Sequenz des MSA in Wirklichkeit um einiges komplizierter und regional variabler ist als ihr in dem vorherrschenden Modell zugestanden wird. Vor allem der intensive Fokus der Forschung auf das Still Bay und Howiesons Poort in den letzten Jahrzehnten hat zu einem verzerrten Bild der archäologischen Realität geführt. Neue Forschungsergebnisse zur materiellen Kultur vor und nach diesen Technokomplexen belegen einen vielschichtigeren Verlauf der kulturellen Evolution von modernen Menschen, zumindest in Südafrika. Unserer Meinung nach tritt die MSA-Forschung zurzeit in eine Phase ein, in welcher die räumliche und zeitliche Variabilität im Verhaltensrepertoire von *Homo sapiens* in den Mittelpunkt rückt und Forscher dadurch sowohl empirisch wie auch theoretisch besser fundierte Modelle zur kulturellen Evolution von modernen Menschen entwickeln werden.

Schlagwörter: Middle Stone Age, südliches Afrika, lithische Technologie, Kulturabfolge, Verhaltensvariabilität

Over the last two decades, studies of the Middle Stone Age (MSA) have moved from relative obscurity to a central focus of international research in early prehistory and paleoanthropology. This development was largely driven by the realization that *Homo sapiens* originated in Africa around 200 ka BP. The MSA spans the vast period between roughly 300 and 30 ka BP, encompassing the archaeological record for the evolution of anatomically and culturally modern humans in Africa.



Fig. 1: Participants of the international workshop “Contextualizing technological change and cultural evolution in the MSA of southern Africa” at Hohentübingen Castle. Front row from left to right: Nicholas Conard, Mareike Brenner, Susan Mentzer, Regine Stolarczyk, Daniela Rosso, Chantal Tribolo, Panagiotis Karkanis, Christopher Miller, Viola Schmid, Darya Presnyakova, Iris Guillemard; second row: Alex Mackay, Jorden Peery, Magnus Haaland, Michael Bolus, Patrick Schmidt, Manuel Will, Gregor Bader, Laura Basell, John Parkington, Sarah Wurz; third row: Pierre-Jean Texier, Stanley Ambrose, Benoît Chevrier, Norbert Mercier, Ralf Vogelsang, Andrew Kandel, Götz Ossendorf, Isabell Schmidt, Katja Douze, Will Archer, Guillaume Porraz. Photo: I. Gold.

From September 8 – 10, 2014, Nicholas Conard and Christopher Miller of the Department of Early Prehistory and Quaternary Ecology and the Institute of Archaeological Sciences at the University of Tübingen, together with Guillaume Porraz from the CNRS and the University of Paris X in Nanterre, hosted an international workshop at Hohentübingen Castle. The meeting aimed to address new trends in the study of the MSA, with a focus on lithic technology in southern Africa. In keeping with its main goal, the workshop bore the name: “Contextualizing technological change and cultural evolution in the MSA of southern Africa”. Gregor Bader, Viola Schmid, and Manuel Will, all Ph.D. candidates at the University of Tübingen, assisted in all stages of the planning and execution. Thirty-five researchers from Africa, Europe and North America participated in the meeting, including most of the active research teams studying the MSA. The workshop was funded by the German Science Foundation (DFG) and the French Ministry of Foreign Affairs (Fig.1).

Although stone artifact technology from southern Africa formed the central focus of the meeting, sessions also addressed topics concerning geoarchaeology and chronostratigraphy, as well as new research in eastern and western Africa. The program of the workshop and all abstracts can be found on the website of the Department of Early Prehistory and Quaternary Ecology of the University of Tübingen.

The long-term cooperation between the organizers at sites in southern Africa including Diepkloof, Sibudu, Elands Bay Cave, Hoedjiespunt, and Bushman Rock Shelter has produced a wealth of new information about the cultural and technological evolution of modern humans during the MSA. The presentation of new data from these projects to an international audience represented one central aspect of the workshop. Immediately prior to the main meeting, the members of the Elands Bay Cave project, which was funded by the German Science Foundation, met to report on results from recent excavations at this important site on the Western Cape of South Africa. Scholars from other active research teams working in southern Africa presented their work on Klasies River Mouth (Sarah Wurz), Blombos (Katja Douze), Pinnacle Point (Panagiotis Karkanas), Mertenhof and Varsche Rivier (Alex Mackay) as well as Holley Shelter (Gregor Bader).

Similarly, researchers from the collaborative research center in Cologne (SFB 806) reported new research on sites in Namibia including Apollo 11 and Pockenbank (Götz Ossendorf, Isabell Schmidt and Ralf Vogelsang).

To help contextualize the new research from southern Africa, Stanley Ambrose reported on excavations in the Central Rift region and southwestern Kenya and Benoît Chevrier presented his work in eastern Senegal. Additional papers addressed the various uses of ochre at Porc Epic in Ethiopia (Daniela Rosso), and cultural stratigraphic trends from the long sequence of Mumba Cave in Tanzania (Knut Bretzke), which have implications for large-scale cultural exchange and human migrations. Similarly, Laura Basell examined the relationships between cultural and environmental changes in eastern Africa.

In his keynote address, Christopher Miller presented an overview of the innovative geoarchaeological research in southern Africa and illustrated the many new insights about human behavior that studies using micromorphological methods and Fourier Transform Infrared Spectrometry have facilitated. Chantal Tribolo discussed the current

state of chrono-stratigraphic research on the MSA of southern Africa and pointed to uncertainties in what we refer to as the Synthetic Model advocated by Jacobs, Henshilwood and colleagues (Jacobs et al. 2008; Henshilwood 2012). Patrick Schmidt reported on his research that focuses on the tempering of silcrete. In contrast to colleagues such as Brown (Brown et al. 2009) and Wadley and Prinsloo (2014), he found that heat treating of silcrete does not require special cognitive skills or complex technology, but is rather a fairly straightforward process that can be done parallel to other activities at hearths (Schmidt et al. 2013). These are clearly areas of ongoing dynamic research and debate, where we can expect further breakthroughs in the coming years. In other methodological developments, Will Archer presented results from the Max Planck Institute in Leipzig that focus on developing new numerical methods for capturing patterns of variation in bifacial points of the Still Bay (SB). Archer and colleagues used three-dimensional CT scans to document lithic variability and to test competing explanations for technological change.

Turning to broader issues in human evolution, Regine Stolarczyk used the methods derived from problem-solution-distance analysis (Haidle 2010, 2012) to examine the cognitive complexity involved in the manufacture of organic artifacts from the MSA of southern Africa. Finally, Andrew Kandel presented a model, developed by the ROCEEH team of the Heidelberg Academy of Sciences and Humanities, for the evolution of behavioral hyperplasticity among *Homo sapiens* to help explain the appearance of cultural innovations, such as new lithic technologies and abstract engravings on ochre and ostrich eggshell.

What have we learned from the workshop? First, it is becoming increasingly clear that the Synthetic Model for the cultural chronology of the MSA of southern Africa, proposed by many scholars including Jacobs, Henshilwood, and others (Jacobs et al. 2008; Henshilwood 2012), reflects an oversimplification of the archaeological reality (Fig. 2). This model came into focus in recent years, and it represented a major breakthrough at that time. Its main thrust was the proposition that the Still Bay and Howiesons Poort (HP), which had previously been defined solely on their characteristic stone artifacts, represented well-defined cultural entities and periods of exceptional innovation. Proponents explained these observations by increases in population sizes as well as exchange of information between groups over long distances. The Synthetic Model was significantly based on results from excavations at sites including Blombos, Diepkloof, Sibudu, Hollow Rock Shelter, Klein Kliphuis, and Apollo 11, as well as from Jacobs' optically stimulated luminescence (OSL) dates from MSA sites across southern Africa. Building on these observations, many researchers argued that the SB and HP represented well-dated and short episodes of cultural florescence that correspond to ca. 75–71 ka BP and 65–59 ka BP, respectively. This synthesis of what had previously been rather unstructured information met considerable support in the archaeological community, since it fits expectations and perhaps also the longing for order and clarity in what had previously been a complicated and uncertain cultural sequence. The Synthetic Model had implications for many ideas under discussion related to the nature and tempo of cultural change and innovation during the MSA. The model, if valid, would also have major implications for our understanding of the relationships between environmental change, cultural change and population dynamics, as well as topics including claims for a causal relationship between the Toba volcanic super-eruption, population bottlenecks, and the spread of modern humans out of Africa (Mellars 2006; Mellars et al. 2013).

In recent years, this model has come under criticism. First, problems in reproducing the dates at Diepkloof raised questions about previous chronometric results (Tribolo et al. 2009, 2013). The sequence at Diepkloof also demonstrated that the HP is less narrowly restricted in time than was previously thought, and instead that the HP represents a long, multi-phased period of cultural and technological development rather than a homogeneous episode (Porráz et al. 2008, 2013). Additionally, Porráz and colleagues published data indicating that the HP was not a uniform spatial and temporal phenomenon.

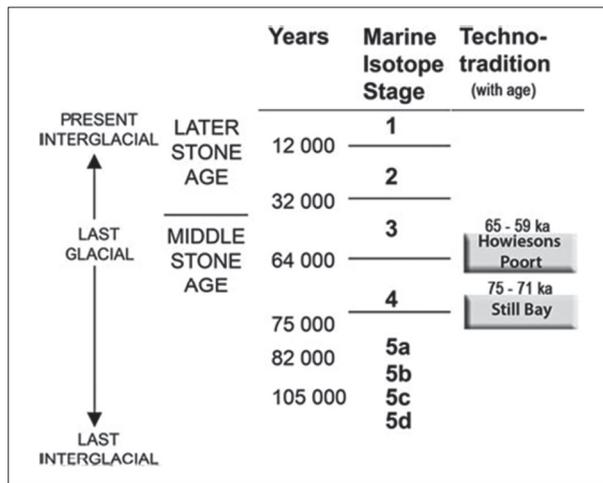


Fig. 2: Schematic representation of the cultural chronostratigraphy of the MSA in southern Africa after Henshilwood (2012). The authors point to the need to revise what we refer to as the Synthetic Model proposed by Henshilwood, Jacobs and colleagues (Jacobs et al. 2008). New data from Sibudu, Diepkloof and other sites indicate that the Still Bay and Howiesons Poort are not uniform cultural entities narrowly focused in time but rather dynamic, heterogeneous cultural phases. Additionally, as the cultural units before and after the SB and HP come into better focus, it has become increasingly clear that the material culture of these periods also shows greater spatial and temporal variability than had previously been assumed. Many of the participants of the Tübingen workshop are currently working to refine our view of the MSA in the light of new data on the cultural sequence from across southern Africa.

At the same time questions emerged about the SB. A critical look at Apollo 11 raised issues about the definition of the SB and to what extent any small assemblage with bifacial artifacts could be considered to belong to this cultural entity. The recent finding of small bifacial points made on quartz in an otherwise typical HP context characterized by an abundance of backed artifacts at Sibudu underlines this observation (de la Peña et al. 2013). Meanwhile excavations at Sibudu continued beneath the horizons Wadley had defined as “pre-Still Bay” and which Jacobs had dated to before the Still Bay (Wadley 2007). To the surprise of the team from Tübingen, the deepest stratigraphic units at Sibudu, called Adam, Annie, Bart, and Bea, all yielded abundant evidence for bifacial technology (Fig. 3) and assemblages that based on available arguments and our present knowledge, must be placed within the Still Bay complex rather than belonging to the “pre-Still Bay” (Conard 2013, 2014). Obviously, these observations are in no way a criticism of Wadley’s outstanding work at Sibudu, since her excavation stopped in the stratigraphic unit BS (Brown Sand) above these layers. Together with new technological and chronometric data from Diepkloof (Porráz et al. 2013; Tribolo et al. 2013) these

observations suggest a longer duration and a more complicated cultural trajectory of the SB than was previously acknowledged.

On a more general level, other colleagues, including Lombard, Conard, Porraz, and Will (Conard et al. 2012; Lombard et al. 2012; Will et al. 2014) have questioned the hypothesis that the SB and HP represented periods of exceptional cultural innovation and perhaps even the epicenter for the evolution of cultural modernity from both theoretical and empirical perspectives. These researchers demonstrated that modern humans after the HP continued to possess highly structured and sophisticated lithic technologies and maintained high population densities. These studies highlight the fact that a selective research focus on the HP and SB in recent years has led to a distorted picture of the periods that preceded and followed these technocomplexes. This bias is best exemplified by the usage of terms such as “pre-SB” or “post-HP”, the latter denoting a ca. 20,000 year-long period of cultural evolution following the HP.

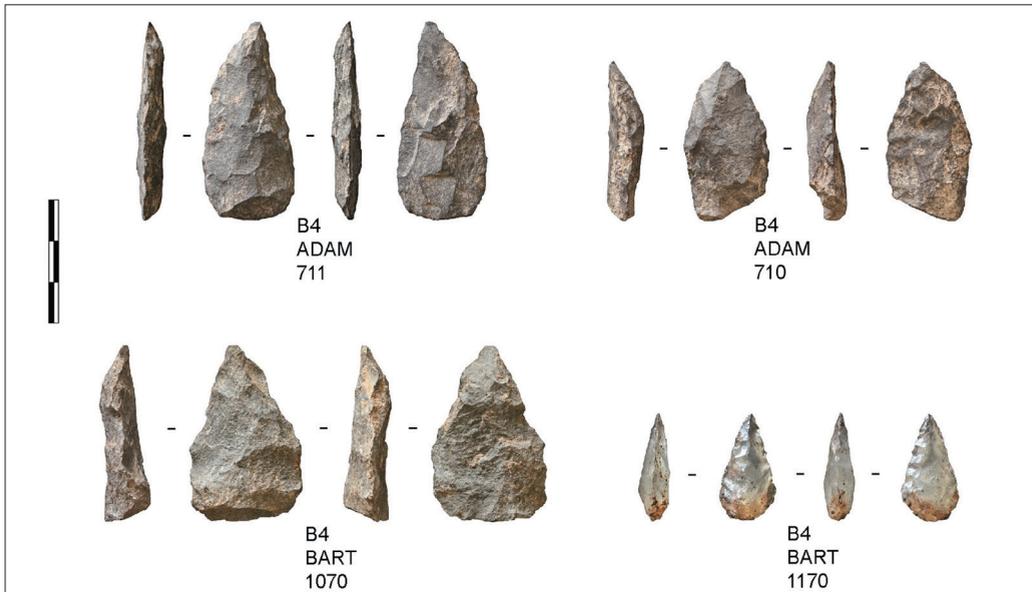


Fig. 3: Sibudu, KwaZulu-Natal, South Africa. Bifacial points from the so-called “pre-Still Bay”-layers at the base of the current excavation.

All of these observations raise serious questions about the validity of the Synthetic Model. While debate continues about the specific answers to the ambiguities raised above, new interpretations are gradually coming into focus. First we need to view technologies such as the manufacture and use of bifacial points and segments as dynamic functional adaptations that are mediated through learned behavior and cultural transmission, rather than as strict chrono-cultural markers or *fossils directeurs*. The new results from Sibudu and Diepkloof indicate that previous models for the SB and HP were too simplistic, suggesting a lack of more sophisticated approaches to interpret our data. At the moment, we are working to develop new ways of explaining the chrono-stratigraphic and cultural variability in the MSA. Work of international scholars including

those who presented papers at the workshop in Tübingen will help to correct errors in current views and will help to define a path that provides a more refined understanding of the cultural evolution during the MSA.

Finally, the presentations and discussions at the workshop have shown that the study of the MSA is an international, ever-growing and vibrant field of research. The fact that the Tübingen workshop yielded more questions than answers underlines the vitality of the field and illustrates the important challenges that the scientific community studying the MSA still faces. Having said that, the workshop showed that we have moved a long way forward in understanding the archaeological record of the MSA during the last two decades, both from theoretical and empirical points of view. More than just filling gaps, new results emerging from across Africa are elucidating the complex pathways of the cultural evolution and population dynamics of modern humans.

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Archaeological and Anthropological Sciences

Assemblage variability and bifacial points in the lowermost Sibudan layers at Sibudu, South Africa

--Manuscript Draft--

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Abstract:	<p>Building on the important work of Lyn Wadley at Sibudu, archeologists from the University of Tübingen have excavated the upper stratigraphic units of the Middle Stone Age (MSA) sequence down to the Howiesons Poort (HP). Here we present the main results from lithic analyses of the lowest part of the Sibudan sequence to assess its overall variability and taxonomic status. Based on the new findings, we also discuss the implications for archaeological systematics and the cultural evolution of modern humans in MIS 3 from a more general perspective.</p> <p>The Sibudan deposits encompass over 20 archaeological horizons that span a 1.2 m thick, well-stratified sequence whose base and top have been dated to ~58 ka (MIS 3). In contrast to the upper stratigraphic units, the lower Sibudan assemblages that we analyzed here show much higher use of local sandstone, quartz and quartzite. These older units are characterized by frequent use of expedient core reduction methods, bipolar reduction of locally available quartz and quartzite, less retouch of blanks, and lower find densities. Tongati and Ndwedwe tools, which feature abundantly in the upper part of the Sibudan sequence, are entirely absent, as are unifacial points. Instead, notched and denticulated tools are common. Surprisingly, knappers manufactured small bifacial points, mainly made from quartz, by means of alternating shaping in the course of the oldest occupations.</p> <p>The results highlight the great diversity of human technological behavior over even short periods during the MSA, raising important questions about the mechanisms of behavioral change, cultural taxonomy, appropriate scales of lithic analyses and the relationship between the HP and the Sibudan. Our findings further erode the old idea that bifacial technology in southern Africa is limited to the Still Bay. Research is increasingly showing that bifacial points come and go in different forms and contexts of African Late Pleistocene technology, impeding their use as chrono-cultural markers.</p>	
Response to Reviewers:	For detailed comments and replies to the reviewer comments see "Reply to Reviewers" in the attached files.	

1 **Assemblage variability and bifacial points in the lowermost Sibudan layers** 2 **at Sibudu, South Africa**

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15

16 **Abstract**

17 Building on the important work of Lyn Wadley at Sibudu, archeologists from the University
18 of Tübingen have excavated the upper stratigraphic units of the Middle Stone Age (MSA)
19 sequence down to the Howiesons Poort (HP). Here we present the main results from lithic
20 analyses of the lowest part of the Sibudan sequence to assess its overall variability and
21 taxonomic status. Based on the new findings, we also discuss the implications for
22 archaeological systematics and the cultural evolution of modern humans in MIS 3 from a
23 more general perspective.

24 The Sibudan deposits encompass over 20 archaeological horizons that span a 1.2 m thick,
25 well-stratified sequence whose base and top have been dated to ~58 ka (MIS 3). In contrast to
26 the upper stratigraphic units, the lower Sibudan assemblages that we analyzed here show
27 much higher use of local sandstone, quartz and quartzite. These older units are characterized
28 by frequent use of expedient core reduction methods, bipolar reduction of locally available
29 quartz and quartzite, less retouch of blanks, and lower find densities. Tongati and Ndwedwe
30 tools, which feature abundantly in the upper part of the Sibudan sequence, are entirely absent,
31 as are unifacial points. Instead, notched and denticulated tools are common. Surprisingly,
32 knappers manufactured small bifacial points, mainly made from quartz, by means of
33 alternating shaping in the course of the oldest occupations.

34 The results highlight the great diversity of human technological behavior over even short
35 periods during the MSA, raising important questions about the mechanisms of behavioral
36 change, cultural taxonomy, appropriate scales of lithic analyses and the relationship between
37 the HP and the Sibudan. Our findings further erode the old idea that bifacial technology in
38 southern Africa is limited to the Still Bay. Research is increasingly showing that bifacial
39 points come and go in different forms and contexts of African Late Pleistocene technology,
40 impeding their use as chrono-cultural markers.
41

42 **Keywords:**

43 Lithic technology; Middle Stone Age; bifacial technology; behavioral change; cultural
44 evolution; South Africa
45
46

1 Introduction

2 Owing to its long research history and the concomitant wealth of excavated sites, the MSA of
3 southern Africa plays a central role in current research on the evolution of modern humans
4 (Goodwin and Van Riet Lowe 1929; Clark 1959; Volman 1984; Lombard et al. 2012). Most
5 importantly, the southern African MSA features many cave and rockshelter sites such as
6 Klasies River (Singer and Wymer 1982; Wurz 2002), Blombos (Henshilwood et al. 2001),
7 Sibudu (Wadley and Jacobs 2006), Diepkloof (Porraz et al. 2013) and Apollo 11 (Vogelsang
8 et al. 2010) that provide long, stratified and well-dated chrono-cultural sequences alongside a
9 rich record of stone tools and other elements of material culture.

10 Bringing order into the temporal, spatial and formal variability of the recovered material
11 has been one of the main challenges for Stone Age archaeologists. To this end, scholars
12 devised classificatory schemes or taxonomies for cultural successions. Early classifications
13 for the southern African MSA (e.g., Goodwin and Van Riet Lowe 1929; Breuil 1930; Clark
14 1959) were based on the typology of certain retouched stone tools (type fossils or *fossiles*
15 *directeurs*), but recently more attention has been paid to technological aspects (e.g., Wurz
16 2002; Lombard et al. 2012). Researchers have developed several cultural-historical schemes
17 for the MSA in southern Africa, including those of Goodwin and Van Riet Lowe (1929),
18 Clark (1959), Sampson (1974), Singer and Wymer (1982), Volman (1981; 1984), Wurz
19 (2002) and recently Lombard *et al.* (2012). It is one of the main concerns of this article to
20 assess and scrutinize the most current and influential of these cultural taxonomies.

21 In the past years, what we have named the “Synthetic Model” (see Conard et al. 2014)
22 has become the widely held paradigm with regard to questions of the chronological and
23 geographical structure of the southern African MSA and its implications for the cultural
24 evolution of early modern humans. Based on combining long-term archaeological
25 observations with new luminescence dates from crucial sites such as Blombos, Diepkloof,
26 Sibudu, Klein Kliphuis, Apollo 11 and Hollow Rock Shelter, the Synthetic Model proposes

1 that the Still Bay (SB) and Howiesons Poort (HP) represent two well-defined cultural entities
2 of short duration that can be used as horizon markers (Jacobs et al. 2008a; Jacobs and Roberts
3 2008; Henshilwood 2012; Jacobs et al. 2012). Historically, the relative and absolute
4 chronology of these technocomplexes had been notoriously difficult to resolve (see discussion
5 in Lombard 2005; Tribolo et al. 2006; Jacobs and Roberts 2008). According to the Synthetic
6 Model, the SB dates to ca. 77-72 ka and is characterized by the presence of bifacial points,
7 some of which were retouched by pressure flaking. Various geometric forms of backed tools
8 and an elaborate laminar technology distinguish the HP which succeeds the SB after a short
9 hiatus at about 65-59 ka (Jacobs et al. 2008a; Wadley 2008; Jacobs and Roberts 2008;
10 Lombard 2009; Villa et al. 2009; Mourre et al. 2010; Henshilwood 2012; Soriano et al. 2015).

11 Apart from providing new information on temporal relations and leading to a strong
12 research emphasis on the SB and HP, proponents also emphasize the evolutionary
13 implications of this model, maintaining that many complex elements of material culture that
14 are associated with modern behavior are frequently found in these two sub-stages of the South
15 African MSA (e.g., Jacobs and Roberts 2009; Henshilwood 2012). The SB and HP are thus
16 considered periods of exceptional innovation, reflecting advanced cognition and sophisticated
17 socio-economic behaviors. Some scholars relate these innovations to increased population
18 sizes, large-scale information transfer between groups, and subsequent dispersals of modern
19 humans to Eurasia (e.g., Ambrose 2002; Mellars 2006; Jacobs et al. 2008a; Jacobs and
20 Roberts 2009; Henshilwood and Dubreuil 2012; McCall and Thomas 2012; Mellars et al.
21 2013). Regarding trajectories of cultural evolution, many researchers view the SB and HP as
22 two short-lived but culturally advanced episodes that are preceded and followed by less
23 behaviorally sophisticated phases. Based on this reasoning, some scholars invoked a model of
24 discontinuous cultural evolution in modern humans in which complex material culture
25 appears and disappears abruptly in the South African MSA (McCall 2007; Cochrane 2008;

1 Jacobs and Roberts 2008; 2009, Powell et al. 2009; Henshilwood and Dubreuil 2012; Jacobs
2 et al. 2012; Ziegler et al. 2013).

3 Elsewhere we have argued that the focus on the HP and SB leads to a biased view of the
4 past (Conard et al. 2014; Will et al. 2014; Conard & Porraz 2015; see above). The emphasis
5 put on these cultural units has often resulted in a view that earlier and later periods of the
6 MSA are less innovative, with younger stages of the MSA following the HP being interpreted
7 as a return to an earlier "pre-SB" technology (Sampson 1974; Deacon 1989; Henshilwood
8 2005; McCall 2007; Mellars 2007; Jacobs and Roberts 2008; 2009). The frequent application
9 of informal terms such as "pre-SB" and "post-HP" – denoting periods that encompass tens of
10 thousands of years with their own history – exemplifies this research bias. In sum, the
11 emphasis on the SB and HP has led to a comparative lack of detailed studies for other phases
12 of the MSA in an otherwise well-studied region, as was most prominently argued by Mitchell
13 (2008) for MIS 3 archaeology (for similar opinions see: Villa et al. 2010; Lombard and
14 Parsons 2011; Conard et al. 2012; Mohapi 2012; Porraz et al. 2013). Yet, in order to
15 adequately assess behavioral change and the cultural evolution of early *Homo sapiens* during
16 the southern African MSA, all of its phases must be studied with equal intensity.

17 In this article, we are concerned with two issues pertaining to the discussion above.
18 First, the nature and variability of lithic technology after the HP remains largely unknown.
19 We have recently started to fill this gap by providing detailed and high-resolution data on
20 stone artifact assemblages from Sibudu dating to MIS 3 (Conard et al. 2012; Will et al. 2014;
21 Conard and Will 2015). Historically, scholars defined the lithic technology following the HP
22 for the most part on the basis of what it lacks, such as bifacial points or backed pieces, instead
23 of what it contains (see Conard et al. 2012). In contrast to this approach, we explicitly
24 characterized the assemblages by their positive features. In this process, we proposed the term
25 "Sibudan" as a cultural taxonomic unit of the MSA in early MIS 3, based on the type locality
26 of Sibudu. A more detailed discussion of this concept, its theoretical underpinnings, as well as

1 the characteristic elements and variability of lithic technology in this sequence can be found
2 below and in the published literature (Conard et al. 2012; Will et al. 2014; Conard and Will
3 2015). In these publications we also stressed that cultural taxonomies make sense only as
4 heuristic devices – or analytical units – in relation to research questions posed by
5 archaeologists (see also Brew 1946; Roberts and Vander Linden 2011). Especially in areas
6 where little research has been done – such as the MSA of MIS 3 in southern Africa and
7 KwaZulu-Natal in particular – constructing a culture-stratigraphic framework helps to
8 organize, understand and communicate the temporal and spatial variation found in the
9 archaeological record. This approach constitutes a necessary prerequisite for addressing
10 questions of higher relevance such as the mechanisms that underlie behavioral change through
11 time, the causes of observed regional similarities and differences in material culture, and
12 general patterns of cultural evolution (see Tschauner 1994; Trigger 2006: 312-313; Roberts
13 and Vander Linden 2011; *contra* Shea 2014).

14 The second issue that we address here is the use of so-called type fossils to define and
15 identify archaeological cultures or chronological phases within the southern African MSA.
16 This approach has a long history and played an important role in the formative years of
17 archaeological research in Eurasia and Africa (de Mortillet 1883; Gobert 1910; Childe 1929;
18 Goodwin and Van Riet Lowe 1929; Breuil 1930). In past and present studies within southern
19 Africa – and within the Synthetic Model in particular – the presence of segments and other
20 geometric backed tools has often been used to delineate the HP (Stapleton and Hewitt 1927;
21 1928; Goodwin and Van Riet Lowe 1929; Sampson 1974; Singer and Wymer 1982;
22 Thackeray 2000; Lombard 2005; Wadley 2008; Henshilwood 2012), whereas the occurrence
23 of bifacially worked foliate or lanceolate points constitutes the typical marker of the SB
24 (Heese n.d.; Goodwin 1928; Goodwin and Van Riet Lowe 1929; Peers 1929; Breuil 1930;
25 Clark 1959; Evans 1994; Henshilwood et al. 2001; Minichillo 2005; Wadley 2007; Jacobs et
26 al. 2008a; Villa et al. 2009; Högberg and Larsson 2011; Henshilwood 2012; Wadley 2015).

1 Especially for the SB, critical comments on its ambiguous definition, integrity and status go
2 far back in time (Malan 1956; Clark et al. 1966; Sampson 1974; Deacon 1979; Volman 1981;
3 Clark 1988) and have re-surfaced today with the question in how far any assemblage with
4 bifacially retouched artifacts could be considered to belong to this cultural entity (Conard et
5 al. 2014; Conard & Porraz 2015). The recent finding of small bifacial points in an otherwise
6 typical HP context at Sibudu constitutes a case in point (de la Peña et al. 2013). A closer look
7 at SB localities such as Blombos, Diepkloof, Apollo 11 and Hollow Rock Shelter further
8 reveals variable quantities and modalities of bifacial technology (Vogelsang et al. 2010;
9 Högberg and Larsson 2011; Porraz et al. 2013; Archer et al. 2015; Soriano et al. 2015). These
10 observations lead us to ask: Are bifacial points in southern Africa largely confined to the SB
11 or do they constitute dynamic elements of lithic technology that come and go in time and
12 space? And if the latter applies, how do different bifacial technologies compare? Answers to
13 these questions will shed light on the behavioral and adaptive role of bifacial technology in
14 various contexts during the Late Pleistocene, and potentially compromise the use of bifacial
15 artifacts as *fossiles directeurs* or chrono-cultural markers.

16 Here we tackle these issues by looking at lithic assemblages from the high-resolution
17 archaeological sequence at Sibudu dating to MIS 3, one of the thickest and richest deposits for
18 this period in southern Africa. Elsewhere, we described results from ca. 7,800 lithic artifacts
19 (>30 mm) from 11 successive layers of the middle and upper part of the Sibudan sequence
20 (Will et al. 2014; Conard and Will 2015; see Table 1), and here we provide data on the
21 lowermost and oldest 12 assemblages from layers RB to G1. Our interests lie in the nature and
22 diachronic variability of lithic technology in these lower layers, the relation of these
23 assemblages to the rest of the sequence, and their implications for models of behavioral
24 change within the MSA of southern Africa. In addition, we report on the presence of bifacial
25 points in layers that directly overlie the HP, assess the modalities of their production and
26 discuss their wider implications with regard to the questions raised above.

1 **Material and Methods**

2 *Overview of the Sibudan sequence: Methods of excavation and general description*

3 Sibudu is a large rockshelter overlooking the uThongathi River near the east coast of South
4 Africa in KwaZulu-Natal, around 40 km north of Durban and 15 km from the Indian Ocean.
5 In 1983, Aron Mazel dug the first small trial trench (ca. 1 m deep) at the site. Subsequently,
6 Lyn Wadley from the University of the Witwatersrand directed 25 field seasons of excavation
7 at Sibudu from 1998-2011. Wadley's team excavated MSA deposits over an area of 21 m² to
8 a depth of up to three meters. This sequence, dating between <75-37 ka, includes Wadley's
9 pre-SB, SB, HP, post-HP, late MSA, and final MSA strata (Wadley 2001; Wadley and Jacobs
10 2006; Jacobs et al. 2008b; Wadley 2013).

11 Current work at Sibudu has been carried out by a team of the University of Tübingen
12 under the direction of N. Conard since 2011, and follows Wadley's naming system for
13 stratigraphic layers to facilitate comparisons between both phases of excavation (see Wadley
14 and Jacobs 2006: Table 2). We excavated in *Abträge* to establish reliable and high-resolution
15 cultural chronological units that follow the contours of the stratigraphic sequence. Our
16 excavations proceeded carefully in 1 to 3 cm thick *Abträge*, following the slope of the
17 sediments but never crosscutting geological strata. We group these *Abträge* in larger units that
18 we call find horizons. Using the abbreviated designation from Wadley's excavation, such as
19 "LBYA" (Lower Brown under Yellow Ash), these find horizons form the main units of
20 analyses. The find horizons have been excavated with careful piece-plotting of artifacts, using
21 a Leica total station and the EDM program (Dibble and McPherron 1996).

22 Sibudu preserves a long and complex stratigraphy that comprises over 50 distinct MSA
23 find horizons. The upper part of the depositional sequence at Sibudu – postdating the HP –
24 includes a succession of centimeter thin, distinct and often brightly colored layers and lenses,
25 which partially inter-finger. These deposits encompass a multitude of palimpsests of hearths
26 and ash lenses, contributing to the complex sequence of the sediments. They are almost

1 entirely of anthropogenic origin (Wadley and Jacobs 2004; 2006; Pickering 2006; Schiegl and
2 Conard 2006) with minimal vertical mixing (Goldberg et al. 2009; Wadley et al. 2011). This
3 being said, the deposits are often affected by post-depositional diagenesis and contain
4 concretions that in some areas form cemented plate-like structures that complicate excavation.
5 C. Miller and S. Mentzer from the University of Tübingen are currently studying these
6 diagenetic processes in great detail.

7 The rich record from MIS 3 described above consists of pulses of intense occupations
8 dated by luminescence methods to ~58 ka, ~48 ka and ~38 ka (Wadley and Jacobs 2006;
9 Jacobs et al. 2008a; 2008b). The oldest part of these sediments, dating to ca. 58 ka, has a
10 thickness of around 1.2 m and lies directly on top of the HP. This "post-HP" sequence at
11 Sibudu contains over 20 finely laminated find horizons. Occupations at the base, middle and
12 top of the sequence have been dated indistinguishably to ~58 ka by OSL (weighed mean age
13 of ~58.4 +/- 1.4 ka) from a total of six layers, providing an exceptionally high temporal
14 resolution for an MSA site (Table 1). Together with the fine lamination of the sequence and
15 the high density of archaeological materials, these observations attest to multiple intense and
16 repeated human occupations over the course of only a couple of centuries or millennia at most
17 (Wadley and Jacobs 2006; Schiegl and Conard 2006; Jacobs et al. 2008b; Wadley 2013).

18 In total, the Tübingen team has excavated 23 archaeological find horizons from the so-
19 called "post-HP" sequence at Sibudu down to the HP, removing a sediment volume of about 5
20 m³ from these strata (Fig. 1; Table 1 & 2). We recently proposed that the upper 11 layers
21 (WOG1-BSP) of these deposits could be considered part of the "Sibudan", a new cultural
22 taxonomic unit of the later MSA (Conard et al. 2012; Will et al. 2014; Conard & Will 2015).
23 Summarizing previous results, the Sibudan sequence is generally characterized by frequent
24 procurement and use of dolerite and hornfels with mostly complete reduction sequence,
25 multiple core reduction methods that vary in their frequency, the production of a variety of
26 blank types including (convergent) flakes and blades, as well as a distinction between a

1 predominant manufacture of flakes by hard hammer percussion and soft stone knapping for
2 blades. Regarding the retouched components, the Sibudan features abundant unifacial points
3 and retouched pieces particularly in its upper part (BSP-BM), and four distinct techno-
4 functional tool classes – Tongati and Ndwedwe tools, asymmetric convergent tools and
5 naturally backed tools – generally in high frequencies (see description below). More detailed
6 diachronic observations (Conard and Will 2015) showed that the Sibudan can be divided into
7 three phases (see Table 1) which build upon each other in a gradual and cumulative manner.
8 The lowest part of the previous analyses (WOG1-SP), approximately located in the middle of
9 the overall ~58 ka sequence (see Figure 1), is characterized by the use of both dolerite and
10 sandstone, frequent application of parallel methods, lower levels of retouch and artifact
11 density with notches and denticulates as the most common tool types, and a near-absence of
12 unifacial points and the techno-functional tool classes mentioned above. In contrast, the
13 overlying assemblages SU-POX are marked by an almost exclusive use of dolerite
14 predominantly knapped with inclined methods, high density of knapping products, as well as
15 the first appearance of unifacial points and the four main techno-functional tool classes. In the
16 upper part of the sequence (BSP-BM), knappers increased their use of non-local hornfels,
17 more frequently produced blades by platform methods, and manufactured abundant unifacial
18 points as well as Tongati and Ndwedwe tools.

19 The archaeological find horizons which are the focus of this study (layers RB to G1)
20 constitute the lowermost 50 cm of the Sibudan sequence that we have not analyzed so far. The
21 twelve assemblages lie right above the uppermost HP horizon Grey Rocky (GR) and below
22 WOG1 (Fig. 1). The Tübingen team excavated RB-G1 over an area of 4 m² between 2015 and
23 2016, amounting to a total sediment volume of 2.0 m³ for RB-G1 (Table 2). In terms of
24 clarity, the following descriptions will informally denote these new layers as the “lower
25 Sibudan” (RB-G1) in contrast to the “lower middle Sibudan” (WOG-SP), the “upper middle
26 Sibudan” (SU-POX) and the “upper” or “classic Sibudan” (BSP-BM; see Table 1).

1 *Methods of lithic analysis in the lower Sibudan layers RB-G1*

2 Table 2 provides a complete overview on the lithic finds from all assemblages of the sequence
3 dated to ~58 ka, showing that the entire Sibudan deposits (RB-BSP) now amount to a total of
4 10,882 stone artifacts >30 mm and 161,847 artifacts <30 mm. In this study, we focus on
5 analyzing the lithic artifacts from layers RB-G1 that derive from squares C2, C3, D2, and D3.
6 The sample analyzed for this study thus consists of twelve assemblages, each featuring more
7 than 100 artifacts. These assemblages (RB-G1) include a total of 3,081 stone artifacts >30
8 mm and 22,985 artifacts <30 mm. The large number of successive layers and lithic finds
9 allows us to assess intra- and inter-assemblage variability in great detail. The high ratio of
10 artifacts <30 mm to artifacts >30 mm in RB-G1 (89:11%) attests to intense stone knapping
11 with little post-depositional disturbance and sorting based on size as well as excellent
12 recovery of finds. For the presentation of results, we first report the findings from the new
13 layers RB-G1, followed by a short comparison to the results of the sequence above that were
14 published in Will *et al.* (2014) and Conard and Will (2015). We chose this diachronic in order
15 to guide the reader through the long sequence with over 20 archaeological assemblages and to
16 put the results in the larger picture of the entire ~58 ka deposits.

17 Regarding the methods of lithic analyses, we principally followed our previous studies
18 of the upper part of the sequence (Will *et al.* 2014; Conard and Will 2015). Due to the large
19 size of the collections (Table 2) we used a size cut-off of 30 mm instead of a more typical 20
20 mm threshold. Retouched pieces and cores constituted the only exception to this approach as
21 they were included in all further analyses regardless of size. We studied all stone artifacts >30
22 mm – as well as all cores and tools – individually through a combination of multiple methods,
23 drawing from German, French, North American and South African traditions of lithic
24 analyses. In particular, we combined information from reduction sequence analyses of entire
25 assemblages and raw material units (Boëda *et al.* 1990; Conard and Adler 1997; Inizan *et al.*
26 1995; Bleed 2001; Shott 2003; Soressi and Geneste 2011; Faivre *et al.* 2016) with data from

1 attribute analysis of individual artifacts (Auffermann et al. 1990; Hahn 1991; Shott 1994;
2 Andrefksy 1998; Tostevin 2003; Odell 2004; Tostevin 2013). We employed typological
3 approaches (Bordes 1961; Brezillon 1983; Debeneath and Dibble 1994) – with particular
4 consideration of South African tool taxonomies (Volman 1981; Wurz 2000; Villa et al. 2005)
5 – but also techno-functional analyses of retouched pieces (Lepot 1993; Boëda 1997; Soriano
6 2001; Bonilauri 2010) to obtain comparable data on tool manufacture across sites and regions.

7 In brief, the techno-functional analysis divides tools into a transformative, prehensile
8 and intermediate part and studies the treatment of these portions separately (Lepot 1993;
9 Boëda 1997; Soriano 2001; Bonilauri 2010). In combination with an emphasis on the
10 reduction and transformation of tools (Krukowski 1939; Dibble 1984; 1987; 1995) we
11 previously classified tools based on the identification of specific patterns of repetitive retouch
12 on different parts of the tool which indicate distinct retouching sequences (Conard et al. 2012;
13 Will et al. 2014). The four main techno-functional tool classes and reduction sequences at
14 Sibudu comprise Tongatis, Ndwedwes, naturally backed tools (NBTs), and asymmetric
15 convergent tools (ACTs). Although these tool classes do not function as type fossils, their
16 frequent and joint occurrence is part of the original definition of the “Sibudan” (Conard et al.,
17 2012). Detailed descriptions, additional drawings and a discussion of the potential function of
18 these tool concepts and reduction sequences are provided in the supplementary material
19 (SOM Text S1) as well as in Conard *et al.* (2012) and Will *et al.* (2014).

20 In terms of core classification, we followed the unified taxonomy by Conard *et al.*
21 (2004) to derive at results that are comparable within the sequence, across sites and regions as
22 well as between different Stone Age periods (see description in SOM Text S2). In addition,
23 we quantified samples of small lithic artifacts (<30 mm) from each assemblage according to
24 raw material to evaluate patterns in the raw material economy. Within these samples, we also
25 identified retouch debitage to assess the level of on-site tool production and recycling (see
26 description in SOM Text S3). In combination, these methods allow to reconstruct

1 technological strategies of the individual assemblages by providing information on the
2 procurement of raw materials and their reduction sequences, the methods of core reduction,
3 the techniques of blank production, and the approach used for tool manufacture and recycling.

4 5 **Results**

6 *Procurement and representation of lithic raw materials*

7 The lithic assemblages RB-G1 are characterized by a variety of raw materials (Table 3). The
8 inhabitants collected and knapped dolerite, quartz, quartzite and sandstone which derive from
9 local sources such as the shelter wall itself (sandstone), outcrops close-by (dolerite, sandstone;
10 <1 km), and pebbles from the uThongathi River (sandstone, quartzite, quartz). Knappers at
11 Sibudu also used hornfels and CCS which they imported from some distance, as the nearest
12 known outcrops are 10 km distant from the site (Wadley and Kempson 2011).

13 From a quantitative perspective, dolerite (n=1176) and sandstone (n=1131) constitute
14 the overall most frequent raw materials in RB-G1, followed by quartz (n=360) and quartzite
15 (n=356). Looking into diachronic changes throughout the sequence, sandstone is the most
16 abundant material in seven assemblages, particularly in LBYA-YA2, almost at the very
17 bottom (Table 3; Fig. 2). Quartz reaches a peak frequency in YA2i and GM (27% each),
18 where it is almost as abundant as sandstone. The oldest assemblage (RB) that directly overlies
19 the HP features only little use of quartz (1.3%) with an almost equal share of dolerite (43%)
20 and sandstone (40%) as most frequent materials. Quartzite never amounts to more than a fifth
21 of an assemblage, but constitutes an important raw material in RB-YA (11-20%) compared to
22 layers above YA (<10%). Dolerite exhibits the lowest use of for the entire Sibudan sequence
23 with only 15% in BYA2i, and generally fluctuates at low values in the lowest part of the
24 sequence up until YA2 (15-30%) with the exception of RB at the very bottom (43%). Above
25 these assemblages (YA-Y1), knappers increasingly procured dolerite (44-57%), but also
26 knapped sandstone frequently (26-36%). Coming to the topmost layers of the sequence RB-

1 G1, sandstone (43-46%) and dolerite (41-42%) are almost equally used in CH2 and G1 and
2 make up an even greater proportion of all raw materials (ca. 86%). Quartzite (3-9%) and
3 quartz (6-13%) play a minor role in the sequence YA-G1.

4 The inhabitants of Sibudu also imported small fractions of non-local raw materials
5 such as hornfels (0-5%) and other raw materials (mostly CCS; 0-1%) to the site during the
6 lower Sibudan occupations. Most of the time, hornfels makes up less than 2% of the
7 assemblages (Table 3). In sum, assemblages RB-G1 are characterized by the frequent use of
8 dolerite, sandstone, quartzite and quartz which fluctuate within the sequence. Dolerite and
9 sandstone alternate as the most abundant raw material, whereas hornfels plays a minor role.
10 Knappers predominantly procured local rocks (95-100%) from both primary and secondary
11 sources around the shelter.

12 In terms of overall diachronic patterns, there are some major differences in raw
13 material provisioning between the lower, middle and upper part of the Sibudan sequence (Fig.
14 2). While the inhabitants mostly procured hornfels and/or dolerite in the upper layers (SU-
15 BSP) to the exclusion of other tool stones, the lowest part of the sequence described here is
16 characterized by the frequent use of four main raw materials, particularly at its very base.
17 Sandstone plays a major role in RB-G1 (26-51%) but not above these levels (1-20%). In
18 contrast, dolerite is always the dominant material in the middle and upper part of the sequence
19 (WOG1-BSP: 58-94%) but was used much less in the lower deposits (RB-G1: 15-57%),
20 where it is often replaced by sandstone. Moreover, the inhabitants commonly procured
21 quartzite (3-20%) and particularly quartz (2-27%) in these assemblages compared to WOG1-
22 BSP (quartzite: 0-4%; quartz: 0-2%). A final difference concerns the exploitation of non-local
23 hornfels. While hornfels is almost absent in the older part of the sequence up until POX (0-
24 6%), it is abundant in the youngest occupations BM-BSP (25-38%).

25
26 *Representation of debitage products*

1 All debitage products >30 mm were categorized into blanks, tools, cores and angular debris
2 (n=3,081). Quantitative analyses of the assemblages demonstrate a uniform pattern in which
3 blanks without modifications constitute the dominating debitage products left at the site
4 during the occupations corresponding to layers RB-G1 (89-93%; Table 4). At the same time,
5 tools or retouched pieces comprise only 1-4%, suggesting little retouch and recycling of
6 blanks on-site. These patterns compare well with the directly overlying assemblages of the
7 middle part of the sequence (WOG1-POX), but differ strongly from the upper layers BM-BSP
8 which feature abundant retouch (17-27%). Cores are rare throughout RB-G1 (1-4%) as they
9 are in the entire archaeological sequence (Table 4). In contrast to the middle and upper
10 Sibudan sequence, the lowest layers – GM, LBYA and BYA2i in particular – feature more
11 than twice as much angular debris on average. This high number of amorphous pieces,
12 lacking recognizable striking platforms as well as dorsal and ventral surfaces, is associated
13 with more frequent use of coarse-grained sandstone and quartz.

14 15 *Core reduction, blank production and reduction sequences*

16 The MSA knappers employed a variety of core reduction methods during the deposition of
17 find horizons RB-G1. Due to the scarcity of cores in each assemblage (Table 5) and their
18 intense degree of exploitation, the following discussion of reduction strategies also draws
19 heavily on information gained from studying the morphology, geometry, knapping traces and
20 dorsal scar configuration of debitage products. This approach includes the identification and
21 quantification of diagnostic technological products that are typical of well-documented MSA
22 and Middle Paleolithic core reduction methods (see also Faivre et al. 2016).

23 Informal, or expedient, reduction methods are most characteristic and prevalent for the
24 assemblages of the lower Sibudan sequence. They include opportunistic single and multi-
25 platform reduction strategies with one or multiple removal surfaces being exploited in
26 unidirectional, bidirectional or multidirectional manners. These cores were often initiated

1 from flat natural surfaces (e.g., on slabs) without preparation, intensely used and rotated
2 during exploitation. Frequent core rejuvenation products such as redirecting and overshot
3 flakes, as well as core tablets, also attest to this approach. Assemblages RB-G1 also exhibit
4 the highest proportion of bipolar reduction – or hammer-on-anvil technique – among the ~58
5 ka sequence. Cores of this knapping strategy occur in each layer and represent the overall
6 most abundant core type (Table 5). Bipolar reduction constitutes the second most common
7 method in BYA2i-GM: knappers applied this strategy particularly to quartz in BYA2i-GM,
8 whereas the very base of the sequence (RB-LBYA) features frequent bipolar cores and small
9 debitage products on quartzite. Parallel reduction, which at Sibudu mostly follows a Levallois
10 system with both preferential and recurrent modalities, occurs in intermediate frequency, but
11 some assemblages feature abundant use of this method (G1, BBGM, YA). In contrast,
12 knappers used laminar platform and inclined methods only as a rare option or not at all. In
13 terms of diachronic changes within the entire Sibudan sequence, the frequent use of non-
14 formal platform and bipolar methods in RB-G1 contrasts markedly with assemblages above
15 where either parallel (G1-SP; BM-BSP), laminar platform (BM-BSP) or inclined methods
16 (SU-POX) dominate overall.

17 Knappers used the various reduction methods – informal platform, bipolar and parallel
18 – almost exclusively for the production of flakes of various shapes and size within RB-G1 at
19 constantly high levels ranging between 91-96% of all blanks (see Fig. 3). Convergent pieces
20 are rare in all 12 assemblages and never exceed 5% (range: 0-5%). These flake-based
21 assemblages also feature generally few blades (1-6%) – mostly by-products of flake
22 production – and almost no bladelets (n=12). This is in agreement with the observation on
23 cores, which mostly show flake negatives (65/73). From a diachronic perspective, knappers
24 manufactured substantial amounts of blades and convergent flakes only above G1 (Fig. 3).

25 Within RB-G1, knapping characteristics such as bulbs that are visible on the majority
26 of debitage products (74.6%; from these 50.6% are pronounced bulbs), the presence of

1 contact points of the hammerstone on the striking platforms (identifiable by a semicircular
2 break of the internal delineation of the platform and crushing in this circumscribed area) and
3 rare proximal lips on the ventral surface (2.1%) suggest percussion with a hard stone hammer.
4 There is, however, little evidence for *erailure* scars on the bulbs (0.9%) or the development
5 of a Hertzian cone (0.7%). Comparatively high frequencies of shattered bulbs (21.4%) and
6 exterior platform angles with a grand mean of $\sim 83^\circ$ (range of means=81-86°) are more typical
7 for the application of soft stone hammers as suggested by replication experiments (see
8 Pelegrin 2000; Soriano et al. 2007; Roussel et al. 2009). In addition to the observation of
9 generally thick striking platforms (mean=7.4 mm, mode=5.0 mm; range of means=6.0-8.7
10 mm; n=2047), the overall attributes conform best to flakes being produced by a combination
11 of internal percussion with both hard stone and soft stone hammers. This interpretation is
12 supported by the existence of hammerstones of both types within the sequence (sandstone;
13 quartzite; dolerite). Diachronic variation in knapping traces and morphometric attributes of
14 flakes within RB-G1 are associated with the use of differential raw material. Even though
15 knappers employed consistent techniques, they varied their approach to platform preparation.
16 The percentage of faceted platforms fluctuates between 10-22%, without a consistent
17 temporal pattern. These variations are explicable by the differential frequency in the use of
18 parallel methods that include ample preparation of cores (i.e., Levallois). Faceting in RB-G1
19 is less abundant compared to the upper Sibudan sequence (BM-BSP: 22-29%), and more
20 comparable to the upper middle part of the find horizons (SU-POX: 12-16%).

21 In general, the inhabitants reduced dolerite and sandstone – and to a lesser degree
22 quartz and quartzite – on site during RB-G1, although the completeness of these reduction
23 sequences varies slightly throughout the sequence. Across all raw materials there is an
24 emphasis on early phases of knapping such as decortification and blank production, at the
25 expense of retouch of blanks and recycling of tools. These observations on artifacts >30 mm
26 is also supported by the low amount of retouch debitage among artifacts of 10-30 mm in these

1 layers (0.3-3.0%; Table 6), which attests to little on-site modification or resharpening of
2 blanks. The abundance of small artifacts (<30 mm) for the four main raw materials also
3 supports the interpretation that reduction took place on site during RB-G1 (Table 6).

4 We observed a particularly strong signal of the early stages of reduction for sandstone,
5 with the presence of fully cortical flakes (“first flakes”), large cortical flakes and amorphous
6 blocks of raw material, but almost no retouched artifacts. Dolerite and quartzite show similar
7 patterns with a slightly higher incidence of retouch. Quartz exhibits little retouch but by far
8 the lowest ratio of blanks to cores – roughly five flakes per core when pooling all quartz
9 pieces of RB-GR1 (272 blanks / 51 cores) – indicating an underrepresentation of debitage
10 products for this raw material within the lower part of the sequence. Non-local raw materials
11 like hornfels and CCS occur in the form of singular and imported pieces with little cortex,
12 missing most of the products of the manufacture chains. In contrast to RB-G1, the middle and
13 upper sequence show truncated reduction sequences for sandstone, quartzite and quartz
14 (WOG1-BSP), but all manufacturing stages for hornfels (BM-BSP; Tables 3 & 6).

15 As in previous analyses, we found a highly significant positive correlation between the
16 frequency of retouched artifacts and the abundance of hornfels throughout the sequence
17 ($p < 0.001$; $R^2 = 0.913$; Fig. 4). The raw material retouch index (RMRI; *sensu* Orton, 2008) also
18 suggest that knappers preferentially modified hornfels throughout the sequence (Hornfels:
19 3.56; Dolerite: 0.83; Quartzite: 0.51; Quartz: 0.28; Sandstone: 0.20). A chi-square test of
20 retouched vs. non-retouched artifacts of hornfels vs. all other raw materials pooled for all
21 assemblages further indicates highly significant differences ($\chi^2_1 = 695.98$; $p < 0.001$), with a
22 strong overrepresentation of hornfels among tools. In combination, these results lend support
23 the interpretation that hornfels was preferentially retouched by knappers when in use, owing
24 to its specific raw material characteristics and transport distance (see Wadley and Kempson
25 2011; Bader et al. 2015; Conard and Will 2015), with other factors such as general patterns of
26 mobility and site use potentially playing an additional role.

1 Finally, some raw materials show a distinct association with certain core reduction
2 methods. Due to its very coarse-grained and intractable nature, knappers predominantly
3 reduced sandstone with informal single and multi-platform methods, often initiated on flat
4 surfaces with natural right angles. An increased use of quartzite and quartz in particular, on
5 the other hand, co-varies strongly with more abundant use of bipolar reduction. This being
6 said, some freehand percussion and even parallel reduction is visible on quartz. Finally,
7 knappers employed parallel methods comparatively often on dolerite and quartzite.

9 *Tool assemblages*

10 Compared to the upper part of the archaeological deposits (BM-BSP), the lower layers feature
11 less retouch of blanks, similar to the middle of the occupation sequence (WOG1-POX).
12 Owing partly to the lower number of retouched specimens in RB-G1 (total n=69; Table 4)
13 there is a reduced variety of tool types (Table 7). The scarcity of tools – with exception of the
14 lowest layers LBYA (n=15) and RB (n=10) – also renders diachronic comparisons within this
15 sequence problematic. Combining layers RB-G1, the most frequent implements in the
16 sequence are denticulates and notches (n=24), splintered pieces (n=11), side scrapers (n=7)
17 and minimally retouched pieces (n=12; Table 7). Together these categories constitute ~78%
18 of the tool assemblages. In marked contrast to the upper middle and upper parts of the
19 sequence – BM-BSP in particular – which are characterized by the production of unifacial
20 points (Fig. 5), these tool types are absent in RB-G1 with the exception of BBGM (n=1).
21 Unexpectedly, invasively shaped bifacial artifacts feature frequently in the very bottom of the
22 lower sequence with a total of 7 examples. They constitute the most notable retouched pieces
23 and occur in layer YA as well as the three oldest assemblages BYA2i, LBYA and RB (see
24 Fig. 1). The bifacial tools are described in more detailed below. In the oldest occupation
25 horizons RB and LBYA – and in contrast to layers BYA2i-G1 above – bifacial pieces
26 together with splintered pieces constitute the most frequent tool type (Fig. 5), representing the

1 most distinctive diachronic change in tool assemblages within the lower Sibudan sequence.

2 Although the studied assemblages overlie the HP occupations, RB-G1 do not feature any tool
3 types generally considered typical of this technocomplex such as backed segments or
4 strangulated pieces, attesting to little or no vertical displacement of artifacts.

5 In addition to the low number of tools in RB-G1, knappers mostly applied marginal
6 retouch to blank edges – single layers of fine or notched retouch negatives – instead of the
7 multiple, overlapping and more invasive modifications that are particularly frequent in the
8 upper part of the sequence (BM-BSP). Bifacially shaped pieces constitute the only exception
9 to this pattern. These observations indicate that the inhabitants put little effort into retouch of
10 blanks or production of tools on-site. Regarding preferences of blanks, knappers mostly
11 retouched flakes (80-100%), underlining a reduction sequence mostly geared toward the
12 production and occasional modification of flakes in RB-G1.

13 As in previous analyses (Conard et al. 2012; Will et al. 2014; Conard and Will 2015)
14 we also applied a techno-functional approach to classify retouched specimens. Three of the
15 main techno-functional tool classes and reduction chains at Sibudu that are typical for the
16 upper part of the sequence – Tongatis, Ndwedwes, and asymmetric convergent tools (ACTs) –
17 are absent from RB-G1 (Fig. 6). Naturally backed tools as the fourth techno-functional tool
18 class feature only in 6 of 12 assemblages and never reach frequencies above 33%. Instead,
19 other tools, including notches, denticulates and scrapers, constitute the dominating techno-
20 functional classes in a uniform manner (Fig. 6). While being internally coherent, the
21 composition and abundance of tool classes in RB-G1 differ strongly from the upper sequence
22 (SU-BSP) in which the four main categories occur, often in high frequencies.

23

24 *A closer look on bifacial technology*

25 The presence of bifacially shaped pieces constitutes one of the most exceptional signatures of
26 the tool assemblages in RB-G1. Technical drawings and photographs of the bifacial artifacts

1 from the lower part of the Sibudan sequence are provided in Figures 7 and 8. We performed a
2 technological, morphometric and contextual analysis on all 7 pieces to shed more light on
3 their production and life histories, following the study designs of Villa *et al.* (2009), Högberg
4 and Larsson (2011) and Soriano *et al.* (2015). Furthermore, we analyzed an additional 12
5 bifacials excavated in 2016 from the youngest HP layer Grey Rocky (GR and GR2) that lies
6 directly below RB in order to provide a comparative perspective on the Sibudan bifaces.
7 These results follow the description of the Sibudan bifaces and also include a discussion of
8 the bifacials deriving from the HP layers of Wadley's excavations.

9 The bifacial pieces derive from the lowest 20 cm of the sequence (see Fig. 1) and occur
10 in all four excavated squares. There is no clear diachronic trend with only one bifacial piece in
11 the lowest Sibudan assemblage (RB; n=1), ensued by a higher number in LBYA (n=4) and
12 followed by a decline upwards to BYA2i (n=1) and YA (n=1). Other than their variable
13 frequencies, the bifacials from these assemblages encompass an overall homogeneous sample
14 in terms of their raw materials, morphological variability, production modalities, metrical
15 dimensions and state of preservation. Of the 7 bifacial specimens, 5 are made on milky quartz,
16 with one on CCS and quartzite each. This is of particular interest, as a total of 65% of all
17 retouched quartz specimens in the lower sequence are bifacial tools. Only one of the
18 specimens is complete, showing that the inhabitants mostly discarded the bifacial pieces after
19 breakage. Concerning fracture patterns, two bifacials exhibit a broken tip, two specimens are
20 broken on both the base and tip, and two have a broken lateral edge.

21 We analyzed the stages of manufacture according to the characteristics described in
22 Villa *et al.* (2009) and Soriano *et al.* (2015). Most of the bifaces were discarded in advanced
23 manufacturing stages (phase 2a: n=4; phase 3: n=2), meaning that both surfaces are
24 completely covered by invasive negatives from removals used to shape the morphology of the
25 blank (*façonnage*). Non-worked or cortical edges do not remain on these pieces and both hard
26 and soft hammer negatives are visible. Either deep negatives deriving from hard hammer

1 percussion or fine retouch that cuts shaping negatives mark the last actions of (re-) shaping.
2 There is only one biface (C2-2198; Fig. 8) belonging to an early manufacturing phase (stage
3 1). The quartzite specimen (C2-2198) retains a dorsal surface that is almost completely
4 cortical, but bears negatives from the shaping process on the ventral side. The nature of the
5 transversal break of the specimen suggests that it broke during production and was
6 consequently abandoned. Regarding the process of reduction, knappers shaped most of the
7 small bifaces in an alternating fashion (6/7), in which removals alternate from one surface to
8 the other in a non-hierarchical, non-sequential manner (Boëda 1995; Soriano et al. 2015:
9 Figure S11). Due to this production modality, most of the finished specimens show a double
10 plano-convex cross-section. Even the last stages of resharpening and shaping were performed
11 in an alternating fashion.

12 The variable morphology of the bifacials is the result of different reduction stages,
13 breakage patterns and raw materials. Only two pieces retain their distal end and can be
14 definitely classified as bifacial points with a V-shaped termination (85-90° distal angle). The
15 preserved form, however, suggests pointed shapes for most bifacials in advanced shaping
16 stage. The pieces commonly have their maximum thickness and width located slightly below
17 the half-way point of the total length, always with some distance to the base. Only two bifaces
18 (C2-2173; D3-1719.1; see Figs. 7 & 8) from reduction stage 3 possess a complete bilateral
19 and bifacial symmetry, resembling a foliate shape. All other pieces show non-symmetrical
20 lateral edges and surfaces. In most cases, ventral and dorsal surfaces of the blank cannot be
21 distinguished due to intensive shaping, but two pieces bear evidence of having been
22 manufactured on thick flakes. Regarding their size, the bifaces are generally small, with 31
23 mm and 36 mm length for complete specimens. None of the other broken pieces would have
24 likely exceeded 40 mm in maximum length judging from the preserved parts. Looking only at
25 bifaces from stages 2 and 3, the ranges of maximum widths (20-25 mm) and maximum
26 thicknesses (9-13 mm) are narrow, as are the values for lateral edge angles (55-70°).

1 Additional contextual information can help to integrate the bifacial pieces in their
2 assemblages and reduction sequences. Interestingly, layers YA, BYA2i, LBYA and RB are
3 not characterized by unifacial or bifacial shaping (*façonnage*) but by a dominance of several
4 debitage methods (see above). The overall technological analyses suggest that the bifacial
5 tools represent finished and potentially imported products, as they are mostly (6/7) in
6 advanced phases of shaping (stages 2-3). For the single biface on CCS, no other flakes of this
7 raw material variety have been found yet. There are also no or only few bifacial pieces on
8 sandstone and dolerite although they represent the most commonly knapped raw materials at
9 the site during the lower part of the sequence. This being said, sampling of small artifacts
10 (<30 mm) provided a few bifacial shaping flakes of quartz (n=19), dolerite (n=2), and
11 quartzite (n=1) from the lowermost five assemblages RB-YA. They even make up the largest
12 proportion of retouch flakes in layer YA. This attests to the reduction of some bifacial tools
13 on site. In accordance with these observations, the single quartzite and dolerite bifaces were
14 discarded in an early stage of production on site.

15 Comparisons to 12 bifacial specimens from the uppermost HP layer GR excavated in
16 2016 show that these pieces are very similar in terms of raw material, morphology, production
17 modalities and metrics. The majority of the bifaces in GR are manufactured on quartz (10/12)
18 and all of the pieces are broken. Three quarters of the bifacial pieces are in advanced
19 manufacturing stages (2a or 3). Knappers produced the bifaces predominantly by alternating
20 shaping, with the final products rarely exhibiting bifacial or bilateral symmetry. The average
21 length of the pieces is 35 mm (n=3), with a mean width of finished bifaces at 22 mm (n=2)
22 and a thickness of 9.8 mm (n=5). TCSAs range from 72-169 mm² with a mean of 120.5 mm²
23 (n=2). The results on the HP bifacials from the Tübingen excavation match well with analyses
24 of similar pieces from the larger sample of Wadley's excavations. The HP bifacials are
25 comparable regarding their small size, predominant manufacture on quartz, high incidence of
26 broken pieces, unstandardized morphology, short production sequences, and shaping by

1 alternating bifacial reduction (de la Peña et al. 2013; de la Peña & Wadley, 2014; de la Peña
2 2015). In sum, the HP bifacials of layer GR from both excavations are principally
3 indistinguishable from the bifacial pieces of the lower Sibudan layers reported here.

4 Comparing metric dimensions on a more general level (Table 8), the Sibudan bifacials
5 are much smaller compared to specimens that derive from the SB at Blombos (Villa et al.
6 2009), Hollow Rock Shelter (Högberg and Larsson 2010) and Umhlatuzana (Lombard et al.
7 2010). The length, width and thickness of the Sibudan bifaces are almost identical to the HP
8 specimens from Sibudu deriving from both excavations (own data; de la Peña et al. 2013; de
9 la Peña, personal communication) and resemble those from the surface collections at
10 Soutfontein (particularly on quartz; Mackay et al. 2010). Tip cross-sectional areas (TCSA;
11 calculated after Shea 2006) from stage 2 and 3 bifaces of the Sibudan sequence range from
12 94.5-162.5 mm² (n=5) with a mean of 121.2 mm² (Table 8), lying closest to the values of
13 ethnographically known hand-held and thrusting-spear points (Shea 2006). The TCSAs fall in
14 between bifaces of stage 2b and 3 found in the SB at Blombos (Villa et al. 2009: Tab. 5) and
15 are almost identical to those in the SB of Sibudu (Wadley 2007: Tab. 3) and the HP of the
16 Tübingen excavations. In general, the TCSAs of bifacial tools in the Sibudan layers are lower
17 compared to bifacials assigned to a combined sample of SB tools from southern Africa (Shea
18 2006; see Table 8), with the reservation that “bifacials from the SB” are likely in invalid
19 entity due to the high internal variability within this category (see Introduction).

21 **Discussion**

22 *Technological variability and taxonomic status of the Sibudan sequence*

23 In previous publications (Will et al. 2014; Conard and Will 2015) we distinguished three
24 techno-typological phases of the Sibudan within the thick sequence dating to ~58 ka,
25 discussed their implications for cultural taxonomies and assessed potential causes of short-
26 term behavioral change during MIS 3 in southern Africa. Our results from the lowest part of

1 this sequence reveal an additional level of diachronic variability in relation to the upper three
2 phases (see Table 1). Assemblages RB-G1 are characterized by a focus on local raw material
3 with abundant use of dolerite, sandstone, quartz and quartzite. In contrast the middle and
4 upper part of the sequence (WOG1-SP; SU-POX; BM-BSP), knappers frequently employed
5 informal and bipolar core reduction methods – and to a lesser degree Levallois – to produce
6 various sizes and shapes of flakes. The older units feature low frequencies of retouch
7 (generally <3%) and less regular production of specific unifacial tool types compared to the
8 phases above. Tongati and Ndwedwe tools, which feature abundantly in the upper part of the
9 sequence, are entirely absent, as are unifacial points. Instead, marginally retouched, notched
10 and denticulated tools are common. The knappers at Sibudu also manufactured bifacials by
11 invasive shaping with a preference for quartz, particularly in the oldest levels of the sequence.
12 Although there are subtle variations, mostly due to slightly differential raw material use, these
13 technological characteristics are found in a uniform manner throughout the assemblages and
14 can thus be considered as the coherent first phase (“lower Sibudan”) among a total of four
15 subdivisions in the ~58 ka sequence (Table 1).

16 The new technological data add to the previous picture (Conard and Will 2015),
17 underlining that the sequence after the HP at Sibudu is characterized by a high variability with
18 regard to the procurement of raw materials and their reduction sequences, the methods of core
19 reduction, the techniques of blank production, and the approach used for tool manufacture.
20 This is an unexpected pattern when one considers that both the top and bottom of this meter-
21 thick sequence are dated to ~58 ka, implying that archaeological material accumulated rapidly
22 and occupations span only a duration of centuries or at most very few millennia. We
23 previously (Conard and Will 2015) discussed this short-term behavioral variability in terms of
24 its potential causes and consequences. By comparing our data with proxies on
25 paleoenvironments and hunting behavior, we found support for explanations that emphasize
26 differences in site use, raw material use, and overall organization of technology as well as

1 variable patterns of cultural transmission. We did not find evidence for environmental forcing
2 or demographic causation. While all of the above remain plausible causal mechanisms for the
3 behavioral patterns of this study, we consider it premature to advance a final interpretation.
4 This will require additional fine-grained diachronic and synchronic data on lithic technology,
5 subsistence and paleoenvironments at the site and regional level, particularly in relation to the
6 factors underlying the shift from the HP to the Sibudan (see below).

7 In part, the unexpectedly high tempo of technological change for the MSA that we
8 observe here can also be related to the fine scale of our analyses and the high-resolution
9 stratigraphy of Sibudu. In contrast to previous assessments of the ~58 ka layers at Sibudu
10 from Wadley's excavations which treated this part of the sequence as a monolithic and
11 homogeneous block that was consequently studied as one large aggregated assemblage
12 (Cochrane 2006; 2008), our fine-grained analyses reveals that the sequence reveals abundant
13 diachronic variability in terms of raw material procurement as well as technological,
14 typological, techno-functional and techno-economic parameters. From a general point of
15 view, our results thus highlight the great diversity and flexibility of human technological
16 behavior (see Kandel et al. 2015) over even short periods during the MSA, a factor that
17 studies with coarser scales – operating on the level of stratigraphic aggregates or
18 technocomplexes instead of individual find horizons – tend to miss or ignore.

19 What are the implications of our new results with regard to the taxonomic status of the
20 Sibudan? Or in other words, is the Sibudan still a useful heuristic device for structuring the
21 spatio-temporal pattern of archaeological material in the southern African MSA? With the
22 sequence presented here, we face the central issue of how we can best view cultural change
23 over narrow time spans (see Conard and Will 2015). The 23 find horizons are of
24 indistinguishable OSL ages of ca. 58 ka (Wadley & Jacobs 2006; Jacobs et al. 2008a; 2008b)
25 and thus reflect a nearly continuous sequence of occupations. In accordance with these dates,
26 the short-term technological and typological changes at Sibudu are of gradual, incremental,

1 and often cumulative nature, likely reflecting inter-generational transmission of information
2 (see Conard and Will 2015). While it is reasonable under such circumstances to put all
3 assemblages into the same cultural taxonomic unit, this would necessitate incorporating a
4 great degree of lithic variability. On the other hand, opting for a narrow definition of the
5 Sibudan by splitting up the section in several phases (*sensu* Clark et al. 1966) – such as RB-
6 G1, WOG1-SP, SU-POX and BM-BSP (Table 1) – might render comparisons with other sites
7 easier. Such division, however, would impose arbitrary boundaries in an essentially
8 contemporaneous sequence characterized by cumulative changes. This is the reason why we
9 provided them with informal designations (phases or *facies*) put within the same cultural-
10 taxonomic unit (see also Conard and Will 2015).

11 Returning to our initial discussion, the utility of any cultural taxonomy can only be
12 assessed in relation to research questions, how it helps us gain insight into past human
13 lifeways and for testing specific hypotheses (e.g., Brew 1946; Tschauner 1994; Roberts and
14 Vander Linden 2011). In our view, using the term Sibudan based on high-resolution lithic
15 analyses instead of a generic, informal and spatio-temporally coarse term such as “post-HP”,
16 helps to lay the groundwork for comparative research aimed at characterizing and explaining
17 patterns of cultural change within this time frame. By emphasizing both the distinctive
18 elements (Will et al. 2014) and the high variability (Conard and Will 2015) we can
19 characterize MIS 3 industries based on positive characteristics instead of what they lack, look
20 in more detail at patterns and causes of short-term behavioral change, inform discussions on
21 spatial and temporal variability in the MSA and contextualize the disappearance of the HP in
22 different regions.

23
24 *Implications for models of behavioral change and cultural evolution in the MSA of southern*
25 *Africa*

1 On a geographical level, many technological and typological similarities of the Sibudan with
2 the nearby sites of Umhlatuzana and Holley Shelter in KwaZulu-Natal are already emerging
3 from our current data and previous comparisons (see Will et al. 2014; Bader et al. 2015;
4 Conard and Will 2015). At the same time, we observed marked differences to further removed
5 but broadly contemporaneous localities on the southern coast and Western Cape of South
6 Africa. By providing structure to the geographical and temporal variation in the
7 archaeological record of MIS 3, the Sibudan can serve as a useful analytical tool. A
8 systematic comparison of other assemblages for this period is currently underway as part of a
9 general overview on lithic technology during the early part of MIS 3 in southern Africa (Will
10 et al. in prep). This study will shed further light on the utility of the “Sibudan” as an analytical
11 device in other parts of southern Africa. Regardless of the outcome of this work and its
12 implications for an understanding of cultural variability during the later phases of the MSA,
13 the work at Sibudu is helping to establish new research agendas in what until recently was an
14 area of scientific stagnation.

15 Regarding models of cultural evolution, it is becoming increasingly clear that the lithic
16 technology following the HP in southern Africa is not less innovative, unsophisticated or a
17 return to an earlier "pre-SB" technology as has at times been claimed (Sampson 1974; Deacon
18 1989; Henshilwood 2005; McCall 2007; Mellars 2007; Jacobs and Roberts 2008; 2009). This
19 casts serious doubts on some of the main tenets of the Synthetic Model. We emphasize this
20 point since such distorted views have been borrowed without further reflection by scholars
21 outside southern Africa, where they are integrated into larger-scale, global models of the
22 evolution and dispersal of modern humans (e.g., Mellars 2006; Mellars et al. 2013; Ziegler et
23 al. 2013). On the contrary, we found that the lithic technology of southern Africa during MIS
24 3 shows repeated development and use of technological innovations such as bifacial
25 technology that is commonly seen as hallmark of the SB (see below), highly structured tool
26 assemblages with repetitive forms and distinctive reduction chains (e.g., Tongati and

1 Ndwedwe tools; Conard et al. 2012; Will et al. 2014; Bader et al. 2015), the production of
2 morphometrically standardized blades executed by soft stone hammer percussion (Will et al.
3 2014; Bader et al. 2015), and the reduction of cores by the Nubian method, a specific and
4 elaborated variation of Levallois reduction which has so far been found only during this time
5 frame in the Cederberg area of western South Africa (Will et al. 2015; see also Hallinan and
6 Shaw, 2015).

7 In sum, our results from Sibudu and elsewhere demonstrate that lithic technology in
8 southern Africa after the HP does not show evidence for cultural regression but is
9 characterized by the occurrence of structured and sophisticated technologies, dynamic cultural
10 change with flexible approaches to stone knapping over short time spans, and possibly an
11 increased regionalization among more isolated populations with principally the same degree
12 of behavioral and cognitive complexity as during the preceding technocomplexes (see also
13 Soriano et al. 2007; Mitchell 2008; Villa et al. 2010; Lombard and Parsons 2011; Mackay
14 2011; Lombard et al. 2012; Porraz et al. 2013; Wurz, 2013; Mackay et al. 2014; Wadley,
15 2015). Taken together, thus research shows that only an increased knowledge of MIS 3
16 archaeology can provide a realistic picture of the spatio-temporal patterning of technological
17 variability and behavioral complexity of modern humans during the later part of the MSA in
18 southern Africa. These insights need be taken into account when building larger-scale models
19 for the early cultural evolution of *Homo sapiens*.

20 Finally, our findings carry implications for the disappearance of the HP in southern
21 Africa, as assemblages RB-G1 directly overlie the HP layers at Sibudu. Previous models for
22 the abandonment of HP lithic technology characterize this process as either abrupt (Singer &
23 Wymer 1982; Cochrane 2008; Jacobs et al. 2008a; Jacobs & Roberts 2009) or gradual
24 (Soriano et al. 2007; Mackay 2008; Villa et al. 2010; Mackay 2011), potentially happening at
25 different times (Porraz et al. 2013; Tribolo et al. 2013) and in divergent manners at different
26 sites (Soriano et al. 2015). Although we refrain from final conclusions until we have studied

1 all HP layers (PGS-GR) excavated by our team, comparing our results on the Sibudan to the
2 findings on the HP layers by Wadley's team provide preliminary insights.

3 The three lowest Sibudan layers (RB, LBYA, BYA2i) feature a low incidence of
4 bifacials that are also typical for the HP in Wadley's excavations (de la Peña et al. 2013; de la
5 Peña and Wadley 2014a; de la Peña 2015; see also Wadley 2008). A comparison with the
6 published HP bifacials shows that they resemble each other in their small size, selection of
7 raw materials with a predominant manufacture on quartz, and their production modalities by
8 alternating bifacial shaping. Another continuous element between the lower Sibudan
9 assemblages and the HP is the preferential retouch of quartz (see de la Peña & Wadley,
10 2014a; de la Peña 2015) which is only found within RB-YA but not in the middle and upper
11 parts of the Sibudan sequence. This being said, the lowermost Sibudan assemblage RB lacks
12 HP-like cores, small backed pieces, blade and bladelet production by a variety of core
13 reduction methods including frequent cores on flakes, and other elements found typical for the
14 HP in layers GS and GR that underlie the sequence studied here (see description in Wadley
15 2008; de la Peña & Wadley 2014a; de la Peña & Wadley 2014b; de la Peña 2015).
16 Assemblage RB is different from these HP assemblages and more comparable to the directly
17 overlying layers LBYA-YA presented here in the dominance of expedient platform and
18 bipolar reduction methods for flake manufacture, a lack of bladelet production, strong
19 dominance of local raw materials with a high frequency of sandstone and quartzite, internal
20 hard stone hammer percussion even for blades, and similar tool inventories.

21 In sum, the bifacials are the only striking techno-typological characteristic that is
22 maintained throughout the shift from the HP to the Sibudan at Sibudu. The generally low and
23 decreasing number of bifaces in the lower Sibudan sequence suggests a gradual decline of
24 these implements between the HP and the Sibudan. In contrast we, like Cochrane (2006;
25 2008) and Soriano *et al.* (2015), see a relatively abrupt break at Sibudu between the HP and
26 Sibudan with regards to many other techno-typological parameters. This observation is

1 consistent with chronometric data for an occupation hiatus of ca. 4,000 years between the two
2 technocomplexes at Sibudu (Wadley & Jacobs 2006; Jacobs et al. 2008a; 2008b; Wadley
3 2013), but difficult to reconcile with the evidence from the bifacials so far. Future work by
4 our team at Sibudu will study the nature of the shift between the HP and Sibudan in more
5 detail, cross-compare the findings to Wadley's excavation and also assess the causal
6 mechanisms for these technological changes.

8 *Bifacial technology in the MSA of southern Africa: a recurrent phenomenon*

9 Bifacial technology in the southern African MSA has long been considered an important and
10 even defining part of the technological repertoire of modern humans, particularly during the
11 SB period (Goodwin and Van Riet Lowe 1929; Clark 1959; Evans 1994; Henshilwood et al.
12 2001; Minichillo 2005; Wadley 2007; Jacobs et al. 2008a; Villa et al. 2009; Henshilwood
13 2012). In the recent years, however, it has become clear that the SB encompasses: a) variable
14 quantities of bifacial points; b) a wide range of morphometric variation in bifacial forms; and
15 c) different modalities of bifacial technology (Minichillo 2005; Vogelsang et al. 2010;
16 Högberg and Larsson 2011; Porraz et al. 2013; Archer et al. 2015; Soriano et al. 2015).

17 Here, we demonstrate the presence of bifacial technology from a stratigraphically and
18 chronologically secure context during early MIS 3 in southern Africa. In contrast to the SB
19 (Wadley 2007; Villa et al. 2009; Högberg and Larsson 2010; Lombard et al. 2010; Porraz et
20 al. 2013; Soriano et al. 2015), the bifacials found in the Sibudan are few in number, and
21 characterized by smaller dimensions (Table 8), a predominant manufacture on quartz and the
22 production by alternating removals in a non-hierarchical, non-sequential manner. The
23 excavations by Wadley at Sibudu have not yet identified comparable shaped points in the
24 early MIS 3 layers (Cochrane 2006; Mohapi 2012; de la Peña et al. 2013: 120) but only in the
25 underlying HP occupations (see below). Due to the careful excavation strategy outlined
26 above, we are certain in our placement of these bifacial tools in the lower Sibudan layers up

1 until ca. 20 cm within this sequence. Large-scale vertical movement of the pieces from
2 underlying layers can also be excluded by high-resolution geoarchaeological observations
3 (Goldberg et al. 2009; Wadley et al. 2011; Miller 2015) and the absence of any artefacts
4 typical for the HP such as blades, bladelets or backed artifacts in the lower Sibudan strata.

5 Invasively shaped bifacial points are generally not recognized as part of the tool
6 inventories in the southern African MSA postdating the HP (Volman 1984; Henshilwood et
7 al. 2001; Wurz 2013; Mackay et al. 2014; Wadley 2015). They do not feature in MIS 3
8 deposits of the long sequences at Klasies River (Singer and Wymer 1982; Wurz 2000; 2002),
9 Diepkloof (Porráz et al., 2013) and Die Kelders 1 (Grine et al. 1991; Thackeray 2000) or other
10 localities such as Peers Cave (Peers 1929), Strathalan (Opperman 1996), Melikane (Stewart et
11 al. 2012), and Rose Cottage Cave (Wadley and Harper 1989; Soriano et al. 2007). While we
12 know of no further case of fully shaped bifacials being present in stratigraphically secure
13 deposits dating to early MIS 3, Sibudu (~38 ka) and Umhlatuzana (~36 ka) have also yielded
14 distinct, bifacially retouched hollow-shaped points in the final MSA (Kaplan 1990; Wadley
15 2005; Jacobs et al. 2008a; Lombard et al. 2010; Mohapi 2013).

16 Bifacial pieces are, however, also present in other MSA phases of southern Africa (see
17 Mackay et al. 2010; 2014). Most prominently, two recent studies found that knappers
18 produced bifacial points in secure and dated HP contexts. At Diepkloof, bifacials occur in 4
19 out of the 24 assemblages of the “Early HP” in low frequencies (n=1-8; in Jess, Julia, Kenny,
20 Kegan) which are located in the lower part of the sequence right above the SB (Porráz et al.
21 2013). The situation is different at Sibudu where the manufacture of small bifacials from
22 quartz constitutes a frequent technological strategy throughout the two main HP horizons (GR
23 and GS; de la Peña et al. 2013; de la Peña and Wadley 2014a; de la Peña 2015). These
24 findings are in accordance with observations during the early and mid-20th century, which
25 sporadically cited bifacial elements associated with the HP (Stapleton and Hewitt 1927;
26 Malan 1955; Goodwin 1958; see Henshilwood et al. 2001; Henshilwood 2012). Such early

1 claims, however, came from uncertain cultural stratigraphic contexts including surface finds.
2 In a recent regional overview of HP sites in southern Africa, including Diepkloof, Hollow
3 Rock Shelter and the Howiesons Poort name site, de la Peña *et al.* (2013: 133) conclude that
4 “*there is evidence for the co-occurrence of bifacial points and backed tools in several*
5 *different southern African sequences*” (see also Sampson 1974; Singer and Wymer 1982;
6 Volman 1984; Thackeray 1992; McBrearty and Brooks 2000; Wurz 2000; Porraz *et al.* 2013;
7 Mackay *et al.* 2014). Earlier in time, the Pietersburg technocomplex (Sampson 1974) of
8 Border Cave in northern KwaZulu-Natal features leaf-shaped bifacial points that are dated by
9 ESR to between ~230-80 ka (Grün and Beaumont 2001; Grün *et al.* 2003), and similar sites
10 with bifacial pieces such as Wonderwerk Cave and Cave of Hearths also likely pre-date the
11 SB (Beaumont and Vogel 2006).

12 Turning back to the level of the individual site, Sibudu currently represents a unique
13 case for bifacial technology. Together with data presented here, there is evidence for bifacials
14 and their production in the “Pre-SB”, SB, HP, Sibudan and final MSA layers. This being said,
15 knappers made differential use of this technological option, utilized a range of raw materials,
16 employed various methods and produced a broad spectrum of morphological and metric
17 variants during these different MSA phases (Wadley 2005; 2007; Mohapi 2012; de la Peña *et al.*
18 *et al.* 2013; Conard *et al.* 2014; de la Peña 2015; Soriano *et al.* 2015). As elaborated above, the
19 bifacial pieces from the lower Sibudan layers show many similarities to similar artifacts from
20 Wadley’s excavation of the HP layers below (see de la Peña *et al.* 2013; de la Peña and
21 Wadley 2014a; de la Peña 2015). Bifacial shaping could thus constitute a knapping strategy
22 maintained by the inhabitants of Sibudu after the abandonment of HP lithic technology.

23 What do these observations mean with regard to the questions we raised in the
24 introduction? Are bifacial pieces in southern Africa largely confined to the SB or do they
25 rather constitute dynamic elements of lithic technology? In a recent overview, Henshilwood
26 (2012: 218) stated that “*bifacial points serve to identify the presence of a Still Bay phase at a*

1 *site*”, a statement to which many archaeologists in southern Africa currently agree. Based on
2 our results as well as other recent studies (de la Peña et al. 2013; Porraz et al. 2013; Mackay et
3 al. 2014) we must, however, conclude that bifacial technology is a recurrent and dynamic
4 element of the southern African MSA, compromising its use as an unambiguous chrono-
5 cultural marker. Bifacially shaped tools occur in various chronological, geographical and
6 environmental contexts as well as on various raw materials such as silcrete, dolerite, hornfels,
7 quartz and crystal quartz (Mackay et al. 2010; de la Peña et al. 2013).

8 On a larger comparative scale, various forms of bifacial technology are also present in
9 other regions and phases of the African Stone Age (see McBrearty and Brooks 2000;
10 McBrearty 2003) as they are in the Eurasian Paleolithic (Otte 2003; Moncel et al. 2016). To
11 name but a few pertinent examples from the MSA, bifacial technology features in the
12 Lupemban of central and eastern Africa (McBrearty 1988; Clark 2001; Taylor 2011; Tryon et
13 al. 2012; Faith et al. 2016; Taylor 2016), assemblages in adjacent areas of the northeastern
14 central African rainforest (Cornelissen 2016), the early Nubian complex of north-eastern
15 Africa (Van Peer 1998; Van Peer et al. 2003; Van Peer and Vermeersch 2007; Van Peer
16 2016), the MSA sequence at Mumba (Bretzke et al. 2006) and the Aterian (or Atero-
17 Mousterian) of North Africa (Débenath 1992; Garcea 2004; Barton et al. 2009; Dibble et al.
18 2013; Scerri 2013). The latter technocomplex also presents an instructive example of the
19 plethora of problems that arise when using the presence and absence of particular *fossiles*
20 *directeurs* – in this case tanged, or stemmed, artifacts – as the primary or single element of
21 classification. An exclusive focus on such types hindered comparative research and cultural
22 systematics in the northern African MSA by masking both technological variability and
23 similarities between taxonomic units (see discussion in Dibble et al. 2013; Scerri 2013; also
24 Kleindienst, 2006). The same applies to bifacial pieces in the southern African MSA.

1 **Conclusion**

2 The intense and successively stratified Sibudan occupations at Sibudu – over 20
3 archaeological horizons with both the bottom and top of the ca. 1.2 m thick deposits dating to
4 early MIS 3 at ~58 ka – provide a rare high-resolution cultural depository of the MSA that
5 spans only a couple centuries or millennia at most. Analyses of these lithic assemblages reveal
6 a previously unknown level of short-term behavioral variability and an unexpectedly high
7 tempo of technological change for the MSA (see also Conard & Will 2015). Our findings
8 underline the importance of studying MSA lithic assemblages on scales that are as finely
9 resolved as the stratigraphical and depositional conditions permit, such as individual layers,
10 lenses or even features, instead of focusing exclusively on technocomplexes or MIS stages
11 which constitute analytical units of much higher order based on ever higher levels of
12 aggregated data. Such coarser-grained analyses will necessarily lose important information
13 and underestimate the temporal variation in material culture below the level of
14 technocomplexes. These observations are in agreement with recent analytical stances by some
15 MSA scholars who urge to move away from treating entire periods or technocomplexes as
16 homogeneous blocks or monolithic entities. Instead, research is increasingly emphasizing the
17 variability in lithic technology at various spatial and temporal scales as well as the various
18 causal mechanisms for apparent similarities and differences that apply at different levels of
19 analyses (e.g., Porraz et al. 2013; Tryon & Faith 2013; Will et al. 2014; Conard & Will 2015;
20 de la Peña 2015; Soriano et al. 2015; Mackay 2016; this also applies to faunal analyses:
21 Discamps & Henshilwood 2015).

22 The results presented here, alongside other studies (e.g., de la Peña et al. 2013; Porraz et
23 al. 2013; Conard et al. 2014), further erode the old idea that bifacial technology in southern
24 Africa is limited to the SB. Although early modern humans in southern Africa made more
25 frequent use of bifacial technology during the SB at many sites, we can no longer equate
26 single bifacial pieces or the occasional use of bifacial shaping techniques with this

1 technocomplex. The sequence from Sibudu, featuring bifacial technology almost throughout
2 the entire span of its MSA occupations, constitutes a case in point. Viewed from a continental
3 perspective, recent studies show that bifacial pieces come and go during the African MSA and
4 are present in different forms and contexts of Late Pleistocene technology. Bifacial
5 technology thus constitutes another example of independent innovation – or technological
6 convergence – in lithic technology within different phases of the MSA of Africa, alongside
7 small backed pieces (Barham 2000; Marks and Conard 2007; Hiscock et al. 2011), Levallois
8 methods (White et al. 2011; Tryon and Faith 2013) or Nubian core reduction (Will et al.
9 2015). Importantly, and analogous to homoplasies that do not provide phylogenetic
10 information on organisms in biological analyses (Losos 2011; Wake et al. 2011; Pearce 2012),
11 convergent technologies cannot be used in a straightforward manner to resolve historical
12 relationships between populations and cultures in archaeological studies. Researchers should
13 thus be cautious in their use of bifacial technology as *fossiles directeurs*, chrono-cultural
14 markers or tracking devices for early human dispersals in southern Africa and beyond (see
15 also Otte 2003; McBrearty 2003; Dibble et al. 2013; Porraz et al. 2013; Moncel et al. 2016).
16 Changing the focus to the morphological, spatial and temporal variation of bifacial technology
17 in different functional, cultural and environmental contexts will be a more fruitful approach.
18 Such an enterprise might also allow researchers to establish the reasons for why early modern
19 humans repeatedly developed and used bifacial tools during the course of the MSA.

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7 **Conflict of Interest**

8 The authors declare that they have no conflict of interest.

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1 **Figure captions**

2
3 **Fig. 1.** Stratigraphic section of the Eastern Excavation (combined north and east profile) of Sibudu with all
4
5 Sibudan layers (RB-BSP) indicated in color. Layers RB-G1 are analyzed in this study and were excavated by the
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7 Tübingen team in 2015 and 2016. Located in the lowest part of the sequence, these assemblages are likewise
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9 dated to ~58 ka. Red stars indicate the approximate projected location of bifacial points within the Sibudan
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11 sequence, clustering in its lowest part.
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15 **Fig. 2.** Percentual abundance of raw materials throughout the Sibudan at Sibudu. RB = oldest layer; BSP =
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17 youngest layer
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21 **Fig. 3.** Frequencies of blank types produced throughout the Sibudan at Sibudu. RB = oldest layer; BSP =
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23 youngest layer
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27 **Fig. 4.** Linear regression of tool frequency and hornfels percentage of all Sibudan assemblages with indication of
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29 layer designation ($R^2 = 0.913$; $p < 0.001$).
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33 **Fig. 5.** Frequencies of classic tool types throughout the Sibudan an Sibudu. Assemblages CH2, G1 and GM are
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35 missing as they do not feature any of the presented tool types. RB = oldest layer; BSP = youngest layer
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40 **Fig. 6.** Frequencies of techno-functional tool classes (see Conard et al., 2012; Will et al., 2014) throughout the
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42 Sibudan at Sibudu. RB = oldest layer; BSP = youngest layer
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46 **Fig. 7.** Photographs of bifacial pieces from Sibudu with indication of find number and layer. D2-1777 (CCS);
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48 D3-1791.1, C3-1925, C2-2173, C3-2319; D2-1691, C2-2445 (all quartz).
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52 **Fig. 8.** Drawings of bifacial pieces from Sibudu with indication of find number and layer. D2-1777: CCS; D3-
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54 1791.1, C3-1925, C2-2173, D2-1691 (all quartz); C2-2198 (quartzite).
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Tables

Table 1

Overview of the Sibudan sequence deriving from the Tübingen excavations (see also Figure 1).

Layers	Number of layers	Informal designation	Publications	Chronometric ages^a (Layer in brackets)
BM-BSP	6	“Upper “ / “classic“ Sibudan	Conard et al. 2012; Will et al. 2014	57.6 +/- 2.1 (BSP); 59.6 +/- 2.3 (SS);
SU-POX	3	“Upper middle“ Sibudan	Conard and Will 2015	59.0 +/- 2.2 (POX)
SP-WOG1	2	“Lower middle“ Sibudan	Conard and Will 2015	- 58.3 +/- 2.0 (CH2); 58.6
RB-G1	12	“Lower“ Sibudan	This study	+/- 2.1 (Y1); 58.2 +/- 2.4 (BGMIX)

^a Absolute ages are from OSL dating (in ka) and taken from Jacobs et al. (2008b) during Wadley’s excavations.

Table 2

Overview of stratigraphic layers, sediment volumes, lithic finds and find density from the Sibudan layers (~58 ka) at Sibudu.

Layer	Sediment	Lithics	Lithics	Total lithics	Find density (n/m ³)
	volume (m ³)	>30 mm	<30 mm		
BSP	0.387	822	13644	14466	37360.5
SPCA	0.300	580	10019	10599	35330.0
CHE	0.090	133	2792	2925	32500.0
MA	0.136	178	4421	4599	33816.2
IV	0.424	676	20389	21065	49681.6
BM	0.142	262	5694	5956	41944.7
POX	0.575	2192	43418	45610	79391.8
BP	0.048	261	4039	4300	89583.3
SU	0.400	1624	26816	28440	71189.0
SP	0.232	705	5060	5765	24903.8
WOG1	0.188	368	2210	2578	1334.7
G1	0.334	185	1505	1690	5059.9
CH2	0.189	109	971	1080	5714.3
Y1	0.194	279	1794	2073	10701.0
BG MIX	0.262	487	4063	4550	17366.4
BBGM	0.162	260	2020	2280	14074.1
YA	0.131	247	2288	2535	19351.1
YA2	0.125	224	2291	2515	20120.0
GM	0.096	133	1285	1418	14770.8
YA2i	0.097	164	1043	1207	12443.3
BYA2i	0.192	310	1457	1767	9203.1
LBYA	0.188	451	2299	2750	14627.7
RB	0.064	232	1969	2201	34390.6
<i>TOTAL</i>	<i>4.954</i>	<i>10882</i>	<i>161847</i>	<i>172369</i>	<i>34789.9</i>

Table 3

Distribution of raw materials (>30 mm) in the ~58 ka layers at Sibudu. Highest values per raw material within the sequence are highlighted in boldface.

Layer	Dolerite	Hornfels	Sandstone	Quartzite	Quartz	Other	TOTAL	MFRMU ^a
BSP	535 (65.1%)	262 (31.9%)	11 (1.3%)	8 (1.0%)	5 (0.6%)	1 (0.1%)	822	Dolerite
SPCA	334 (57.6%)	222 (38.3%)	11 (1.9%)	9 (1.6%)	3 (0.5%)	1 (0.2%)	580	Dolerite
CHE	79 (59.4%)	50 (37.6%)	4 (3%)	-	-	-	133	Dolerite
MA	111 (62.4%)	58 (32.6%)	4 (2.2%)	3 (1.7%)	1 (0.6%)	1 (0.6%)	178	Dolerite
IV	406 (60.1%)	235 (34.8%)	21 (3.1%)	6 (0.9%)	-	8 (1.2%)	676	Dolerite
BM	181 (69.1%)	66 (25.2%)	12 (4.6%)	2 (0.8%)	1 (0.4%)	-	262	Dolerite
POX	1919 (87.5%)	134 (6.1%)	93 (4.2%)	42 (1.9%)	1 (0.1%)	3 (0.1%)	2192	Dolerite
BP	245 (93.9%)	7 (2.7%)	5 (1.9%)	4 (1.5%)	-	-	261	Dolerite
SU	1479 (91.1%)	22 (1.4%)	80 (4.9%)	41 (2.5%)	1 (0.1%)	1 (0.1%)	1624	Dolerite
SP	567 (80.4%)	7 (1.0%)	100 (14.2%)	26 (3.7%)	4 (0.6%)	1 (0.1%)	705	Dolerite
WOG1	270 (73.4%)	-	74 (20.1%)	15 (4.1%)	9 (2.4%)	-	368	Dolerite
G1	75 (40.5%)	1 (0.5%)	85 (45.9%)	11 (5.9%)	11 (5.9%)	2 (1.1%)	185	Sandstone
CH2	46 (42.2%)	-	47 (43.1%)	3 (2.8%)	13 (11.9%)	-	109	Sandstone
Y1	124 (44.4)	2 (0.7%)	99 (35.5%)	16 (5.7%)	37 (13.3%)	1 (0.4%)	279	Dolerite
BG MIX	272 (55.9%)	5 (1.0%)	145 (29.8%)	24 (4.9%)	41 (8.4%)	-	487	Dolerite
BBGM	149 (57.3%)	-	70 (26.9%)	23 (8.8%)	18 (6.9%)	-	260	Dolerite
YA	120 (48.6%)	2 (0.8%)	63 (25.5%)	27 (10.9%)	34 (13.8%)	1 (0.4%)	247	Dolerite
YA2	67 (29.9%)	1 (0.4%)	69 (30.8%)	36 (16.1%)	49 (21.9%)	2 (0.9%)	224	Sandstone
GM	30 (22.6%)	2 (1.5%)	39 (29.3%)	26 (19.5%)	36 (27.1%)	-	133	Sandstone
YA2i	33 (20.1%)	8 (4.9%)	53 (32.3%)	26 (15.9%)	44 (26.8%)	-	164	Sandstone
BYA2i	47 (15.2%)	17 (5.5%)	157 (50.6%)	37 (11.9%)	52 (16.8%)	-	310	Sandstone
LBYA	114 (25.3%)	11 (2.4%)	211 (46.8%)	92 (20.4%)	22 (4.9%)	1 (0.2%)	451	Sandstone
RB	99 (42.7%)	2 (0.9%)	93 (40.1%)	35 (15.1%)	3 (1.3%)	-	232	Dolerite
<i>Total</i>	<i>7302</i>	<i>1114</i>	<i>1546</i>	<i>512</i>	<i>385</i>	<i>23</i>	<i>10882</i>	

^aMFRMU = Most frequent raw material unit

Table 4Representation of debitage products (>30 mm) in the ~58 ka layers at Sibudu^a.

Layer	Blank	Tool	Core	Angular debris	Lithic finds (>30 mm)
BSP	637 (78%)	142 (17%)	19 (2%)	24 (3%)	822
SPCA	453 (78%)	104 (18%)	14 (2%)	9 (2%)	580
CHE	99 (74%)	29 (22%)	3 (2%)	2 (2%)	133
MA	123 (69%)	48 (27%)	1 (1%)	6 (3%)	178
IV	473 (70%)	179 (26%)	14 (2%)	10 (2%)	676
BM	196 (75%)	57 (22%)	3 (1%)	6 (2%)	262
POX	2018 (92%)	133 (6%)	12 (1%)	29 (1%)	2192
BP	251 (96%)	8 (3%)	1 (0.5%)	1 (0.5%)	261
SU	1539 (95%)	52 (3%)	11 (1%)	22 (1%)	1624
SP	680 (97%)	9 (1%)	6 (1%)	10 (1%)	705
WOG1	352 (96%)	5 (1%)	5 (1%)	6 (2%)	368
G1	170 (92%)	3 (1.5%)	4 (2%)	8 (4.5%)	185
CH2	99 (89%)	1 (1%)	4 (4%)	7 (6%)	109
Y1	258 (92.5%)	5 (1.5%)	8 (3%)	8 (3%)	279
BG MIX	442 (91%)	5 (1%)	12 (2.5%)	28 (5.5%)	487
BBGM	240 (92.5%)	6 (2%)	5 (2%)	9 (3.5%)	260
YA	226 (92%)	7 (3%)	6 (2%)	8 (3%)	247
YA2	204 (91%)	4 (2%)	7 (3%)	9 (4%)	224
GM	122 (91.5%)	1 (1%)	2 (1.5%)	8 (6%)	133
YA2i	148 (90%)	6 (4%)	4 (2%)	6 (4%)	164
BYA2i	281 (90.5%)	6 (2%)	3 (1%)	20 (6.5%)	310
LBYA	399 (88.5%)	15 (3%)	11 (2.5%)	26 (6%)	451
RB	208 (89.5%)	10 (4.5%)	7 (3%)	7 (3%)	232
<i>TOTAL</i>	<i>9616</i>	<i>835</i>	<i>164</i>	<i>267</i>	<i>10882</i>

^a Rounded percentages are given in brackets.

Table 5Distribution of core categories^a in the ~58 ka layers at Sibudu.

Layer	Parallel	Platform	Inclined	Bipolar	IBR ^b	TOTAL
BSP	6	5	2	3	3	19
SPCA	8	5	-	1	-	14
CHE	2	1	-	-	-	3
MA	-	1	-	-	-	1
IV	5	7	1	-	1	14
BM	2	1	-	-	-	3
POX	1	4	3	-	4	14
BP	-	-	1	-	-	1
SU	5	3	1	-	2	11
SP	3	2	-	1	-	6
WOG1	1	1	-	3	-	5
G1	-	1	-	3	-	4
CH2	-	2	-	2	-	4
Y1	-	3	-	5	-	8
BG MIX	-	4	-	7	1	12
BBGM	2		-	3	-	5
YA	1	1	-	4	-	6
YA2	1	3	-	3	-	7
GM	-	-	-	2	-	2
YA2i	-	-	-	4	-	4
BYA2i	-	-	-	3	-	3
LBYA	-	1	-	8	2	11
RB	-	2	-	5	-	7
<i>Total</i>	<i>37</i>	<i>48</i>	<i>8</i>	<i>58</i>	<i>13</i>	<i>164</i>

^a Core classification follows the taxonomy of Conard *et al* (2004).^b IBR = indeterminate broken.

Table 6

Frequencies of small artifacts (10-30 mm) from representative samples of individual layers at Sibudu^a, differentiated by raw material (n) and retouch debitage (% of all sampled small artifacts).

Layer	Dolerite	Hornfels	Sandstone	Quartzite	Quartz	TOTAL	% Retouch debitage
BSP	636	381	0	12	5	1034	13.6
SPCA	470	517	10	7	4	1008	23.4
IV	594	469	24	3	1	1091	15.7
POX	1480	75	0	9	1	1565	3.5
BP	1697	91	116	18	0	1922	3.4
SU	1604	17	158	38	2	1819	2.0
SP	1743	5	304	44	4	2100	1.7
WOG1	1097	2	490	53	68	1710	1.1
G1	118	1	209	3	105	436	0.5
CH2	93	1	91	26	96	307	0.3
Y1	308	5	387	35	142	877	0.3
BG MIX	643	0	466	17	119	1245	0.4
YA	644	42	707	169	453	2015	1.8
YA2i	92	28	65	148	539	872	2.1
BYA2i	126	25	159	105	442	857	1.9
LBYA	157	20	495	205	180	1057	1.9
RB	438	32	244	127	81	922	3.0
<i>Total</i>	11940	1711	3925	1019	2242	20837	5.6

^aIn total, 17 of 23 layers from the Sibudan sequence at Sibudu were sampled. Layers not sampled include CHE, MA, BM, BBGM, YA2 and GM.

Table 7

Distribution of traditional tool types in the ~58 ka layers at Sibudu.

Layer	Unifacial Point	Side Scraper	Lateral Retouch	Denticulate & Notch	Splintered piece	Backed tool	Bifacial Point	Hammer- stone	Minimal retouch	Other
BSP	67 (47%)	24 (18%)	14 (10%)	4 (3%)	4 (3%)	2 (1%)	2 (1%)	2 (1%)	19 (13%)	9 (6%)
SPCA	48 (46%)	24 (23%)	6 (6%)	4 (4%)	4 (4%)	-	-	2 (1%)	9 (9%)	9 (9%)
CHE	11 (38%)	7 (24%)	3 (10%)	-	-	-	-	-	8 (28%)	-
MA	26 (54%)	10 (21%)	3 (6%)	-	1 (2%)	-	-	-	5 (11%)	5 (10%)
IV	97 (54%)	23 (13%)	15 (8%)	11 (6%)	3 (2%)	2 (1%)	1 (1%)	1 (1%)	20 (11%)	10 (6%)
BM	29 (52%)	7 (12%)	6 (11%)	-	1 (2%)	-	-	-	10 (18%)	6 (11%)
POX	49 (37%)	9 (7%)	9 (7%)	17 (13%)	1 (1%)	2 (1%)	-	-	42 (31%)	5 (4%)
BP	5 (62%)	1 (13%)	-	-	-	-	-	-	2 (25%)	-
SU	14 (27%)	12 (23%)	4 (8%)	10 (19%)	-	-	-	-	11 (21%)	5 (10%)
SP	-	-	2 (22%)	7 (78%)	-	-	-	-	-	-
WOG1	1 (20%)	1 (20%)	-	2 (40%)	-	-	-	-	1 (20%)	1 (20%)
G1	-	-	-	-	-	-	-	-	3 (100%)	-
CH2	-	-	-	-	-	-	-	-	1 (100%)	-
Y1	-	2 (40%)	-	2 (40%)	1 (20%)	-	-	-	-	-
BG MIX	-	2 (40%)	-	3 (60%)	-	-	-	-	-	-
BBGM	1 (17%)	1 (17%)	-	3 (50%)	-	-	-	-	1 (17%)	-
YA	-	-	-	3 (43%)	-	-	1 (14%)	-	3 (43%)	-
YA2	-	-	-	3 (75%)	-	-	-	-	1 (25%)	-
GM	-	-	-	1 (100%)	-	-	-	-	-	-
YA2i	-	1 (17%)	1 (17%)	2 (33%)	1 (17%)	-	-	-	1 (17%)	-
BYA2i	-	-	-	4 (66%)	1 (17%)	-	1 (17%)	-	-	-
LBYA	-	1 (6.5%)	1 (6.5%)	3 (20%)	4 (27%)	-	4 (27%)	1 (6.5%)	1 (6.5%)	-
RB	-	-	-	2 (20%)	4 (40%)	-	1 (10%)	-	3 (30%)	-
<i>Total</i>	<i>348 (41.5%)</i>	<i>104 (12.5%)</i>	<i>64 (7.5%)</i>	<i>81 (9.5%)</i>	<i>25 (3%)</i>	<i>6 (0.5%)</i>	<i>10 (1%)</i>	<i>6 (0.5%)</i>	<i>141 (17%)</i>	<i>56 (7%)</i>

Table 8

Metric comparison between bifacial tools from Sibudu and other MSA assemblages of southern Africa.

Assemblage	Sample size (n) ^a	Mean length (mm)	Mean width (mm)	Mean thickness (mm)	Mean TCSA mm ² (range)	Source
Sibudu (~58 ka)	7	33.5	23.0	10.3	121.2 (94.5-162.5)	This study
Sibudu (HP), Conard's excavation (layer GR)	12	35.0	22.0	9.8	120.5 (72-169)	This study
Sibudu (SB)	9	-	27.2	8.5	117 (63-183)	Wadley, 2007
Sibudu (HP), Wadley's excavation	55	33.6 ^b	20.1 ^b	8.9 ^b	- ^c	de la Peña et al., 2013
Blombos, phase 2a points (SB)	25	-	-	-	195.0 (99.1-551.9)	Villa et al., 2009
Blombos, phase 2b points (SB)	16	-	-	-	148.9 (49.4-344.1)	Villa et al., 2009
Blombos, phase 3 points (SB)	23	55.0 ^d	-	8.3 ^d	99.4 (28.8-190.4)	Villa et al., 2009
Hollow Rock Shelter (SB)	69	-	27.0	10.0	-	Högberg and Larsson, 2010
Umhlatuzana (Layers 16-24; late MSA)	17	49.7	26.9	10.1	140.2 (60-331.5)	Lombard et al., 2010
Umhlatuzana (Layers 25-27; SB)	47	51.9	21.9	8.7	107.5 (30-270)	Lombard et al., 2010
Soutfontein (surface)	60	-	27.0	11.0	152 (63-418)	Mackay et al., 2010
South African SB points	203	-	-	-	145 (25-754)	Shea, 2006
Blombos (all SB points)	239	-	-	-	143 (4.0-842)	Shea, 2006

^a Sample size denotes the total sample of bifacials in the pertinent study but does not necessarily reflect the number of cases for each measurement.

^b Raw data and averages were kindly provided via personal communication by P. de la Peña.

^c A mean of 39.5 mm² is provided by de la Peña *et al.* (2013) which could be an incorrect calculation given the mean value of the other measurements on which it is based (width; thickness). The authors themselves note that their mean is probably invalid due to high variability in the measurements.

^d "Finished" Still Bay points in Villa *et al.* (2009).

Figure 2

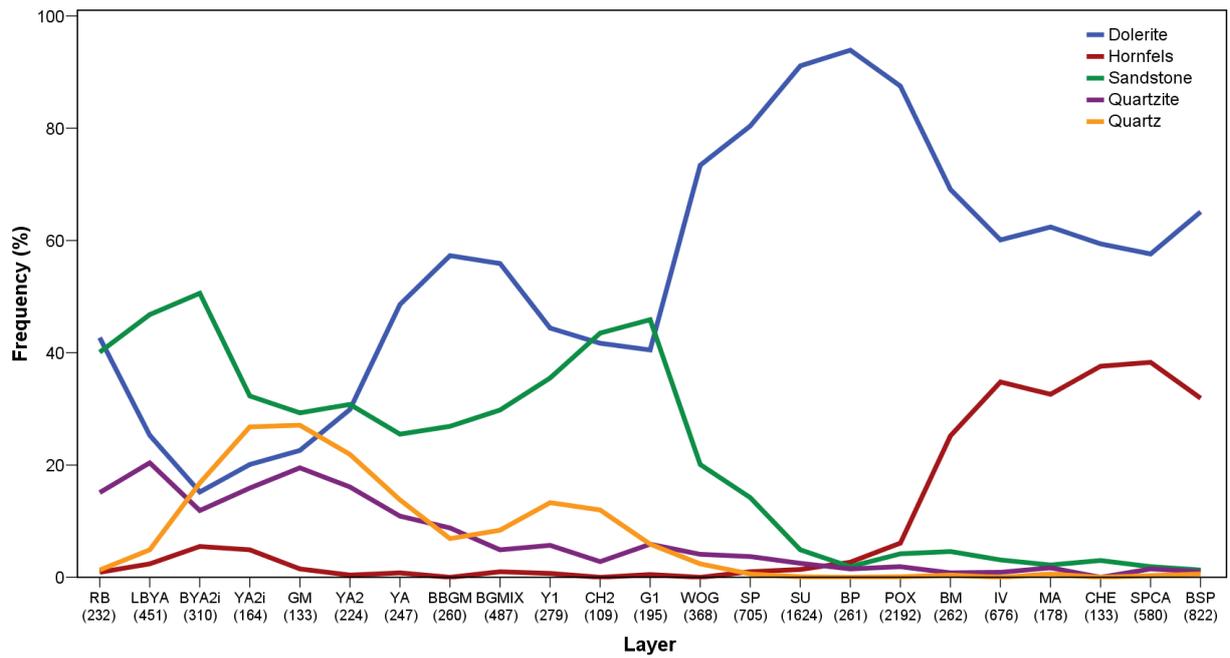


Figure 3

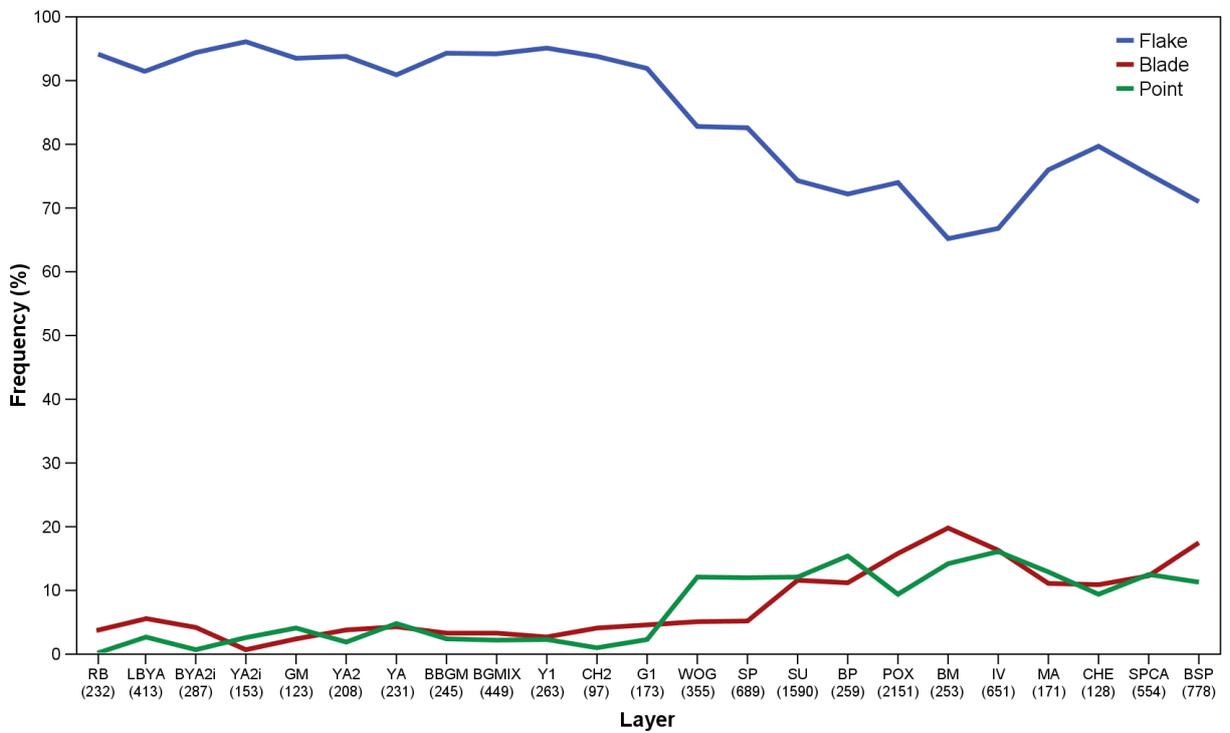


Figure 4

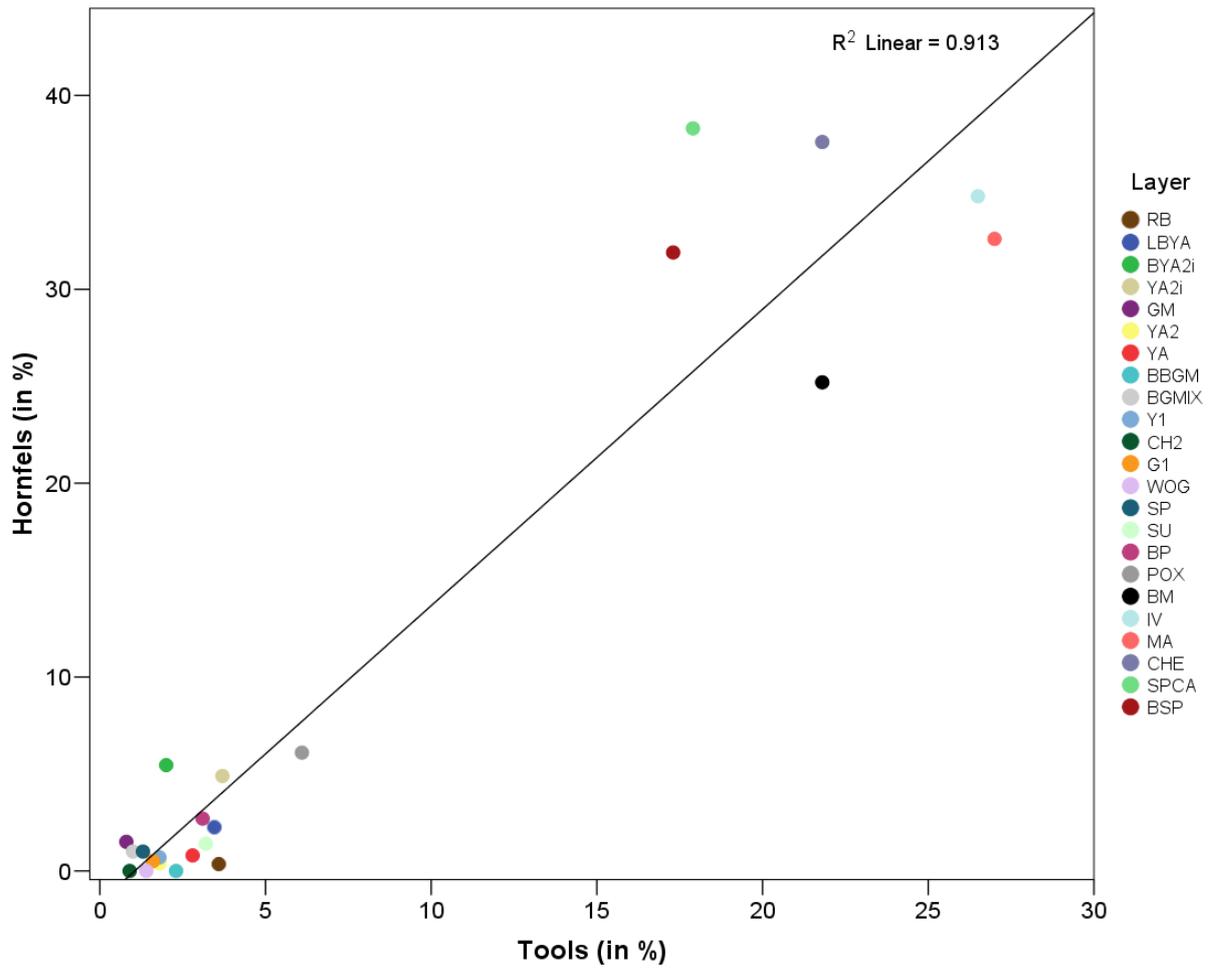


Figure 5

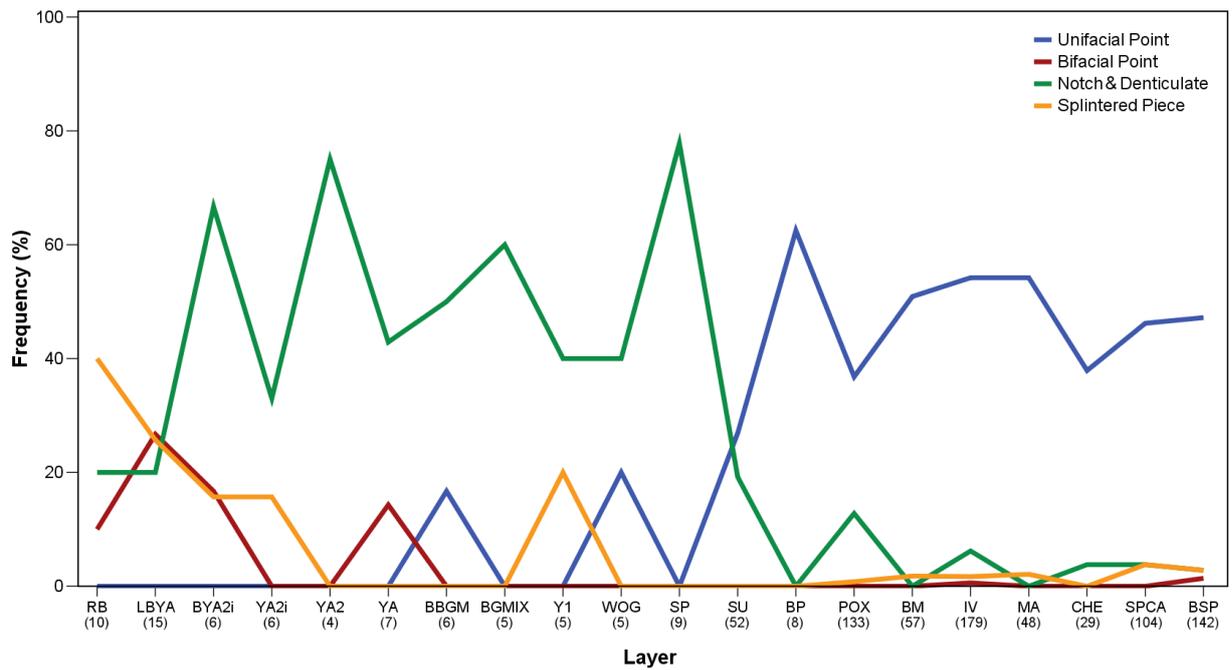


Figure 6

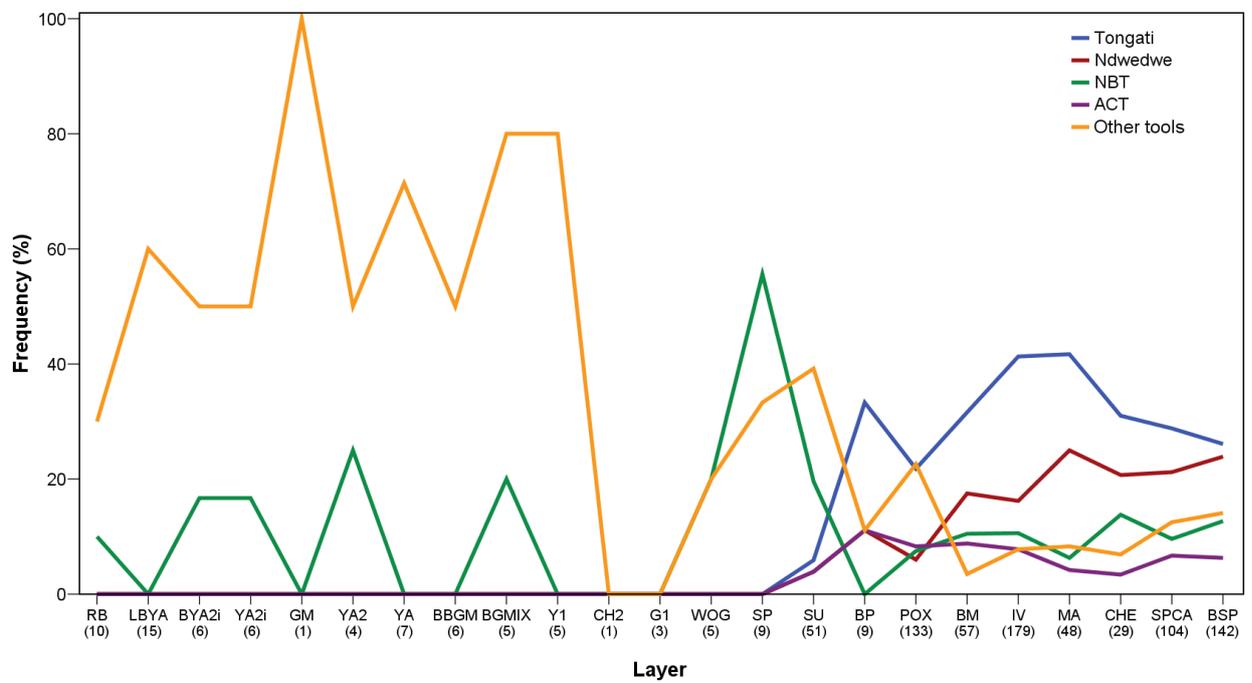


Figure 7

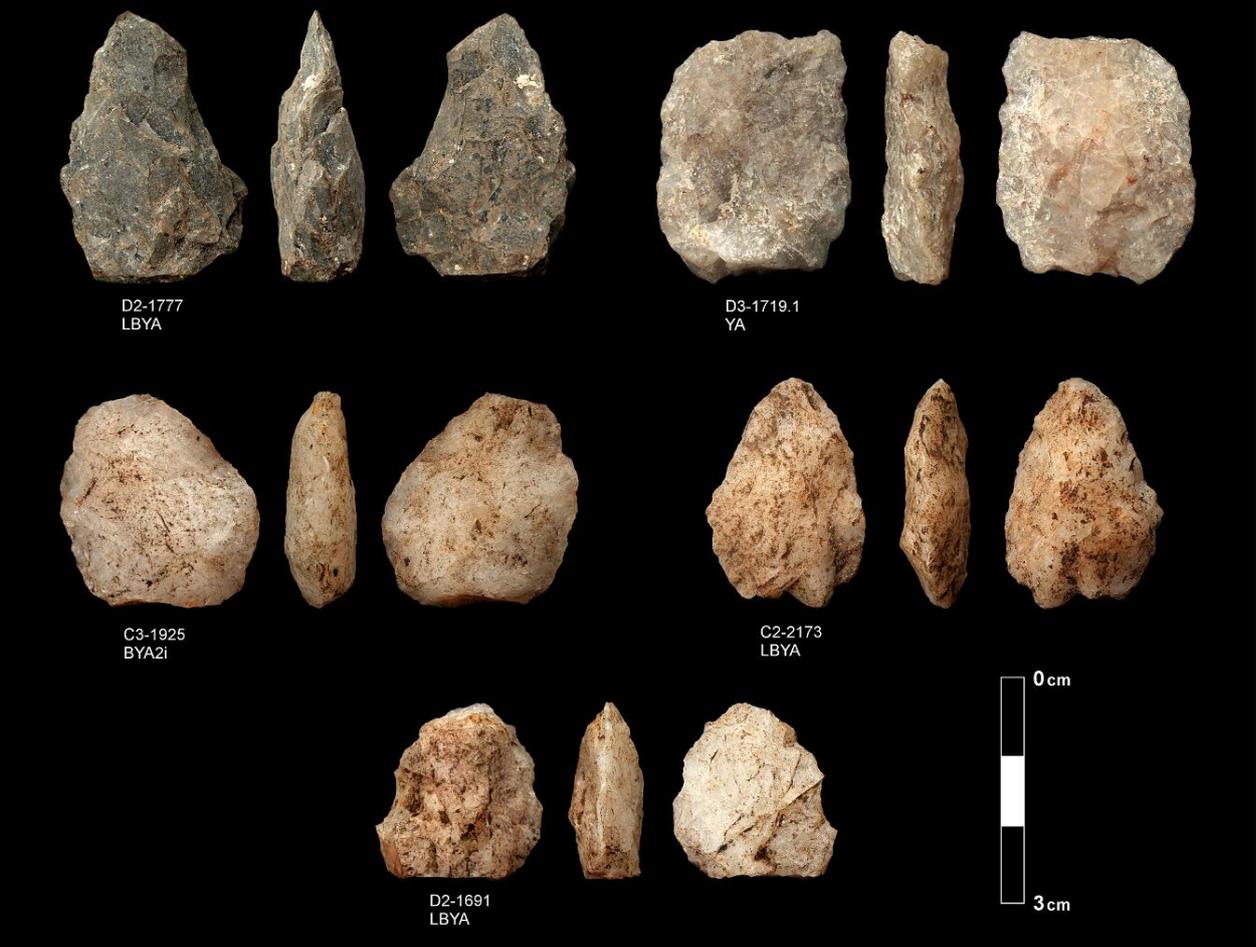
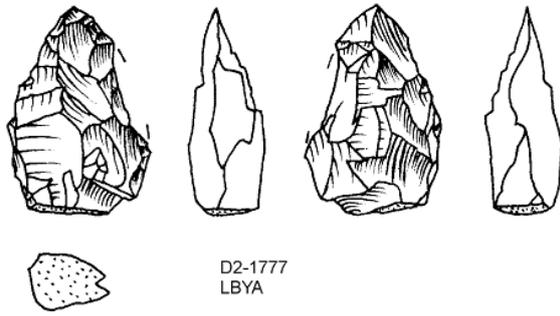
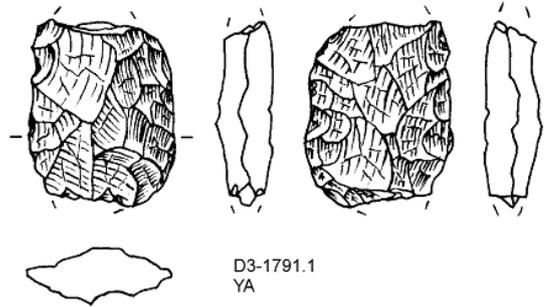


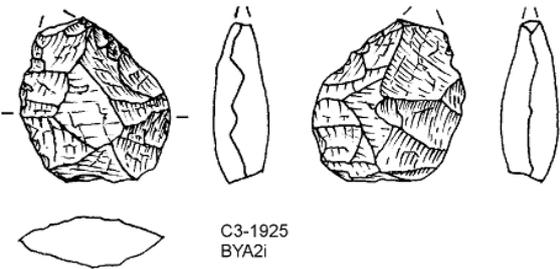
Figure 8



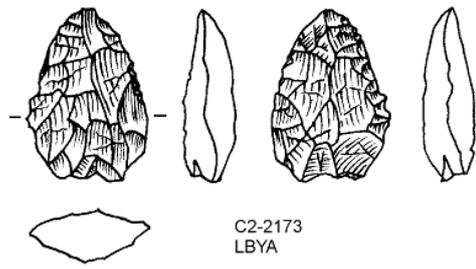
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LBYA



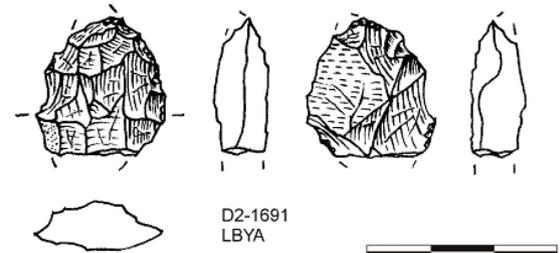
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YA



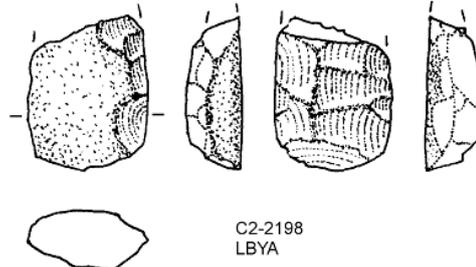
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BYA2i



C2-2173
LBYA



D2-1691
LBYA



C2-2198
LBYA

