Spatial Temporal Visualisations of the Southern African Middle Stone Age

Thesis submitted in partial fulfilment of the requirements for the degree of Doctor of Philosophy

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Abstract

This thesis explores the chronology of the Middle Stone Age (MSA) in southern Africa across three nested spatial and temporal scales. The MSA (300-30 ka) is typically associated with moments of innovation and symbolic behaviour. However, understanding this period has been hindered by the limitations of traditional frameworks, chronological constraints, and research bias. This thesis's first study critically evaluates the historical development of southern African MSA chronology, revealing how political influences and research traditions have shaped our understanding of this period. The second study presents a comprehensive chronological database for the southern African MSA, documenting over 1,840 absolute ages associated with archaeological assemblages. This database enables the exploration of spatial-temporal patterns and reveals significant research gaps that limit exploration of population dynamics, environmental interaction and technological trends. The third study begins to fill in some of these spatial gaps through the first luminescence dating project in a Mozambiquan archaeological site. The 20 newly dated luminescence and Radiocarbon samples from Daimane Rock Shelter II provide insights into site formation processes and highlight the necessity of engaging with complex chronologies. The final study employs artificial intelligence as a visualisation tool to reimagine MSA environments and people, demonstrating how novel approaches can enhance our understanding and communication of sites with limited visual representation. Collectively, these studies demonstrate the value of multi-scalar approaches in addressing questions which have long characterised MSA research as well as exploring where future research needs to go in order to obtain a fuller more complete picture of the human past.

Acknowledgements

Archaeology is storytelling—piecing together lives from fragments that survive countless unseen processes. As I complete this thesis, I'm struck by how little we know of past lives, yet how many people have profoundly shaped mine. This thesis's story ends in St John's College library where reflect gratefully on the Oxford community. I am thankful for Christopher Ramseys bi-weekly meetings and ongoing input into developing this thesis and database, and co-supervisor's Peter Mitchells valuable insights into the southern African archaeological landscape. Dr Jean-Luc Schwenninger, for your guidance and support for the luminescence dating. Decio Muianga for generously sharing your archaeological site, research and insights.

My friends, Henrique Aguiar, who taught me to stay curious and ask unexpected questions; Razia Chowdhry, whose resilience inspires me daily; Yusra Shammoon, whose morning walks and adventures reminded me to embrace this incredible city, Jannus Estoesta for always pushing my creativity, Jonathan Lim for sharing in my enthusiasm for pretty maps and archaeological visualisation and Michael Leadbetter, from pandemic writing group to lifelong friend, whose thoughtfulness now threads through all my work and enabled this thesis from pushing me to engage with archaeological theory to helping test the AI protocol.

My journey, however, did not begin in Oxford. In 2014, a last-minute decision to enrol in a BSc in Geographical and Archaeological Sciences at the University of Witwatersrand transformed my world in ways I will never fully appreciate. Though I didn't initially research the MSA, friends like Mpumi Maringa shared her experiences that made this thesis possible. Her kindness is representative of the South African archaeological community generously offered publications and wisdom when I needed them most. While Alex Schoeman, whose ongoing support, has taught me how to be a better archaeologist.

Within the first few weeks of joining Wits, I met Mary Evans, then a lecturer in geology, who mentioned she ran Wits' luminescence dating lab. She offered to train interested students as a lab technician in her lab. Over the next four years, Mary trained and mentored me. She supported me as a supervisor in my honours and encouraged me to continue my academic journey. Mary started this journey with me, and when she realised, I was struggling to cross the finish line, mentored and guided me through the end of this thesis. I can never overstate my gratitude for her support and friendship.

My mother, Toni Birin, raised me to be inquisitive, ambitious and thoughtful. Without her I would not be who I am, nor would this endeavour be possible. My father, Jonathan Birin's, unwavering belief in me, grit and drive has pushed me forward through this challenge. And finally, to my husband, Benjamin Burman, we began this adventure not knowing where it would lead us, yet through it all, your support, kindness, compassion and understanding keep me grounded while enabling me to fly.

Thank you.

“I can, I will, I must”

Thuso Magonya (1994-2017)

Thesis outputs and authorship contributions

This thesis has produced four co-authored publications ready for journal submission. All papers conform to a standardised referencing system to enable easier assessment and thesis consistency. Some papers have been altered to reference each other as Chapter 2, Chapter 3, Chapter 4 and Chapter 5. In the journal format this will be become standardised in-text references. I am the first author on all four papers and wrote all the text, conducted all data analysis and created all unreferenced images. Co-authors primarily aided in methodological development, proof-reading and providing raw data.

Chapter 2:

Birin, R-A. & Evans, M., in prep. Taking time: Reviewing half a century of southern African Middle Stone Age dating. Unpublished manuscript.

Ruby-Anne Birin led the study, undertook the literature review, sourced all relevant publications, designed the visualisations, and wrote the manuscript. Mary Evans verified the historical accuracy of the review, contributed contextual insights as a South Africa-based researcher, and critically reviewed the manuscript for factual and stylistic accuracy.

Chapter 3:

Birin, R-A. & Evans, M., in prep. A Southern African Middle Stone Age Chronological database. Unpublished manuscript and database.

Ruby-Anne Birin compiled the chronological database, implemented all quality-control procedures, produced the visualisations, and wrote the manuscript. Mary Evans contributed expertise in luminescence dating, provided guidance on appropriate data inclusion criteria, and reviewed the manuscript.

Chapter 4:

Birin, R-A, Muianga, D., Schwenninger, J-L., Evans, M. Dating Diamane II: chronological explorations of a Mozambiquan rock shelter. Unpublished manuscript.

Ruby-Anne Birin conducted all luminescence and radiocarbon dating, developed the stratigraphic interpretation, and wrote the manuscript. Decio Muianga excavated the site, contributed contextual information derived from his doctoral research on phytoliths and aDNA, and analysed the lithic assemblage. Jean-Luc Schwenninger provided specialist guidance on the execution, analysis, and interpretation of luminescence measurements. Mary Evans contributed to discussions concerning bioturbation and site-formation processes in the southern African context. All authors reviewed the manuscript for factual accuracy and stylistic clarity.

Chapter 5:

Birin, R-A. & Evans, M., in prep. Reimagining the Stone Age: AI-Powered Archaeological Visualisation. Unpublished manuscript.

Ruby-Anne Birin developed the methodological framework, authored all AI prompts, generated and selected the visual outputs, and wrote and edited the manuscript. Mary Evans provided guidance on methodological development, including testing and evaluation of the AI-based procedures.

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List of Abbreviations

AAR	Amino Acid Racemisation
AMS	Accelerator Mass Spectrometry
ESA	Early Stone Age
ESR	Electron Spin Resonance
HP	Howiesons Poort
ICP-MS	Electron Spin Resonance with Inductively Coupled Plasma Mass Spectrometry
IRSL	Infrared Stimulated Luminescence
IRSL DRC	Infrared Stimulated Luminescence using Dose Response Curve
IRSL H&L	Infrared Stimulated Luminescence using Huntley & Lamothe method
IRSL-IR50	Infrared Stimulated Luminescence at 50°C
LM-OSL	Linearly Modulated Optically Stimulated Luminescence
LSA	Later Stone Age
MSA	Middle Stone Age
OSL	Optically Stimulated Luminescence
OSL-SG	Single Grain Optically Stimulated Luminescence
pIR-IRSL	post-Infrared-Infrared Stimulated Luminescence
pIR-IRSL250	post-Infrared-Infrared Stimulated Luminescence at 250°C
pIR-IRSL290	post-Infrared-Infrared Stimulated Luminescence at 290°C
Post-HP	Post-Howiesons Poort
Pre-HP	Pre-Howiesons Poort
SB	Still Bay

SG TT-OSL	Single Grain Thermally Transferred-Optically Stimulated Luminescence
TL	Thermoluminescence
TT-OSL	Thermally Transferred-Optically Stimulated Luminescence
U-Pb	Uranium-Lead dating
U-series:	Uranium series dating
U-Th	Uranium-Thorium dating
US-ESR	Uranium-series Electron Spin Resonance

1. Introduction

The southern African Middle Stone Age (MSA) represents a pivotal period in human evolution, spanning approximately 300,000 to 30,000 years ago (Wadley, 2015; Wurz, 2014). This time frame coincides with the emergence and development of anatomically modern humans and significant cognitive advancements reflected in material culture (Christopher S. Henshilwood et al., 2002; Henshilwood et al., 2011b; Vanhaeren et al., 2019). However, as time passes, the resolution with which individual decisions and lived experiences can be discerned diminishes (Chirikure et al., 2012). In the absence of direct testimony or identifiable personal records, researchers rely on spatiotemporal associations of material cultural remains, geography (location) and chronology to infer the structure, dynamics, and lifestyles of past communities and cultural systems.

These spatiotemporal patterns are vital to understanding how people and communities responded to a changing landscape. Prior to the development and widespread application of absolute chronology, landscape and proposed technological industries (technocomplexes) dictated these patterns. With the advent of radiometric dating in the 1950s, understanding of timespans for this critical period of innovation expanded and the antiquity of African archaeology was established (Aitken, 1990; Aitken and Valladas, 1992; Vogel and Beaumont, 1972; Wilkins, 2020). Subsequent chronological, isotopic and computational innovations aided archaeologists in better visualising, interpreting and communicating across different spatial and temporal scales. This thesis examines how advances in developing and interpreting archeologically associated chronologies continue to influence our understanding of humanity while bringing new approaches to old questions.

1.1. Background

The southern African Middle Stone Age (MSA) in Sub-Saharan Africa is typically described as a period of technological diversity, innovation and emergent symbolism (Wadley, 2015; Wurz, 2014). This period coincides with the emergence and development of anatomically modern humans and significant cognitive advancements reflected in material culture (Henshilwood et al., 2002; Wadley, 2015). This period of diversification and complexity has elements of the Earlier Stone Age (ESA) and Later Stone Age (LSA). The MSA's shifts in tool manufacturing techniques and technological diversity opens the potential to explore spatial and temporal trends (Barham and Mitchell, 2008). The terminology originally proposed for these trends dates to amateur collectors and selective collection pressures (Goodwin et al., 1929). In the absence of numeric (absolute) dating, technocomplexes or named stone tool industries (NASTIES) played an important role in linking, comparing, and identifying patterns through time; however, with the advent of absolute dating, the validity of these grouped trends as chrono-markers has increasingly been questioned (Shea, 2019; Wilkins, 2020).

Prior to the advent of radiocarbon dating, understanding the MSA's chronology was particularly challenging to explore. Typically, archaeological sites were chronologically linked through technocomplexes (i.e. stone tool industries). On a macro scale this includes the Earlier Stone Age (ESA) or Palaeolithic (>300 ka), characterised by relatively uniform stone tools across continents, with Large Cutting Tools (LCTs), the Middle Stone Age (MSA) or Mesolithic (300-30 ka), associated with flake and prepared core technology, and the Later Stone Age (LSA) or Neolithic (<30 ka), noted for its microliths and composite tools. The southern African MSA's regionally specific sub-industries, such as the Still Bay (characterised by bifacial points) and the Howiesons Poort (known for backed tools and advanced blade technology) were amongst the earliest ways of chronologically linking archaeological sites

(see: Goodwin, 1929). These industries draw significant research attention as they contain early evidence of symbolic behaviour and complex tool manufacturing (Archer et al., 2016; de la Peña, 2020). Even after the advent of radiocarbon dating, absolute ages linked to tool industries remained a tempting way to treat technocomplexes (stone tool industries) as time-horizon markers. However, the uncritical use of technocomplexes as marker horizons imply that when a new tool manufacturing process becomes adopted, the other is completely abandoned.

In an attempt to circumvent the bounded temporal, technological and cultural assumptions associated with ESA, MSA and LSA , Clark (1969) created an alternative five Mode system to describe lithic types (Barham and Mitchell, 2008). Instead of chronologically and spatially defined industries, modes are categorizing stone tools based on manufacturing techniques: Mode 1 (simple core and flake technologies), Mode 2 (handaxes and bifacially worked tools), Mode 3 (prepared core technologies such as Levallois), Mode 4 (blade technologies), and Mode 5 (microliths and composite tools). Unlike the ESA-MSA-LSA system, which implies sequential replacement of technologies, the Mode system acknowledges that multiple tool types can coexist within the same period or even be employed by the same communities. For example, an individual living in the peak of the MSA can use both Mode 1 and Mode 3 technology. This method also affords large scale site comparison without national naming conventions, something that geographically bounded subdivisions, do not.

The restrictions of traditional classification systems for visualising chronological change become further apparent when examining specific sites. For instance, Saxonomunya, Senegal, demonstrates the complexity of understanding the occurrence of different tool types across both large and small scales. At Saxonomunya, MSA-like assemblage's date to 11 ka, concurrent with LSA sites in neighbouring valleys. This contemporaneity indicates strong cultural choices and importance of chronology independent of technocomplex (Scerri et al., 2021). Similarly,

at Daimane II, Mozambique, lithic classifications do not fall neatly into LSA and MSA categorisations, which increases the necessity for an independent absolute chronology (Muianga, 2025). Clearly, in order to address such inter-, and intra-site complexity, multiple scales and different chronological and technological methodologies are required to avoid drawing overly simplified scenarios (Thomas and Burrough, 2012). Wilkins (2020) argued in order to address this complexity there is a need to develop chronologically based datasets which can be used to visualise changes in specific lithic innovation.

Looking beyond southern Africa provides potential applications of chronological databases for addressing these challenges. In eastern Africa, Blinkhorn and Grove (2018) developed a database to examine technological clusters in relation to geographic, climatic and temporal clusters without weighted technocomplexes. The findings indicate both patterns of diversification and periods of stability and continuity. The authors argue that "only with a comprehensive data[set] of this kind can we begin to link archaeological patterns with potential abiotic causes" (Blinkhorn and Grove, 2018, p. 19). While the potential for a chronological database independent of technocomplexes is promising, discarding technocomplexes must come with some caution as it can make comparisons with older literature overly complicated and lead to only sites with more complete reporting systems garnering attention. Chazan (2015) suggested a theoretical middle ground – whereby technocomplex may mean different things for different proposed industries. For example, Chazan (2015) argued that technocomplexes like the Howiesons Poort (HP) may be a known entity of packaged tools, the Still Bay (SB) may need to refer to something looser than the Howiesons Poort but still a signifier of a change in human behaviour, whereas the Fauresmith may simply imply increased diversity in the type of stone tool production.

This research critically engages with the use of technocomplexes as temporal markers in the study of the southern African MSA, acknowledging their limitations and the current lack of comprehensive lithic datasets. While retaining technocomplexes as an exploratory framework to bridge archival and contemporary research, the thesis simultaneously seeks to advance methodological approaches by developing a robust database (as presented in Chapter 3) to enhance the applicability of absolute chronologies (as in Chapter 4). This dual approach enables both small- and large-scale analytical investigations that are less reliant on typological classification systems.

1.2. Rationale

Southern African Middle Stone Age chronological research primarily focuses on the MSA's technological and symbolic innovations (Wadley, 2015). This includes identifying an artefact category's first or last occurrence, temporally constraining a trend, or understanding questions relating to human-environment relationships. These applications are evident in chronological work dating engraved ochre to ~77 ka, shell beads to 75.6 ± 3.4 ka and the ongoing attempts to temporally constrain engraved ostrich egg shell (OES) at Diepkloof and Klipdrift (Assefa et al., 2018; Henshilwood et al., 2004; Christopher S. Henshilwood et al., 2002). It is the use of these chronologies, however, that enables more complex questions. Constraining technological trends was notably advanced by Jacobs and Roberts (2008), who examined the HP and SB to understand the spatial and temporal spread of these technological clusters. More complex questions relating to human-environmental interaction or the migration of people and cultural behaviours across the landscape involve correlating chronological data with other types of archaeological and environmental information (Basell, 2008; Blome et al., 2012; Chan et al., 2019; Maslin et al., 2014; Stewart and Stringer, 2012).

These phenomena, the occurrence of new technologies, their spread, and individual community responses to change, are visible at different spatial and temporal scales (Bailey, 2007). A single piece of ochre, visible in a specific stratigraphic layer at a precise moment in time, speaks to individual creativity but may not be visible within a large-scale investigation of migration patterns. In contrast, the widespread adoption of ostrich eggshell beads or backed pieces could indicate cultural exchange or population movement at regional scales while remaining invisible at the individual level (Miller and Wang, 2022). Exploring both macro and micro spatial-temporal scales enables archaeologists to grapple with complex archaeological data across multiple dimensions (Kandel et al., 2016).

Despite the potential of using chronology to spatially link sites and understand cultural change, no accessible chronological database or framework exists to correlate these data or explore phenomena at different spatial and regional scales. While previous efforts to document the South African MSA chronology exist, these focus on constraining the archaeological sequence rather than untangling what these ages mean or how they can be applied to broader questions (Lombard et al., 2022, 2012). This lack of a comprehensive chronological framework limits researchers' ability to move beyond asking about "firsts" to addressing more profound questions about patterns and variations in human behaviour across time and space.

This thesis addresses this gap by developing a multi-scalar approach to visualising MSA chronology that enables temporal patterns to be examined at continental, regional and site-specific scales. Through creating a comprehensive chronological database, investigating underrepresented regions, and developing novel visualization techniques, this research provides the methodological foundations needed to correlate sites across southern Africa and understand the complex interplay between technological innovation, human mobility, and environmental change during this pivotal period in human cognitive and cultural evolution.

1.3. Aims and objectives

This thesis aims to explore how different methodological approaches, across nested spatial and temporal scales, can enable us to better visualise the chronology of the southern African MSA.

Objective 1: Critically evaluate the historical development of southern African MSA chronology to identify and address inherent biases in current frameworks.

Objective 2: Develop a comprehensive database that enables archaeologists to explore spatial-temporal trends across southern Africa from 300 ka to 30 ka, facilitating multi-scale analysis of technological and behavioural patterns.

Objective 3: Contribute to the paucity of chronological research in Mozambique by constraining the timing of Diamane II, a MSA site in Mozambique.

Objective 4: Implement novel AI visualization technologies to represent previously under-represented archaeological contexts, improving the accessibility and interpretation of complex spatial-temporal data.

Starting at a larger scale these objectives progressively zoom into increasingly small regional and temporal scales. By starting with critically examining the historiographical background of southern African chronologies the biases and research gaps pertaining to this period are identified. This subsequently supports the development of a new chronological database, stresses the importance of filling in understudied regions and finally enables the representation of findings for both specialist and non-specialist audiences.

1.4. Overview of Methodology

1.4.1. Spatial and temporal scope of research

This thesis examines the southern African Middle Stone Age, and to a lesser extent Later Stone Age, across three progressively focussed spatial-temporal scales (Figure 1.1). This macro to micro approach enables the systematic engagement of similar archaeological questions across different spatial and temporal contexts. This multi-scalar approach utilises Bailey (2007) concept of 'time perspectivism' whereby we can perceive different phenomena through utilising varied temporal resolutions.

Figure 1.1: Map of research area including sites mentioned in Chapter 4 (Daimane) and Chapter 5 (Border Cave, Blombos Rock Shelter and the Kalahari Desert)

Starting at a large scale and zooming in, Chapter 2 and Chapter 3 encompass a macro-regional scale, encompassing southern Africa– Namibia, Botswana, Zimbabwe, Mozambique, eSwatini, Lesotho, and South Africa (Figure 1.1). Chronologically, these papers span 300 ka–30 ka, with Chapter 2 also incorporating historiographical analysis of archaeological research over the past fifty years. Chapter 4 narrows the focus to Mozambique's Middle and Later Stone Age chronologies. This intermediate scale begins with a country-wide assessment before concentrating on developing a chronology for a single site, Daimane II. Finally, Chapter 5 adopts a micro-scale approach, examining specific moments and contexts within three South African archaeological sites. The visualization technique particularly engages discussion on how to make momentary events in deep time conceptually accessible (Bailey, 2007). This nested approach from regional to site specific to episodic frames the different spatial-temporal visualisations discussed across this thesis.

1.4.2. Visualisation tools

This thesis employs a suite of graphical visualization tools to represent spatial-temporal data effectively across multiple scales. ArcGIS Online (https://www.arcgis.com/index.html) serves as the primary platform for all cartographic visualizations throughout the thesis, enabling the integration of chronological data with spatial information. Statistical analysis and graphical representations were generated through RStudio v4.4.2, utilizing libraries including base *stats*, *dplyr* (Wickham et al., 2023) and *tidyr* (Wickham et al., 2014) for statistical analysis, data manipulation and data transformation, and *ggplot2* (Wickham, 2016) for creating data-driven visualizations. Claude AI (www.claude.ai) v3.7 Sonnet and v.5 Haiku was utilised as an assistant for writing statistical code and data visualization scripts. Midjourney (https://www.midjourney.com/) and DALL-E 3 via Bing image generator

(http://www.bing.com/images/create) were used to generate AI visualisations presented in Chapter 5.

All maps, graphs, images and hand-drawn infographics underwent final refinement and digitisation in Adobe Illustrator to ensure visual consistency, enhance clarity, and presentation. This multi-stage visualization workflow facilitated the translation of complex spatial-temporal patterns into accessible visual formats that effectively communicate the research findings across the different scales of analysis presented in this thesis.

1.4.3. Dating techniques

The chronological tools available to understand technological change across time have expanded significantly since the advent of radiocarbon dating. Absolute dating methodologies applicable to the Middle Stone Age include, uranium-series (U-series), Electron Spin Resonance (ESR), Amino Acid Racemisation (AAR), radiocarbon dating and luminescence techniques (Figure 1.2) (Aitken, 1990). This thesis uses these techniques and their derived ages as a way to chronologically understand the history of the southern African MSA as well as explore new ways chronology can help us answer complex questions pertaining to our past.

While each of these techniques contributes to our gaps in understanding archaeological sites' chronology, no absolute dating technique is a perfect solution. Rather, each methodology, and the associated dated materials, provides differing resolution, precision and interpretation. Even within a shared methodological system, the information provided may necessitate different interpretations. For example, Optically Stimulated Luminescence (OSL) dates when quartz grains are buried, which provides a depositional information; in contrast, Thermoluminescence (TL) dates when an artefact was heated above 300°C, potentially providing a manufacturing age for heated flint (Aitken, 1998; Richter, 2007; Valladas et al., 2005; Zimmerman, 1971). Within radiocarbon dating, the object dated is typically the age at which the dated material

died. This however is complicated by inorganic carbon (e.g. speleothems) as these materials can incorporate older dissolved inorganic carbon or undergo post-depositional alteration (Bird et al., 2014, 2003). Meanwhile, organic and inorganic remains from coastal sites are susceptible to the marine reservoir effects (Dewar et al., 2012). Additionally, each methodology provides differing temporal scale through precision – how large or small the error margins, accuracy – how close the resulting date is to the true age, and interpretation – what does the age mean (Jacobs et al., 2008a; Loftus et al., 2019; Lombard et al., 2022, 2012; Mac kay et al., 2014).

While this methodological divide, and the errors associated errors with each derived date, complicates our ability to synchronize regional cultural sequences and understand population movements across landscapes (Chapter 3), through purposefully utilising a multimethod approach archaeologists have the potential understand complex site formation processes (Chapter 4). However, as radiocarbon dating and luminescence dating are referred to throughout the thesis, their methodologies, and the implications of them, is discussed in greater depth below.

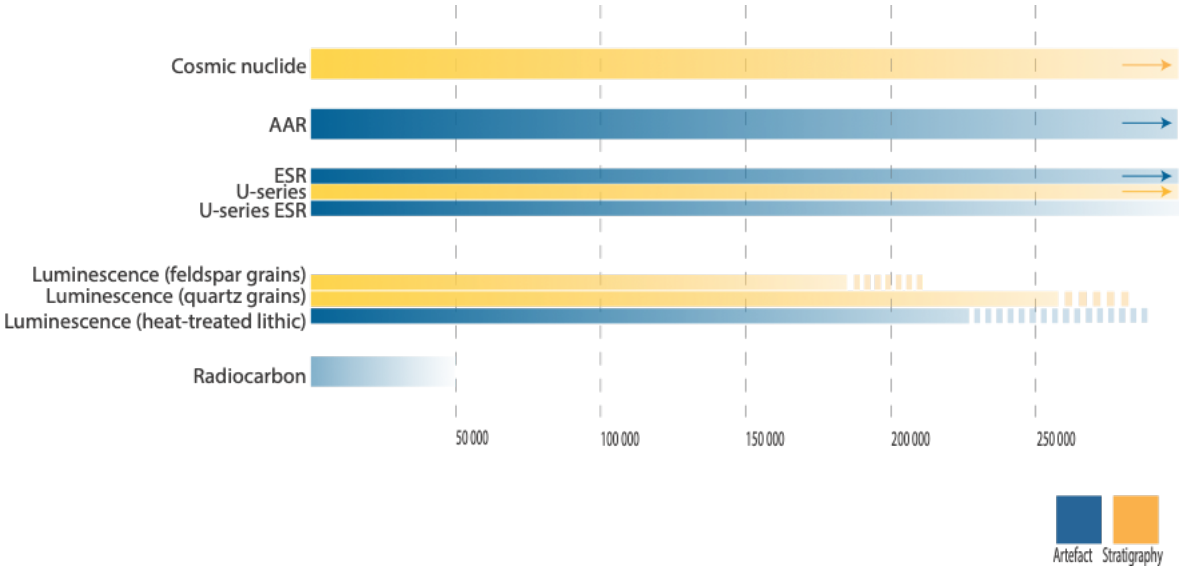


Figure 1.2: Dating techniques applicable to the MSA

Radiocarbon dating

Radiocarbon dating is amongst the most accurate and most popular dating techniques for dating the last 50,000 years. This technique measures the amount of remaining radiocarbon within an organic sample. Radioactive carbon is formed when cosmic rays provide enough energy for a neutron to attach to Nitrogen-14 (^{14}N). Over time ^{14}C loses a proton and converts back to ^{14}N (Figure 1.3).

In all living organisms, as ^{14}C decays, it is replenished through the carbon cycle (e.g., breathing, eating, photosynthesis). Once the organism dies, the radioactive element cannot be replenished and the amount of radiocarbon within the remains begins to decline. Any date obtained from these remains is the date of death of the organism, and not the date of use or deposition. This cycle reveals how the complex interaction between cosmic radiation, atmospheric chemistry, and biological processes creates an important tool for temporal investigations (Figure 1.3).

Radiocarbon decays with a known half-life of 5,730 ± 40 years. Alfred Libby's 1946 measurements slightly underestimated this value, reporting a half-life of 5,568 ± 30 years. In order to maintain consistency with legacy radiocarbon dates the older, Libby half-life is used. After approximately 8 or 9 half-lives, at around 50 000 years, the amount of carbon left is too small to measure, this is considered the upper limit of radiocarbon dating (Loftus, 2023; Wright, 2017a). This timeline places radiocarbon dating at a critical juncture for southern African MSA research, encompassing the later phases but requiring alternative techniques for earlier periods. The implications of this upper limit for understanding human migration and population dynamics in southern Africa is explored in Chapter 2.

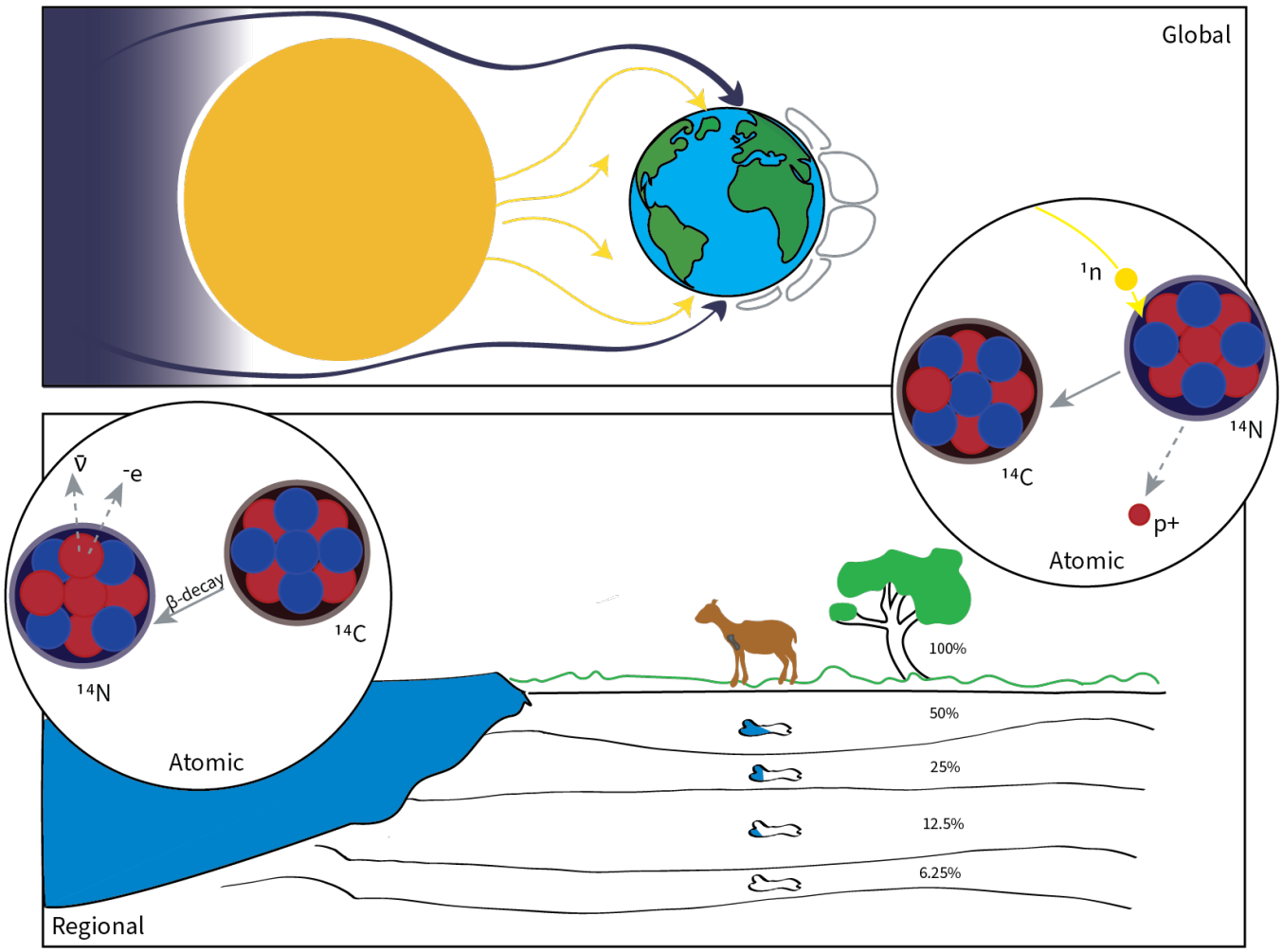


Figure 1.3: The radiocarbon cycle, (top panel) depicts solar radiation interacting with the earth, (bottom panel) depicts uptake through photosynthesis and diet, death and subsequent radioactive decay, (circle right) the collision of protons and Nitrogen, (circle left) the decay of radiocarbon to stable nitrogen

The closer we reach radiocarbon dating's upper boundary the greater the uncertainties and the more opportunity for a less accurate age (Wright, 2017a). This uncertainty breaks down into three main areas, atomic, atmospheric and anthropogenic. (i) Atomic scale: because of the small amounts of ^{14}C left in a sample, in small, old samples like the ones associated with the southern African MSA, measuring the amount of radiocarbon is difficult and less accurate. This makes proper sample selection vital for obtaining an accurate age. (ii) Atmospheric variations: the issue of old dates is compounded by the fluctuation in the amount of radiocarbon through time (Anderson and Libby, 1951; Ramsey, 2008). The amount of radiocarbon within the atmosphere, and thereby within all living organisms, is affected by cosmic weather influencing its

production. Calibration allows correction for fluctuations in ^{14}C. (iii) Anthropogenic contamination: conservation and storage treatments or handling can heavily influence samples with little ^{14}C remaining in them, leading to erroneously young ages where even minor contamination can significantly skew results in older samples towards the present (Higham, 2011).

Radiocarbon Measurement Techniques

Obtaining a radiocarbon date involves measuring the amount of ^{14}C left in the bone, charcoal, or other organic remains relative to the amount of stable carbon isotope. Before any radiocarbon measurement takes place, careful sample selection and pretreatment is required. In order to remove contaminants need to be removed from the sample which is then turned into graphite. For charcoal this includes acid-base-acid (ABA) and Acid-Base-Oxidation (ABOx). ABOx, in particular is effective at removing contaminants otherwise missed by traditional acid-base-acid (ABA) treatments, this enables reliable dates from contaminated samples or samples close to the radiocarbon limit (Bird et al., 2014; Higham, 2011; Wood et al., 2012). Similarly, ultrafiltration for bone collagen represents removes contamination from old bone samples. This technique separates high molecular weight collagen (>30 ka) from degraded collagen and other contaminants, resulting in more accurate dates (Brock et al., 2010; Higham, 2011). The implementation of these more aggressive pretreatment methods has significantly pushed back chronologies at Mesolithic sites in Europe (Devièse et al., 2021; Higham et al., 2014). However, both ABOx and ultrafiltration are more time consuming than traditional treatments and require good charcoal or collagen preservation.

Once pretreated and converted to graphite (pure carbon), the sample is measured (Chapter 4.3.1). Two main mechanisms exist for radiocarbon measurement: Beta-counting and the newer, more accurate Atomic Mass Spectrometry (AMS) – the measurement technique used in

Chapter 4. The shift to AMS methodology has enabled dating of much smaller samples—crucial for precious archaeological materials from poor preservation contexts or older periods (Brock et al., 2010; Wood, 2015). For Chapter 4, charcoal was specifically selected for radiocarbon dating instead of bone due to concerns surrounding collagen preservation in the Mozambique rock shelter environment. The high humidity and acidic soil conditions in the region severely impact collagen preservation, making charcoal a more reliable material for obtaining accurate chronometric data in this specific geographical context (Wright, 2017; Wood pers comm, 2023).

Radiocarbon calibration and its influences

Once the radiocarbon age is measured, this age needs calibration to account for, (i) the changing amount of radiocarbon in the atmosphere caused by solar activity and the Earth's magnetic field, (ii) hemispheric differences due to the Southern Hemisphere's larger oceans, along with limited atmospheric mixing, and (iii) variation in carbon owing to regional carbon sinks (Hogg et al., 2020; Loftus, 2023; Wright, 2017a). As a result, several calibration curves exist to account for these differences. These curves can be globally relevant (e.g., IntCal20) or regionally specific (e.g., SHCal20) (Hogg et al., 2020a). The SHCal20 is used throughout this thesis as it incorporates southern hemisphere carbon reservoirs and atmospheric circulation patterns that differ from the northern hemisphere, providing more accurate calibrations for southern African samples.

Software like OxCal is capable of seamlessly converting radiocarbon dates with the chosen calibration curve (Bronk Ramsey, 1995; Ramsey et al., 2010). The derived ages are usually presented within 95% probability ranges (2σ). Within OxCal, precision can also be increased through running a Bayesian model which combines ages with additional knowledge, e.g.,

stratigraphy or additional ages from previous projects of different dating techniques. This modelling can increase accuracy up to the 50,000-year radiocarbon limit.

Luminescence dating

Luminescence dating is the most dominant set of techniques for the southern African Middle Stone Age (Chapter 3). While several different minerals and luminescence methods exist (Table 1.1), all luminescence dating follows similar principles. These methods measure when quartz or feldspar grains, or a heat-treated artifact (e.g., heat-treated lithic), was last exposed to light or heat. Optically Stimulated Luminescence (OSL), the most frequently employed luminescence dating technique, uses quartz grains and in ideal situations can date archaeological sites to approximately 300 ka; meanwhile, other luminescence techniques, primarily using feldspar grains, have the potential to reach 1 000 ka (Aitken, 1990; Tribolo, 2023).

When a quartz or feldspar grain is exposed to light or heat, electrons are excited from the valence band to the conduction band and the grain loses its charge (Aitken, 1989; Duller, 2008). While most electrons quickly return to the valence band, some become trapped in defects within the crystal lattice - vacancies, or impurities that create energy states within the band gap. This process is referred to as bleaching. The grain is then buried. During this burial period, ionizing radiation (U, Th, K, Rb) and cosmic rays, the environmental dose rate (Gy. ka^{-1}), continuously excite electrons from the valence band to the conduction band, and these electrons become trapped in crystal defects (Durcan et al., 2015; Erfurt et al., 2003; Lapp et al., 2012; Vogel et al., 1999).

The lab measurement, the equivalent dose (Gy), measures the energy/light emitted from the electrons trapped within these defects. The age of last exposure to light or heat is calculated by

dividing the equivalent dose by the environmental dose rate (Equation 1.1) (Aitken, 1997; Roberts et al., 2015):

$$Age\ (ka) = \frac{Equivalent\ Dose\ (Gy)}{Environmental\ Dose\ Rate\ (Gy.ka^{-1})} \qquad \text{(Equation 1.1)}$$

Bleaching, dose accumulation and measurement can be analogous with a battery (Figure 1.3). When a grain is exposed to light or heat (is bleached), the battery loses charge. The accumulation of trapped electrons (dose) from the surrounding radiation (environmental dose rate) is recharging the battery. The measurement is, therefore, how much time has passed in order to accumulate the dose. However, it is important to note that, if the battery is fully charged (saturated – i.e. all the measured traps are filled), only a minimum age can be derived.

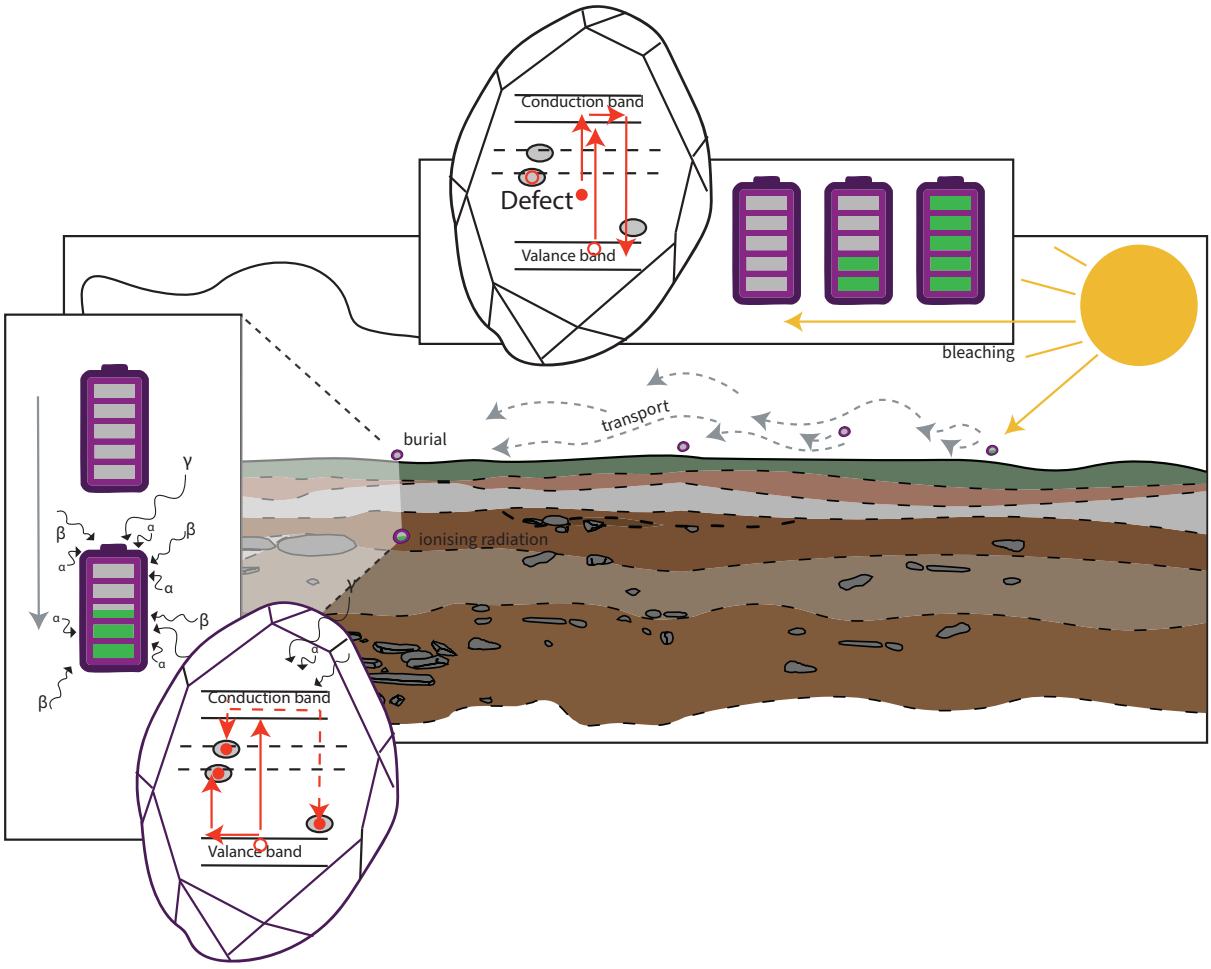


Figure 1.3: Quartz grains exposed to sunlight are bleached, transported and then buried. Once buried, the surrounding alpha, beta, gamma and cosmic rays (dose rate) then enable the grain to accumulate charge.

Within quartz, saturation occurs much faster than with feldspar. This makes feldspar a more likely dosimeter for obtaining accurate ages for older sites. However, it is important to note that while quartz traps are stable, some feldspar traps undergo anomalous fading once they are removed from their burial context. Therefore, for more traditional feldspar luminescence measurements [e.g. thermoluminescence (TL), or Infrared Stimulated Luminescence (IRSL)] further calculations are needed to accommodate the amount of charge lost between sampling and measurement. In addition to adjusting for this fading, luminescence specialists are exploring more stable feldspar traps through innovative techniques like pIR-IRSL, VSL and IR-RF (Table 1.1).

Table 1.1: Different equivalent dose measurement techniques

Luminescence technique	**Sample**	**Age range**	**Notes**
Optically Stimulated Luminescence (OSL) (Aitken, 1990; Murray and Wintle, 2003; Wintle and Murray, 2006)	Quartz	~100-150 ka (up to 300 ka in optimal conditions; upper limit depends on the individual grain's saturation and environmental dose rate)	Most widely used technique in the southern African MSA. The signal resets quickly with sunlight exposure.
Single Grain Optically Stimulated Luminescence (SG-OSL) (Jacobs and Roberts, 2007)	Quartz	~100-150 ka	Measurement of individual quartz grains, this is good for understanding mixed sediment populations. This technique, popularised in southern Africa by Jacobs and Roberts (2008, 2015) is useful for detecting partial bleaching and post-depositional mixing.
Thermoluminescence (TL) (Aitken, 1982; Furetta, 2010)	Quartz, Feldspar, lithics	~300-500 ka	Feldspar is known to fade presenting problems for dating the true age depth. The signal is harder to reset than OSL signals, however, once removed from the depositional context feldspar is known to fade. This technique is used extensively at heat-treated lithics at Blombos Cave, Diepkloof and Klasies River Cave (Tribolo et al., 2013, 2006).
Infrared Stimulated Luminescence (IRSL) (Erfurt and Krbetschek, 2003)	Feldspar	~100-200 ka	Feldspar is known to fade presenting problems for dating the true age depth and ages therefore require additional corrections. While less popular than many other luminescence techniques it has been applied successfully at

			Bushman Rock Shelter and Wonderkrater (Barré et al., 2012; Porraz et al., 2018)
Post-IR IRSL (Colarossi et al., 2015; Li et al., 2014; Thomsen et al., 2008)	Feldspar	~200-500 ka	Measurement of more stable feldspar traps leading to increased accuracy. This technique has been applied at interior South African sites including Mwulu Cave (Feathers et al., 2020).
Single Grain post-IR IRSL (Trauerstein et al., 2012)	Feldspar	~200-500 ka	Measurement of individual feldspar grains using post-IR IRSL protocols. Allows for detection of anomalous fading and partial bleaching at the single grain level, combining the benefits of both single grain analysis and the more stable post-IR IRSL signal.
Violet Stimulated Luminescence (VSL) (Ankjærgaard et al., 2013)	Quartz	~400-500 ka	Targets deeper, more stable electron traps in quartz. While this technique offers potential to date older sites, it is yet to be applied to a southern African archaeological context.
Infrared Radiofluorescence (IR-RF) (Frouin et al., 2015)	Feldspar	~300- 1 000 ka	Measures radiofluorescence during irradiation. Not affected by anomalous fading, and therefore has potential for older dates. While applied in eastern African contexts, in southern Africa this technique has only been applied in an unpublished master's thesis (Birin, 2018).

i) Field Sampling and laboratory measurement

Given the light-sensitive nature of the luminescence signal and the need to accurately measure both accumulated radiation and environmental dose rates, specialized protocols have been developed for sample collection and analysis. When conducting luminescence sampling and measurements, to prevent accidently bleaching, it is important that samples are not exposed to white light (Aitken, 1989; Frouin et al., 2015). First, sediment samples are extracted from stratigraphic sequences using light safe tubes. These tubes are then transported to a laboratory where, under red or orange light conditions, the quartz and/or feldspar grains are removed through a combination of mechanical and chemical techniques (Duller, 2008). Once the grains are extracted, two further measurements take place: (a) Environmental Dose Rate and (b) Equivalent Dose (see Chapter 4 for further details on sample preparation).

Environmental Dose Rate

Ideally, the environmental dose rate, which provides the radiometric information required to calculate the rate at which the dose accumulated, is measured *in situ* by inserting portable dosimeters into the stratigraphic sequence. This approach accommodates for any additional radiation from large rocks or bedrock below. However, when this is not possible (e.g., availability of equipment), unprocessed sediment samples, extracted during sampling, undergo laboratory-based gamma spectrometry, alpha and beta counting. Assumptions about the depositional environment can later be modelled using specialised software (see: Durcan et al., 2015). Regardless of dosimetry method, the measurements are then combined with the cosmic dose derived from site geographic location (latitude, longitude, altitude) and sample depth. For heated materials like heat-treated lithics, the internal dose rate may also need to be considered (Tribolo et al., 2009). The subsequent environmental dose rate calculation also accounts for

water content. In most cases this is considered constant although modelling for variation through time is possible.

Equivalent Dose

The second component of luminescence dating is measuring the equivalent dose (the amount of charge within a grain or grain population). The standard procedure for doing this is the single aliquot regenerative (SAR) protocol (Murray and Wintle, 2003, 2000; Wintle and Murray, 2006). First, the equivalent dose is measured by exposing grains with light or heat and measuring the amount of charge released from the sample. The sample is then bleached. The sample is sequentially irradiated with different amounts of light or heat and bleached. This measurement process creates a dose-response curve which the original measurement can be plotted onto. This enables the calculation of the equivalent dose, the predicted amount of charge within the sample at the time of collection. Once the equivalent dose is measured, the overdispersion, amount of scatter within the grain calculation, is also reported. Through understanding this scatter, and the contextual burial information, an appropriate age model can be determined.

Luminescence age models

Luminescence derived ages, unlike radiocarbon ages, do not require calibration. Instead, different statistical models are used to obtain an accurate age (Mahan et al., 2022). Chapter 4 uses three models for age determination. These include the Central Age Model (CAM) is which presents an overall average of the grain population of a well-bleached sample. The MAM is useful for samples with a >20% overdispersion (scatter within the grain population) and can provide a minimum age, or *terminus post quem*, to samples which have a mixed sediment population, while the Finite Mixture Models (FMM) provides information about age clusters within a mixed or poorly bleached sediment population. While these age clusters are powerful

for understanding sedimentary movement, these results can further complicate site interpretation by removing otherwise visible trends. These different models help identify which grains in the population most accurately represent the burial age of the sampled sediment. The database presented in Chapter 3 preserves these models and documents their interpretation within the notes to ensure that archaeologists can accurately interpret these ages.

1.5. Structure of the thesis

This thesis comprises of an introduction, four papers written for submission to different academic journals, a discussion and conclusion chapter. References are collated at the end of the entire thesis. Supplementary information follows the individual chapters as would be the case in a published journal. The database developed in Chapter 3 is included as an additional document separate to the main thesis (Appendix A). It is important to note that "Taking time: Reviewing half a century of southern African Middle Stone Age Dating" (Chapter 2) and "A Southern African Middle Stone Age chronological database" (Chapter 3) were written concurrently and refer to each other. The thesis therefore follows the following structure:

Chapter 1 is a comprehensive introduction to the thesis, establishing the broader archaeological, chronological and methodological contexts that frame my research.

Chapter 2 is a critical literature review examining how South Africa's history and politics have influenced MSA chronology development. By examining the development and application of different techniques in this archaeological context, the paper establishes the importance and legacy dates when conducting spatial-temporal analysis. This includes analysing how dating practices have been influenced by research accessibility, apartheid legacies, and contemporary archaeological practices. This historical perspective reveals how methodological advances in

radiocarbon and luminescence dating have repeatedly transformed our understanding of human evolution in the region.

Chapter 3 documents all dates associated with an archaeological context within the southern African MSA. This new comprehensive database for the southern African MSA, integrates previously scattered chronological data into a unified spatial-temporal framework that reveals regional patterns and research gaps. This paper also introduces a mechanism to access the accuracy and precision of published dates, with an emphasis on quality control of luminescence ages. By integrating different chronometric methods in a single database, this paper provides a more holistic chronological framework for visualizing spatial-temporal patterns.

Chapter 4 presents a research paper directly dating an archaeological site in southern Mozambique, representing the first application of luminescence dating to this region. Using the Southern African Radiocarbon Database and the database developed in Chapter 3, I collate all previously determined MSA and LSA dates for Mozambique (Loftus et al., 2019). I subsequently date eleven charcoal samples and sixteen luminescence samples from Daimane II, Mozambique. Charcoal was specifically selected for radiocarbon dating as it is more likely to preserve radiocarbon in Mozambique's wet and humid climate, where collagen preservation in bone is problematic. This process successfully produces 20 newly dated samples that fill critical gaps in our understanding of the regional archaeological sequence. These new dates enhance our ability to visualize and interpret the spatial-temporal patterns within a single archaeological site, particularly highlighting how ages from different techniques contribute to understanding a site's depositional and post-depositional history. Though the resulting dates ultimately fell outside the MSA period, this work critically problematises the reliance on well-established and high preservation sites as representative of the broader southern African Stone Age archaeological record.

Chapter 5: Research paper exploring the application of artificial intelligence as a visualization tool for underrepresented MSA sites with important chronologies. This chapter demonstrates how computational approaches can enhance our understanding and communication of sites and people with limited visual representation.

Discussion and Conclusion: An integrative discussion and conclusion that draws together the findings from each chapter to presents how these tools can be used for future archaeological research.

2. Taking time: Reviewing half a century of southern African Middle Stone Age dating

The role of Africa in understanding human evolution and innovation underwent a profound transformation following the advent of absolute dating techniques. Prior to absolute dating, archaeologists relied on relative techniques and comparative collections. Relative dating techniques, based on stone tool assemblages which lacked absolute controls, enabled the perpetration of Eurocentric biases within the archaeological interpretation of the southern African Middle Stone Age (Vogel and Beaumont, 1972). These assumptions vastly underestimated the actual age of the African archaeological record. In the first chronometrically based review of the southern African MSA, Vogel and Beaumont (1972) disrupted our understanding of modern human origins by providing an infinite >48 ka age for Rose Cottage Cave. Consequently, rather than being perceived as the cultural recipients of novel technologies from further north, southern Africa became the focus for understanding the origins of the MSA culture and innovation. Meanwhile, the HP (HP) and SB (SB) technocomplexes, previously suggested as daughters of European innovation, became the forerunners for understanding early modern human innovation. However, the actual time depth of these technological advances remained obscured by radiocarbon dating's upper age limit.

An explosion of chronometric data and new dating techniques in the past 50 years has been instrumental in reforming our understanding of the southern African MSA. The development of techniques like luminescence dating, electron spin resonance (ESR), radiocarbon and uranium series dating have become vital in untangling the complex temporal trends of Africa's past between Marine Oxygen Isotope Stages (MIS) 7 and 2. These techniques are not just

tools, but the keys to unlocking the temporal relationships and complexities of innovation in our past.

This paper's review of the shifts in chronological applications to the southern African MSA will explore the history of dating in southern Africa, while discussing how archaeologists should address chronological questions in the future. While previous reviews of the history of African archaeology focused on an archaeological period (see: Wadley, 2015) or on papers from a specific journal (see: Mitchell et al., 2024), this paper explores the intersection of technological innovation and scientific inquiry through a targeted literature review of Middle Stone Age papers for which a chronology for a site are provided.

2.1. Methodology

This review explores the chronological papers and trends of the southern African Middle Stone Age from 1950-2022. Particular focus is given to 1972-2022, to mark 50 years since Vogel and Beaumont's (1972) seminal paper. The geographical scope includes South Africa, Namibia, Botswana, Zimbabwe, Mozambique, Lesotho, Zambia and eSwatini. The review process followed a systematic approach while allowing for narrative exploration of key developments and debates. The initial literature search utilised Google Scholar, Science Direct and SOLO. Primary search terms combined key words from three categories: temporal (MSA, Middle Stone Age, HP, SB), methodological (Luminescence dating, OSL, IRSL, TL, Radiocarbon Dating, Uranium-series dating, AAR, chronology) and geographic (southern Africa, South Africa, Namibia, Botswana, Zimbabwe, Mozambique, Zambia, Lesotho, eSwatini).

Both prior review articles (e.g. Mitchell, 2008) and papers producing novel dates (e.g., Jacobs et al., 2008) were included for discussion. The reference lists of key papers were systematically reviewed to identify any additional relevant publications and trace the historical development of dating applications in the region. Papers were excluded if they focussed solely on the

archaeological or environmental interpretations without chronological discussion. This snowball sampling proved useful for identifying older publications and grey literature not well indexed in digital databases (e.g. Google Scholar). Additional quantitative data (author, year, journal, university, laboratory location, dating methods) for papers presenting novel dates were extracted from the comprehensive southern African MSA chronological database presented in Chapter 3 of this thesis.

2.2. Scope of the Review

This review identified 36 articles with an explicit focus on the southern African MSA chronology. Through this comprehensive analysis, 88 sites were documented across the southern African region (Figure 2.1). Furthermore, 152 papers presenting primary chronometric data for the southern African MSA were extracted from the Southern African MSA Chronological Database for detailed historical analysis (Figure 2.2). Open air sites with MSA artefacts but lacking clear archaeological provenance were excluded from the review. The geographical distribution of research reveals pronounced regional imbalances, with South Africa dominating both site representation (66.7% of all documented sites) and the production of absolute ages (85% of all documented MSA ages) (Table 2.1).

Table 2.1: Number of dates and sites per region

Country	Number of Dates	Number of dated Sites
Botswana	43	5
eSwatini	7	2
Lesotho	63	4
Mozambique	16	2
Namibia	69	5
South Africa	1436	58
Zambia	48	4
Zimbabwe	9	2

The distribution of dates across site types demonstrates disparities between site type representation and dating intensity. Despite open-air sites constituting 45.8% of all documented MSA sites, they have produced only 21.6% of absolute dates. In contrast, caves and rock shelters which collectively represent 53.4% of southern African MSA sites have yielded a 78.2% of all documented dates (Table 2.2).

Table 2.2: Number of sites vs number of dates for the southern African MSA

Site type	number of sites	number of dates
cave	33 (24.8%)	676 (37.14%)
open air site	61 (45.8%)	393 (21.6%)
prehistoric mine	1 (0.75%)	3 (0.16%)
rock shelter	38 (28.6%)	748 (41%)

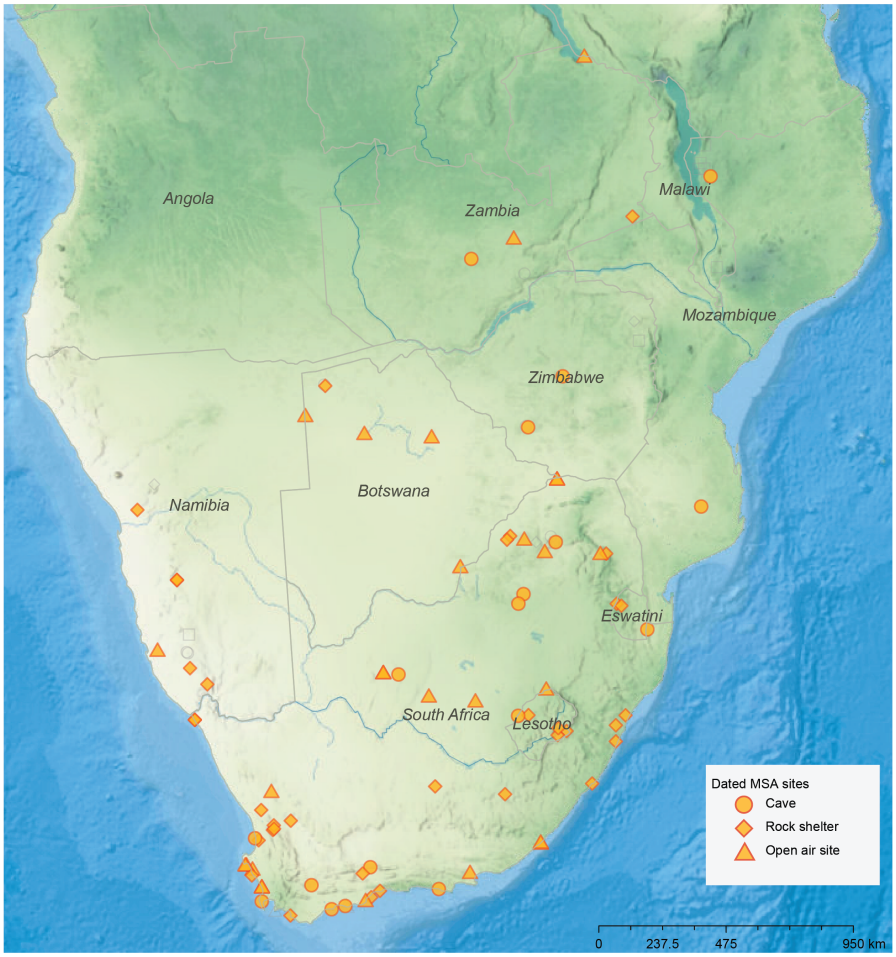


Figure 2.1: Figure showing distribution of dated MSA sites

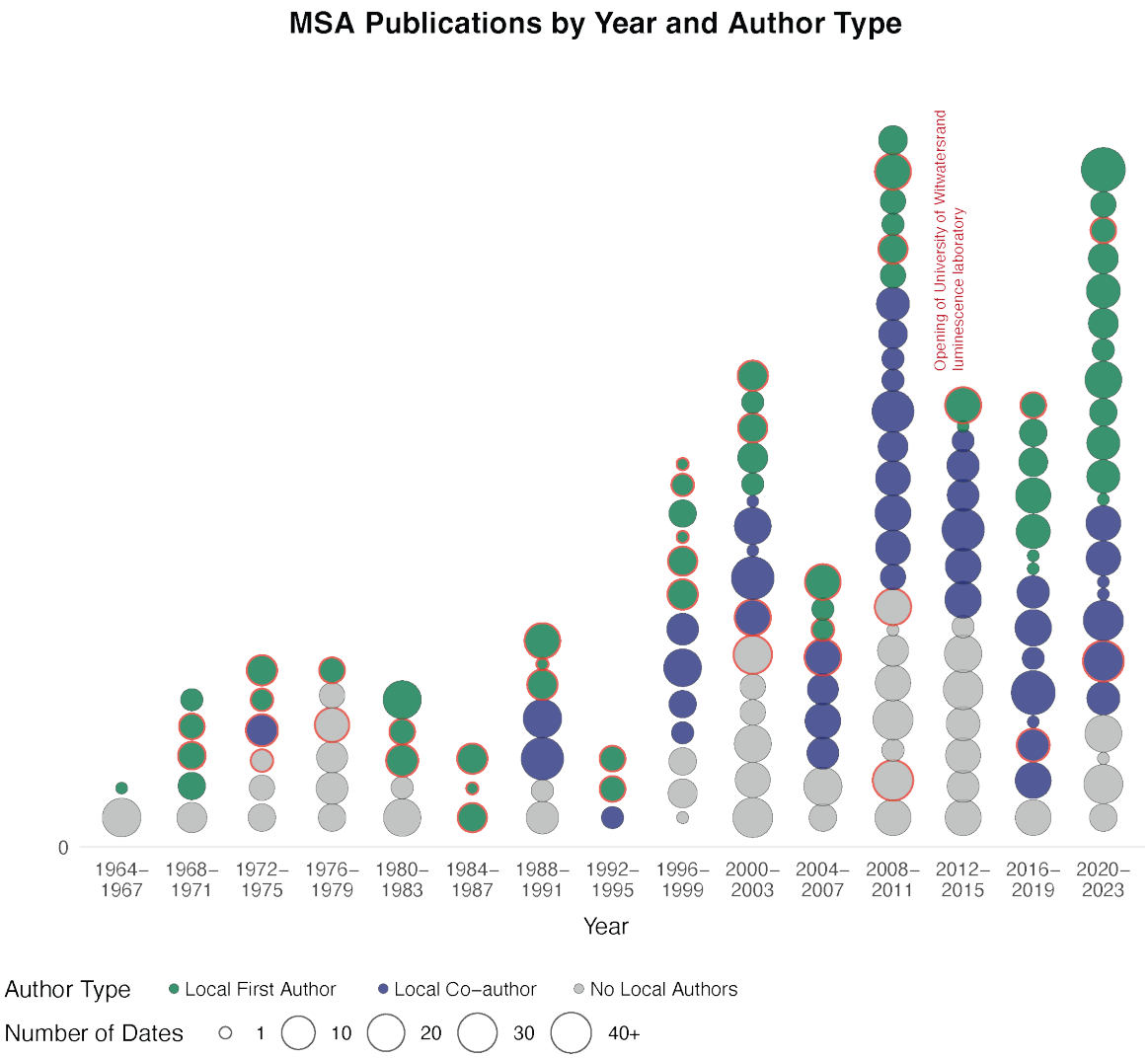


Figure 2.2: Papers presenting a southern African MSA age and their involvement in southern African institutions where each dot represents one publication. The colour of dot represents the degree of involvement, a red circle means at least one sample was dated in a southern African lab, size indicates number dates within the paper.

Meanwhile, authorship patterns reveal important insights into the intellectual geography of southern African MSA research. Analysis of papers producing primary results indicates that 39.5% had a local first author, while an additional 30.9% included at least one local co-author. The remaining 29.6% had no local authorship representation. Laboratory utilization follows a similar pattern, with 27.6% of all publications employing local laboratory facilities for analytical work (Figure 2.2). This increase in southern African lab usage coincides with the opening of the University of Witwatersrand Luminescence lab in 2011. More recently, in 2016,

the iThemba radiocarbon lab, based at the University of Witwatersrand Braamfontein campus replaced QUADRU, CSIR, Pretoria which shut down owing to financial troubles in the early 2000s (Mbele et al., 2017; Woodborne, 1999). Despite the re-introduction of dating laboratories, local theoretical collaboration is more common than local lab usage.

The development and introduction of new dating methodologies demonstrates clear shifts in technical approaches over the past half-century (Figure 2.3). Radiocarbon dating maintained its position as the dominant technique until 1999. Luminescence dating methodologies began their ascendancy from 1996, becoming the predominant dating approach by 2004. Other techniques such as Electron Spin Resonance (ESR), Amino Acid Racemization (AAR), cosmogenic nuclide dating, and Uranium-series dating have experienced more episodic application. ESR, in particular, shows two distinct periods of intensive application (1988-1991 and 2000-2003), while the other methods have remained relatively minor contributors to the overall production of ages.

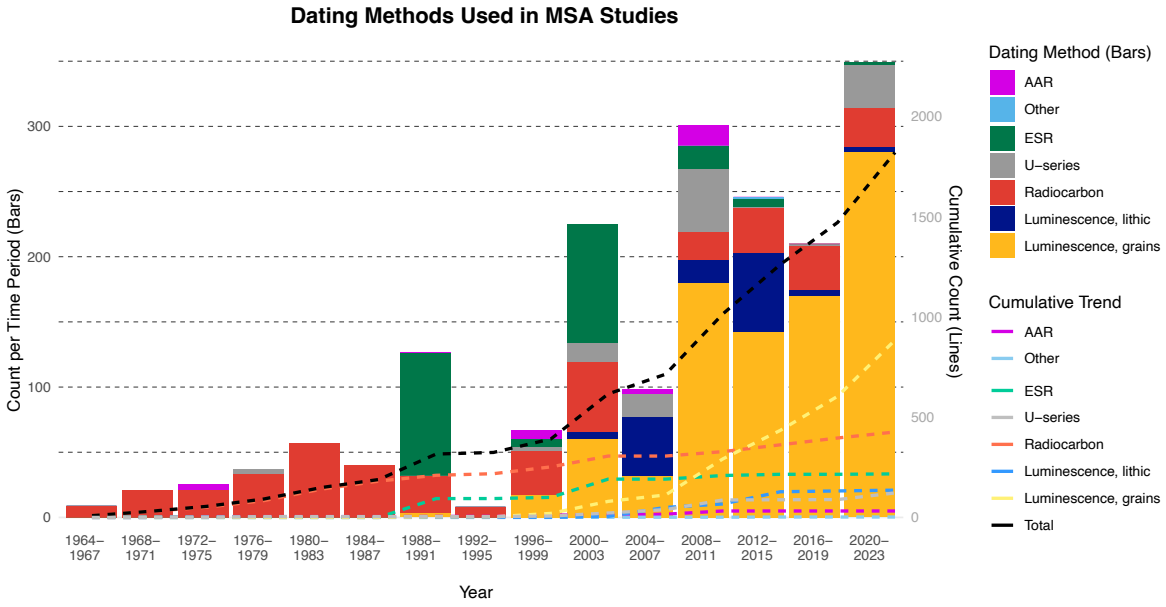


Figure 2.3: Number of dates per dating technique over time. The bars relate to the left y-axis and represent technological use through time, the lines relate to the right y-axis and represent cumulative ages.

2.3. Discussion: Revisiting the past

2.3.1. The Foundation Years (1800s-1950s)

The history of geological and archaeological dating in southern Africa is inherently political. In the early 20th century, amateur collectors described and defined the stone tool industries of South Africa and Zimbabwe. These collectors used evolutionary theory to order technology by their supposed level of sophistication (Goodwin, 1929; Shea, 2019). With the increasing professionalisation of the archaeological and geological world, these tools were divided into three primary industries, the Earlier, Middle and Later Stone Ages (Goodwin, 1929; Goodwin et al., 1929; Shepherd, 2003). These groupings were further broken down into still contested sub-industries of cultural-temporal packages. These cultural-temporal packages became relative chrono-markers or horizon layers to infer the antiquity of man at southern African sites. However, the boundaries between these industries are blurred, and the integrity and necessity of their sub-industries are increasingly questioned (e.g. Wilkins, 2020). Additionally, even when broad attributions are accurate, relative chronologies can lead to temporal misnomers with scientific consequences. Despite this, while flawed, these industries assisted in our earliest understandings of time and therefore frame much of the literature discussed below (Shea, 2019).

The MSA, in particular, is historically important for linking sites across space and time. While the ESA is associated with Large Cutting Tools (LCTs) and relative uniformity, the MSA, in contrast, is a period of diversification, innovation and refinement (Wadley, 2015; Wurz, 2014, 2013). The proposed sub-industries or technocomplexes played a crucial role in linking southern African records temporally and culturally to infer human migration across the continent. Since these southern African MSA tools resembled those of the already well-established European Upper Palaeolithic, early archaeologists and amateur collectors related

these newly defined technocomplexes to pre-defined European industries. This was not without consequence, as Wadley (2015) observes how these colonial preconceptions of European superiority resulted in southern African MSA industries being erroneously described as the daughter industries of their northern counterparts (Goodwin, 1929; Johnston, 1911). This idea, partly routed in Evolutionary Archaeological Theory, persisted into the second half of the 20th century (Clark, 1970; Trigger, 2006), which contributed to the false narrative of modern human behaviour as a European innovation. While speculation on origin, invention and civilisation persisted in archaeological literature, the absence of absolute dating of African sites allowed for these external, politically driven theories to remain largely uncontested (Trigger, 2006, p. 201).

2.3.2. Towards an absolute chronology (1950s-1970s)

The advent of radiometric dating allowed researchers to revisit prior assumptions regarding human origins. Radiometric dating allows archaeological sites and samples to be dated independently of the proposed relative chronology. In 1947, Libby described how the half-life of carbon could be used to measure absolute time (Libby, 1948). The half-life of ^{14}C is 5730 ± 30 years (Hajdas et al., 2021), therefore, after 8-9 half-lives (approximately 50 ka), the amount of ^{14}C left in organic remains is too small to measure accurately (Hajdas et al., 2021; Hua, 2009; Walker, 2013). When all the radiocarbon is depleted or in too small a quantity to measure, samples are given an infinite age. Conventional radiocarbon dating relies on beta-counting. This technique requires larger samples and was more sensitive to contamination, limiting the technique to approximately 40-45 ka. The newer accelerator mass spectrometry (AMS), introduced in the 1970's, requires smaller samples and can push the effective dating range to approximately 50-55 ka (Bayliss, 2009; Harris et al., 1997; Wright, 2017a). Despite this innovation, radiocarbon dating remains limited to the younger portion of the southern African Middle Stone Age, with an upper boundary of approximately 50-55 ka. However, even with

beta-counting's imprecision and temporal limits, radiocarbon dating played a fundamental role in realising the significance of the southern African MSA.

Cole (1954) initially identified the importance of new dating methods for untangling the distant past of southern African sites. Throughout the 1950s and 1960s, a handful of southern African radiocarbon ages were derived (see Klein, 1970; Mason, 1969; Vogel and Waterbolk, 1963). These ages mostly suggested that the African MSA was contemporaneous or later than European Upper Palaeolithic innovation (Klein, 1970). The dominant theory of European Upper Palaeolithic being home to the MSA's innovation persisted for a further 20 years following Cole's initial discussion. Only in 1972 was the true potential of radiocarbon dating for revising understandings for southern African archaeology realised (Robertshaw, 1992). This time delay is in part owing to funding, preservation and accessibility constraints (a recurring theme influencing science in Africa) (Klein, 1970; Robertshaw, 2012).

Beyond the radiocarbon boundary, climatic associations derived from faunal remains remained a useful method for inferring temporal association. If the site is clearly associated with fauna, flora or other environmental proxies, the associated climate provides a powerful, albeit flawed, relative chronology. Environment as a temporal proxy became more accurate with the advent of Marine Oxygen Isotope Stages (MIS) (Aitken, 1990; Emiliani, 1955). MIS are based on the differing ratios of ^{18}O to ^{16}O isotopes in oxygen trapped in ice cores. The derived stages allow for relative dates through climatic-temporal association (Aitken, 1990). Originally, these climatic associations were dependent on European glacial and interglacial cycles. However, Southern Hemisphere differentiation and local microclimates left climatic association open to erroneous temporal correlations (Parkington, 1990; Vandergoes et al., 2005). Additionally, while broad inferences for periods of stability and instability can be garnered from the rate of change, the thousands of years grouped through the MIS are invisible to the generations of humans who lived in them. Furthermore, sites cannot be temporally correlated with high

confidence. While few techniques provide the precision required to understand how past humans observed temporal change, other, more precise, absolute techniques allow us to observe multi-generational shifts within and between sites.

Despite these limitations, early radiocarbon applications led to ideological and theoretical revisions within the archaeological world and prevailing religion (e.g. Pius XII, encyclical Humani generi, 1950), and political doctrines (Hofmann, 2021; O'Connell, 1953). This political association was established as early as the 1950's. Robertshaw (1992, p. 336) comments, "The emergence of ^{14}C as the primary dating method for the later prehistory of Africa came at an auspicious moment. The rise of African nationalism and the granting of independence to many countries in the late 1950s and early 1960s prompted an upsurge of interest in Africa's precolonial past". However, this excitement was tempered in the southernmost part of the continent. The ruling apartheid-era Nationalist Party of South Africa adopted a 'don't ask don't tell' policy regarding precolonial Africa, which subverted and dismissed its findings. This was demonstrated through the exclusion of human evolution in the school syllabus. While this did not directly influence the dating of archaeological sites, the hidden nature of the findings continued to reinforce an educational access gap within apartheid-South Africa's racialised education system (Ndlovu and Smith, 2019).

Despite the South African government's anti-evolutionary stance, South African laboratories and researchers became pivotal in understanding the chronology of the MSA. When the radiocarbon laboratory was established in Pretoria in 1967, its findings presented ages of equivalent or greater time depth than Europe (see: Vogel et al., 1986; Vogel and Marais, 1971; Vogel and Visser, 1981). These findings implied the antiquity of anatomically modern humans in southern Africa. These ages were supported by later genealogical work which suggested a shared African origin for modern humans (Cavalli-Sforza et al., 1988; Deacon, 1992).

Vogel and Beaumont (1972), from the Pretoria Radiocarbon Dating Laboratory, boldly went against the Eurocentric narrative by providing infinite ages for the South African sites of Rose Cottage Cave and Border Cave. These bold initiatives represent an important shift regarding the significance of the southern African MSA for human evolution. Earlier publications from the Gulbenkian Radiocarbon Dating Laboratory, University College of Rhodesia and Nyasaland (1962-1978) hinted at a much older origin for the MSA; however, these publications were cautious, and the ages' true significance was not explicitly stated (Cooke, 1971, 1963; Robins and Swart, 1964). Vogel and Beaumont (1972 p. 50) treated their infinite ages as minimum ages, or *terminus post quem*, to demonstrate the "very early appearance of *Homo sapiens sapiens* in Africa-considerably earlier than in the Middle East and Europe." The paper goes on to suggest that "the continent of Africa is the area where much of modern man's early evolutionary development took place".

This prospect of early Homo sapiens innovation in Africa continued to motivate and push archaeologists and chronologists to seek more appropriate dating techniques for this extended timeframe. In the absence of precise methods extending beyond the radiocarbon limit, archaeologists relied on stone-tool technocomplexes and environmental proxies such as faunal assemblages (biostratigraphy), pollen sequences, and marine shell isotopes, could be correlated to global climate records and Marine Isotope Stages (MIS), thereby providing an indirect chronological framework. As local habitats respond to wider climatic oscillations, their signatures can be matched to specific MIS intervals. This allows for the proposed MIS associations to act as a provisional chronological guide, offering temporal structure in the absence of absolute age estimates.

Klasies River, a series of coastal caves in South Africa, became a forerunner for the application of these proxies. The Klasies River cave sites contain several lithostratigraphic layers, which were initially structured and understood largely through stratigraphic control and tool typology

(Deacon and Wurz, 2005; Singer and Wymer, 1982) . Klein's (1976) macro-fauna identification paved the way for environmental reconstruction at the site, although MIS attributions were only applied later once independent dating became available. Shackleton (1982) offered the first direct temporal constraints for the Klasies assemblage by providing isotopic signatures for thirteen Turbo sarmaticus shells from three MSA layers, linking them to MIS 5. These correlations were further supported by the chronological framework developed in Deacon (1988). Avery's (1987) micromammal analysis reinforces the identification of MIS 5 and additionally suggests environmental changes within its climatic-temporal substages. Building on the use of environmental and MIS correlations as provisional chronological guides, archaeologists in the 1980s and 1990s increasingly turned to new dating methods capable of extending absolute chronologies beyond the radiocarbon limit.

2.3.3. Methodological Diversification (1980s-1990s)

In the 1980s and 1990s, new dating techniques began to contribute greater understanding to extended time ranges beyond radiocarbons 50 ka boundary. Amongst these techniques were Electron Spin Resonance (ESR), which measures the trapped accumulated charge in fossil tooth remains (see: Grün, 1997; Grün and Stringer, 1991), Uranium-series (U-series) on speleothem (Schwarcz, 1992), and luminescence dating , which can be applied to sediment or heated inorganic artefacts (Aitken, 1989; Bøtter-Jensen, 1997; Liritzis et al., 2013). In particular, Aitken (1985) highlighted the usefulness of thermoluminescence (TL) for pushing beyond the radiocarbon temporal limits to understand the Middle and Lower Palaeolithic better. Thermoluminescence can measure when last a lithic artefact or sediment was exposed to heat >250^{o}C. This makes it particularly powerful for understanding MSA innovation around heat-treated flint and hearths. In contrast, optically stimulated luminescence (OSL) and other luminescence dating techniques, are traditionally applied to quartz or feldspar grains the last exposure of light or heat (Aitken, 1989). This proves a useful tool for measuring burial ages.

The ability to measure both sediments and artefacts makes the suite of techniques useful for direct dating (e.g. burnt lithics) as well as depositional contexts (e.g. stratigraphic layers). Despite demonstrated applicability to European (see: Juvigné and Wintle, 1988) and Asian (see: Rendell and Dennell, 1987; Valladas et al., 1988) palaeolithic sequences, luminescence techniques were not widely applied to the southern African Middle Stone Age context until the 1990's (see: Feathers, 1997; Grün et al., 1996; Vogel et al., 1999; Wallsmith, 1990). However, by the turn of the millennia, South Africa played an important role in expanding and validating novel and innovative luminescence techniques (Feathers, 2002; Feathers and Pagonis, 2015; Jacobs et al., 2003; Lukich et al., 2019)

From, ≠Gi, Botswana, Brooks et al. (1990) provide the first published luminescence age for the southern African Middle Stone Age. The 77 ± 11 ka thermoluminescence estimate from sediment samples supports the amino acid racemization (AAR) ages derived from ostrich eggshell (OES) fragments (see: Johnson and Miller, 1997). Early luminescence ages and their associated archaeological interpretation are often published separately with little ability to correlate or verify accuracy (for example: Brooks et al., 1990 and Hornyak, 1990). Data are often focused solely on experimentation or the contextual relevance of the ages themselves and cannot be corroborated by the archaeological or scientific record. Despite the initial general lack of communication between chronological and archaeological data, this period marks the transformation from relative or incidental dating of sites to the quest for an absolute chronology for individual sites.

The application of OSL to sediments also marks a quiet revolution in how dates in southern Africa are derived. Much like tephrochronology (Lane et al., 2017, 2014), which relies on time-synchronous volcanic marker horizons, OSL allows for direct chronological investigation of depositional and environmental contexts. Traditional radiocarbon, TL and ESR ages, in contrast, date specific finds from a layer. Unlike its forebearers, it also allows for the dating of

stratigraphic layers and sites with an absence of suitable material culture. Prior to OSL, and in the absence of volcanic activity in southern Africa, absolute dating primarily focussed on providing an age for a direct archaeological find – e.g. burnt lithics, teeth or charcoal. This limited archaeologists to interpreting a single occupation event rather than the passage of time. In contrast, contextual or stratigraphic layers allow archaeologists to explore reasons behind the absence of human activity within these layers – e.g. human-climate mediated occupation. Contextual dates also allow for a deeper understanding of depositional processes and environmental forces that influence the preservation of sites. Collectively these different types of ages, be it contextual (e.g. dating the depositional event) or direct (i.e. the artefact itself), provide a more complete, albeit complex, understanding of the past.

Direct dating of individual artefacts (e.g. burnt lithics with TL) and faunal remains (e.g. fossil teeth with ESR) continued in parallel to the adoption of contextual/stratigraphic dating. Grün et al. (1990) published the first robust ESR ages for southern Africa at Border Cave, South Africa. These ages were derived from local macro fauna, including Bovid, Equus and Hippotragus, located throughout the excavated assemblage. Grün et al. (2001) revised these ages in the wake of newer statistical models and better dose rate measurements. Grün et al. (1990, 2001) were significant as they closely combined the archaeological results with the chronological data. These newer ages agreed with the prior radiocarbon ages and within error of the Miller et al. (1999) Amino Acid Racemization (AAR) ages, increased reliability and accuracy of both sets of ages. The validity of these ages is also supported by the proposed HP association with the AAR ages averaging 69 ± 7 ka and the ESR ages averaging 63 ± 2 ka. The ages themselves are published with full scientific measures which allowed for later recalculation and assessment. This open data approach in and of itself was a forerunner for future publications. At Klasies River, Goede and Hitchman (1987) attempted to further refine the sequence by dating *Turbo sarmaticus* shells using Electron Spin Resonance (ESR). While

this ESR application was unsuccessful in providing an absolute date, it was part of this discrete turning point in the use of southern African sites for developing chronological tools. Southern Africa was no longer only the recipient of established techniques but also the host of novel experimentation.

These exciting advances in dating of the MSA accelerated towards the end of the 20th century (Figure 2.3). The massive advances in PCR amplification and establishment of comparative mtDNA lineages similarly support these new ages for modern humans' southern African origins. Watson et al. (1997) established a 60 ka-80 ka age for shared mitochondrial origin in Africa. Southern Africa, once again, was demonstrated as a probable ancestral home and important for understanding our human past. The collective findings from DNA, early radiocarbon ages, the adoption of novel techniques and archaeological finds firmly established the antiquity of modern human behaviour within southern Africa. These exciting findings existed in parallel with the political and scientific upheaval of the time, collectively setting the stage for a new century of scientific discoveries about our complex past.

2.3.4. A New Era for southern African chronologies (1990s-2000s)

The discoveries of the prior decades came at a politically advantageous time in South Africa's history. The politically favourable post-1994 atmosphere allowed archaeological fieldwork and international collaboration to become more frequent. Then vice-president Thabo Mbeki's proposed *African Renaissance* aimed to place South Africa as a centre of knowledge production of both the present and the Archaeology was prioritised, albeit briefly (Bongmba, 2004; Wadley, 2000). With this came international collaboration (Figure 2.4) and funding with a strong focus on South Africa (Ndlovu and Smith, 2019). Concurrently, Mozambique and Zimbabwe faced internal political and financial constraints directing internal resources and external archaeological interest towards South Africa's safer contexts.

In prior decades, fieldwork was more evenly spread across southern African countries, with research spread across Botswana, Namibia, South Africa and Zimbabwe. In the new political atmosphere, the focus now turned towards South Africa's coastal sites where South Africa's share of southern Africa MSA ages increased from ~70% to ~85% in the pre to post-1994 era. The developments on South Africa's coast became part of a positive feedback loop which contributed to an explosion in dating information during the latter half of the 1990s and early 2000s (Figure 2.3). This loop resulted in (i) increased number of MSA excavations that uncovered artefacts associated with modern humans, (ii) **new scientific techniques** which increase the availability and reliability of dating methods, (iii) increased interest in the region owing to the production of exciting, **precise and accurate ages which supported growing evidence of a southern African modern human origin**; and, (iv) **political** interest and increased **funding** to support the South African post-apartheid movement for an *African Renaissance,* chronological and archaeology assessments of the southern African MSA significantly matured. This feedback loop went on to improve the scientific dates themselves. Sites with well-understood climatic models and comparable tool collections promoted the improvement of underlying assumptions that limit the precision and accuracy of luminescence techniques. The following sections explores two elements of this cycle, *new luminescence techniques* and *more precise and accurate ages.*

Luminescence dating played a significant role in the development of the South Africa's chronological record. Two assumptions underlie the basic principles of luminescence dating (i) the entire sample is fully bleached at the time of burial, and (ii) the sample accumulates dose at a steady rate. Rarely are both these assumptions correct, and methodological and statistical models are required to acquire more accurate ages. South Africa's MSA rock shelters became host to several studies attempting to rectify these concerns.

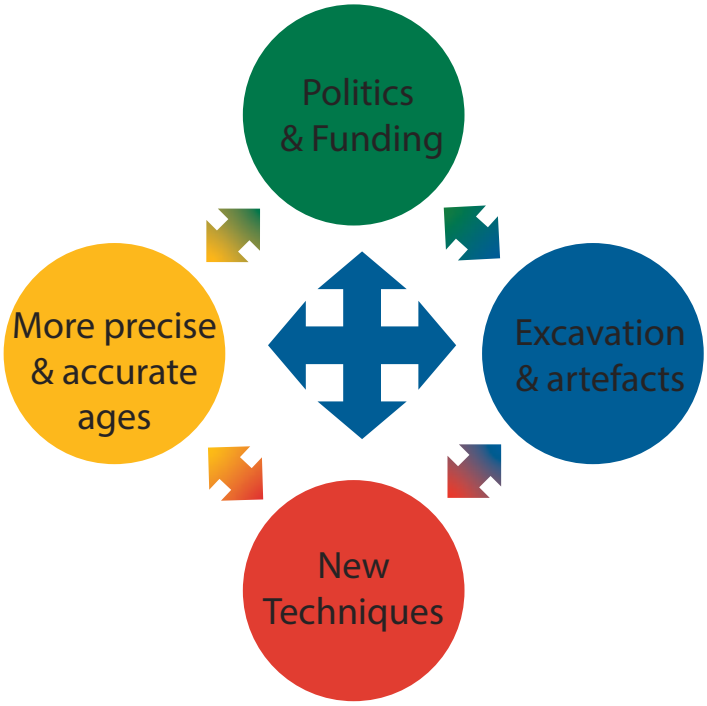


Figure 2.4: Feedback loop promoting a dating boom in post-apartheid South Africa

Blombos Cave, is not only important for its historic archaeological finds, it also hosted experimentation for developing luminescence techniques. Henshilwood et al. (2002) demonstrated the value of combining direct and indirect/contextual age models in their multi-method chronological exploration of Blombos Cave for MIS4-MIS5. TL was applied directly to five burnt lithic artefacts from two layers. The lower layer (CC) lithics report ages of 73.7 ± 6.1 ka, 84.8 ± 7.3 ka and 77.3 ± 7.9 ka. The upper layers (CA/CB) have two TL ages at 68.5 ± 7.5 ka and 82.2 ± 8.5 ka. It is evident that these ages lack high precision, with error margins ≈ 10% of the age. However, as the lithics are capped by a sterile layer (69. 6 ± 4.5 ka), the authors

can "confirm the stratigraphic integrity" by applying "optically stimulated luminescence (OSL) dating to the aeolian dune (BBC Hiatus) separating the LSA and MSA layers" (C. S. Henshilwood et al., 2002, p. 1274). This provides an accurate, if not precise, chronology. The authors therefore proposed that the associated engraved ochre was approximately 77 ka, >35 ka before symbolic behaviour in the European Upper Palaeolithic.

This technological innovation, previously thought to be a hallmark of the LSA, indicated a significant shift within human innovation not only regarding symbolism but also the adoption of increasingly complex composite tools (Ambrose, 2002). Subsequent studies in northern and eastern Africa indicated that these innovations may have a broader, shared African origin (Barton and d'Errico, 2012; Barton et al., 2016). However, at the time of publication, Henshilwood et al. (2002) represented a fundamental shift in our understanding of human evolution. Not only did modern humans genetically originate within Africa (see: Bandelt et al., 2006; Stringer and Andrews, 1988), but so too did symbolism and technological complexity.

At neighbouring Duinefontein and Klasies River, through applying the subtraction technique to OSL measurements from quartz and potassium-feldspar grains for the proposed HP and SB industries, Feathers (2002) explored the implications of non-steady dose rates through time. At Duinefontein, the observed dissolution of marine shells indicated fluctuations in the water table, which would have affected the movement of uranium within the sediments. As uranium contributes to the environmental dose rate, any such leaching or movement means that the rate of dose accumulation could not have remained constant. Under these conditions, Feathers (2002) demonstrated that it was not possible to obtain accurate luminescence ages for the sequence. While this particular application was unsuccessful, it nonetheless marked an important moment in establishing southern African MSA sites as test subjects for luminescence experimentation.

Returning to Blombos, Jacobs et al. (2003a) and Jacobs et al. (2003b) continued experimentation of OSL techniques on remnant dune sand/aeolian sand in cave deposits. They compared and contrasted OSL results from multi-grain measurements with pioneering single-grain measurements. Jacobs (2003a) initially applied OSL single-aliquot measurements using the (then) novel single-aliquot regenerative dose protocol (SAR), developed by Murray and Wintle (2003). This protocol continues to remain popular and undergo refinement to improve accuracy. The Jacobs (2003b) paper is pioneering in its application of optically stimulated luminescence single-grain (OSL-SG) to an archaeological context, representing the first large-scale archaeological application since the techniques proposal by Murray and Roberts (1997).

OSL-SG addresses a problem of the first significant assumption in luminescence dating. It does not assume a homogenised sediment population that was bleached fully and deposited uniformly. Rather, it explores the equivalent dose (De) for each individual grain. Jacobs' (2003b) application removed unsuitable grains within the sediment population. These were identified by poor recycling ratios, incomplete bleaching, unstable luminescence signals, or signals that appeared modern. Both the single aliquot and the single grain data resulted in similar ages with similar precision. This was attributed to the homogenous origin of the sediment. Subsequent applications of OSL-SG present ages as statistical clusters of sediment ages. This exploration of heterogenous pace and episodes of sedimentation with a sediment sample allows for further interpretation of the depositional processes within archaeological sites.

The innovations in luminescence dating demonstrate the prominence of South Africa's coastal MSA sites in the development of luminescence techniques. These luminescence developments were accompanied by continued interest in the direct dating of burnt lithics. Tribolo et al., (2005) applied TL to five lithics from Blombos. These lithics came from layers with evidence of symbolic behaviour- in the form of shell beads and ochre. The ages are within agreement

with the previously established OSL and ESR ages. Similarly Valladas et al. (2005) applied TL to 12 lithics from the proposed HP industry at Rose Cottage Cave in South Africa's central interior. The derived ages corroborated the proposed antiquity of the SB and HP. Unlike OSL, which focuses on sediment, TL is best applied to burnt layers and artefacts. The dates derived are therefore more clustered around layers of artefact creation, not deposition.

2.3.5. Contemporary Approaches (2010s-Present)

A boom in OSL and TL ages in the new century brought about a fundamental shift in chronological perspective. While the significance is considered somewhat less noteworthy than the radiocarbon revolution (Cochrane et al., 2013), its impact should not be understated. This is seen through both the scope and depth of chronological questions. Luminescence dating in interior southern Africa is dominated by paleo-climatic questions. In the prior decades of excavation, many interior sites, with poorer preservation, and consequently poorer ability to precisely date, were ignored for their coastal counterparts with arrays of absolute dating potential. However, the spatial biases of focussing on a few outlier sites, with great preservation and long stratigraphic sequences, ignore the presence of past humans throughout the southern continent (Figure 1). In the absence of absolute dates for the interior, some archaeologists have assumed that modern human *firsts* are coastally driven (Marean, 2011). It allows us to make assumptions about what drives technological innovation and creativity without evidence to contrast or support it. By dating interior sites, we can infer other forms of the economy as well as test whether our modernity truly hinges on the coast or whether it is a false positive from lack of data (Wallach, 2019).

While the oldest portions of the MSA's interior presence are documented in some of the earliest archaeological surveys of the country, the temporal and archaeological importance of these poorly preserved, early interior sites are often underestimated. This can be attributed to three

reasons. Firstly, limitation and novelty of techniques applied. For example, Kathu Pan 6, an open-air site visible through sink-hole activity, contains proposed Fauresmith, MSA, HP and LSA assemblages (Lukich et al., 2019). However, the nature of the site does not allow for U-series, ESR or other techniques available to the MSA. Lukich et al. (2019) address this through applying multiple luminescence dating techniques to quartz (OSL and TT-OSL) and feldspar (post IR-IR290). The luminescence ages between the quartz and feldspar are not directly in agreement. If the K-feldspar ages were older than the quartz this would not be unexpected. Feldspar is known to not fully bleach, reset to zero charge, when exposed to light, which may lead to overestimating the age. However, in this case, the feldspar returned younger ages than the quartz. Lukich et al. (2019) report a negligible feldspar fading rate (~0.3% per decade), ruling it out as the source of the discrepancy, and instead highlight the limited development of the pIR-IR290 protocol as a possible factor. Therefore, while the quartz ages are proposed as more accurate, the restriction of the poor preservation means that alternative dating methodologies to further investigate the discrepancy are not possible at this time. This makes resolving the contested dates troubling.

The second challenge is post-depositional processes, as seen at Canteen Kopie. Canteen Kopie, Northern Cape, has high levels of bioturbation where older grains mix with recently bleached samples (Chazan et al., 2013). Chazan et al. (2013) provide an OSL-SG age of ~300 ka to the Hutten Sands which gives a minimum age for the underlying Younger Vaal Gravels. However, the SG population suggest the age may be as recent as ~165 ka. However, even this age is complicated as the layer is clearly mixed until 23 - 26 ka – which neatly coincides with the end of the MSA.

Wonderwerk Cave is an extreme example of post-depositional unconformity; at this site, however, it is owing to early excavation techniques. Despite its relatively high preservation conditions, the six excavation areas in the cave cannot be culturally linked (Chazan, 2015;

Chazan and Horwitz, 2014). Instead, they are understood as independent units, only linked through absolute dating. As Wonderwerk is relatively well preserved within a cave complex, palaeomagnetism, U-series, and luminescence techniques are available to it (Chazan et al., 2020). However, as the stratigraphy is disjointed into six distinct areas. Connecting these areas remains a challenge, and while St. 2 there has been some success, connecting the ages across the site remains a challenge (Birin, 2019).

The final consideration is methodological in nature, particularly regarding absolute dating in the interior of southern Africa (Feathers et al., 2020). Unlike the coastal sites with proposed SB and HP industries, the interior MSA industries are not as constrained by the same temporal expectations. This presents opportunities to date archaeological contexts without as many prior assumptions. However, without this contextual framework, when multiple methodologies produce contradictory results, resolving chronologies from sites like Mwulu Cave, Canteen Kopie, and Kathu Pan 6 becomes increasingly challenging and can lead to unclear interpretations which require more nuanced interpretation (Chazan et al., 2013; Feathers et al., 2020; Lukich et al., 2019).

At Mwulu Cave, for example, the dating results are complicated by the use of different luminescence methods across two laboratories. Both feldspar (IRSL and post-IRSL) and quartz grains (OSL and OSL-SG) were measured, but the results diverge: OSL-SG quartz ages are younger than the multi-grain OSL tests, and feldspar ages appear too old. Feathers et al. (2020) attribute this discrepancy to two factors. Firstly, a significant proportion of the quartz grains had reached saturation, the upper limits at which grains can accumulate luminescence signal, meaning these grains can no longer accurately record burial age. The multi-grain aliquots, which measure many grains together, therefore underestimate the true age of the site. The single-grain approach, which measures individual grains separately, helps identify these saturated grains within the broader population, explaining why OSL-SG results differ from the

bulk multi-grain measurements. Secondly, the complex sedimentary setting at Mwulu Cave made determining accurate dose rates particularly difficult, as varying sediment compositions affect the rate at which grains accumulate radiation damage. With only a proposed Pietersburg industry, previously loosely constrained at Border Cave and Bushman Rock Shelter, and unlike at Diepkloof Rock Shelter with its clearer stratigraphic context framing the SB and HP, it is clear that this is a methodological challenge that needs addressing, not the archaeological interpretation (Feathers et al., 2020; Grün et al., 1990; Grün and Beaumont, 2001; Porraz et al., 2018).

The multi-application applications to South Africa's interior demonstrate the complexity and the nuance of archaeological dating. They also once again establish the importance of southern Africa for the development and refinement of luminescence techniques. When multiple techniques produce ages within error of each other, we can build models which provide unique and precise ages. However, when techniques are in conflict, we need to explore the science and site formation processes to find wherein the true age of the artefact lies. The inconsistencies at inland sites like Kathu Pan 6 and Mwulu, and coastal sites like Diepkloof illustrate our need to consider these implications.

2.4. Debating time and technocomplexes

MSA ages are rarely straightforward. They rely on a complex web of archaeological and methodological relationships to verify their accuracy and precision. These issues are amplified in when aiming to refine chronologies associated with lithic industries. Two of these industries, the younger HP, associated with small, hafted/composite lithic tools, engraved ostrich eggshell, bone tools and ochre (see: de la Peña, 2020; Way et al., 2022), and older SB, a more diverse industry associated with the presence of biface points, stone tool industries (see: Archer et al., 2016; McCall and Thomas, 2012), have undergone intense chronological attention (Cole, 1954;

Goodwin, 1929; Thackeray, 1992; Wadley, 2015; Wurz, 2021). In the age of absolute dates, a precise age attached to either industry would allow for relative dates with absolute associations, cutting down on money and time when in the field. However, the use of technocomplexes to infer ages hinges, not only the industries validity, but also an agreed and tightly bounded chronology.

The Diepkloof Rock Shelter (DRS) chronological debate goes to the heart of the issue on our use of the technocomplexes as a horizon markers (Feathers, 2015; Jacobs and Roberts, 2015, 2015; Tribolo et al., 2013, 2013, 2009, 2005). This is because Diepkloof boasts one of the few archaeological sequences that contain both the SB and HP industries (Porraz et al., 2013; Tribolo et al., 2009). Prior to absolute dating, the site's relative chronological sequence confirmed that the SB is older (occurred before) the Howison Poort; resolving chronological speculation from some of the industries' earliest descriptions (Goodwin, 1931; Goodwin et al., 1929; Malan, 1943). Despite Diepkloof's well understood technological sequence, the dates attached to these sequences remains contested.

The contestation surrounds two different absolute chronologies suggested for the SB layers at the site – what has become known as the old vs young chronology. Before proceeding, I need to note that this paper serves to review the history of the science for an archaeological audience - as opposed to reconciling opposing chronological interpretations. The old and young chronologies emerge from two parallel dating projected between 2005 and 2015. The old chronology suggests the SB is a long-lived industry with loose chronological and spatial constrains – with its initial occurrence at Diepkloof Rock Shelter ~10 ka before its appearance at other sites (Tribolo et al., 2013, 2009). In contrast the young chronology proposes the SB industry is a short-lived, precise moment time. This debate has significant implications for if the industry's presence can be used as a proxy age – analogous to the appearance of a tephra layer indicating a specific volcanic eruption or faunal species which go extinct.

The old chronology, was initially derived from OSL dating of four sediment samples and thermoluminescence (TL) dating on 22 burnt lithics from the 1999 excavation of the site (Tribolo et al., 2009, 2005). The samples suggested a range from 127 ± 10 ka to 99 ± 10 ka for the SB and 96 ± 10 ka to 60 ± 6 ka for the HP. Bayesian modelling placed to most likely switch from the SB to HP at 93 ± 8 ka. Tribolo et al. (2013) revised their previous 22 TL ages with newer statistical models and presented, 18 new TL ages and five OSL-SG measurements. These new OSL-SG samples are consistent the TL samples from the same laboratory. Both favour a longer duration and time depth for the SB when compared with young chronology derived from Jacobs et al. (2009) OSL-SG ages. Archaeologically, Porraz et al. (2013) suggests a technological framework which favours and supports this older age. The framework amplifies the variability of the SB at Diepkloof and cautions against using it as a horizon marker. It is important to note, while Tribolo et al.'s (2013) OSL-SG ages provide a more direct methodological comparison with the Jacobs et al. (2008) ages, neither of the laboratories share samples from the same excavation square.

In contrast, the young chronology is derived from the seminal Jacobs et al. (2008) paper where the main objective was not to date Diepkloof Rock Shelter but rather to constrain the HP and SB across multiple sites. The paper presents ages for three sites (Apollo 11, Diepkloof Rock Shelter and Sibudu) with identified SB layers and eight sites with HP layers (Jacobs et al., 2008a). From Diepkloof Rock Shelter itself OSL-SG was applied to 10 samples spanning the post-HP (1 sample), HP (6 samples) and SB (2 samples) lithic industries. Importantly, there is no contention regarding the latter HP ages, and the SB layers are very similar across the three sites dated in this paper. The results indicated ~71 ka age for the SB with a approx. 1 ka duration and a ~62 ka age for the HP with a 5.3 ka duration. The SB ages are significantly younger than those proposed by Tribolo et al. (2013, 2009). These ages offer a level of precision rarely achieved in sites of such time depth. The tightly bounded chronological controls led authors to

suggest that the presence of HP and SB layers may be used as separate chronological marker horizons. The SB ages appear to document a distinct, precise moment in time.

The potential of the SB horizon marker is tempting. The old vs. young disconnect however, is an ongoing concern. Enticingly, at first glance, the difference might be identified as a mismatch between two different techniques measuring the ages of different materials (i.e. OSL-SG on sediment and TL on burnt lithics). This however becomes more complicated on further investigation. The different laboratories, and methods, are within 1σ error for the HP and lower MSA while remaining within 2σ error for the pre-SB. The problem clearly arises for the middle SB layers. Tribolo et al. (2013) attributed the difference to Jacobs et al.'s (2009) miscalculation of the environmental dose rate – the rate at which luminescence dosimeters (like quartz) receive charge. Guérin et al., (2013) suggested Jacobs et al. (2008) contained errors in dose rate calculations and applied inaccurate statistical models to derive these ages. Galbraith (2015) refuted the statistical accusations. Jacobs and Roberts (2017, 2015) revaluated their ages based on the Guérin et al., (2013) criticism but found no significant changes from their previous findings. They concluded they could not find any reason for the difference between the laboratories. It is possible that this could be another issue with the quartz being near saturation and therefore cannot be considered accurate.

Feathers (2015), a third laboratory, attempted to offer three new dates from the contested layers to address the issue. The samples were from a previously unpublished chronological project – collected in 1995 from a 1973 test pit. Feathers (2015) and Feathers and Pagonis (2015) noted that the quartz at Diepkloof is near saturation (the upper limits of OSL dating at this site). This makes both accuracy and precision challenging (Feathers and Pagonis, 2015). Both OSL-SG on quartz and IRSL on feldspar were performed. The new IRSL ages showed some variability but generally tended to support Tribolo et al. (2013). Notably, Feathers and Pagonis (2015) applied a low-fading post-IR IRSL protocol to reduce the effects of anomalous fading, which

is a common challenge in feldspar dating. However, relatively few grains were accepted for analysis, limiting confidence in the resulting ages. Furthermore, the complex environmental dose rates at Diepkloof and residual fading, introduce additional uncertainty, particularly for the contested middle layers of the SB horizon. Feathers (2015, p. 173) further suggested that the “narrow time frame postulated by Jacobs et al. (2008), however, may not be sustainable”. However, Jacobs and Roberts (2017) attributed the precision of their ages to the tight controls achieved by using a single laboratory for measurements

Despite Diepkloof Rock Shelter’s extensive dating projects the chronological difference between the two laboratories remains unresolved. Tribolo et al. (2013, p. 3401) suggested given the long-range HP and SB ages, these proposed "chrono-cultural" technocomplexes "can no longer be considered as horizon markers". This scientific argument for the abandonment of these technocomplexes as single chronological entities is compelling. However, as the ages themselves are still under debate, Jacobs and Roberts (2015) suggested that Tribolo et al. (2013) was "premature" in their discussion. Notably, Jacobs and Roberts (2015, p. 175) "caution against the development of HP and SB age models based on only one of the chronologies". As suggested by Jacobs and Roberts (2015), it is most probable that the only way to truly resolve these inconsistencies is to obtain fresh TL, feldspar and quartz samples from these sites. New ages, possibly using techniques which exploit older and more stable traps (e.g. p-IR IRSL or VSL), will help address the potential of lithic industries as chrono-markers in the archaeological record.

Beyond the integrity of the technocomplex, it is possible, as suggested by Wilkins (2020 300), that irrespective of the validity of the technocomplex, individual typological investigation may prove more useful for discovering “some informative environmental and temporal structuring” than the use of defining named industries. Therefore, while both the SB and HP remain hotly

debated (see: Wurz, 2021) chronological investigations of individual innovations from these archaeological layers offer promising avenues for understanding human interaction in the past.

Regardless of the outcome of the old vs. young chronology, Jacobs et al. (2008)'s inter-site analysis to determine when the SB and HP industries accrued marks a defining moment for types of chronological studies in the MSA. This attempt utilised 57 pre-existing and 44 new ages from 13 sites across southern Africa. This inter-site is an acknowledgement that the region had enough ages for comparative and statistical analysis.

2.5. The southern African MSA – a way forward

It is clear that despite technological advances we need to act with caution when exploring ages of sites. To do this, intra and inter - technique comparison along with novel innovation is needed. With the rise of large databases and machine learning, inter-site and inter-regional chronological relationships are increasingly possible. While the potential of these innovations is yet to fully reach southern African MSA, Archer (2021) demonstrates their potential through applying existing databases to explore the MSA/LSA transition and population density. Grove and Blinkhorn, (2020) apply neural networks to understand MSA/LSA transitions. Stratford et al., (2021) documents all known rock shelters in southern Africa for paleoenvironmental reconstruction and stratigraphic analysis. With a complete and accessible chronological database (see Chapter 3), coupled with technological and environmental data, future studies will be able to expand this type of study to better understand the spatial and temporal networks of interwoven sites. These machine learning applications are part of a new tipping point for understanding the chronology of the southern African MSA.

In the half century since the advent of radiometric dating applications in a southern African MSA context have expanded dramatically with over 1844 unique and revised ages, associated with southern African Middle Stone Age contexts (Chapter 2, this thesis). 39 of the 152 papers

containing unique numeric ages for the MSA utilised laboratories based in southern Africa, 60% of publications had some affiliation with a regional institution (Figure 2.3). Southern African lab usage coincides with the changes in regional availability. Notably the opening of the University of Witwatersrand Luminescence lab in 2011 has increased not only availability of local testing but also awareness of the methods. However, this is only responsible for 2.5% of the ages produced since opening.

While researchers trained in southern African, now located in the global north, often retain a southern African research focus, this does not absolve us from forming local collaborations and training the students who exist within the locality of the sites. This responsibility needs stressing as previous, past arguments regarding the antiquity of these sites and therefore their universal ownership were superficially appealing, and allowed archaeologists to acquit responsibility to modern peoples, in the post-colonial context, these arguments hold less weight (Young, 2006). Much like Raja et al., (2021), analysis of botanical fossil collections, archaeology needs to acknowledge that the current lab location disparity and grant distribution is still unduly reliant on and influenced by the Global North (Yao et al., 2021).

These ages are not only skewed by the political bias's which influenced their development but also spatial bias's which lean towards well-preserved rock shelters and caves (Table 1). This spatial bias inherently informs the questions we can answer, and the questions in which we ask. With this interest archaeologists need caution to avoid drawing false positives (e.g. concentration of research equating concentration of people) created from the spatial and temporal sampling biases.

In the coming decades archaeologists need to focus future studies to rectify these gaps within our current understandings. This will open up opportunities for new revolutions in understanding our shared time. Without data for the older layers of the MSA, there is little

possibility of understanding the origin and reasons for rapid technological innovations during MIS4-MIS5; likewise, if we do not turn our attention to the interior or beyond South Africa's borders we cannot establish if the coastal occupations are genuine firsts or from a preservation and excavation bias. Therefore, while calls for better chronological resolution for the southern African MSA remain relevant (Wurz, 2013), these calls need to be targeted to fill in the gaps for regions and periods which experience lower archaeological attention. However, despite this caution, southern African MSA chronology is in a strong position to start interrogating new statistical techniques to improve accuracy, precision while uncovering new lines of inquiry.

2.6. Conclusion

Over the past half-century, the development and application of absolute dating techniques have profoundly reshaped our understanding of the southern African Middle Stone Age (MSA).The evolution of dating techniques and their application to southern African MSA sites has not only refined our understanding of human technological and cognitive development but has also highlighted the complex interplay between methodology, interpretation, and politics for the construction of past narratives. As this review has demonstrated, the introduction of methods such as radiocarbon, luminescence, electron spin resonance (ESR), and uranium series dating has allowed archaeologists to overcome the limitations of relative dating systems, challenging Eurocentric narratives that once dominated the interpretation of Africa's role in human evolution. While the debates surrounding the SB and HP technocomplexes still highlight the challenges of establishing precise temporal markers in a region as archaeologically rich as southern Africa. The application of Bayesian modelling, machine learning and multi-method dating approaches offers a path forward. These tools provide greater precision and clarity, allowing us to test the validity of past assumptions while forging new interpretations of human innovation during this critical period.

Beyond addressing the much debated technocomplexes, moving forward, addressing spatial and temporal sampling biases should be a priority. Southern Africa's coastal sites have dominated the narrative due to their exceptional preservation, but interior regions and open-air sites remain underrepresented. Future research should focus on these less-studied areas, applying cutting-edge methodologies to generate a more complete picture of human activity across southern Africa. By closing the gaps in our knowledge, particularly in the early phases and later phases of the MSA and underrepresented regions, we can continue to unravel the complex history of human evolution and innovation in southern Africa.

As we move toward more comprehensive and nuanced interpretations of the past, we need to acknowledge the scientific innovations over the last fifty years that have helped reformat our understanding of modern human evolution and behaviour. The sites of these studies, in turn, became host to a variety of experimental dating techniques, pushing the science for greater precision and increased time depth. Southern Africa MSA chronology has therefore been pivotal in reformatting our understanding as modern humans while shaping the technology that will continue to define our archaeological explorations in years to come.

3. A Southern African Middle Stone Age Chronological database

The Middle Stone Age in southern Africa (~300-30 ka) represents a pivotal period in human evolution, characterised by significant technological innovations and behavioural developments that may have facilitated the long-term evolutionary success of *Homo sapiens* (Jacobs et al., 2008a; Wadley, 2015). However, the chronological information is scattered across multiple publications which limits the research scope and types of archaeological questions asked. A database which includes all numeric ages with an archaeological assemblage from diverse methodologies, would not only improve the knowledge of when and where people were living but also invite archaeologists to ask new questions around the emergence of complex behaviours – including symbolic expression and diversification in tool manufacturing techniques (Wadley, 2015; Wurz, 2014).

Understanding the emergence, spread, and adoption of new industries through time hinges on the development of robust chronologies. Recent decades have seen substantial advances in dating methodologies applicable to MSA contexts (Chapter 2). However, the resulting chronological data remains scattered across numerous publications, making regional and temporal synthesis challenging. This paper presents a southern African Middle Stone Age chronological database which will enable future archaeologists to create comprehensive framework and nuanced discussions of the southern African MSA.

This paper aims to develop this framework through (i) documenting and standardizing chronological data from MSA sites in southern Africa in a comprehensive database; (ii) establishing a flexible approach to quality assurance which accommodates multiple dating methods; and (iii) presenting a case study which demonstrates the potential use of the data base

to explore temporal and spatial patterns in the dating record. Throughout this process, this paper explores the potential biases and gaps in our current understanding of MSA chronology which may influence future applications of the current database.

3.1. Background

The availability of large databases opens new doors to understanding temporal patterns between sites and technological trends. Perhaps one of the simplest uses of archaeological databases is as an indicator of human presence and occupation intensity (Blome et al., 2012). This technique was used by Klein et al., (2004) to argue that there was reduced human occupation in South Africa during ~60 ka and 30–20 ka. However, this conclusion is limited as it falls into the absence-of-evidence fallacy, whereby the absence of evidence provides the illusion of the validity of a proposed claim. Furthermore, this interpretation is complicated by dating-technique thresholds—most notably, radiocarbon dating becomes unreliable between ~30–50k years due to too little ^{14}C remaining. In contrast, several researchers argue that the interior regions of southern Africa were clearly occupied throughout the MSA (e.g., Barham & Mitchell, 2008; Wadley, 2015; Wilkins, 2021). Wadley (2015, p. 167) notes that "there are abundant ages for the late MSA in southern Africa's interior," a point reinforced by multiple well-dated sites. This is supported by sites like Melikane Rock Shelter in Lesotho, located in Maloti-Drakensberg Mountains, Wonderwerk Cave which overlooks the Kalahari Pans, Florisbad's Flat, grassy, semi-arid interior landscape or the high preservation Border Cave's Lebombo Mountains escarpment overlooking low-laying plains (Chazan et al., 2020; Pinder, 2021; Stewart et al., 2012; Wadley et al., 2020). These settings demonstrate the diversity of MSA occupations, a contrast to the more homogenous temperate, high-preservation coastal caves traditionally associated with the southern African MSA (Stewart et al., 2012).

Statistical methods and machine learning applied to databases further enable exploration of human presence and absence across diverse landscapes and time periods. This is demonstrated by Bousman and Brink (2018) who combined radiocarbon dates with archaeological records to model the emergence of the early LSA in southern Africa. In eastern Africa, Timbrell et al. (2022) developed a spatiotemporal paleoenvironmental framework to understand MSA/LSA transitions. These papers collate data from multiple sites, allowing researchers to access and evaluate both chronological, environmental and archaeological associations. Despite these statistical applications, few databases exist, thereby limiting the depth of inquiry. Wilkins (2020, p. 300) suggests that:

"*If the right dataset for this kind of meta-analysis was available to them ka could have, for example, examined the relationship between different environments and backed pieces (presence/absence of backed pieces, relative frequencies, different morphologies of backed pieces), and potentially discovered some informative environmental and temporal structuring. Likewise, Jacobs et al., (2008) could have established robust chronologies for the occurrences of bifacial points and backed pieces, completely independent from NASTIES [Named Stone Tool Industries].*"

To achieve this depth of inquiry requires two sets of data (1) archaeological data of a standardised reporting system for stone artefacts and (2) a chronological database. Several databases are moving towards this direction (Table 3.1). While Kandel et al. (2023)'s Role of Culture in Early Expansions of Humans Out of Africa Database (ROCEEH) moves towards the first type, with detailed descriptions of layer finds and stratigraphy, it does not include the ability to rigorously explore or model the chronology of the site. Chronologically and environmentally focussed databases may include archaeology bearing sites, but this information is considered secondary to the chronology itself. This results in low preservation of the archaeological contextual data. The southern African Radiocarbon database of Loftus et

al. (2019) is an exception to these pitfalls, providing both chronological and archaeological data.

Table 3.1: Databases utilised in the design and structure of the southern African Middle Stone Age

Database	Period	Region	Data type	Quality control method
ROCEEH (Kandel et al., 2023)	3 Ma-20 ka	Global	Summarised high resolution archaeological data	Systematic flow chart for each category
Southern African Radiocarbon Database (Loftus et al., 2019)	<~50 ka	Southern Africa	Radiocarbon ages and Archaeology association	unknown
Quaternary paleoenvironmental record from fluvial sediments in south-western Africa (Walsh et al., 2023)	132 ka - present	South-western Africa	Luminescence and radiocarbon dates for fluvial sediments from paleoenvironmental sites	Only peer-reviewed studies; Three-tier data categorises based on clearly located and stratigraphically constrained sites; metadata recorded for method, dose, and uncertainty
INQUA (Lancaster et al., 2016)	500 ka – present (upper limits of luminescence dating)	Global	Luminescence and radiocarbon ages for sand dunes Note: it does not contain dose rates	Four-tier data quality categories (1-4) based on completeness of metadata

The southern African Middle Stone Age faces a particular challenge as it is the focus of multiple established and experimental dating techniques (Chapter 2) which has baring on the interpretation of the age derived from each method. While it is important to infuse some level of knowledge on the data within the database as to prevent its misuse, this can prove challenging as multiple dating techniques provide ages for different contexts (Table 3.2, Supplementary Table 3.I). For example, luminescence dating, cosmogenic radionuclides for depositional events, ESR and uranium series dating constrain the timing of depositional events. This makes them important tools in understanding depositional events and site chronologies. However, these techniques do not provide the direct age of the artifact's manufacture or initial use. However, radiocarbon, ESR on teeth and AAR measure the timing of the death of organic remains, which provides a minimum age for manufacture. Meanwhile, thermoluminescence on heated lithics dates the last heating event, which potentially records the production of heat-treated tools. Understanding these differences, combined the statistical method used to derive each dated sample (Supplementary Table 3.II), is important for understanding what each individual age in the database is reporting.

Table 3.2: Summary of techniques applied to the southern African MSA

Technique	Age range (years ago)	Material	What are you dating?	Notes
Radiocarbon Dating (Ramsey, 2008; Loftus, 2023)	50-50 000	Organic remains	Death of organic organism	Requires Calibration; Contamination of modern carbon can result in erroneously young age.
Luminescence Dating – Grains (Aitken, 1990; Tribolo, 2023)	0-200 000 +	Quartz (OSL, SG-OSL, VSL); Feldspar (IRSL, post-IR IRSL, SG post-IR IRSL, IR-RF)	Burial event	Requires light exposure to reset signal followed by burial. OSL on quartz most widely used in southern African MSA; resets quickly with sunlight. Single grain techniques detect partial bleaching and post-depositional mixing. Feldspar accesses older age ranges but fades over time, requiring corrections. VSL and IR-RF target deeper, more stable quartz traps for older sites.
Luminescence -Lithics (Aitken, 1982, 1990; Furetta, 2010; Tribolo, 2023)	0-500 000 +	Quartz, feldspar in burnt lithics (TL)	Heating event	Requires exposure to heat to reset the signal. Used extensively on heat-treated lithics at Blombos Cave, Diepkloof and Klasies River Cave.

U-series (Grün and Stringer, 2023)	0-500 000	Calcium carbonite features (e.g. speleothems, shells, teeth)	The formation or uptake1 of the CaCO3 artefact	Open systems require caution as uptake may be non-linier, requires additional calibration
ESR (Grün, 2008)	1000-1 000 000+	Tooth enamel, quartz, carbonates, shells	The burial event or formation of the artefact	Dependent on environmental dose rate and internal dose rate
U-series ESR (Spötl and Boch, 2019)	1000 – 200 000	Tooth enamel, shells	Burial event of teeth/fossil	Combines U-series dating with ESR to account for uranium uptake history in fossils
AAR (Penkman, 2023)	0-1 000 000 (relative)	Organic remains (often shells)	The death of the organic organism	Sensitive to heat within the ambient environment, requires careful localised calibration
Cosmic nuclide dating (Schaefer et al., 2022)	1000-10 000 000	Rocks, sediments (containing quartz, olivine, etc.)	Surface exposure time or erosion rates	Landscape evolution studies and exposure dating

3.2. Methodology

This database comprises peer-reviewed ages from Middle Stone Age (MSA) sites in southern Africa (South Africa, Namibia, Botswana, Zimbabwe, Zambia, Mozambique, Lesotho, Mozambique). Ages were derived from multiple dating techniques including radiocarbon, luminescence (OSL, TL), ESR, U-series, U-series/ESR, and AAR (Table 3.2). First, data collection included identifying archaeological sites, their associated chronologies and relevant low resolution archaeological data (Figure 3.1). Second, sites and ages underwent an initial screening process for inclusion/exclusion. Finally, ages were reviewed for reliability.

3.21. Date Collection: Search and entry

The initial database construction followed a two-phase approach:

a) Phase 1: Site Identification:

Sites were identified through three distinct approaches, first through comprehensive Middle Stone Age review articles and edited volumes [see: Jacobs et al., (2008), Lombard et al., (2022), (2012), Mitchell, (2008), Stratford et al., (2021), Wadley, (2015), Beyin et al., (2023) and Stewart and Jones, (2016)]. Second, we searched established archaeological databases (see: ROCEEH and Southern African Radiocarbon Database). Finally, additional sites were identified through systematic searches in digital academic catalogues including Google Scholar and Scopus using the following keyword combinations:

> *[MSA, Middle Stone Age, Howiesons Poort, Still Bay, Fauresmith] + [southern Africa, South Africa, Namibia, Botswana, Zimbabwe, Zambia, Mozambique, Lesotho].*

b) Phase 2: Chronometric Data Collection

Once Middle Stone Age sites were identified, primary publications with original age determinations were extracted from the review articles. Additionally, each site underwent a targeted search on Google Scholar using site-specific keywords:

> *[Site name] + [chronology, dating, ages, luminescence, OSL, uranium-series, radiocarbon, amino acid racemisation].*

3.2.2. Initial Screening: site and sample inclusion

All dates explicitly associated with an archaeological assemblage, regardless of quality, were extracted from their papers and documented within a spreadsheet. Notably, sites which are environmentally focused and have archaeological implications, but no documented chronology association with archaeological layers, were excluded. Similarly, open air finds were not included as their provenance is complex. Appropriate ages primarily relied on Level 2 sources – primary data published within the initial chronological report (Kreutzer et al., 2023). When only Level 3 data – a paper only reporting on the primary data available elsewhere – is available the original reference is noted in the "primary reference" column within the database (Table 3.4). This approach is to ensure preservation of data and easy correlation with the original publication. This approach is similar to the Southern African Radiocarbon Database, presented in Loftus et al., (2019), whereby the raw data is included and dates are not excluded if they have chronological concerns. Additionally, original and revised ages were kept in the database. Notably, this includes select 'grey literature' ages from Masters and Doctoral theses which are subsequently referenced in peer-reviewed journals and edited volumes. In cases of duplicate ages, if an age is revised, we recommend going with the most recent recalculation.

The data collected and recorded include location, publication data, archaeological association, dating information, any additional notes and quality control across 49 columns (Table 3.3). Columns were ascribed 'required' and 'additional' status. 'Required' data is necessary

irrespective of methodology used to on the dated samples. These are required in order to track and access the validity of the age or whether the age is misreported or repeated elsewhere. Additional data, in contrast, is used to support the age and ensure quality control for specific techniques. All data reported is sourced from the original publication associated with the ages. These columns enabled the subsequent quality control, where missing data and its associated concerns are documented directly in the dataset.

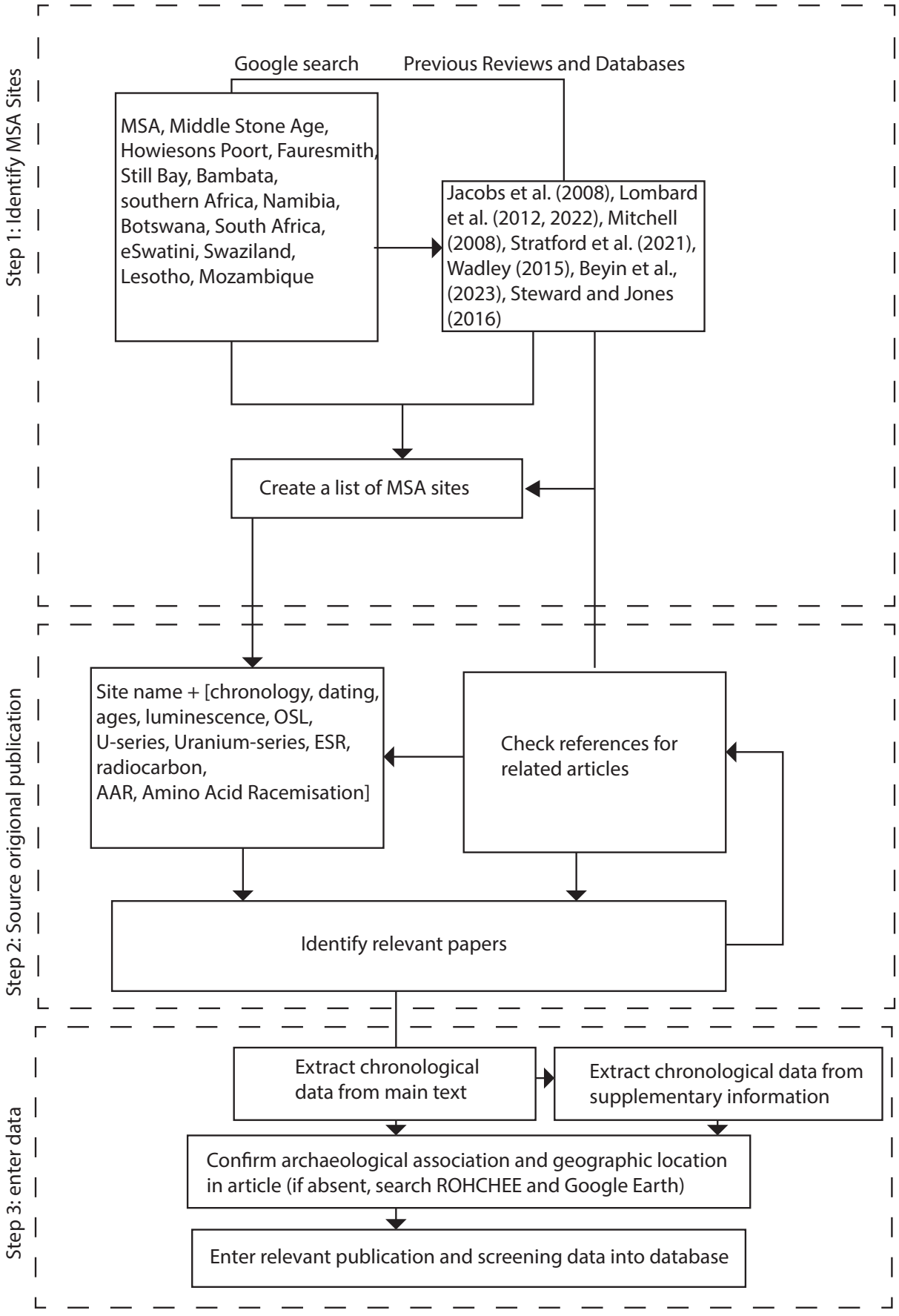


Figure 3.1: Workflow of database construction from initial search to data entry

Table 3.3: Data included in the database

Category	Column	Description	Required/Additional
Location	Site	Name of site	Required
	abbreviation	short site code	
	DD (S)	Latitude (Decimal degrees)	
	DD (E)	Longitude (Decimal degrees)	
	country	modern country that the site resides in	
	Site type	cave, rock shelter, open-air site, or sand dunes	
Publication	paper	In text reference	
	Publication year	Publication year	
	Sup info	Is data included in the supplementary information of the paper?	
	DOI	stable link (e.g., DOI) or complete reference	
Excavation data	Sampling year	Calendar year of sample collection	Additional
	Strat layer & unit	Layer and unit designation within site stratigraphy	
	Depth (cm)	Vertical position of sample relative to site datum (in cm)	
	Square	Excavation grid reference for sample location	
Archaeological	Assigned Industry	Technocomplex associated with the dated layer, or notation if sterile or unassigned	Required
	Assigned_Industry_Sum	Lower resolution archaeological association	

Dating information	method	Specific technique used for age determination (e.g., AMS 14C, single-grain OSL)	Required
	sum_method	Broader category of dating technique (e.g., radiocarbon, luminescence)	
	dated artefact/geology/organic	Type of sample analysed (e.g., quartz grains, feldspar, charcoal, faunal remains)	
	Sample notes	Relevant details about the sample (e.g., species, grain size, field code)	Required
	Lab name	Facility where the chronometric analysis was conducted	
	lab reference	Unique identifier assigned by the dating laboratory	Required
	Flag (>/<)	Is the age provided as a minimum or maximum age	Additional
	reported age ka	Numerical age and error (reported to 1σ unless otherwise stated) in thousands of years (Ka) before present Note: Radiocarbon ages are reported as uncalibrated	Required
	reported age (±) ka		
	Dose rate (Gy. ka-1) (luminescence & ESR only)	Environmental Dose Rate (Dr) and Error: Measured in Grays per thousand years Note: If known, method of measurement (e.g. in situ, laboratory, or combined) is reported in chronology notes	Additional
	Dose rate (±) Gy. ka-1 (luminescence & ESR only)		
	De Gy (luminescence & ESR only)	Equivalent Dose (De) and Error: Measured radiation dose and associated uncertainty in Grays (Gy)	
	De ± Gy (luminescence & ESR only)		
	Model	Analytical approach used to derive the final age	
	Overdispersion (luminescence, grains only)	The scatter in De values, expressed as a percentage	

	Number of Grains/sizes of aliquot (luminescence, grains only)	Number of individual grains or aliquots accepted for determining the age Note: Larger numbers generally increase age accuracy and precision	
	FFM proportion (luminescence, OSL-SG only)	Proportion of grains used for De calculation	
	Original error (+) ka	If the error was originally reported differently, this is the (+) and (-) which is averaged in the presented database	
	Original error (-) ka		
Additional information	Archaeological notes	Relevant information about associated artifacts or features	Additional
	Notes	Any additional information	
	Location/stratigraphic Notes	Additional details about location or correlation of the sample	
	Method notes	Additional details about sample preparation or analysis	
	Minimum age (True)	If true, this age must be treated as a minimum age or *terminus post quem*	
	Maximum age (True)	If true, this age must be treated as a minimum age or *terminus ante quem*.	
Quality control	Dating concerns	Any information discussed in the paper relating to the reliability of the age	Additional
	Archaeological association concerns		
	Grey literature	This paper is not in a peer reviewed journal	
	Missing data	This sample is missing data	

	Primary source	If the reported paper is referencing a previous publication which could not be accessed, what is the reference for the age	
	Revised ages	Is this age a revision of a previous publication	
	Missing data (required)	Which ‘required’ columns of data are missing. If any, this age must be treated with significant caution.	
	Missing data (additional)	Which ‘additional’ columns of data are missing. If any, this age must be treated with caution	

3.2.3. Quality Assurance: A Nuanced Approach to Data Robustness

Quality assurance is a crucial yet challenging aspect of database development, especially in dating of archaeological sites. Striking a balance between stringent criteria and inclusivity is essential to avoid excluding valuable information while maintaining data integrity. Our approach to quality assessment in this database aims to address these challenges effectively. This database adopts a methodology similar to that used by Boisard and Arous, (2024). This approach emphasizes understanding the trustworthiness of each age determination and clearly communicating potential concerns. By doing so, we provide a nuanced quality assessment that recognizes the complex and often ambiguous nature of archaeological dating. This approach differs from more rigid quality control measures, such as those employed in environmental chronological datasets (e.g.,Woor et al., 2022), for several key reasons:

i) Avoiding Bias Reinforcement: Strict robustness tests can inadvertently favour well-resourced regions or sites, potentially reinforcing existing biases in the field. This more flexible approach allows for the inclusion of data from less extensively studied areas.

ii) Accommodating Multi-Method Complexity: Unlike databases focused on a single dating technique, our multi-method approach necessitates a more adaptable quality assessment system. Each dating method offers different temporal resolutions, precisions, and interpretative challenges, which we address through detailed methodological notes rather than a one-size-fits-all quality metric.

iii) Preventing Data Misinterpretation: A simplified quality indicator (e.g., a "green standard") can be misleading. Archaeologists might mistakenly apply such ratings to artefacts or stratigraphic layers rather than the dating process itself, while chronologists might make unwarranted archaeological claims without considering

contextual integrity. Our system encourages users to engage critically with both chronological and archaeological aspects of the data.

Instead of assigning quality ratings to individual ages, we provide comprehensive methodological and chronological notes that document any concerns with the data. This approach allows both archaeologists and chronologists to make informed judgments about the applicability of dates to their research questions. While an alternative approach of quality-checking entire site chronologies was considered, we believe that such assessments are best left to the judgment of database users who can evaluate the data in the context of their specific research needs. The case of Diepkloof Rock Shelter illustrates the complexity of this issue. This important MSA site in South Africa has two conflicting chronologies, both published by reputable research teams using state-of-the-art dating methods (Jacobs and Roberts, 2017, 2015; Tribolo et al., 2013, 2009).

If we were to implement a rigid quality control system, both chronologies might receive high ratings based on their methodological rigor. However, they cannot both be correct given their significant temporal disagreement. This situation highlights the limitations of applying standardized quality metrics to complex archaeological contexts. By providing detailed methodological notes and raw data for both chronologies, our database allows researchers to critically evaluate the evidence and make informed decisions based on their own expertise and research objectives.

This approach not only accommodates the Diepkloof Rock Shelter controversy but also addresses other cases where seemingly robust chronologies may be complicated by factors such as site formation processes, sample selection, or evolving dating methodologies. It encourages a more nuanced and context-specific interpretation of chronological data, which we believe is crucial for advancing our understanding of the MSA in southern Africa.

By adopting this flexible yet informative system, this database attempts to provide a valuable resource that balances the need for quality control with the recognition of the complex nature of archaeological dating. This approach encourages users to critically engage with the chronological data, considering both its strengths and limitations in the context of their research. In an ideal world, close collaboration between archaeologists and chronologists would mitigate many of these challenges. However, recognizing the practical limitations often faced in research, this database is designed to serve both disciplines effectively by providing transparent, detailed information about each age determination.

3.2.4. Analysis

The database was analysed using R programming software and ArcGIS Online, ArcGIS Pro. Radiocarbon dates were calibrated in OxCal using the SHCal20 (Hogg et al., 2020; Ramsey, 2009).

3.3. Results

There are 1812 dates from 88 MSA bearing sites included within the database (Appendix A, Supplementary Table 4.I). These dated MSA sites represent 76% of sites with a documented MSA assemblage. Of the 1812 ages, 1440 are dated to >30 ka and <300 ka. The 345 ages dated to <30 ka either are erroneous, transitional/late MSA or contain other information important to interpreting the chronology of their sites. The 27 ages dated to >300 ka predominantly represent early transitional MSA (e.g., Fauresmith) contexts. Of the >30 and <300 ages, 201 (13.9%) are recalculations of the original data presented elsewhere in the database. Both the recalculations and the original are documented within the database, are linked through their sample code and within the revised age column. The remaining 1238 unique ages from 971 samples, >30 ka and <300 ka, are associated with archaeological sites within the studied region.

3.3.1. Temporal distribution of MSA sites

The 57% of ages from MSA sites occur between 30 ka and 90 ka (Figure 3.2). Statistical analysis using the √n method to estimate expected noise reveals several time periods with significantly higher concentrations of dates than would be expected from random variation alone. While these concentrations represent systematic patterns in our chronological dataset, distinguishing between archaeological phenomena (occupation intensity, preservation) and research biases (concentrated dating efforts on particular industries or well-known sites) requires careful interpretation. Specifically, we identified statistically significant concentrations (exceeding the mean + 2×√n threshold) with a spike at 30-35 ka, followed by decrease between the subsequent 35-40 ka and 40-45 ka bands. There is another spike at 45-50 ka. The number of dates once again drops at 50-55, only to jump again at 55-60 ka. The ages then drop between 60-70 ka, 75-80 ka, 80-85 ka, and 90-95 ka. After this, while trends are observed, they are not statistically significant at this level of chronological resolution. The subsequent sections critically evaluate whether these temporal patterns reflect genuine MSA dynamics or research intensity, drawing on the biases and methodological constraints documented in Section 3.2.3.

3.3.2. Temporal distribution of dating techniques

The dominance of different dating methods in different time periods highlights the importance of considering methodological biases when interpreting the significant chronological patterns identified in Section 3.1. However, the statistical significance testing suggests that many of the observed temporal patterns represent archaeological phenomena rather than merely reflecting shifts in dating methodology. Radiocarbon dating remains the dominant method up until its upper limits. However, many of these ages are infinite, i.e. there is too little carbon left within the sample to measure beyond the calculated age and should be treated as minimum ages.

Luminescence dating on sediment increasingly contributes more as we approach radiocarbons upper limit where it becomes and remains the most dominant technique for dating the MSA. Luminescence dating of lithics stays somewhat steady throughout MIS4, after which it does not contribute many ages. While U-series and ESR are not exceptionally popular they contribute to developing chronologies throughout most of the MSA. AAR makes a very small contribution but is often coupled with better established methodologies. While sites like Pinnacle Point, Klasies River, Blombos Cave are good examples of this multi-method approaches to dating (e.g. Jacobs, 2010; Jacobs et al., 2013; Marean et al., 2010; Tribolo et al., 2006), at most sites a single method dominates (Figure 3).

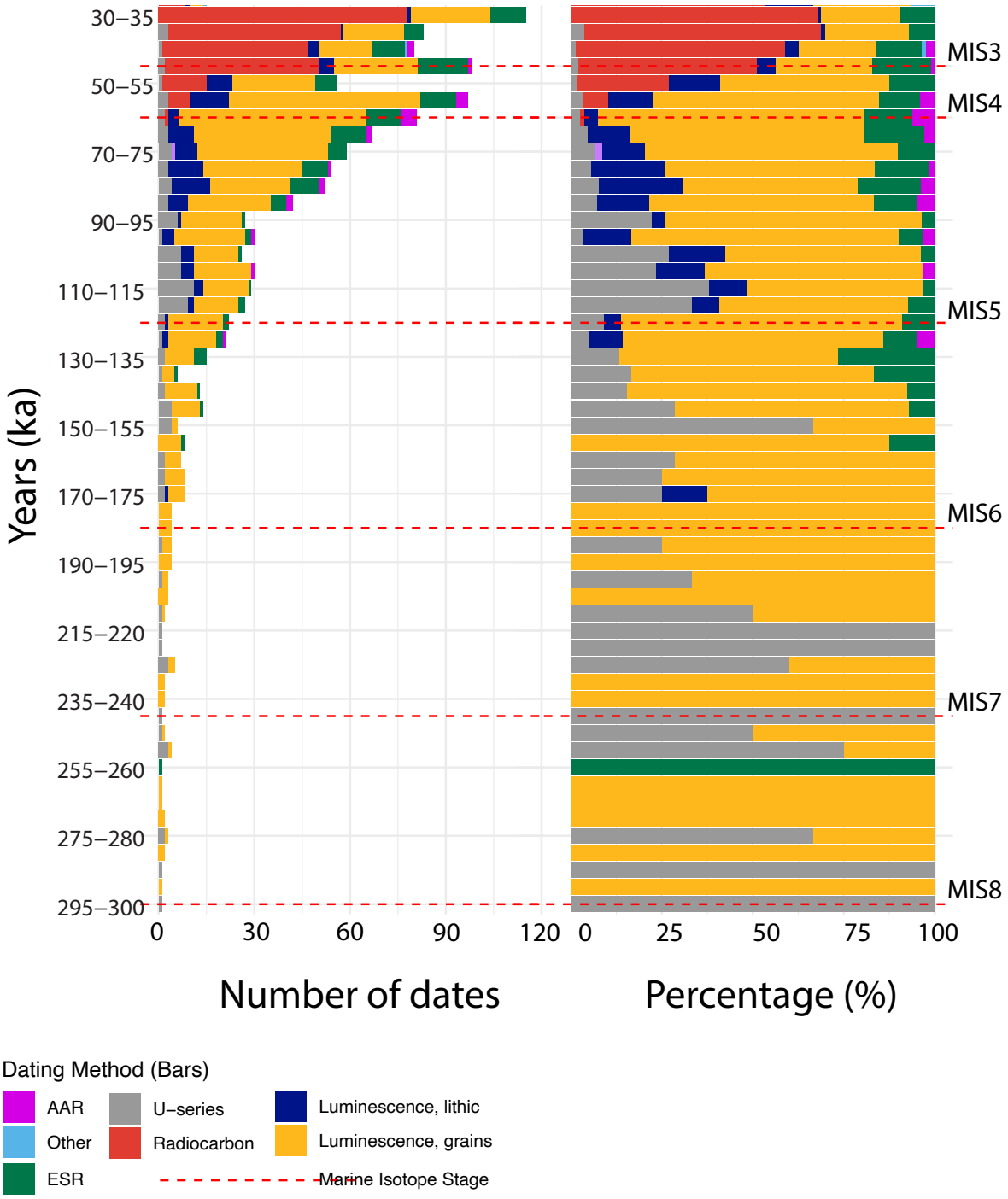


Figure 3.2: Numeric ages within the southern African Middle Stone Age chronological database, this includes all unique ages and excludes recalculations age. (a) number of ages per 5 ka time bracket (b) techniques used to obtain dates within 5 ka time brackets.

3.3.3. Spatial Distribution of MSA sites in southern Africa

Despite South Africa only representing 56.3% of documented sites, 85% of these ages are within its borders (Figure 3.3). While Botswana and Namibia have limited archaeological site

chronologies, evidence of human presence appears in luminescence studies focused on paleoenvironmental research (see: Burrough et al., 2009; Burrough and Thomas, 2013; Stone et al., 2024; Walsh et al., 2023). However, inconsistent reporting of archaeological findings in these environmentally focused studies prevented their inclusion in our initial database. Within South Africa, chronologies are predominantly clustered within the Western Cape. With Border Cave as an exception, more ages are derived for these well-preserved coastal sites when compared with southern Africa's interior (Chapter 2).

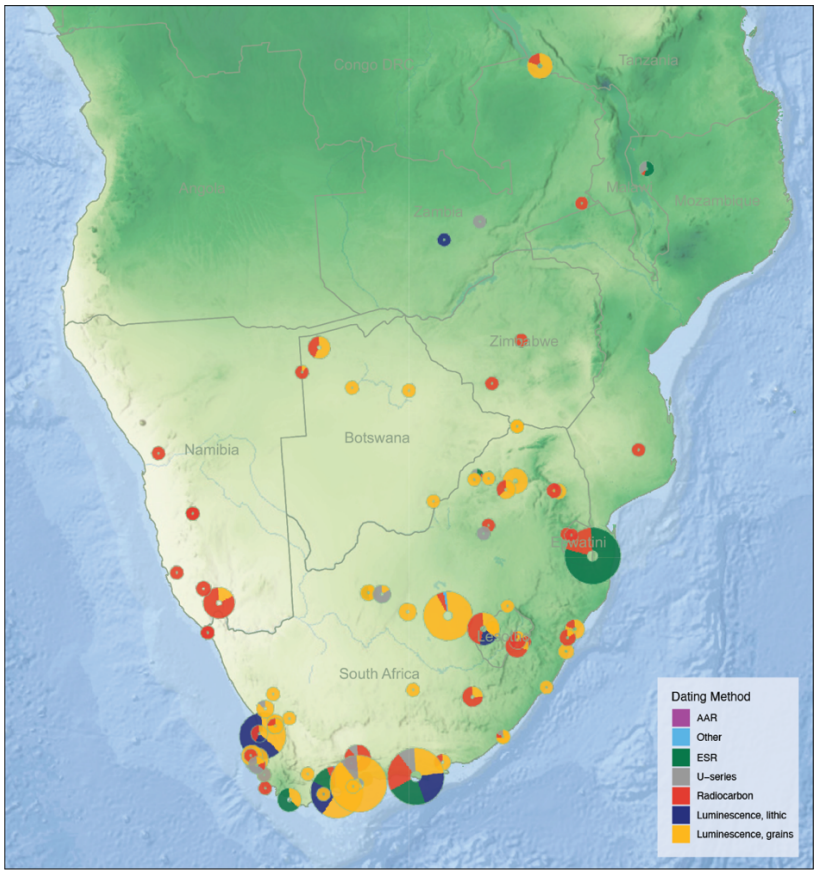


Figure 3.3: Map displaying proportion of ages associated for MSA sites in southern Africa and their associated methodologies. The larger the circle the more dates present at the site.

3.3.4. Quality assessment outcomes

81 ages from 21 sites are missing required data [i.e. ages, error margin (if not minimum or maximum age), sample/laboratory reference]. While included in the database for completeness, these results, without an age, error margin, or minimum flag, should be excluded from inter-

site chronological analysis, though they may still be appropriate when discussing the chronology of a single site, or history of research at that site. While ages lacking a unique identifier (i.e. sample name) may still hold merit, there should be increased caution as there is a risk that the sample is duplicated or reported in another form, it also complicates quality checking control. 244 dates are missing additional data, of these 230 are from luminescence methodologies while 14 are from ESR ages. Older samples, often lacking reported dose rates and equivalent doses, overdispersion and models should be treated with caution and rejected from further analysis if equivalent, more complete alternatives exist (Mahan et al., 2022). Some sites contain all required data but have other archaeological (74 ages) or chronological concerns (158 ages). Addressing these concerns are vital as while the standalone age seemingly correct age, what is being dated is problematic or unclear. Other issues should be addressed on a case-by-case basis by referring to the primary source and accessing whether the age can be trusted or holds merit for the specific question.

3.4. Discussion: Spatial -Temporal Visualisation of MSA lithic trends

This new southern African MSA database reveals several important temporal (Figure 1) and spatial (Figure 2) patterns throughout the MSA. Investigation of these patterns enables further engagement with existing archaeological theory as well as open up the potential for new types of archaeological enquiry. Importantly, this database also enables us to determine if any spatial or temporal bias exists within the data which may influence current archaeological theories. In order to address these patterns, first, the temporal pattens within the MSA will be explored, followed by an investigation of the emergence of technology using spatial-temporal maps.

3.4.1. Early MSA Foundations: Human Occupation Before 130 ka

There are a limited number of samples dating to before 130 ka in the database. Despite this paucity of archaeologically associated dates, the evidence clearly indicates that southern Africa

was not devoid of human occupation during this period. While the density and distribution of occupation remain poorly understood, we know that *Homo sapiens* and other hominin species inhabited both coastal and interior regions (Chazan et al., 2020, 2013; Dirks et al., 2017; Marean, 2011; Wadley, 2015; Wurz, 2014). The chronological evidence for early MSA occupation follows a geographical pattern that can be divided between coastal and interior sites. Coastal evidence comes from several key sites including Pinnacle Point, Nahoon Point, Elands Bay Cave, and Duinefontein (Feathers, 2002; Jacobs, 2010; Jacobs and Roberts, 2009; Tribolo et al., 2016).

Interior sites have yielded even older evidence for human presence in southern Africa. On the highveld, the famous Florisbad *Homo sapiens* cranium has a direct ESR age of 259 ± 35 ka (Grün et al., 1996). When initially published, this discovery positioned Florisbad as the oldest *Homo sapiens* cranium in the world, supporting a southern African origin hypothesis for our species. However, subsequent discoveries at Jebel Irhoud, Morocco, dated to 315 ± 34 ka using TL methods (Hublin et al., 2017; Richter et al., 2017), have shifted consensus toward a pan-African origin model. Despite this, the Florisbad findings remain crucial evidence for the early presence of *Homo sapiens* in southern Africa. It is important to note that the Florisbad skull lacks clear spatial association with lithic technology, leaving the possibility that this individual could have produced either ESA or MSA artefacts (Feathers, 2002).

Additional interior evidence for early MSA occupation comes from Border Cave, Mwulu's Cave and Wonderwerk Cave. Border Cave has some of the best-preserved early MSA occupations, containing both lithic artefacts and grass bedding dated to 200 ka (Wadley et al., 2020). At Wonderwerk, Chazan et al. (2020) provided four TT-OSL ages (238 ± 13 ka, 188 ± 21 ka, 172 ± 16 ka, and 153 ± 15 ka) for the Fauresmith layers. These dates, with approximately 10% precision, overlap with earlier U-Th ages on stalagmites reported by Beaumont and Vogel (2006). Although these dates have relatively larger absolute error margins (albeit regular error

percentages) compared to those from more recent periods (30-130 ka), they nonetheless provide valuable temporal resolution for understanding the presence and movement of early MSA populations in southern Africa's interior.

3.4.2. Limited Evidence or Limited Occupation? The 80-130 ka Transitional Period

The 80-130 ka period shows a slight increase in the number of directly dated samples compared to earlier periods, making it potentially viable for statistical analysis. However, the quantity of dates remains relatively low, prompting questions about what this pattern represents in terms of human occupation. Two primary hypotheses might explain this pattern of limited dates. First, it may reflect genuinely lower human occupation density that only begins to increase during late MIS6/MIS5. The archaeological evidence from this period, while present, does suggest less intensive occupation compared to later periods of the MSA. Alternatively, preservation factors may be responsible for the relative scarcity of dated samples as the older the site the less likely the context and artefacts survive.

For coastal sites specifically, sea level fluctuations have significantly impacted preservation. Cawthra et al. (2018), using OSL-dated offshore cores, demonstrated that the southwestern South African coastline experienced dramatic shifts between ~29-36 m below and ~9-13 m above current mean sea level during the period from ~150 to ~125 ka. These substantial fluctuations correlate closely with the observed reduction in archaeological dates from coastal sites. Consequently, coastal human occupation evidence from this period may have been destroyed by erosion during marine regression and transgression cycles or may remain submerged beneath current sea levels. However, it is important to note that sea level fluctuations cannot explain the similar pattern of limited dates observed at interior sites, which would have been unaffected by these coastal processes. Interior sites may still be effected by fluctuations in rainfall and formation and drying up of pans (Burrough et al., 2009; Walsh et

al., 2023). The consistent pattern across both coastal and interior regions lends some support to the hypothesis of genuinely lower human occupation intensity during this period. Without significantly more research and systematic surveys targeting sites with early technological innovations, both coastal and interior, these interpretations remain speculative. The database highlights this period as a critical target for future chronological research to better understand human presence and behaviour during this important transitional time.

3.4.3. Peak Innovation and Research Intensity: The MIS4 Period (80-50 ka)

The number of dated samples increases substantially throughout MIS4 (80-50 ka), with a notable peak occurring at 55-60 ka. This chronological pattern reflects both archaeological realities and research biases that require careful interpretation. The peak in dating frequency at 55-60 ka likely stems from intense research interest in the HP and SB technocomplexes, which has led to concentrated scientific investigation of coastal sites containing these industries. This may be compounded by complexity of obtaining funding and conducting research for newer sites. This research bias must be considered when interpreting the temporal distribution of dates in our database. This is because, as with other periods, without explicitly exploring spatially diverse sites as well as periods of hiatus and site abandonment, age intensity cannot be taken as occupation intensity (Attenbrow and Hiscock, 2015).

The dating methods applied during this period also reveal interesting patterns that reflect both methodological developments and changes in past human behaviour. While luminescence techniques analysing sediment (particularly OSL and OSL-SG) dominate the dating record for this period, there is a notable increase in thermoluminescence (TL) dating. This increase in TL application coincides with the earliest evidence of heat treatment lithics at Pinnacle Point around 164 ka, allowing direct dating of these artefacts. However, the widespread proliferation of heat-treated lithics only occurs much later, around 72 ka (Brown et al., 2009; Mourre et al.,

2010). This temporal pattern represents an important behavioural marker captured within our chronological database, demonstrating how dating efforts can track technological diffusion through time. The substantial increase in numeric dates during MIS4, while partly reflecting research interests, nonetheless provides a robust framework for understanding this pivotal period in MSA technological and behavioural development.

3.4.4. Reassessing Population Continuity: The Late MSA (50-30 ka)

The 50 - 30 ka period (roughly corresponding to MIS3) shows comparatively fewer dated samples than the preceding period, particularly when compared to sites with layers dating to 50 - 55 ka (Figure 3.2). This apparent reduction in chronometric dates requires careful interpretation, as it may reflect methodological constraints and research biases rather than actual patterns of human occupation. A primary methodological consideration is the technical limitation of radiocarbon dating. As we approach radiocarbon's upper reliable limit (approximately 50 ka), the number of viable samples naturally decreases. While luminescence dating techniques could theoretically compensate for this limitation, their application has not been as widespread for this time period (Figure 3.2), creating a potential methodological gap in the chronological record. It is important to note, however, that these trends appear to be statistically significant and therefore further archaeological investigation is required.

Despite this, there is an established research bias for the SB and HP industries of the preceding period. This concentrated research interest has resulted in fewer dating efforts directed toward the 50-30 ka timeframe, making it difficult to use the available dates as reliable markers of occupation intensity. Our database analysis therefore challenges Klein et al.'s (2004) hypothesis that the reduced number of dates from this period reflects an actual reduction in human population. The evidence suggests instead that the apparent decline in chronometric dates is

more likely a product of the methodological and research biases described above rather than demographic changes.

The spatial distribution of dates from this period also reveals significant regional disparities. Interior sites generally have fewer dates than coastal locations, creating a geographical bias in our understanding of human occupation patterns. While it remains possible that interior occupation during this period was indeed more sporadic than coastal settlement, the current evidence is insufficient to draw firm conclusions. However, understanding these patterns is important as it enables understanding of migration patterns and responses to climatic change – something coastal sites are more protected from (Burrough et al., 2009; Burrough and Thomas, 2013; Walsh et al., 2023). This period clearly highlights the need for targeted dating projects specifically focused on the 50-30 ka timeframe, particularly at interior sites. Addressing these chronological gaps would significantly enhance our understanding of later MSA occupation patterns and provide a more complete picture of human presence across southern Africa during this important transitional period.

3.4.5. Spatial analysis

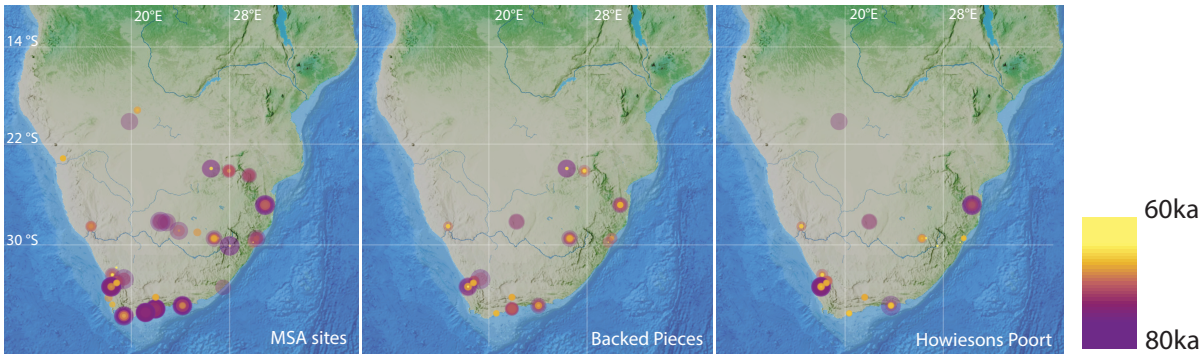


Figure 3.4: Population and technological trends through 80 ka-60 ka the larger the dot the further away in time (i.e. to 80 ka), the smaller the dot, the closer it is to 60 ka. Similarly, colour indicates the depth in time. Clustering of sites is visible with reduced transparency. 2 ka time slices of each map are available in Supplementary Figures I.

While the current data are not sufficient to conclusively support strong population density structures through time, the presence of dated archaeological sites can still inform on human and technological spatial trends. Figure 4 explores the prevenance of the presence of people, backed tools and the HP Industry. While these spatial trends have been explored in higher chronological resolution (see: Jacobs and Roberts, 2008; Kandel et al., 2016), or higher technological resolution, albeit lower chronological resolution (see: Mac kay et al., 2014), this case study demonstrates the applicability of combining these approaches through combining high resolution chronological and spatial data with archaeological assemblages. The mapped data uses the database mean of each age and the associated stone tool industry. All ages within this period are also matched to archaeological data noting the presence/absence of backed pieces from the ROCEEH database (Kandel et al., 2023).

From the time slices three clear patterns can be seen:

i) The population of southern Africa appears more evenly spread between 80-68 ka (Figure 3.a). At around 68 ka-64 ka there appears to be a clear reduction in archaeological sites in the interior. While sites like Melikane (29.95 ’S, 28.75 ‘E) disrupt the idea of an empty interior, it seems, at the least that interior occupations are not continuous in the same way the coastal sites are (Stewart et al., 2012). This discontinuity most likely is represented in the reduction of ages for this period. Interior sites begin to increase again at 64 ka.

ii) Backed pieces begin to increase in prevalence at 74 – 72 ka, 4 000 - 6 000 years before the rise in layers with documented HP presence. The backed pieces appear relatively evenly spread across the coast and interior MSA sites and is not exclusive to sites claiming HP assemblage. Interestingly, at around 66 ka their presence begins to decline in the interior and by 64 ka are mostly restricted to coastal sites with a reported HP assemblage. This interior decline and

subsequent HP restriction is in alignment with Jacobs and Roberts's (2008) timing of the HP to 64.8 - 59.5 ka.

iii) The HP is predominantly reported along South Africa's south-western coast. While some interior sites are present, these are predominantly older sites (78-72 ka) and may reflect improper association with the technocomplex (Lombard, 2005; Will and Conard, 2020). At 72 ka HP begin to appear across the South African coastline. Reports of this industry peak of 66 - 62 ka and then begin to decline. The peak we observe corresponds remarkably well with the controversial Jacobs and Roberts' (2008) findings, which precisely dated the industry to between 64.8 ka and 59.5 ka. Their comprehensive dating and statistical approach demonstrated that the HP represents a marker horizon of about 62 ka for southern Africa.

These three findings align with, and chronologically refine Mac kay et al. (2014)'s model of population coalescence and fragmentation. The appearance of backed pieces preceding the HP supports Mac kay's findings at Diepkloof and Pinnacle Point. However, this larger database suggests that backed pieces are not only restricted to sites with a reported SB assemblage but are in fact more broadly emerging within southern Africa. This suggests that emergent technologies may not be restricted to the southern African coastline but indeed have a broader or more nuanced origin. This broader distribution pattern supports ka concept of behavioural flexibility as the key adaptation of MSA populations, allowing for the flexible adoption of technologies across different environments. The subsequent reduction of backed pieces in the interior around 66 ka adds crucial spatial nuance to Mac kay's climate-region model, demonstrating that coastal-interior dynamics were as significant as broader climate zones in shaping technological distributions. Despite this, the similarities of lithic trends along the coastal sites are clearly not only an artefact of archaeological research bias but also a genuine feature of MIS4. This supports the observation that technological transmission patterns were complex and not solely determined by environmental pressures, with evidence for both Mac

kay et al.'s (2014) suggestion of population interconnectedness as a key driver of innovation, and Kandel et al.'s (2016) emphasis on behavioural flexibility as a key component of human adaptation of the MSA.

3.5. Conclusion

This database presents the first chronological database for the southern African Middle Stone Age. These ages were collated through exploring existing literature and digital libraries. Wherever possible, dates were extracted from the primary literature. These dates, their associated archaeological and chronological contextual data and the references were then documented into the new database. The ages underwent screening process to enable future users to make informed decisions about the quality and applicability of the data. Through including all dates form a secure archaeological context in the southern African MSA, this work provides complimentary on the chronological data to information documented in ROHCEE (Kandel et al., 2023), documents the human side captured in the luminescence only database presented in Walsh et al. (2023), and adds time-depth not captured in the Southern African Radiocarbon Database owing to methodological limitations (Loftus et al., 2019).

With 1840 documented dates from 145 sites, there is sufficient chronology to begin addressing question relating to spatial scales as well as technological innovation, adoption and abandonment. However, without high resolution lithic and faunal data, understanding new and emergent climatic and technological trends remains restricted. With the rising accessibility of machine learning and neural networks, archaeologists can use databases like this to explore old questions and critically, ask new ones previously obscured by poor chronological or spatial resolution. However, it is important that future research to acknowledge the potential spatial and temporal bias within the data collection and aims to address it through adjusting the research focus. While this database is small step towards understanding the spatial and temporal

trends of our collective past, it also offers us a window into the possibility of exploring previously restricted or neglected questions pertaining to the southern African Middle Stone Age.

Future research using this database opens up for larger scale studies of human occupation in the MSA. Understanding climatic trends and migration patterns may become more feasible as research are able to correlate archaeological sites with high resolution, localised climatic models. Similarly, combining robust lithic data with this database may help further untangle patterns of human migration and technological innovation, or resistance. While databases like ROCEEH provides a unique opportunity to do this with preexisting data, it is important to think about how to structure and publish upcoming data (Kandel et al., 2023). Once other categories of data are identified and correlated, new questions, exploring depth and breadth of human behaviour will be possible – from enabling collaboration across multiple sites, to exploring unique changes in adoption, abandonment and continuation of technological trends.

These questions will be further enhanced by focussing on the interior sites, and sites outside South Africa. This is particularly exciting as it provides the opportunity to explore the presence of people in less stable climatic regions. While these, often open-air sites, may be challenging to provide chronologies for, they cannot be ignored. If not explored, we cannot explain what humans were doing in the regions where ancient DNA suggests ancestral heritage, nor what people continued to do while others left Africa for different parts of the world (Chan et al., 2019; Schlebusch et al., 2021). While dating the SB and HP stone tool industries have clearly dominated chronological investigations, it is only a small fraction of the time (and space) which humans occupied. This new database, however, now enables us to reach beyond these spatial, temporal and terminological limits and explore new questions with old data.

Supplementary Tables 3

Supplementary Table 3.I: All dating techniques used for the southern African MSA

AAR		Amino Acid Racemisation	(Penkman, 2023)
Cosmogenic nuclide dating			(Schaefer et al., 2022)
ESR:		Electron Spin Resonance	(Grün, 2008)
	ICP-MS	Electron Spin Resonance with Inductively Coupled Plasma Mass Spectrometry	
	US-ESR	Uranium-series Electron Spin Resonance	
Luminescence:		Luminescence dating	(Tribolo, 2023)
	IRSL	Infrared Stimulated Luminescence	
	IRSL-IR50	Infrared Stimulated Luminescence at 50°C	
	IRSL DRC	Infrared Stimulated Luminescence using Dose Response Curve	
	IRSL H&L	Infrared Stimulated Luminescence using Huntley & Lamothe method	
	LM-OSL	Linearly Modulated Optically Stimulated Luminescence	
	OSL	Optically Stimulated Luminescence	
	OSL-SG	Single Grain Optically Stimulated Luminescence	
	OSL/TL	Optically Stimulated Luminescence/Thermoluminescence	
	pIR-IRSL	post-Infrared-Infrared Stimulated Luminescence	
	pIR-IRSL250	post-Infrared-Infrared Stimulated Luminescence at 250°C	

	pIR-IRSL290	post-Infrared-Infrared Stimulated Luminescence at 290°C	
	Subtraction	Dating using subtraction of background signals	
	TL	Thermoluminescence	
	TT-OSL	Thermally Transferred-Optically Stimulated Luminescence	
	Weighted Average	Statistical method for combining multiple age determinations	
	SG TT-OSL	Single Grain Thermally Transferred-Optically Stimulated Luminescence	
Radiocarbon:		Radiocarbon dating	(Becerra-Valdivia and Higham, 2023; Loftus, 2023)
	AMS	Accelerator Mass Spectrometry	
	Conventional method	Beta counting	
Tephrochronology	Cryptotephra	Microscopic volcanic glass shards in sediments	(Lane and Woodward, 2020)
U-series Methods:		Uranium series dating	(Grün and Stringer, 2023; Spötl and Boch, 2019)
	U-Pb	Uranium-Lead dating	
	U-Th	Uranium-Thorium dating	

Supplementary Table 3.II: Statistical models included in the southern African Middle Stone Age database

Luminescence Models for dose rate measurements	(Mahan et al., 2022)	
	ADM	Average Dose Model
	Bayesian	Bayesian statistical analysis
	CAM	Central Age Model
	CAM+nMAD	Central Age Model plus n Median Absolute Deviations
	FMM	Finite Mixture Model
	LogN_ML	Log Normal-Maximum Likelihood
	MAM	Minimum Age Model
	MC-ICPMS	Multi-Collector-Inductively Coupled Plasma Mass Spectrometry
	SAR-ITL	Single Aliquot Regenerative - Isothermal Thermoluminescence
	Weighted average	
	Additive dose	
Uptake Models ESR/U-series:		
	EU/LA	Early Uptake/Late Uptake
	US Model	U-series/ESR combined approach
	f=0.8	Linear uptake factor of 0.8

Supplementary Table 3.III: Summary of all MSA sites reviewed for this database, the complete database is in a separate Excel Spreadsheet (Appendix A)

Site	country	Papers	Industries	Methods
Gi (Gi)	Botswana	Brooks et al. 1990	HP	AAR; Radiocarbon; Luminescence, TL
Kgale Hill (KH)	Botswana	Walker and Downey 2019	MSA (?); ESA/MSA (?)	Luminescence, TL
Kudiakam Pan (KP)	Botswana	Robbins 1989	Generic MSA	Not dated
Makgadikgadi Basin (MKB)	Botswana	Burrough el al. 2022	MSA and LSA	Luminescence, OSL
Rhino Cave (RC)	Botswana		Generic MSA	Not dated
Toteng Quarry (TQ)	Botswana	Brook et al. 2008	MSA	Luminescence, OSL
White painting rock shelter (WPS)	Botswana	Ivester et al. 2010; Robbins et al. 2000; Feathers et al. 1997; Brook et al. 2008	LSA; early LSA/late MSA; MSA	Luminescence, OSL; TL, Radiocarbon, AMS
Lion Cavern (LC)	eSwatini	Vogel 1970; Dart and Beaumont 1971	Generic MSA	Radiocarbon
Sibebe/Langubhela (SB)	eSwatini	Vogel 1970; Vogel et al. 1986; Bader et al. 2022	late final MSA; early final MSA	Radiocarbon
Ha Soloja (HAS)	Lesotho	Cater and Vogel 1974; Vogel et al. 1986	MSA	Radiocarbon
Melikane (MLK)	Lesotho	Vogel et al. 1986; Stewart et al. 2012; Jacobs et al. 2008	historic; LSA; MSA; late MSA; Post-HP; HP	Radiocarbon; Luminescence, OSL-SG
Ntloana Tsoana (NT)	Lesotho	Jacobs et al. 2008	Post-HP; HP	Luminescence, OSL-SG
Sehonghong (SEH)	Lesotho	Jacobs et al. 2008; Loftus et al. 2015; Cater and Vogel 1974; Mitchell and Vogel 1994; Pargeter 2017	Robberg (early phase); transitional LSA/MSA; Post-HP, MSA III; MSA	Luminescence, OSL-SG; Radiocarbon, AMS; Radiocarbon
Malowa (MAL)	Malawi	Volman 1984	Generic MSA	Not dated
Chissomonji (NAI)	Mozambique	Mercader et al. 2012	MSA	Not dated

Cobue (CB)	Mozambique	Mercader et al. 2012	MSA	Not dated
Daisesi (DSI)	Mozambique	Mercader et al. 2012	MSA	Not dated
Fubue (FB)	Mozambique	Mercader et al. 2012	MSA	Not dated
Kolongwe (KOL)	Mozambique	Mercader et al. 2012	MSA	Not dated
M'fululuchi (MF)	Mozambique	Mercader et al. 2012	MSA	Not dated
Malango (MAL)	Mozambique	Mercader et al. 2012	MSA	Not dated
Manheza (MHZ)	Mozambique	Mercader et al. 2012	MSA	Not dated
Mbalanenga (MBL)	Mozambique	Mercader et al. 2012	MSA	Not dated
Mchepa (MCH)	Mozambique	Mercader et al. 2012	MSA	Not dated
Mechumua (MCM)	Mozambique	Mercader et al. 2012		not dated
Mikuyu (MIK)	Mozambique	Mercader, Bennett & Raja 2008	MSA	Not dated
Mitumbati (MTB)	Mozambique	Mercader et al. 2012	MSA	Not dated
Mvumu (MVU)	Mozambique	Mercader et al. 2012	MSA	Cosmogenic nuclide dating
Nacasona (NAC)	Mozambique	Mercader et al. 2012	MSA	Not dated
Nanchiwa (NAN)	Mozambique	Mercader, Bennett & Raja 2008	MSA	Not dated
NgaLUe Cave (NGA)	Mozambique	Mecadar et al. 2009	Late MSA	ESR
Ngalue Cave (NGA)	Mozambique	Mecadar et al. 2009	Late MSA	Radiocarbon, AMS; ESR; U-series
Tulo (TLO)	Mozambique	Mercader et al. 2012	MSA	Not dated
Aar 1 (Schlangengrotte) (AA)	Namibia	Vogelsang 1998	Mixed MSA	Not dated
Aar 2 (AA)	Namibia	Vogelsang 1998	Generic MSA	Not dated

Apollo 11 (AP)	Namibia	Miller 1999; Vogelsang et al. 2010; Jacobs et al. 2008; Freundlich 1980; Wendt 1976	LSA II; early LSA; late MSA; HP; Post-HP; Pre-HP; SB; Late MSA III; Late MSA II; Late MSA I; Early MSA	Radiocarbon; AAR; Luminescence, OSL-SG
Bremen 1C (B1C)	Namibia	Vogelsang 1998	Generic MSA	Not dated
Brenam 2B (B1B)	Namibia	Vogelsang 1998	Generic MSA	Not dated
Erb Tanks Rockshelter (ETR)	Namibia	McCall et al. 2011	MSA; LSA/MSA	Radiocarbon, AMS; AAR
Etemba 14 (ET-14)	Namibia	Schmidt 2011	MSA 1	Not dated
Haalenberg (HAA)	Namibia	Vogel and Visser 1981	early LSA	Radiocarbon
Pockenbank (POC)	Namibia	Vogel and Visser 1981; Vogelsang 1998; Schmidt et al. 2023	early LSA; MSA; HP	Radiocarbon
Tiras 5 (TIR)	Namibia	Vogelsang 1998	Generic MSA	Not dated
Zebrariver (ZB)	Namibia	Vogelsang 1998	LSA (?); MSA	Radiocarbon
Aasvoekop (ASS)	South Africa		Pietersburg, MSA	Not dated
Amanzi Springs (AS)	South Africa	Deacon 1969; Herries 2022	Acheulean; MSA	Radiocarbon; Luminescence: OSL-SG; SG TT-OSL; pIR-IRSL
Blind River (BR)	South Africa	Wang et al. 2008	human remains, unclassified lithics	Luminescence, OSL
Blombos (BBC)	South Africa	Vogel et al. 1999; Henshilwood et al. 2002; Jacobs et al. 2003a; Jacobs et al. 2003b; Jacobs et al. 2006a; Jacobs et al.	MSA; SB; pre SB	Luminescence: TL; IRSL; subtraction; OSL; OSL-SG; Radiocarbon; ESR; U-series, U-Th

		2006b; Tribolo et al. 2006; Tribolo et al. 2013; Henshilwood and Sealy 1997; Tribolo et al. 2005; Jacobs et al. 2008; Jacobs et al. 2013; Henshilwood et al. 2011; Jacobs et al. 2020		
Blombosch Sands (BBS)	South Africa	Henshilwood 2012	SB	Not dated
Boegoeberg 1 (BOG1)	South Africa	Klein et al. 1999	not archaeological	Radiocarbon
Boegoeberg 2 (BOG2)	South Africa	Klein et al. 1999	MSA	Radiocarbon
Boomplaas (BPA)	South Africa	Pargeter et al. 2018; Deacon 1982; Fairhall et al. 1976; Miller 1999; Vogel 2001	Albany; Robberg; LSA; early LSA; MSA/LSA; HP; MSA; MSA III	Radiocarbon, AMS; AAR; U-series
Border Cave (BC)	South Africa	Grün et al. 1990; Grün and Beaumont 2001; Grün et al. 2003; Millard 2006; Bird et al. 2003; Vogel et al. 1986	Early LSA; MSA III; HP; MSA I; late MSA; Pietersburg	ESR; ESR, ICP-MS; AAR; Radiocarbon
Buffelskloof (BK)	South Africa	Opperman 1978	early LSA	Radiocarbon
Bushman Rock Shelter (BRS)	South Africa	Vogel 1970; Porraz et al. 2018	MSA; LSA; Pietersburg	Radiocarbon; Luminescence, OSL-SG; Luminescence, pIR-IRSL290; Luminescence, IRSL-IR50
Canteen Koptjie (CK)	South Africa	Chazen et al. 2013; De wit 2008	early LSA/late MSA; Smithfield (?); MSA	Luminescence, OSL; Luminescence, OSL-SG
Cape Hangklip (CHK)	South Africa	Gatehouse 1954	SB	Not dated
Cave James (CJ)	South Africa	Mitchell 2008	early LSA/late MSA	Radiocarbon
Cave James (CJ)	South Africa	Mitchell 2008	Generic MSA	Not dated

Cave of Hearths (CH)	South Africa	van Riet Lowe 1954	Pietersburg, MSA	Not dated
Die Kelders (DK)	South Africa	Feathers and Bush 2000; Schwarcz and Rink 2000; Avery 1997	MSA	Luminescence: TL; OSL; IRSL, ESR
Diepkloof (DRS)	South Africa	Feathers 2015; Tribolo et al. 2005; Jacobs et al. 2008; Tribolo et al. 2009; Tribolo et al. 2013; Jacobs and Roberts 2015	Post-HP; late HP; intermediate HP; HP; early HP; SB; pre SB; lower MSA; MSA-Jack; Lower MSA	Luminescence, OSL-SG; pIR-IRSL; LM-OSL; TL
Driekoppen (DRI 1)	South Africa	Wallsmith 1990	Orangian, MSA	Luminescence, TL
Duinefontein (DNF)	South Africa	Feathers 2002	Acheulean	Luminescence, OSL/TL; IRSL; subtraction
Duinfontein (DNF)	South Africa	Klein 1999	Acheulean	U-series, U-Th
Elands Bay Cave (EBC)	South Africa	Tribolo et al. 2016	Robberg; early LSA; MSA; MSA I	Luminescence, OSL-SG; IRSL-IR50; pIR-IRSL290; TL, Radiocarbon
Florisbad (FB)	South Africa	Grün 1996; Kuman and Clarke 1986; Pinder 2021	MSA; LSA; pre-SB	Luminescence, OSL; OSL-SG; TT-OSL; IRSL-IR50; pIR-IRSL250 ESR, Radiocarbon
Ga-Mohana (GHN)	South Africa	Wilkins et al. 2021; Wilkins et al. 2020	MSA; LSA	U-series, U-Th; Luminescence, OSL-SG, Radiocarbon, AMS
Geelbek Dunes (GB-D)	South Africa	Fuchs et al. 2008	MSA; LSA	U-series, U-Th; Luminescence, OSL; Luminescence, IRSL
Goergap 113 KR	south Africa		MSA	Not dated

Grassridge Rock Shelter (GRS)	South Africa	Ames et al. 2020; Opperman,1984; Collins et al. 2017	LSA; MSA	Luminescence, OSL-SG, Radiocarbon
Hackthorne (HT)	South Africa	Pollaro et al. 2010	MSA	Luminescence, OSL-SG
Herolds Bay Cave (HB)	South Africa	Braun et al. 2019	MSA	U-series, U-Th
Heuningeskrans (HNK)	South Africa	Vogel and Marias 1971; Linick 1977; Miller 1992	Oakhurst Complex, LSA; Robberg	Radiocarbon
Hoedjies Punt (HDP1)	South Africa	Tribolo et al. 2022	MSA	Luminescence, OSL; OSL-SG
Hollow Rock Shelter (HRS)	South Africa	Hogberg and larsson 2011; Feathers 2015	SB	Luminescence, OSL; OSL-SG
Kathu Pan 1 (KP)	South Africa	Porat et al. 2010	Fauresmith	Luminescence, OSL. US-ESR
Kathu Pan 6 (KP)	South Africa	Lukich et al. 2019	Early MSA; HP; LSA	Luminescence: OSL; TT-OSL; pIR-IRSL290
Keratic Koppie (KEK)	South Africa	Pollaro et al. 2010	MSA	Luminescence, OSL-SG
Klasies River (KRM)	South Africa	Grün et al. 1990; Nami 2016; Tribolo et al. 2013; Wurtz 2022; Vogel 2001; Bada and Deems 1975; Singer and Wymer 1982; Feathers 2002; Jacobs et al. 2008; Tribolo et al. 2005	Post-HP; HP; MSA III; Post-HP, MSA III; Mossel Bay (MSA II); MSA I	Luminescence: OSL-SG; TL; subtraction; IRSL, Radiocarbon, U-series: U-Th; US-ESR, AAR
Klein Kliphuis (KKH)	South Africa	Mac kay and Welz 2008; Jacobs et al. 2008	LSA; Post-HP; HP	Radiocarbon: conventional; AMS, Luminescence, OSL-SG
Kleinjongensfontein	South Africa	Henshilwood 2008	SB	Not dated
Klipdrift Rock Shelter (KRS)	South Africa	Henshilwood et al. 2014	MSA; HP	Luminescence, OSL-SG

Klipfonteinrand (KLP)	South Africa	Mac kay et al. 2023	LSA; HP; MSA	Luminescence, OSL-SG
Koedoesrand (KOE)	South Africa		Pietersburg, MSA	Not dated
Kudu Koppie (KK)	South Africa	Pollaro et al. 2010	MSA	Luminescence, OSL-SG
Lincoln Cave North, Sterkfontein (LCN-STK)	South Africa	Reynolds et al. 2003	MSA	U-series, U-Th
Montagu Cave (MON)	South Africa	Archer et al. 2023	Acheulean	Luminescence, TT-OSL
Moshebi's Shelter (MOS)	South Africa	Mitchell 2022		Not dated
Mwulu's Cave (MW)	South Africa	Feathers et al. 2020	Pietersburg, MSA (?)	Luminescence: OSL; OSL-SG; IRSL; pIR-IRSL
Nahoon Point (NP)	South Africa	Mountain 1966; Roberts 2008; Vogel et al. 1999; Jacobs and Roberts 2009	human footprints	Radiocarbon, U-series, Luminescence, TL; IRSL; subtraction; OSL
Nelsons Bay Cave (NBC)	South Africa	Fairhall and Young. 1973; Fairhall et al. 1976	MSA	Radiocarbon
North Brabant (New Belgium 608LR) (NBB)	South Africa	Shoonraad and Beaumount 1968	MSA	Not dated
Oakleigh Farm (OAK)	South Africa	Derricourt 1977	HP	Not dated
Olieboomspoort (OBP)	South Africa	Val et al. 2021	Pietersburg, MSA	Radiocarbon; ESR; U-series; US-ESR
Paardeberg (PAR)	South Africa		MSA	Not dated
Peers Cave (PC)	South Africa	Volman 1981	MSA I	Radiocarbon
Pinnacle Point (PP13B)	South Africa	Smith et al. 2018; Jacobs et al. 2010; Marean et al. 2010; Marean et al. 2007	MSA	Luminescence: OSL-SG; OSL; TT-OSL; Weighted Average, U-series, U-Th crypto tephra

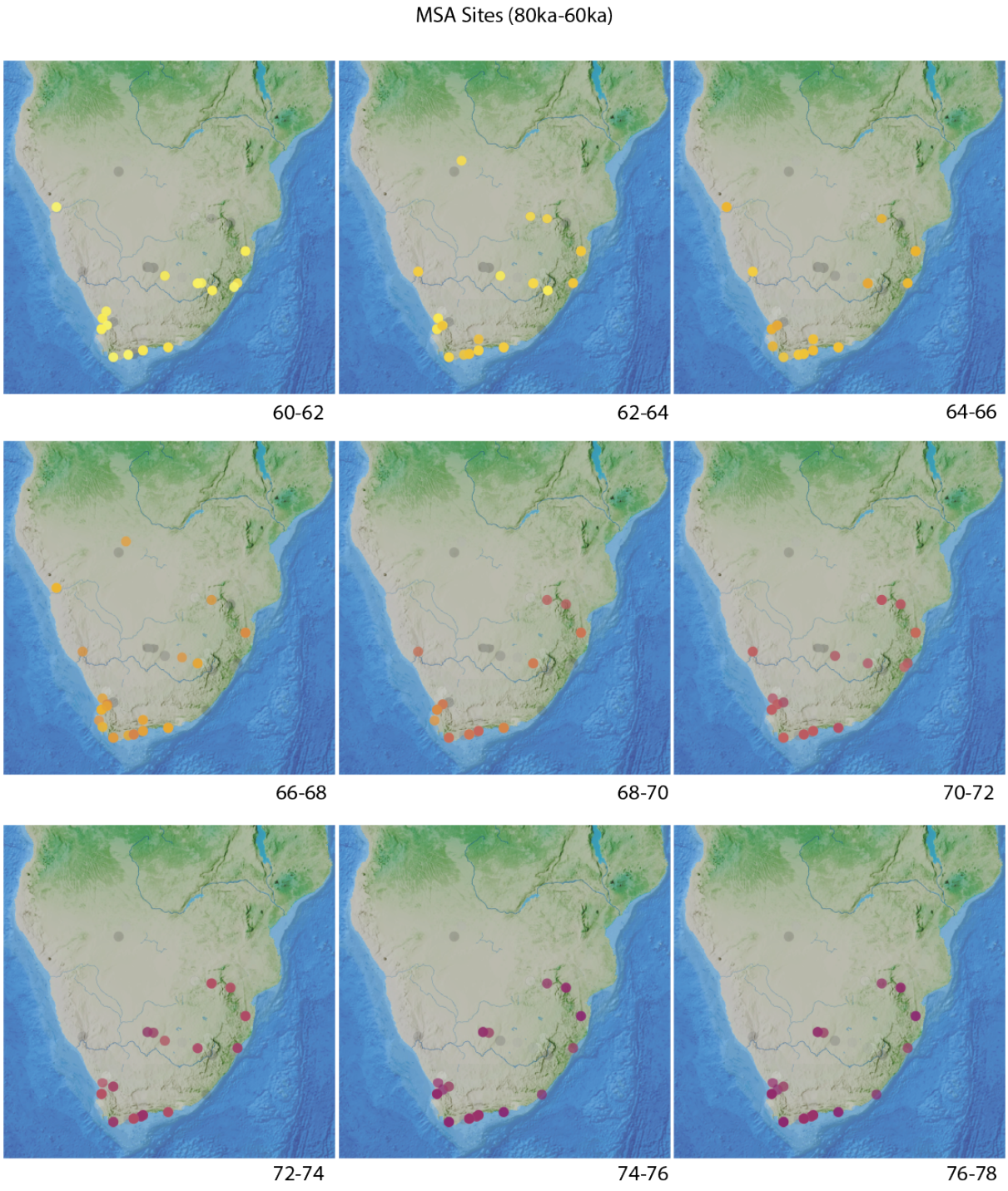
Putslaagta 1 (PL1)	South Africa	Mac kay et al. 2014	MSA	Luminescence, OSL-SG
Putslaagta 8 (PL8)	South Africa	Mackey et al. 2015	early LSA; Late MSA; HP/post-HP/SB (?); MSA; pre-SB (?); late MSA	Luminescence, OSL-SG; Radiocarbon, AMS
Rainbow Cave (RAI)	South Africa	Tobias 1954	Pietersburg, MSA	Not dated
Red Balloon Rock Shelter (RBS)	South Africa	Wadley et al. 2021	MSA	Luminescence, OSL
Rooidam 1 (RD)	South Africa	Szabo & Butzer, 1979	Fauresmith	U-series: U-Pb; U-Th
Rooidam 2 (RD)	South Africa	Eltzholtz 2020	unknown	Luminescence, OSL
Rose Cottage Cave (RCC)	South Africa	Valladas et al. 2005; Jacobs et al. 2008; Pinaaret al. 2008; Clark 1997; Wadley 1991; Wadley 1995; Wadley 1997; Woodborne and Vogel 1997; Vogel and Marias 1971; Loftus et al. 2019; Beaumont and Vogel 1972	Post-HP; HP; early LSA/late MSA; MSA IV; Post-HP, MSA III; Pre-HP MSA IIb; MSA; early LSA	Luminescence: TL; OSL; OSL-SG; Radiocarbon, AMS
Rufus Cave (RUF)	South Africa	McNabb et al. 2003	Pietersburg, MSA	Not dated
Samaria	South Africa	Kuman et al. 2004	MSA	Not dated
Schurfpoort 112KR (Sch)	South Africa		MSA	Not dated
Sea Harvest (SH)	South Africa	Fairhall et al. 1976	MSA	Radiocarbon
Sibhudu (Sibudu) (SIB)	South Africa	Wadley 2001; Jacobs et al. 2008b; Jacobs et al. 2006.2; Jacobs et al. 2008	Final MSA; MSA; Late MSA; Post-HP; HP; SB; pre SB	Radiocarbon; Luminescence, OSL-SG; Luminescence, OSL

Skoonheid (SKO)	South Africa	Mason 1959	Pietersburg, MSA	Not dated
Soutfontein (SFT-001)	South Africa	Mac kay 2010	MSA	Not dated
Steenbokfontein 9KR (SBF)	South Africa	Wadley et al. 2016	MSA	Luminescence, OSL
Strathalan Cave B (STH-B)	South Africa	Opperman and Heydenrych 1990	Generic MSA	Radiocarbon
Sunnyside 1 (Sun1)	South Africa	Handerson et al. 2016	MSA	Luminescence, OSL
Trappieskop (C103, Neros Cave and G/107)	South Africa	Goodwin and Peers 1953	SB	Not dated
Tunnel Cave (TC)	South Africa	Malan 1955	HP	Not dated
Umbeli Belli (UB)	South Africa	Bader et al. 2018	final MSA; LSA; early LSA/late MSA	Luminescence: SG-OSL; pIR-IRSL290
Umhlatuzana (UMH)	South Africa	Lomard et al. 2010; Kaplan 1990	Late MSA; HP; Pre-HP; LSA; Late Robberg; Early Robberg; early LSA/late MSA; HP/pre-HP	Luminescence: OSL-SG; Radiocarbon
Varsche Rivier 003 (Reception rock shelter) (VR003)	South Africa	Mac kay et al. 2022; Steele et al. 2016	HP; MSA; pre SB	Luminescence: OSL-SG; pIR-IRSL; U-series, 230U-Th burial dating
Vleesbaai (VB)	South Africa	Smith et al. 2018	MSA	Luminescence, OSL-SG
Waterfall bluff (WFB)	South Africa	Fisher et al. 2020	low occupation Robberg	Luminescence, OSL-SG
Waterval (WAT)	South Africa		Middle Pietersburg, MSA	Not dated

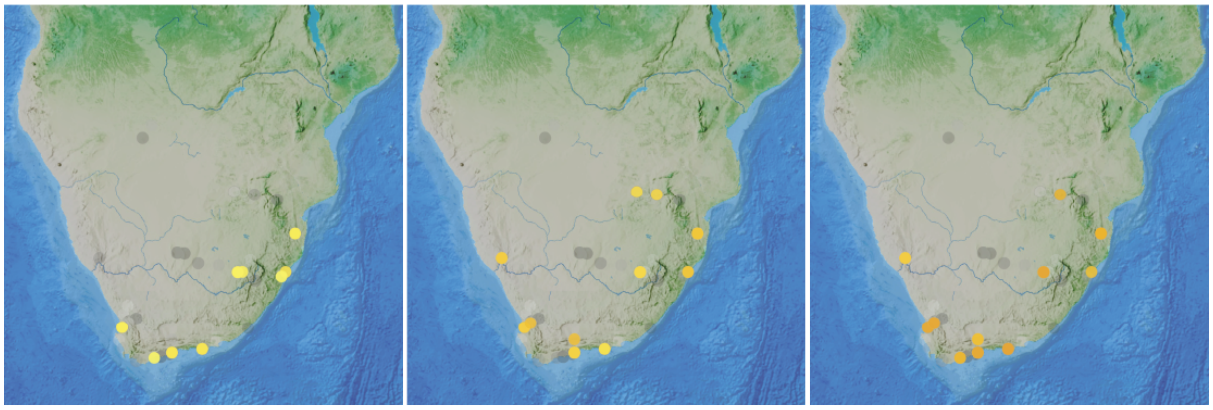
Wonderkrater (WKR)	South Africa	Blackwell et al. 2014; Barré et al. 2012	MSA	Luminescence, IRSL(DRC); IRSL(H&L); OSL-SG; OSL, Radiocarbon
Wonderwerk Cave (WK/WWC)	South Africa	Chazen et al. 2020; Beumont and Vogel 2006; Pickering 2015	Early MSA; MSA; Fauresmith	Luminescence: TT-OSL; U-series: U-Th; U-Pb
Ysterfontein 1 (YS)	South Africa	Halkett et al. 2003; Niespoloa et al. 2020; Avery et al. 2008	MSA; Early MSA	Radiocarbon, AMS; U-series, U-Th; Luminescence, OSL
Kabwe/Broken Hill (KAB)	Zambia	Grün et al. 2020	Homo heidelbergensis skull	U-series
Kalambo Falls (KF)	Zambia	Duller et al. 2015; Vogel and Waterbolk 1964	Mode 2/3; MSA; Sangoan; Acheulean	Luminescence, OSL-SG; TT-OSL; Radiocarbon
Kalemba (KAL)	Zambia	Phillipson 1973	MSA; late MSA; early LSA	Radiocarbon
Leopard's Hill Cave (LEA)	Zambia	Phillipson 1977	MSA	Not dated
Mumbwa (MBW)	Zambia	Barham 2023	MSA	Luminescence, TL
Twin Rivers (TWI)	Zambia	Barham and Smart 1996	overlying MSA	U-series, U-Th
Amazimba (AMA)	Zimbabwe	Volman 1984	Bambata	Not dated
Bambata Caves (BMC)	Zimbabwe		Tshangula; Bambata; Mode 3	Not dated
Gumani (GUM)	Zimbabwe	Volman 1984	Bambata	Not dated
Hwange National Park (HNP)	Zimbabwe	Haynes and Klmiwicz 2009	MSA	Not dated
Inyanga Site XIXB (INY)	Zimbabwe	Volman 1984	Tshangula	Not dated

Inyanga Site XXVII (INY)	Zimbabwe	Volman 1984	Bambata	Not dated
Mtemwa Rocks (MTE)	Zimbabwe	Robbinson 1952	MSA	Not dated
Ntswatugi Cave (NTS)	Zimbabwe	Henshilwood and Lombard 2000	Generic MSA	Radiocarbon
Nyazongo (NYA)	Zimbabwe	Lombard 2012	Bambata	Not dated
Redcliff Cave (RC)	Zimbabwe	Vogel 1970; Klein 1978	Bambata; Tshangula	Radiocarbon
Shashabugwa Shelter (SHA)	Zimbabwe	Lombard 2012	Generic MSA	Not dated
Tshangula Cave (TC)	Zimbabwe		Late MSA, Bambata	Not dated
Zombepata Cave (ZC)	Zimbabwe	Cooke 1971; Sheooard and Swart 1973	Tshangula; Bambata	Radiocarbon

Supplementary Figures 3.I:



Backed pieces (78ka-60ka)



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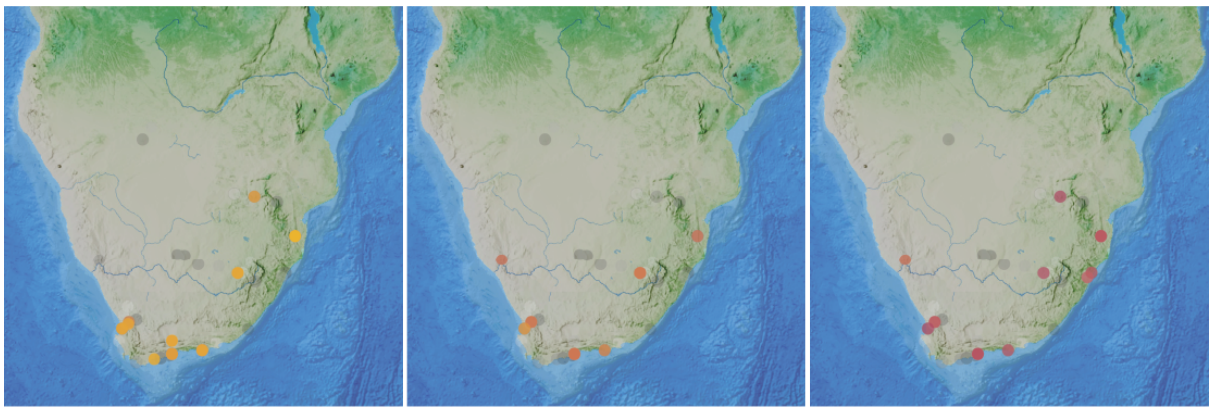

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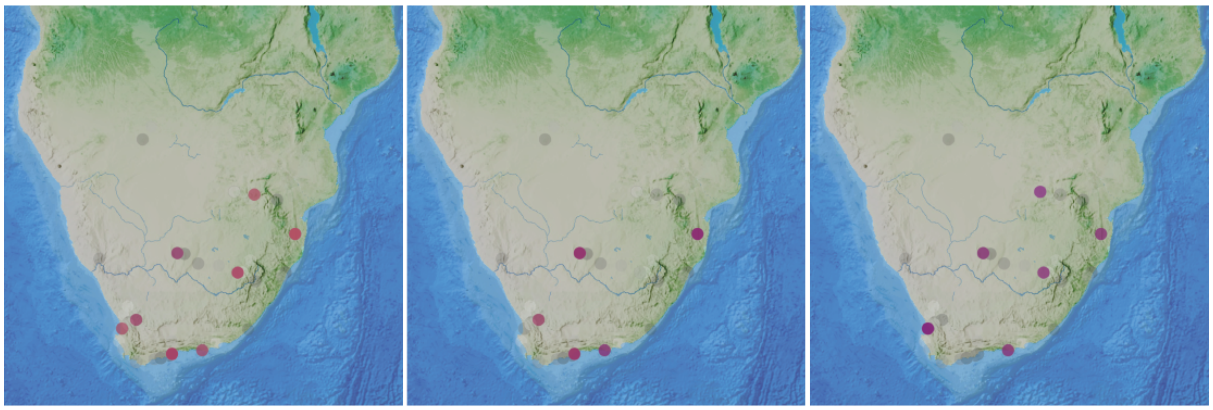
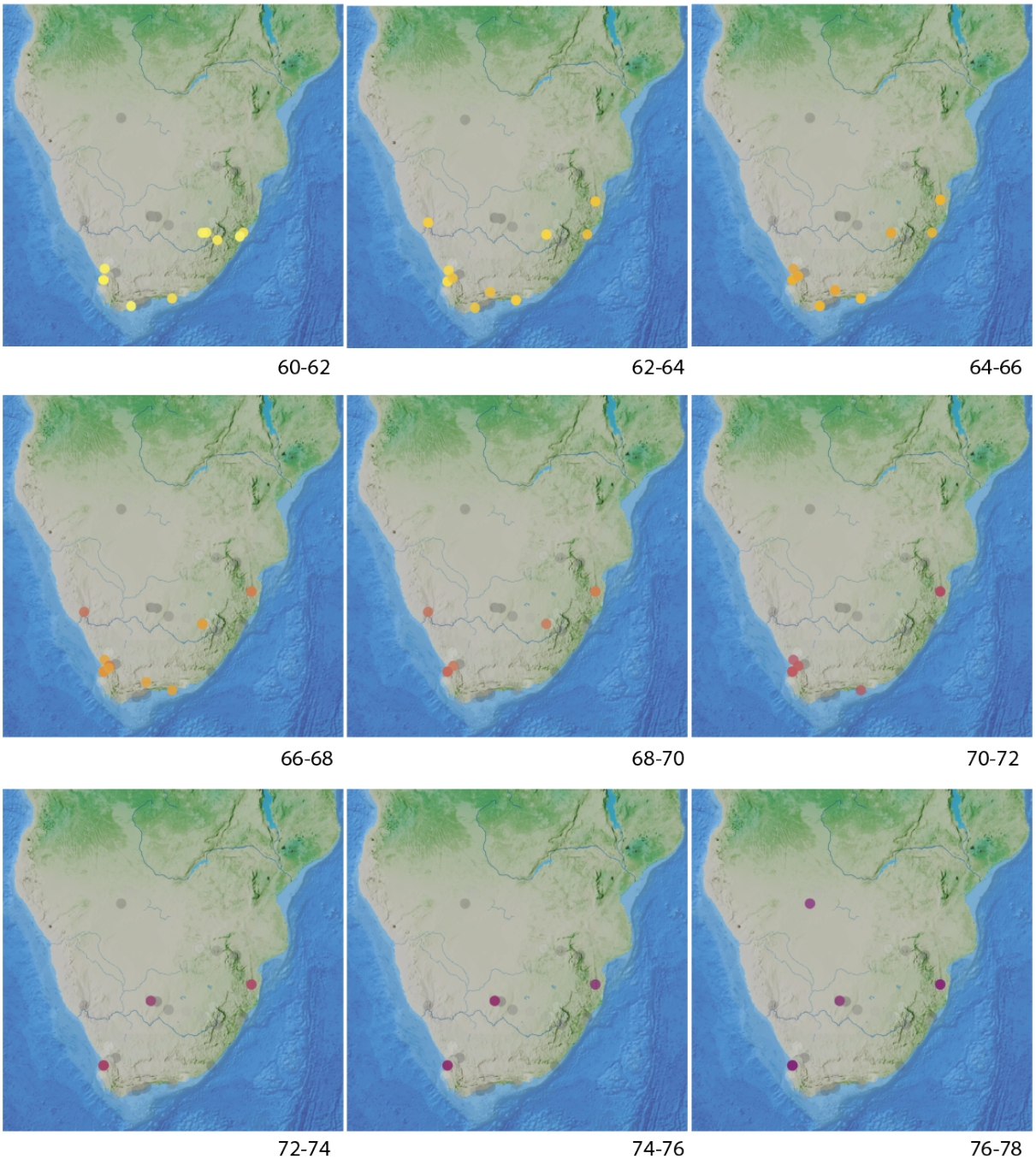


72-74 74-76 76-78

Sites claiming HP industry present (78ka-60ka)



4. Dating Daimane II: chronological explorations of a Mozambiquan rock shelter

Daimane Rock Shelter is the only excavated rock shelter in the Lower Lebombo range in southern Mozambique. This site, therefore, presents a unique opportunity to date previously neglected southern African Stone Age assemblages. The lack of detailed of chronological data for archaeological sites in Mozambique has limited our understanding of the region's rich, and complex, cultural heritage (Ekblom et al., 2015). This is troubling as the reliance of lithic industries as temporal markers in southern African archaeology remains contentious (Bader et al., 2022b; Shea, 2019; Wilkins, 2020). While some stone tool typologies or technocomplexes are distinctive (e.g. HP) and are often treated as time horizon markers, others are more ambiguous (e.g. Fauresmith). Increasingly, it is accepted that the presence of a single tool type alone is not enough to provide temporal control, but rather it is part of a package or set of clues (Wilkins, 2020). Bader et al. (2022) suggest that this is particularly true of the increasingly blurred lines between the Later Stone Age (LSA) and Middle Stone Age (MSA). However, Bader et al. (2022) concur with Wilkins (2020) that through contextualising well established sites like Border Cave with new chronologies from previously underrepresented regions such as Sibebe, eSwatini, archaeologists can gain better understanding of distinct, albeit non-linear, cultural shifts currently recognised through the LSA/MSA nomenclature. The increased focus on LSA/MSA transitions at interior sites demonstrates that through increasing attention to regionally specific comparative sites, it is possible to use lithic identification in conjunction with absolute dating to add nuance to this moment in humanities past.

Mozambique's often understudied archaeological record offers a unique opportunity to develop new chronological frameworks for the southern African LSA and MSA. This paper contributes

to this gap by providing a chronological model for Daimane Rock Shelter, Mozambique. In order to achieve this this paper has three objectives (i) understand the chronological landscape of Mozambique's MSA and LSA (ii) obtain optically stimulated luminescence (OSL) and radiocarbon ages; and (iii) explore the implications of these ages for understanding the region.

4.1. Dating Mozambique's Archaeological Record

4.1.1. Regional Chronological Background

Increasing interest in Mozambique's archaeological record through new field surveys and excavations offers an exciting opportunity to better understand the southern African archaeological record outside the well-established South African tradition (Figure 1). While the archaeological potential of the region was recognised in the latter 20th century, its sites often remain overlooked (Gonçalves et al., 2016; Morais, 1984). In 1974, a rescue survey before the flooding of Massinger Dam, 286 km north of Daimane Rock Shelter, revealed multiple Early Stone Age (ESA), MSA, and LSA surface scatters as well as Early and Later Farming Communities (Meneses, 1999). However, researchers largely ignored or remained unaware of these assemblages or were unable to access them owing to political conflict. This resulted in relatively few sites undergoing excavation survey or subsequent dating (Table 1).

In northern Mozambique, surveys in Niassa Province provide Mozambique's only published MSA dates. At Ngalue Cave, Niassa, ESR dating of faunal teeth and radiocarbon dating of hearth beds indicate MSA occupation at 38.8 ± 3 – 50.66 ± 4.35 ka, while U-series dating of a stalagmitic conglomerate suggests a minimum age for these MSA layers at 105.22 ± 13.58 ka. This conglomerate also provides a maximum age for a space archaeological occupation below this layer (Mercader et al., 2009). Further north, but still within Niassa Province, at the open-air site of Mvumu, cosmogenic nuclide burial dating indicates an MSA presence at 29 ± 7 ka (Mercader et al., 2012). Subsequently, through applying a Bayesian Model to the cosmogenic

nuclide ages and obtaining an MSA occupation at $29\ ^{+3}/_{-11}$ ka. Mercader et al. (2012), demonstrates the potential to develop a chronological framework for this landscape.

In central Mozambique, Saeterdal (2004) identified LSA features while documenting rock art sites within the Vumba range, however, no dates are directly associated with these features. Further south, Bicho et al. (2016) provided eight LSA radiocarbon dates from Chicaza. Bicho et al. (2023, 2018) subsequently identified over two hundred LSA and MSA sites along the Chiniti stream, including two rock shelters, Txina-Txina and Machampane 1. Test excavations at Txina-Txina uncovered Iron Age layers overlying LSA layers capping MSA lithics (Bicho et al., 2023). Radiocarbon dating, performed on ostrich eggshell (OES), mammal bone, land snails and charcoal at the radiocarbon dating laboratory of the University of Waikato, New Zealand, revealed a sequence with an Iron Age assemblage, 1163 ± 24 y BP (1060–960 cal BP), capping at an older LSA assemblage, 6791 ± 20 y BP (7670–7570 cal BP). The lowest LSA layer is 28 571 ± 170 y BP (33,310–32,035 cal BP), thereby providing a minimum age for the MSA (Bicho et al., 2023; Raja, 2021). These ages are impressive considering Mozambique's challenging tropical environment, where heat and moisture accelerate decomposition, negatively impacting carbon preservation. (Wright, 2017; Wright et al., 2017b; Becerra-Valdivia et al., 2020; Hare and Loftus, 2018; Hogg et al., 2020b).

The lack of updated chronological ages for Mozambique is therefore clearly not an absence of archaeological sites but rather a paucity of research carried out in this region than in neighbouring South Africa (Chapter 2, this thesis). However, it is important to recognise that while modern national borders influence archaeological site excavation and scientific enquiry, they are irrelevant to past peoples' behaviour; therefore, neighbouring sites, within geographic (if not national) proximity of Daimane should also be considered when conducting site comparisons. In eSwatini, despite Sibebe and Lion Cavern producing some of the first radiocarbon ages for southern Africa, eSwatini also has a paucity of radiometric dates for its

documented archaeological sites (Bader et al., 2022a; Barham, 1989; Dart, 1971; Vogel, 1970; Vogel et al., 1986). In South Africa, Bushman Rock Shelter, first dated alongside Sibebe, has more recent single-grain OSL ages for its MSA and LSA layers (Porraz et al., 2018; Vogel, 1970). Shibudu (formally Sibudu) in South Africa, is dated with radiocarbon dating and single-grain OSL dating (Jacobs et al., 2008c, 2008b; Jacobs and Roberts, 2008; Wadley, 2001). Border Cave contains more ESR ages than any other archaeological site in southern Africa (Grün et al., 2003, 1990; Grün and Beaumont, 2001). These sites' geography proximity enables archaeological association and investigation when investigating Diamane.

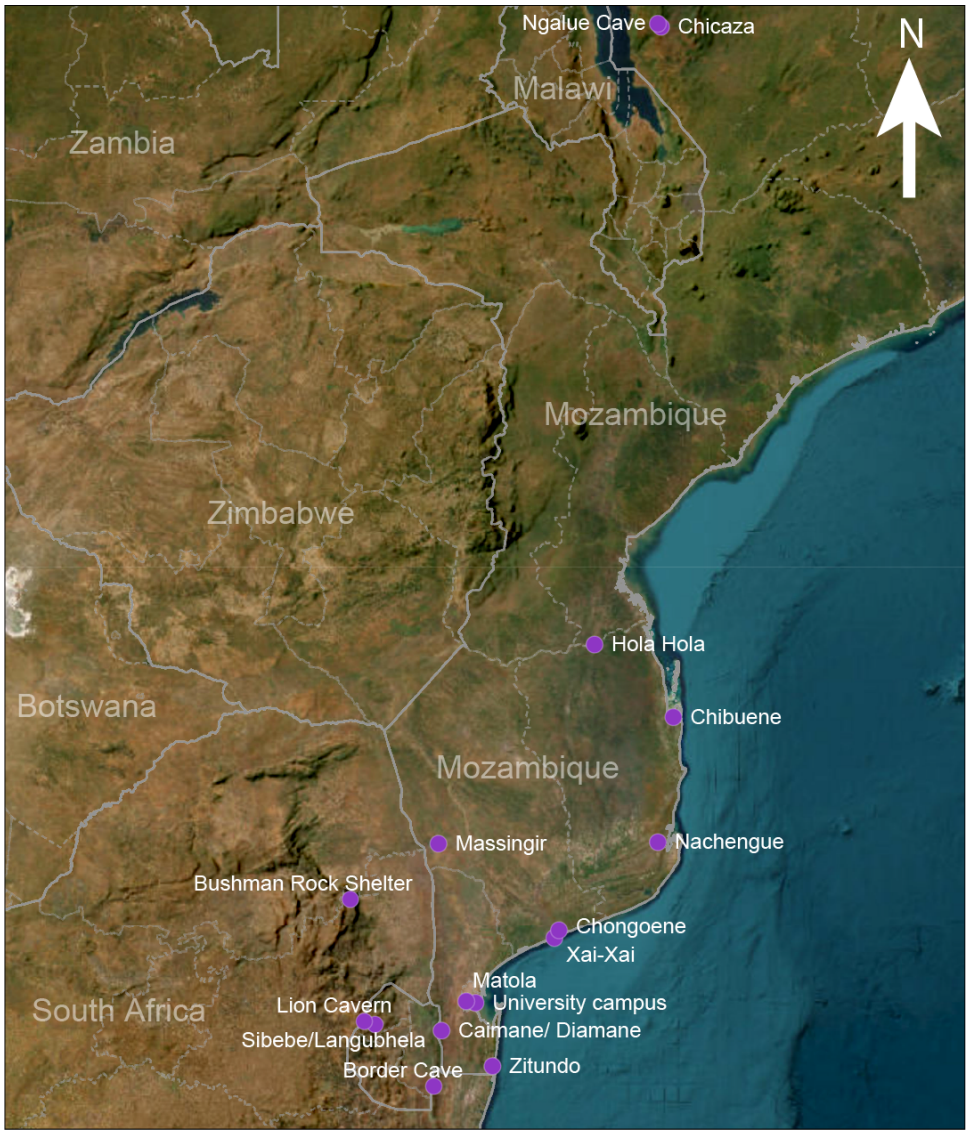


Figure 4.1: Dated Mozambiquan archaeological sites and neighbouring sites mentioned within the paper

Table 4.1: Mozambique's Stone Age and Iron Age archaeological sites with published numeric ages

Site	Location	Type	Period	Sample	Technique	lab code	Age*	error
Caimane/ Daimane (Morais, 1987)	-26.32 (S), 32.13 (E)	settlement	Later Iron Age	charcoal	conventional 14C	St-8873	880	210
			Later Iron Age	plant remains		St-8874	715	90
Chibuene (Sinclair et. al., 2012)	-22.24 (S), 35.42 (E)	settlement	Iron Age		conventional 14C	R-1325	1180	50
			Iron Age			St-8493	665	80
			Iron Age			St-8494	1270	80
			Iron Age			St-8495a	1400	85
			Iron Age			St-8495b	1080	80
			Iron Age			St-8496	1155	85
			Iron Age		AMS	Ua-12267	1225	70
			Iron Age			Ua-16266	305	65
			Iron Age			Ua-16268	1005	70
			Iron Age			Ua-16269	890	50
			Iron Age			Ua-16270	1235	50
			Iron Age			Ua-16271	1105	70
			Iron Age			Ua-16272	1410	75
Chicaza (Bicho et. al., 2016)	-12.89 (S), 35.25 (E)	rock shelter	Later Iron Age	bone	AMS	Wk-40712	489	35
			LSA	charcoal		Wk-40713	4048	20
			LSA	bone		Wk-40714	6793	30
			LSA	charcoal		Wk-40715	183	20
			LSA	bone		Wk-40716	8293	40

			LSA	charcoal		Wk-40717	1230	20
			LSA	bone		Wk-40718	19807	100
			LSA	charcoal		Wk-40719	9163	25
Chongoene (Morais, 1987)	-25.02 (S), 33.80 (E)	settlement	Later Iron Age	charcoal	conventional 14C	St-8590	880	100
Hola Hola (Morais, 1987)	-21.29 (S), 34.30 (E)	settlement	Early Iron Age	bone		R-1326	1060	50
Massingir (Morais, 1987)	-23.90 (S), 32.07 (E)	settlement	Early Iron Age	charcoal		Pta-1640	1030	40
Matola (Morais, 1987)	-25.93 (S), 32.47 (E)	settlement	Early Iron Age	charcoal		R-1327	1880	50
Matola (Morais, 1987)	-24.93 (S), 32.47 (E)	settlement	Early Iron Age	charcoal	conventional 14C	R-1328	1120	50
			Early Iron Age	charcoal		St-8546	1720	110
			Early Iron Age	charcoal		St-8547	1470	80
			Early Iron Age	shell		St-8548	2025	80
Nachengue (Morais, 1987)	-23.88 (S), 35.20 (E)	settlement	Early Iron Age	charcoal	conventional 14C	St-8497	1235	105
Txina-Txina (Bicho et. al., 2023)	−23.89(S), 31.91 (E)	Open air site	Wilton	Ostrich eggshell	Radiocarbon, AMS	Wk-44419	6791	20
			Oakhurst	Achatina sp.		Wk-44420	12190	30
			early LSA	Ostrich eggshell		Wk-45795	28571	170
			Iron age	Mammal bone		Wk-49193	105	0.2
			LSA	Charcoal		Wk-50400	1083	24
			LSA	Charcoal		Wk-50399	1163	24

			early LSA	Chambardia petersi		WK-45796	21146	74
			early LSA	Achatina sp.		Wk-45797	25064	110
			LSA	Melanoides tuberculata		WK-49192	909	21
University campus (Morais, 1987)	-25.95 (S), 32.60 (E)	settlement	Early Iron Age	charcoal	conventional 14C	St-9836	1775	85
			Early Iron Age	charcoal		St-9837	1355	100
			Early Iron Age	charcoal		St-9838	1590	75
Xai-Xai (Morais, 1987)	-25.12 (S), 33.72 (E)	settlement	Later Iron Age		conventional 14C	St-8589	510	165
Zitundo (Morais, 1987)	-26.77 (S), 32.85 (E)	settlement	Early Iron Age	charcoal		St-8909	1775	105
			Early Iron Age	charcoal		St-8910	1435	105
			Early Iron Age	charcoal		St-8911	1760	105
			Early Iron Age	charcoal		St-8912	1685	105
			Early Iron Age	charcoal		St-8913	1575	105
Mvumu (Mercader et. al., 2012)	−12.73(S), 34.82 (E)	cave	Sterile	quartz	Cosmogenic nuclide dating		42000	46000
		cave	MSA	quartz			29000	7000
Ngalue Cave (Mercader et. al., 2009)	-12.86 (S), 35.20 (E)	open air site	Late MSA	organic material	Radiocarbon, AMS	Beta-236941	42120	920
			Late MSA	Fauna, tooth	ESR	PT21, Enamel, 1	43110	3560
			Late MSA	Fauna, tooth		PT21, Enamel, 2	45250	3720
			Late MSA	Fauna, tooth		PT21, Enamel, 1	38800	3000
			Late MSA	Fauna, tooth		PT21, Enamel, 2	40640	3250

			Late MSA	Fauna, tooth		PT23, Enamel, 1	46200	3830
			Late MSA	Fauna, tooth		PT23, Enamel, 2	50660	4350
			Late MSA	Fauna, tooth		PT23, Enamel, 1	45980	3870
			Late MSA	Fauna, tooth		PT23, Enamel, 2	50320	4400
			Late MSA	speleothem	U-series	NGA-A	55060	5770
			Late MSA	speleothem		NGA-B	55200	14580
			Late MSA	speleothem		NGA-C	324200	14170
			Late MSA	speleothem		NGA-E	251070	5160
			Late MSA	speleothem		NGA-F	105330	13580

*Radiocarbon ages are uncalibrated

4.1.2. Daimane Rock shelter

Daimane II, (10 m wide and 3 m deep) is a small rock shelter situated 24 m east of Daimane I (30 m wide and 8 m deep). First archaeologically described by Dias (1947), Daimane I exhibited signs of recent occupation, whilst Daimane II appeared undisturbed. At Daimane I, Jonsson and Adamowicz (1983) excavated four test pits and a trench, along with one test pit in Daimane II. Although the excavators reached depths of 1.5 m, they suggested that deposits extended beyond this depth. Early Iron Age pottery, LSA and MSA artefacts and faunal remains are mixed, and their contemporaneous production cannot be ruled out. Iron and slag are absent from the assemblage. While excavators noted recent disturbance, the nature of this disturbance was not further elaborated upon. However, the EIA/LSA layer lies below a stratum of intact land snails, a known bioturbating species, followed by a surface of crushed snails, indicating their presence both during occupation and a potential occupation hiatus. Below this occupation is an LSA layer characterised by small, fine-grained scrapers, segments, retouched flakes and flakes. In contrast, the preceding MSA layer is dominated by larger rhyolitic flakes (including one bifacial specimen), irregular cores and prepared cores. Meneses (1999) subsequently excavated a 2 m x 2 m test pit at Daimane I where ESA artifacts were found near the surface, followed by a sterile layer until 40-50 cm which contained an artefact baring layer. In contrast to the finds described by Jonsson and Adamowicz (1983), these lithics were dominated by late ESA-early MSA flakes, cores, handaxes, cleavers from diverse geological contexts. Bedrock was reached at approximately 70 cm. No fossil fauna was uncovered in this excavation.

When faunal remains are present, both Daimane I and Daimane II demonstrate good bone preservation. Human and faunal remains are present in Daimane I's LSA layers. A burial, cut into Daimane’s LSA layer, contains no grave goods and possibly originates from a later occupation. Additional human remains from a burial were recovered from the EIA/LSA layers, though their precise provenance remains unclear. Jonsson and Adamowicz's (1983) initial

analysis of Daimane I suggested that MSA and LSA layers exhibited similar faunal assemblages (albeit with lower density in the MSA). These assemblages include antelope, warthog, bushpig, hyena, smaller carnivores, as well as fish (catfish and tilapia), birds, frogs and undifferentiated micromammals. Additionally, monitor lizards and tortoises are frequently represented. In contrast to Daimane I, faunal remains from Daimane II exhibit evidence of burning. Both sites offer a promising opportunity to understand human presence and behaviour over a long sequence of time.

4.2. Modern Excavations

4.2.1. Excavations

A team of local archaeologists led by Décio Muianga excavated Daimane II (-25.02 S, 33.80 E) in 2019 and, 2021-2023. Excavators support Dias's (1947) observation suggesting the floor showed little signs of recent human disturbance. A 2 m x 2 m trench was subdivided into four 1 m x 1 m squares (100/98, 100/99, 101/98 and 101/99). Excavation occurred in 3 cm - thick spits. Ten visually distinct layers/features were identified across the trench's south wall. These stratigraphic layers represent the sediment accumulation over time, with each identified through the Munsell Soil Book of Colour and texture. The first four top layers of the excavation are dominated by soft and very fine silt soils in reddish brown, light grey, light brown, and greyish brown. Layer I (0-12 cm) of the soil, excavated during the 2019 excavation season, was grey-ashy (soft), with disturbance from roots from the bush. Layer II (12-27 cm), the colours of the soil started to change to grey and then dark brown. Here, excavators identified a termite nest on quadrant 100/99 from 10-20cm. Layers III and IV are 27-57 cm, 57 – 87 cm respectively.

From Layer V (87-114 cm), brown soils dominate the stratigraphy but are later replaced with grey soils that are harder to excavate than the first layers. Layer VI, a lens between Layer IV

and V has a similar composition to Layer V. Layers VIII, IX and X are very hard with brown and grey colours, with little lithics and faunal elements identified (Muianga, 2025). These may represent disturbances or other stratigraphic features within the deposit. These disturbances may be attributed to bioturbation caused by animals living or using the site. In addition to the termite mound identified by the archaeological team, local guides identified known burrowing species including *Varanus niloticus*, commonly referred to as Nile Monitor Lizards or, locally called 'Salamandra', and a variety of snake species. Apart from the ten identified layers, and noted disturbances, the presence of stones, concentration of burnt bones, charcoal and shell was also recorded.

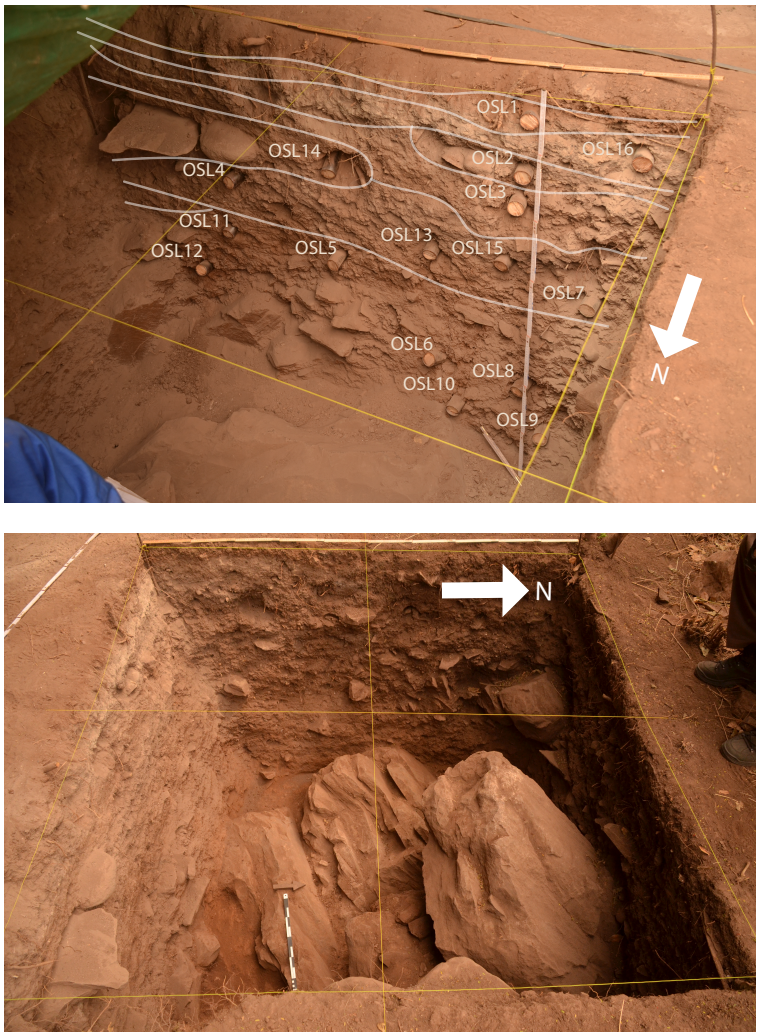


Figure 4.2: (top) Daimane II excavation profile with stainless steel luminescence tubes inserted, (bottom) Excavation square with rockfall fully exposed, photographs taken by , Décio Muianga, July 2021

4.2.2. Archaeological Finds

Excavation findings include formal and informal MSA and LSA lithic tools as well as worked and unworked faunal remains. Rhyolitic MSA Levallois flakes and cores are still persistent in the LSA deposit. Formal LSA tools include backed blades, backed bladelet, backed pieces, point bifacial, point unifacial, retouched blade, retouched bladelet, retouched flake, retouched point, retouched points, scraper convergent, scraper end, scraper nosed, scraper round, scraper side, scraper thumbnail (Muianga, 2025). Other material cultural remains include ostrich eggshell beads, land snail beads, worked bone, bone points, fire cracked rocks, charcoal, shells, engraved land shells and ceramics.

Zooarchaeological analysis of bones determined a varied diet but with a distinct absence of domesticated species. Catfish (*Clarias gariepinus)*, followed by monitor lizards (*Varanus niloticus*), are the most commonly occurring species. This is pronounced at 10-30cm where catfish, followed by Leopard tortoise (*Geocephalone pardalis*) are the most abundant species. This is distinctly different to other layers where mammals and freshwater mussels are more dominant (Scott, 2024). Within deeper sediments, impala (*Aepyceros melampus*), zebra (*Equus quagga*) and warthog (*Phacochoerus aethiopicus*) make up a large portion of the assemblage. Leopard tortoise and giant African snail (*Achatina* sp.) have a high Number of Identified Specimens (NISP) throughout the sequence, but this is mainly due to the fracturing of their shells as opposed to the number of individuals present. Anthropogenic activity is indicated on faunal remains through burning (430), cut marks (7), suspected bite marks (4) and modification (15 rounded bone shafts, engraved snail shells). Other techonomic types of post-depositional modification are present on 20 bone fragments which have an unusual flower weathering.

4.2.3. Environmental reconstruction

Twenty-nine sediment samples were collected at 5 cm intervals from the excavation profile (5-145 cm) at Daimane II (Figure 4.3). The phytolith assemblage throughout indicates a consistently wooded environment with notably low grass phytolith frequencies and no evidence of domesticated plants. Principal Component Analysis (PCA) of preservation state (PC1=82%, PC2=13.3%) and morphological composition (PC1=89.7%, PC2=5.3%) revealed strong patterning (Hattingh, 2024). The uppermost deposits (samples 1-16 and 20) were characterised by normal, undamaged phytoliths (Figure 4.3), with elongate entire, rugose spheroid, and acute bulbous forms dominating the assemblage. The middle sequence (samples 17-18 and 21-25, 29) was distinguished by high frequencies of polyhedral and blocky phytoliths, coinciding with increased weathering and discoloration (Hattingh, 2024). The deepest deposits (samples 19, 26-28) were defined by the prevalence of globular/psilate phytoliths and showed the highest degree of weathering. Despite samples 7-9, demonstrating unexpectedly low preservation when compared with their stratigraphic position, the statistical robustness combined with the clear vertical patterning supports minimal post-depositional disturbance in the sequence. This contrasts with the ancient DNA on sediment which reports high levels of termite activity (Figure 4.4). While future work on phytoliths and sedimentary behaviour may resolve this disconnect (see: Fishkis et al., 2010, 2009; Humphreys et al., 2003), at the present a limited vertical disturbance is assumed for throughout the site.

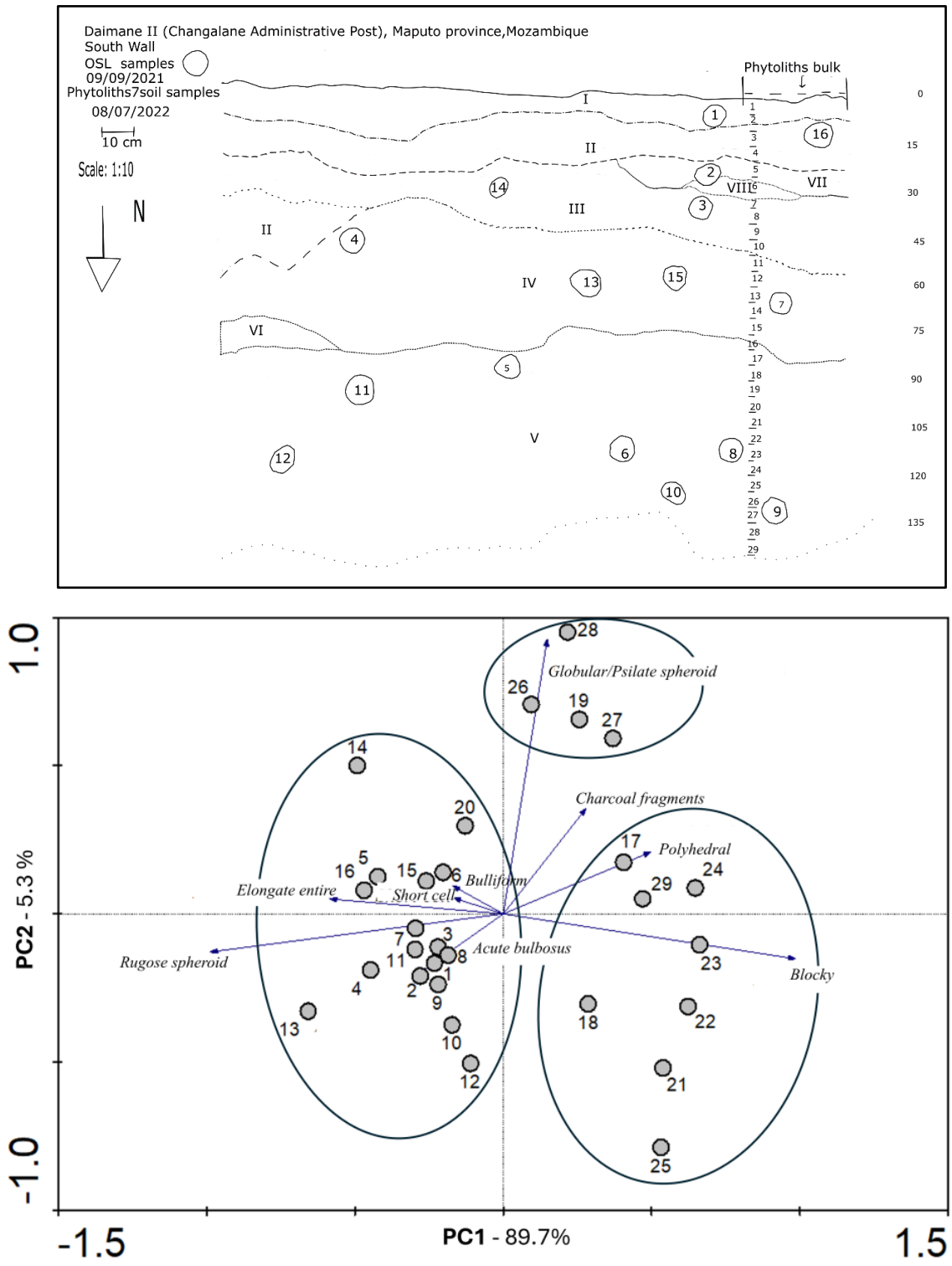


Figure 4.3: Phytolith sampling and morphological analysis from Daimane II. (Top) Stratigraphic profile showing sample locations at 5 cm intervals (0-145 cm depth). (Bottom) PCA biplot of phytolith morphology. Three distinct groupings correspond to preservation states: upper samples (1-20, excluding 17-19) with well-preserved elongate entire, rugose spheroid, and acute bulbous forms; middle samples (17-18, 21-25, 29) dominated by weathering-susceptible polyhedral and blocky forms despite increased degradation; and lower samples (19, 26-28) with highly weathered assemblages dominated by globular/psilate spheroids (Hattingh, 2024)

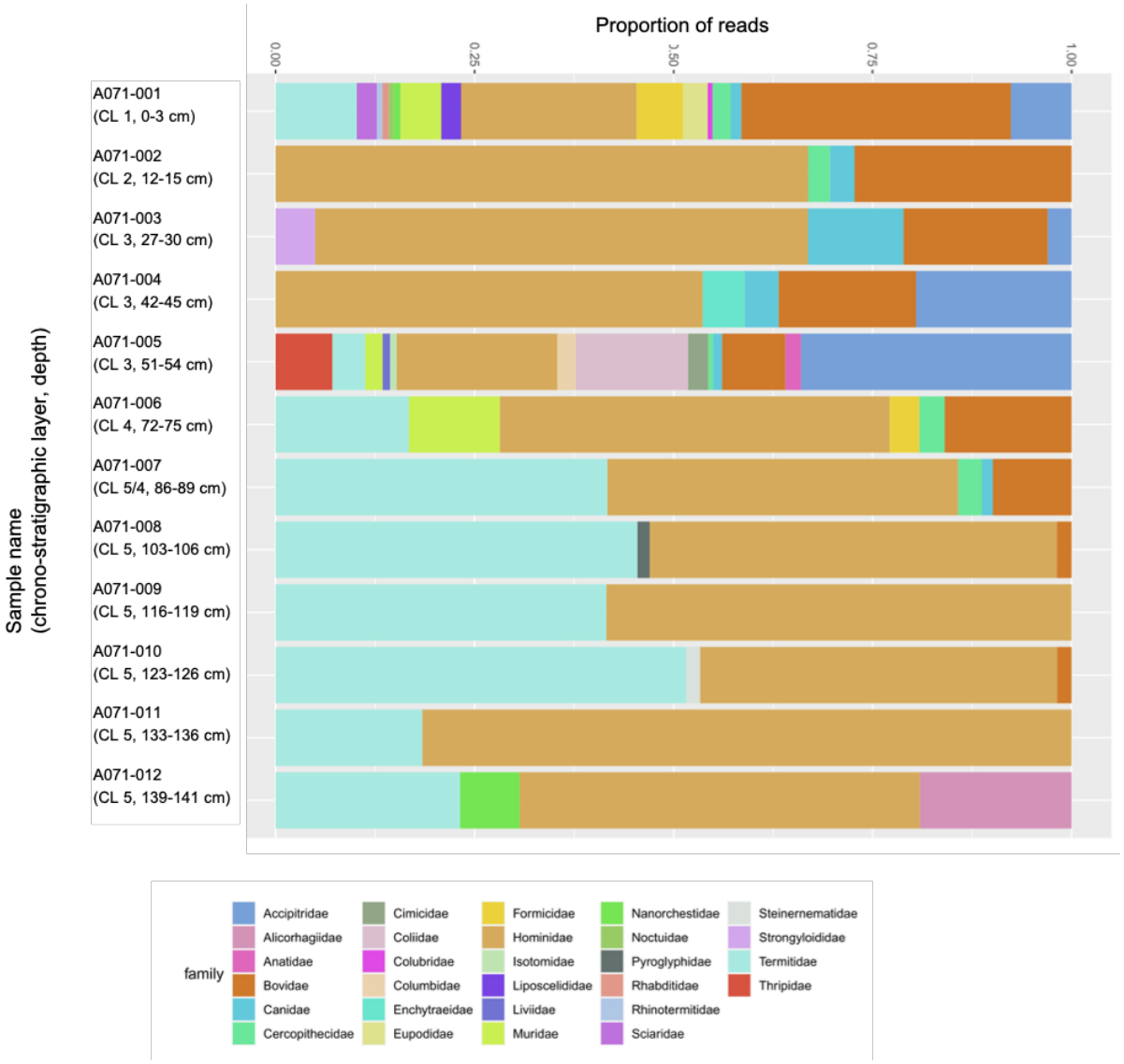


Figure 4.4: Relative abundance of animal families across the section based on aDNA read counts (reproduced with permission from Muianga)

4.3. Dating Methodology:

4.3.1. Radiocarbon Dating

In July 2022, eleven charcoal samples were recovered through flotation from Excavation Square 100/98 and transported to the Research Laboratory for Archaeology and the History of Art (RHALA) at the Oxford University (U.K.) for radiocarbon analysis. The eleven charcoal samples and two standards underwent Acid-Base-Acid (ABA) pre-treatment following established procedures outlined in Brock et al., (2010). Samples were handled with minimal

manipulation to prevent material loss during processing. After pretreatment, samples were freeze-dried overnight before combustion and graphitization. The graphite was pressed into aluminium cathodes (bullets) for AMS measurement. Two samples (P-55107, Square 100/98, 52 cm and P-55109 Square 100/98, 100 cm) failed to produce a date due to low ^{14}C yield. In total there were nine successful radiocarbon determinations. Ages were calibrated in OxCal v4.4 using the Southern Hemisphere calibration curve SHCal20 (Hogg et al., 2020b; Ramsey, 2009). The ages are presented as cal BP, where BP is 1950.

4.3.2. Luminescence Dating

Sample collection

In 2021, sixteen sediment samples and two fire-cracked rocks were collected from Daimane rock shelter for analysis in a future study (Figure 4.2). All sediment samples were obtained from squares 100/98 and 100/99 in the south wall of the excavation area. Sampling was conducted during daylight hours, with a tarp employed to minimise light exposure to the south wall, which receives morning sunlight. Sample extraction involved initially cutting back the exposed sediments using a trowel, followed by the insertion of 15 cm stainless steel tubes via controlled hammering. To prevent light contamination, the tubes were sealed with wooden discs, secured with duct tape, and wrapped in aluminium foil. The top two samples OSL1 (X7593) and OSL2 (X7594) are from layer I and II respectively. Samples OSL3 (X7595) and OSL14 (X7605) were collected from Layer III, whilst samples OSL13 (X7604), OSL15 (X7606), and OSL7 (X7598) were obtained from Layer IV. Additionally, within Layer IV, sample OSL4 (X7596) was collected from beneath a large rock and depressed Layer II. In descending stratigraphic order, samples OSL5 (X7596), OSL11 (X7602), OSL6, OSL8 (X7599), OSL12 (X7603), OSL10 (X7601), and OSL9 (X7600) were retrieved from Layer V. Samples OSL11 (X7602) and OSL12 (X7603) were collected near substantial rockfall deposits

(Figure 4.3) that could not be fully removed. Sample OSL6 (X7597) was taken from immediately below Feature IX. Two potential burnt stones were sampled for thermoluminescence (TL) dating from the west wall: the first originated from cave spall in square 101/98 at 13 cm depth and the second was taken from a fire-cracked rock in square 101/98 at 66 cm depth. However, analysis of these TL samples was beyond the scope of this paper. All luminescence samples were shipped to the luminescence dating laboratory at the Oxford Luminescence Laboratory, University of Oxford, United Kingdom.

Equivalent Dose Measurement

The luminescence tube samples were opened under amber-filtered light conditions (low intensity LEDs with a peak emission of 594 nm). The outer 2 cm of sediment from each tube was removed and retained for dosimetry analysis. The light-protected inner sediment was wet sieved into >355 μm, 355-255 μm, 255-180 μm, 180-125 μm, 125-90 μm, and <90 μm fractions. Sample X7604 contained an unidentified lithic tool. Samples X7597 and X7595 contained common small roots. For all samples, the coarse grain fraction (180-255 μm) was selected for analysis. This grain size fraction was selected as it was relatively abundant in the coarse-grained sediments, ensuring sufficient quartz grains for reliable luminescence analysis. Carbonates were removed by treating samples with 10% HCl for 24 hours. Following three rinses with distilled water, organic material was removed using 32% H_2O_2, which produced a strong reaction in all samples. The samples were then rinsed with distilled water, dried overnight at room temperature, and dry sieved to isolate the 180-250 μm fraction. Further isolation of lighter fraction, including quartz and feldspar minerals, included density separation using sodium polytungstate (SPT) (2.58 g cm^{-3}). These fractions were rinsed and dried overnight at room temperature. Feldspar grains and other contaminants were removed using 30% HF for 60 minutes. This treatment also removed the outer alpha irradiated shell of quartz grains. A final dry sieving helped to isolate the ~180 μm fraction.

All quartz grains were mounted as a monolayer onto small sized (2 mm) aluminium discs using silicone oil adhesive (Viscasil). For single grain analysis, grains from X7598 were dispersed into 300 µm holes on special anodized Risø disks. Disks were placed on a carousel and loaded into an automated Risø TL/OSL DA-15 luminescence reader. Following Murray and Wintle (2000) and Banerjee et al. (2001), a modified single aliquot regenerative dose (SAR) protocol (Figure 4.4) was adopted for all OSL measurements.

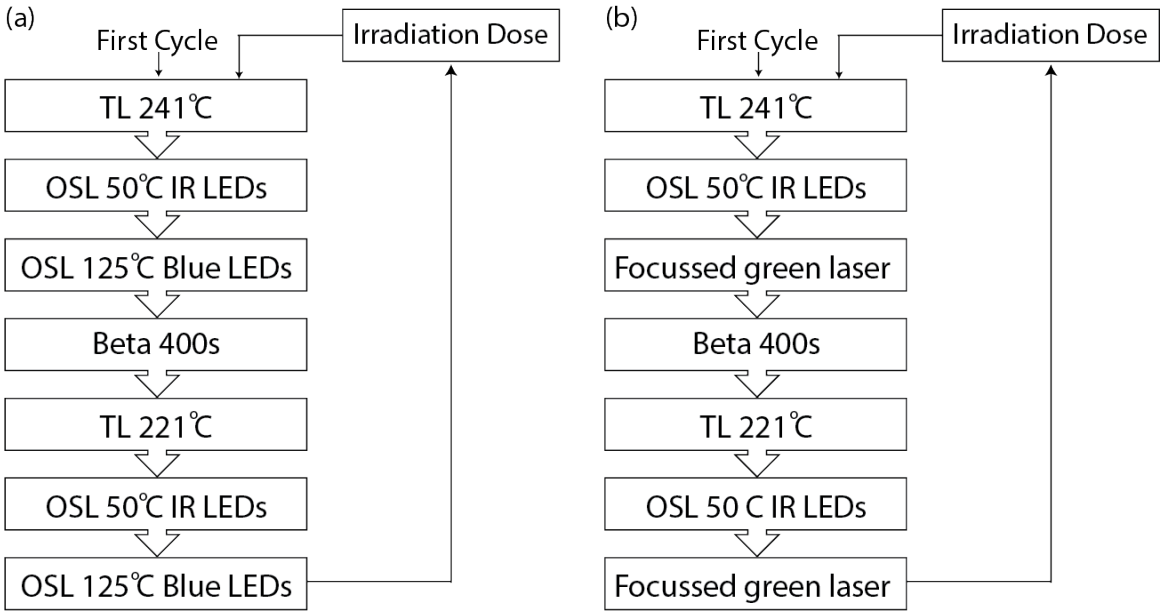


Figure 4.4: Single aliquot Regenerative cycle programmed for (a) OSL and (b) OSL-SG analysis

The Analyst v.4.31.9 programme was used to review all the data The Analyst v.4.31.9 programme was used to review all the data (Duller, 2015). A test dose of 400 Gy was used for each sample. Rejection criteria included a recycling ratio outside 10% of unity and/or recuperation >10%. Accepted equivalent dose (De) values were exported and analysed using Microsoft Excel and the luminescence package in RStudio (Supplementary Code) (Kreutzer et al., 2012). Initial De values were converted from seconds (s) to Grays (Gy) using the laboratory beta source dose rate (0.0346 Gy/s). For single aliquot measurements, both the central age model (CAM) and minimum age model (MAM) were calculated following Galbraith et al. (1999). Given the high overdispersion values, and the ability to compare it across all samples,

the minimum age model (MAM) was favoured in the subsequent analysis, the ages are interpreted considering potential sedimentary disturbance. For single grain measurements, the finite mixture model (FMM) was applied to help identify discrete components within the De distribution (Roberts et al., 2000).

Environmental Dose Rate

The light-exposed outer sediment from each OSL tube was weighed and dried overnight in an oven to obtain an estimate of the modern water content. Subsequently, approximately 10-20 g of material was sent to a specialist accredited laboratory (Actlabs in Canada), to determine the concentrations of natural radionuclides (U, Th, K and Rb). The cosmic ray contribution was calculated based on the recorded sample depth as well as the geographical position and altitude of the site following data presented in Prescott and Hutton (1994). Using DRAC v1. (Durcan et al., 2015), these data were used to calculate the environmental dose rate (Dr). The calculations included accounting for attenuating factors by water following Zimmerman (1971), conversion factors following Guérin et al. (2011), alpha-grain size attenuation following Brennan et al. (1991), beta-etch depth attenuation from Guérin et al., (2011), and beta-grain size attenuation from Brennan, (2003). While all samples produced viable results, the absence of direct in situ assessments of the environmental dose rate make it impossible to accurately determine the external gamma dose rate contribution from samples secured near sedimentary boundaries or bedrock. In the case of samples OSL12 (X7604) and OSL4 (X7596), their proximity to large rocks makes it likely that the assessment of the environmental dose rate may be erroneous and should be treated with caution. The final OSL age estimates were calculated (Equation 4.1) by dividing the equivalent dose determinations by the environmental dose rate (Aitken, 1997; Roberts et al., 2015):

$$Age\ (ka) = \frac{Equivilent\ dose\ (Gy)}{Environmental\ dose\ Rate\ (Gy.ka^{-1})} \qquad \text{(Equation 4.1)}$$

The unit for the D_e is Grays (Gy), where 1Gy=1J/Kg (Galbraith and Roberts, 2012; Roberts et al., 2015). The ages are presented as years before present where present is 2021, the excavation year. When luminescence and radiocarbon age estimates were plotted and compared on a depth/age regression using the ggplot package in Rstudio, luminescence ages were adjusted to cal BP.

4.4. Results

4.4.1. Radiocarbon results

The site produced nine successful radiocarbon ages ranging from 285 – 145 cal BP to 1056 – 910 cal BP (Table 4.2). The $\delta^{13}C$ values (-23.63‰ to -27.6‰) are consistent with C_3 vegetation and are indicative of good preservation. However, the radiocarbon ages show no statistical clustering and several age inversions (Figure 4.4).

Table 4.2: Radiocarbon Results

Sample	Depth (cm)	**δ** 13 ‰	Radiocarbon age (BP)	Calibrated age (cal BP)
OxA-44119	13	-23.84	195 ± 16	282*
OxA-44120	70-75	-23.66	505 ± 17	528 - 496
OxA-44131	80-85	-24.65	254 ± 17	304 - 151
OxA-44132	90-95	-25.96	223 ± 17	285 - 145
OxA-44121	95-100	-23.63	1322 ± 21	1275 - 1119
OxA-44122	105-110	-26.88	130 ± 16	252**
OxA-44133	115-120	-27.6	546 ± 32	553 - 500
OxA-44123	120-125	-25.23	1095 ± 32	1056 - 910
OxA-44124	140-145	-24.41	397 ± 33	495 - 322

*Date may extend out of range - 195+/-16BP

**Date may extend out of range - 130+/-16BP

The uppermost sample OxA-44119 (13 cm), and the deepest sample, OxA-44124 (140-145cm), failed to generate reliable calibrated ages. These ages are excluded from further analysis. OxA-44132 (90-95 cm), in the middle of the sequence provides the oldest age 1056 – 910 cal BP. This is directly above OxA-44121 (95-100cm), which has the second youngest age, 304 – 151 cal BP and is within error of the youngest OxA-44122 (100-105 cm), 285 – 145 cal BP. This suggests that from 90-110 cm there was complex post-depositional mixing. This is supported by an extremely weak regression (Figure 5) where only the R^2 value of 0.006 indicates almost no variation in depth is explained by age, and a high p-value of 0.8666 suggests that even this weak association is not statistically significant.

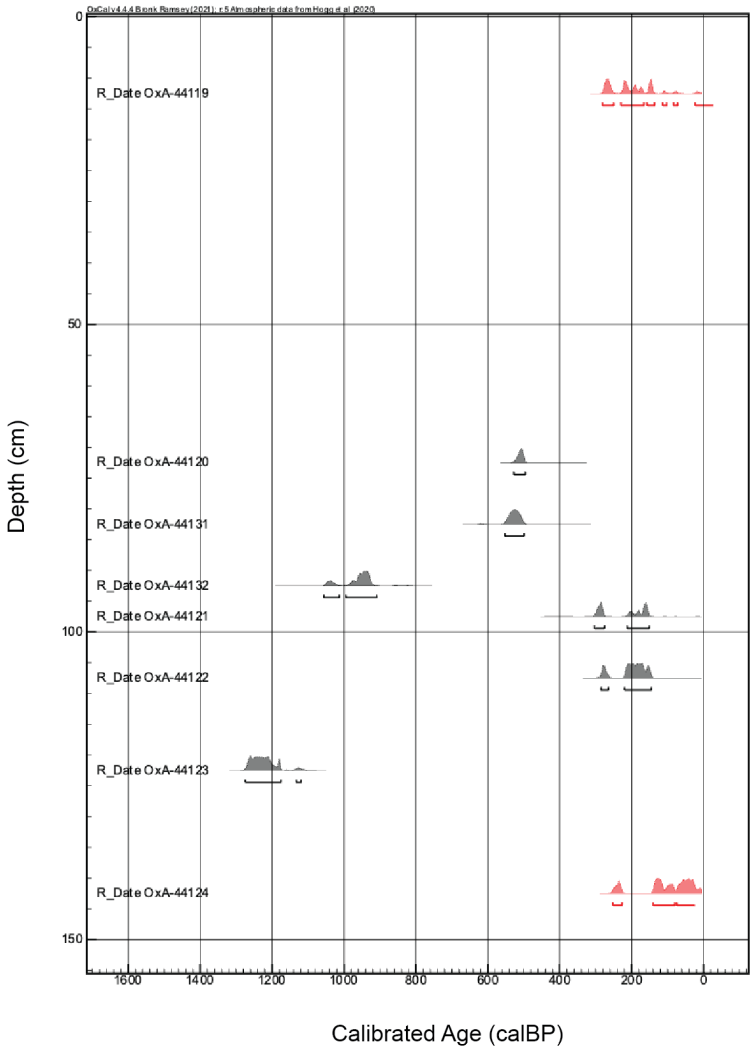


Figure 4.5: Radiocarbon ages calibrated against depth, samples in red are excluded from analysis owing to ages potentially reaching the present.

4.3.2. Luminescence dating results

Sixteen samples were analysed from Daimane II, of which thirteen yielded acceptable De measurements (Table 4.3). Acceptable De measurements were determined based on samples having at least 10 aliquots combined with overdispersion values below 50%. Three samples were excluded owing to less than 10 aliquots combined with a high (>50%) overdispersion. Samples were evaluated based on the number of accepted aliquots, overdispersion values (OD%), and their stratigraphic context (Supplementary Figures II). While the De values of samples X7601, X7604, and X7605 are presented in Table 3, these samples were excluded from further analysis owing to having insufficient accepted aliquots ($n < 7$), making them less reliable than the remaining thirteen samples. The accepted samples show varying degrees of reliability. X7600, X7606, X7607, X7608 provide the most robust analysis with 18-21 accepted aliquots each; however, their overdispersion values vary considerably. X7608, despite showing exceptionally high overdispersion (102%), maintains reliability as the overdispersion stems from just three high aliquots within an otherwise homogenously bleached population. In contrast, X7606 (36.4% overdispersion) shows a distinct bi-modal distribution with two major grain populations. The remaining nine samples, yielded between 7-12 accepted aliquots. Overdispersion values across the sequence range from 25.9% (X7597) to 70.8% (X7595). Despite this, X7595 (70.8%) presents a largely homogenous distribution with only two outliers. Sample, X7598 which has relatively low overdispersion, 30%, initially appears bimodal in single aliquot analysis. However, subsequent single grain analysis of X7598 revealed two closely aligned clusters with a gradual progression towards a third larger De cluster (Figure 4.6). The single aliquot analysis masked some grains with larger De values because the averaged signal from multiple grains on each disc was dominated by the brighter, well-bleached younger grains. These older, more faded grains contributed a smaller percentage to the total light sum and were consequently discarded as outliers during statistical analysis. The single

grain analysis revealed these individual older grains that had been obscured in the averaged aliquot signal, potentially indicating an earlier MSA occupation. Given the overall consistency of the De results across methods, combined with the large uncertainties associated with each component, we selected the Minimum Age Model (MAM) for final age determination.

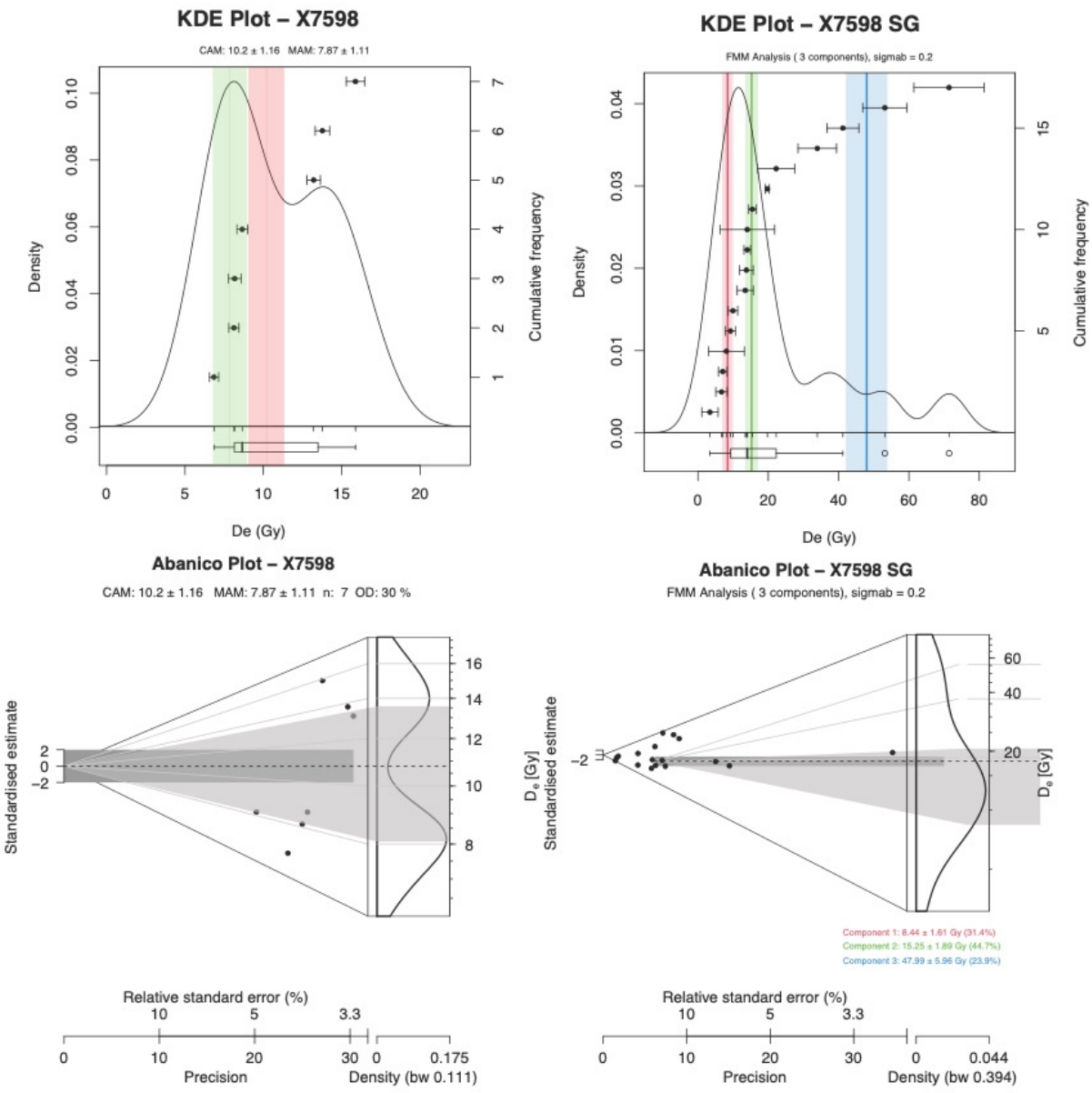


Figure 4.6: Single aliquot (left) and Single Grain (right) Abanico Plot and KDE for Sample X7598

The complex De distribution patterns and high levels of overdispersion throughout the sequence informed our decision to select the MAM model ages over CAM or FMM ages. In

the absence of more single-grain analysis, using the MAM – a *terminus post quem*, or the earliest possible age for the depositional layer – reflects the site's complex depositional history as it acknowledges the complex post-depositional context of the deposit.

The accepted MAM ages establish a chronological framework spanning 384 ± 79 years ago to 4,041 ± 626 years ago (Figure 4.7, Table 4.4). A simplified age model using the most reliable samples (X7606, X7607, X7608 and X7600) indicates a clear age regression with Layer II at 286 ± 5 ka (X7608), Layer III at 376 ± 4 years ago (X7606), Layer IV at 528 ± 83 years ago (X7607) and Layer V (X7600) at 2 197 ± 286 years ago. However, upon further inspection of all accepted ages and levels of overdispersion, it is clear that complex depositional and post-depositional factors are affecting Daimane II. This is evident in Layer V, where two samples from similar depths yield ages of 2 197 ± 286 years ago (X7600) and 4 041 ± 626 years ago (X7601), despite a general chronological trend supported by an R^2 value of 0.554 and a p-value of 0.0035 (Figure 4.5).

Layers I, II, III and VII all yield minimum ages that overlap within two sigma error margins. With Layer I dating to 384 ± 79 years ago, Layer II dating to 286 ± 5 years ago, Layer VII dating to 242 ± 51 ka, and Layer III's two ages in agreement with an average of 338 ± 59 years ago. Layer IV's oldest age is also its shallowest, 2 639 ± 51 years ago (X7596). This sample has the second lowest overdispersion at 27.2%, indicating a relatively homogenous grain population. Given its location in Square 100/98, beneath two large rocks, which may be affecting the environmental dose rate, and its distance from other samples in this layer, X7596 may be reporting a less disturbed age than the two samples from Layer IV located in Square 100/99.

Overdispersion is particularly apparent in X7607 with 72.6% (the site's second highest) and a MAM age of 528 ± 83 years ago. Below it, X7599, is slightly less disturbed at 56.6% and a

MAM of 1 213 ± 229 years ago. This pattern of variability in sediment mixing continues into Layer V, the deepest layer. Layer V similarly complex ages range from 1 650 ± 231 years ago (X7603) to 4 041 ± 626 years ago (X7597). However, it is important to note that these samples are from approximately the same depth. Notably, X7597, is the oldest sample and has the lowest overdispersion (25.9%) within the entire site. The deepest sample (X7602) provided an age estimate of 2 277 ± 469 years ago, which is in overall agreement with other results obtained from Layer V samples of 3 042 ± 437 years ago (X7598) and 2 197 ± 286 years ago (X7600). The MAM age for X7598 is in 3 042 ± 437 agreement with the second largest component (31.4%) of the FMM model 3316 ± 846.

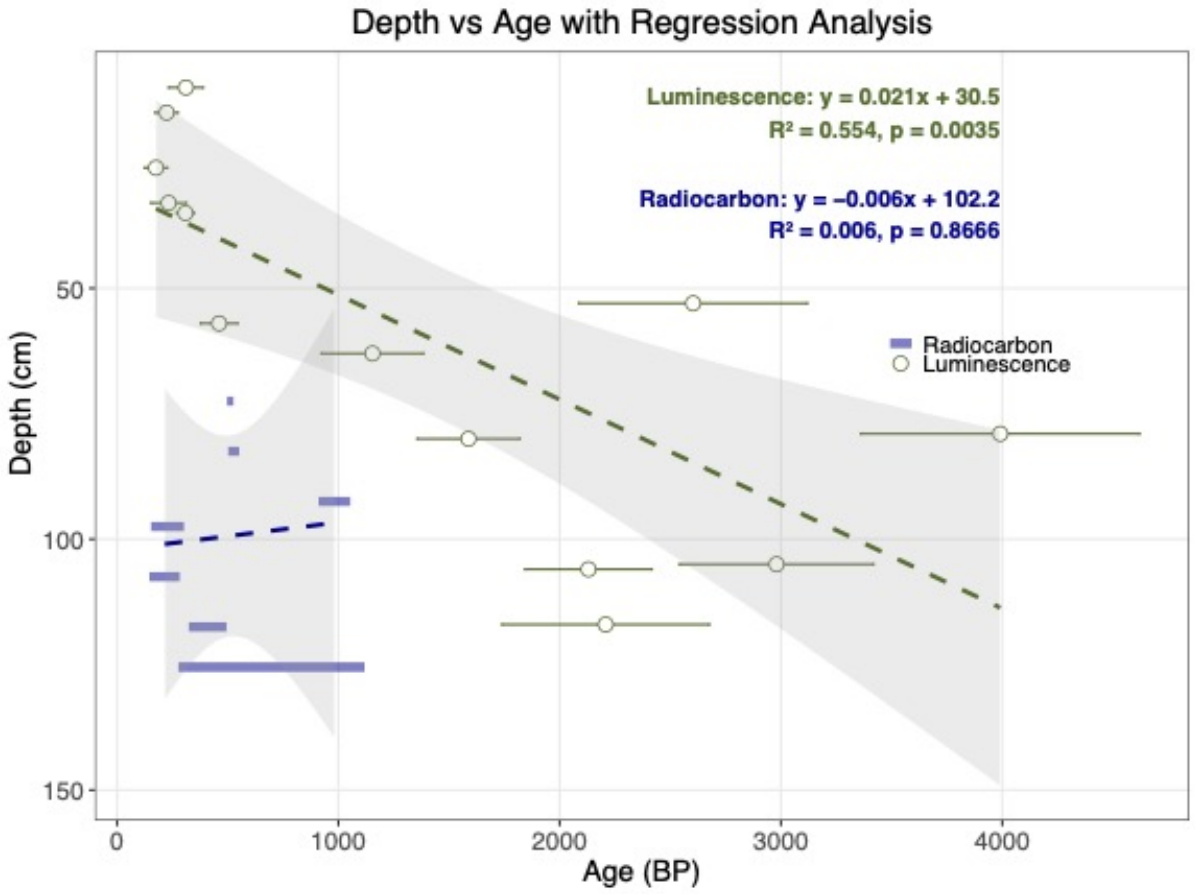


Figure 4.7: Depth vs Age of accepted luminescence MAM ages and radiocarbon ranges, all samples are represented with 94.5% confidence, the dotted line is the unweighted regression, luminescence samples were adjusted so that BP=1950.

Table 4.3: Dosimetry measurements and Equivalent Dose Results

Sample	Field ID	Depth (cm)	Layer	Water Content (%)	U (ppm)	Th (ppm)	K (%)	Cosmic dose rate	Environmental Dose Rate (Gy. ka-1)
X7593	OSL1	10	I	30.2	2.4	10.6	1.83	0.264 ± 0.026	2.42 ± 0.077
X7594	OSL2	26	II	53.9	2.1	10.4	2.08	0.234 ± 0.023	2.186 ± 0.06
X7595	OSL3	33	VII	46.89	2.9	15.7	2.17	0.226 ± 0.023	2.696 ± 0.075
X7596	OSL4	53	IV	40.7	2.5	13	1.95	0.208 ± 0.021	2.478 ± 0.072
X7597	OSL5	79	V	39.32	4	14.1	1.84	0.191 ± 0.019	2.698 ± 0.078
X7598	OSL6	105	V	43.84	3.9	14.1	1.84	0.184 ± 0.018	2.587 ± 0.073
X7599	OSL7	63	IV	43.76	3.3	11.9	1.93	0.201 ± 0.02	2.473 ± 0.07
X7600	OSL8	106	V	40.45	4.6	14.2	1.99	0.184 ± 0.018	2.864 ± 0.083
X7601	OSL9	125	V	59.15	3.4	15.3	1.88	0.179 ± 0.018	2.328 ± 0.059
X7602	OSL10	117	V	25.45	3.4	15.2	1.78	0.181 ± 0.018	2.916 ± 0.094
X7603	OSL11	80	V	44.09	2.7	14.6	1.98	0.19 ± 0.019	2.522 ± 0.071

X7604*	OSL12	104	V	14.22	4.8	15.2	2.02	0.184 ± 0.018	3.709 ± 0.134
X7605	OSL13	68	IV	16.56	4.6	9.5	1.42	0.197 ± 0.02	2.781 ± 0.097
X7606	OSL14	35	III	5.73	2.5	12.4	2.15	0.224 ± 0.022	3.533 ± 0.141
X7607	OSL15	57	IV	12.32	2.4	10.5	1.94	0.205 ± 0.021	2.972 ± 0.11
X7608	OSL16	15	II	5.28	1.4	7.4	1.53	0.253 ± 0.025	2.446 ± 0.097
*Sample was taken near large bolder and lab measured environmental dose rate is considered inaccurate									

Table 4.4: OSL Single Aliquot results

Lab ID	Field ID	Depth (cm)	Layer	Aliquots (n)	OD (%)	Total environmental dose rate (Gy. ka^{-1})	Central age De (Gy)	Central age estimate	Minimum age De (Gy)	Minimum age
X7593	OSL1	10	I	10	61.3	2.420 ± 0.077	2.15 ± 0.42	889 ± 176	0.93 ± 0.19	384 ± 79
X7608	OSL16	15	II	21	102.5	2.446 ± 0.097	0.95 ± 0.26	388 ± 107	0.70 ± 0.12	286 ± 50
X7594	OSL2	26	VII	11	41.8	2.186 ± 0.060	0.76 ± 0.11	348 ± 51	0.53 ± 0.11	242 ± 51
X7595	OSL3	33	III	11	70.8	2.696 ± 0.075	2.03 ± 0.44	753 ± 165	0.81 ± 0.21	300 ± 78
X7606	OSL14	35	III	21	36.4	3.533 ± 0.141	1.72 ± 0.14	487 ± 44	1.33 ± 0.13	376 ± 40
X7596	OSL4	53	IV	8	27.2	2.478 ± 0.072	7.63 ± 0.88	3079 ± 366	6.54 ± 1.25	2639 ± 510
X7607	OSL15	57	IV	21	72.6	2.972 ± 0.110	4.25 ± 0.67	1430 ± 232	1.57 ± 0.24	528 ± 83
X7599	OSL7	63	IV	8	56.6	2.473 ± 0.070	5.97 ± 1.20	2414 ± 490	3.00 ± 0.56	1213 ± 229
X7597	OSL5	79	V	10	25.9	2.698 ± 0.078	14.47 ± 1.20	5364 ± 471	10.90 ± 1.66	4041 ± 626
X7603	OSL11	80	V	12	44.2	2.522 ± 0.071	5.92 ± 0.77	2348 ± 312	4.16 ± 0.57	1650 ± 231
X7598	OSL6	105	V	7	30	2.587 ± 0.073	10.20 ± 1.16	3942 ± 462	7.87 ± 1.11	3042 ± 437

X7600	OSL8	106	V	18	39.8	2.864 ± 0.083	11.10 ± 1.04	3876 ± 380	6.29 ± 0.80	2197 ± 286
X7602	OSL10	117	V	8	48	2.916 ± 0.094	12.32 ± 2.09	4225 ± 730	6.64 ± 1.35	2277 ± 469
Rejected samples owing to too few accepted aliquots										
X7605	OSL13	68	IV	2	1.1	2.781 ± 0.097	1.13 ± 0.14	-	1.06 ± 0.35	-
X7604	OSL12	104	V	6	132	3.709 ± 0.134	1.97 ± 1.08	-	0.69 ± 0.26	-
X7601	OSL9	125	V	4	51.1	2.328 ± 0.059	16.99 ± 4.35	-	11.68 ± 2.52	-

Table 4.5: Single Grain OSL Results

Lab ID	Field ID	Depth (cm)	Layer	Grains (n)	OD (%)	Total Dr (Gy. ka^{-1})	Component	FMM Age (Gy)	FMM age estimate
X7598	OSL6	105	V	17/200	70.08 ± 13.36	2.587 ± 0.073	FMM1 31.4%	8.44 ± 1.61	3316 ± 846
							FMM2 44.7%	15.25 ± 1.89	5992 ± 1259
							FMM3 23.9%	47.99 ± 5.96	18858 ± 3964

4.4. Discussion

The Daimane II assemblage indicates human presence across the later LSA. Despite strong anthropogenic presence through lithics, ceramics, OES, Land Snail Shells (LSS), fauna and aDNA, there are several unexpected results, from discordant radiocarbon and OSL ages to high levels of overdispersion within the OSL samples. Luminescence dating produced 13 minimum ages, the most recent possible age for occupation, ranging from 4060 ± 63 years ago until 380 ± 8 years ago. While FMM3 (47.99 ± 5.96 ka) from single-grain analysis presents the possibility of older MSA mixing with the layers above. Meanwhile, all radiocarbon ages fall within the last 1000 years and do not show any stratigraphic patterning or correlation with the luminescence ages of a similar depth (Figure 4.5). This may be owing to a preservation bias where older charcoal did not survive and smaller, lighter artefacts, including charcoal moving deeper into the stratigraphy. The same factors that moved the charcoal may also be responsible for the complex overdispersion patterns seen within the luminescence results. Therefore, while the charcoal may be indicative of later occupation or disturbance of the site, it is not useful for understanding the initial occupation.

4.4.1. Luminescence ages Chronology

The MAM luminescence ages (Figure 8) indicate a recent occupation or disturbance of Layer I (384 ± 79 BP), Layer II (286 ± 50 BP), VII (242 ± 50 BP), and Layer III (300 ± 78 BP and 376 ± 40 BP). These ages are all within 2σ of each other and may reflect the same disturbance or burial event. There is a significant chronological jump in Layer IV. While, well-bleached sample (OD, 27.2%), sample OSL4 (X7596) in square100/100 has an age of 2639 ± 510 BP, its stratigraphic pairs in square 100/99 (OSL15) and 100/98 (OSL7) have significantly younger ages of 528 ± 83 BP and 1213 ± 229 BP respectively. However, these age inversions may be explained through their high overdispersions of 72.6% and 56.6%, demonstrating a mixed

sediment population. Therefore, OSL15 and OSL7's ages may be indicating a more recent disturbance whereas OSL4 is more representative of the initial depositional event. Where age inversions in previous layers may be accounted for differences in stratigraphic disturbance, Layer IV offers a more complex chronological challenge.

Between Layer IV and Layer V, there is an unconformity or chronological gap. OSL5, square 100/99, is the highest sample from Layer V but has the oldest minimum age of 4041 ± 626 BP. The low overdispersion (25.9%) suggests that this is a well bleached sample with low disturbance. OSL11, from square 100/100 has the youngest age of 1650 ± 321 BP. Meanwhile, OSL 6, OSL 8 and OSL10 which are in close proximity to each other, have similar minimum ages of 3042 ± 437 BP, 2197 ± 286 BP and 2277 ± 469 BP respectively. Subsequent single grain analysis of OSL6 presents three grain populations with the majority falling in 3316 ± 846 BP (31.4%) and 5992 ± 1259 BP (44.7%). These single-grain FMM ages also indicates a potential for an older layer (23.9% of the sample is 18858 ± 3964) below the current excavation. However, this significantly older age may also be an artefact of incomplete bleaching or abnormalities in beta dosimetry (Jankowski and Jacobs, 2018; Smedley et al., 2020).

The inversions and abnormalities of these luminescence results combined with high overdispersion patterns indicate either poor bleaching at the time of deposition, abnormalities in the dosimetry or post-depositional mixing, possibly as a result of bioturbation. However, through combining these results with the young radiocarbon ages, post depositional mixing is most likely responsible for some, if not all, of the unexpected ages. It is probable that by at least 4000-3000 years ago Layer V had an anthropogenic occupation. While there is potential, for an occupational hiatus between layer V and IV, the people responsible for Layer IV accumulation are present at the site before or around ~2 600 years ago. Around ~2200 years ago there is a significant disturbance to the underlaying Layer V.

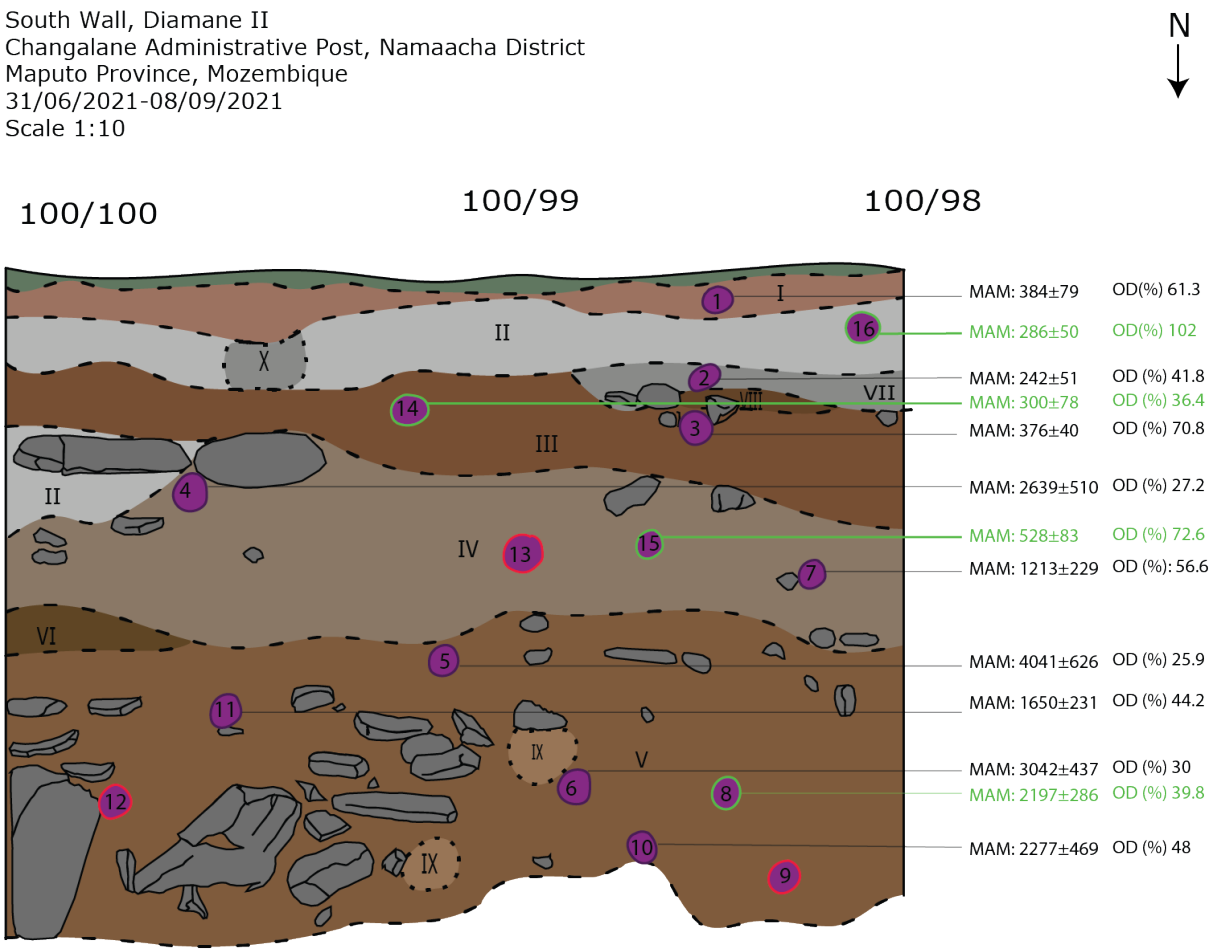


Figure 4.8: Luminescence ages plotted in stratigraphic positions. Purple dots represent each tube, a green line is indicative of samples with high confidence while a red outline indicates the sample is rejected.

These layers subsequently undergo further disturbance between ~500 and ~1200 years ago. The date of disturbance is supported by radiocarbon dating. Charcoal from layers IV and V, suggest intrusions of younger material from at least three other occupation periods at ~600, ~350 and ~1200 years ago. Lithics and pottery sherds from Layers III, VII, II and I indicate that site was subsequently reoccupied by a late iron age or farmer community. However, the age of these upper deposits is obscured by highly disturbed sedimentary processes during the last 300 years.

4.4.2. Sedimentary disturbances

While these luminescence and radiocarbon ages indicate a complex palimpsest, ancient DNA and zooarchaeology allow us to hypothesise about the causes of this disturbance. Bioturbation

has long been established as causing artefact displacement in geomorphological and archaeological contexts (Darwin, 1892; Tsi kalas and Whitesides, 2013). While the presence of burrowing species including rats, mice, tortoises, wild pigs and monitor lizards is troubling, their presence may also be part of the diet of people living within the area (see: Sackey et al., 2023). This anthropogenic attribution is supported by the archaeological investigation where (1) the bones show patterns typically associated with human modification and (2) no large burrows indicating a more mixed assemblage appear to be present within the stratigraphy; and (3) bones do not appear mixed across different layers (Karin Scott pers. comm., December 2024). Additionally, there is no additional evidence, such as bite marks or partially digested bones, suggesting Daimane II is a carnivore assemblage, as was the case at the Pleistocene site of Boegoeberg 1, South Africa (Klein et al., 1999). Despite, this, larger fauna's ability to modify the environment between human occupations cannot be excluded, particularly in the upper layers, which show distinct changes in dietary patterns and exceptionally high overdispersion values among luminescence measurements (Bateman et al., 2007; Kristensen et al., 2015). This is of particular concern in the upper layers, where there are a distinctly different fauna including burrowing species, such as monitor lizards that are associated with tortoise and catfish, which are dominant parts of their diet.

A dual explanation of the presence of species is clearer when investigating the presence of smaller fauna, notably snails. While some snails were initially introduced through anthropogenic behaviours like consumption and ornamentation they are also part of the post-depositional history of the site, as bioturbating agents who burrowed within the stratigraphy and left distinctive flower-patterned marks on bones (Dirks et al., 2015; Miller et al., 2018; Walz, 2017). This second process is most likely responsible for the high concentration of *Achatina sp* snails (316 specimens) in Layer IV, square 101/99 [associated with the inverse ages and high overdispersion, 72.6%, from X7607 (OSL15)]. Additional sources of

bioturbation may originate from smaller fauna including termites. Their presence was noted during the excavation and through aDNA analysis.

4.4.3. Implications for understanding the archaeological record

Despite their importance for interpreting chronological and archaeological data, understanding the reasons for post-depositional processes and bioturbation in southern African sites is largely underexplored. However, important works like Chazan et al., (2013) and Feathers et al. (2020) are beginning to direct the discussion with regards to using luminescence dating to understand these complex sites. While exceptional preservation exists, ignoring the thousands of years between deposition and excavation only limits our ability to make strong archaeological inferences (Henry, 2012). While these well-preserved sites often dominate the archaeological record (Chapter 3), sites with more complex histories offer new pathways for understanding the human past and environmental change in under-researched areas.

The palimpsest nature of Daimane II's deposits therefore reflects both anthropogenic and natural processes. Overall, while Daimane appears to be a largely anthropogenic accumulation which is evidenced by the continuous lithics and faunal remains. The OSL ages provide a broad, if low precision, pattern of this Later Stone Age and Farming Communities occupation. Significantly, the persistence of MSA-style tools and the absence of indicators of domestication throughout the sequence adds to ongoing debates about technological transitions in southern Africa (Bader et al., 2022a). However, after the deposition of these layers, termites, snails, and potentially larger fauna in the upper layers, subsequently burrow through the archaeological layers, causing sedimentary disturbances of lighter artefacts and mineral grains.

4.5. Conclusion

This multi-method analysis of Daimane II uses archaeological science, in combination with traditional archaeology, provides insights into depositional and post-depositional processes

otherwise hidden when only traditional methods are applied (Mentzer, 2023). These 20 newly dated samples expand Mozembique's chronological record and pave way for further research in the region. At Daimane, future research, combining direct dating of artefacts (such as thermoluminescence on fire-cracked rocks and radiocarbon dating on faunal remains), with analysis of the depositional context will aid in better understanding artefact procurement and use prior to burial. This approach would better capture both the timing of human activities and the complex techonomic histories that shape archaeological deposits.

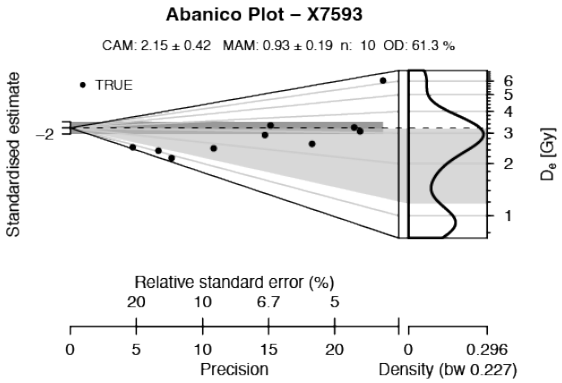
Daimane II therefore presents an important reminder of both the human agency and subsequent natural forces which influence site formation. Taking similar multidisciplinary approaches to understanding of archaeological site's palimpsests opens archaeological and chronological inquiry beyond the well-preserved deposits of coastal and cave sites. Through applying multiple methods to explore tricky and complex chronologies, Mozambique's less understood stone age offers the unique opportunity to explore southern African archaeology's anthropogenic and post depositional histories.

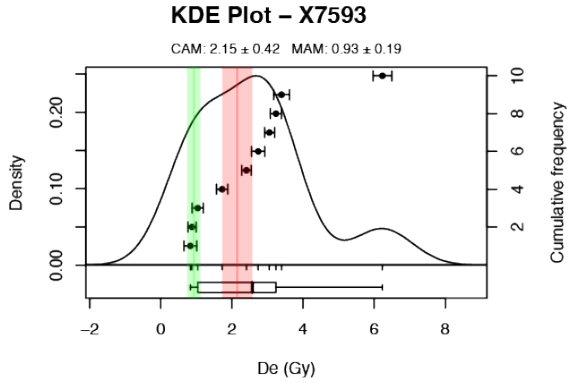
Acknowledgements:

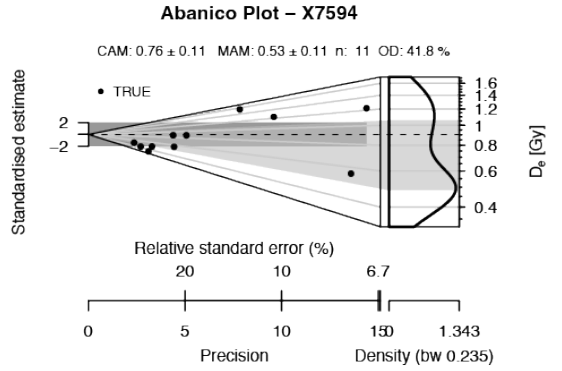
We would like to extend our thanks to Dr Monty Ochocki for his preparation assistance and training for measuring charcoal samples and Prof Christopher Ramsey for his insights into radiocarbon dating and advice for chronological modelling.

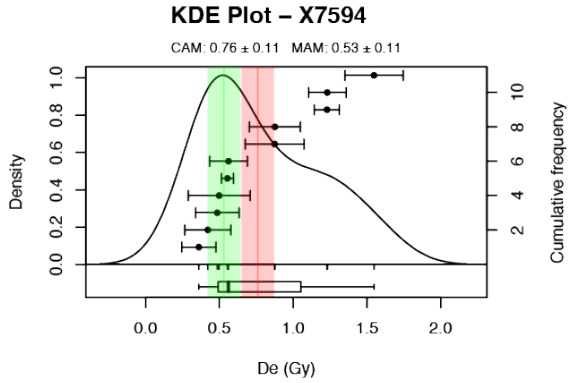
Supplementary Figures 4.I:

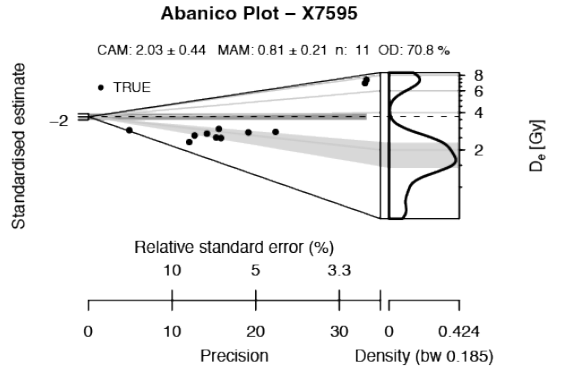
Abanico and Kernel Density Estimate plots for X7593-X7608. Samples outlined in red were rejected.

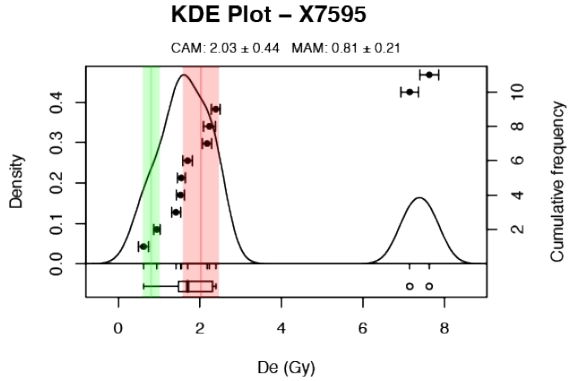


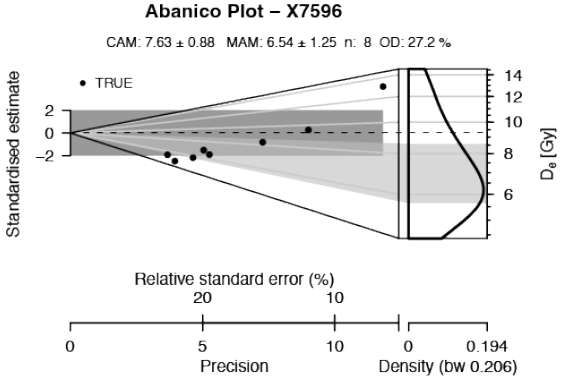


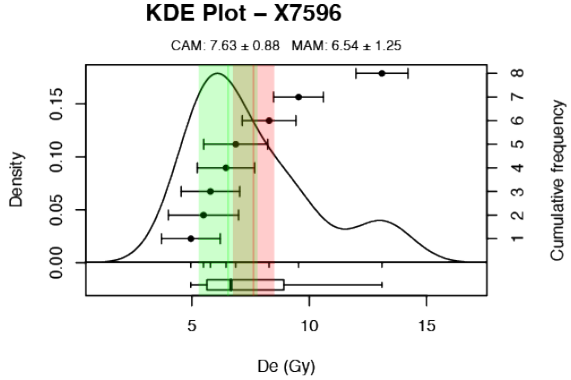


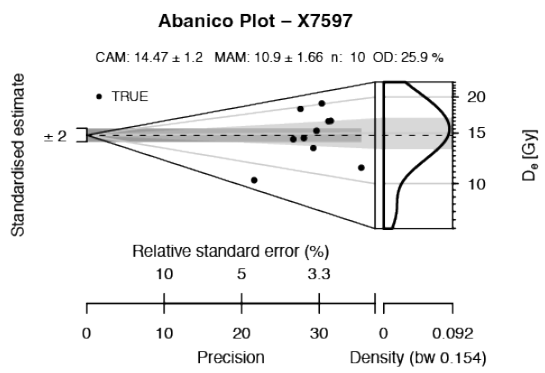


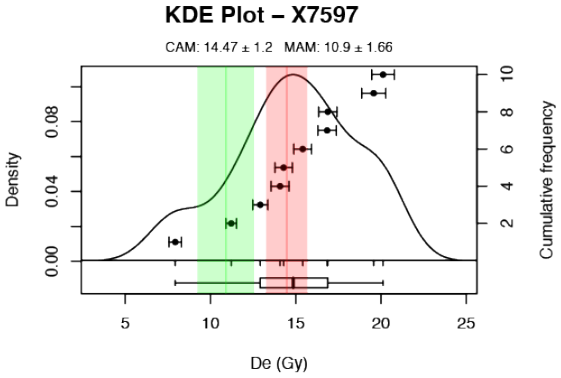


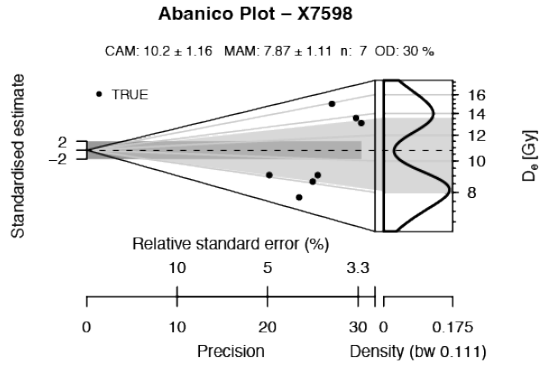


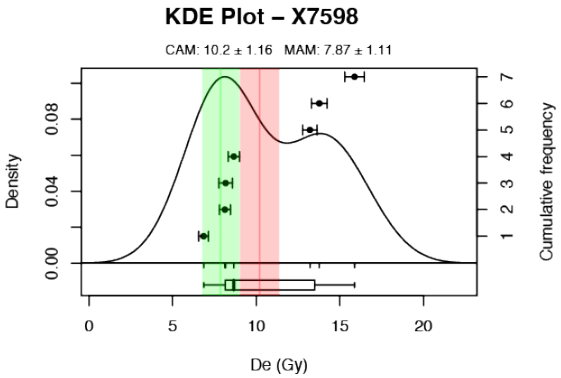


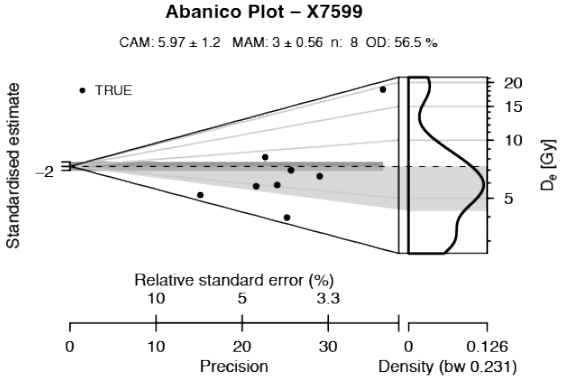


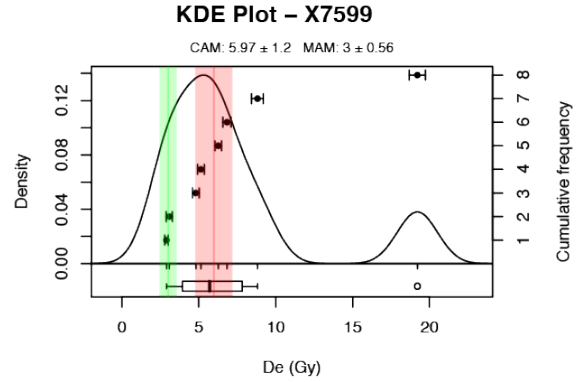

Abanico Plot – X7597
CAM: 14.47 ± 1.2 MAM: 10.9 ± 1.66 n: 10 OD: 25.9 %
TRUE
± 2
Standardised estimate
De [Gy]
Relative standard error (%)
10 5 3.3
0 10 20 30 0 0.092
Precision
Density (bw 0.154)

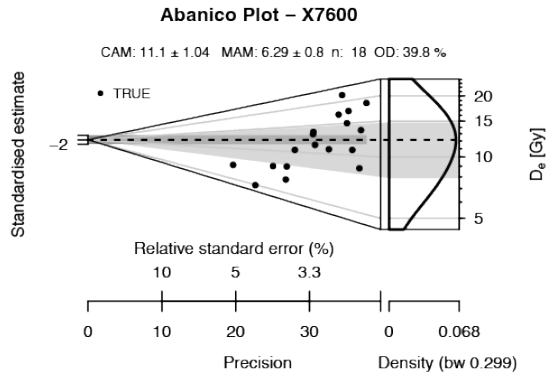

KDE Plot – X7597
CAM: 14.47 ± 1.2 MAM: 10.9 ± 1.66
Density
Cumulative frequency
De (Gy)

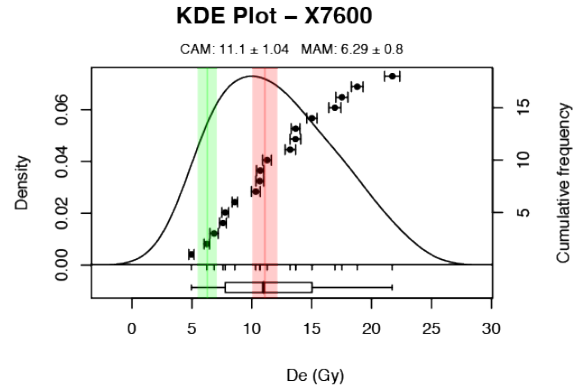

Abanico Plot – X7598
CAM: 10.2 ± 1.16 MAM: 7.87 ± 1.11 n: 7 OD: 30 %
TRUE
2
−2
Standardised estimate
De [Gy]
Relative standard error (%)
10 5 3.3
0 10 20 30 0 0.175
Precision
Density (bw 0.111)

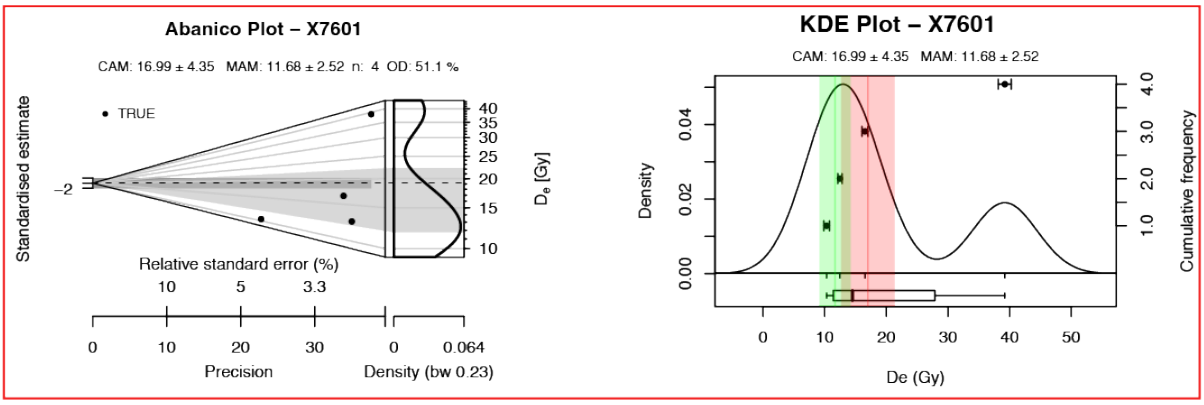

KDE Plot – X7598
CAM: 10.2 ± 1.16 MAM: 7.87 ± 1.11
Density
Cumulative frequency
De (Gy)

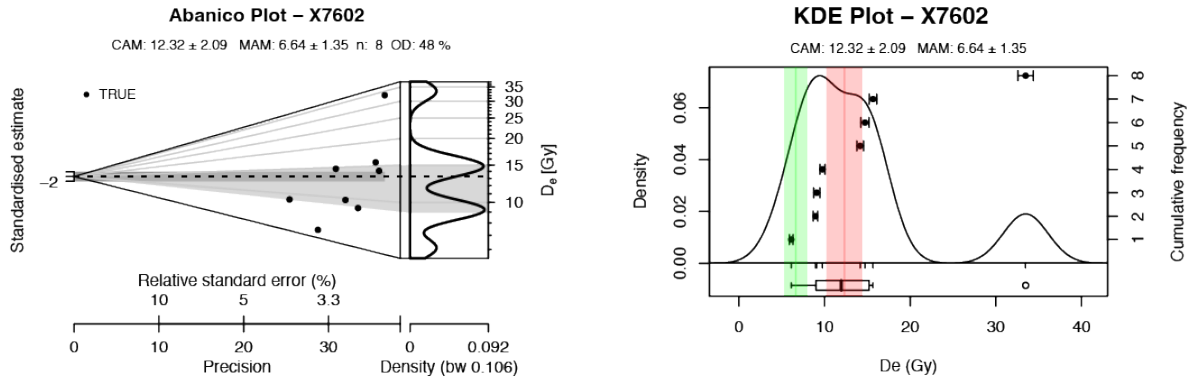

Abanico Plot – X7599
CAM: 5.97 ± 1.2 MAM: 3 ± 0.56 n: 8 OD: 56.5 %
TRUE
−2
Standardised estimate
De [Gy]
Relative standard error (%)
10 5 3.3
0 10 20 30 0 0.126
Precision
Density (bw 0.231)

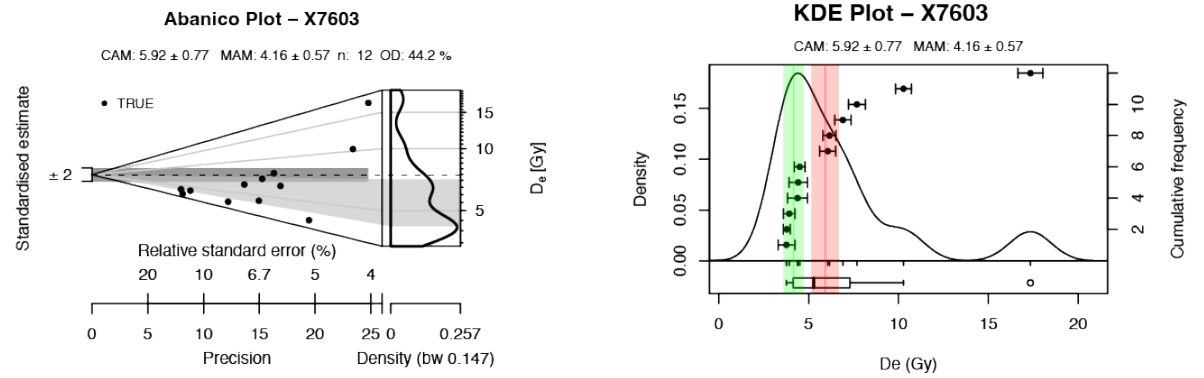

KDE Plot – X7599
CAM: 5.97 ± 1.2 MAM: 3 ± 0.56
Density
Cumulative frequency
De (Gy)

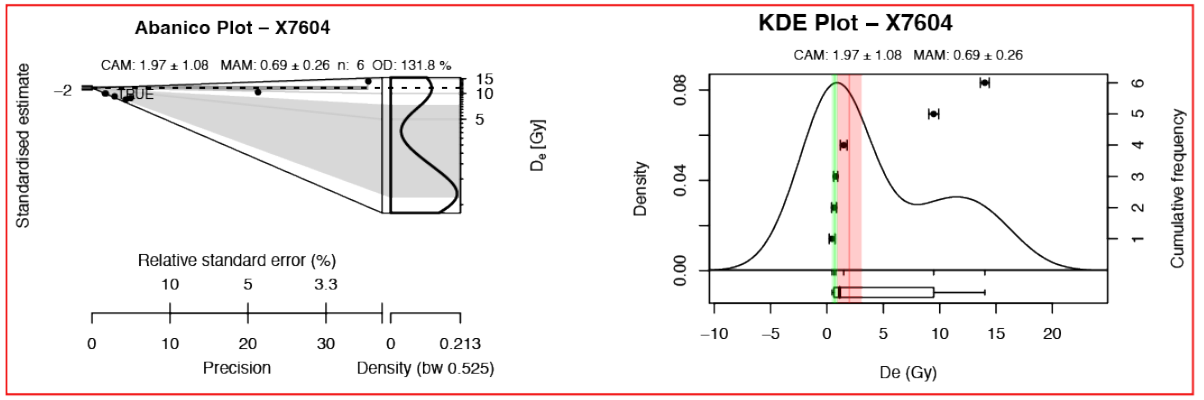

Abanico Plot – X7600
CAM: 11.1 ± 1.04 MAM: 6.29 ± 0.8 n: 18 OD: 39.8 %
TRUE
−2
Standardised estimate
De [Gy]
Relative standard error (%)
10 5 3.3
0 10 20 30 0 0.068
Precision
Density (bw 0.299)

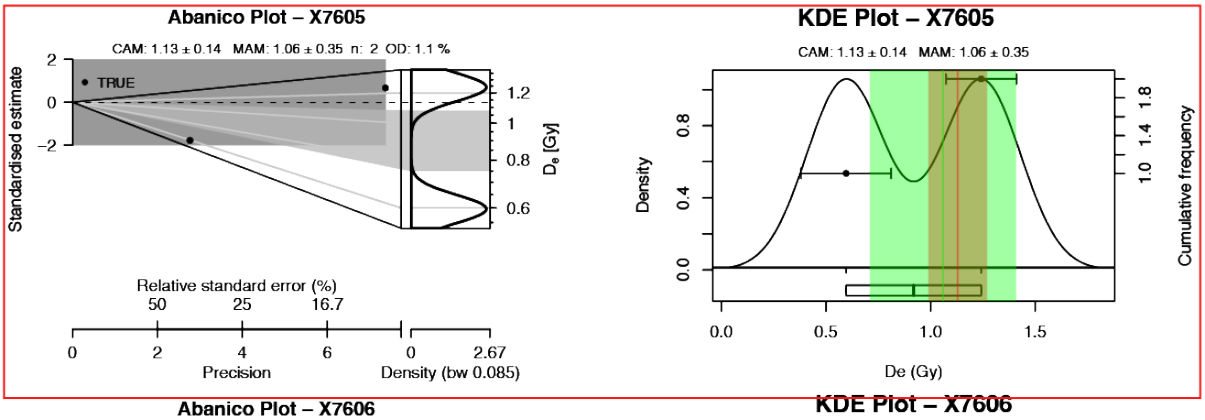

KDE Plot – X7600
CAM: 11.1 ± 1.04 MAM: 6.29 ± 0.8
Density
Cumulative frequency
De (Gy)

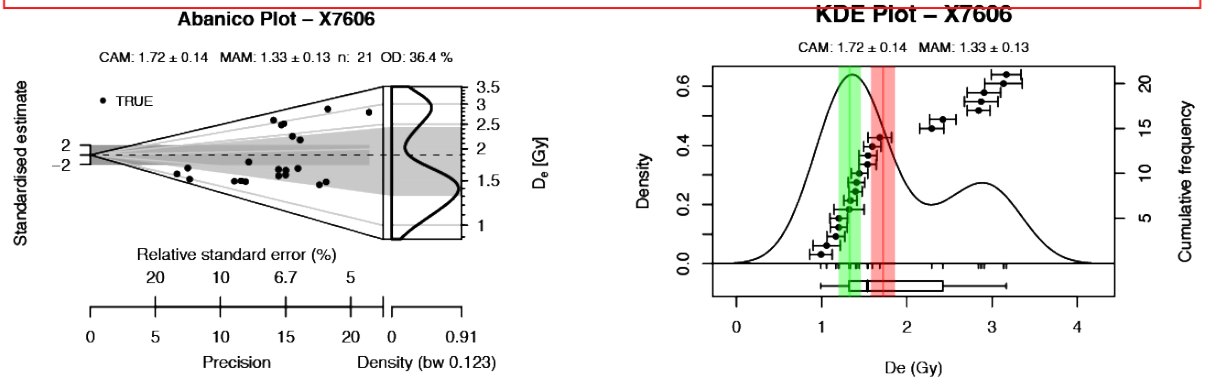

Abanico Plot – X7601
CAM: 16.99 ± 4.35 MAM: 11.68 ± 2.52 n: 4 OD: 51.1 %
TRUE
Standardised estimate
−2
40
35
30
25
20
15
10
D_e [Gy]
Relative standard error (%)
10 5 3.3
0 10 20 30 0 0.064
Precision
Density (bw 0.23)
KDE Plot – X7601
CAM: 16.99 ± 4.35 MAM: 11.68 ± 2.52
Density
0.00 0.02 0.04
Cumulative frequency
1.0 2.0 3.0 4.0
0 10 20 30 40 50
De (Gy)

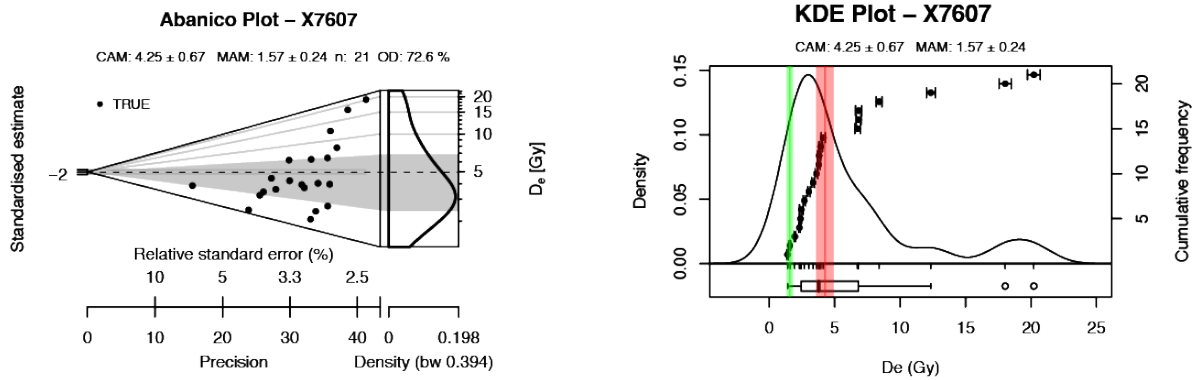

Abanico Plot – X7602
CAM: 12.32 ± 2.09 MAM: 6.64 ± 1.35 n: 8 OD: 48 %
TRUE
Standardised estimate
−2
35
30
25
20
15
10
D_e [Gy]
Relative standard error (%)
10 5 3.3
0 10 20 30 0 0.092
Precision
Density (bw 0.106)
KDE Plot – X7602
CAM: 12.32 ± 2.09 MAM: 6.64 ± 1.35
Density
0.00 0.02 0.04 0.06
Cumulative frequency
1 2 3 4 5 6 7 8
0 10 20 30 40
De (Gy)

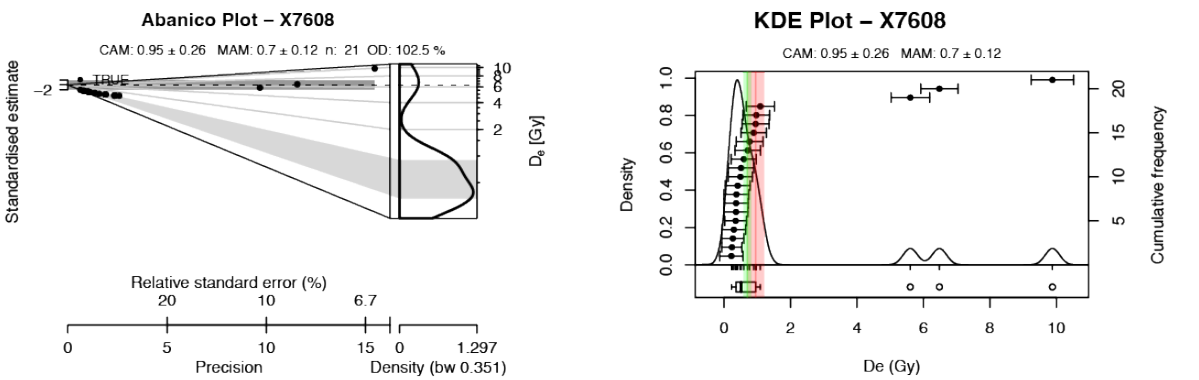

Abanico Plot – X7603
CAM: 5.92 ± 0.77 MAM: 4.16 ± 0.57 n: 12 OD: 44.2 %
TRUE
Standardised estimate
± 2
15
10
5
D_e [Gy]
Relative standard error (%)
20 10 6.7 5 4
0 5 10 15 20 25 0 0.257
Precision
Density (bw 0.147)
KDE Plot – X7603
CAM: 5.92 ± 0.77 MAM: 4.16 ± 0.57
Density
0.00 0.05 0.10 0.15
Cumulative frequency
2 4 6 8 10
0 5 10 15 20
De (Gy)


Abanico Plot – X7604
CAM: 1.97 ± 1.08 MAM: 0.69 ± 0.26 n: 6 OD: 131.8 %
TRUE
Standardised estimate
−2
15
10
5
D_e [Gy]
Relative standard error (%)
10 5 3.3
0 10 20 30 0 0.213
Precision
Density (bw 0.525)
KDE Plot – X7604
CAM: 1.97 ± 1.08 MAM: 0.69 ± 0.26
Density
0.00 0.04 0.08
Cumulative frequency
1 2 3 4 5 6
−10 −5 0 5 10 15 20
De (Gy)


Abanico Plot – X7605
CAM: 1.13 ± 0.14 MAM: 1.06 ± 0.35 n: 2 OD: 1.1 %
TRUE
Standardised estimate
De [Gy]
Relative standard error (%)
50 25 16.7
Precision
Density (bw 0.085)
KDE Plot – X7605
CAM: 1.13 ± 0.14 MAM: 1.06 ± 0.35
Density
Cumulative frequency
De (Gy)


Abanico Plot – X7606
CAM: 1.72 ± 0.14 MAM: 1.33 ± 0.13 n: 21 OD: 36.4 %
TRUE
Standardised estimate
De [Gy]
Relative standard error (%)
20 10 6.7 5
Precision
Density (bw 0.123)
KDE Plot – X7606
CAM: 1.72 ± 0.14 MAM: 1.33 ± 0.13
Density
Cumulative frequency
De (Gy)


Abanico Plot – X7607
CAM: 4.25 ± 0.67 MAM: 1.57 ± 0.24 n: 21 OD: 72.6 %
TRUE
Standardised estimate
De [Gy]
Relative standard error (%)
10 5 3.3 2.5
Precision
Density (bw 0.394)
KDE Plot – X7607
CAM: 4.25 ± 0.67 MAM: 1.57 ± 0.24
Density
Cumulative frequency
De (Gy)


Abanico Plot – X7608
CAM: 0.95 ± 0.26 MAM: 0.7 ± 0.12 n: 21 OD: 102.5 %
TRUE
Standardised estimate
De [Gy]
Relative standard error (%)
20 10 6.7
Precision
Density (bw 0.351)
KDE Plot – X7608
CAM: 0.95 ± 0.26 MAM: 0.7 ± 0.12
Density
Cumulative frequency
De (Gy)

Supplementary Information 4.I:

```
# Function for CAM and MAM ages with ED to De conversion
# Required packages
library(readxl)
library(dplyr)
library(Luminescence)

# Function to process a single sheet
analyze_luminescence <- function(file_path, sheet_name, sigmab = 0.15, ed_to_de_factor = 1.0) {
  # Read data
  data <- read_excel(file_path, sheet = sheet_name)
  cat("\nProcessing sheet:", sheet_name)

  # Check if ED and ED_Err columns exist
  if ("ED" %in% colnames(data) && "ED_Err" %in% colnames(data)) {
    # Apply conversion factor from ED to De
    data$De <- data$ED * ed_to_de_factor
    data$De_Err <- data$ED_Err * ed_to_de_factor
  } else {
    cat("\nWarning: ED and/or ED_Err columns not found in sheet:", sheet_name,
        "\nPlease ensure your data has ED and ED_Err columns.")
    return(NULL)
  }

  # Create dose data frame
  dose_data <- data.frame(
    DE = data$De,
    DE_ERROR = data$De_Err
  )

  # Calculate CAM with output capture
  cam_output <- capture.output(
    cam <- calc_CentralDose(data = dose_data, plot = FALSE)
  )

  # Calculate MAM with output capture
  mam_output <- capture.output(
    mam <- calc_MinDose(data = dose_data, sigmab = sigmab, plot = FALSE)
  )

  # Print MAM output for debugging
  cat("\nMAM output:\n")
  print(mam_output)

  # Extract CAM values from output
  cam_de <- as.numeric(gsub(".*abs. central dose:\\s*(\\d+\\.\\d+).*", "\\1",
                            cam_output[grep("abs. central dose:", cam_output)]))
  cam_se <- as.numeric(gsub(".*abs. SE:\\s*(\\d+\\.\\d+).*", "\\1",
                            cam_output[grep("abs. SE:", cam_output)][1]))
  od_percent <- as.numeric(gsub(".*OD \\[%\\]:\\s*(\\d+\\.\\d+).*", "\\1",
                                cam_output[grep("OD \\[%\\]:", cam_output)]))

  # Extract MAM values from output - updated to get from symmetric error section
  mam_rows <- grep("^\\s+De\\s+error\\s*$", mam_output)
  if(length(mam_rows) > 0) {
    values_row <- mam_output[mam_rows[1] + 1]
```

```
    values <- as.numeric(unlist(strsplit(trimws(values_row), "\\s+")))
    mam_de <- values[1]
    mam_error <- values[2]
  } else {
    cat("\nWarning: Could not find MAM values in output for sheet:", sheet_name)
    mam_de <- NA
    mam_error <- NA
  }

  # Create results data frame
  result <- data.frame(
    Sample = sheet_name,
    n = nrow(data),
    CAM_Gy = cam_de,
    CAM_error = cam_se,
    OD_percent = od_percent,
    MAM_Gy = mam_de,
    MAM_error = mam_error,
    ED_to_De_factor = ed_to_de_factor
  )

  # Print extracted values
  cat("\nExtracted values for", sheet_name, ":\n")
  print(result)

  return(result)
}

# Function to process all sheets with a specified conversion factor
process_all_sheets <- function(file_path, ed_to_de_factor = 1.0, sigmab = 0.15) {
  sheets <- excel_sheets(file_path)

  # Process all sheets and combine results
  results_list <- lapply(sheets, function(sheet) {
    analyze_luminescence(file_path, sheet, sigmab = sigmab, ed_to_de_factor =
ed_to_de_factor)
  })

  # Remove NULL results (sheets where ED/ED_Err columns weren't found)
  results_list <- results_list[!sapply(results_list, is.null)]

  # Combine results if any valid results exist
  if (length(results_list) > 0) {
    results <- do.call(rbind, results_list)
  } else {
    stop("No valid data found in any sheet. Please check that your Excel file contains ED
and ED_Err columns.")
  }

  # Round numeric columns
  results <- results %>%
    mutate(across(where(is.numeric), ~round(., 2)))

  return(results)
}

# Main script
file_path <- "/Documents/DPhil/2_Diamane/Diamane_For R analysis_exp+lin.xlsx"

# Set the conversion factor from ED to De (Gy)
# IMPORTANT: This value must be updated based on your specific Risø calibration
```

```
ed_to_de_factor <- 0.0346

# Set the sigmab value for MAM calculation
sigmab_value <- 0.15

# Process all sheets with the conversion factor
results <- process_all_sheets(file_path, ed_to_de_factor = ed_to_de_factor, sigmab =
sigmab_value)

# Round numeric columns (optional)
results <- results %>%
mutate(across(where(is.numeric), ~round(., 2)))

# Display and save results
print(results)
write.csv(results, "Diamane_luminescence_results.csv", row.names = FALSE)
```

5. Reimagining the Stone Age: AI-Powered Archaeological Visualisation

Abstract

Archaeological artefacts from the Middle Stone Age and Mesolithic have been well documented; numerous dates have been generated to constrain their timing, and field descriptions of the sites have been published. However, realistic descriptions and visualizations of the environment and people living during that period are limited. Artistic renditions often reveal binary perspectives, such as Edenic scenes or barbaric savages, based on the perception or interpretation of the artist. The development of artificially intelligent (AI) generative platforms makes it possible to recreate visualizations of various scenes, and the iterative process of prompt changes allows for multiple images to select the best representation. We used Midjourney v6.0 and DALL-E 3 to generate images of environmental scenes and people using various prompts. Both AI tools generated similar images but tended to render Stone Age people as middle-aged, white males. When prompted to generate images of women, the tools included more diversity in their image generation. However, generating images of people from past lives comes with moral and ethical constraints which need to be addressed within the social and cultural context of the archaeological period. Therefore, we noted that AI-generated images must be supported by knowledgeable creators.

5.1. Introduction

The future of archaeology is deeply tied to our ability to engage interdisciplinary academic communities and the public and governmental stakeholders. Before archaeology became formalised as a discipline, humans used art, literature, scientific theories, and religious texts to

reconstruct the past. However, these reconstructions were limited to artistic renditions. Recently, there has been a widespread acknowledgement of the profound impact of digital technology applications on the fields of archaeology and cultural heritage. These applications have significantly contributed to cultural heritage documentation, preservation, analysis, and dissemination (Pavlidis, 2023). The development of modern, generative artificial intelligence (AI) tools like DALL-E 3 and Midjourney provides novel, cost-effective means to recreate images representing past people. However, there is a clear need for more applications of AI in archaeology, especially considering the limited applications of AI in the field so far, which have mostly been focused on neural network- and classification-based(Argyrou and Agapiou, 2022; Chapinal-Heras and Díaz-Sánchez, 2023; Cobb, 2023; Magnani and Clindaniel, 2023); or using AI to detect archaeological sites from satellite imagery (Casini et al., 2023).

In this paper, we explore how archaeologists may leverage generative AI visualisation technologies — quickly and inexpensively – to develop accurate, impactful images of archaeological settings. To achieve this aim, we will (i) explore the historical context of archaeological visualization, (ii) investigate the potential, limits, and ethical considerations when applying AI visualization tools to the archaeological past, and (iii) democratize the process of image creation through developing a prompting methodology for archaeologists.

5.2. Illustrations and visualisations of Archaeological scenes

The past two centuries of archaeological visualisation and representation, combined with the lack of imagery up to date with present archaeological theories, have resulted in a limited visual vocabulary for depicting the past (Gamble, 1997, p. 184). This limited vocabulary has resulted in biases influencing the database's visual language, the accumulation of images, which trains the AI programs (Gamble, 1997; Magnani and Clindaniel, 2023). Generative AI works by accumulating and aggregating thousands of images (Cobb, 2023; OpenAI, 2023;

Radhakrishnan, 2023). While it is almost impossible to know the individual images collated to create these databases or how the software weights them, we can explore some background drivers influencing their production. This section explores three categories of scene reconstruction and visualisation influencing the visual catalogue: (1) artistic representations of the past, (2) creative collaboration between archaeologists and artists, and (3) site photography. Two further categories are commonly associated with archaeological visualisations, museum reconstructions, and technical artefact illustrations. The former will not be discussed in this paper as they do not significantly contribute to the images available online and, therefore, is not expected to contribute significantly to AI databases. The latter, artefact illustrations, follow their own set of norms and rules and are not the precursor for the reconstructed scenes within this paper (Cobb, 2023; OpenAI, 2023; Radhakrishnan, 2023).

5.2.1. Artistic representation

Images of Palaeolithic or Stone Age people have a limited visual catalogue based on outdated information and assumptions (Gamble, 1997; Stoczkowski, 1997). Most of these images emerge from artistic representations. These artistic representations do not include direct archaeological contributions; rather, they are based on the artists' independent knowledge, research, and interpretation of the past (Perry, 2014). The 19th and early 20th century's artistic representations often depict struggle and hardship, where humanity was pitted against a hostile natural environment (Horrall, 2017; Moser, 2012; Moser and Gamble, 2018). As a result, this left a lasting impression on visualisations which often depict the brutality and primitivism of 'early man' while simultaneously reinforcing the cultural norms of the white middle class (Horrall, 2017; Stoczkowski, 1997). Horrall (2017) demonstrates this by exploring the lasting influence of The Flintstones, a popular children's TV show originally aired from 1960-1966, which used prehistoric life to satirise a 1960s middle-class Anglo-Saxon family. Even without direct archaeological or scientific influence, the artistic representation left a lasting impression

that influenced the collective visual memory of life in the Stone Age. Subsequent visualisations and public understanding of the past are, therefore, influenced by these recreations (Gamble, 1997).

5.2.2. Creative Collaboration

In contrast to Artistic Representation, archaeologists and artists collaborate creatively to develop an archaeological scene. Early use of creative collaboration is witnessed in *Die Urwelt in ihren verschiedenen Bildungsperioden* (*The primitive world in the different periods of its formation*), published in 1851 – eight years before Darwin's Origins of the Species (Unger, 1858). In collaboration with Josef Juwasseg, geologist Franz Unger depicted the first known visualisation of humans in deep time (Figure 5.1). These white European figures, surrounded by a lush landscape, contain limited archaeology, but they attest to the antiquity of man. By the early parts of the 20th century, archaeologists utilized archaeological illustrations to incorporate tools and theoretical and architectural discoveries. While the depictions of people's behaviour remain speculative and steeped in preconceived bias and tropes of 'primitivism,' the images themselves became more human centred including portraits and use of objects found in archaeological contexts (Berman, 1999; Stoczkowski, 1997).

Creative collaboration requires thoughtful compromise and interpretation at each step (Gamble, 1997; Stoczkowski, 1997). This science-informed process has several stages, beginning with data collection and description and concluding with the artist's visualisation. Archaeologists and artists must balance the known archaic plant life and environment with the unknown, like tools and clothing that may not be preserved (Spennemann, 2023). Similarly, while forensic analysis and DNA increasingly offer new knowledge about people's physical across multiple in Mesolithic and Neolithic sites (e.g. Chedder Man), these images deal with many unknowns (Hjemdahl, 2017; Klusener, 2018). While these depictions have the capacity

to combat biases, the visual language is slow to adjust (Booth, 2023). This is concerning as, much like other forms of archaeological visualisations, these apparently realistic images capture the public imagination, playing a powerful tool in promoting archaeological heritage (Colomer, 2002).

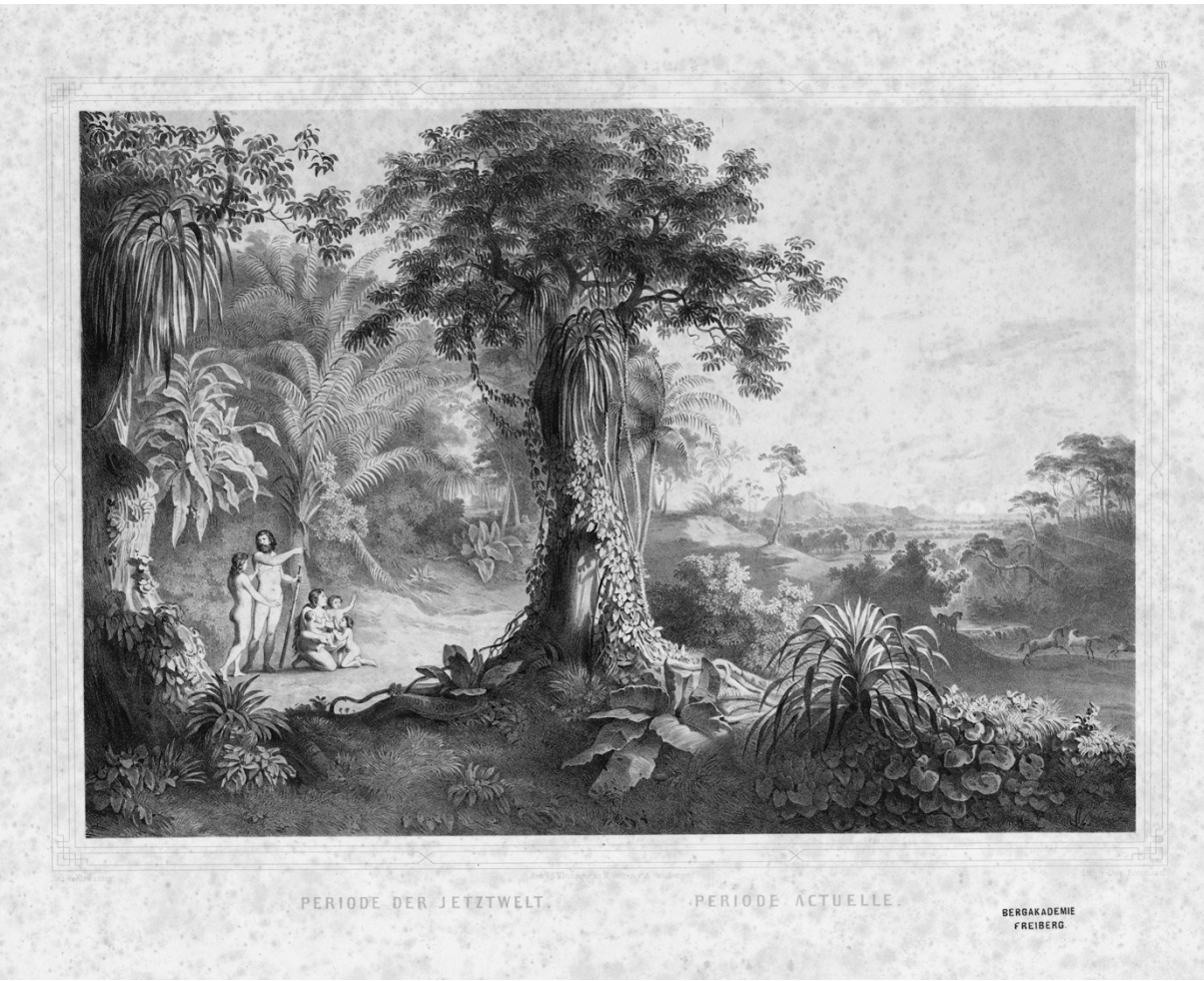


Figure 5.1: Urweltliche Landschaft mit Urpferd. *Plate 14 from* Die Urwelt in ihren verschiedenen Bildungsperioden: Sechzehn landschaftliche Darstellungen. *2nd ed., 1858. (SLUB Dresden, accessed 2025)*

Ethical concerns arise when depicting these unknown objects and their associated behaviours. This is compounded when speculating about transient and emotionally charged moments in past lives. Giles, (2016) argues that the very act of reconstructing the death (see Case Study 2) of a person humanises them. Traditionally, limited time and budgets forced archaeologists to commit to a single visual interpretation, compounding the implications of these ethical considerations. However, with the advent of AI, Magnani and Clindaniel (2023) explore how

AI reconstructions can efficiently create multiple outcomes, potentially addressing these constraints and ethical concerns.

5.2.3. Photography

Photography allows material culture and archaeological sites to speak for themselves without the uncomfortable compromises of interpretation or supposed threat to neutrality and objectivity of reconstruction (Markiewicz, 2022). Photography holds the added benefit of recording a site before alteration or destruction through excavation (Markiewicz, 2022). However, as Hicks, (2019, p.28) points out, photography and archaeology deal with the "temporally fixed snapshots, remnants, fragments" of the past. The appeal of the photograph is to capture how things truly were (Thomas, 2019). However, unlike other forms of archaeological site representation, the moment capture is documenting the post depositional condition, or ongoing excavation of a site, not how things were when in use (Baird, 2019; Thomas, 2019). Despite this, landscape photography is incredibly valuable within an AI context as it is useful for developing the scene.

5.2.4. Generative AI for visualization

Generative AI is trained on large datasets. While these datasets have an element of curation, what is uploaded is the creation of centuries of human intelligence – and bias (Cobb, 2023). The extent of this bias is of growing concern and is evidenced by Luccioni et al. (2023), who explored text-to-image (TTI) bias by exploring representation, gender norms and racial diversity in different professions, and Nicoletti and Equality (2024), who explore the intersection of race, gender and profession in Stable Diffusion and Open AI's DALL-E 2. The balance between creating a safe internet and a representative one represents an ongoing problem for generative AI (Irving and Askell, 2019; Makhortykh et al., 2023a, 2023b; Manca et al., 2023; Prabhakar Raghavan, 2024). The consequences of these biased depictions extend

to representation in the past as the software will reinforce the stereotypes of historical visualization, power imbalances and outdated interpretations (Tenzer et al., 2023). This is already evident in a growing amount of popular news articles dealing with visualizations of the past (Anglesey, 2023; Liberatore, 2023; Perera, 2023; Xiang, 2023). These images often reinforce the historic, normative view of the past instead of re-exploring it.

Despite the clear public interest, few archaeological publications explore image generation. Instead, archaeology has been focussed on using AI to deal with preexisting archaeological data and site discovery. Puyol-Gruart (2023) presents three potential uses of AI in archaeology: (i) Knowledge Discovery in Databases (KDD), large datasets (e.g. Loftus et al (2019)), (ii) Visual Information Management (VIM), within the management and storage of archaeological images and (iii) Multi-agent systems (MAS), simulating past environments (e.g. Grove and Blinkhorn, 2020). Argyrou and Agapiou (2022) note a general upward trend in AI and archaeology research. They identify the main approaches of AI in archaeology as machine learning, deep learning, neural networks, natural language processing, computer vision and cognitive computing. While the authors hint at the potential of using AI to identify, classify and utilise remote sensing and archaeological images, there is no mention of generative AI or using AI to create new visualisations. Similarly, Chapinal-Heras and Díaz-Sánchez (2023) review of AI in human science research focuses on the potential of AI in dealing with remote sensing and archaeological data, not creating new information or communication tools.

In contrast, Cobb (2023) discusses the potential of generative AI for creating line drawings, or 3D models but not how it might be used to visualize people or landscapes in the past. However, Magnani and Clindaniel (2023) push this further by proposing the first methodology for generating AI visualisations of archaeological contexts through (1) base image generation, (2) base image selection, and (3) image modification. This novel and effective application aims to democratize archaeological image generation through a temporal and financially cost-effective

approach. Their application to represent multiple versions of an archaeological past is exciting but falls short of creating a new style of archaeological illustration (Magnani and Clindaniel, 2023). Rather, they reinforce styles used within artistic representation and creative collaboration.

Similar applications outside archaeology are increasingly popular. Verdiani et al., (2024) recreated urban landscapes based on the style of Renaissance paintings. Edler (2023) explores how generative AI may develop to change the cartographic representation of current and future cities. This theme of urban exploration with generative AI is particularly popular in the architectural field (Karahan et al., 2023; Müezzinoğlu et al., 2023; Ploennigs and Berger, 2023; Radhakrishnan, 2023; Sukkar et al., 2024). Interestingly, Sukkar et al., (2024) test the time-control and architectural style limits of Midjourney. The authors demonstrate that Midjourney creates a good approximation of known sites well documented in large datasets, but it is limited with high levels of complexity and accuracy.

Despite increasing use and case studies, the potential of generative AI to contribute to developing new, reliable information and resources remains contentious. This issue deserves attention as Spennemann, (2023, p. 3599) argues that generative AI will become the main place of interest to understand "cultural heritage in a gen-Ai and post-gen-AI world". ka notes that the potential of generative AI to textually reinterpret or reshape the past is particularly troubling to historians dealing with nuance, authorship and bias in written sources. These concerns feed what may be the most dangerous use of generative AI to understand the past – not only reinforcing bias but reinventing history through visual memory culture (Kansteiner, 2022; Makhortykh et al., 2023a, 2023b). While this has mostly been discussed in relation to more recent historical events, the dangers of using AI visualization to convey authority to an event, an interpretation of an event, or reinforce the norms in a false narrative cannot be underestimated (Makhortykh et al., 2023a; Srinivasan and Uchino, 2021).

5.3. How AI Visualization Tools Work

The bias and limitations within an AI model differ between programs. This is because of differing databases, generative workflows and program protections. Midjourney v6.0, DALL-E 3, Stable Diffusion and Google Imagen are amongst the most popular AI image generators. While anticipating which tools will dominate which tools will dominate in the next five or ten years is impossible, this article focuses on Midjourney v6.0 and DALL-E 3 as they maintain strong communities necessary for continued success. This section explores how DALLE-3, developed by OpenAI and Midjourney, rely on two different mechanisms for image generation. Understanding these differences will assist prompters in choosing an appropriate tool while being aware of the advantages and limitations of both systems.

DALL-E 3 and Midjourney use a diffusion model approach. This is where visual noise is removed through a text prompt. The image is refined as latent space is filled with information to match the text description better. DALL-E 3's training data contains billions of paired text/captions and images (t, i) scraped from the internet – capturing the diversity and bias within the existing online. OpenAI is aware of this and has purposefully refined the model to increase diversity (OpenAI, 2023). The output of a single image is fixed unless modified through third-party extensions (Magnani and Clindaniel, 2023). Importantly, the resulting images are owned by the prompter. In contrast, Midjourney, a paid service, is trained on five million human-curated images. Unlike DALL-E 3, the image can then iterate based on user feedback, improving the outcome of the desired output. At time of writing, prompters of Midjourney's images have non-exclusive use of the image, while Midjourney remains the copyright holder.

Prompters should thoughtfully develop prompts which work with the AI's language and syntax in order to get desired outcomes (Betker et al., 2023; Oppenlaender et al., 2023). While the AI's ability to understand the nuance of human language is improving, at present, some words

hold more weight or power to influence the produced image than others. The ability of the AI to capture and understand the prompt, “prompt following”, differs between programs and versions (Betker et al., 2023, p. 2). Effective prompting depends on two factors: the first is how the AI was trained. In DALL-E 3, training comprises (t, i) where t is the description applied to the image and i is the image itself. This presents three potential pitfalls: (i) the image is poorly described, (ii) the description is wrong, and (iii) stereotypes and biases within the text. This is important in archaeological reconstructions as often, media inclusion of an image does not align with the current understanding of the past, or the text reinforces biases or problematic language associated with the image. Betker et al. (2023) address some of these concerns by creating an image captioner to redescribe the training data. While this addresses the first and second concerns, it does not entirely solve the third (OpenAI, 2023). OpenAI (2023) notes that mitigations to improve prompt coherence may increase these biases, and positively specific prompt outcomes are more authentic and inclusive. Midjourney relies on a greater degree of human curation to achieve a greater understanding of natural syntax and language use. Unlike DALL-E 3's automated captioning approach, Midjourney's training dataset incorporates images paired with carefully curated, human-written descriptions that better capture natural language patterns and artistic terminology. This curation strategy allows Midjourney to interpret more nuanced and varied prompt structures, though it may also inherit the biases and perspectives of its human curators.

The current focus on increasing the ability of the AI to understand human intent and desire will make prompting easier and more accessible. Oppenlaender et al., (2023) explore the accessibility and ease of prompting by testing participants' ability to identify, write, and revise effective text-to-image prompts. While most participants could identify a good prompt, most struggled with creating their own or modifying it for a desired outcome. This is partly owing to the lack of understanding of style-specific vocabulary and prompting patterns. Oppenlaender

et al. (2023) concluded that prompting can be learnt and taught and should not be assumed intuitive.

5.4. Methodology

This section describes a proposed methodology for prompting image generation applied to two components: (i) bias – exploring the visual vocabulary associated with the southern African Middle Stone Age (Supplementary Figures 5.1) and (ii) case studies – visualisations of three important MSA discussions and contexts. First, we describe the AI programs used in this study. Second, we explain the macro workflow for image generation. Finally, we propose a prompting methodology to obtain accurate and representative images.

5.4.1. AI programmes

We used both DALL-E 3 and Midjourney platforms to create the AI-generated images. We accessed DALL-E 3 free image generation through the Bing image generator in April 2024, http://www.bing.com/images/create. Midjourney was accessed through its own website as they are an independent company, although the program can also be accessed through internet messaging and digital distribution platform, Discord. This study accessed Midjourney through the April 2024 version of www.midjourney.com. The Midjourney images were generated on v6.0 which has a greater understanding of human language and relationships between people and place when compared with prior models. To maintain as much control over the images as possible, we set all Midjourney image generation to "-style raw" and "--stylize 0", which has "less automatic beautification applied" ("Midjourney Style Parameter," n.d.).

5.4.2. Workflow to generate images

A prompt involves a series of words describing the object or scene. We first used simple text prompts to test the visual vocabulary and underlying bias of Midjourney and DALL-E 3

(Supplementary Results 5.1, Supplementary Table 5.2). This involved testing different known archaeological sites and temporal periods. In order to explore bias, an additional four prompts (i) palaeolithic (ii) palaeolithic person (iii) stone age person and (iv) stone age women were run four times in each program – generating a total of 190 images (Supplementary Results 5.1).

When developing prompts for more complex archaeological contexts, we identified six categories to consider and include (i) period/time, (ii) environment, (iii) subject, (iv) action, (v) object, (vi) style, (Supplementary Table 2). These categories do not need to be in a specific order.

[Prompt(period, environment, subject, object, style)][image generation]

[selection][alteration/iteration][final selection]

Once each category was identified, the prompt keywords were converted into prose text which aligned with the chosen program. Three case studies of increasing complexity were selected for this paper (Table 1). These case studies explore aspects of the archaeological past that have been visually underrepresented despite their theoretical and academic importance. Each scene adds a new layer of complexity. Using environment and style as the foundation, we attempted to test the ability of AI to imagine the MSA landscape under these past environmental circumstances. For Case Study 1, the selected reconstruction is based on (Burrough et al., 2009), where the authors described the episodes of wet and dry lake pans in the Makgadikgadi, Botswana. Despite its implications for human migration and presence, the dramatic environmental difference is not currently visualised.

For Case Study 2, the selected portrait is reimagined from a burial at Border Cave, which contains some of the best preserved MSA artefacts in southern Africa (Grün et al., 2003, 1990; Grün and Beaumont, 2001; Tribolo et al., 2022; Wadley, 2000). Border Cave is one of the few MSA sites with human remains (Cooke et al., 1945; Grine, 2016; Grün et al., 2003; Grün and

Beaumont, 2001; Villiers, 1976). Tommy et al. (2021) noted the presence of partial remains of eight adults and one almost complete infant. This site has added significance as it is the only directly dated human remains from the southern African MSA — an adult mandible, BC5, dated to 74 ± 5 ka with ESR (Grün et al., 2003). Despite their significance, there are no visual reconstructions of these individuals (Barham and Mitchell, 2008; d'Errico and Backwell, 2016; Grün and Beaumont, 2001; Tommy et al., 2021). This is surprising as the 3–6-month infant burial, BC3, found in a pit with a Conus shell, is significant for the cultural and physiological understanding of early *Homo sapiens* and is the oldest site associated with grave goods (d'Errico and Backwell, 2016; Martinón-Torres et al., 2021; Tommy et al., 2021). The lack of photographs and images of the reconstruction for such an important discovery is striking given the significance of the finds for early human symbolism.

Case Study 3 is envisioned at the Blombos Cave Rock Shelter, South Africa. Symbolic use associated with (and before) HP is found at Blombos Cave. The use of ochre is evidenced by an engraved piece with geometric lines from a layer dated by TL on lithics to 77 ± 6 ka, and even earlier, by two abalone shells used as part of an ochre-processing kit from a layer dated by OSL to 101 ± 4 ka (Christopher S. Henshilwood et al., 2002; Henshilwood et al., 2018, 2011a). Like the Conus shell from BC5, Border Cave, there is a very limited visual reconstruction of this object's use. However, in contrast to BC5, these ochre finds are photographed, well-documented and publicized.

Each prompt was run three to four times on Midjourney v6.0 and DALL-E 3 to produce several images (see Supplementary Figure 5.II). However, not all images were usable. Case Study 1 followed the standard outlined methodology with little need for alteration. However, Case Study 2 encountered restrictions from DALL-E 3, which would not generate an image owing to the word "burial". The word was removed, and a more detailed description of the subject was provided. Case Study 3 proved the most complex for both Midjourney v6.0 and DALL-E

3. This case study demonstrates the importance of careful language selection when producing images. Midjourney also faced problems owing to induced nudity in image production. While Midjourney initially produced 16 plausible images, only one was suitable for discussion. In addition, Midjourney initially produced images using cloth and the prompt required direct instruction to use "—no woven fabrics". While DALL-E 3 required a shorter prompt than Midjourney, its sensitivity filters required several iterations. DALL-E 3 produced 7 images over four iterations. This is explicitly owing to the nature of the images generated, not displaying any images determined as "Unsafe image content detected". To solve this, ChatGPT provided the Midjourney prompt and the outlined prompt methodology. The result produced an acceptable prompt for DALL-E 3.

Table 5.1: Prompts used to visualise the southern African Middle Stone Age for each case study, using the various categories and separate platforms. Each case study increases in complexity. Prompting categories are explained in the Supplementary Table 1.

Case Study	Categories	Prompt planning
Case Study 1	environment, style	Prompt[Environment(Makgadikgadi pans, Botswana covered in lakes)][Style(photograph taken with drone photography, Diji Marvic)]
Case Study 2	period, environment, subject, object, style	Prompt[period(Mesolithic)][subject(small African child, a 4 month old San baby wrapped in soft leathers)][environment(burial, a sandy pit)][object(conus shell placed above the heart)][style(Award-winning photograph, cinematic lighting, ariel shot)]
Case Study 3	period, subject, environment, action, object, style	Prompt[period(Neolithic)][subject(two southern African woman with scarification)][environment(Blombos rock Shelter)][action(applying makeup)][object(abalone shell

		with red and yellow ochre)][style(documentary photography)]

5.5. Results

The following section presents the results and discussion of the visual vocabulary (Supplementary Table 5.II, Supplementary Figures 5.III) and the three case studies (Figures 1-3). For the case studies, the prompts were run multiple times (Supplementary Figures IV), however, only one image per prompt discussed below.

5.5.1. Exploring Bias through Developing a visual Vocabulary

Through running vocabulary tests (Supplementary Table 5.II), it is evident that programs lack the ability to differentiate between different Stone Age periods. The four simple prompts generated a total of 190 images (Supplementary Figures 5.III). DALLE-3 only has 46 images, in contrast to Midjourney v5.2 and Midjourney v6.0's 48. This may be attributed to OpenAI's filtering to exclude explicit images during generation. Each tool associates the prompts with its visual language. For example, Midjourney v6.0 associates Palaeolithic or Neolithic persons with middle-aged European men (Supplementary Figures 5.III). Whereas DALL-E 3 increased human diversity slightly but still tended towards Eurocentric men. Interestingly, the algorithms for both programs attach greater racial diversity when prompted to depict women. However, these depictions of a Stone Age woman are young, attractive, and sexualized. Despite this, Case Study 3 demonstrates overcoming some of these more complex limitations.

5.5.2. Case Study 1: Environmental reconstruction – reconstructing landscapes

Environmental reconstruction is more dependent on the visual vocabulary of the program than the prompt itself. The environment can remain a fixed approximation of the present or be redesigned by describing environmental and climatic changes. Both Midjourney v6.0 and DALL-E 3 depict a landscape in the Makgadikgadi, Botswana, covered in lakes, gentle mid-morning daylight with a few clouds, and photographs taken with drone photography. Both programs captured the additive nature of water in the dessert (Figure 5.2). Midjourney, however, created images filled with greenery and trees, which are objects associated with wetter environments. In contrast, DALL-E 3 added the lakes but did not change the surrounding landscape to account for this different climate. As a result, the images appear to be generic landscapes, as no distinguishing features indicate that this is a Stone Age setting.

Figure 5.2: Images generated of the flooded Desert, (left) Midjourney and (right) DALL-E 3.

5.5.3. Case Study 2: Subject and Object – The people of Border Cave

The AI visualisation of the child's burial at Border Cave aimed to capture the significance of possible funerary practices of the people experiencing this tragic event (Figure 5.3). The prompt was developed to represent the child with dignity and the sombre nature of the findings. The infant is depicted supine with the Conus shell above their heart. The infant is swaddled in leather to ensure the dignity of the child, within modern sensibilities surrounding nakedness.

These decisions used creative license as no images or descriptions of the orientation of the in situ remains existed, nor were there any soft tissue remains. Midjourney v6.0 and DALL-E 3 similarly depict a Mesolithic burial of a small African child in a sandy pit, a 4-month-old San baby wrapped in soft leathers, with a Conus shell placed above the heart.

Figure 5.3: Image of an infant burial at Border Cave using (left) Midjourney and (right) DALL-E 3.

5.5.4. Case Study 3: Blombos Ochre use

The final visualisations (Figures 5.4) aim to represent women, who are not frequently the main subject in Stone Age archaeological visualizations. Through imagining Blombos's crushed ochre and abalone shell toolkit as make-up, the image increases the diversity of who was represented in the past and their relation to art, symbolism and culture – as opposed to pure survival. Midjourney v6.0 generated an image of a southern African woman on the right using red and yellow ochre in an abalone shell to apply makeup to a second woman on the left. The woman is seated on a beach by Blombos Rock Shelter, South Africa. They are wearing leather hides. The woman on the right holds an abalone shell filled with red and yellow ochre. She uses her fingers to cover the woman on the left with this crushed red ochre. DALL-E 3 renders a similar, if more figurative, image. However, troublingly DALL-E 3's image introduces pottery which did not exist in the Middle Stone Age.

Figure 5.4: Women use ochre to decorate each other, using Midjourney (left) and DALL-E 3 (right).

5.5. Discussion

Generative AI promises to revolutionise the way we visualise the past. The challenge presented to the prompter is to leverage the visual vocabulary (Supplementary Table 5.I) to create predicted, reproducible outcomes without reinforcing negative tropes and outdated concepts, which might have trained the software. We can assess some of these biases by inputting common words associated with the Stone Age (Supplementary Figures 5.III). Midjourney clearly associates Palaeolithic or Neolithic persons with middle-aged European men. It is also evident that there lacks clear temporal definition between periods. However, the software does associate style with different temporal periods. Without any style guidelines, the images may vary between realism, museum wax figurines and watercolour-esque representations.

Despite this, with additional prompting free (DALL-E 3) and paid (Midjourney v6.0) programs are clearly capable of creating convincing images of past people, the photorealistic images from Midjourney v6.0 convey a sense of authenticity. This is particularly true with increased levels of complexity. However, Midjourney does not have the world knowledge or language processing found in OpenAI's tool. While DALL-E 3 often appears less realistic, it can capture more elements of the prompt with natural human language and less prompt engineering. While

broader world knowledge allows for better scene comprehension, its ability to innovate contextual clues is limited. This is evident in Case Study 1, where it captures the scope of the Makgadikgadi and the lakes but lacks the ability to create the greenery associated with a less arid and more humid environment. Researchers will require knowledge of the environmental setting to add prompts that will generate a more realistic setting rather than a generic one.

Realistic and convincing images evoke emotional responses, help build empathy and humanize people in the distant past. Gamble (1997, p. 188) argues the farther back in time, the more critical artistic representations are for "communicating the vast time scale of human antiquity". However, the representation of past people poses several ethical challenges. First, it may be disingenuous to represent realistic images of people who never existed purely based on archaeological conjecture and imagination. The second concern relates to the complexity of maintaining the dignity of the deceased, not only the imagined living. Without knowing the morality and norms of a society, it is challenging to represent individuals with culture-specific dignity, including representations of the dead. Case Study 2 represents a deceased infant, and one is drawn into the reality, tragedy and humanism of the people and the community who experienced this loss. The image is not only a tool to convey archaeological content which has received strikingly little publicized attention, but also a way to induce empathy. While the image presents a moral challenge to those who do not believe that the dead should be witnessed, we argue that it is only through understanding that this child is dead that we can imagine them alive. Even though AI tools can generate images as they are prompted, the moral ambiguity of producing such images must be addressed within social and cultural contexts.

Depicting past people as living individuals with their own practices, cultures, and behaviours requires a level of imagination. This is most evident in Case Study 3, where the prompter took the greatest creative liberty with the archaeological findings. These images challenge the conventional male-dominated depictions of artists or the use of artistic materials. The ochre,

instead of being the foundation of art, is explicitly used as symbolism for womanhood. This visualization of the Middle Stone Age reflects an interpretation of what we believed the past to be and the lived reality of the prompter. By making visualizations more accessible we can capture more of the diversity of the lived experiences within the past. We are not restricted to Edenic or savage scenes which prioritize male dominance, nor are we limited to sanitized scenes which remove personality for fear of costly errors. Instead, we can bring new light, interpretations and theories to the past – increasing the feminist, queer, Black, Indigenous, and people of colour (BIPOC) representation and life experience.

Generative AI allows us to democratize archaeological visualization and opens new opportunities for visualization and creators. These powerful images need good, responsible, insightful prompters. Profound and accurate collaboration involving AI requires the archaeologist's knowledge, ability, and perspective in collaboration with the AI's visual vocabulary and capability. This opens a new category of archaeological visualization – *knowledgeable creators*. Knowledgeable creators are people with specialist knowledge and are skilled in using Generative AI. These individuals can potentially re-envision the past in line with up-to-date archaeological theory. However, the knowledgeable creator must be mindful not to be affected by technology's influence in this co-creation process. They must remain vigilant about what they know and not what the software may make them believe they know. As technology becomes increasingly convincing on the authenticity of the past, knowledgeable creators must grapple with conveying what is "known, what is inferred, and what is a wild guess" within the image (James, 1999, p. 119).

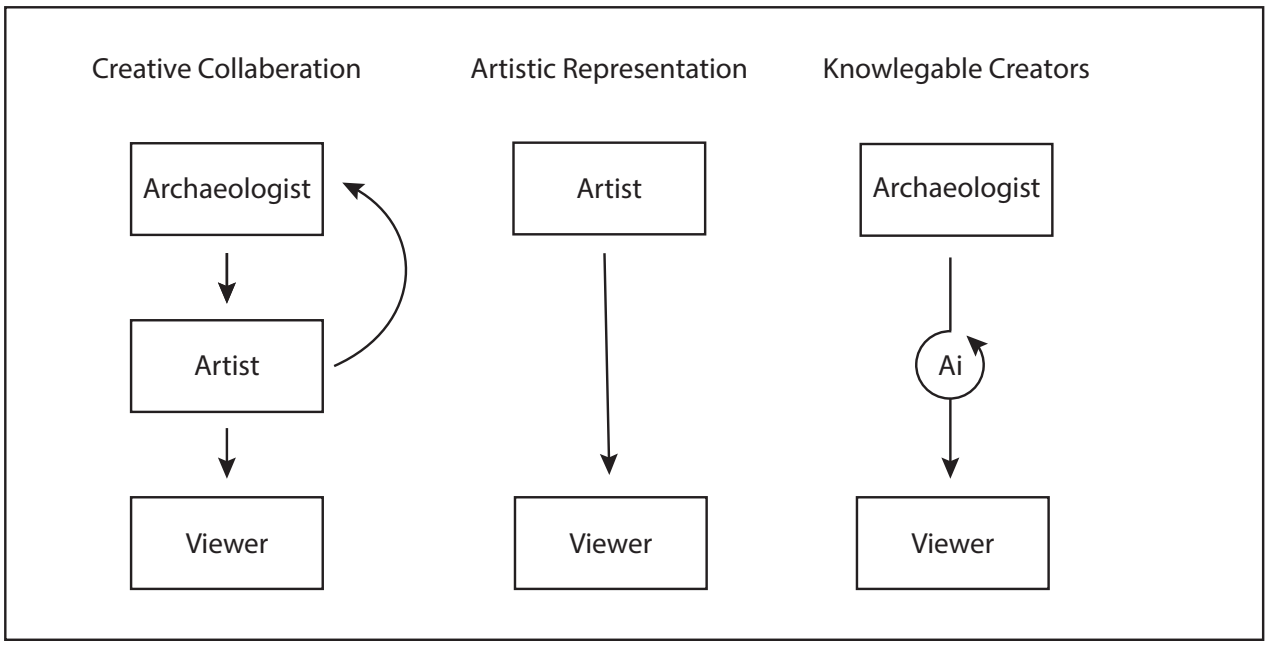


Figure 5.5: Ways in which archaeologists and artists interact with archaeological reconstruction and representation

5.6. Conclusion

The representation of the past, through AI, will happen with or without archaeologists, but with the aid of knowledgeable creators, we can ensure archaeological visualization is one that favours the archaeological record and represents the enormous diversity in our collective and divergent histories.

If the Middle Stone Age is about the foundations of human creativity, rather than stripping creative reconstructions from our arguments, we should allow ourselves to lean into it and leverage it to better understand the people we are trying to describe. Archaeology is a diverse field filled with multiple methodologies and techniques, within which Generative AI is a new tool. While it represents an array of methodological and ethical challenges, it also offers us a unique opportunity to reimagine the past – this time, including women, children, who represent the range of human diversity while also depicting environmental change. This opportunity will allow us to repopulate the visual landscape and the collective mind's eye that currently informs the AI database. By allowing ourselves to accept the imperfections and leaning into the

creativity of our forbearers, we are granted an unparalleled opportunity to communicate, engage and reimagine how past people may have lived, as well as communicate this beyond academic audiences.

Acknowledgements:

We would like to extend our thanks to Michael Leadbetter for his continued encouragement and assistance in testing the proposed methodology and Dr Jonathan Lim for discussions on the potential and ethics of human representation in the past.

Supplementary Tables 5

Supplementary Table 5.I: Prompts used to visualise the southern African Middle Stone Age.

Case Study	Categories	Prompt planning	Midjourney v6.0	DALLE-3
Case Study 1	environment, style	Prompt[Environment(Kalahari pans, Botswana covered in lakes)][Style(photograph taken with drone photography, Diji Marvic)]	Kalahari pans in Botswana covered in lakes, gentle midmorning daylight with a few clouds, photograph taken with drone photography, Diji Marvic	Kalahari pans in Botswana covered in lakes, gentle midmorning daylight with a few clouds, photograph taken with drone photography, diji Marvic
Case Study 2	period, environment, subject, object, style	Prompt[period(Mesolithic)][subject(small African child, a 4 month old San baby wrapped in soft leathers)][environment(burial, a sandy pit)][object(conus shell placed above the heart)][style(Award-winning photograph, cinematic lighting, ariel shot)]	a Mesolithic burial of a small African child in a sandy pit, a 4 month old San baby wrapped in soft leathers, with a conus shell placed above the heart. The child is in a pit is dug into a dark sand and lined with a springbok hide. The small child looks peaceful with their eyes closed. The scene is sombre and filled with emotion. Award-winning	a 4 month old San baby swaddled in soft leathers, with a very small white and orange conus ebraeus conus judaeus shell placed above the heart. The child is laying a pit is dug into a dark sand. The small child looks peaceful with their eyes closed. The scene is sombre and filled with emotion. Award winning photograph taken on Sony avii, firelit

			photograph taken on Sony avii, firelit scene cinematic lighting, ariel shot	scene cinematic lighting, ariel shot
Case Study 3	period, subject, environment, action, object, style	Prompt[period(Neolithic)][subject(two southern African woman with scarification)][environment(Blombos rock Shelter)][action(applying makeup)][object(abalone shell with red and yellow ochre)][style(documentary photography)]	An Neolithic southern African woman on the right is using red and yellow ochre in a abalone shell to apply makeup to a second woman on the left. A San, hunter-gatherer, Stone Age woman, with elaborate braids, 4c curls and scarification and realistic textured skin, is crouched next to a second woman with cornrows, They are seated on a beach by Blombos rock shelter, south Africa. They are wearing leather hides. The woman on the right is holding an abalone shell filled with red and yellow ochre. She is using her fingers to cover the	In Southern Africa, an older Neolithic woman with hair with braids, type 4c curls, real textured skin applies red and yellow ochre to a younger San woman, with cornrows, and scarification. Both wear leather hides on a beach by Blombos rock shelter. The older woman holds an abalone shell filled with red and yellow ochre, using her fingers to paint the younger woman.

			woman on the left with this crushed red ochre. documentary photography, diffuse lighting, Sony avii	

Supplementary Table 5.II: Archaeological reconstruction prompting categories with associated terminology understood by Midjourney and DALL-E 3

Category	Description	Relevant Vocabulary
Period/Time	Ideally, through defining the historical or archaeological time or period of an image, we would have barriers for the technology and clothing introduced into the image. Sadly, such temporal control is not yet possible. While more recent, or better researched periods, can generate a more authentic images with minimal prompting, with prehistory, much of the vocabulary is muddled together. Neither Midjourney nor DALL-E 3 has a clear differentiation between archaic, Neolithic, Mesolithic, Palaeolithic and Middle Stone Age. While you can use these words to provoke archaic features and suggest antiquity, it may introduce objects that do not exist in that part of the world – either specially or temporally. Similarly, *archaeology*, *archaeological* or *excavation* are more likely to give you a picture of an excavation than a photograph of a reconstruction. Words like *historical*, in contrast, can both impact the style of the image to be that of a historical photograph and draw on preconceived ideas of the past.	Neolithic Palaeolithic Sone Age Neanderthal X years ago
Environment	Defining the "where", you provide greater realism and familiarity. It is easy to give a subject description and obtain an impressive and emotive portrait, however, without introducing environment, your image will either be misplaced or on a black background as if in a studio portrait (see Appendix A). One of the most exciting aspects of using large AI	Setting: Cave, Beach, Vynbos, Highfield, dessert Known sites: Border Cave, Pinnacle Point, Blombos, Klasies River Mouth, karoo Weather: cloudy, stormy, clear, sunny, wet, flooded, arid Lighting: Twilight, Sunrise, Sunset, midday, night

	system is its incredible ability to place subjects in realistic locations of known places. These locations may not be as accurate as a modern photograph, but they provide a sense of place. Unlike with creative collaboration where each plant species can be precisely chosen and placed, ai generations are limited to the programme's approximation of species accuracy. While floral representation is limited, these locations can be modified (to an extent) to appear as they may have been climatically in the past (see: Case Study 1). This ability to transform a familiar landscape into the slightly unfamiliar can disrupt the viewer and can help place the subject both in Space and Time.	
Subject	Creating realistic human subjects is seemingly the simplest aspect of a scene, however, in reality; they require the most careful instruction. Without a real time machine, we cannot know what people looked like in deep time. We know that people today have lower genetic diversity than in the past and that diversity decreases as populations move out of Africa. That said, the ability for all human variation existed in the genomes of our ancient ancestors. Much like the images are influenced by a visual catalogue, the ways people describe the past influence the images produced. Being aware of the linguistic bias attached to image prompts allows us to be aware of how we need to adapt to representation. While skin colour may be guessed with some level of accuracy, with distance from equator and increased genome sequencing, other factors like hair texture, nose shape and eye colour remain unknown. Providing	Nationality/Race Age: provide a numerical age, young, old, toddler, child, baby Facial features: Nose shape, forehead size, eye colour Hair: 4c curls, braids, dreadlocks, straight, fine, bald Skin: provide an age and some description of the texture, mention imperfections Gender: Man, Women, Boy, Girl, He, She, grandmother, mother, aunt Emotion: happy, sad, joyful, excited, thoughtful, wise, intense

	modern nationality or racial classification can assist with ensuring diverse outcomes however, it may also reproduce unwanted tropes or packaged features. Adding additional information on age, gender and appearance can also help in creating realistic people who reflect those that exist in the mind's eye.	
Action	Actions speak to how people interact with each other or with objects. These reconstructions provide us ability to quickly, and cheaply, display an array of human experience and appearance which align with the most recent literature. It is the ability to capture, joy, sadness, success, love and struggle without being limited to a singular image or reconstruction. These can be conveyed through adjectives to your subject. More complex actions, including movement, holding, or making are achieved through verbs. In an English grammar your actions would be the verb. Repetition of the verb- action at the start and middle of the prompt will more to accurately depict an action depict complex actions. As AI still struggles with hands, reinforcing this action or focus helps direct the software to more accurate object-person interaction.	Person-Object: Holding, making, weaving, showing, painting, placing Person-Environment: Running, sitting, crouching Person-Person: Playing, talking, looking, teaching, holding
Object	Objects are amongst the most complex creations for an AI reconstruction. This is because of the limited visual vocabulary. While you may be able to generate a stone stool it will not be accurate to period or location. Similarly, because there is not a large visual vocabulary of tool use, the scale and way the object is held is greatly limited. While it will soon be possible to feed an object image to be used in an AI image,	Ochre, shell beads, fire, grass, meat, stone tool, lithic, animal species, spear, stick, necklace

	the scale will remain a problem. Objects like Ochre, shells, leathers and furs are far better understood but as these do not preserve well, and how they were used is largely unknown, the image generated remains speculative rather than scientifically accurate.	
Style	Style is the most personal component within image generation. Style can influenced through photographic techniques, painting materials or even artists. The ethics surrounding style is controversial as artists, still in the public domain, did not consent to their images being used to develop train these styles. Theis grey area is troubling and therefore I recommend using as much your own style knowledge to create your own 'look'. Additional style parameters can include lighting, time of day and using adjectives to generate an atmosphere. This can be enhanced through using Midjourney's --raw which removes much of the Midjourney style and allows more customisation. The final adjustment to style is creating the parameters/crop of the image. This can be achieved through --ar *aspect ratio*.	Cameras: Sony viii, Fuji TX4, 35mm film, GoPro View: High angle, low angle, portrait, Lighting: Cinematic, Golden Hour, Diffuse, sharp Aspect Ratio (only Midjourney): 3:2, 2:3

Supplementary Figures 5.I

Midjourney V-5.2

paleolithic --v 5.2 --style raw --s 50

paleolithc person --v 5.2 --style raw --s 50

stone age person --v 5.2 --style raw --s 50

stone age woman--v 5.2 --style raw --s 50

Dalle-3 via Bing Image creator

paleolithc

paleolithc person

stone age person

stone age woman

paleolithic --v 6.0 --style raw --s 50

paleolithic person --v 6.0 --style raw --s 50

stone age person --v 6.0 --style raw --s 50

stone age woman--v 6.0 --style raw --s 50

Supplementary Figures 5.II

Each prompt was run three to four times on Midjourney v6.0 and DALL-E 3. Images are referred to following the following naming convention – CS = Case Study, M = Midjourney, D = DALL-E 3, small letter = run/row, roman numeral = column. Case Study 1 (CS1) has a total of 16 Midjourney (4 runs) and 15 DALL-E 3 (4 runs) images. For Case Study 1 no reason can be attributed to DALL-E only producing three images on run 'CS1.D.a'. All Images are acceptable at displaying the content and the selected images for discussion were based on aesthetic preferences. Case study 2 has a total of 12 Midjourney and 15 DALL-E, with one failed image on DALL-E 3 run 'CS2.D.b'. Midjourney run 'CS2.M.a' produced four plausible images. Three of the four images were rejected. 'CS2.M.a.i' was rejected owing to problematic hands, 'CS2.M.a.iii' appeared slightly waxy and not in a pit as desired while 'CS2.M.a.iv' had a visual hallucination including antlers. Image 'CS2.M.a.ii' was provisionally selected owing to the placement of the shell and anatomically correct child. Row 'CS2.M.b' produced four unsuitable images with incorrect placement of shells and unrealistic cloth. Instead of running the prompt four times, subtle variation tool was applied to image 'CS2.M.a.ii'. Row 'CS2.M.c' represents these variations. 'CS2.M.c.iv' was selected owing to the correctly coloured and shaped shell. DALL-E 3 produced multiple plausible images. 'CS2.D.c.iv' was selected owing to the shell and the realistic leathers.

Case Study 3 proved challenging owing to the complex nature of the prompt. DALL-E 3 only produced 7 images over four iterations. This is explicitly owing to the nature of the images generated, with 'CS3.D.b' not displaying any images at all owing to "Unsafe image content detected". 'CS3.D.a.i' and 'CS3.D.d.ii' were immediately rejected owing to either a plastic bottle or pottery in the bottom left of the image. 'CS3.D.d.i' was rejected owing to the European woman with white skin. 'CS3.D.d.ii" created an evocative scene filled with people, atmosphere and people. The main subjects were a man and a woman instead of two women. Despite this

the image is evocative, ultimately, this image was not selected owing to the bone spoon for which there is no evidence. Image 'CS2.D.a.ii' is not ideal for representation either as the woman look unrealistic with strange furs and many beads that do not appear in the archaeological record. Despite this, it is included in the results and discussion below owing to appropriate setting and good composition. Midjourney also faced problems owing to induced nudity in the image production. While Midjourney initially produced 16 plausible images, only one was suitable for discussion. 'CS3.m.b' produced impactful images but they appeared slightly computer generated, the clothing also felt too modern. Most images in 'CS3.M.d' included unrealistic hands or visual hallucinations like makeup brushes. Ideally these would be removed through the variation tool, like in Case Study 2, or removal through the inpainting tool, these images could not be varied or altered owing to the sensors against nudity in the variation tools[1]. Run 'CS3.M.a' was rejected owing to anatomical issues and the absence of a clear abalone shell. Run 'CS3.M.c' produced several possible images, 'CS3.M.c.i' and 'CS3.M.c.ii' were rejected owing to the class bead jewellery. The woman on the right in 'CS3.M.c.ii' had strange patterning on her skin. Ultimately 'CS3.M.c.iv' was selected as the most probable capturing most of the main elements of the prompt.

[1] While alterations in photoshop or in an add-in application as done in Magnani and Clindaniel (2023) are possible; this goes beyond the scope of the current article.

1. Case Study 1

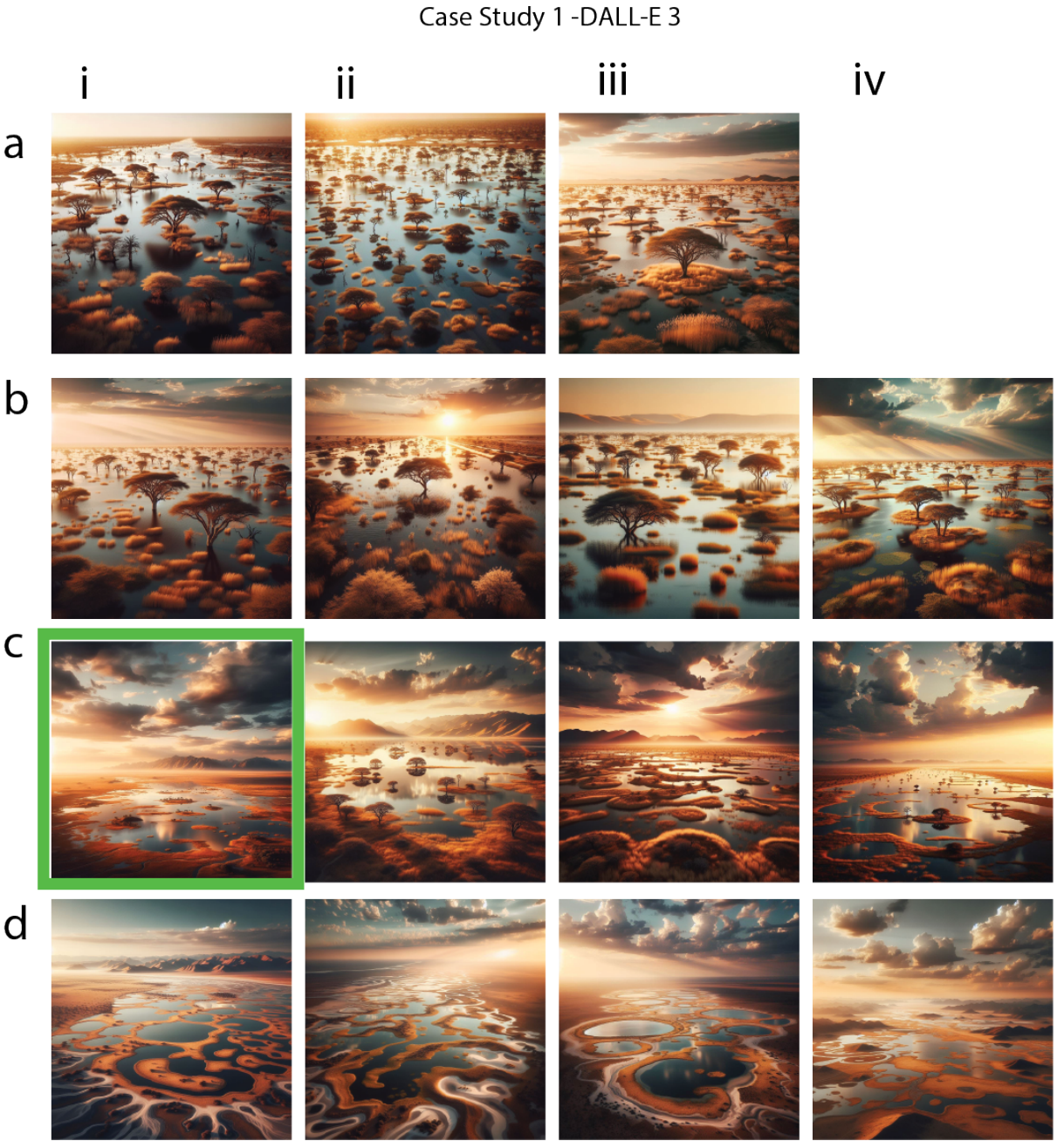
Midjourney

Prompt: The Makgadikgadi pans, Botswana flooded with water creating large lakes, the landscape is filled with southern African plant life including acacia trees and grasses on the shoreline, Ariel Photography, Drone photograph taken on Diji Mavic Pro, late afternoon lighting, golden lighting, cinematic -- raw --stylize 0 -- ar 3:2

Case Study 1- Midjourney v6

DALL-E 3

Prompt: Makgadikgadi pans in Botswana covered in lakes, gentle midmorning daylight with a few clouds, photograph taken with drone photography, diji Marvic

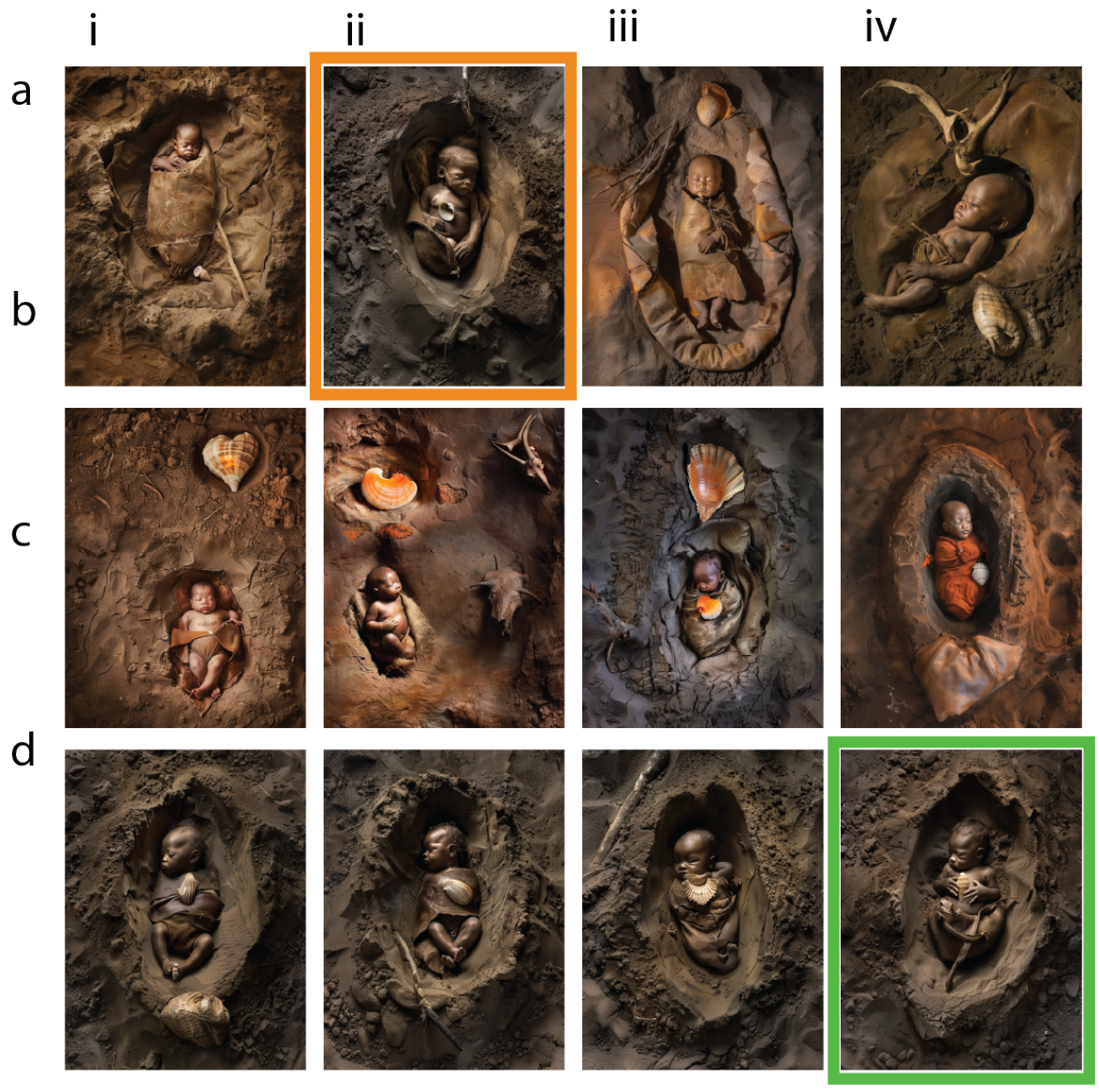


2. Case Study 2

Midjourney

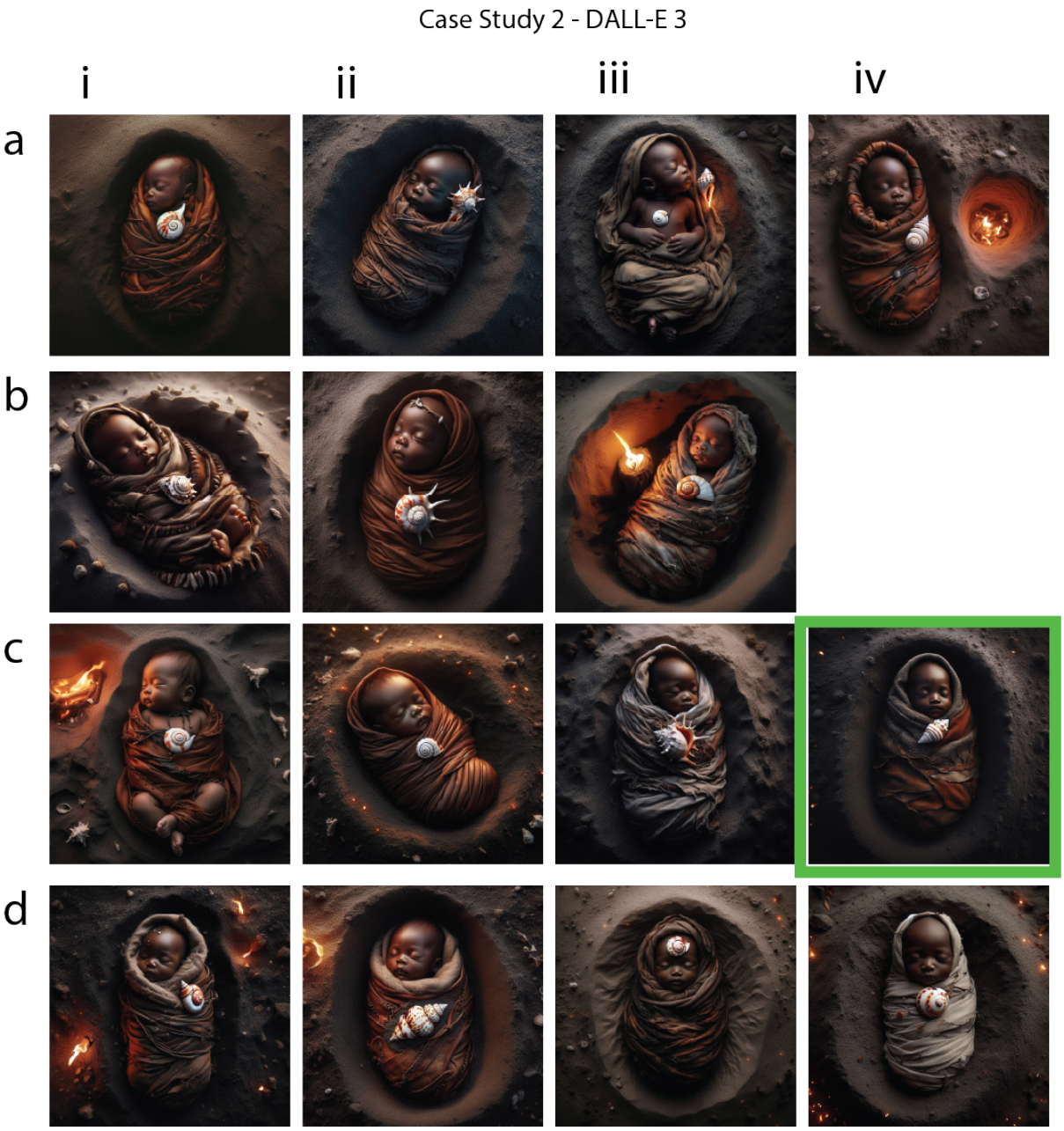
Prompt: a Mesolithic burial of a small African child in a sandy pit, a 4-month-old San baby wrapped in soft leathers, with a conus shell placed above the heart. The child is in a pit is dug into a dark sand and lined with a springbok hide. The small child looks peaceful with their eyes closed. The scene is sombre and filled with emotion. Award-winning photograph taken on Sony avii, firelit scene cinematic lighting, ariel shot -- raw --stylize 0 -- ar 3:2

Case Study 2 - Midjourney v6



DALL-E 3

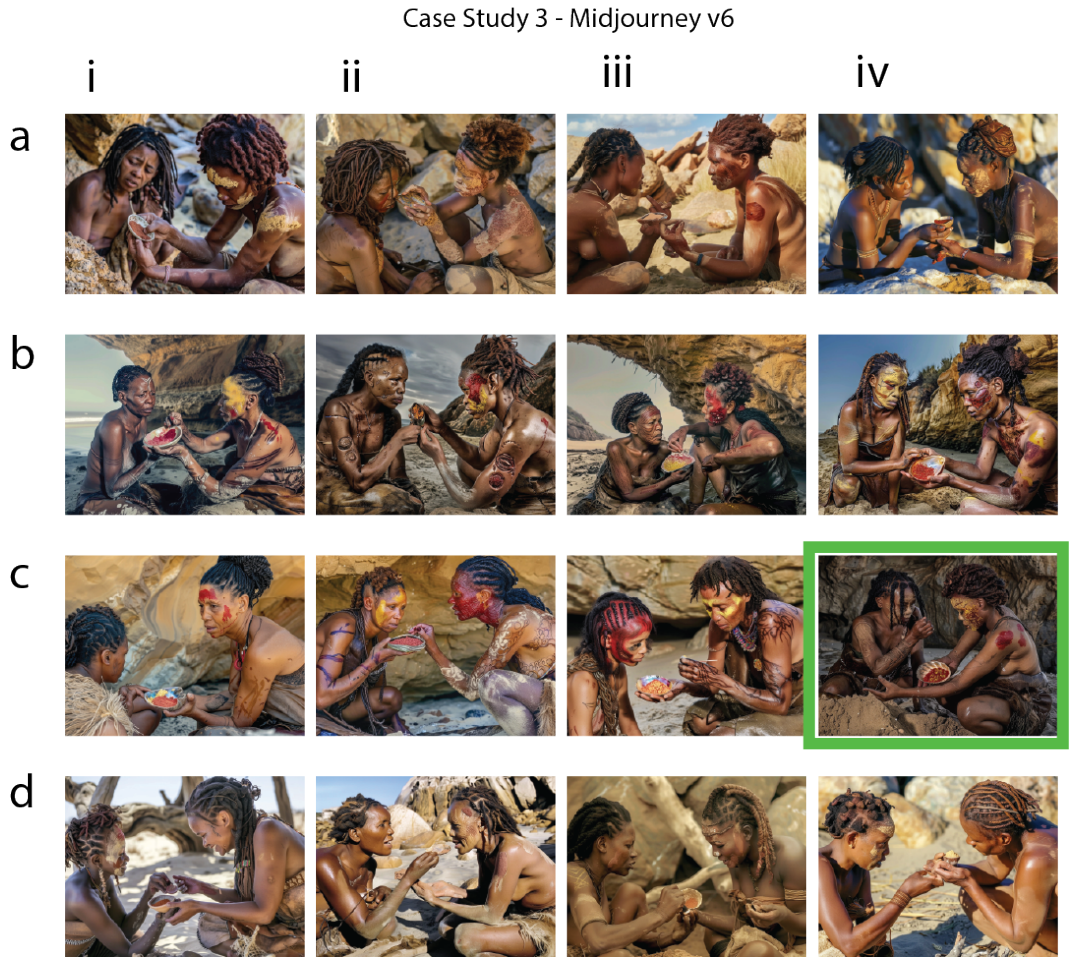
Prompt: A 4-month-old San baby swaddled in soft leathers, with a very small white and orange conus ebraeus conus judaeus shell placed above the heart. The child is laying a pit is dug into a dark sand. The small child looks peaceful with their eyes closed. The scene is sombre and filled with emotion. Award winning photograph taken on Sony avii, firelit scene cinematic lighting, ariel shot



Case Study 3

Midjourney

Prompt: A Neolithic southern African woman on the right is using red and yellow ochre in an abalone shell to apply makeup to a second woman on the left. A San, hunter-gatherer, Stone Age woman, with elaborate braids, 4c curls and scarification and realistic textured skin, is crouched next to a second woman with cornrows, they are seated on a beach by Blombos rock shelter, south Africa. They are wearing leather hides. The woman on the right is holding an abalone shell filled with red and yellow ochre. She is using her fingers to cover the woman on the left with this crushed red ochre. documentary photography, diffuse lighting, Sony avii -- raw -- no woven fabric --stylize 0 -- ar 3:2



DALL-E 3

Prompt: In Middle Stone Age Southern Africa, by Blombos rock shelter, two women sit on a beach. One, a San hunter gatherer woman, holds an abalone shell filled with red and yellow ochre, she is using her fingers to apply the crushed ochre to the other woman, a woman with elaborate braids and scarification. Documentary photography captures this scene with diffuse lighting

Case Study 3 - DALL-E 3

6. Discussion

Over the last fifty years, Middle Stone Age archaeology has undergone profound shifts in chronological understanding – from a Eurocentric worldview to one that embraces Africa as humanity's origin and home of cognitive modernity (Wadley, 2015). This thesis tracked and visualised the chronology that supported these theoretical shifts by meeting four key objectives. First, explore the history of dating within southern Africa and highlight the political and social forces that influenced archaeological inquiry. Second, the development of a database including all numeric ages associated with a southern African archaeological assemblage from 300 ka to 30 ka. This database exposed several gaps in current research, showing an intense focus on South Africa's southwestern coast and a lack of data for interior sites and neighbouring countries. In order to begin to balance this regional gap, I dated a recently excavated Mozambiquan archaeological site. Finally, I generated images of sites lacking artistic visualisation to demonstrate the potential of and power of reconnecting archaeological findings with ordinary people.

This chapter discusses the findings from the four key objectives of this thesis and explores their implications for our understanding of the southern African Middle Stone Age. I begin with a comprehensive summary of results from the chronological visualizations created at multiple scales. This summary establishes the foundation for examining four interconnected themes that emerged through this research. First, I explore how different scales of analysis reveal distinct patterns in MSA technological development and human behaviour. Second, I analyse how gaps in our chronological and geographical coverage create limitations and biases in interpretations. Third, I demonstrate how absolute dating methods are transforming our ability to trace temporal patterns across regional landscapes. These findings, however, highlight the important awareness towards spatial and temporal excavation and preservation biases which influences

the spread and depth of archaeological inquiry. Finally, I examine how complex site formation processes and multi-method chronologies require nuanced approaches to dating interpretation. Together, these themes highlight both the advances made through this research and critical directions for future investigation.

6.1. Contributions to understanding the MSA across multiple scales

The spatial and chronological visualisation across multiple scales presented in this thesis reveals regional and chronological patterns and gaps in our current understanding of the southern African MSA. From the macro scale, we can visualise meaningful trends; this multi-scale approach aligns with Bailey's (2007) concept of time perspectivism, which emphasises how different temporal resolutions reveal different aspects of past human behaviour. Bailey's understanding of time can be broken down into: (i) a substantive perspective, in which different phenomena operate over different time-spans, resulting in distinct forms of archaeological record (as discussed in Chapter's 3 and 4); (ii) a methodological recognition that different research questions are best examined at different temporal resolutions (as explored throughout this thesis); (iii) a strict perspectival awareness that the aggregation or disaggregation of time can distort perceived patterns, including apparent peaks and gaps in the MSA record (discussed in Chapter 3); and (iv) a subjective acknowledgement that chronologies are understood differently depending on cultural lens and archaeological scale.

Within this thesis, at the macro scale, the history of the southern African MSA chronology is established. This highlights the political, social and scientific systems and processes that influence the application and production of numeric ages. Subsequently, the southern African Middle Stone Age chronological database (Chapter 3) presents the first comprehensive database of the chronological data for this region and period. The database documents all 1812 absolute dates from the 88 dated MSA sites in southern Africa. The database significantly

expands on the Southern African Radiocarbon Database (Loftus et al., 2019) by documenting all archaeologically associated ages, irrespective of technique, between 300 ka and 30 ka. The strong luminescence focus enables correlation with other environmentally focused databases such as Walsh et al. (2023).

This new database enables future researchers to examine technological trends through multiple theoretical and methodological approaches, independent to or accommodating for older approaches including technocomplexes (Wilkins, 2020). Chapter 3 demonstrates this potential through exploring MSA peaks at 30-35 ka, 45-50 ka, and 55-60 ka. While these patterns may be influenced by methodological factors, particularly radiocarbon's upper limit around 50 ka, as well as research interest and preservation bias, they also likely reflect genuine archaeological phenomena. Looking through a medium-term, albeit still regional, lens further patterns relating to the emergence of backed pieces and the presence of the HP were observed. These findings align both with Kandel et al.'s (2016) concept of behavioural flexibility as a key adaptation of MSA populations as well as Jacobs et al.'s (2008) dating of the industry to between 64.8 ka and 59.5 ka, providing independent validation of their HP chronology.

At the intermediate scale it is evident that Mozambique has significant chronological gaps in its MSA record (Chapter 4). As a country which geographically links southern to eastern Africa, this obstructs the development of geographically connected research (Bicho et al., 2018; Mercader et al., 2013). This review of Mozambican Middle and Later Stone Age chronology supports the potential for further archaeological research in the region. This is further demonstrated through the dating Daimane II.

This thesis provides the first archaeological OSL ages for Mozambique. This local, zoomed-in, high-resolution exploration of a single site's palimpsest illustrates the challenges of understanding site formation processes and human occupation patterns at individual sites

(Bailey, 2007). The seemingly contradictory results from luminescence and radiocarbon dating at this site reveal different aspects of its history, OSL capturing sediment deposition and post-depositional events spanning several millennia, while radiocarbon predominantly records more recent organic additions, through post-depositional processes, to the sequence. These chronological data, combined with ancient DNA and more traditional faunal studies demonstrates the potential of archaeological science to synthesise information from complex sites and understand depositional and post-depositional complexity.

At the micro, ephemeral scale, the AI visualisations in Chapter 5 reconnect these abstract chronological patterns to human experiences, the environmental settings people inhabited, the technological choices they made, and the rich symbolic lives they experienced. The development this systematic prompting methodology enables is the application of generative AI to visualise archaeological contexts that are lost within chronological discussions. Additionally, the discussion revolving ethics and bias further a much-needed engagement on how to approach novel technological advances. By visualising specific moments in time, such as the Border Cave infant burial or the use of ochre at Blombos Cave, these images remind us that the archaeological record is simply the accumulation and memory of millions of human moments.

These multi-scale findings demonstrate the necessity of examining archaeological data at varying levels of resolution. The following section explores how this thesis operationalized different scales through a photographic analogy that helps visualize the methodological approach.

6.2. Archaeology of Scale

This thesis's four papers cover nested regional and spatial scales. In order to understand these scales, we need to understand the data in the visualisations created. This links to Bailey's (2007)

idea of time perspectivism, which emphasises that different phenomena are visible at different scales and resolutions. These scales, or snapshots, enable archaeologists to reconstruct a moment in time (Gupta and Devillers, 2017). The spatial, temporal and archaeological data and computational techniques can be analogised to camera settings. Cameras have four dominant photographic settings. First is focal length or zoom (regional scale); how close or far do you see the object? If you are zoomed out, you see the entire context and see but miss the small details; as you progressively zoom in, you get closer to the smaller details but see less of the context. Second is the aperture (archaeological and environmental data); this is the amount of light/data let into the image. This affects the depth of resolution – the smaller the aperture/amount of data let in, the less of the image is in focus. This correlates to the amount of data obtained in a site, more data you have the better the resolution of for your investigation's findings. Third is shutter speed (temporal scale), which is how quickly you take a photo. A slow shutter speed compresses time by capturing motion over several seconds or minutes, while a fast shutter speed lets you see a dynamic moment. In archaeological visualisation we this can range from understanding a single moment in time to compress hundreds of years to understand slow, long-term changes. Finally, cameras use ISO (computational modelling) to amplify the data/light received. This amplification inherently introduces noise and imperfections. In the models applicable to the southern African MSA this amplification can provide a more complete image of the past, like ISO it can introduce noise or amplify errors/bias.

In archaeology, as with photography, selecting one feature of resolution or scale influences the outcome and interpretation. However, unlike photography, archaeology contains many *known unknowns* and *unknown unknowns* (Karl, 2015; Lane, 2021). Archaeology's incomplete data, combined with known probabilities and temporal ranges, produces high levels of uncertainty (Crema et al., 2010). It is through the process of matching the correct data, regional scale,

temporal scale and modelling technique that we can address the *known unknowns* and visualise different phenomena.

Table 6.1: Photographic terms useful for understanding resolution, and scale in archaeological visualisations

Photographic term	Archaeological data	Application
Focal length	Regional scale	How much context do you show?
Aperture	Material cultural/environmental data	How much data is available or used in your model?
Shutter speed	Temporal scale	How much time does your visualisation cover?
ISO	Computational modelling	How do you amplify and make sense of your data?

Beginning in the zoomed in, high resolution spatial and temporal extreme, in Chapter 5, there is a small aperture or amount of known data, a zoomed-in focal length (narrow context) and a very fast shutter speed (ephemeral moment). These visualisations convey the ephemerality of human experience and the variability of the global environment. Yet all three images miss the context of the larger landscape, of what other people and the cultures surrounding them were doing. The images focus on a single image of the past with limited supporting data. The AI's computational models (ISO) generated noise through filling in gaps for *known unknowns* (e.g. clothing, physical appearance). In Chapter 4, I zoom out and include more data (a wider aperture) and a moderate temporal scale (shutter speed), and a moderate focal length (single site). In this configuration, archaeological regional trends are still absent. However, we are no longer focusing on the ephemeral but rather on the site history- from formation processes to disturbances and later excavation. Moving towards the other spatial and regional extreme, Chapter 3 has a large regional scale (small focal length) and extensive temporal range (slow shutter speed) and explores the different outcomes of varying the amounts of data while using a fixed spatial and chronological framework.

Chapter 3's exploration of regional technological trends over large time scales demonstrates the potential of varying scales with a fixed chronological framework. The use of varying data quantity moves from broad to specific: first, by documenting MSA sites. Second, by the HP association at these sites and finally, the presence of backed pieces. With MSA, we can see the presence and absence of people through time, and it enables us to visualise the movement of people and not technology. When we focus on HP, we lose the detail of sites which do not have this assemblage; however, we are better able to access the validity of Jacobs and Roberts's (2008) conclusion of the HP being a short-term event from 64.8 ka to 59.5 ka. However, when we introduce even more data on backed pieces, we can see how HP's focus missed earlier and later technological trends. This finding supports Mac kay et al.'s (2014) conclusions on coalescence and fragmentation. Further resolution, moving beyond an absence/presence approach used in this thesis to one that uses the percentage of backed pieces in an assemblage or one that models changes in multiple took types, would enable an even more refined understanding of these patterns or test models of population migration and movement during periods of climatic change (McCall and Thomas, 2012; Ziegler et al., 2013).

The potential for using large-scale regional analysis combined with detailed lithic data is increasingly apparent in the existing literature. Wurz (2021) suggests that while technocomplexes do not seem affected by paleoenvironmental data, lithic densities and proportions are seemingly sensitive to climatic shifts. Similarly, by combining radiocarbon, luminescence and uranium series ages with high-resolution lithic data, Bousman and Brink (2018) mathematically model the MSA/LSA and early LSA/Robberg transition in South Africa and Namibia. The MSA/LSA transition reveals a flexible adoption of new technologies. These findings challenge the concept of discrete phases defined by rapid or synchronised change. In contrast, the early LSA to Robberg is more rapid and corresponds to ancient DNA diversification. While the authors use these findings to explore theoretical demographic shifts,

in the absence of continuous climate models of similar temporal and spatial scale, they refrain from linking these findings to climatic and environmental data. Additionally, the analysis is limited by a paucity or gap in site locations.

6.3. Grappling with Gaps

Incomplete databases risk the introduction of noise, misleading or overly simplistic results (Bischoff et al., 2021; Thomas and Burrough, 2012). Without care, the computational models that aggregate complexity within databases can "introduce or amplify meaningless noise" or bias (Green, 2023, p. 1250). Additionally, the amplification of data means outliers or under-researched areas may be masked or otherwise missed. These risks are present in both the smaller spatial-temporal database (Chapter 3) and the massive generative AI databases (Chapter 5) utilised in this thesis. In the case of the southern African Middle Stone Age, these gaps (see: Chapter 2, Chapter 5) are features of preservation bias, political landscape and academic interest (Chiwara-Maenzanise, 2025). For example, the intense focus on the SB and HP makes modelling sites before 80 ka challenging as their statistical validity is questioned (Chapter 3). This is supported by Wurz's (2013, p. 305-308) observation that “No spatial and chronological patterns can be identified from the Early Middle Stone Age until marine isotope stage (MIS) 5” while “spatial and chronological patterning remains vague” for MIS5. However, Wurz's (2013) assessment of MIS5 supports Chapter 3's assessment that this lack of patterning may be an artefact of research bias rather than a true absence of people and cultural patterns. The disproportionate research attention devoted to MIS 4 assemblages (the HP and SB) has resulted in comparative under-investigation of earlier periods, including MIS 5 and the Early MSA, leaving their patterns poorly understood or seemingly absent in the archaeological record. Meanwhile, spatially, the intense focus on South African coastal rock shelters means there is limited understanding of the interior sites. This is problematic as sites with diverse environmental contexts (e.g. Stewart et al., 2012), less than ideal preservation such as open-air

sites (e.g. Lukich et al., 2020, 2019) or sites which could connect the eastern African and southern African record are missed. In the case of larger databases used by generative AI, these gaps are the result of accumulated social imaginations and bias in representations of the past (Ain and Carta, 2023; Molyneaux, 1997; Nicoletti and Equality, 2024; Zhou et al., 2024).

Despite the reality of incomplete databases, careful prompting (Chapter 5) and controlled statistical analysis (e.g. Monte Carlo models, neural networks, Bayesian Modelling and Optical Linear Estimation) is valuable for visualising past trends and behaviours that are otherwise hidden from us. While overcoming generative AI bias is in its infancy (see: Ain and Carta, 2023; Zhou et al., 2024), computational techniques for modelling and checking the statistical reliability for known databases is better established (Bousman and Brink, 2018; Grove and Blinkhorn, 2020; Key et al., 2021; Kolář et al., 2016; Ramsey, 2009).

The new development of a southern African MSA database, coupled with environmental and lithic data will enable computational techniques applied to similar contexts in other parts of the world. An established starting point would be directly using Bayesian modelling to model southern African site occupation. This methodology enabled incredibly precise ages for the extinction of Neanderthals in Europe (Higham et al., 2014). Alternatively, Key et al. (2021) presents Optical Linear Estimation (OLE), a conservation science methodology, as a way to model more gradual changes like the adoption of new technologies. Tested in Eastern Africa on the Oldowan and Lomwekian this methodology presents an accessible way for modelling lithic changes through time (Key et al., 2024). Staying in eastern Africa, Grove and Blinkhorn (2020) utilised neural networks to explore changes in MSA and LSA assemblages independent of technocomplexes. This work is advanced by Timbrell et al.'s (2025) application of random-forest modelling to understand the use of refugia in the MSA in eastern Africa. It is therefore clear, that with care, good understanding of the chronology and appropriately scaled data, the chronological data, documented in Chapter 3, has potential for producing robust analysis.

Despite these data gaps, the accumulation of chronological information now makes it possible to use absolute chronologies to trace temporal patterns across broader spatial ranges than previously possible.

6.4. Tracing time

With over 1840 dates from 145 sites available linking archaeological sites across large spatial ranges is now possible. This enables site temporal correlation independent to problematic cultural horizon markers (Loftus et al., 2019; Wilkins, 2020; Wurz, 2021). Even if these cultural marker horizons held more weight as chronomarkers, they would remain spatially bounded. This regionality would keep regional records separated and remove the possibility of pan-African archaeological investigation (Blackwood and Wilkins, 2022). For example, a pan-African exploration of the MSA is possible through combining the North African database in Boisard and Arous (2024) and the data utilised by Grove and Blinkhorn (2020) with the southern African MSA database presented in this thesis.

This ability to correlate sites also provides the possibility to explore environmental trends and patterns. Timbrell et al. (2022) apply cluster analysis to the eastern African MSA to explore the relationships between toolkit diversity, raw material choice and environment. This is enabled by the high-resolution environmental data in the region including the near-continuous Lake Tana and Olorgesailie cores, pollen records from Lake Magadi and wet-dry phases dated at the Chew Bahir basin. These data are locally specific and required high resolution climatic simulations. While this is particularly promising for understanding human response to large-scale environmental change – from migration responses to the formation and drying of pans to the effects of sea level change on coastal occupations, in southern Africa this work is currently hindered by non-standardised lithic documentation (Compton, 2011; Cooper and Green, 2021; Thomas and Burrough, 2012; Walsh et al., 2023).

Unlike eastern Africa which is not weighed by technocomplexes and therefore has more robust lithic reporting structures, the southern African MSA is steeped in the history of technocomplexes. Therefore, while the database developed in this thesis supports Wilkin's (2020) call to retire technocomplexes in exchange for a chronological framework, without a matching archaeological (material cultural) database of similar scale and robustness, the potential applications of this database falls short of Wilkins's (2020) aspirations.

Once increased material culture resolution is available for inter-site analysis, it is important to remember that across large distances, of space or time, local climates seen with radii of tens or low-100's of km's or periods of weather extremes will be lost in the climatic averages. It is, therefore, necessary to link appropriately scaled environmental proxy data or models to the scale of the research question. The data from exceptionally well-preserved archaeological sites have the potential for exciting high-resolution examination of local responses to climate change. For example, at Klasies River, micro-fauna introduced by owl pellets provide good local climatic proxy (Maringa, 2020). Further localised environmental data can include traditional archaeological zooarchaeological analysis on macrofauna (Maringa, 2020; Reynard and Wurz, 2020). Additionally, established isotopic methods as well as innovations in phytoliths offer differing and exciting localised environmental proxies (Cordova, 2013; Johnson et al., 1997; Murungi, 2017).

These data, combined with chronological databases, present exciting possibilities for future environmental and cultural research. While throughout this discussion, I have called for more research beyond the well-sampled southern coast, this is not to say we should entirely turn away from these exceptionally well-preserved sites. It is, instead, a suggestion that these sites' potential is being overplayed on large-scale research questions, where their level of resolution is unmatched and makes correlation difficult or misleads the answer through false positives. For example, correlating these site's data with a more regionally contained chronological

framework a high-resolution understanding of the southern African coastline would be enabled. This information could then be modelled to explore human response to sea-level changes and cultural patterns. If we utilise the potential of these coastal sites' high preservation and well-documented chronology, we can begin to ask archaeological questions beyond the first appearance of lithic innovations or macro-scale environmental trends.

A more novel application could include the spatial temporal modelling of macrofauna. Macrofauna, in the MSA, is traditionally used to make environmental inferences. However, this anthropogenic process in this accumulation (hunting, skinning and butchering) is not frequently explored (Badenhorst et al., 2021). While discussion surrounding the importance of nutrition is explored in the archaeological literature of "becoming modern" and yet data driven studies remain scarce (Kyriacou et al., 2014, p. 64). If a high-resolution faunal database were developed, this data could be used much like lithic data, or symbolic markers of modern human cognitions. Combining this fauna data with the chronological framework would enable changes in faunal remains to become a signifier of innovation, diversification or coalescence, and change (Wadley, 2015).

Food is often a potent signifier of cultural preferences and norms. However, despite theorised interest, (see: Parkington, 2010; Wadley, 2010), this aspect of faunal remains is rare in MSA faunal analysis (Dusseldorp and Langejans, 2013; Weaver et al., 2011). Through chronologically correlating faunal remains researchers could explore whether neighbouring sites eat the same or different foods in the same period. Alternatively, a shift within a single site over a rapid period may indicate environmental change, a new population or the development of a different culture. These observations may support or introduce culturally relevant information otherwise invisible when exclusively using lithic analysis.

6.5. Complex Chronologies

The multi-method nature of chronological data presents conceptual challenges for both regional and site-specific analysis. Absolute dating techniques provide numeric ages, but these values represent fundamentally different temporal phenomena (Chirikure et al., 2012). A radiocarbon date captures the moment of an organism's death, a thermoluminescence date records when a lithic was last heated, while an optically stimulated luminescence date reflects a longer depositional process. These events may be simultaneous, overlapping, or appear statistically similar despite being separated by generations of lived experience (Bailey, 2007). Ideally, multiple methods would produce a similar numeric age, agree with the cultural context and validate each other's reliability (Quinn et al., 2023). However, this is not always the case as methodological anomalies, site preservation and post-depositional forces can influence the ages stratigraphic and scientific integrity. This reality is exemplified by two key examples from this thesis: the unresolved chronological debate at Diepkloof Rock Shelter and the complex post-depositional processes identified at Daimane II.

At Diepkloof Rock Shelter the thermoluminescence (TL), dates on the lithics, and the optically stimulated luminescence (OSL) dates generated two disjointed chronologies for the SB layers. This presents challenges to both the investigation of the SB and the validity of one or the other chronology. Despite this undesirable and still unresolved complexity, without utilising both methods, the chronology may be misinterpreted creating false correlations and interpretations of the site and region's archaeological and chronological record.

At Daimane, multi-method techniques also produce also produce a disjoined result. However, these, 20 new optically stimulated luminescence (OSL) and radiocarbon dates, rather than confusing the archaeological history, they enlighten on depositional and post-depositional processes. The luminescence dates constrain human occupation at Daimane II from 4 041 ± 626 years ago to 384 ± 79 years ago, revealing a complex Holocene occupation with intensive LSA forager use combined with the presence of MSA style tools. These findings parallel

observations at Saxonomunya, Senegal, where MSA-like assemblages dated to 11 ka were contemporary with LSA occupations in neighbouring valleys (Scerri et al., 2021). Similar technological overlaps have been documented at sites like Sibebe in Eswatini (Bader et al., 2022a) and Grassridge in South Africa (Ames et al., 2020), suggesting that transitional or mixed assemblages may be more common than previously recognised.

However, the analysis also identified significant post-depositional disturbance throughout the sequence, evidenced by high overdispersion values (25.9-102%) in luminescence measurements and stratigraphic inversions in radiocarbon dates, which cluster within the last millennium. This is supported by radiocarbon ages that do not correlate with the OSL samples nor occur in stratigraphic order. This disturbance weakens Daimane II's contribution to this larger argument of MSA style tool persistence in Holocene communities. This complexity underscores Thomas and Burrough's (2012) caution against drawing "overly simplified scenarios" and supports the use of individual lithic types independent of packaged industries.

The disturbance found at Daimane II is not unique. Bioturbation is a known issue at Canteen Kopie and Kathu Pan 6 (Chazan et al., 2013; Lukich et al., 2019). These issues are even more obvious when radiocarbon and luminescence dating are paired. This is because of charcoals tendency to filter and move around in archaeological sites (Boaretto, 2009). This is clearly demonstrated from the disjoined radiocarbon and OSL ages at Nauwalabila I, a middle Pleistocene contemporaneous with the latter parts of the MSA in southern Africa. This site demonstrates how radiocarbon dating on charcoal reduces in accuracy not only with age but also stratigraphic depth (Bird et al., 2002). At Nauwalabila I the radiocarbon and thermoluminescence ages support each other up to 120cm, with the radiocarbon diverging after this. However, since optically stimulated luminescence dating was not possible, unlike Daimane II the sedimentary behaviour remains unknown. At Ifri n'Ammar, North-East Morocco micromorphology is used alongside radiocarbon, TL on stone tools, single grain and

multi grain OSL on quartz grains and pIRIR on feldspar grains to validate and understand complex depositional patterns (Klasen et al., 2018). Through the comparison of the different features of each dating method, alongside the micromorphology, a good understanding of the site occupation was established. While Diepkloof has a micromorphological analysis, the accuracy of the competing TL and OSL ages may be assessed with new chronological methods (Mentzer, 2023; Miller et al., 2013; Parkington and Porraz, 2023). Similarly, at Daimane II, the chronological precision could be improved with further work directly dating lithics or large fauna.

From Diepkloof's competing chronologies to Daimane II's post-depositional disturbances, these site-level complexities are clearly visible. If these complexities are not acknowledged or understood on a regional level this could lead to incorrect macro scale analysis. The database presented in this thesis attempts to resolve this by including the stratigraphic notes, differing interpretations and whether the age is seen as a maximum or minimum. However, this does not mean that all the ages in the database are reliable. It is only through multiple dating, geoarchaeological and archaeological investigations that both the accuracy and precision of each individual site can be definitively established. This is not always possible and therefore the need to shift from macro-scale regional visualization to micro-scale site analysis needs to be used to assess, validate and understand whether outliers are genuine features of the archaeology (e.g. Saxonomunya) or whether they are in fact a result of post-depositional mixing.

These multi-method challenges and opportunities encountered at both regional and site-specific scales reinforce a central theme of this thesis – that archaeological visualization requires temporal perspectivism. It is through shifting between macro-scale patterns and micro-scale visualisations that researchers can understand how different chronological tools shape the archaeological patterns.

6.6. Future Directions for Research

The multi-scalar approach employed in this thesis has revealed significant patterns in the southern African MSA chronology while simultaneously highlighting critical gaps in our knowledge. Through analysis at regional, site-specific, and micro-temporal scales, we can now identify where research efforts should be concentrated to build a more comprehensive understanding of human behaviour and technological development during this pivotal period.

The patterns observed—from the geographical distribution of sites to chronological clusters of technological innovations—provide valuable insights into human adaptations and movements across southern Africa. However, these patterns are constrained by uneven research intensity, with coastal South African sites receiving disproportionate attention compared to interior regions and neighbouring countries. This imbalance creates blind spots in our understanding, particularly regarding connections between eastern and southern African populations and technologies.

Building on these observations, three interconnected research priorities emerge that would significantly advance our understanding of the southern African MSA: addressing geographical and temporal research gaps. Second, standardizing data collection and reporting protocols, and third, developing computational approaches that integrate diverse datasets. Each of these directions builds upon the methodological foundations established in this thesis and addresses specific limitations identified through the multi-scalar visualization of chronological data.

Addressing Spatial and Temporal Gaps

While current research on the southern African MSA contributes powerful and impactful visualisations and understandings of the human past, these representations, whether data-driven or imaginative, remain heavily influenced by existing research patterns. These patterns exacerbate geographical and temporal biases, particularly notable in the overrepresentation of

South African coastal rock shelter sites at the expense of the country's interior and open-air sites. Additionally, this regional financial and academic focus means that other southern African countries remain underexplored despite known sites from older excavations and new sites observed through environmental and luminescence exploration (Burrough and Thomas, 2013; Stone et al., 2024; Walsh et al., 2023). Similarly, chronological research needs to explore periods before and after the well-studied HP and SB (80 ka - 60 ka) industries to examine the validity, occurrence and absence of different innovations. Addressing these gaps will significantly enhance our ability to reconstruct human presence across southern Africa.

Standardising publication and reporting structures

The challenges and gaps encountered while creating the chronological database in Chapter 3 highlight a second key direction for future research: the need for standardised data collection and reporting protocols. During database construction, inconsistent reporting of contextual information across publications complicated efforts to integrate chronological data with archaeological associations. The dangers of not obtaining this contextual information are demonstrated through Daimane II (Chapter 4), where interpreting the relationship between luminescence and radiocarbon ages required detailed stratigraphic and archaeological information. This critical data, however, is sometimes missing from primary publications and almost always absent in secondary reporting of dates. Similarly, the analytical power of the regional patterns identified in Chapter 3 was limited by inconsistent recording of lithic attributes.

The development of standardised protocols for recording and documenting chronological information, lithic data (tool types, counts, raw material), faunal remains, and the stratigraphic and archaeological associations of dated samples would enable researchers of the southern African Middle Stone Age to produce precise, accurate and meaningful data with novel

computational and statistical techniques. As part of development of these protocols' researchers should also explore how to convey the temporal scale of the event being dated, distinguishing between momentary events (e.g., death of an organism), production events (e.g., heat-treated lithics), and longer-term processes (e.g., sediment deposition).

Integrating Diverse Datasets and Computational Approaches

While the chronological database and the expansion of archaeological research focus represent important first and second steps, further integration with other existing archaeological and chronological datasets (e.g., with ROCEEH, ka would enable these questions to be tackled (e.g. investigation of climatic niches, dietary trends or responses to macro-scale changes in the environment). Additionally, through integrative diverse datasets there is the potential to revisit and reassess old questions pertaining to innovation and technological package standardisation.

7. Conclusion

The Middle Stone Age is a period of diversification and innovation (Wurz, 2013). Archaeologists' intense interest in the southern African coastline has uncovered evidence of early art, symbolism and complex toolmaking (Wadley, 2015). The reasons for this increased complexity remain unknown, with theories including climatic and environmental factors, genetic or dietary influences (Kandel et al., 2016). To understand these reasons and innovations, archaeologists have used several techniques to correlate sites and understand shifts through time. Numeric ages provided from diverse dating techniques offer the opportunity to explore these trends (Aitken, 1990; Loftus et al., 2019; Wilkins, 2020; Tribolo, 2023).

This thesis explored the relationship between time, site and reported ages through scaled chronological frameworks. In order to achieve this, I first explored the modern political and academic pressures that have shaped the southern African MSA chronology and visualisations. This revealed significant regional and chronological gaps in our knowledge. Despite these limitations, I was able to collate 1,840 numeric MSA ages from 145 sites in a new comprehensive database that preserves methodological distinctions and contextual information. This is the first chronological database for southern African MSA. To address the regional data paucity identified in my review and database development, I temporally constrained the depositional and post-depositional processes with luminescence and radiocarbon dating at Daimane II in Mozambique – producing 20 new dates. This was the first application of OSL to a Mozambiquan archaeological site. While the site itself dates to the Holocene, the presence of MSA-style tools indicates potentially more complex relationships to stone tool technologies through time than simple linear progression models would suggest. Finally, I developed a systematic prompting methodology which explores how to visualise the

transitory moments that contribute to the archaeological record, reconnecting abstract archaeological data to human experiences.

The vastness of time and space, and the importance momentary human experience, are paradoxical and yet necessary companions in understanding archaeological findings. This thesis's findings demonstrate how moving between different spatial and temporal scales enables archaeologists to visualise different phenomena that would otherwise remain invisible at any single scale. These scaled visualisations enable easier communication across these research groups, aiding each other in communicating complex data both to colleagues and to broader public audiences. This approach is particularly beneficial for future big data and computational studies, as well as archaeologists aiming to better communicate the impact of their findings to different audiences (Green, 2023; Gupta and Devillers, 2017; karl, 2015). This includes understanding trends in stone tool adoption and innovation, correlations with environmental changes, site formation processes and the life history of archaeological remains before deposition. However, caution is advised as mismatched scaled correlations can lead to overly simplistic or misleading visualisations. To fully utilize this approach to scale and visualisation standardised reporting protocols for both material cultural and scientific findings are required.

Future research combining the MSA chronological database with environmental and detailed lithic data may reveal patterns in human behaviour across large scales. On a smaller scale, further work would support the development and understanding of cultural patterns without focusing solely on stone tools. The development of these questions moves archaeological inquiry away from using chronology to temporally constrain cultural firsts, something that would be almost impossible to truly determine, but rather works towards understanding how people behaved, innovated and interacted across regional and generational scales. The introduction of this framework, coupled with increased research attention to underexplored periods and regions, would enable more rigorous investigations of climatic trends, migration

patterns and cultural phenomena. The discovery of these phenomena, coupled with provocative imagery, would support *knowledgeable creators* in making the past relevant, the human capacity for innovation palpable, and the possibility for resilience and adaptation relevant to the diverse strands of humanity today.

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