Variability in Ostrich Eggshell Beads from the Middle and Later Stone Age of Africa

by

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Abstract

Ostrich eggshell (OES) beads are the first kind of ornaments in human history to be mass-produced, and they exhibit variations that simulate cultural boundaries. Previous research into the stylistic variation of OES beads identified the importance of bead diameter in assemblages from southern Africa over the last 5000 years. Specifically, hunter-gatherer beads have small diameters, while larger beads appear only in conjunction with the first herding communities. This observation led to the general conclusion that OES bead size was a cultural marker that allows us to distinguish between hunting and herding sites, in absence of other forms of evidence.

This dissertation builds upon the previous research to explore whether OES bead variation can reveal social boundaries in the Middle and Later Stone Age. Using principles of cultural transmission through social networks, I examine 2570 OES artifacts from five countries, searching for regional or temporal stylistic trends. This work expands this time depth of OES bead diameter research to 0-50 thousand years ago (kya), and includes data from sites around southern and eastern Africa.

Results reveal that the previous understanding of bead size, and its link to the first herders in southern Africa, was incomplete. The initially negative correlation between time and size from 0-2500 years turns into a positive relationship from 2500-50,000 years ago, a result that contradicts the previously held belief that bead size alone can distinguish hunter-gatherer from herder sites. The oldest southern African diameters (40-50 kya) are actually comparable in size to the younger herder beads (~2 kya).

Comparing the eastern and southern data shows regional differences in bead size. The sizes of southern beads shift considerably through time, while the eastern sizes stay

consistent over the entire 50,000-year history. The most surprising result is that the oldest beads (40-50 kya) from both eastern and southern Africa overlap in diameter, before the southern African beads begin to reduce in size from 40 to 2.5 kya. This similarity in size opposes the Isolation By Distance model of stylistic similarity, and may indicate a long distance trade network that connected eastern and southern Africa during the Middle Stone Age.

This dissertation also documents two previously unknown stylistic variables, and a distinctive type of recycled OES ornament. The first variable (Outer Rim Donut Index 3) appears to result from a preform shaping technique, and is found preferentially in southern Africa. The second trait (pinching) is found only on finished beads, never preforms, and appears to be the result of a specific (but currently unidentified) stringing pattern. Future work should review ethnographic literature and conduct experimental replication to examine the importance of these traits further. I also documented a small number of OES preforms that have engravings on the cuticle surface. These specimens appear to be fragments of OES containers that were repurposed to make beads, and may be the first evidence for recycling in human history.

OES beads and other decorative handicrafts are more than mere ephemera; they can be used to examine social relationships in the past. They are not only physical evidence of ancient technology, but they can also afford a glimpse into the minds of Palaeolithic people. The emergence of beads in the Palaeolithic is a tangible record of the increasing complexity of social interactions, and rising importance of symbolic communication, which are core issues in the study of human evolution.

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Chapter 1 – Introduction

Symbolic ornaments are powerful tools for communication. They are used to maintain group membership, to govern interactions between people, and to express our individual identities (Keblusek et al. 2017). In the archaeological record, ornaments can tell us about the technological abilities of their makers, but also about the individual who wore them and their society as a whole. These remarkable artifacts can be traced back more than 100 thousand years ago (kya) to Africa, in the form of beads.

Today, people wear ornaments with symbolic meanings in order to convey information; however, it was not always this way in our history. The earliest signs of symbolic artifacts (specifically beads) signal a new era of social complexity that coincides with the widespread dispersion of our species, *Homo sapiens,* out of Africa (Kuhn 2012; Stiner 2014). The synchronous timing of the expansion out of Africa and the emergence of clear symbolic expression suggests that this new mode of communication is an important part of our species' success. Therefore, documenting the origin and spread of early symbolic artifacts is a key to unraveling the human story.

New techniques and discoveries are constantly advancing our understanding of human evolution, but many questions remain. Much of the research in palaeoanthropology has focused on lithic analysis or zooarchaeology, and while these subjects are vital, they are not well suited to answer questions about the evolution of social networks, the rise of cultural diversification, and the advantages of symbolism. As a result, for the Palaeolithic, this type of information is poorly understood. The development and collection of standardized data on personal ornaments could help fill this knowledge gap. Symbolic ornaments artifacts are often overlooked as analytical units, perhaps due to a focus on sensationalized activities such as making weapons or hunting large game. However, these marginalized artifacts, including beads, have the potential to contribute to the study of human evolution.

The earliest known beads can be found in northern Africa, southern Africa, and the Near East, dating between 70 and 120 kya (Assefa et al. 2008; Bar-Yosef Mayer et al. 2009; Bouzouggar et al. 2007; d'Errico et al. 2005, 2008, 2009; d'Errico and Backwell 2016; Vanhaeren et al. 2006). These artifacts are collected shells, often belonging to marine organisms, with natural or intentional perforations, that were suspended on cordage. Some thousands of years later, humans began experimenting with ostrich eggshell (OES) as a bead material.

The first OES beads were made at least 40-50 kya (Ambrose 1998; d'Errico et al. 2012; Miller and Willoughby 2014; Tryon et al. 2018). Though they are not as ancient as their marine shell predecessors, OES beads are the first to be mass-produced in a fully transformed, standardized shape. OES beads are still made and worn today, and remain one of the few forms of material culture that has persisted from the Stone Age into modern times. Their fully imposed shape and long tradition of use make them excellent candidates for a stylistic analysis.

Previous research into OES beads found a relationship between diameter and age. Specifically, researchers documented that hunting and gathering groups had smaller beads than the first herding populations to enter southern Africa. These size differences may be emblematic of ethnic preferences, and as such they have been used as a proxy for migration and interaction among people in the past. However, the previous analyses were restricted to sites in the western part of southern Africa, from the last 5000 years, and no similar analysis has taken place on beads from other regions or times.

Building upon the work of these earlier studies, I study the oldest examples of OES beads in search of stylistic preferences that represent social boundaries in the Stone Age. My dissertation research draws upon data from 2570 OES artifacts from eleven sites in Kenya, Tanzania, Botswana, Namibia, and South Africa. This dissertation not only expands the scope of previous research geographically, but also through time to include beads dating from 100 to 50,000 years ago. As this work is the first compilation of such data, it was difficult to formulate testable hypotheses prior to data collection. Instead, I seek to explore three questions:

- What happens to southern African OES bead sizes from 5000-50,000 years ago?
- Do the same changes happen to eastern African OES beads?
- Are there bead characteristics other than diameter that may have regional or temporal signatures?

Ultimately, I find that the previously documented trend of diameter change in southern Africa reverses, and beads from 40 kya are similar in size to the average recent herder beads. I also find that there are regionally distinct sizes between eastern African and southern Africa OES beads. Finally, I identify two previously undocumented bead traits that link to use wear and manufacture, although further study is required to document their extent and range of variability. Nevertheless, this is the first study to record and compile such data from sites older than 5000 years BP (before present), and is an important step towards documenting and decoding the social lives of the earliest modern people.

Hominins and material culture

The ancestors of all living people originated in Africa, where sometime prior to 50,000 years ago, one or more groups of *Homo sapiens* left Africa and ultimately their descendants inhabited all areas of the globe. Just as it was the genetic center of all people, Africa likewise appears to be the wellspring for cultural innovation. Precocious developments such as technological advances and the appearance of art in the African Middle Paleolithic / Middle Stone Age coincide with the radiation of modern humans, and may have facilitated the expansion and success of our species. Key among these African developments is the first occurrences of symbolic ornaments, including beads.

Beads are small, perforated embellishments that can be suspended and used as decoration. They appear relatively recently, with the use of beads being widespread in the last 50,000 years of an archaeological record that spans more than 3.3 million years (Table 1). The evolution of symbolic ornaments in the archaeological record may be a part of the intellectual or social changes that contributed to the success of humans today. Therefore, understanding the evolution of these artifacts is important to understanding the evolutionary success of our species.

In order to understand their significance, it is important to review where these symbolic objects fit in relation to preceding technology. This chapter is a brief overview of the evolution of hominin material culture from the first fossil members of the lineage to the widespread appearance of symbolism. Scientific knowledge is constantly broadening in the light of new discoveries, perhaps more in the field of palaeoanthropology. New information that changes our understanding of the evolutionary record is published regularly.

Through a combination of genetic and fossil evidence, we know that hominins - a taxon including modern humans and our ancestors - originated sometime in the last 5-6 million years in Africa. According to genetic data, our lineage branched off from chimpanzees, our closest living relatives, between 4 and 8 million years ago (Hasegawa et al. 1985; Langergraber et al. 2012; Patterson et al. 2006; Sarich and Wilson 1967). The fossil evidence for divergence of our Tribe (Hominini) originates with the appearance of bipedal locomotion, and these transitional forms are found between 4.3 to 7 million years ago (Mya) in eastern and central Africa (Wood and Lonergan 2008). It is difficult to know for certain which fragmented fossil species are our ancestors, but they arguably include *Sahelanthropus tchadensis* (Brunet et al. 2002), *Orrorin tugenensis* (Senut et al. 2001), *Ardipithecus kadabba* (Haile-Selassie et al. 2004), and *Ardipithecus ramidus* (Lovejoy 2009). Each of these demonstrates some trait indicating the evolution of bipedalism, such as an anterior position of the foramen magnum, elongated femoral neck, dorsally canted pedal phalanges, or curved shape of the innominate (Wood and Harrison 2011).

There are no known artifacts prior to 3.3 Mya, but it is likely that tools did exist. Only modified stone, or bones under the right conditions, are suited to survive millions of years of degradation, but these are only some of the potential raw materials that an early hominin may have used. Researchers have observed chimpanzees and crows modifying organic materials such as sticks and leaves into tools (McGrew 2013). If the earliest hominins were likewise using perishable materials, there would be no trace for us to

Table 1. Overview of technological periods and sites, as mentioned in text.

Age	Technology	Industry	Sites	Reference
40 kya	Upper Palaeolithic / Later Stone Age	-	Border Cave (South Africa), Enkapune Ya Muto (Kenya), Kisese II (Tanzania)	Ambrose 1998; d'Errico et al. 2012; Tryon et al. 2018
44 kya	?	Châtelperronian	Various sites in France and Spain	Higham et al. 2010; Welker et al. 2016
46 kya	?	Uluzzian	Various sites in Italy and Greece	Douka et al. 2014; Peresani et al. 2016
77-59 kya	Middle Palaeolithic / Middle Stone Age	Howiesons Poort / Still Bay	Various sites in South Africa	Henshilwood and Dubreuil 2011; Lombard 2005; Wadley 2007
300 kya		-	Olorgesailie (Kenya)	Deino et al. 2018
1.76 Mya	Lower Palaeolithic / Early Stone Age	Acheulean	Olduvai Gorge (Tanzania), Kokiselei (Kenya), Konso (Ethiopia)	Beyene et al. 2013; Diez-Martín et al. 2016; Lepre et al. 2011
2.8 Mya		Oldowan	Gona (Ethiopia), Hadar (Ethiopia), Omo (Ethiopia), Lokalalei (Kenya), Kanjera (Kenya)	Plummer and Bishop 2016; Semaw et al. 2003
3.3 Mya		Lomekwian	Lomekwi 3 (Kenya), Dikika (Ethiopia)	Harmand et al. 2015; McPherron et al. 2010

discover today, making it appear as if they lacked material culture.

The first widespread genus in fossil hominin evolution is *Australopithecus*. Australopithecine fossils are found in eastern and southern Africa between 4.2 and 1 Mya, and directly precede the first evidence for stone tool use. The basal member of this clade is *A. anamensis*, with fossils identified at Kanapoi and Allia Bay in Kenya, in sediments dating between 3.8 and 4.2 Mya (Ward et al. 1999). After *A. anamensis*, two gracile australopithecines appear which seem to be likely candidates for our direct ancestors. *A. afarensis* is found in eastern Africa, and *A. africanus* is found in southern Africa, thought there is an unclear evolutionary relationship between the regional species (Kimbel et al. 2006; Leakey et al. 1995; White et al. 2006). There are a number of other recently named australopithecine species (e.g. *A. sediba*, *A. deyiremeda*, and *A. bahreghazali*), and an array of contemporary hominin that have unique genera designations but may be grouped as australopithecines depending on the classification scheme used (such as *Kenyanthropus*, *Zinjanthropus*, and even *Ardipithecus*). Robust forms of *Australopithecus* (sometimes referred to as the genus *Paranthropus*) appear to have descended from these earlier gracile forms.

The oldest known lithic technology dates to 3.3 Mya, however due to the overlap of australopithecine species at that time it is unclear which of these (or a yet undiscovered hominin) was responsible for this development. Lomekwi 3 in Kenya is currently the oldest known stone tool site (Harmand et al. 2015). It has more than 100 cores, flakes, cobbles, and anvils exhibiting a combination of passive hammer and bipolar knapping technology. The flake removals are described as poorly controlled, with a low degree of precision, and may suggest a combination of battering and pounding in conjunction with lithic reduction behavior (Harmand et al. 2015, p. 313). Animal bones with linear incisions from Dikika, Ethiopia, dating to 3.4 Mya may have been the result of a hominin ancestor using a piece of sharp stone to cut the flesh of the animal (McPherron et al. 2010). However, not all scholars agree that the marks from Dikika are hominin made (Domínguez-Rodrigo et al. 2012), and so far no fossil hominin remains have been recovered in association with any of these early tools.

This first tool technology (the Lomekwian Industry), belongs to the overarching category of the Early Stone Age in sub-Saharan Africa, known as the Lower Palaeolithic in other areas. The tool making species remains unknown, although the only contemporary hominin documented in the region at that time was *Kenyanthropus platyops* (Leakey et al. 2001), which despite its name is typically grouped as a gracile australopithecine. The Lomekwian Industry is identified only at Lomekwi 3, so it is unclear whether this is a widespread technology, or an early form of the Oldowan Industry.

There is chronological overlap between the appearance of our genus (*Homo*) and the later forms of australopithecines, and according to the prevailing knowledge *Homo* likely descended from some member of the australopithecine lineage. The earliest member of *Homo* is identified from a fossil found in Ledi-Geraru, Ethiopia, dating to 2.8 Mya. This jaw fragment has features that are distinct from terminal members of the australopithecines, but primitive compared to the earliest members of the *Homo* lineage (Villmoare et al. 2015, p. 1354). This unnamed species from Ethiopia is a probable ancestor of other early *Homo*, including *H. habilis* and *H. erectus*.

The Lomekwian Industry predates the appearance of *Homo*, however the emergence of the Oldowan Industry roughly coincides with it. Still part of the larger Early Stone Age / Lower Palaeolithic, the oldest Oldowan tools are found in Gona, Ethiopia, at 2.6 Mya (Semaw 2000; Semaw et al. 2003). The Gona artifacts show a degree of control and raw material selectivity that are suggestive of an earlier development, perhaps as old as 2.9 Mya (Semaw et al. 2003, p. 176). Other early instances of Oldowan technology include Hadar and Omo in Ethiopia, and Lokalalei and Kanjera in Kenya (Plummer and Bishop 2016). Hard hammer percussion and bipolar flaking are characteristic of the Oldowan, and assemblages include hammerstones and sharp unmodified flakes, with no imposed tool forms (Plummer and Bishop 2016).

The Acheulean Industry begins around 1.76 Mya, which is approximately the same time that *H. erectus* first appears. The three oldest Acheulean sites are Olduvai Gorge in Tanzania (Diez-Martín et al. 2016), Kokiselei in Kenya (Lepre et al. 2011), and Konso in Ethiopia (Beyene et al. 2013). 'Ubeidiya, in Israel, has evidence of an early Acheulean industry, but dating has been problematic, with its age estimated to be somewhere between 640,000 and 1.7 Mya (Horowitz et al. 1973; Repenning and Fejfar 1982). Acheulean technology differs from the preceding Oldowan by the presence of bifacial shaping found on large cores and flakes. Although the teardrop-shaped hand axe has become iconic of Acheulean technology, finely shaped examples are found only in the later Acheulean.

The development of the Acheulean coincides roughly with a wave of hominin leaving Africa for the first time. The oldest known fossil hominins outside Africa are found in Dmanisi, Georgia, and date to approximately 1.77 Mya (Gabunia et al. 2000).

Five hominin skulls were recovered, and although they are considered members of the genus *Homo*, their taxonomic classification is debated. Some traits (such as the cranial capacity) overlap with *H. habilis*, other traits are more similar to *H. erectus*, and still others may merit a new species designation - *H. georgicus* (Rightmire et al. 2006).

By 1.6 Mya, a number of fossil hominin sites can be found outside Africa, reaching as far east as Gongwangling, China (Zhu et al. 2015); however, they do not have Acheulean lithic technology. Rather, these earliest migrants out of Africa used the same Oldowan technology made for the preceding million years (Carbonell et al. 2010; Gabunia et al. 2000; Swisher et al. 1994). This observation is surprising since the onset of the Acheulean coincides with the first dispersal of hominins, one could assume that technological innovation facilitated this migration.

Towards the end of the Acheulean, signs of technological change appear. Specifically, Later Acheulean tool kits may include Levallois technology. Levallois is a prepared core method for creating standardized flakes or blades that require little to no retouching. Early examples of Levallois technology are found in Africa as early as 500 kya (Porat et al. 2010), and in Eurasia by 325 kya (Adler et al. 2014)

The next development is the Middle Stone Age (MSA), which ends the Early Stone Age / Lower Palaeolithic. MSA lithic assemblages are similar to the preceding Acheulean Industry, and may still include handaxes. However, in the MSA large cutting tools are replaced by triangular flakes and retouched points (Willoughby 2007). A characteristic MSA (also called Middle Palaeolithic outside of sub-Saharan Africa) assemblage include few formal categories, with basic retouched tools including scrapers and points, with variable amounts of Levallois tool production (Klein 2000; Willoughby

2007). Olorgesailie in Kenya has the earliest known MSA, which may be as old as 320 kya and has Levallois technology, pigment exploitation, and faunal assemblages showing a widened range of prey (Brooks et al. 2018; Deino et al. 2018).

The first anatomically modern humans appear at approximately the same time as the earliest MSA. Jebel Irhoud, in Morocco, currently has the oldest fossil evidence of *H. sapiens*, with recent excavations recovering at least five individuals from a layer dated to approximately 315 kya (Hublin et al. 2017). The bone fragments show a mix of archaic and derived features. However, a statistical analysis shows that these remains fall within the range of modern human traits rather than Neanderthal or *H. erectus* (Hublin et al. 2017, p. 291).

Just as with the emergence of Early Stone Age technology, the MSA appears to develop first within Africa before spreading outwards. A number of *Homo* species existed during the MSA including *H. sapiens*, *H. neanderthalensis*, Denisovans (Reich et al. 2010), *H. floresiensis* (Sutikna et al. 2016), and *H. naledi* (Dirks et al. 2017). However, we are the only one of these species that remains. During the MSA / MP, humans were somehow able to persist in a way that other species could not, and this unknown factor appears to have been the difference between survival and extinction.

The last relevant technological period, for the purposes of this overview, is the Later Stone Age (LSA). The equivalent time is known as the Upper Paleolithic (UP) in Europe and Asia, and begins approximately 30-50 kya. During this time, some populations of *H. sapiens* migrate out of Africa to inhabit Eurasia. Also during this time, contemporary archaic *Homo* (such as Neanderthals and Denisovans) significantly diminish or disappear altogether, though interbreeding left traces of their genes in our

DNA. New technological innovations of the LSA / UP include blade technology with abundant backed pieces and microliths, bone and ivory tools, long-distance exchange networks, structured use of domestic space, art, and personal adornment (McBrearty and Brooks 2000, p. 492; Willoughby 2007, p. 245).

The appearance of UP assemblages is associated with the first waves of *H. sapiens* spreading out of Africa and into Europe. The final stages of the European MP occur between 39 and 41 kya, associated with Neanderthals (Higham et al. 2014). In Europe, UP modern human culture replaces MP Neanderthal culture, though some argue that Neanderthals may also have developed UP technology. A series of transitional industries in the European early UP have been the subject of debate for many years, with some researchers saying they are evidence of modern human expansion, and others saying they are evidence of *in situ* Neanderthal cultural evolution. Here I will briefly summarize two such examples.

The Uluzzian technocomplex is one example of a potentially transitional industry, with some suggesting it was developed by Neanderthals (Peresani et al. 2016; Zilhão et al. 2015), and others suggesting it is a mark of the earliest arrival of modern humans (Douka et al. 2014). This industry is believed to be Neanderthal-created, based on two deciduous molars found in association with it. A recent re-assessment classified them as modern human (Benazzi et al. 2011), however the context of the finds is contested. The Uluzzian is geographically restricted to Italy and Greece, first appearing by 43,000-46,000 cal BP (Douka et al. 2014). Assemblages can be identified by a combination of MP / UP lithics with distinctive crescent microliths, bone tools, and marine shell beads (Peresani et al. 2016). The Uluzzian is always found sandwiched between MP and UP layers, indicating that both Neanderthals and modern humans both occupied these same places, so either could plausibly be responsible for the creating the assemblage.

The Châtelperronian is another industry that may be transitional. Found in France and northern Spain from 44-40 kya, this industry is the subject of debate, being either the product of Neanderthals or modern humans. At the Grotte du Renne, Châtelperronian tools and ornaments have been found in association with Neanderthal remains. However, advances in radiocarbon dating allowed for a re-examination of archaeological finds from the site, finding significant variation in dates within levels, indicating stratigraphic mixing (Higham et al. 2010). Even though Welker et al. (2016) conducted genetic sequencing and found that the Grotte du Renne hominin remains had Neanderthal mitochondrial sequences, the link between the bones and the Châtelperronian material culture cannot be ascertained at this time.

Recent research has exposed strong evidence that Neanderthals were at least capable of Upper Palaeolithic-like culture. Previous evidence has been heavily debated, and included abstract carvings (Majkić et al. 2017; Rodríguez-Vidal et al. 2014), structures (Jaubert et al. 2016), and shell containers for mineral processing (Zilhão et al. 2010). However, the recent findings of Hoffman et al. (2018) of Neanderthal cave art seem to provide definitive evidence. They published Uranium-Thorium dates for three cave sites in Spain (La Pasiega, Maltravieso, and Ardales), that predate the entry of modern humans into Spain and therefore could only have been created by Neanderthals. Dates were obtained by sampling carbonate crusts precipitated out of mineral rich water; carbonate that formed overtop of artwork gives a minimum possible age, while dating carbonate behind the artwork gives a maximum age. The La Pasiega artwork is a red scalariform (a curvilinear zigzag) design, which has a minimum age of 64,800 years ago (Hoffmann et al. 2018, p. 913). It should be noted that only one portion of the La Pasiega scalariform had an ancient date, other dates were significantly younger (3-12 kya), suggesting that the work was begun by Neanderthals but elaborated or refreshed over thousands of years by modern humans. The Maltravieso work is a red hand stencil, dated to a minimum of 66,700 years ago (Hoffmann et al. 2018, p. 913). Ardales has a series of connected stalactite forming an undulating curtain of carbonate, which not only has red colouring visible on the outermost layers but a small break in the carbonate reveals at least one additional underlying layer of red. The ages for Ardales in conjunction with the multiple layers of colouring indicate a tradition of cave art that occurred in this location sometime between 32,100 and 65,500 years ago (Hoffmann et al. 2018, p. 913).

Debates continue about whether Neanderthals could have evolved to produce the full range of UP culture, but in general, Eurasian UP sites are associated with modern humans while MP ones are associated with Neanderthals. There is no evidence that modern humans created MP assemblages in Europe. These are firmly associated with Neanderthals. In Africa, on the other hand, *H. sapiens* created both the former and latter assemblages. As discussed above, the transitional industries are not definitely associated with either moderns or Neanderthals.

The two most famous African LSA complexes showing technological amplification are the Still Bay and Howiesons Poort. These are precocious industries found in South Africa, the presence of which appears and disappears between 59 and 77 kya. Leaf-shaped points, bone tools, engraved ochre, and marine shell beads (Henshilwood and Dubreuil 2011; Wadley 2007) characterize Still Bay, the earlier of the two industries, while the later-dating Howiesons Poort consists of backed geometric microliths, bone tools, hafting technology and engraved OES (Lombard 2005). Both of these industries hint at a new stage of social and intellectual development, but disappear after a few thousand years. Meanwhile, in Europe and Asia, there are no known equivalents for the cultural amplification seen in South Africa.

The technological developments of the Still Bay and Howiesons Poort are notable, but the most significant factor is the appearance of a new class of artifacts that was previously absent: beads. Prior to this time, artifacts were for survival purposes, helping to procure necessities such as food, shelter, or clothing. There were likely decorative elements that don’t preserve in the archaeological record, such as scarification or body painting. Ochre is a likely candidate for colouring clothing, skin and hair for symbolic purposes, however ochre also serves a number of functional purposes such as hafting adhesive (Wadley et al. 2009; Zipkin et al. 2014), fire making (Heyes et al. 2016), sunscreen (Rifkin et al. 2015), and insect repellant (Rifkin 2015). While ochre appears to have been used in the distant past, its presence at a site cannot be immediately associated with decoration in the same way a bead can. Another potential decorative colouring is charcoal, but finding charcoal is not considered to be evidence of aesthetic behaviour. The creation of beads, on the other hand, is clear evidence for investment in non-subsistence activity. The evolution of symbolic ornaments could indicate a cognitive reorganization, such as the breakdown of specialized knowledge in favour of fluid intelligence, or they could signal complex social behaviours, such as syntactic language, social hierarchies or kinship systems. For now their evolution remains an enticing mystery, however they are unique in the archaeological record as the first signs of purely social technology.

The earliest beads

The oldest known beads are perforated mollusc shells from the MP / MSA of southern Africa, northern Africa, and the Near East (e.g. Bouzouggar et al. 2007; d'Errico et al. 2005; Vanhaeren et al. 2006). Despite this large geographic range, all these early beads share remarkably similar forms. They all retain the natural external shape of the shell, and some bear natural perforations that render them ready-made beads. Shells that were naturally perforated but worn as beads may be distinguished from ecofacts by the presence of smoothed edges, or wear facets within the aperture. Figure 1 shows the relative spatial distribution of the earliest shell beads and the earliest OES beads, and Table 2 lists these finds and their ages.

Blombos Cave in South Africa is probably the most famous site to produce Stone Age shell beads. A total of 68 perforated *Nassarius kraussianus* shells were recovered from levels at Blombos dated to 75 kya (d'Errico et al. 2005). The presence of aquatic shells is expected, as Blombos Cave was never more than 3 km from the coast, even during MSA times. However, the *N. kraussianus* species is specific to estuary environments, which are transition zones between rivers and oceans, and the nearest suitable riverine habitat is located 20 km away from the cave. This distance makes it unlikely that the shells are the result of a natural accumulation. In addition, only adult

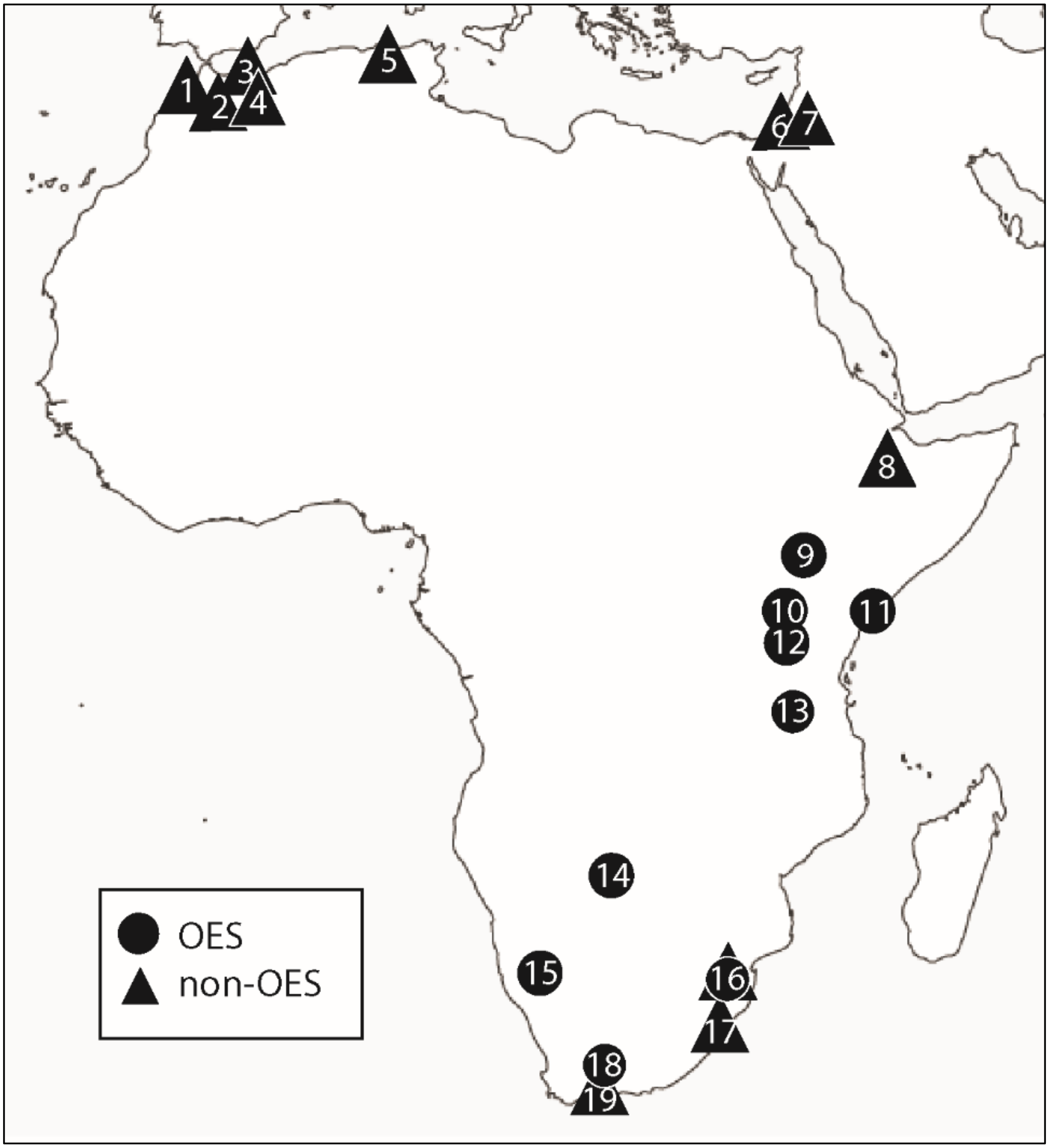

Figure 1. Sites with the oldest archaeological beads, as mentioned in text; 1-Contrebandiers, 2- Ifri n'Ammar, 3-Taforalt, 4-Rhafas, 5-Oued Djebbana, 6-Skuhl, 7-Qafzeh, 8-Porc Epic, 9-Enkapune Ya Muto, 10-Mumba, 11- Panga Ya Saidi, 12-Kisese II, 13-Magubike, 14- White Paintings Shelter, 15-Apollo 11, 16- Border Cave, 17-Sibudu, 18-Boomplaas, 19-Blombos.

Table 2. Sites with the oldest archaeological beads; numbers correspond to Figure 1.

Site	Approx. Age	Type of shell	Reference(s)
1.Contrebandiers	12-137 kya	marine gastropod	d'Errico et al. 2009
2.Ifri n'Ammar	83-130 kya	marine gastropod	d'Errico et al. 2009
3.Taforalt	82.5 kya	marine gastropod	Bouzouggar et al. 2007; d'Errico et al. 2009
4.Rhafas	60-80 kya	marine gastropod	d'Errico et al. 2009
5.Oued Djebbana	90 kya	marine gastropod	Vanhaeren et al. 2006
6.Skuhl	100-135 kya	marine gastropod	Vanhaeren et al. 2006
7.Qafzeh	96-115 kya	marine bivalve	Bar-Yosef Mayer et al. 2009
8.Porc Epic	34-40 kya	land snail opercula	Assefa et al. 2008
9.Enkapune Ya Muto	40 kya	OES	Ambrose 1998
10.Mumba	52 kya	OES	McBrearty and Brooks 2000
11.Panga Ya Saidi	25 kya	OES	Shipton et al. 2018
12.Kisese II	40 kya	OES	Tryon et al. 2018
13.Magubike	47-50 kya	OES	Miller and Willoughby 2014
14.White Paintings Shelter	26-32 kya	OES	Robbins 1999
15.Apollo 11	20 kya	OES	Vogelsang et al. 2010; Wendt 1976
16.Border Cave	74 kya, 38 kya	marine gastropod, OES	d'Errico et al. 2012; d'Errico and Backwell 2016
17.Sibudu	60-70 kya	marine gastropod	d'Errico et al. 2008
18.Boomplaas	42 kya	OES	Fairhall et al. 1976; Miller et al. 1999; Vogel 2001
19.Blombos	75 kya	marine gastropod	d'Errico et al. 2005

specimens are at the site, suggesting that people selected and transported these shells. Fifty-nine of the shells have microscopic use wear visible in the apertures, and all have perforations consistent with experimental piercing with a sharp elliptical tool (d'Errico et al. 2005, p. 15). The distinctive traces of natural shell perforation, including decalcification and predatory snails, are absent, leaving the most parsimonious explanation that a human collected, transported, pierced, and strung these shells.

While Blombos is the most prominent MSA bead site, there are other lesser-known South African sites with similar finds, such as Border Cave and Sibudu Cave. Border Cave has an infant burial from Howieson's Poort layers (dated at 74 kya) with a single shell (*Conus ebraeus*) bearing a perforation (d'Errico and Backwell 2016). The interred infant was excavated in the 1940s (Cooke et al. 1945), and subsequent attempts to directly date the bones and shell have provided mixed results, so the association with MSA levels is contested (d'Errico and Backwell 2016). Sibudu Cave yielded three perforated marine gastropod shells from MSA levels. The shells belong to the species *Afrolittorina Africana*, and date to between 60-70 kya. Experimental analysis is consistent with perforation from the inner surface of the body whorl, a feature which does not match predatory behavior of birds or crabs (who would puncture the shell from the outer surface), and suggests the perforations are anthropogenic (d'Errico et al. 2008, p. 2682).

At the opposite end of the continent, four sites in Morocco (northern Africa) have reported beads from MP contexts. Taforalt (aka Grotte des Pigeons) is located 40 km from the modern Mediterranean coast, but has marine shell present in archaeological layers, suggesting long distance transport. To date, 27 *Nassarius gibbosulus* shells have been recovered *in situ* from depositional Unit E (Bouzouggar et al. 2007; d'Errico et al. 2009), and nine additional shells were found in a presumed secondary context. Dating the upper and lower portions of the thick layer containing the beads constrains the age to between 60 and 92 kya, with a likely age estimate of 82,500 years (Bouzouggar et al. 2007, p. 9966; d'Errico et al. 2009, p. 16053). Rhafas Cave, also in Morocco, has five *Nassarius* shells from MSA levels. Similar to Taforalt, Rhafas is located 50 km from the coastline, strengthening the argument that these do not result from a natural accumulation. Only one of the five was recovered *in situ*, but associated artifacts and TL dating suggests an age of 60-80 kya (d'Errico et al. 2009, p. 16053). Ifri n'Ammar is another cave site, almost 60 km from the Moroccan coast. It has only two perforated shells, one belonging to the *Nassarius* genus and the other is unidentified. The date ranges for these beads are 83-130 kya (d'Errico et al. 2009, p. 16053). The final Moroccan site, Contrebandiers (aka El Mnasra I), is located directly on the coast, unlike the others. The dating at this site has proved to be a problem, therefore the single *Nassarius* bead recovered here may date anywhere from 12-137 kya (d'Errico et al. 2009, p. 16053). The low number of finds from Rhafas, Irfi n'Ammar, and Contrebandiers (a combined 8 artifacts) make their designation as beads uncertain, although one from Contrebandiers is described as having use wear.

Also in northern Africa, the Algerian site of Oued Djebbana has a single reported MP bead. Unlike the previously mentioned sites, which are all caves or shelters, Oued Djebbana is an open-air site located 200 km from the Mediterranean coast. Similar to the Moroccan beads, this artifact is a perforated *N. gibbosulus* shell. A single, non-finite radiocarbon date is all that is available for the context of the of the bead. However, based on its lithic association and similarities to the Moroccan MP beads, it is estimated to date at 90 kya (Vanhaeren et al. 2006, p. 1787). Although it is only a single specimen, the presence of this marine shell so far from the sea is compelling and suggestive of human agency.

Moving just outside of Africa, Skhul Cave and Qafzeh Cave in Israel have potential early bead use dating to the MP, but in even lower numbers than the northern African sites. While both date to the MP, they are considered to be among the earliest *H. sapiens* sites outside of Africa. Skhul Cave has one perforated shell found in its MP layers and it has been identified as *N. gibbosulus*, but since the initial publications, the classification of the shell has changed to *Tritia gibbosulus*. It was found in association with the remains of several human burials, one of which has been dated between 100 and 135 kya (Vanhaeren et al. 2006, p. 1786). A single perforated shell is hardly convincing of bead technology, but Skhul is currently 4.5 km away from the coast and was up to 20 km away during the MP. This long distance and the low food value of the small shell suggest that it had some significance. Qafzeh is even farther from the nearest coastline, being 40 km from the modern coast (Bar-Yosef Mayer et al. 2009, p. 310). Ten *Glycymeris insurbrica* shells were recovered (seven of which had perforations near the valve) from deposits dated between 96 and 115 kya (Bar-Yosef Mayer et al. 2009, p. 308). All of the shell perforations were determined to be of natural origin, but the authors argue that some perforations bear modifications from human use. The Skhul and Qafzeh shells are older, but not as widely accepted as the other MSA beads. While the low number of shells and natural perforations might be taken to indicate these are not beads, their distance from the coast and the shells' low food value strengthens the argument that they are genuine beads.

The Porc-Epic Cave in Ethiopia provides one example from the Horn of Africa. During the 1975-1976 excavation season, MSA levels at the site yielded more than 400 whole (and many fragmented) opercula, all of which appeared to be perforated in the center (Assefa et al. 2008). An operculum is a calcified disc found in some gastropods that can be closed to seal the organism within the shell, protecting it from environmental stressors and predators. The opercula from Porc-Epic's MSA layers belong to *Revoilia guillainopsis*, a land snail. Three of the opercula were directly radiocarbon dated, producing ages from 34-40 kya (Assefa et al. 2008, p. 747). Microscopic analysis of holes in the shells did not find proof of anthropogenic alteration, and there is evidence that taphonomic alteration could produce similar perforations. However, there is only a small amount of snail shell excavated at Porc-Epic, none of which appear to be from *R. guillainopsis*. The authors argue that a natural accumulation should produce a higher ratio of shell to opercula (Assefa et al. 2008, p. 753). This lack of other shell combined with some superficial use wear on the surfaces of the discs led Assefa et al. (2008) to conclude that the Porc-Epic opercula were naturally perforated beads.

These MSA / MP beads span a distance of more than 6,000 km, but all share the important similarity that they retain the appearance of the original shell. In these earliest examples, the species of shell dictated the outline of the ornament, with no further alteration. The shape of the shell was the shape of the bead, and even in cases where the shell has a fabricated perforation, it does not alter the silhouette of the ornament. There is no additional manufacturing involved in these examples, rather the bead is collected in its final form, with the only modification perhaps being the perforation. This feature is conceptually and methodically different than shaping a raw material into a bead, and an important contrast with the ostrich eggshell (OES) beads that appear at the end of the MSA.

By 50 kya, OES beads were produced in at least two places in eastern Africa. The oldest directly dated OES bead is from Mumba Rockshelter, in Tanzania. Amino Acid Racemization dated this bead at 52 kya (McBrearty and Brooks 2000, p. 522). The challenging stratigraphy at Mumba (see Prendergast et al., 2007; Gliganic et al., 2012) renders the bead's cultural affiliation uncertain, meaning that it is either terminal MSA or early LSA. The oldest OES beads that have been directly radiocarbon dated are from Magubike Rockshelter, also in Tanzania, and they are in association with MSA lithics. One preform and one completed bead at this site dated to 47,750 ± 750 BP and >50,100 respectively (Miller and Willoughby 2014, p. 120), demonstrating strong evidence that the tradition of OES beadmaking began prior to the LSA. Although not directly dated, there are also early LSA beads from Kisese II Rockshelter in Tanzania at 40,600 ± 1000 BP (Tryon et al. 2018, p. 6), and from Enkapune Ya Muto in Kenya at 39,900 ± 1600 BP (Ambrose 1998, p. 381). A recent publication by Shipton et al. (2018) notes that there are OES beads from the LSA of Panga Ya Saidi, a Kenyan site. They do not describe the finds or their context in detail, except to say that 70 of the 88 recovered OES beads come from Layer 8, which dates to 25 kya (Shipton et al. 2018, pp. 2–3).

Southern Africa also has OES beads, though they tend to be slightly younger than their eastern African counterparts. The oldest OES beads from the south are from Border Cave, South Africa, and are directly radiocarbon dated to 38,020 ± 1240 BP (d'Errico et al. 2012, p. 13217). There are also reportedly OES beads dating to approximately 42 kya from MSA levels at Boomplaas Cave, South Africa (Fairhall et al. 1976; Miller et al. 1999; Vogel 2001; see Chapter 3 for further comment). The next oldest southern African OES artifacts come from White Paintings Shelter in Botswana. They consist of a broken preform and a shaped disc, and both have been directly radiocarbon dated at 26,460 ± 300 BP and 31,880 ± 510 BP respectively (Robbins 1999, pp. 11, 13). Although the latter artifact does not appear to be a bead, it does show evidence of shaping, and there are one OES bead each in the layers above and below, suggesting that the capability existed in this period. Finally, the Apollo 11 Cave in Namibia has early OES beads. There are OES beads from the early LSA layers dated to 19,760 ± 175 BP (Vogelsang et al. 2010, p. 202; Wendt 1976, p. 6), and possibly addition specimens from older levels, but their stratigraphic context is unclear.

Although marine shell beads are the oldest known personal ornaments, OES beads have unique characteristics that make them important tools to understand Stone Age people. First, OES beads are the first ornaments to have a fully imposed shape. This means that the resulting bead does not resemble the original ostrich egg. The fragments of shell transform into something new. Previously the shells dictated the shape of the bead, but with the development of OES beads we see extensive shaping. Second, and perhaps even more importantly, OES beads are the first ornaments to be mass-produced, and show a degree of standardization. OES beads have always tended to be rounded discs less than 1 cm in diameter with a central perforation. The consistency in form is present from the earliest examples in eastern and southern Africa, to those produced and sold in tourist shops today.

Why is the evolution of beads significant?

Symbolic ornaments, including beads, evolved relatively recently in human history. For the first few millennia, our early hominin ancestors focused on immediate survival activities, and it was not until sometime after 100 kya that we have evidence that people began investing in ornaments. The driving forces behind the evolution of these artifacts, and the potential advantages their use afforded, are still being explored.

In this dissertation, and in human evolution studies in general, the term *symbol* is used broadly as a way to encompass a range of potential meanings. The American philosopher Charles Saunders Peirce famously distinguished three types of reference: iconic, indexical, and symbolic (Peirce 1894, as cited in Hardwick 1977). Icons imitate or otherwise bear some resemblance with the thing they signify, such as the Upper Palaeolithic paintings of horses at Lascaux Cave, France, that represent horses. Indexes point to their reference in time or space, the way that a cloud of smoke or the aroma of charcoal is connected to a fire. Indexes can also have a causal relationship, the way fire causes smoke. When the relationship between the object and its meaning is arbitrary, this relationship is symbolic reference. For example, the Chumash used marine shell beads as currency, in the Channel Islands 800 years ago (Arnold 2001), yet shell beads do not resemble or connect to the concept of currency. Stone Age beads appear on the surface to be symbolic references, but they may have simultaneously been indexes. Perhaps as certain people wore beads, the decorations gained indexical meaning through their physical connection with people of social status or power. The significance of the evolution of beads, in the context of my work, requires assenting only that they can stand for something else. It is not required that one understands the nature of connection between the object and its meaning. Therefore, for the purposes of this dissertation, the term *symbolic* will encompass any of the three Peircian levels, with the understanding that multi-layered meanings are likely.

Successfully transmitting a symbolic message from one mind to another requires that the receiver be equipped with a shared framework for interpreting the communique. Without this feature, the message will be misunderstood, or perhaps remain undetected. As an example, when I was a MA student conducting an archaeological survey in Alberta, I walked right past an axe-cut tree blaze without noticing it. A blaze is an anthropogenic mark left on a tree trunk after the removal of a wedge of bark / wood; historically, these have been used in heavily wooded areas to mark trail paths or property boundaries (Henderson 2014). I was brand new to archaeological surveying in Alberta, and I did not have the information needed to interpret the symbol, so I failed to recognize it as a message.[1]

Some research has suggested that from a cost-benefit perspective, symbolic ornaments evolved in response to a specific communication need. This idea is built upon the work by Hockett and Hockett (1960) that suggested communication can be described as a system with thirteen key design features. Similar to Hockett and Hockett, others (Gamble 1998; Kuhn and Stiner 2007a; Wobst 1977) have since worked backwards from the potential receivers of symbolic messages, to reason that personal ornaments are meant to communicate with socially distant, but culturally similar, strangers. These unfamiliar people from a shared culture would be able to decode the symbolic message, and would not already have access to the information through other means.

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[1] Subsequent to writing this, Andie Palmer brought to my attention that anthropologist Robin Ridington had written about a similar experience, in Ridington 1998.

Under this hypothesis, potential target audiences for communication through objects include the members of four near-distant levels of social relationships. The first group, those socially closest to the wearer, is unlikely to benefit from symbolic messages encoded in ornaments. This group includes household family and close friends who have direct, often daily communication with the wearer (Gamble 1998, p. 434). With this level of familiarity, the costs of producing decorative objects outweigh the benefits, and verbal information sharing would be far more efficient (Wobst 1977, p. 323). The next group is more socially remote, and includes distant relatives and acquaintances. These people comprise important material and emotional support systems, but do not have daily contact with the wearer (Gamble 1998, pp. 434–436). At this level, it is still more costly to use symbolic ornaments as communication, since any information would be more easily transmitted through other modes (Kuhn and Stiner 2007b, p. 42; Wobst 1977, pp. 324–325). The most likely audience for symbolic communication is virtual strangers from the same culture. These people are likely not directly familiar with the wearer, but they would be able to decode the transmission, and would otherwise not have access to the information (Kuhn and Stiner 2007b, p 42; Wobst 1977, p. 325). Based on studies of living primates, there is a direct link between neocortex ratio and social group size (Dunbar 1992, 1995); using the data as a predictive model, social group sizes 300-400 kya are estimated to total 150 individuals (Gamble et al. 2011, p. 119). Using material objects to communicate with members of this group seems to efficiently balance the costs and benefits, and the larger this category of culturally similar strangers, the more efficient symbolism becomes in comparison to other forms of communication (Wobst 1977, p. 326). At the farthest end of the spectrum are strangers from foreign cultures. Any symbolic communication would be lost on this group, as they would not have the social constructs to decode culturally specific messages (Kuhn and Stiner 2007b, p. 42; Wobst 1977, p. 325). The emergence of symbolic ornaments may represent a rise in the frequency and importance of stranger interactions (Rossano 2010, p. S94).

Kuhn (2014), who argues that the permanence, quantity, and cost of signals represent subtle transitions in human sociality, expresses an alternative view. He suggests that ochre powder can colour the skin easily, but is a temporary decoration that quickly reaches the maximum visual impact, and cannot be amplified further. This type of signaling would be best for coordinating small, egalitarian groups, and may have strengthened group identity and cooperation (Kuhn 2014, pp.45-46). On the other hand, beads are durable, and can be transferred between individuals (Kuhn 2014, p. 47). The earliest beads are made from local materials, bear minimal modification, and are found in low quantities rather than large caches. The permanence of the media, but low cost and impact, may suggest an emerging permanence in social roles, and an increase in social network size (Kuhn 2014, p. 47). Finally, the profusion of beads in the Upper Palaeolithic suggests an increase in social competition, large social networks, and economic stratification (Kuhn 2014, p. 47).

Perhaps it is possible to explore the evolution of beads by the type of messages they could convey. Three specific types of information that may have been conveyed symbolically in the Palaeolithic are ownership, social status, and group affiliation. These communications are important to people today, and it is worth exploring their significance in the Stone Age.

Decorative objects, or decoration *on* objects, can be symbols of ownership, connection, or affinity. This variation is not restricted to non-utilitarian items, but can include embellishments incorporated onto subsistence gear. Hockett (1973) proposed that it is only necessary to claim a possession when that item is in limited supply, and that there is no benefit in owning access to objects that were plentiful and readily available for everyone. Perhaps then, the emergence of decoration is linked with resource ownership, personalization, or commodification.

An archaeological example of ownership decoration (and possible ownership) is the engraved OES fragments at Diepkloof Rockshelter, South Africa. Broken pieces of OES with engraved patterns were recovered from Howiesons Poort levels at Diepkloof, dated between 58,100 ± 1900 BP and 63,300 ± 2200 BP (Texier et al. 2010, p. 6182). In ethnographic accounts, whole ostrich eggs have been used as containers to store liquids (Jacobson and Noli 2018; Schapera 1930; Silberbauer 1981), and these engraved fragments from Diepkloof appear to be early fragmentary examples of such items. OES containers are made by carefully pecking open one end of an unhatched egg, removing (and possibly consuming) the contents, and filling the empty egg with water (Lee 1979, p. 23; Schapera 1930). The hole can then then be plugged with grass or resin, and the egg may be buried in the ground to store and protect it for future use (Dunn 1931; Humphreys 1974a; Marshall 1976). OES containers from modern ethnographic accounts often have designs scratched into the surface. These scratches, made with a sharp implement such as a flaked stone, create a pattern by removing the thin cuticle surface to reveal the palisade layer. The contrast between the original cuticle and the exposed palisade layer is what makes the pattern visible, and ochre or other residue could be applied to the incised grooves to heighten the contrast. In this case, the OES container is a survival item that holds liquid, and the lines scratched into the surface of it are the decoration perhaps indicating commodification. The linear designs of the archaeological fragments at Diepkloof are remarkably similar to modern designs, and this observation supports the assertion that the OES container tradition has persisted since the MSA. For further discussion on OES containers, refer to Chapters 4 and 5.

Egalitarian societies, however may conceive of ownership differently than we do in a capitalistic economy, so inferences should be applied with caution. There are well-known ethnographic studies in South Asia where prestige and influence are gained by acting altruistically, and ceremonially redistributing wealth rather than stockpiling it (Mines and Gourishankar 1990; Sahlins 1963). Among the Ju / 'hoansi in sub-Saharan Africa, there is a cultural etiquette of "insulting the meat," when a successful hunt is met with indifference or displeasure (Lee 1984, pp. 56–58). This behaviour provides for the needs of community members while also helping to level egos. These cultural behaviours serve as obstacles against selfishness and wealth accumulation, while promoting communal well-being, as is typical of hunting and gathering societies. This observation suggests that the concept of ownership may be an important part of western society, but may not have been as important in the evolution of symbolism.

The emergence of social stratification supplies another potential explanation for the evolution of decorative objects. Sometime in the past, certain egalitarian communities shifted towards becoming vertically stratified societies with unequal distributions of wealth and power. In these groups, an individual could earn or inherit social regard, and wearing special garb would communicate and reinforce this status with the rest of the members. One of the earliest known archaeological examples of this development is from Sunghir, in Russia. This site is widely known for its elaborate burials dating from 22-24 kya, one of which contains two children, aged 9-13 years old (Pettitt and Bader 2000). Their burial includes lavish grave goods such as rings, bracelets and figurines carved from reindeer antler, ceremonial ivory spears, and over 13,000 hand-made beads. Estimates have suggested the beads would have taken between 3,000 and 10,000 hours to produce (Trinkaus et al. 2014, p. 25), demonstrating that these burials are a massive investment of time and resources. It would be unsustainable to invest this intensely for every group member, so this burial stands out as prestigious. The children from Sunghir are widely believed to represent the first proof of ascribed or inherited status. An earned or achieved status would have taken years or decades to develop, and the children would not have time to develop this reputation in their short lives (Trinkaus et al. 2014).

Finally, symbols can delineate, establish, and maintain group affiliation. Having access to a network of allies is an important form of social capital. Social capital is the ability to draw benefits from membership in a social network (Portes 1998, p. 8). By spending time and resources creating alliances, people invest in relationships that offer advantages such as protection, diverse marriage partners, long-distance trade opportunities, information transfer, and resource sharing in times of stress. However, maintaining extended social networks is not easy. It requires a high degree of communication, social maintenance, and conflict resolution. A group that cannot satisfy these demands will eventually fission, as the neglected relationships wane (Dunbar 1993, p. 687).

Using symbolic items is an effective mode of communication (Coward and Gamble 2008; Dunbar 1993), and thus a good way to maintain or accumulate social capital. Symbolic objects can themselves be powerful actors that exert agency upon people, as proposed in Actor Network Theory (see Latour, 2005). Unlike other methods of social maintenance (such as social grooming, gestural / postural signals, and auditory cues), a symbolic item communicates effortlessly over time and space (Coward and Gamble 2008). The receiver can obtain the message from some geographic or chronological distance from the sender. Further, if the information is encoded in a physical item (such as a decorative ornament), it continuously broadcasts the message with minimal constraints on audience size. Therefore, perhaps decorative ornaments evolved as a way to invest in social capital, which contributed to the success of some *H. sapiens*.

The reason behind the emergence development of decorative objects is unclear, but what is important is that decorative objects are non-survival related items that emerge shortly before *H. sapiens* expand out of Africa, and they are still widely used today. The manifestation of beads is a proxy for the internal states of Palaeolithic people, and I suggest that it illustrates the increased importance of communication and social networks. Further study into these important artifacts has potential to provide insight into the minds of Stone Age people, and into larger questions about human evolution.

Chapter 2- Literature Review, Theory, and Methods

Beads made from OES are present at many sites in sub-Saharan Africa, but they remain understudied in archaeology. In published literature, OES analysis has rarely moved beyond quantification, with most publications providing only a total count of beads, or perhaps average diameter. In this chapter, I provide background information on ostriches, an overview of the research that has contributed to OES bead examination, thoughts on theoretical frameworks that pertain to my research questions, and methodological tips for gathering OES bead data.

Ostriches

Ostrich (*Struthio camelus*) are imposing creatures. They stand approximately two meters tall, weigh up to 150 kilograms, and can reach top speeds of 60-70 kilometers per hour (Unwin 2011, p. 17). They are the largest living ratite (flightless bird) in the world, and the earliest fossil specimens are found 20 Mya in Namibia (William 2013, p. 7). There are currently four accepted sub-species of wild ostrich (*S. c. australis, S. c. camelus, S. c. massaicus,* and *S. c. molybdophanes*), all of which are restricted to the African continent today (Freitag and Robinson 1993).

The past distribution of ostriches is poorly understood, but evidence suggests they lived in Africa and Asia during the Pleistocene. Shells from ostrich eggs are extremely durable material that provides evidence for ostrich presence, though the bones rarely preserve. OES has been recovered from a number of contexts around Asia, and is assigned to the extinct species *S. asiaticus* that entered India approximately 60 kya (Blinkhorn et al. 2015).

Ostriches are generally herbivorous, but not fussy eaters. They will eat a variety of plant species, a trait that makes them suitable for a wide range of habitats from semi-desert to dense woodland (Jarvis et al. 1985, p. 442). Although plants are their food source, ostriches may also ingest small amounts of bones or shells, perhaps as a source of calcium, and small stones to aid the breakdown of plant matter (Milton et al. 1994). The majority of their water requirements are fulfilled from plant material, although during the dry season when plants are desiccated ostriches may cluster around water sources (Milton et al. 1994, p. 244).

Ostrich groups usually consist of one cock (male) and a dozen or more hens (females). Reproductive activity peaks just before the rainy season, however ostriches are opportunistic breeders and in the wild they may produce eggs throughout the year in six week intervals (Jarvis et al. 1985, pp. 447-448). A main hen and several minor hens will lay their eggs communally in a hollow that they scratch into the ground, with the main female's eggs in the center and the other hens eggs on the margin (Williams 2013, p. 45). The number of eggs in a clutch can range from less than ten to more than twenty (Jarvis et al. 1985, p. 442), however when there are too many eggs then they cannot all be properly incubated, and those on the periphery will not hatch (Williams 2013, p. 46). Those eggs that don't hatch may be broken open and have their contents eaten by the breeding ostriches (Williams 2013, p. 51).

Ostrich eggs are creamy white in colour, with variable gloss and texture, and all three attributes are somewhat affected by the feeding habits of the ostrich (Prynne 1963, p. 81). An ostrich egg weighs 1-2 kilograms (or 240 g when emptied), takes 90 minutes to hard boil, and is equivalent to two dozen chicken eggs (Kandel 2004, pp. 381-384;

Williams 2013, pp.117-118). Previous researchers (e.g. Cooper et al. 2006; Blinkhorn et al. 2015) have suggested that OES can be distinguished by sub-species based on slight differences in pore structure, size, and density. These structures are believed to vary in order to create optimal conditions for the developing embryo, and would therefore change depending on environmental conditions. Unfortunately, there is rarely enough surface area on OES beads to assess pore characteristics.

Previous studies of OES beads

While reporting the presence of OES beads is important to understand their distribution, in this section I only include those published works that have moved beyond quantification and contributed to the analysis or understanding of OES beads. The first formal OES bead analysis is by Plug (1982). In this work she describes finds from the upper 18 levels of Bushman Rockshelter, South Africa, which date to the late Pleistocene (Plug 1982, p. 57). Even though there were no standards for OES bead analysis, Plug manages to report on traits that are significant in later studies, such as a preference in the upper layers of the site for trimming blanks before drilling, and for drilling prior to trimming in the site's lower layers (Plug 1982, p. 60). She also describes the aperture shapes as they relate to direction of drilling with a preference for biconical apertures drilled from the inner surface (Plug 1982, p. 60). Plug also records mean external and aperture diameters of completed beads at 5.3 mm and 1.9 mm respectively (Plug 1982, pp. 60–61). Publishing these observed traits was well ahead of the time, but Plug had no way of knowing how these would be useful.

Later that same decade, Jacobson (1987a, 1987b) published what I consider to be the most important early works on OES beads. In these papers, he examined the changing archaeological assemblages as herders migrated into Namibia, eventually displacing or incorporating the existing hunter-gatherer populations. The article observes assemblages from seven archaeological sites (Lower Numas Cave, Orabes Lower Shelter, Zais, Eros, Geduld, Wortel, and Kuiseb) which span approximately the last 5000 years. Jacobson worked to classify sites based on the associated lithics, pottery, and OES beads as either hunter-gatherer, herder, or transitional.

As part of his study, Jacobson measured and compared the diameter of OES beads between the three types of sites. Using maximum diameter measurements for completed beads, he identified a trend of an increase in mean diameter of nearly 2 mm between hunter-gatherer and herder beads. This is to say that hunter-gatherer beads, which come from older contexts, are smaller on average than herder beads from younger layers. Rather than being consistently larger, the younger beads have a wider range of diameters which skews the average upwards, with no hunter-gatherer bead larger than 7.5 mm (Jacobson 1987a, p. 57).

Jacobson suggests that the diameter changes may represent cultural variations. He explains that OES beads are particularly well suited for stylistic analysis, more so than lithics, as the morphology of a stone tool is constrained by function or raw material, adding difficulty to inter-site comparisons. Ostrich eggshell beads, however “have been made from a uniform raw material over the entire subcontinent and can thus be used in comparative studies with some confidence,” according to Jacobson 1987a (p. 57).

Over the next 20 years, Jacobson’s work was expanded upon by Smith et al. (1991, 1995, 2001), Sadr et al. (2003), and Orton et al. (2005). These subsequent studies examined sites around South Africa, which span the shift from hunting to herding economies. The studies ultimately confirm the general presence of diameter change between hunting and herding sites (the boundary being at approximately 2 kya), but find that the nature of the change varies between sites. They are unable to determine the reason for the diameter change, but confirm that OES bead diameters do change over the transition to herding in southern Africa. Bead diameter is still the most commonly analyzed characteristic.

The introduction of herding to southern Africa marks an important transition in OES bead diameters, so it is necessary to contrast it with the introduction of herding in eastern Africa, which is slightly earlier. Signs of pastoralism first appear in Africa approximately 8 kya, when sheep and goats (non-endemic species) enter North Africa via the Near East (Marshall and Hildebrand 2002). Pastoralism spread southward, moving rapidly across the Sahara and first reaching eastern Africa by 5 kya (Hildebrand et al. 2018). However, the uptake of herding was patchy, and lasted from 5000 to 1500 years BP, with some areas not realizing animal management until the Iron Age (Bower 1991). During the time that pastoralism is slowly spreading in parts of eastern Africa, it is also migrating towards southern Africa, reaching the sites studied by Jacobson, Smith and Sadr by 2000 years BP. So, in order to examine bead diameters across the transition to herding in eastern Africa, it is necessary to use a slightly earlier time frame.

Returning to the literature on OES, the next major development in bead analysis came in 2005 when Kandel and Conard published a set of standards for evaluating OES bead manufacture. They use the term *production value* as a way "to quantify the degree to which a group of beads has reached the endpoint of manufacture," (Kandel and Conard 2005, p. 1713). Production values range from zero (an unmodified piece of OES), to twelve (a broken bead). The numbers alternate between broken and unbroken artifacts. For example, Stage Three is a "*complete*, partially drilled blank", and Stage Four is a "*broken*, partially drilled blank" (Kandel and Conard 2005, p. 1714). For a full description of Kandel and Conard's production stages, refer to Appendix A.

Their reason for creating this typological analysis is to test a premise put forth by Jacobson (1987a) that links production stages, site activities, and length of occupation. Jacobson posits that women are the primary makers of beads, and that beads are likely made in spare time after daily activities are completed. Therefore, sites which are very short term or where women are absent (such as a kill site) would not be expected to have bead preforms but may have completed beads (Jacobson 1987a, p. 57). On the other hand, a long term camp site would have a much higher ratio of preforms, since women would be present with free time for craft production (Jacobson 1987a, p. 57).

To test Jacobson's premise, Kandel and Conard (2005) apply their production value analysis to data from the Geelbek Dunes of the Western Cape, South Africa. The Geelbek Dunes of today are highly mobile sand dunes, however in the past this area was a more stable and suitable place for hunter-gatherers. Twenty-three sites were excavated, revealing deposits which range from MSA to modern (Kandel and Conard 2005, p. 1711). These sites are all open-air localities with unknown amounts of disturbance.

Some initial lithic and faunal analysis by Kandel and Conard supports Jacobson's model of site activity and intensity; other analyses seem to oppose his model. Production values were calculated for four of the seven excavated sites, as they had statistically relevant numbers of beads. The sites of Pottery, Shelly, Nora, and Toaster yielded production values of 9.08, 6.26, 3.91, and 7.82 respectively (Kandel and Conard 2005, pp. 1716–1717). If Jacobson's model is correct, then the Pottery site (which has the highest production value) should be a short-term site, such as a kill area or transit camp. However, Pottery includes a hearth, working surfaces, faunal bones, shellfish, and a rich concentration of lithics with diverse raw material, suggesting that it was more than merely an overnight camp or meat processing area. The site of Nora has the lowest production value of the group, which should represent a long-term camp or aggregation site in Jacobson's model. This assessment seems to work, as Nora has a central hearth around which intensive lithic knapping took place, and there are some faunal and shell remains scattered around the site. These mixed results suggest that Jacobson's model is incorrect, incomplete, or the Geelbek Dune sites are too disturbed for this type of analysis.

In 2008, Orton improved upon the production value scheme by including alternative sequences for bead manufacture. Orton used ethnographic documentation of OES beadmaking strategies and incorporated them into a comprehensive scheme, which expands the previous method by describing alternative sequences for bead manufacture. He refers to these variants on bead manufacture as "Pathways". Pathway 1 beads are perforated before having their outer diameter shaped, while Pathway 2 beads are shaped into circular forms first and then the aperture is drilled. For a full description of Orton's production stages, refer to Appendix A.

There are different numbers of stages in Kandel and Conard versus Orton, so it is not a simple one-to-one translation between them. Kandel and Conard outline twelve production stages, while Orton uses seven with I being a "modified OES fragment" and VII being a "completely ground" bead (Orton 2008, p. 1766). Rather than alternating between broken and unbroken beads as Kandel and Conard do, Orton leaves them as the same stage, followed by either an "a" for unbroken, or "b" for broken. Stage VIa and VIIb are described as having their external edges "partly ground" (Orton 2008, p. 1766). This feature exists somewhere between Kandel and Conard's Stages 9 and 11.

Orton (2005) applies his production stages, along with traditional OES bead analysis, to five bead-rich sites in the Northern Cape of South Africa. Three of the sites (Jakkalsberg L, M, and N) are open air sites located within the floodplain of the Orange River, northwestern Richtersveld, with radiocarbon dates ranging from 1740 ± 75 to 4500 ± 50 BP (Orton 2008, p. 1770). The remaining two sites (KN2005 / 067 and SK2005 / 057A) are located on the Namaqualand coast, south of the Jakkalsberg sites. Similar to the Orange River sites, these coastal sites are also open air but are currently undated. The sites vary in occupation duration and intensity, but each is described by Orton (2008, p. 1770) as a "bead factory."

Similar to the work by Kandel and Conard (2005), Orton (2008) compares his findings to Jacobson's (1987a) model of site intensity and bead manufacture. The presence of bead preforms at short-term sites in the Geelbek Dunes is in opposition to Jacobson's 1987a hypothesis. Whereas Jacobson (1987a) predicted preforms at long-term campsites, where women would work on beads during extra time, Orton offers that unfinished preforms may have been transported from place to place, to be completed when time permitted. This explanation would mean that OES bead manufacture could potentially take place at any site where people had spare time, and beads would not necessarily be finished in one sitting at one location.

A 2015 publication by Wilmsen summarized the bead size debate, and challenges the previous assertions that bead size corresponds to cultural groups. Wilmsen seeks to explore the effect that taphonomic processes play on bead diameter. Using modern OES eggs, he measured the thickness of different parts of the shell, and found a range from 1.74-2.14 mm within a single shell (Wilmsen 2015, p. 93). To examine how taphonomic processes after deposition might artificially thin the shells, Wilmsen soaked modern OES beads in vinegar and measured the resulting changes in shell measurements. After submerging beads for several hours, both the thickness and the diameter shrunk by an average of 0.12 and 0.36 mm respectively, while the aperture diameter grew by 0.13mm. The vinegar bath, which mimicked an acidic depositional environment, began decalcifying the OES carbonate, leading to the loss of some of the original surfaces (Wilmsen 2015, pp. 94–95). Towards the close of the article, Wilmsen measured a variety of bead diameters from ethnographic garments, and found that the type of garment (necklace, headband, apron, leather bag) was a better predictor of bead size than age. He concludes that bead size is “a function of a complex interplay between a shell’s original chemical structure, environmental influences pre-and post-bead fabrication, and a bead maker’s original intent,” (Wilmsen 2015, p. 99). Therefore, bead diameter alone cannot accurately serve as a marker to distinguish assemblages produced by hunting and herding groups.

Dayet et al. (2017) re-examined the Bushman Rockshelter bead assemblage that was previous described by Plug (1982). This collection has early Holocene beads on a variety of media, including OES, *Achatina*, bone, and marine shell. The authors highlight the lack of attention to bead analysis, and suggest more in-depth investigations into bead technology, use wear, and pigment traces through the use of scanning electron microscopy, elemental analysis, and Raman molecular analysis. They re-assess the production stages of Kandel and Conard (2005) and Orton (2008), and come up with their own production stage system loosely based on the previous works. They use additional attributes not previously considered to describe production stages, including edge profile, edge circumference, and striations on edge and faces (Dayet et al. 2017, p. 640). For further comment on their proposed system, refer to the Laboratory Methods section of this chapter.

Over the last ten years, a series of English language articles on an OES assemblage from a UP site in the People's Republic of China have been published. Shuiddongo (SDG) is an open-air site complex located near the junction of the Yellow River and the Great Wall, and is one of the oldest known Late Palaeolithic sites in China. It was first excavated in the 1920s, and subsequently between 2003 and 2008 (Wang et al. 2009, p. 3887). The upper layers of sediments at the site have been OSL dated to 12,000 ± 1,000 BP (Wang et al. 2009, p. 3893), with the lowest OES bead-bearing layers dated to 27,200 ± 1500 BP. The shell microstructure, pore arrangement, and canal system of the shells indicate they are from a species of now extinct ostrich, *Struthio anderssoni* (Wei et al. 2017; Yang et al. 2016). Publications on the site include a description of the sizes and production stages of the beads (Wang et al. 2009), a microCT investigation of the drilling techniques (Yang et al. 2016), and a description and experimental study of use wear and production traces on the beads (Wei et al. 2017).

Wang et al. (2009) reported on 109 OES fragments, 54 of which bore traces of bead manufacture. All fragments appear to correspond to Pathway 1 manufacture, with the aperture drilled prior to the outer shaping (Wang et al. 2009, p. 3891). Most stages of manufacture were present, with 50% of the assemblage being Stage I that are potentially unmodified. The external diameters of Stages IVa to VIIb range from 1.52 to 3.74 mm (Wang et al. 2009, p. 3893). Unfortunately, Wang et al. (2009) did not publish the diameters of finished beads. Instead, likely due to the low number of finished beads, they grouped their mean external diameters and reported Stages V, VI and VII together. This presentation makes it impossible to compare their findings to those in Africa, as in the latter the standard is to report only Stage VIIa diameters. Interestingly, while the inclusion of unfinished beads likely skews the results larger than if only finished beads were included, the averages are still on the small when compared to those from African sites.

Previous studies have mentioned that perforating drilling often takes place from the inside of the OES, noting that it is softer and thus an easier place to initiate drilling (e.g., Plug, 1982; Kandel and Conard, 2005; Orton, 2008). Wang et al. (2009) used Scanning Electron Microscopy (SEM) to further illustrate why this preference exists. Their SEM photos show that the outer surface of an OES is relatively uniform even under extremely high magnification, making it smooth, slippery, and difficult to start drilling. The SEM image of the inner surface, however shows regular indentations, which allow the drill bit to gain traction. In some experimental drilling, Wang et al. (2009) discovered that the drill was more likely to slip, and more likely to break the OES upon perforation when drilled from the outside rather than the inside. They conclude that early humans chose to drill from the inside, having learned to minimize breakage through experimentation.

Yang et al. (2016) examined the drilling technologies of Holocene beads at SDG with a study that employed synchrotron radiation micro computed tomography (SR-μCT). They suggest that SR-μCT technology is a non-destructive way to assess the microstructure, drilling marks, and perforation shape of archaeological OES beads. By comparing the characteristics of experimentally drilled perforations to archaeological perforations, Yang et al. (2016) seek to distinguish between hand-held twisted drilling, and multi-rotary drilling (accomplished with a bow drill or pump drill).

The experimental perforations scanned with SR-μCT rendered both positive and negative 3-D models of the apertures, and these models were used for analysis. The authors describe that asymmetrical apertures that appear waved or fluted on the inner walls are the result of hand-held drills, while a smooth and circular perforation is the result of multi-rotary drilling. When comparing these results to the SR-μCT scans of the archaeological beads, Yang et al. (2016) find that both hand-held and multi-rotary drilling techniques are present in the SDG assemblage.

Wei et al. (2017) conducted further work on the morphology and manufacture of the SDG beads. Experimental drilling showed that some materials are unsuitable for creating perforations in OES. In particular, the drill bits made from bone, wood (including fire hardened wood), and horn were unable to make a significant dimple before becoming worn down and too dull to continue (Wei et al. 2017:89). Of the materials used in the study, only the lithic drills were able to perforate the OES, suggesting that ancient bead makers used such drills.

The archaeological SDG beads have a polished appearance which led Wei et al. (2017) to question whether they had been intentionally ground smooth as part of their production. Experiments produced mixed results, with grinding on sandstone, granite, and volcanic rock all leading to the eventual loss of the mammillary layer. Grinding with quartzite and slate partially damage the mammillary layer, but do not match the wear on the archaeological beads. To simulate natural weathering, Wei et al. (2017) soaked modern OES fragments in a 10% acid solution for 3-6 minutes. This result was the closest match for the taphonomic damage on the beads, but did not create the polished sheen observed on the SDG beads. The authors concluded that beads at the SDG site may have been polished by natural corrosion and / or involuntary friction against clothes or skin, but alternatively could have been slightly ground and then rubbed against leather to produce a sheen.

Wei et al. (2017) describe eight bead types (named A through G), based on a suite of characteristics for the 78 beads from SDG2. The characteristics include type of drilling (hafted or hand turned), direction of perforation, overall bead shape, presence of chipping scars, and intensity of polish. Five of the beads do not fit into any of the eight categories, although two appear to group with existing types when considering a scatterplot of perforation diameter against bead diameter. Wei et al. (2017) surmise that types A, B, and G are beads produced by skilled artisans who have mastered drilling and shaping, types C and H were produced by people of an intermediate skill level, and types D and E represent the work of an amateur bead maker. They further clarify that type F beads could be type D beads (amateur) that have undergone intense wear, or they may be a unique group. For further comment on these bead type groupings, refer to the "Laboratory methods" section of this chapter.

In sum, it appears that OES bead analysis is in a period of relative infancy, especially when compared to lithic or faunal analyses, with minimal previous research and no clear guidelines for data collection. In my opinion, this situation is because very little research has focused on OES beads themselves. The most commonly reported variable is diameter, followed closely by production value, but there is ample room for future work including experimental studies on production (see Werner and Miller, 2018), and use wear.

Why do artifacts vary, and what does this mean?

The ultimate goal of my project is to examine regional and temporal variations in OES beads as a window to the Stone Age social boundaries. The previous research documenting OES bead variation has not explicitly stated a theoretical approach, but much of it uses variation in bead forms through time as evidence. It is necessary, then, to briefly explore why artifact variation occurs, and how archaeology can use it to detect underlying population structures.

Cultural variation, or the "differential persistence of alternative traits through time" (Teltser 1995, p. 53), can be observed by examining one kind of artifact through time or space. Variation is *stylistic* when the alternatives are selectively neutral, meaning that the performance of each variant confers equal fitness (Neiman 1995, p. 8). On the other hand, variation is *functional* when alternatives confer differential success (Neiman 1995, p. 8). Therefore, an example of stylistic variation would be incised decoration around the rim of a ceramic vessel, while functional variation could include vessel shape or material.

People from the same community will tend to do things in the same styles, and one framework examining the propagation of cultural traits is Social Network Analysis (SNA). This is not a formal theory, but a strategy originating in Sociology that examines relationships within and between populations (Otte and Rousseau 2002, p. 441). It seeks to visualize, describe, and explain societal behaviour by reducing a social network to a cluster of nodes, connected by links or ties. These links represent the relationships by which information, resources, and influence flow from one node to another. In a perfectly connected system, every node is directly tied to every other node but in larger social systems this is rarely the case. According to SNA, the links between nodes create webs of interactions, and this is the governing structure of social order in a society.

SNA is particularly useful in archaeological research because its definition of *network* is flexible. The network can be scaled up or down to suit the needs of the study, so a node can represent a range of social entities varying from a single individual, employees of a company, members of a religious congregation, or citizens of a country. SNA is such an adaptable model because the importance is on the relationships between nodes and the cultural backdrop, rather than the properties of individual actors (Wellman 1999; Wetherell et al. 1994).

While SNA often aims to identify and study the relationships within a network, it also indicates that there would be detectable distinctions between networks. SNA posits that nodes with common relationship ties will become more similar over time, and the more ties they have in common, the faster they will homogenize (Borgatti et al. 2009, p. 894). By contrast, then, nodes from different networks should become more dissimilar over time, and as two populations diverge, drift and innovation will shape the cultural norms of each new group (Neiman 1995). The more geographic or temporal distance between two networks, the more distinct their norms should be. Today, probably very few networks are completely isolated, as it is so easy to travel long distances or to communicate with people who are far away and outside of one's close network. However, in the ancient past, connections between networks would have been constrained by distance.

The Isolation by Distance (IBD) model describes the inverse relationship between gene frequency and geographic distance within a breeding population (Wright 1943). The math is complex, but the idea is simple: organisms that are close together will share more genetic similarities than those who are farther away. This feature is because organisms that are close together will have more opportunities for genetic transmission, leading to more genetic similarities in offspring.

As with SNA, Isolation by Distance applies to cultural material as a model for variation. Cultural similarities between two populations may be due to convergent evolution (similar adaptations due to similar pressures), inheritance through ancestry (knowledge is passed from elders), or horizontal transmission (learning through inter-group interaction) (Collard et al. 2006; Crema et al. 2014). Cases of convergent evolution should occur only for selectively advantageous traits, whereas neutral traits including stylistic variation will occur from inter or intra group cultural transmission. Inheritance through ancestry seems like it would only have a temporal component, but it can also have a geographic factor caused by migration or fission. Spatial variation in stylistic cultural elements may be a function of either transmission within groups (branching) or between groups (blending). Determining whether branching or blending played a role in past populations is still being explored, however it is accepted that the likelihood of two unconnected cultures sharing a specific, stylistic variation is directly related to their degree of interaction.

Although I do not subscribe to a particular theoretical approach, I draw upon characteristics of both SNA and IBD as they apply to stylistic variation. These two approaches provide an intuitive framework for the interpretation of OES bead styles. SNA explains why similar traits would propagate through network ties, while IBD rationalizes that geographically distant cultures have less opportunity for shared stylistic traits and therefore more variation is expected. For example, the sudden introduction of new styles, such as the larger bead sizes in southern Africa, may represent the introduction of a new social network of migrants. Variables shared over large distances could indicate social connection through trade or migration, while regional clusters of traits may suggest isolated populations with distinct stylistic signatures. SNA and IBD provide the freedom to consider various social explanations while seeking regional and temporal variations in OES beads.

Laboratory methods

As discussed in this chapter, very few publications outline tips or techniques for OES bead analysis. With limited literature to guide me, the methods I employ for this dissertation were largely refined through first-hand experience. In my MA thesis, I recorded the standard characteristics, as well as a host of others of my own design, resulting in a potential maximum of 34 characteristics recorded for each specimen, although some derive from comparisons of the same characteristics (e.g., minimum diameter, maximum diameter, average diameter, ratio of minimum to maximum diameter). My Master's research focused on a single collection of OES beads, and although the collection spanned approximately 17,000 years, it provided a limited view of the potential variations in OES beads. For my dissertation research, I wanted to continue collecting the full suite of variables from my previous research, but also to refine my descriptions and consider additional characteristics.

This list of characteristics that I recorded as part of this research is extensive, and I do not believe that all traits were useful in this thesis. My reason for creating such a gratuitous trait list is that I could not predict which characteristics would be significant until I processed the data. By being as comprehensive as possible, I attempted to record the highest quality data to identify regional or temporal sequences of characteristics. The list of traits can then be reduced in future studies after data analysis has identified significant traits.

Appendix A contains a full description of all bead variables recorded during my data collection. I coded my qualitative variables with numerical values, so they are quantifiable in statistical software. Here I used IBM's Statistics Package for the Social Sciences - SPSS. It is important to be explicit when describing the anatomy of OES beads, since no systematized language exists. For this reason, Figure 2 describes the basic OES shell structure, and bead terms used in my analysis are shown in Figure 3.

The list of traits in Appendix A is similar to my MA data collection, but updated in a few ways. First, I added intermediary grading for some of the qualitative variables. Rather than just being present or absent, certain features such as surface patina may be now be described as absent, weakly present, or strongly present. Accompanying each grade is a thorough description of the visual characteristics for assessment. Second, in an effort to limit bias in my data collection, I refined some of the characteristics from my MA. For example, I removed the *well-worn* variable. That term, adopted from other published OES bead research, implied details about the life history of that bead which may or may not be true. It relied upon intuitive ideas of what a well-worn bead might look like without any supporting experimental or observational data. It also does not specify how long a bead must be worn to be considered well-worn. Further, I suspect that use wear would be highly influenced by the display configuration of the beads. For example, those strung back to back on a single string would experience different wear than those in a staggered, brick wall-like pattern, and different still would be those beads sewn flat onto clothing. The instinctive classification of well-worn is therefore not descriptive of all use-wear patterns.

Based on my experience analyzing artifactual OES beads, I have developed some useful tips for data collection, which I will outline here in the hope they may aid novice bead researchers. I encourage taking a photographic record of the beads, including original labels, prior to any analysis or cleaning. This record will be useful to refer back to, however if time is constrained, then I often skip this step. My data collection uses equipment that is typical for archaeological research, such as a binocular microscope, digital calipers, and a Munsell Soil Color book. Any prolonged handling of the OES should be conducted while wearing gloves (latex, nitrile, or cotton) to limit the transfer of skin oils or other contaminants to the artifacts. I prefer cotton curatorial gloves because they are more comfortable to wear for long periods, and they are washable. I typically wear one glove on my left hand, leaving my right hand free to hold tools, adjust the microscope, or take notes. Typical tools include nylon tipped tweezers, bamboo skewers, and digital calipers. Nylon tipped tweezers are excellent for manipulating beads because their tips provide flexibility while still keeping a firm grasp on the bead.

I begin every analysis with a visual inspection of the bead under a binocular microscope. The purpose of this procedure is to assess the structural integrity of the shell, and to identify ochre or other substances that would require special consideration. Sometimes a coating of sediment obscures analysis and a light cleaning is required to reveal the surface characteristics. When the bead's integrity permits, cleaning should begin first with the least aggressive technique (e.g., a soft brush or camera lens blower). I prefer using a hog bristle brush with a wooden handle, as these are inexpensive and work well for cleaning off hardened sediment. They are durable and firm, but also gentle enough not to damage the surface of archaeological OES. After loosening sediment with a brush, I use the lens blower to move away any loosened particles. It's a good idea to hold the bead in place with a tool or gloved finger while using the lens blower, as aggressive squeezing can cause the OES beads (which are very lightweight) to take flight.

If further cleaning is required to document surface features, use extreme caution. I do not advise that people who are inexperienced with OES (or other delicate archaeological materials) attempt this type of cleaning, and I strongly suggest this cleaning take place under a binocular microscope to monitor for signs of surface damage. Although I keep metal dental tools and bamboo skewers in my cleaning kit, these should not be scraped against the artifact. Nothing more aggressive than a hog bristle brush should rub the surface of an archaeological OES bead or preform. I have found the best way to remove lingering hardened sediment is to press gently with the tip of a bamboo

Figure 2. Cross-section of OES, showing layers.

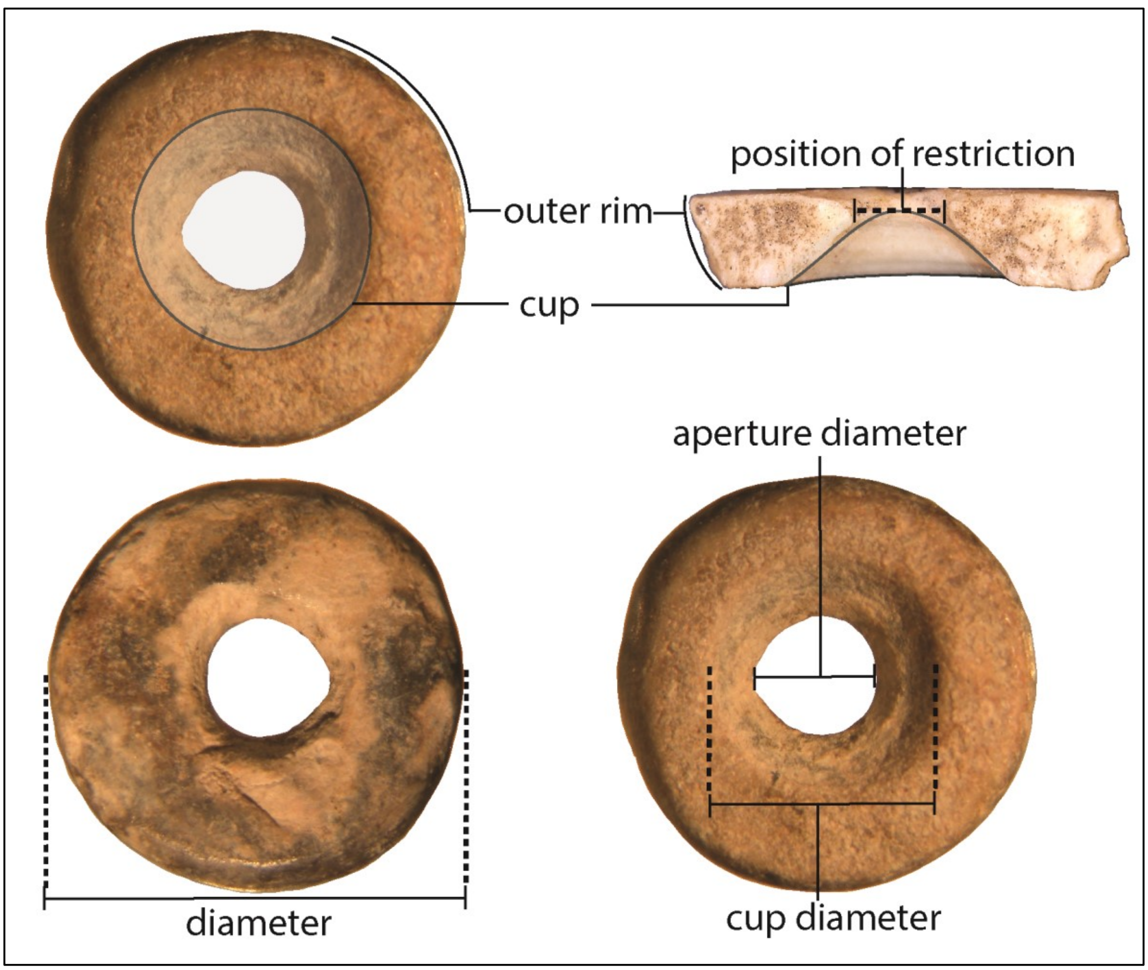

Figure 3. Commonly used OES bead terms.

skewer (or dental implement) against the sediment at an oblique angle. Be prepared to immediately stop applying pressure if the sediment loosens, and lift the tool so it doesn't scrape against the surface of the bead. The sediment, if able to be removed, will eventually flake away under the pressure of the tool, without the tool having to touch the surface of the bead itself. Clean only as much of the bead as necessary for analysis, and leave the rest of the sediment adhered.

Measurements of bead diameter and shell thickness can be recorded with calipers. For my dissertation research, I purchased a pair of Toolway 70401 digital calipers, which are relatively inexpensive, and register measurements to one hundredth of a millimeter. Using my gloved hand to hold the bead, I take a series of measurements for each characteristic, recording only the lowest and highest measurements, to two decimal places. Some researchers have commented that plastic calipers are better to use than metal calipers, as they are less likely to break breads during analysis. I have exclusively used metal tipped calipers and have not experienced breakage while measuring thickness or diameter. However, if plastic calipers are available, then it seems wise to use them.

Existing debates about bead size (outlined in this chapter) are relevant only for beads that have reached the end stage of manufacture, so it is important to distinguish and record the production value of each specimen. I record production value for every OES artifact with both Kandel and Conard's (2005) and Orton's (2008) systems, as each provides different benefits. Kandel and Conard's scheme works well with the statistics software I use, as the categories are all numerical. Orton's system is important because it records the presence of different manufacture Pathways. In this dissertation, unless otherwise indicated, my discussion of bead diameters is limited to those in Orton's stages VIIa / VIIb, or the Kandel and Conard equivalent stages 11 / 12.

There were a few instances in which the two schemes did not agree on whether the specimen was a completed bead, and in these cases I used Orton's system as the deciding factor. Orton distinguishes completed beads from those still in the production sequence by the presence of "use polish" (Orton 2008, p. 1768), while Kandel and Conard (2005) suggest that the form of the bead (specifically how finely shaped it is) indicates the end stage. Orton does not further define what use polish looks like, or where it should occur, so I have taken it to mean smoothing / patina around the outer rim and / or within the aperture at the position of restriction. In this dissertation, any bead with such smoothing or patina present is deemed as completed, even if it was not finely shaped.

For all discussions relating to diameter, unless otherwise stated I use the average individual bead diameter measurements. These are obtained by calculating the average of the highest and lowest diameter measurements. In addition, whenever possible I included the diameters of completed but broken beads (Orton Stage VIIb, or Kandel and Conard Stage 12). When a completed but broken bead had at least 50% of its circumference remaining, I record the maximum width, and use that instead of average diameter.

As described earlier in this chapter, Dayet et al. (2017) proposed a new classification system for scoring production value. Although it incorporates characteristics similar to those I recorded, I choose not to use this model. First, it is based on beads from a single site, with a narrow time range, which provides a limited view of the potential variation in bead manufacture, which may not be widely applicable. In fact, the Bushman Rockshelter collection has some unusual traits that do not appear in other collections I examined (see Chapters 4 and 5 for further discussion on this topic). Second, their model is not based on any experimental or ethnographic manufacturing data. They decide that the presence of use wear should be re-defined as “the presence of lustrous areas covering all parts of the beads,” (Dayet et al. 2017, p. 639), a feature which is a significant improvement upon the non-existent use-wear description by Kandel and Conard (2005) and limited description by Orton (2008). However, by ignoring those beads that lack lustre, Dayet et al. (2017) may be disregarding taphonomically altered beads, such as those deposited in an acidic environment. Further, the intensity and location of lustre is likely related to the stringing pattern, type of garment, or duration of wear, and therefore not reliable as an indicator of use. If the existing two models of production methods are to be reworked it should be with an increased scientific rigor and supporting data. I agree with their call for improved analyses on Palaeolithic beads. However, I cannot support their production value model as a replacement for the Kandel and Conard (2005) or Orton (2008) guidelines.

Aperture diameter and cup diameter may be accurately measured from microscope photographs, and should never be measured with the prongs of digital calipers. In my MA, I experimented with ways to record aperture diameter accurately and without risking harm to the beads. The safest and most accurate method I found is to take a microscope photo (with a visible scale bar), then use image software such as the freeware program ImageJ to measure lengths in the photo. This procedure eliminates the potential for breakage during aperture measurements, and provides significantly higher accuracy than other techniques. This procedure would potentially also be useful for measuring external diameter, and when I cannot assess beads in person, I employ this technique.

In order to document the colour of OES, I prefer using the Munsell colour system. It is a standardized scheme used to describe archaeological soil and sediment colours, using three descriptors (hue, value, and chroma). The Munsell Soil Colour Chart (*Munsell Soil Color Charts* 2000) works surprisingly well to record the colours of OES beads. The Munsell Bead Colour Book (*Munsell Bead Color Book* 2012), however is not useful for organic beads. The only OES colours which do not match well with the Soil Colour Chart are the iridescent blue / black that comes from intensive heating in an oxygen reduced environment, and the pale cream / white colour of the natural shell (5.0Y 9 / 2 – Pearl) that is rarely present in archaeological OES beads. From observation while examining collections and an experimental heating project (the results of which were presented in a conference paper in 2012), I can verify that the colours created from heating exist in a gradient (see Figure 4). In that experiment, I sought to recreate the range of colours observed in archaeological beads through the application of heat, and to test whether heat that penetrates sediments is sufficient to alter OES colour after deposition. Ultimately, I found that the application of heat to OES creates a seamless gradient from the natural egg colour through black, and that the unintentional transfer of heat through sediments is enough to alter the colour of OES. I also found that using common-sense colour terms such as “light brown”, “pale brown”, and “tan-orange” are highly subjective, and promote inter-observer error. Archaeological OES is deserving of the same treatment as any other site data, and its colour can provide important data, including insight on the taphonomic history of the site. While the results of my

Figure 4. Experimentally heated ostrich eggshell; photos by Dr. K. Waterhouse.

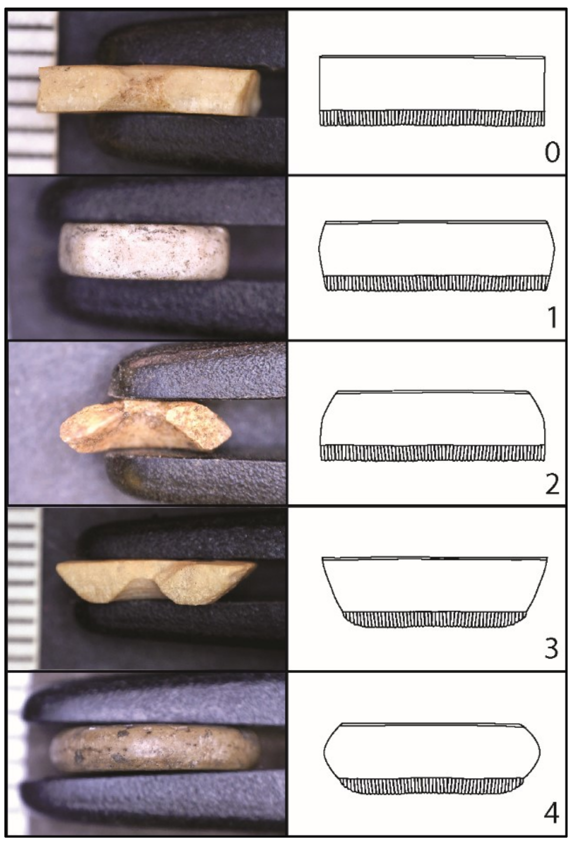

Figure 5. Examples of the Outer Rim Donut Index scoring.

conference paper were never published, Collins and Steele (2017) came to similar findings.

It is important to note that the Munsell chats should be used in natural daylight, since light wavelength can affect the appearance of colour, however bead analysis typically takes place indoors, often in back rooms which purposely limit access to natural light. This problem can be remedied by adding a daylight or full spectrum light bulb to a desk lamp.A category that I had not developed in my MA work is a standardized description of the outer rim profile shape. In my dissertation, I classify the outer rim of beads and preforms with a characteristic I lightheartedly call the Outer Rim Donut Index. The reference to donuts is because pictures of OES beads, especially in conference posters, have been mistaken for donuts. Figure 5 visually demonstrates the differences between categories, and a text description of each is in Appendix A.

The study by Wei et al. (2017), summarized in this chapter, outlined a classification system that grouped their OES beads into eight types, however I have chosen not to adopt this system in my own analysis. I believe these authors have unknowingly introduced an assumption that dilutes the explanatory power of their system. They assume that the end goal of OES bead production is always a perfectly circular, finely shaped bead, and any other type fell short of the goal due to a lack of skill. While perfectly circular and finely shaped beads may be visually pleasing, I believe the claim that this was always the goal is unsupported. For example, if Stone Age artisans were creating beads for trade or wealth generation, then they may have sought to create as many beads as possible, in as short a time as possible, to minimize labour and maximize return. This practice could lead to the intentional creation of beads that were less well rounded and less polished, which would require less manufacturing time compared to perfectly smoothed and shiny beads. Wei et al. (2017) also assume that the quality of the finishing relates to the skill of the bead maker, but there may not be a direct connection between level of finishing and skill. An experienced artisan may produce many poorly finished beads in the same amount of time that a novice produces a few finely finished ones. Further, Wei et al. (2017) assume that the intended audience of the beads always prefers circular, shiny, well-shaped beads. It is equally plausible that it didn't matter if the beads had these characteristics, because at most distances the distinction is negligible. An archaeological example of this factor was recorded by Plug (1982, p. 61) who noted that there seem to be a variety of accepted bead finishes based on the infant burial at Bushman Rockshelter, which contained beads which were trimmed but not ground to shape. Wei et al. (2017) based this classification system on beads from the SDG2 site, where bead diameters range from 5.5 - 9.5 mm. I suggest that it would not be possible to distinguish between finely or poorly shaped beads of this size from a distance. The diameter ranges of the SDG2 beads are equivalent to a type font size between 16 and 28. General guidelines for advertising (and for academic posters) suggest that text of this size is legible from 0.7 to 1.5 m away. Although beads and fonts are not interchangeable, I suggest that details of beads that are under 1 cm in diameter may not be visible beyond a few meters away, and that fine shaping was not necessarily a crucial feature of OES beads.

Despite the data collection forms being as exhaustive as possible, I still encountered beads which had unexpected characteristics that my variables did not account for; this makes the photographic record a crucial part of the data. Moving

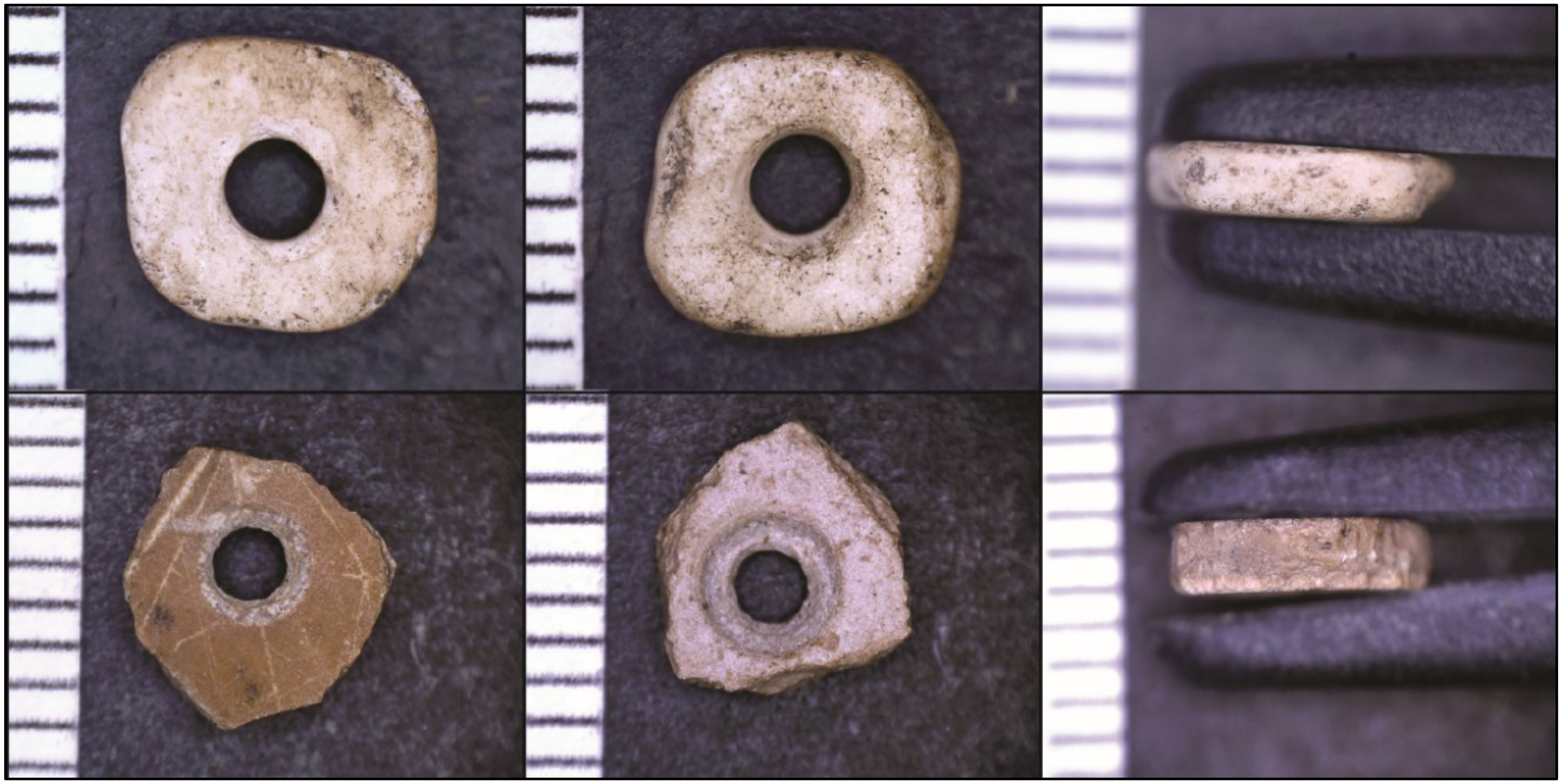
Figure 6. Example of OES bead inventory photos; cuticle surface on left, mammillary surface in center, shell profile on right.

forward, as a best practice for creating a record of the beads and preforms, a minimum of three photos of each specimen should be captured. For photographing beads during my dissertation, I purchased a Celestron Digital Microscope Pro, with an adjustable height stand. The three pictures should be taken vertically (top down) rather than at an oblique angle, and consist of the cuticle surface, the mammillary surface, and at least one picture of the profile view (see Figure 6 for examples). I obtained the profile photo by holding the specimen gently with nylon tipped tweezers, one tong against the cuticle surface and the other against the mammillary surface, and turning the bead so the edge of the shell is towards the camera. For consistency, I suggest the profile photo always be taken in the same orientation, with the cuticle surface of the shell towards the top of the image. The cuticle and mammillary surface photos should have a photo scale visible in the picture, as this scale will allow accurate digital measurements to be taken later of the aperture diameter and cup diameter. The technique I used does not have an appropriate photo scale, so thickness measurements cannot be accurately recreated from these pictures.

This chapter has demonstrated that although the study of OES beads is still under development, these small artifacts show promising interpretive value. Bead form, manufacture, and use wear are stylistic traits that are highly influenced by cultural norms, a feature that makes OES beads excellent candidates to document cultural variation through the Stone Age. The past 30 years of research into OES beads has made significant strides, but a larger scale approach is required to understand the full range of variation. With my research, I hope to highlight the concealed significance of OES beads to studies of human evolution.

Chapter 3 – Overview of OES Bead Collections

In the preceding chapter, I reviewed the existing OES bead analysis and found no systematic study of OES bead forms through the LSA. The publications, specifically those from 1987 to 2005, discussed a pattern of diameter change that occurs around 2 kya, coinciding with the time when the southern African archaeological record shows a transition from hunter-gatherer to herding economies. These studies were limited in scope to the western portion of southern Africa between 150 and 5000 years ago. The use of OES beads, however extends at least 50,000 years into the past, and no systematic study of bead diameters from 5000 – 50,000 years has taken place. Further, there has been no exploration of bead sizes from other regions, such as eastern Africa.

My doctoral research project builds upon the foundation of the previous research, and explores OES bead variation from a broader perspective. There are two interrelated goals to my study. The first is to explore bead diameters beyond the geographic and temporal limits of previous work in an effort to document and interpret the range of variation. The second is to search for characteristics in addition to diameter that may also vary over time or space. Prior to seeing the range of bead and preform variation, there was no way to predict which characteristics would vary, if any, so creating an analysis that encompassed as many traits as possible was crucial. Expanding upon the analysis I developed during my MA, I recorded an extensive number of characteristics for each bead, and took digital microscope photos for later reference.

This chapter is an overview of the bead collections I examined (or sought to examine) as part of this dissertation. To explore the temporal variation in OES, it was important to seek out the oldest well-dated collections. There are currently nine sites with reported OES beads older than 20 kya, across five countries, detailed in Table 3. I was able to examine collections from six of these sites, as well as an additional four collections that are not as old but presented themselves as good opportunities.

My dissertation research draws data from 2570 OES artifacts from eleven collections in Kenya, Tanzania, Botswana, Namibia, and South Africa. A further two collections (specifically Kathu Pan 5 and Boomplaas Cave, both in South Africa) were intended to be part of my study, however upon my arrival at their respective museums the collections could not be located. Nevertheless, I include them in this chapter as they are significant sites and their assemblages should be part of the discourse for future studies. To correspond with the map in Figure 7 showing the location of each collection, I will discuss each one from roughly north to south.

Kenya

Enkapune Ya Muto Rockshelter

Enkapune Ya Muto (EYM), also known as Twilight Cave, is famous for its ancient OES beads. Located in the central Rift Valley of Kenya, EYM rockshelter (SASES number GtJi-12) has more than five meters of deposits spanning portions of the Middle and Later Stone Age, as well as the later occupations (Ambrose 1998, p. 380). It appears that only two seasons of excavation (1982 and 1987) were conducted at EYM, however they yielded OES beads from the early LSA.

I was able to collect data from the EYM assemblage through access to photos, but never examined the beads in person. Initially I intended to visit the collection so I began

Table 3. African sites with OES beads older than 20,000 cal BP; (*) denotes a directly dated bead.

Uncalibrated Years BP	Age (cal BP)	Site	Reference(s)
*ca. 52,000	-	Mumba Rockshelter, Tanzania	Gliganic et al. 2012; McBrearty and Brooks 2000, p. 522
*>50,100	-	Magubike Rockshelter, Tanzania	Miller and Willoughby 2014, p. 120
*47,750 ± 750	*49,355-46,368	Magubike Rockshelter, Tanzania	Miller and Willoughby 2014, p. 120
39,900 ± 1600	47,664-41,819	Enkapune Ya Muto Rockshelter, Kenya	Ambrose 1998, p. 383
40,600 ± 1000	46,170-42,660	Kisese II Rockshelter, Tanzania	Tryon et al. 2018, p. 6
*38,020 ± 1240	*44,856-41,010	Border Cave, South Africa	d'Errico et al. 2012, p. 13217
ca. 42,000 years		Boomplaas Cave, South Africa	Fairhall et al. 1976, pp. 225–226; Miller et al. 1999; Vogel 2001
31,480 ± 1640	41,031-33,187	Kisese II Rockshelter, Tanzania	Deacon 1966, p. 26
*31,810 ± 180	*36,748-36,189	Magubike Rockshelter, Tanzania	Miller and Willoughby 2014, p. 120
26,960 ± 760	28,750-25,550	Mumba Rockshelter, Tanzania	Mehlman 1991, p. 182
*26,460 ± 300	*31,381-30,552	White Paintings Shelter, Botswana	Robbins 1999, p. 11; Robbins et al. 2000, pp. 1100–1101
*20835 ± 75	*25,300-25,030	Panga Ya Saidi, Kenya	Shipton et al. 2018, p. SI-11
19,760 ± 175	24,190-23,046	Apollo 11 Cave, Namibia	Maggs 1977, p. 185; Vogelsang et al. 2010, p. 202; Wendt 1976, pp. 6–7

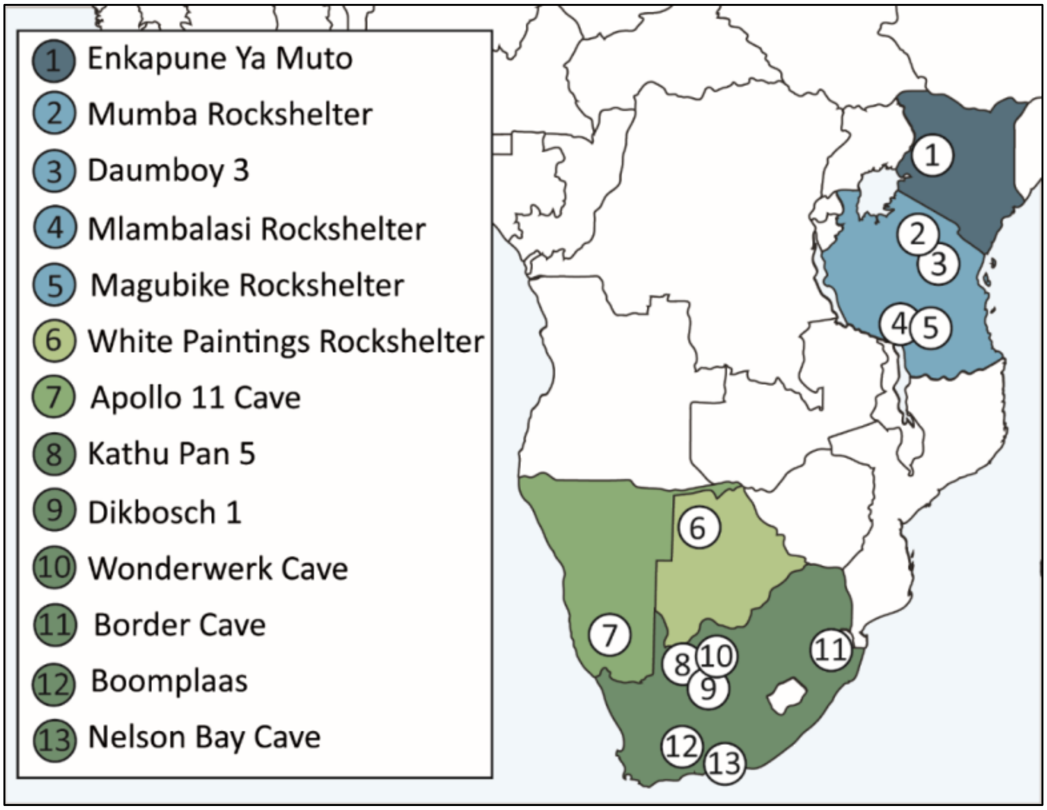

Figure 7. Location of sites mentioned in this chapter.

contacting the original excavator (Dr. Stanley Ambrose, University of Illinois), determining the current location of the collection (National Museum of Kenya), and looking into the permit process in Kenya. However, once travel plans began coming together, I made the financially motivated decision not to travel to Kenya to study this single collection. Some time later, I learned from my colleague (Dr. Philip Slater) that he had taken digital microscope photos of the beads during a visit to the National Museum of Kenya. Both Dr. Ambrose and Dr. Slater gave me permission to use the photographs to gather data for my research, however Dr. Ambrose asked me not to use the images in my dissertation, or any other works, as he is preparing his own publications on the EYM assemblage that includes many of the photos.

The EYM assemblage, based on the photos I received, consists of 111 OES artifacts, and a few bone beads. Of the OES artifacts, 31 are preforms, and 80 are completed beads. Interestingly, there are no completed and broken beads in this assemblage, which is very unusual. I wonder if this absence may be a bias of the collection methods, or perhaps these are present but not photographed by Slater. Two of the 111 artifacts do not have their provenience listed on the photo, so I am unable to determine what level they came from. The majority of the other 109 beads come from four levels, separated by tens of thousands of years. Seventy three percent (n=81) of the OES artifacts at Enkapune Ya Muto come from levels RBL2.1 and RBL2.2, which range from 3110 ± 70 BP to 5265 ± 220 BP. The remaining 20 OES artifacts (18% of the total) were recovered from levels DBL1.3 and DBL1.4 which date to 37,000 ± 1100 BP and 39,900 ± 1600 BP, respectively (Ambrose 1998, p. 381).

I was able to extract some data from the EYM collection, however it should be more thoroughly described in the future. The photos available to me consist of a single picture per bead, showing a view of one surface (usually the cuticle surface). With these pictures, I was unable to subject the EYM assemblage to my full range of analysis, so they are not fully comparable to the other assemblages. In addition, by not receiving permission to use images or likenesses of the beads in my dissertation, I cannot portray the unique variations in manufacture and form that are visible to me in several of the pictures. This collection deserves further attention, and I look forward to reading the upcoming work by Dr. Ambrose.

Tanzania

Mumba Rockshelter

Located in the north of Tanzania, Mumba Rockshelter is probably the most famous MSA site in the country. Excavations began there nearly 100 years ago, and have continued into the present, revealing a rich continuous archaeological sequence from the MSA through the Iron Age. Margit Kohl-Larsen originally excavated the site in 1938, as she and her husband Ludwig Kohl-Larsen travelled around Africa doing amateur archaeological work (Kohl-Larsen 1943). Work was resumed at the site in the late 1970s and early 1980s by Dr. Michael Mehlman (1989) as part of his PhD research, and then again in the early 2000s by a team including Dr. Mary Prendergast, Dr. Manuel Dominguez-Rodrigo and Dr. Audax Mabulla (Prendergast et al. 2007). The stratigraphy at Mumba is challenging, and despite the long history of research there, the depositional sequence remains poorly understood.

Weiß (2000) analyzed a portion of the OES beads recovered from the earlier Kohl-Larsen excavation for a Master's thesis at the University of Tübingen. The beads in her analysis (n=1780) were all recovered from geological Bed III in arbitrary 20 cm spits. Recently, a re-dating of the site gave an OSL age of 36,800 BP for the lower levels of Bed III (Gliganic et al. 2012, p. 545). The dates for upper levels of Bed III were less certain, and indicated that they may date to as recent as 1,000 years ago (Gliganic et al. 2012, p. 545). Therefore, the beads from Bed III may represent occupations over a span of 36,000 years. Ultimately, in her analysis of the bead diameters, Weiß (2000) finds that there is no apparent change in diameter through the excavation spits.

Work resumed at Mumba in 2005, in an effort to clarify the depositional sequence. The results of this excavation are presented in Prendergast et al. (2007) and Gliganic et al. (2012). I contacted Dr. Prendergast (Saint Louis University) to request information about the beads, and found out they were currently on loan to her. After conferring with her co-investigators, Dr. Prendergast permitted me to analyze the Mumba collection.

I examined 65 preforms and 125 OES beads from Units 5, 6, and 8 of the 2005 Mumba assemblage. All stages of manufacture are present. Unit 5 has the most finds, yielding 140 OES artifacts, however this number is predictable as it is the deepest of the three excavation units, reaching a maximum depth of 263 cm below surface (Prendergast et al. 2007, p. 231). The deepest OES artifacts from these excavations appear to come from Bed III-8. Bed III spans three geological layers, as described in Prendergast et al. 2007, and a charcoal date for upper Bed III is 844 ± 78 BP (Prendergast et al. 2007, p. 219). However, Mehlman (1987, p. 141) previously reported a radiocarbon date on OES from lower Bed III at 26,900 ± 760 BP, and Gliganic et al. (2012, p. 543) reported an OSL date of 36,800 BP for a similar area. So, the oldest OES beads from the 2005 Mumba assemblage seem to come from early LSA levels, and are therefore important to this study.

Daumboy Rockshelter 3

Daumboy Rockshelter 3 (DMB3) is part of a shelter complex on Daumboy Hill, Tanzania. Approximately one kilometer southeast from the Ufana River, the surface scatter of potsherds and lithics at DMB3 looked promising for excavation. Prendergast et al. (2013) explored it as part of a study on Pastoral Neolithic sites in the region. This collection was not one that I sought out, but the opportunity to study it arose when I was communicating with Dr. Prendergast about the Mumba collection. She mentioned that she also had the DMB3 beads on loan, and was able to mail them to me for analysis.

Four separate excavation units were opened in 2012, with a number of radiocarbon dates available for the stratigraphic layers. The largest trench (Unit 4) was abandoned once it proved to be in a disturbed context. From the three intact trenches, a depositional sequence was determined, with six different layers (A-F) identified, although no single unit contained all six layers. Only 23 artifactual pieces of OES were recovered from the excavations, all came from layers A, C, or D. The lower portion of Layer A provided a date of 1120 ± 72 BP, Layer B is dated to 4060 ± 70 BP, and layer D is 9280 ± 25 BP. Pottery is found only in Layers A and B, suggesting that layers C-F predate the Pastoral Neolithic and belong to the terminal stages of the LSA.

The DMB3 OES collection is small, containing only 24 artifacts: thirteen beads and eleven preforms. Three of the preforms recovered cannot be attributed with certainty to a depositional layer and therefore their age cannot be estimated. However, more than half of the OES beads from DMB3 come from Layer D and therefore belong to the terminal stages of the LSA.

Kisese II Rockshelter

Kisese II is a rockshelter site located in the Kondoa District of Tanzania. Situated on a hillside overlooking the steppe, two large stone blocks make up the walls and roof of the shelter. A massive slab which may have once been part of the root is partially buried in the shelter floor (Inskeep 1962, p. 250). The shelter initially drew interest because of its red pigmented rock art which depicts wild animals in a naturalistic style.

The site was originally test excavated in 1951, and initial results were very promising, as there were at least 4.3 m of sediments, all of which bore cultural material (Inskeep 1962, p. 250). Further excavation by Inskeep in 1956 revealed deposits to a maximum depth of 6.1 m below surface (Inskeep 1962, p. 253). There were a number of hearth areas in the upper 1.5 m, however no other stratigraphy was identified as the sediment was consistent and dusty (Inskeep 1962, p. 253). Finds were dense in the upper 4 m, but began to peter out below that, with the lowest 2.1m of excavation yielding only sparse accumulations. At 6.1 m below surface, a large horizontal slab halted excavations. Inskeep (1962, p. 253) suggests this horizontal slab is the original surface of the rockshelter.

A series of four radiocarbon dates were obtained from a sequence spanning from the LSA to an intermediate LSA / MSA layer. A date of 18,190 ± 306 BP was obtained on a piece of charred OES from an LSA level (Deacon 1966, p. 38). An even older date of 31,480 ± 1640 BP comes from a piece of charred OES associated with a transitional LSA / MSA level (Deacon 1966, p. 33). The dated materials do not appear to have been artifactual, however it is implied that beads from the same layers should have similar ages.

Dr. Chris Tryon (Harvard University) and Dr. Kathryn Ranhorn (Arizona State University) recently renewed research on Kisese II by examining the previously excavated collections. In their recent publication (Tryon et al. 2018), they observed a subtle shift in diameter through time by measuring 1400 completed beads. The oldest OES beads at Kisese come from Level XX, which is dated at 40,600 ± 1000 BP, while the youngest are from Level I at 3870 ± 30 BP (Tryon et al. 2018, p.9). The stratigraphic levels and their associated dates are not homogenously distributed, rather they appear clustered around several long-term occupations, with lengthy hiatuses in between. For example, layers XI - XVIII all date between 33 and 40 kya, while Levels III – X date from 17 to 23 kya. There is a 12,000 year gap between Levels XI and X, and a 13,000 year hiatus somewhere between Levels III and I. The graph by Tryon et al. (p. 11) which plots the bead diameters against the excavation level is deceiving, as at first glance it appears to show a slow but consistent diameter shift over 40,000 years. If the units of the graph are adjusted to display years BP rather than excavation level, the plot will be quite different.

The Kisese II collection seemed like a well-suited addition to my research, however unforeseen circumstances ruled it out. Through email contact with the Head of the Collection Department at the National Museum of Tanzania, I received confirmation that the Kisese II collections are housed at the museum in Dar es Salaam, Tanzania. However, a colleague studying at the National Museum of Kenya later informed me that a portion of the Kisese collection (including OES beads) was stored there along with some human remains as part of an internment feature. This situation meant that to see the entire assemblage, I would have to travel to and arrange research permits from both Kenya and Tanzania. Given the difficulty of this situation, and the fact that Tryon had already recorded bead diameters, the Kisese II OES beads have not been included in my data, although a more in depth study of them would be useful in the future.

Magubike Rockshelter

Magubike rockshelter (HxJf-1) is located on the periphery of Magubike Village, in the Iringa Region of Tanzania. It consists of an angled granitic overhang at the top of a gently sloped hill. The majority of the site is poorly protected from the elements, and there are signs that (at least in some spots) rain water trickles down the underside of the roof and towards the rear of the shelter.

Magubike is currently under investigation by members of the Iringa Region Archaeological Project (IRAP), headed by Dr. Pamela Willoughby (University of Alberta). The site was recorded in 2005, and subsequent excavations occurred in 2006, 2008, 2012, and 2016. Magubike has evidence of occupation ranging from the historic Iron Age well into the MSA, and perhaps earlier. A number of exciting finds have been recovered from Magubike, including six fossil hominin teeth and a Sangoan-like trihedral pick. Findings consderning the hominin teeth were recently published (see Willoughby et al., 2018), however Magubike is probably best known for its OES beads (see Miller and Willoughby, 2014)

The majority of the Magubike OES collection was recovered from the 2012 excavations. Thirty-nine of the OES artifacts (31 beads and seven preforms) were recovered from the upper 100 cm of excavation in 2012, and a further two beads and one preform were collected during the 2016 excavation. No artifactual OES was reported from the 2006 or 2008 excavations, possibly because sediment screening was not practiced in the initial stages of the project. Beads of all types (including those made from glass and land snail shell) are more prevalent from 0-50 cm, with only a few recovered below that level.

There is significant taphonomic disturbance at Magubike (much of it from water percolation), and this situation has contributed to difficulty interpreting the assemblage. The lithic typological sequence (along with the presence or absence of pottery and iron) has been relied upon to estimate the age of a given excavation spit. Despite difficulties with stratigraphy, directly dating the beads downplays the significance of taphonomic disturbance. By dating the formation of the eggshell, direct radiocarbon dates give a reasonable, though not certain, estimate of when the bead was made.

Directly dated OES beads have provided some age estimations for the uppermost excavation levels, however the degree of stratigraphic disturbance renders it difficult to discuss the assemblage with accuracy. Five OES artifacts were directly dated with the following uncalibrated ages: 6465 ± 33 BP; 13,125 ± 50 BP; 31,810 ± 180; 47,750 ± 750

BP; >50,100 BP. These dates make the Magubike specimens the oldest directly radiocarbon dated OES beads on record, the first to be associated with MSA cultural material, and an important component of my research.

Mlambalasi Rockshelter

Located near Magubike, Mlambalasi (HwJf-2) is another rockshelter under investigation by Dr. Willoughby and IRAP. Mlambalasi is a granitic overhang nestled amongst a number of other large boulders on the southern slope of a hill, approximately 50 km west of Iringa City. Locally, the shelter is known as the last stand of Chief Mkwawa, 19th century leader of the Wahehe, who avoided capture from the German army by hiding out and eventually killing himself at the site in 1898 (Redmayne 1968). Mlambalasi was first excavated by Dr. Paul Mswemwa in 2002, and subsequently by IRAP in 2006, 2010, and 2016.

The Mlambalasi deposits are more intact than those from Magubike, although some post-depositional disturbance is present. The uppermost excavation layers at Mlambalasi are loose packed and silty, with apparent rodent burrows (and possible land snail movement) throughout. With no moisture present to help consolidate the matrix, these upper levels are prone to collapse with even the slightest touch. The middle and lower layers are peppered with chunks of disintegrating bedrock. The percentage of chunks increase with depth, reaching 100% at approximately 110 cm below surface, halting excavation.

Radiocarbon dates show modern and Pleistocene activity at the site, with a long period of hiatus between them. Charcoal samples from the upper 50 cm of the deposit range from 151 ± 24 to 460 ± 50 BP, while charcoal, snail shell, and OES bead dates from 50-110 cm range from 11,710 ± 90 to 16,690 ± 65 BP (Biittner et al. 2017, p. 282). A few dates in the series are stratigraphically inconsistent, a factor which makes it difficult to associate ages with excavation spits, however three of the OES beads have direct radiocarbon dates, so their ages are more certain. The age of the remaining beads a roughly estimated from bracketing dates.

OES beads were recovered from the 2006 (n=2) and 2010 (n=70) excavations at Mlambalasi. The collection consists of 58 beads and thirteen preforms. According to the report by Dr. Msemwa, the only two beads recovered in the 2002 excavation were of "European origin" (Msemwa 2002, p. 14), so these were likely glass rather than OES. The 2016 excavations at Mlambalasi consisted of two shovel tests to determine the extent of the site, and while they revealed some beads, their analysis is not included here. I analyzed the 2006 and 2010 OES assemblages as part of my MA thesis, and the data from these are included in this dissertation.

This assemblage was another clear choice, as I already had the data from my previous study. My analysis characteristics did change slightly between my MA and PhD data collection, and unfortunately I was unable to retroactively record some of my newer traits for the Mlambalasi beads as they had already been returned to the National Museum of Tanzania. This is one of the reasons that I suggest that photographic documentation should also include a profile view of the bead (see Chapter 3 for details on photographic records of OES beads). Therefore, similar to the Enkapune Ya Muto assemblage, the Mlambalasi data is not fully comparable to the other collections.

Botswana

White Paintings Rockshelter

White Paintings Rockshelter (WPS) is located in the Tsodilo Hills of Botswana. This area is west of the Okavango River, in the northwestern Kalahari Desert. The site contains 7 m of deposits, of which thirty-one 1 m^2 units have been excavated (Robbins et al. 2000). Excavation proceeded in arbitrary 10 cm levels, and all sediment was screened through a "4/5 mm mesh" (Robbins et al. 2000, p. 1088). Robbins (1999, p. 11) described that 2313 pieces of OES were recovered from WPS, with approximately 5% of these being clearly artifactual. No fragments found below 200 cm show signs of use (Robbins 1999, p. 11).

The WPS assemblage is extremely important to the study of artifactual OES because it was the first to have directly radiocarbon dated Pleistocene OES artifacts. In the 90s, two of the deepest artifactual OES pieces were selected for dating. A broken bead preform from 190-200 cm was dated to 26,460 ± 300 BP (Robbins 1999, pp. 11–13), and a disc shaped piece, possibly from a water container mouth, from 180-190 cm was dated to 31,880 ± 510 BP (Robbins 1999, pp. 11–13). These direct dates confirm that the OES artifacts from WPS belong in the early LSA, and are not simply a byproduct of stratigraphic movement. I received a research permit from the Government of Botswana (Ministry of Environment, Wildlife and Tourism) to study the WPS beads. In the summer of 2014 I travelled to Gaborone, Botswana, for analysis.

The direct bead dates make the WPS an important addition to my research, however there are two significant problems with the WPS collection, which I did not discover until I arrived in Botswana. First, of the 241 beads and preforms in storage at the museum, approximately half were in a single plastic bag that had no provenience other than the site name. There was only a computer printed label in the bag, reading “ostrich eggshell beads”. I suspect that this collection is the remains of a museum display, and that bead from a number of units or levels were removed from their provenience information to be shown in the museum. In hopes that they may still prove useful for a regional comparison, I included them in my analysis. Second, although there are still 66 preforms and 69 beads that retained their contextual information, and a series of radiocarbon dates by depth, it is unclear how depth of layers differs between excavation areas. The only stratigraphic profile available is for the main excavation block (Units 10-23), and it shows that horizontal excavation spits would have cross-cut depositional layers. This concern is best illustrated at the 100 cm depth (Robbins et al. 2000, p. 1093), as the same 10 cm horizontal spit could contain artifacts from Layer 2b, 3a, 3b, 4 or 5. These problems are not unique to WPS, and although they present a challenge, they do not deter me from including the bead collection in my research.

Namibia

Apollo 11 Cave

In 1968, an archaeological research program in South West Africa, which sought to establish a link between rock art and archaeological deposits, identified Apollo 11 Cave. The site is located in southwestern Namibia, on land that is now incorporated into the Ais-Richtersveld Transfrontier Park. Situated in a boulder-scattered gorge, Apollo 11 Cave may have been a desirable location for early people due to the two natural springs, which intermittently flow from the surrounding limestone cliffs (Masson 2006, p. 78).

Excavations in 1969 and 1972 identified seven main cultural layers at Apollo 11 Cave. The well-stratified deposits reach a maximum depth of 235 cm below surface before encountering bedrock. A series of 39 radiocarbon dates from these excavations reveal near-continuous occupation through the LSA.

Although it is best known for its early artwork, namely a painted slab dating between 26,300 ± 400 BP and 28,400 ± 450 BP (Wendt 1976, p. 6), Apollo 11 has an extraordinary number of OES beads and preforms. The OES artifacts came from excavation layers C through F, which span the LSA and into the late MSA. The recovered OES artifacts include completed beads, partially made beads, and water container fragments. Beads were even recovered from the lowest horizon of Layer D, which has radiocarbon dates from 18,500 ± 190 BP to 19,760 ± 175 BP (Wendt 1976, p. 6).

Work was resumed in 2007 by a team from the University of Cologne, who aimed to understand the stratigraphy and dating of the MSA deposits at the site. A portion of the trench excavated by Dr. Wendt was re-opened to obtain dating samples, and an additional 0.5 m² of new material was excavated. The recent work does not discuss finds from the LSA layers, however it notes that three shaped pieces of OES were recovered from the Howieson's Poort horizon. These are described as having "smoothed edges, comparable to LSA ostrich eggshell pendants," (Vogelsang et al. 2010, p. 195).

The fact that this site has a series of radiocarbon dates, along with previously unanalyzed OES beads from early LSA (and possibly MSA) layers, made it a perfect candidate for my research. In the summer of 2014, I travelled to Windhoek to study the collection. No bead totals were available in the published literature, so I budgeted myself two weeks in Windhoek to analyze the collection. This was not enough time.

In total, I analyzed 170 beads and 546 preforms that constitute a representative sample from the Apollo 11 collection. This was the largest ratio of unfinished to finished beads that I encountered at any site. It is unclear from the Vogelsang et al. (2010) publication whether their 2007 excavation recovered any new OES beads, and the collection curator (Ms. Emma Haitengi) was unable to locate any OES from that excavation.

The unit and depth designations on the 1967 and 1972 beads are very unusual (e.g. A3.2, $A9X^3$), and no published excavation grid that explained them was available. Dr. Ralf Vogelsang who headed the 2007 excavation and had studied under Dr. Wendt, was able to provide me with an excavation map showing the shelter and location of all units. A stripped down version of this map was published in Fig.1 of Murray-Wallace et al. (2015, p. 144).

The map provided by Dr. Vogelsang reveals that is not feasible to use depth above or below datum as a proxy for age between units. All OES artifacts in the collection are marked with their depth in relation to datum, and based on the map, the datum point for the ’67 and ’72 excavations appear to have been taken on a rock near the mouth of the shelter. The initial surface elevation of the shelter floor is recorded only for four points in the shelter, but these points show vertical differences of over 70 cm in some places. Without knowing the original surface elevations or associated depositional layers, the beads cannot be confidently correlated between excavation units. So, despite having an abundance of artifactual OES, the Apollo 11 collection is hampered because only 14% (n=101) of the 716 artifacts I analyzed have reliable age estimates. However, the Apollo 11 collection can still be useful for regional stylistic variations (as discussed in Chapter 2).

South Africa

Boomplaas Cave

Boomplaas Cave is located in South Africa, and gained special attention for its collection of painted stones found in association with Stone Age occupations. A team studying environmental and cultural change in the Late Quaternary of the southern Cape first investigated the site. This project, based at the University of Stellenbosch, excavated a 1 m^2 test unit in 1974, and found five metres of well stratified deposition spanning the last 80,000 years (Deacon et al. 1976).

From the Boomplaas Cave collection, the most important OES artifacts for my study come from two particular levels. First, the CL (carbonized loam) layer, found approximately 210-240 cm below surface, is important. This layer has a complex stratigraphy with anthropogenic ash lenses, and appears to be a phase of intense site use (Deacon et al. 1976, p. 212). The base of CL was radiocarbon dated to 14,200 ± 240 BP (Deacon et al. 1976). Artifacts from this layer include micro-bladelets, small pyramidal cores, bone points, decorated water container fragments, and beads, all assigned to the Robberg Industry (Deacon 1995, p. 123). The beads from the CL layer are reported as being made from both bone and OES. There are marine shell beads present in the overlying layers, however none were recovered from CL. The second important layer is the OLP layer, which is found approximately 340-390 cm below surface and has two

OES artifacts reported (Deacon 1995, p. 123). When subjected to dating, this layer was beyond the upper radiocarbon limit, suggesting a minimum age of 40,000 years. If the two artifacts from OLP are stratigraphically intact, then they are among the earliest known OES beads.

Ultimately, I was unable to study the Boomplaas collection for this dissertation. The material is stored at the Iziko Museum in Cape Town, South Africa, and after receiving permission to study the collection, I travelled to Cape Town in the summer of 2014 for this purpose. Upon my arrival, I was provided with several boxes labelled as containing OES from Boomplaas, however there were no beads or preforms in any of the boxes, only unmodified OES. I asked the curators to search again, but they were unable to locate any Boomplaas beads. I believe the most likely explanation is that the delicate beads were stored with other small finds rather than the kilograms of unmodified OES, so the box could not easily be identified from the label. Although disappointing, I understand that this type of setback is a normal part of research. The Boomplaas OES bead collection remains unstudied, but should be strongly considered in the future, including direct dating of the OLP artifacts to rule out stratigraphic mixing.

Border Cave

Border Cave is a well-known MSA / LSA site in South Africa, that is located a mere 400 m from the border of KwaZulu-Natal and Swaziland, a location which is how it gained its name. The cave sits just below the rim of a high escarpment, and access to the shelter is limited due to the steep slope (Butzer et al. 1978, p. 318). Preliminary excavations first took place in 1934, by a team from the Department of Anatomy at the

University of Witwatersrand (Cooke et al. 1945, p. 6). The excavators opened a long narrow trench approximately 1 x 10 m. Before reaching bedrock at a maximum depth of 1.67 m, the team exposed a disturbed historic / Bantu deposit with an intact MSA deposit underneath (Cooke et al. 1945, p. 6). This was only a test excavation, and there is no published report.

Interest in Border Cave renewed when several fossilized animal remains and portions of a human cranium were uncovered. A guano collector dug up some portion of the cave floor exposing the remains (Cooke et al. 1945, p. 6). News of the disturbance made it back to the original excavators at Witwatersrand and prompted further work at the site. Back-to-back field seasons in 1941 and 1942 systematically excavated, searching for further human remains. The excavations recovered one *in situ* infant skeleton and some cranial fragments that articulated with the remains found by Horton.

Excavations in 1970-71, led by Dr. Peter Beaumont, uncovered deposits from the terminal MSA and early LSA. The early LSA at Border Cave was found to be among the oldest in Africa, dating to 33,000 ± 2000 BP and 38,600 ± 1500 BP (Butzer et al. 1978, p. 334). These levels yielded fossil human remains, ground bone points, and OES beads.

A recent reanalysis of early organic artifacts from Border Cave confirmed that the OES beads (and other organic artifacts) from those levels are genuinely ancient. New ESR and radiocarbon dates on associated material from bead bearing levels (1WA and 1BS Lower B-C) range from 34,800 ± 930 to 39,800 ± 620 BP (d'Errico et al., 2012), indicating that these OES beads date to the earliest phase of the LSA at Border Cave. To rule out potential stratigraphic mixing, one of the fourteen beads was directly AMS dated, returning a date of 38,020 ± 1240 BP (d'Errico et al. 2012, p. SI-4). This date confirms that Border Cave has some of the earliest known OES beads.

The collection is stored at the McGregor Museum in Kimberley, South Africa, under the care of the curator Dr. David Morris. I budgeted two weeks to study the Border Cave material, which turned out to be far too much time. It was not until I arrived at the museum that I found that the beads described from the early LSA levels were the only OES beads recovered from the site. I had expected that the beads described by Villa et al. (2012) and d'Errico et al. (2012) were highlighted because of their antiquity, not because they were the only ones present.

The Border Cave assemblage is small, however their secure early-LSA context makes them extremely important to the understanding of OES bead variation in the Pleistocene. I examined 20 OES artifacts from the Border Cave assemblage, 16 of which were beads, and four were preforms. Thirteen of the artifacts came from 1BS Lower B-C or 1WA context, meaning that based on the published dates for those layers they are approximately 40,000 years old. Some characteristics from the bead destroyed by AMS dating were included in the supplemental information linked to the d'Errico et al. (2012) article, so I was able to include the metric data on diameter, thickness and aperture from the Supplemental Information Table 3. Two of the beads are labelled as "slump", suggesting they were recovered from a secondary context. One of these further indicates "1BS slump," although radiocarbon dates for 1BS span more than 20,000 years, so it is not possible to estimate the date for that artifact. Finally, three of the Border Cave beads are without attached provenience. These cannot be used for any chronological analysis but may still prove useful for examining regional trends.

Dikbosch Shelter 1

Dikbosch Shelter 1 (DKB1) is located on a family farm at the edge of the Kaap Escarpment, in South Africa. A large boulder divides the 20 m long shelter into two adjacent areas, named A and B. Area A was test excavated in 1973 by Dr. A.J.B. Humphreys, and Area B was tested sometime later by Dr. David Morris, at the request of Dr. Humphreys. Six depositional levels are identified, each recorded with a roman numeral (I-VI). Area A radiocarbon dates on charcoal were taken from Level II (3090 ± 60 BP), Level III (13,510 ± 120 BP), Level IV (12,450 ± 100 BP), the Level V / VI interface (13,770 ± 130 BP), and Level VI (13,240 ± 125 BP) (Humphreys 1974a, 1974b). The Area B radiocarbon dates are inconsistent with those from Area A, giving consistently younger dates of Level II (1720 ± 40 BP), Level III (1570 ± 40 BP), and Level V (8010 ± 60 BP). Humphreys suggests that there appear to be two major occupations represented at DKB1, separated by a hiatus of several thousand years.

I encountered this collection by chance, while at the MacGregor Museum in Kimberley, South Africa. After finishing quickly with the Border Cave assemblage, I inquired to the museum curator (Dr. Morris) about other assemblages housed there that I might study. The curator happened to be the one who had excavated Area B of DKB1, and he suggested several available collections including Dikbosch 1. He said that Area A had approximately 450 OES beads, however when I opened the DKB1 boxes provided to me I found only fourteen beads. This low number leads me to conclude that the beads I analyzed are from Area B, and I will therefore use the dates from that section.

I analyzed only fourteen artifacts from the DKB1 assemblage (three beads and eleven preforms), however this small collection is significant because of the manufacturing Pathways. The preforms from DKB1 show evidence of two different manufacture Pathways, and while no publications documented this evidence, the excavators seemed to be aware of the significance. Humphreys and Thackeray (1983) published a book that includes a report on the work at Dikbosch, along with a number of other sites. Included in the book is an appendix of typologies and definitions, with a section on OES which explains the two methods of manufacture. It distinguishes between the manufacture types by describing the preforms either as "perforated fragments" or "circular discs" (Humphreys and Thackeray 1983, p. 313). However, these categories are not used in the tables that list OES artifacts from Dikbosch, in which "incomplete bead" is used instead. An incomplete bead could refer to either Pathway. My analysis complements the original work by Humphreys and Thackeray by drawing attention to the presence of both Pathways in the DKB1 assemblage.

Kathu Pan 5

Kathu Pan 5 (KP5) is a site in South Africa which reportedly has OES beads from early LSA layers dated between 19,800 ± 280 and 32,100 ± 780 BP (Beaumont 1990, p. 88). The collection is stored at the McGregor Museum in Kimberley, South Africa (the same museum as the Border Cave assemblage), and I thought it was prudent to access the Kathu Pan 5 collection while I was in Kimberley. Unfortunately, the curator and I were unable to locate any OES beads from the site. I personally scoured the storage room, and examined every single box from the site twice over, but none had any beads. The boxes contained lithics, bone, sediment samples, and some small amounts of unmodified OES. Some of the bags were empty, with tags inside saying the contents were "sent to Vogel" in 1988 for analysis. It is possible that these items were OES beads, as the tags probably refer to Johann Carl Vogel who was a well-known dating specialist in South Africa. However, I think it is unlikely that these missing objects were beads, given the small amount of unmodified OES combined with the fact that no other bags contained beads, and there were no references to beads on an artifact tags.

A staff member at the MacGregor Museum suggested that the publication of beads from KP5 might be erroneous. The finds are reported in a larger summary of test excavations from sites in the Kathu region, written by Dr. Peter Beaumont. His co-authored book (written with Dr. David Morris) summarizes excavation work that he oversaw between 1979 and 1990, from eleven archaeological sites. Descriptions of the cultural sequence list anecdotally that OES beads are found at Kathu Pan 1 and 5, although no table of finds is included, and no unpublished reports were cited. Beaumont writes that two OES beads from Kathu Pan 1, Stratum 3, were submitted for direct radiocarbon dating, but I can find no mention of reported dates. All later references to early OES beads from Kathu Pan (e.g., Wadley, 1993; Beaumont and Bednarik, 2013) reference back to the Beaumont (1990) literature. Until the KP5 beads can be located or otherwise verified, I suggest refraining from referencing them in literature as an example of early OES beads.

Nelson Bay Cave

Nelson Bay Cave (NBC) is a large cavern measuring approximately 30 x 15 m, located 550 km to the east of Cape Town, South Africa. The cave deposits were looted in the late 1800s and early 1900s to provide artifacts for museums (Deacon and Brett 1993, p. 99), and the first archaeological work took place between 1964 and 1979 (Inskeep and

Vogel 1985, p. 103). No further excavation has been conducted at the site since that time. However, some restoration work has taken place to secure the open excavation units against erosion (Deacon and Brett 1993).

Study at NBC has largely focused on the Holocene occupation levels, but there is some mention of Pleistocene-aged OES beads. Deacon's publication has a figure of a line drawing of four beads, with the caption "ostrich eggshell beads from Nelson Bay dated *c.* 18500 BP (Deacon 1990, p. 179). In addition, there is mention in the faunal analysis that ostrich eggshell fragments were recovered from the Yellow-Grey Gritty Loam layer (dated to 18 kya) on upwards (Klein 1972, p. 193), although it is not clear if there are beads present in this lowest layer. As I was already heading to the Iziko Museum in Cape Town to study the Boomplaas assemblage, I decided it was worthwhile to also examine the NBC collection.

Unfortunately, no OES artifacts from Pleistocene layers could be located during my research at the Iziko museum in 2014. There were fourteen preforms and 535 OES beads from Holocene levels, all of which I was able to analyze instead. The upper stratigraphy at NBC is extremely complex, with 147 depositional layers, and 18 radiocarbon dates spanning the last 7000 years. This sort of high-resolution context is extremely desirable for my research, even if the beads are significantly younger than I had hoped.

Wonderwerk Cave

The final site to be discussed for use in my research is Wonderwerk Cave, which is probably best known as having early evidence of controlled fire use from 1.0 Mya

(Berna et al. 2012) and possibly as far back as 1.7 Mya (Beaumont 2011). It is an enormous cave, which is 18 m wide at the mouth, and extends nearly 140 m into the rock face, which is far enough that sunlight never reaches the rear of the cave. Wonderwerk was first recorded in the 1800s, and the site was excavated in the 1940s by B.D. Malan. Work intermittently resumed from the 1970s through the 90s by a variety of archaeologists including Dr. K.W. Butzer, Dr. A. Thackeray, Dr. F.J. Thackeray, and Dr. P.B. Beaumont. Today, Dr. Michael Chazan (University of Toronto) heads the research into Wonderwerk Cave.

The Wonderwerk assemblage was not part of my original research plan, as it does not have beads from the early LSA, however when I found myself with extra time at the MacGregor Museum, this collection suited my needs. After receiving permission from the Museum and from Dr. Chazan by email, I analyzed all of the specimens in the bead collection. Two of the artifacts included in the collection were bead preforms but not made from OES. A further six specimens were pieces of OES that were unmodified, but may have been presumed artifactual due to taphonomic degradation. These were excluded from my study, leaving 587 OES artifacts from Wonderwerk (219 preforms and 368 beads).

The upper levels of Wonderwerk Cave, where the OES artifacts were recovered, are well-dated. There are some inconsistencies in level naming conventions between different excavators, however Lee-Thorpe and Ecker's (2015) article clarifies how the layers match up. OES artifacts were collected from nearly all of the occupations from modern through 12 kya, and these layers sometimes have multiple radiocarbon dates with slightly different ages. For example, Layer 3b (also called 3LR) has dates of 2910 ± 60 and 3990 ± 60 BP (Lee-Thorp and Ecker 2015, p. 803). In such cases, I used the average of the radiocarbon dates to provide an estimate for the level.

Summary of collections

In total, I collected data from 2570 OES objects (1566 beads and 1004 preforms) across eleven sites in southern and eastern Africa (see Table 4 for a breakdown by site). Of these, 1685 have reliable age estimates. Figure 8 illustrates that no single collection spans the entire history of OES bead use, but when considered together, they roughly cover from modern times to 50 kya. Many of the artifacts have identical approximate dates because they have the same age estimate, so the squares in Figure 8 are directly overlaid, giving the appearance of a relatively consistent distribution of samples throughout the sequence. However, in reality, younger beads or preforms are over-represented, with 59.4% (n=1001) of the specimens dating from 0-5 kya, 27% (n=455) from 5-10 kya, and only 17% (n=288) from 10-50 kya. This distribution highlights the need to recover more examples from the earlier LSA.

Table 4. Preforms and beads analyzed, by site.

Site	Preforms	Beads	Total
Enkapune Ya Muto Rockshelter	31	80	111
Mumba Rockshelter	65	125	190
Daumboy Rockshelter 3	11	13	24
Kisese II Rockshelter	-	-	-
Magubike Rockshelter	8	34	42
Mlambalasi Rockshelter	13	58	71
White Paintings Rockshelter	71	169	240
Apollo 11 Cave	547	169	716
Boomplaas Cave	-	-	-
Border Cave	4	16	20
Dikbosch 1 Rockshelter	11	3	14
Kathu Pan 5	-	-	-
Nelson Bay Cave	20	535	555
Wonderwerk Cave	223	364	587
Totals	1004	1566	2570

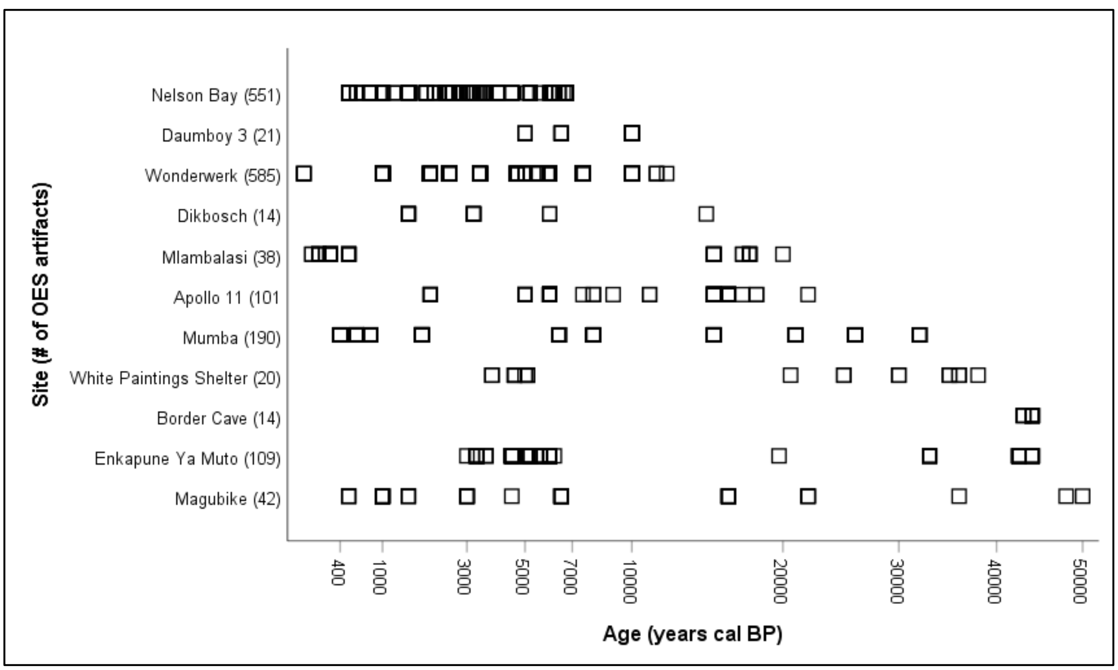

Figure 8. OES artifacts, with age estimates, analyzed in this study (n=1685); each square can represent multiple artifacts with the same age estimate.

Chapter 4 - Analysis and Results

In this section, I summarize important findings as they relate to my original research questions. To aid in visualization, southern African data will be represented in the figures in green, and eastern African data in blue. The data suffer from an irregular distribution through time, as there are far more young beads than old beads, so in some cases the graph was transformed on the x-axis with an exponent of 0.5. This is a useful technique to help to normalize the visual distribution of data without affecting statistical relevance. I used the SPSS regression models to find the best-fit mathematical regression to show any trends through time. General shapes of the available functions (linear, logarithmic, inverse, quadratic, cubic, compound, power, S, logistic, growth, and exponential) can be seen in Figure 9. The resulting equations have not been included, because the models are intended to show statistical relationships between variables, and not to be used as predictive models. Finally, where appropriate, I used a Mann-Whitney U test, which is a statistical way to compare two groups that do not have a normal distribution, and may contain outliers.

What happens to southern African bead sizes from 5000-50,000 years?

Before exploring bead diameters from 5-50 kya in southern Africa, it is important to understand the pattern of bead change from 0-5 kya. As outlined in Chapter 2, previous research identified a negative trend of OES bead sizes in southern African sites over the last 5000 years. Specifically, beads from pastoralist sites are larger than beads from earlier hunter-gatherer sites. This phenomenon remains largely unexplained, but the change coincides with the transition to a herding economy.

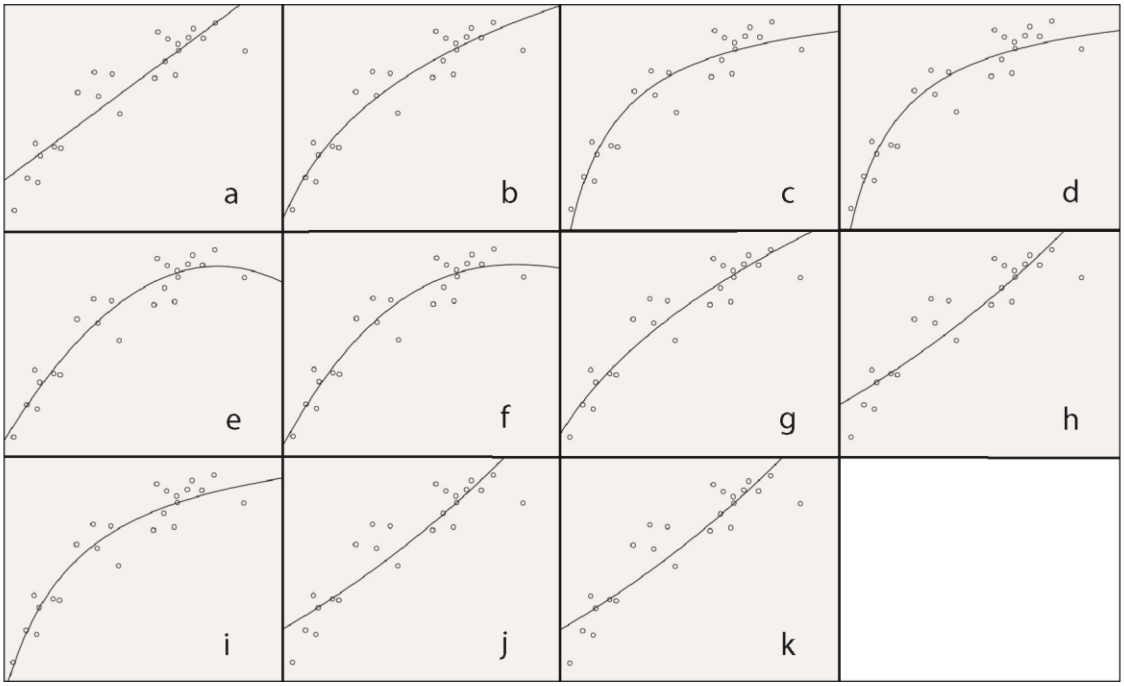

Figure 9. Examples of linear and non-linear regression lines; a-linear, b-logarithmic, c-inverse, d-quadratic, e-cubic, f-compound, g-power, h-S, i-logistic, j-growth, k-exponential; adapted from SPSS.

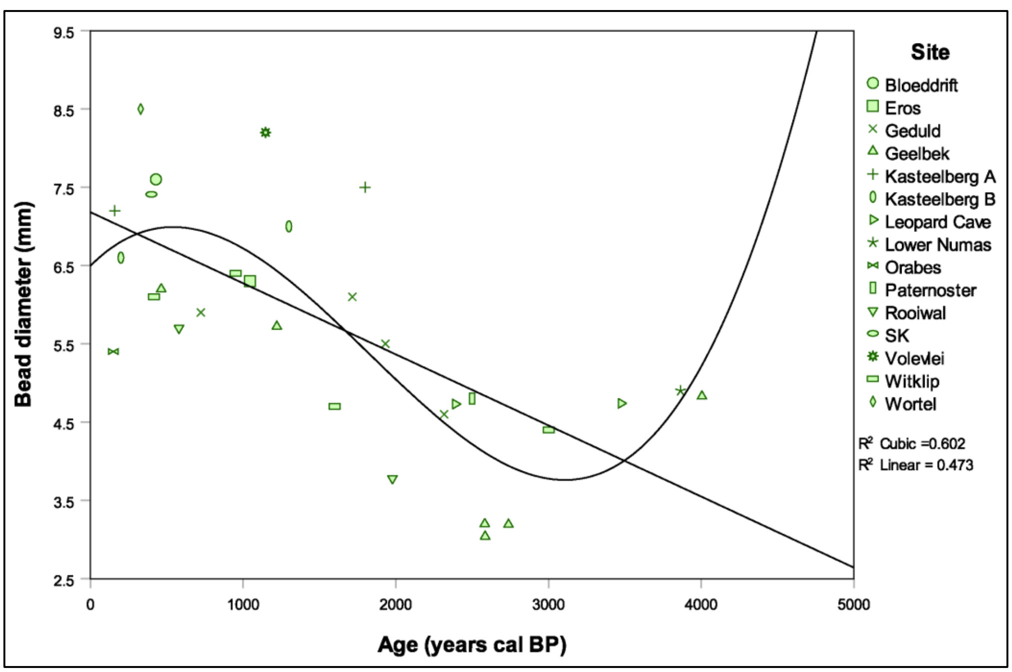

Figure 10. Mean OES bead diameters from published data in southern Africa (n=31), dated 0-5 kya, showing cubic and linear regressions (Jacobson 1987a, 1987b; Kandel and Conard 2005; Orton et al. 2005; Pleurdeau et al. 2012; Sadr et al. 2003; Smith et al. 1991, 2001; Yates 1995).

Plotting published averages for OES bead diameters relevant to this debate shows that there is indeed an observable shift in diameter (Figure 10). Several regression models demonstrate a moderate to strong relationship with a highly significant, negative correlation between bead size and time. The strongest relationship is shown with the cubic curve (n=31, R^2=.602, p<.001), while the linear regression also demonstrates a moderate strength and highly significant relationship (R^2=.473, p<.001). In fact, a number of models (cubic, quadratic, compound, linear, growth, exponential, and logistic) all produce R^2 values greater than .40, implying that a relationship between time and bead size exists, just the mathematical description of the relationship is in question.

A shortcoming of graphing the published diameter data is that it typically consists of the average diameters per level rather than average diameters of individual beads. Using averages by site level hides the range and variability of bead sizes, giving the regressions a deceivingly strong R^2 value. Although Figure 10 shows that beads from younger contexts are larger, previous research has stated that the size change is not a general increase in all beads but rather the inclusion of some larger beads at younger sites. This factor means that older sites always have beads that are small, while younger sites have small and large beads, a distribution which is not evident in Figure 10.

The apparent negative correlation between size and time disappears when individual diameters are added (Figure 11). Now no regression model explains the data. Linear, logarithmic, inverse, quadratic, cubic, compound, power, S, growth, exponential and logistic models, all provide an R^2 between .013 and .050 (n=736), suggesting that there is no regression relationship between time and bead size from 0-5 kya.

Even though there is no relevant regression, there is still an observable and statistically relevant difference. Looking at Figure 11, it is apparent that the increase in diameter size begins a little earlier than 2 kya, perhaps around 2500 years ago. Since the introduction of herding happens at 2 kya, these slightly earlier dates may result from small errors in age estimates of the beads. Regardless, it is prudent to use this 2500-year mark to divide the sample into pre- and post-herding eras for analysis. These groups show the most variation in the upper range of sizes, with beads younger than 2500 years (n=441) ranging from 2.78 - 8.50 mm, while those from 2501-5000 years ago (n=295) range from 2.86 - 5.88 mm. A Mann-Whitney U test of these two groups shows a statistically significant difference (U=57,562, p=.008) between the pre-herding (n=441, 4.63 mm average) and post-herding groupings for southern Africa. Therefore, the findings of previous researchers seem to hold true across southern Africa, even when exponentially increasing the sample size.

Having demonstrated the overall manifestation of southern African OES bead diameters from 0-5 kya, I can now examine the first question I posed in Chapter 1: *What happens to southern African OES bead sizes from 5000-50,000 years ago?* My data contribute 262 new data points to this question, and incorporates some additional data published by Dayet et al. (2017) on the Bushman Rockshelter collection (n=24), and Varsche River 003 (n=1) published in Steele et al. (2016). Twenty-nine of the beads from the 0-5 kya graph are estimated at precisely 5000 years old, and they are included again in the 5-50 kya graph. The southern African OES bead diameters from 5-50 kya are markedly different from the 0-5 kya specimens, as illustrated in Figure 12. The older

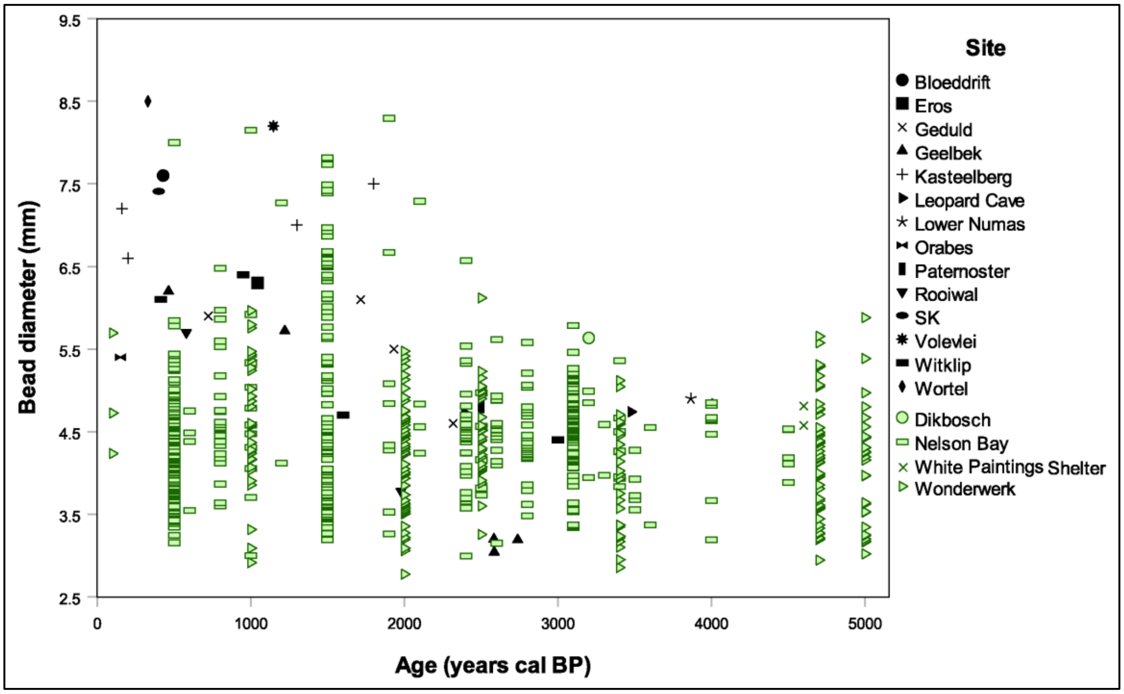

Figure 11. OES bead diameters from southern Africa (n=736), from 0-5 kya, data from publications (Jacobson 1987a, 1987b; Kandel and Conard 2005; Orton et al. 2005; Pleurdeau et al. 2012; Sadr et al. 2003; Smith et al. 1991, 2001; Yates 1995) shown in black.

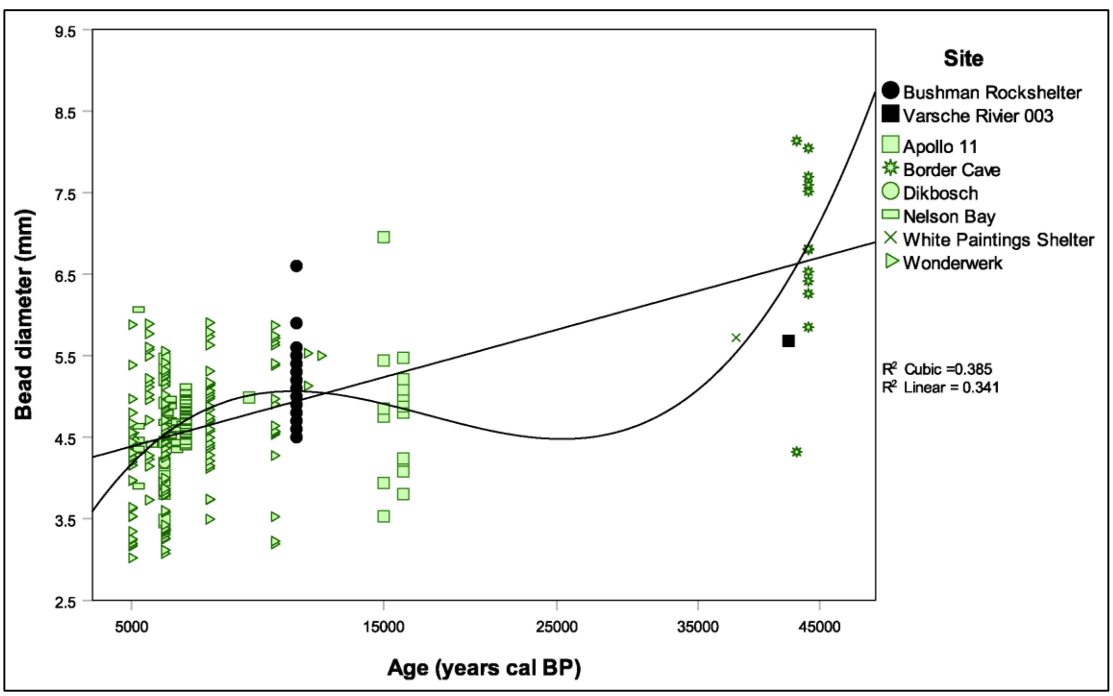

Figure 12. OES bead diameters from southern Africa (n=287), from 5-50 kya, showing cubic and linear regressions, data from publications (Steele et al. 2016; Dayet et al. 2017) shown in black.

beads show a positively correlated, a weak-moderate strength, highly significant relationship between age and bead size (n=287, R^2.385, p<.001). The strongest regression model is a cubic curve, however I suspect the absence of data points between 20 and 30 kya distorts this model. If the Kathu Pan 5, Boomplaas and the Pleistocene Nelson Bay Cave assemblages had been available as in my original plan, these would have helped fill in points from 20-30 kya and perhaps the cubic curve would not show as strong a correlation. The linear regression has a slightly weaker correlation (n=287, R^2=.341, p<.001), but I believe it is more parsimonious because it assumes a simpler pattern in diameter change across the age gap in my samples. Additional data from the mid-to-early LSA periods is needed to better assess the trends in bead size through this long stretch of time. It is also important to note that the oldest portion of the southern African data is largely represented by beads from a single site (Border Cave). These diameters are responsible for skewing the oldest end of the graph upwards, and it is plausible that the relationship will become more complicated with the addition of more data.

Does the same trend of diameter change also exist in eastern African OES beads?

As just shown, the southern African bead sizes have a moderate correlation with time from 5-50 kya, and the range of diameters show a sudden increase for beads younger than 2500 years. The sudden increase in size range during the 0-5 kya period seems to correspond with the movement of herding into the area, but no previous studies have examined whether the introduction of herders into eastern Africa resulted in similar bead size changes. As mentioned in Chapter 2, the transition to herding in eastern Africa begins approximately 5 kya and continues to develop in a patchwork until 1 kya, not reaching all areas. Because of the different times of the introduction of herding, the comparable period in eastern Africa should be approximately 5000 years ago, rather than the 2500 years ago mark I used for southern Africa. So, to fully compare the eastern and southern diameters, I will use three perspectives: 0-8 kya, 5-50 kya, and 0-50 kya. Each graph will display eastern and southern beads from the relevant period. I chose 8 kya as a cut off for the first graph because it marks the introduction of herding into North Africa, therefore any beads of this age in both eastern and southern Africa are undoubtedly pre-herder. For the second graph, I use 5-50 kya rather than 8-50 kya because it helps preserve additional data from southern Africa that is of pre-herder age.

Data from eastern Africa for the 0-8 kya period include 202 bead diameters (compared to the 915 specimens from 0-8 kya in southern Africa). Figure 13 shows that the two regions do not appear to have similar size changes over the transition to herding. No regression model explains the data for eastern Africa, with linear, logarithmic, inverse, quadratic, cubic, compound, power, S, growth, exponential and logistic models all providing a maximum R^2 of .047 (n=202). This result suggests that no regression relationship exists between time and bead size for eastern Africa from 0-8 kya. Additionally, a Mann-Whitney U test shows no statistically significant difference (U=4268, p=.373) between bead diameters from 0-4999 years ago (n=132, 6.55 mm average) and those from 5000-8000 years ago (n=70, 6.30 mm average). There is one outlier (14.49 mm) from the 0-4999 year grouping in eastern Africa which is not visible in Figure 13, but was included in the Mann-Whitney U test. The small sample of the

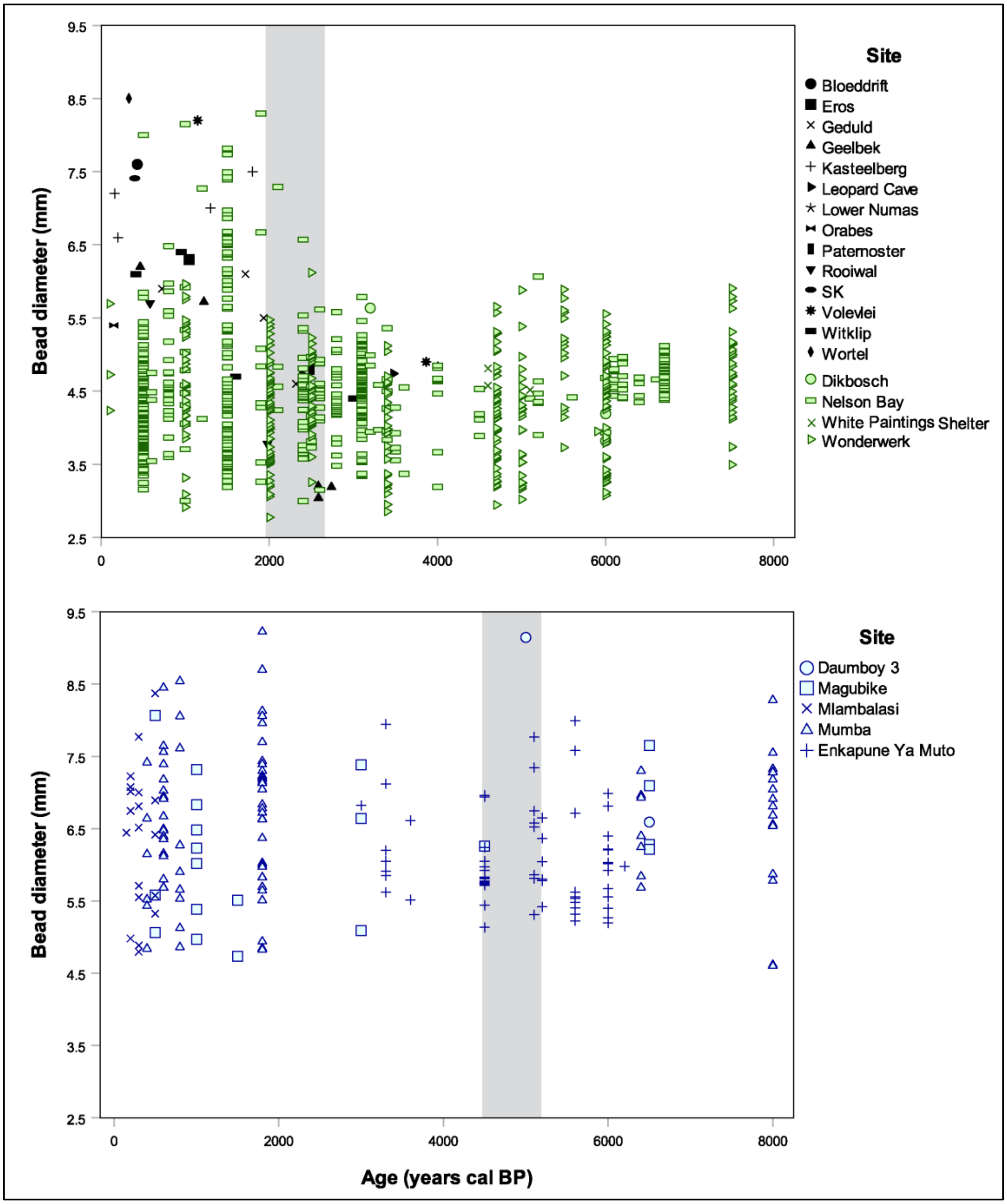

Figure 13. OES bead diameters from southern (n=915, in green) and eastern (n=202, in blue) Africa, from 0-8 kya; previously published data (Jacobson 1987a, 1987b; Kandel and Conard 2005; Orton et al. 2005; Pleurdeau et al. 2012; Sadr et al. 2003; Smith et al. 1991, 2001; Yates 1995) shown in black; shaded bars mark the introduction of herding in each region.

eastern African bead data from 0-8 kya may be biasing the data, as when the outlier is included there are only six beads which exceed 8.50 mm, and these only appear after the earliest herders. Until further data is obtained, it stands that the eastern OES beads are not statistically different in diameter range before and after the introduction of herding.

The differences between regions are most evident when comparing their lower limits and averages. From 0-5 kya, southern beads average 4.50 mm (n=736), while eastern beads are 6.57 mm (n=133). The smallest measured bead diameter from eastern Africa is 4.73 mm, a feature which means that the smallest eastern African bead is still larger than the average of beads from southern Africa. Even though there are some sparsely populated parts of the graphs on Figure 13 with few or no data points, eastern African beads just appear to be larger than the majority of southern African beads. It is apparent that the diameter change observed in southern African beads over the last 5000 years does not exist in eastern African OES beads. I will explore some potential meanings of this observation in Chapter 5.

Turning now to the 5-50 kya period, I will compare and contrast the eastern diameters to their southern African counterparts. The sample sizes from 5-50 kya from southern (n=289) and eastern (n=145) regions are comparable, though the southern diameters are biased towards younger specimens while the eastern data is more balanced (Figure 14). As previously mentioned, the majority of the southern points are younger than 10 kya, and there is only one specimen for the 20-40 kya period. On the other hand, the eastern diameters are well distributed, with good representation through most periods. Even though the eastern bead diameters have a more even distribution through time, they show no statistical correlation between size and age. Eastern OES diameters range from

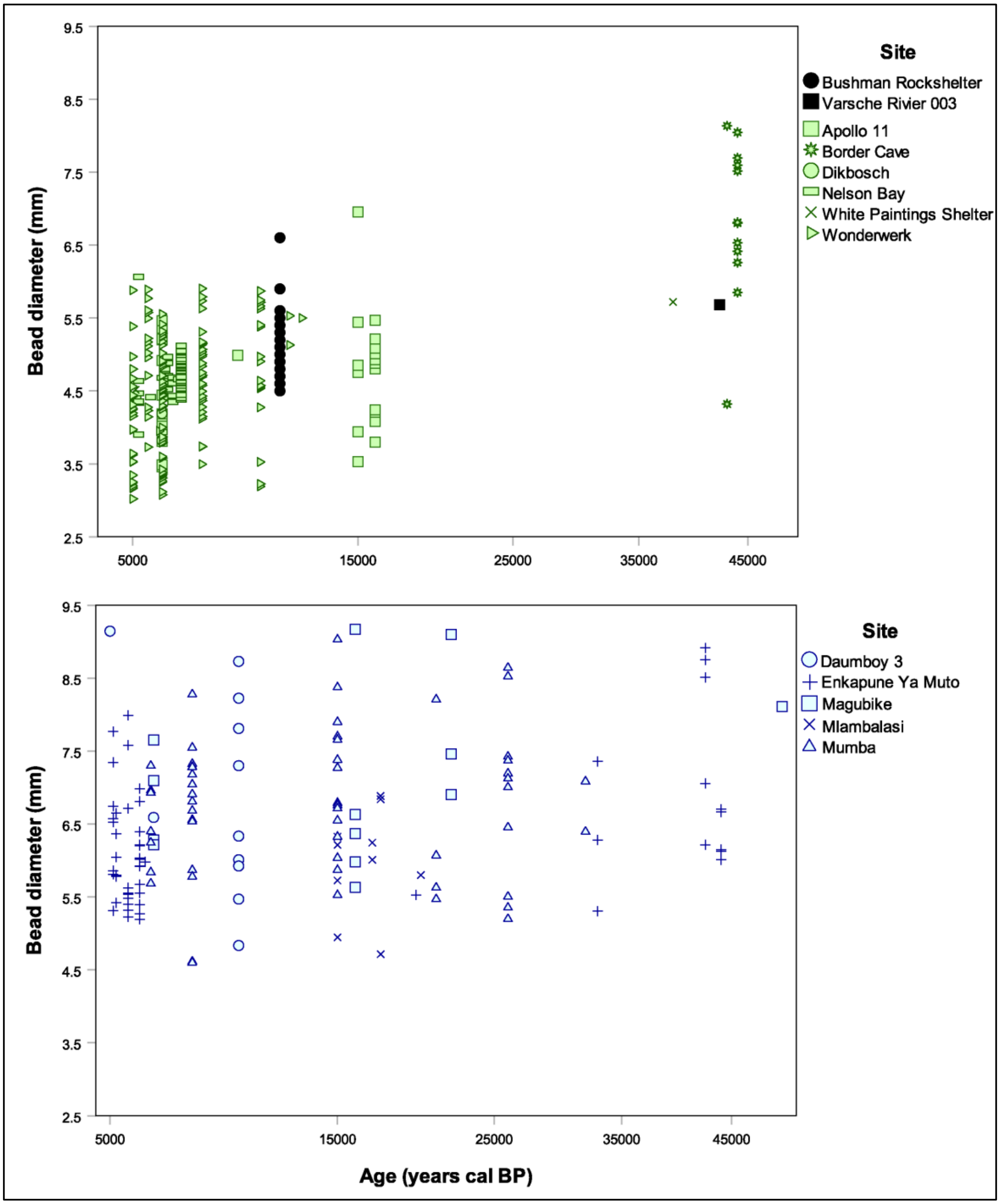

Figure 14. OES bead diameters from southern (n=289, in green) and eastern (n=145, in blue) Africa, from 5-50 kya, previously published data (Steele et al. 2016; Dayet et al. 2017) shown in black.

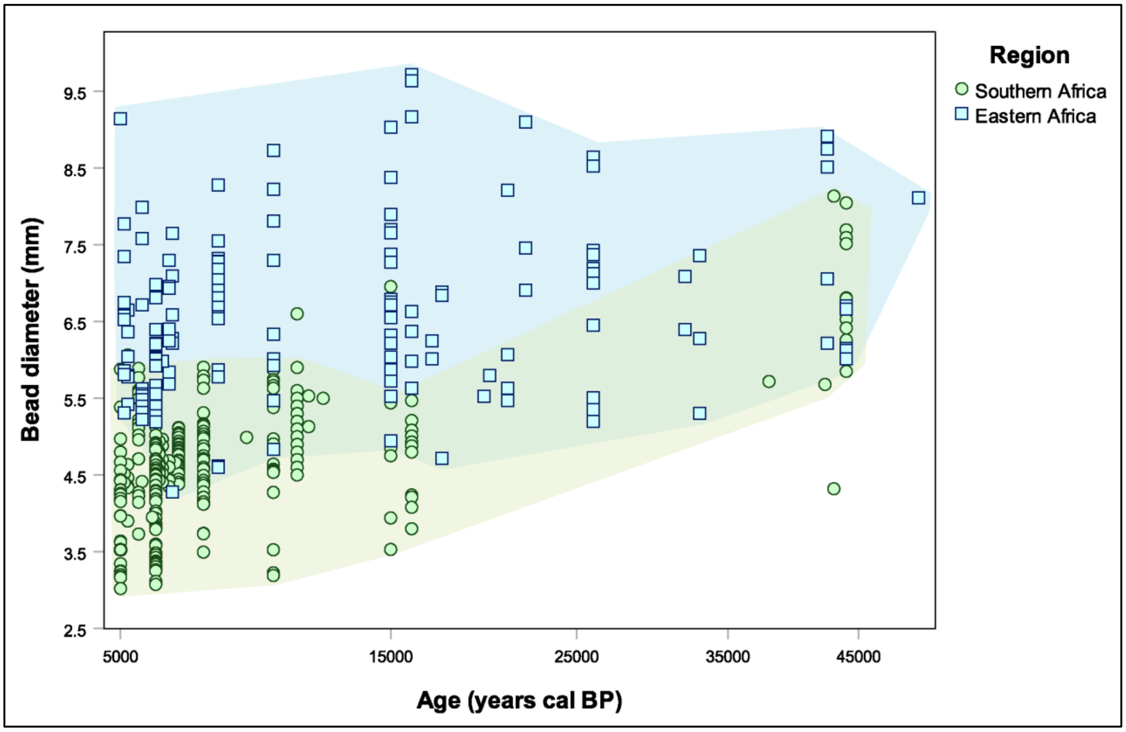

Figure 15. OES bead diameters from southern (n=289, in green), and eastern (n=145, in blue) Africa, from 5-50 kya; polygons encompass >99% of data.

4.28 to 9.72 mm, with a roughly similar range through the entire 45,000 years. Linear, logarithmic, inverse, quadratic, cubic, compound, power, S, growth, exponential,and logistic models all provide R^2 values from .049 - .071 with significance values from .002 - .017 (n=146). So, there is no apparent correlation between size and time for eastern African OES beads from 5-50 kya.

At 40-50 kya, bead diameters in both regions overlap, then moving forward through time the regions diverge (Figure 15). Eastern African diameters from this oldest period (n=11) range from 5.69-8.65 mm, with an average of 6.97 mm, while the southern diameters (n=13) range from 4.15-7.13 mm, averaging 6.50 mm. This size is the largest that southern African beads show in the LSA. Southern African beads, however begin decreasing in size from 40 kya towards 5 kya, with a moderate strength, highly significant relationship between bead size and time (n=287, r^2.385, $p<.001$). A Mann-Whitney U test shows a statistically significant difference (U=38,879, $p<.001$) between bead diameters from southern (n=289, 4.75 mm average) and eastern (n=145, 6.60 mm average) from 5-50 kya. Rather than having bead size drift through time as it does in southern Africa, bead size in eastern Africa appears to have remained consistent and large from 5-50 kya. Once again, the southern and eastern OES bead diameters through time are incongruous.

Considering the entire history of OES beads, neither region shows a significant relationship between size and time for the 0-50 kya period (Figure 16). Regression models (logarithmic, inverse, quadratic, cubic, compound, power, S, growth, exponential, logistic) for eastern African diameters from 0-50 kya (n=279) demonstrate no

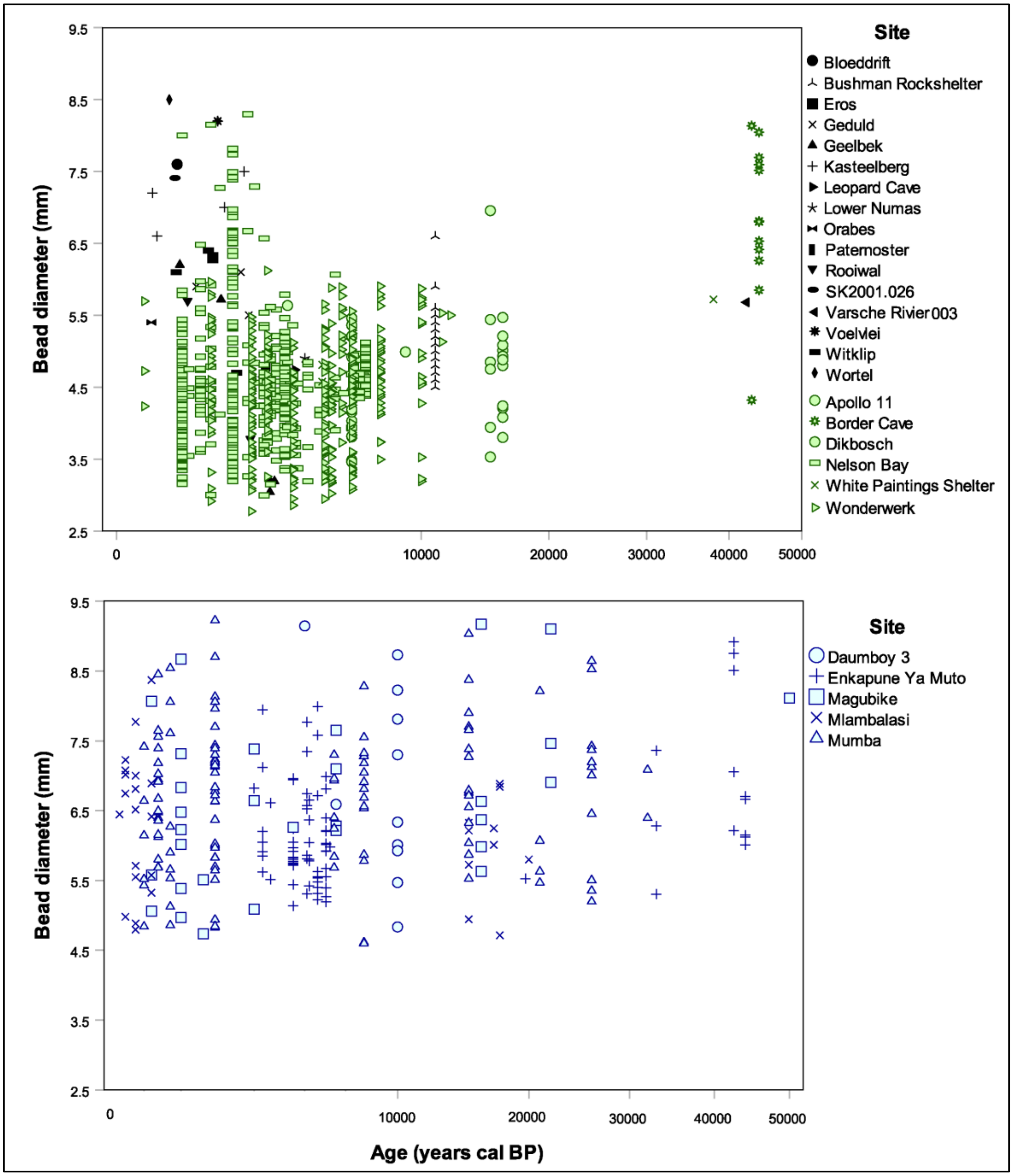

Figure 16. OES bead diameters for southern (n=994, in green), and eastern (n=279, in blue), from 0-50 kya; previously published data (Dayet et al. 2017; Jacobson 1987a, 1987b; Kandel and Conard 2005; Orton et al. 2005; Pleurdeau et al. 2012; Sadr et al. 2003; Smith et al. 1991, 2001; Steele et al. 2016; Yates 1995) shown in black.

relationship between time and size, producing R^2 values between .002 and .017. This range is an unsurprising result, as neither the 0-5 kya nor the 5-50 kya graphs produced a correlation. Southern African beads from 0-50 kya (n=994) also show no correlation between time and size. Regression models provide R^2 values between .001 and .097, demonstrating a weak relationship between the two variables, suggesting that bead diameter and time do not correlate in a meaningful way from 0-50 kya in southern Africa. This observation does not concord with the moderate strength relationship observed from 5-50 kya, and I will explore the potential meaning of this discrepancy in Chapter 5.

Are there characteristics other than diameter that have regional or temporal signatures?

The third question posed at the outset of my study seeks to identify characteristics in addition to the traditionally studied trait of bead size, features which may also vary over time or space. Although I recorded a multitude of variables, the majority of these did not pattern in a meaningful way. In this section, I examine patterning in two previously unknown traits that may be useful for future research into OES bead variation.

Outer Rim Donut Index

Using the Outer Rim Donut Index variable (as illustrated in Chapter 2 and described in Appendix A), I could assign values to 892 preforms. A further 123 preforms could not be accurately assessed due to breakage or cementation. This Outer Rim Donut trait may be evaluated from photos, as long as both the cuticle and mammillary surfaces have been documented. The photographic record permitted the Mlambalasi assemblage to be assessed, but unfortunately the Enkapune Ya Muto collection could not be as there is only a single surface photograph for each specimen. The majority of the preforms I assessed (60.0%, n=536) scored a '0', as they had outer edges that were perpendicular to the shell's surface. A further 5.3% (n=46) scored a '1' (slightly or significantly rounded towards both the inner and outer surfaces), 2 cases (0.2%) scored a '2' (slanted / rounded towards the outer surface), and 3 cases (0.3%) scored a '4' indicating they were slanted or rounded towards both surfaces. The most surprising find was that 34.2% (n=305) preforms had an outer rim that was significantly angled towards the inner surface of the shell (Figure **17**). In profile, this feature gives a funnel-like appearance, with a wider cuticle and narrower mammillary surface.

These preforms with the Outer Rim Donut Index score of 3 (OD3) were not randomly distributed, but present in certain assemblages (Figure 18, Table 5). The highest numbers of OD3 preforms were in the collections from Apollo 11 (41.8%, n=218), Wonderwerk (20.9%, n=64), and Mumba (21.8%, n=14). The Mumba preform assemblage is relatively small (only 65 in total), so its high percentage of OD3 preforms may be misleading. Note that none of these assemblages is solely comprised of OD3 preforms, rather they exist in varying percentages. The trait was also evident in some completed beads (n=58), although usually with a milder angle than on the preforms.

Although more than 1/3 of the preforms I analyzed have the OD3 trait, this ratio is deceptively high. The vast majority of preforms with this trait come from the Apollo 11 assemblage, which not only has the highest percentage of OD3 preforms but also has the highest number of preforms. Specifically, the Apollo 11 assemblage accounts for more than half of all preforms I analyzed (n=547 of 1004). At Apollo 11 the angled rim

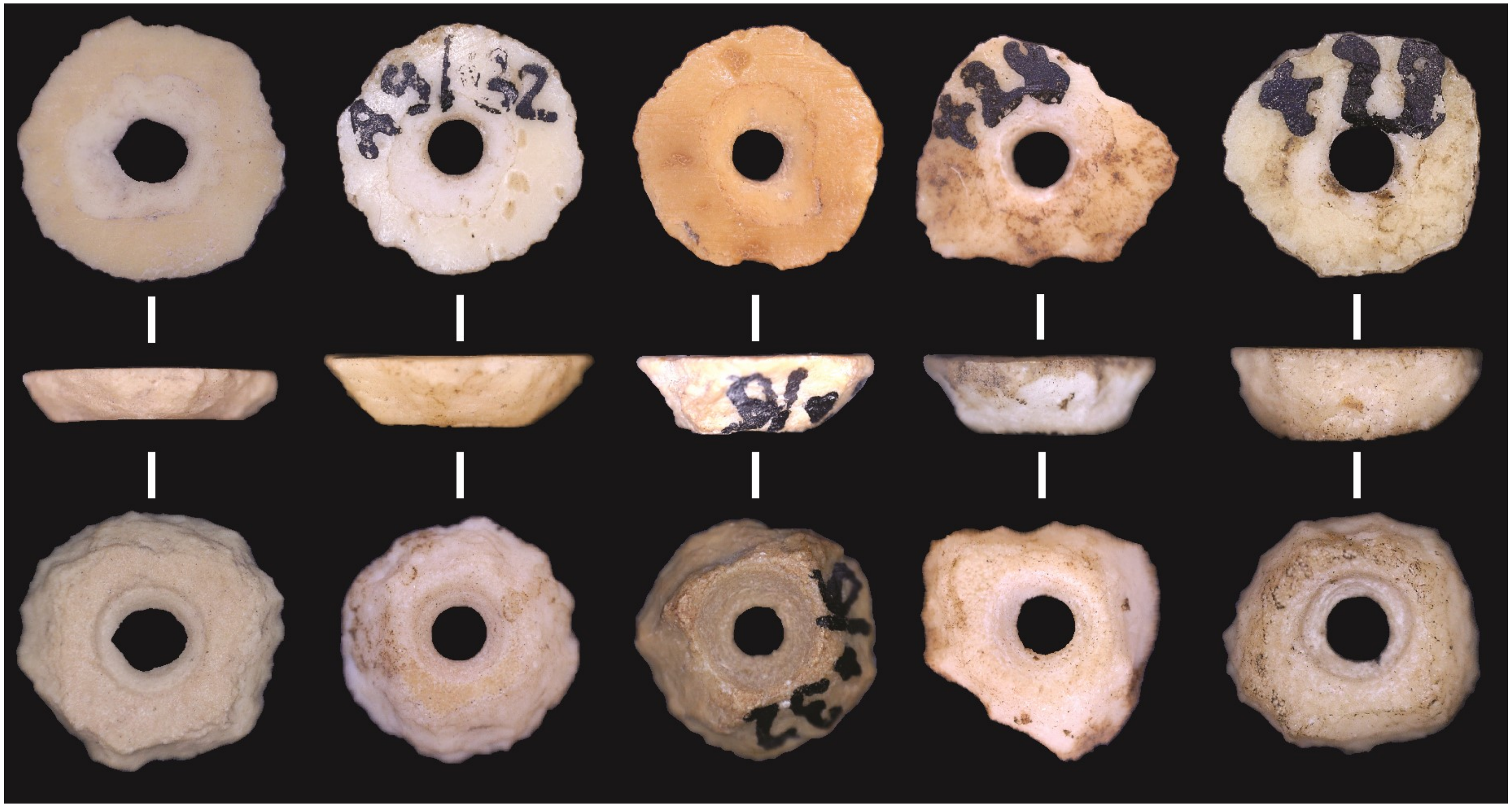

Figure 17. Examples of OES preforms with the Outer Rim Donut Index 3 trait, from Apollo 11.

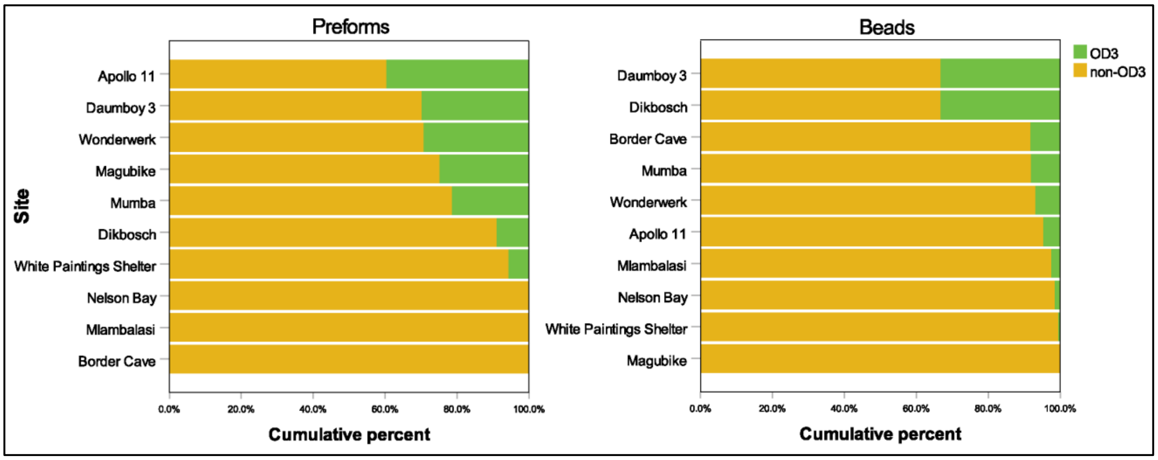

Figure 18. Stacked bar chart showing ratios of Outer Rim Donut Index 3 (OD3) preforms and beads, by site.

Table 5. Table showing ratios of Outer Rim Donut Index 3 (OD3) preforms and beads, by site.

Site	OD3 preforms / Total preforms	OD3 beads / Total beads
Apollo 11 Cave	218 / 547	7 / 169
Wonderwerk Cave	64 / 223	25 / 364
Mumba Rockshelter	14 / 65	9 / 125
White Paintings Shelter	4 / 71	1 / 169
Daumboy Rockshelter 3	3 / 11	4 / 13
Magubike Rockshelter	2 / 8	0 / 34
Dikbosch 1 Rockshelter	1 / 11	1 / 3
Nelson Bay Cave	0 / 20	8 / 535
Mlambalasi Rockshelter	0 / 13	1 / 58
Border Cave	0 / 4	1 / 16

preforms ranged in age from 2-16 kya, with both production Pathways and all manufacture stages showing evidence of this trait. Intriguingly, only 4.8% (n=7 of 169) of the completed beads from Apollo 11 showed this angled rim trait, compared with more than 40% of the preforms. This could suggest that traces of the OD3 trait are largely eliminated during the final shaping of a bead. However, the three preforms from Daumboy 3 Rockshelter with this trait are from later production stages. They are both approximately 10 kya and classified as a 6a in Orton's scheme, which denotes a nearly complete bead with no evidence of use wear.

Examining published photos of beads from other sites, I have observed this angled rim trait in at least two other locations. The SDG2 site in China has the OD3 trait. Although they did not record it as such, it is visible in the worn beads in Figures 9 and 14 of Wei et al. (2017, pp. 97, 99). It is also discernable in photos from Bushman Rockshelter in South Africa, in the Dayet et al. (2017) publication, where they refer to it as a "transverse inside edge profile". It is visible in the authors' Figures 2 (Dayet et al. 2017, p. 638) and 3 (Dayet et al. 2017, p. 641), in both preforms and worn beads. Similar to my dissertation data, not all beads from SDG2 or Bushman Rockshelter have the OD3 trait. If this angling results from a certain way of shaping preforms then it does not appear to be a dominant method at any site.

Pinched beads

This trait was present in the first assemblage I examined during my 2014 data collection. I had not predicted this type of variation, and therefore it does not have a formal coding system. The pinched trait is observed in profile, and occurs when the

Figure 19. Examples of OES beads from Nelson Bay Cave displaying the pinched trait.

opposing cuticle and mammillary surfaces have matching indentations directly across from one another (Figure 19). In a few of the examples, the pinching was evident in more than one place, typically on the opposite ends of the bead. The indentations are smooth and patinated, and I observed these only on finished beads. This concentrated reduction in thickness appears to be the result of intensive use wear, perhaps resulting from a particular pattern of stringing and suspension. This focused wear was so intensive that in some cases the bead appears misshapen at one end, and is a bit flattened rather than rounded.

In total, I examined 1566 beads that had reached completion in the manufacturing sequence, meaning they were a 7a or 7b in Orton's stages. No completed and broken beads (n=86), Stage 7b in Orton's scheme or 12 in Kandel and Conard's, showed the pinched trait, although the specimens from Enkapune Ya Muto and Mlambalasi could not be assessed. Of the 1479 beads that could be assessed, only 2% (n=29) had the pinched trait. The majority of the pinched occurrences are found in the NBC assemblage (n=23). A few other assemblages had examples of pinching, in significantly lower numbers, including Wonderwerk (n=3), Apollo 11 (n=1), Magubike (n=1), and Mumba (n=1).

The pinched beads range in age from 2400-6700 cal BP. This estimate is for 27 of the 29 specimens, as two of them (one each from Nelson Bay Cave and Wonderwerk) do not have associated age estimates. This seemingly narrow period could be the result of a small sample size, rather than a legitimate temporal trend. Even though there were 1479 beads analyzed, only 10% (n=154) of these were older than 7000 years.

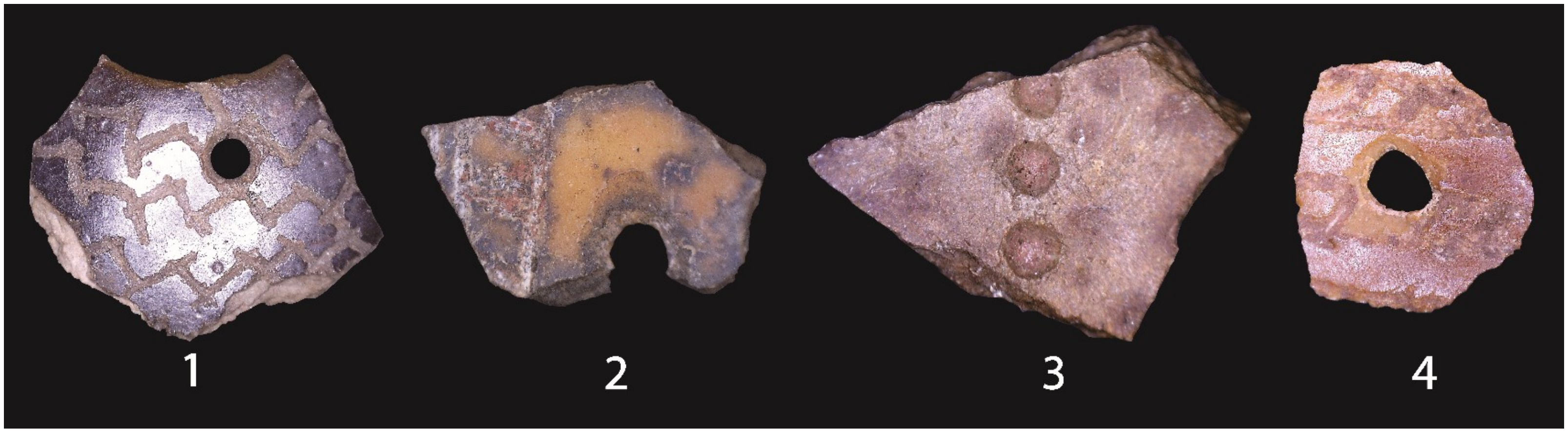

Figure 20. Decorated OES examples; 1- Dikbosch, 2,3- Wonderwerk, 4- Apollo 11; not to scale.

Decorated OES preforms

Some unexpected finds from my data collection included OES preforms with incised decoration on the cuticle surface. In the more than 2500 specimens that I analyzed, there were only three preforms with this type of etching. Figure 20 shows the three specimens, along with one relevant incised fragment that was misidentified by previous researchers as a preform. All are from southern African contexts.

The first specimen is from the Dikbosch 1 assemblage. It was recovered in Layer I C1, which is undated, however the underlying layer dates to 3090 ± 60 BP (Humphreys 1974a, p. 117). The decorated preform is a Pathway 1, Stage IIIa in Orton's system, or a 5 in Kandel and Conard's. It includes a little less than ¼ of an OES container mouth, and has at least three rows of a chevron pattern scratched into the cuticle. The pattern appears to continue off the edges of the fragment, suggesting that the décor was created on a piece of OES larger than the current specimen. The decorated piece does not bear any of the usual shaping associated with preforms, and the perforation is the only evidence suggesting it was being transformed into a bead. The OES fragment was drilled from the inner surface, therefore the aperture must have been created after the shell was broken (and no longer in use as a container).

The next example is from the Wonderwerk Cave assemblage. It was recovered in Layer 4a, the base of which was dated to 4890 ± 70 BP (Humphreys and Thackeray 1983, p. 46). This artifact is approximately 75% of a broken preform, and would be classified as Pathway 1, Stage IVb in Orton's scheme, or 8 in Kandel and Conard's. The cuticle surface bears a ladder-like pattern with traces of a red pigment in and around the grooves. There is no evidence of the container mouth, but similar to the Dikbosch specimen, the incised lines appear to run off the edges as if they were originally scratched into a much larger piece of OES. The perforation is complete, with some minor shaping around the outer edges, which probably occurred when the preform broke and was subsequently abandoned.

A second fragment from the Wonderwork collection appears to be from an OES container, but despite being found in the OES bead collection there are no definitive signs it was a preform. This piece was probably included with the OES beads because of the type of decoration it bears, as other decorated OES fragments were kept in a separate bag. The specimen has three shallow drilled dimples on the cuticle surface, approximately equidistant from one another and in a straight line. The dimples appear to have pigment inside them. This artifact was likely included with the preforms based on the drilling, however I believe these features are decorative rather than functional, for several reasons. First, the holes are drilled from the outer surface of the eggshell, which is extremely uncommon in OES beads. In fact, of preforms with complete or partial apertures that I examined, only 1% (n=9 of 767) had a Position of Restriction rating 2 (significantly towards the inner surface). If the egg were being used as a container, it is unlikely that it would have a hole drilled in it, and it is even less likely that it could be drilled from the inner surface. Second, the dimples are well shaped, with crisp, round cup perimeters, indicating they were likely produced with a hafted drill (Werner and Miller 2018). With a sharp, hafted drill bit, perforating OES takes only a few seconds. If these were failed-attempts at drilling holes, I would expect them to have signs of hand-held drilling, which can up take to 30 minutes to create a single perforation (Werner and Miller 2018, p. 112).

Although this specimen is not a decorated preform, it is useful to note as an example a type of OES container decoration that resembles OES bead manufacture.

The final decorated preform is from the Apollo 11 assemblage. Unfortunately, this artifact was found without provenience information, and it may have become separated while previous researchers were deciding if it should go with the decorated fragments or OES preforms. It is a Stage Va in Orton's system, or a 9 in Kandel and Conard's. Unlike the previous examples, this specimen is close to the end of production and could even be worn as-is. It has at least two rows of ladder-like incised decoration, and some sediment or pigment is present in the grooves.

These specimens make up 0.1% of the 2570 OES artifacts I examined. They are exceedingly rare, but potentially informative about past behaviour. I will explore the significance of these artifacts in Chapter 5.

Summary of results

Through this chapter, I have presented my dissertation results by addressing three primary research questions. I observed that, per previous research, OES bead diameters from southern Africa do show an increased size range from 0-2500 years ago. While the previously published data for southern Africa produced a strongly correlated, negative relationship between size and age from 0-5 kya, this relationship breaks down when using individual bead diameter values rather than site averages. However, a Mann-Whitney U test confirms a statistically significant difference between bead sizes from pre- and post-herding groups from southern Africa. During the 5-50 kya period in southern Africa, the regression relationship is positively correlated, highly significant, and of moderate strength, directly contrasting the 0-5 kya beads and suggesting that some factor(s) began influencing bead styles around 2500 years ago in southern Africa. The pattern of OES bead size in southern Africa is dissimilar to those from eastern Africa, where the range of bead sizes is consistently wide from 0-50 kya and has no significant correlation with time. The most apparent contrast between the regions is evident in the lower limits of bead sizes. The smallest eastern African beads are still larger than the averages of southern African beads from 0-20 kya. A striking similarity between the regions is present from 40-50 kya, when the range of diameters overlap, representing the upper range of southern African OES bead sizes. In addition to diameter measurements, I identified two traits which may be useful in future studies of OES bead variation (pinched beads and Outer Rim Donut Index 3), and reported some decorated OES preforms. In the next chapter, I will explore how these results may be interpreted, and suggest future research directions.

Chapter 5 - Discussion

The previous chapter illustrates that OES beads can retain stylistic information. Not only did I observe regional and temporal differences in diameter, but I also identified two new traits. In this chapter, I add my interpretations, comment on potential errors, and suggest how current and future studies may benefit from this research.

What do beads tell us about the transition to herding?

The transition to food production in Africa is well outside my area of expertise, however it appears that my research can contribute to studies of that period. As proposed in previous studies on OES bead diameter, the sudden appearance of large diameters in southern Africa is the result of a stylistically distinct population (likely herders) bringing new bead styles into the region through migration or trade. There is long-standing debate about how the transition to herding was negotiated in southern Africa with competing hypotheses suggesting diffusion through trade networks, or migration of people (Sadr 2013). By graphing individual bead diameters rather than averages by level, my data show that the small bead tradition that existed in southern Africa before the introduction of herding is still the preferred style after 2 kya. If sites with early evidence of herding consist exclusively of the larger bead sizes, that feature would support physical migration of herders. The eastern African pre- and post-herding era beads are less illuminating. This observation may be due to the patchy nature of the spread of herding in eastern Africa, perhaps the sites I sampled are from areas that never developed the Pastoral Neolithic. Future research into this topic could trace the path of herding into Africa, starting in the Near East, through OES bead styles.

Why are there regional differences in OES bead diameters?

There are several potential explanations for the differences in diameters, any of which could be contributing to the regional trends. The regional differences refer not only to the differences in size between eastern and southern Africa, but also to the changing sizes in southern Africa, and the initial overlap in regional diameters at 40-50 kya. Statistical analyses in Chapter 4, specifically the low p values, demonstrate that the trends are unlikely to be the result of chance, but there are still some potential biases that could influence results. Here I will outline some explanations, beginning with conceivable errors that could be responsible the size differences.

There is some potential that taphonomic disturbance or alteration is affecting the distribution of data. This alteration could include errors in the estimated dates due to excessive movement of sediment, or differences in the acidity of depositional environments. There are very few direct radiocarbon dates on OES beads, and the vast majority of the data for my graph comes from a date for the depositional layer or an estimated date based on surrounding layers. Given the small size of beads (glass and organic alike), they are susceptible to movement through turbulence from wind, water, root growth, burrowing, etc. Taphonomic alteration could also affect the size of the beads, as demonstrated by Wilmsen (2015). If the depositional environment in southern Africa is more acidic than eastern Africa, it may be eating away at the beads, reducing their size.

It seems unlikely that sediment mobility would have played a substantial factor in the diameter trend of the southern Africa, since the distribution is not random. There should be higher potential for taphonomic disturbance with the eastern African beads, as they do not show a correlation with size and age. Many of the assemblages from my dissertation data were excavated decades ago, so it is difficult to assess the quality or attention to detail of the collection methods retroactively.

The only way to eliminate the potential influence of stratigraphic movement is to analyze only those beads that are directly dated, a proposal that would face serious sample size and cost considerations. There are currently only a handful of directly dated OES artifacts from eastern Africa (a list of those dated older than 20,000 cal BP can be found in Miller and Willoughby 2014), so many additional dates would clearly be needed to form a dataset of sufficient size. Radiocarbon dates on shell carbonate typically cost $300-600, so dating 100 samples each from southern and eastern Africa would cost between $60,000 and $120,000. This sum does not include the costs of permits, work visas, flights, shipping, etc. This approach would also result in the destruction of large numbers of artifacts. The southern African beads do not show evidence of significant stratigraphic disturbance, evidenced by their non-random patterning with time. I suggest the eastern African bead distribution likewise be accepted as genuine.

Acidic depositional conditions could break down the OES structure, artificially reducing bead sizes. It is conceivable that the reduction in bead size through time for southern African beads is a result of increasingly acidic sediments. If the natural PH of the environment had decreased from 40-5 kya, then beads surrounded by lower PH sediment would be gradually demineralized, resulting in reduced bead sizes. However, if this situation were the case for southern African beads, then the specimens should have increased evidence of surface degradation in comparison with the eastern African assemblages. Figure 21 shows the relative percentages of artifact scoring in the

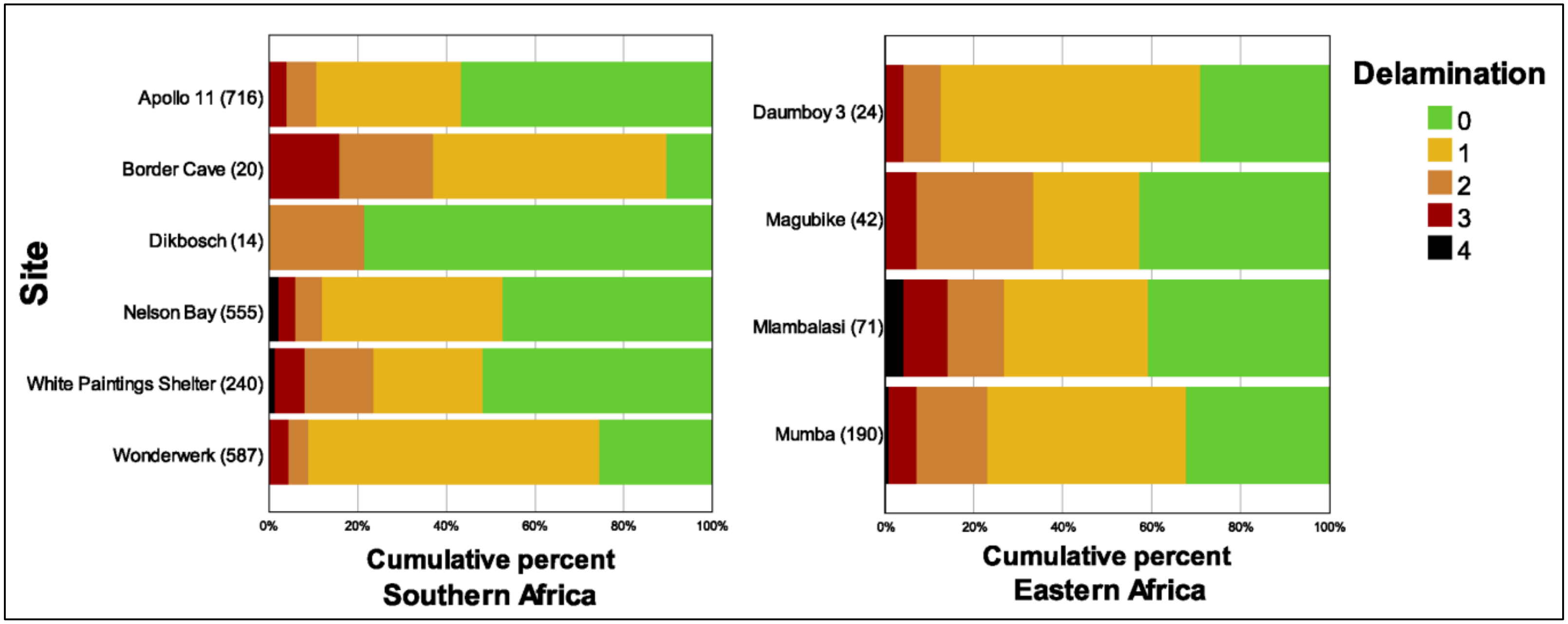

Figure 21. Stacked bar chart of OES delamination scoring, by site and region (n=2459); 0- no delamination, 1-partial delamination of one or both surfaces, 2- complete delamination of one surface, 3- complete delamination of one and partial delamination of second surface, 4- complete delamination of both surfaces.

Delamination category by site and region. Both eastern and southern African collections contain varying percentages of delamination. The relative percentages of artifacts with minimal delamination ratings (scored as 0 or 1) are actually slightly increased in southern African assemblages, suggesting that the preservation of OES surfaces between the two regions is comparable. This observation indicates that acidic depositional environments are likely not responsible for the differences in bead size between eastern and southern Africa.

Another potentially misleading explanation for the differences in diameters is that a functional limitation of the available OES is constraining the range of diameters, resulting in functional (rather than stylistic) variation. Ostriches obtain their dietary carbon almost exclusively from plant material, so the relative abundance of different photosynthetic pathway plants (C_3 / C_4) can be isotopically reconstructed from OES (Von Schirnding et al. 1982). Environmental moisture can be examined through study of OES oxygen istopes, with enriched ^{18}O values reflecting periods of increased aridity, and depleted values representing more humid periods (Lee-Thorp and Ecker 2015, p. 798). No widespread study of OES and environmental conditions has been conducted, although a study by Ecker et al. (2015) found that OES at Wonderwerk Cave varies in shell thickness, pore density, and pore width when comparing fragments from 5 kya to those from 1 Mya.

Bead thickness might provide an independent means of assessing non-stylistic variation through time. To assess whether my data have a pattern of shell thickness through time or by region, I must exclude cases with evidence of factors that alter thickness. First, the act of wearing OES beads will alter their shape, diameter, and thickness. I rejected any beads that had reached completion (denoted by the presence of refined shaping and / or use wear) to avoid reduction in shell thickness due to use wear. Second, archaeological shell can also be worn thinner by an acidic depositional environment, which eats away the shell, as discussed by Wilmsen (2015). I rejected any cases which scored more than a 1 in my Delamination index (0- no delamination, 1- minor delamination of one or both surfaces, 2- complete delamination of one surface, 3- complete delamination of one surface and partial delamination of the opposing surface, 4- complete delamination of both surfaces). Eliminating specimens with these criteria reduced the potential effects of taphonomic degradation.

The remaining specimens that had age estimates and thickness measurements (n=370) were graphed into a scatter plot of age against maximum shell thickness, with regional distinctions (Figure 22). Note that there are far more southern than eastern specimens, as the majority of OES preforms come from a single site in Namibia. There are no linear or non-linear correlations between shell thickness and time, nor any major differences between regions. The findings of Ecker (2015) suggest that OES thickness (and pore characteristics) would be useful in examining smaller scale environments or larger time depths. Nevertheless, for my purposes, there is no evidence that natural variation in shell size through time is responsible for the regionally distinct bead diameters.

Having discussed possible biases that could explain the regional differences in bead size, I move now to three culturally and evolutionarily meaningful explanations. My research focuses on human evolution, and so I find the overlapping of diameters in southern and eastern Africa at 40-50 kya (and their subsequent divergence) to be the most

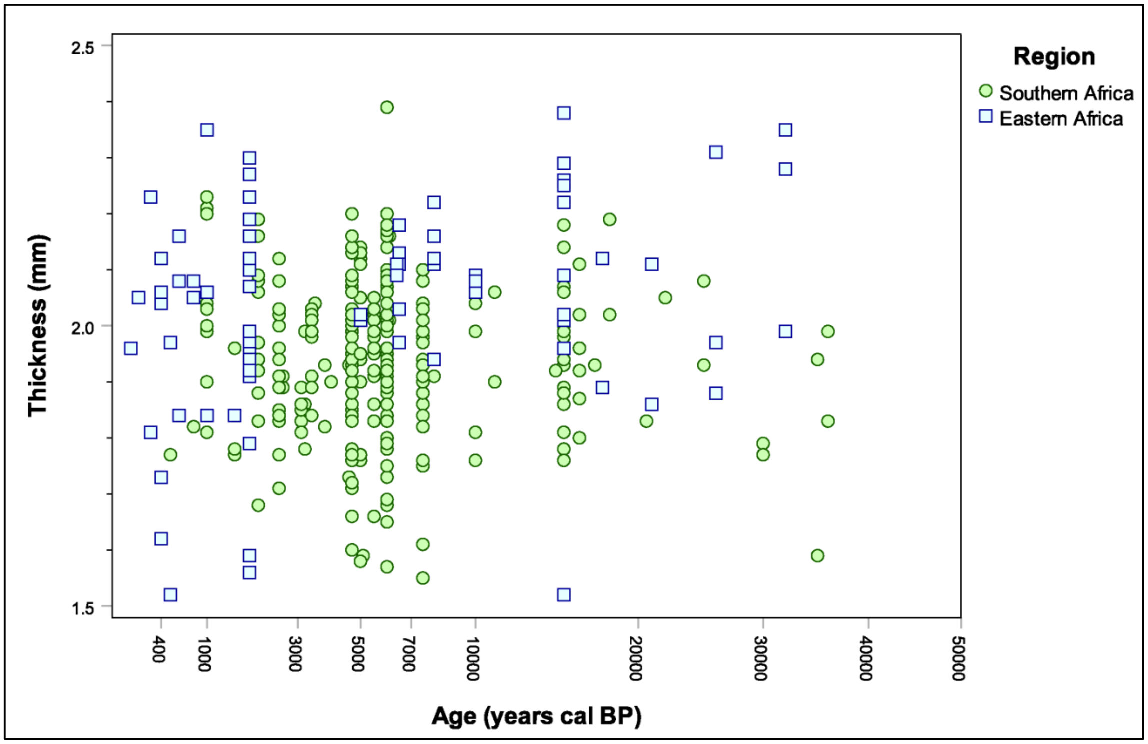

Figure 22. Shell thickness of OES specimens (n=370), by region.

compelling part of the data. As summarized in Chapter 1, the oldest known OES beads come from eastern Africa, where between 40 and 50 kya OES beads are present at Mumba, Magubike, and Kisese II in Tanzania, as well as Enkapune Ya Muto in Kenya. The earliest known southern African beads are from Border Cave (South Africa), and date to approximately 40 kya. According to Google Maps, the approximate walking distance between EYM (the northernmost site), and Border Cave (the southernmost site) is nearly 4000 km, and would take an estimated 750 hours of walking along modern roads. Direct contact between MSA people at these distances is a virtual impossibility. Given the principles of Social Network Analysis and Isolation by Distance (as mentioned in Chapter 2), these regions should not share stylistic similarities in their beads. No social network relationship ties would exist between these two regions, so there would be no direct flow of cultural norms. IBD suggests these regions should have random and likely dissimilar style characteristics, yet, the OES bead diameters between these two regions, at this earliest period, are nearly identical.

There is a chance that this bead similarity results from a shared cognitive similarity among all humans. The earliest known beads, those preceding OES beads, seem to have independently developed at the extreme northern and southern ends of Africa. Although these early beads were collected rather than manufactured, they do share some stylistic similarities with each other. These are natural shells, typically from marine species, and not more than a few centimeters in length. It has not been necessary to invoke the idea of contact between these MSA people to explain these similarities in decoration, so perhaps it is unwarranted to suggest that social networks are required to explain OES bead likenesses. Perhaps some evolutionary predisposition led people to create, or seek out, beads of a similar size and shape. There is certainly some constraint on bead sizes, as it would not be practical for them to be microscopically small, nor so large that they impede the wearer. Likewise, the size of a bead's aperture is constrained by the thickness of available string.

An intellectual predisposition to ornaments would help explain why shell beads independently emerged at opposite ends of the continent, why the earliest OES beads have similar sizes, and why personal ornaments are now a cultural universal. Exploring this cognitive approach further could involve comparing the size and forms of shell beads in the MSA, to document how their sizes relate to the OES beads that come afterwards. In addition to the visual properties, the tactile and auditory traits of these early beads could be explored. Perhaps the sensation of rubbing a smooth shell or hearing the beads clack together elicits an anxiety-reducing response, the way that people today play with a fidget spinner or absentmindedly click a pen. Or maybe OES beads were produced as a specific ratio of body size, such as the width of a pinky finger's nail bed (mine is 8.24 mm). While these avenues could explain a predisposition to bead size, they would not explain why the southern African OES beads reduce in size through the LSA, or why they show sudden increased variation with the introduction of herding.

A tantalizing explanation for the similarities in bead size is that a shared, extended social network linked eastern and southern Africa at 40-50 kya. Face-to-face contact between people from Enkapune Ya Muto, Kenya, and Border Cave, South Africa, would not be possible, but goods, knowledge, or aesthetic preferences could have passed between neighbouring groups, eventually making their way over the large distance.

Through trading, migration, knowledge sharing, or mimicking, stylistic norms could have flowed between social networks in eastern and southern Africa. In a simplified social network model, node A connects with node B, and B connects with C. There is no direct tie between nodes A and C, but they are indirectly connected through node B, and this common connection means that all three can be influenced by the same social norms.

With this hypothesis, OES bead technology would appear to have originated in eastern Africa before spreading rapidly south. There are four eastern African sites with OES beads from 40-50 kya (Enkapune Ya Muto, Kisese II, Magubike, and Mumba), compared to the one southern African site of Border Cave. Further, Border Cave is located in the northeastern portion of South Africa, and contains only a small number of completed OES beads with no evidence of *in situ* production. This observation may suggest that the Border Cave beads were produced elsewhere, perhaps eastern Africa, and transported to South Africa in their finished form.

One of the hallmarks of modern human behaviour is the development of long distance exchange networks, and these are observed in the MSA through obsidian sourcing. Obsidian is a prized tool stone material, and chemical analysis can determine its exact origin. Some sites in the MSA of eastern Africa have evidence of obsidian found more than a hundred kilometers from its source (Blegen 2017; McBrearty and Brooks 2000). But, the hundreds of kilometers that obsidian was moved during the MSA is orders of magnitude smaller than the nearly 4000 km between the earliest instances of OES beads. Regardless, the obsidian data demonstrates that even in the MSA, people had established networks for obtaining exotic goods.

I suggest that OES beads would have the potential to move greater distances along trade networks than tool stone, based on their novelty. By the end of the MSA, stone tools had been around for millions of years, and while high quality stone is prized, it is a regular part of subsistence activities. On the other hand, seeing beaded adornment for the first time would be a striking experience. While some places had developed marine shell beads in MSA, it does not appear to be a widespread innovation. Beads were probably unknown to many people before they first encountered OES beads.

In addition, the small size and light weight of OES beads may have made them easier to transport than stones. Using data collection by Willoughby from Magubike Rockshelter (Iringa, Tanzania) as an example, MSA cores from Test Pit 5 weigh an average of 22.9 g (n=282). Cores from LSA layers in the same unit have a lower average weight of 9.7 g (n=418), however these tend to be heavily reduced or "exhausted", and are unlikely to be curated for further use. A survey of lithic raw material sources in Iringa, Tanzania, revealed large chunks of low quality quartzite ranging from approximately 500 g – 2 kg, while moderate quality chert nodules rarely reached 300 g (J. Werner, pers. comm.). On the other hand, OES is durable and lightweight, with late stage preforms and beads from Mlambalasi Rockshelter weighing an average of less than 0.1 g (n=66). With this estimate, 1000 OES beads would weigh only 100 g (excluding the weight of cordage), while the same weight in lithic material from Iringa would comprise one small chert nodule, or 4 small MSA cores.

Not all lithic material would have been transported as cores, but as least some was. Finished tools would be lighter and easier to transport. Additionally, knapping stone tools is a skill which takes years to perfect. An expertly produced tool may have a higher trade value than a core. However, evidence from the Sibilo School Road site in Kenya shows that at least some stone was transported in the MSA in an unfinished form. Refitting of excavated material shows evidence for *in situ* knapping of Levallois flakes, with material that was originally sourced more than 166 km away (Blegen 2017). A rare or high quality material such as obsidian would probably alter the cost-benefit breakdown, but pound-for-pound the trade value of OES beads may be higher than for tool stone.

Whatever the reason for the initial overlap of bead diameters, the subsequent reduction of southern African bead sizes is intriguing. If a shared network at 40-50 kya was responsible for the similarities in bead form, then the subsequent divergence in bead diameters seems to indicate a breakdown of this network between 20-40 kya. Large scale networks can be disrupted by any number of things. One potential disruptor that has been examined in sub-Saharan Africa is environmental instability. When environments undergo change, humans are forced to adapt. Biogeographic barriers may form that limit the movement of fauna, thereby affecting food sources and dispersal patterns for migrating people (Faith et al. 2016; Timmermann and Friedrich 2016). Technological innovation and land use strategies have also been documented to coincide with environmental change (Kusimba 1999; Wilkins et al. 2017). Unfortunately, the lack of data on bead diameters from 20-40 kya in southern Africa makes it impossible to speculate whether environmental changes correspond with the changes in bead diameters. A next step should be to seek out OES beads from the 20-40 kya period in southern Africa to help narrow down when the regional divergence occurs.

The cause of the divergence in regional bead sizes is unknown, and so is the reason for the reduction in southern bead sizes. They could conceivably have shrunk due to changing tastes, transmission errors, limited availability of OES, or any number of other reasons. Previously, Wilmsen (2015) suggested that the bead size (and degree of fine shaping) varies with the type of garment (e.g., headband, necklace, apron, bags), an explanation which he based on examination of ethnographic OES items from the Kalahari. If this explanation also applies to prehistoric OES beads, then it suggests the regional bead trajectories result from different garment types. From this perspective, the shrinking of southern diameters may represent a narrower range of uses for OES beads in southern Africa, and a wider range of garment and decoration types in eastern Africa.

Another suggestion is that regionally distinct wealth sharing practices are responsible for the difference in bead sizes. Intuitively, OES beads should shrink in diameter or thickness as a result of wear. Beads that have been passed down through generations then should have smaller diameters than newer beads. If property was inherited in southern Africa, but interred with an individual in eastern Africa, then this custom could play a role in the regional diameter differences among OES beads. This hypothesis cannot be directly tested, but modern ethnographic data can provide a starting point to examine this premise. A cursory review of the literature reveals that information about the transfer of property in written accounts was not always documented. In a personal communication from well-known anthropologist Polly Wiessner, Jacobson (1987a) quotes her as saying: "…in the Kalahari at least, amongst the San the possessions of a deceased person are distributed to exchange partners and are not interred with the body," (Jacobson 1987a, p. 57). This same practice was referenced in an ethnographic account from Bleek (1928, p. 10) who writes that daughters inherit the OES beads of their mothers among the Naron in Botswana (southern Africa). These two accounts of bead sharing in southern Africa support the idea that property sharing could influence size changes, however this hypothesis also requires that eastern African communities do not transmit property in this way. The one eastern African account I found was by Hollis (1909, p. 73) about the Nandi in Kenya, and he notes that intergenerational transmission of OES beads is practiced. These three examples are not sufficient to support or refute this hypothesis, and I suggest that a review of ethnographic literature and archaeological internments could help determine if this avenue has merit.

I have presented a number of suggestions for why there are regional variations in OES bead diameters. Ultimately I do not believe that any single explanation is sufficient to justify the history of change and stasis among OES beads. It is likely that bead diameters are the result of a complex interplay of factors, the relative weights of which shifted over time with technological advances and social evolution. These suggestions are starting points for future inquiry into OES bead size.

Pinched beads

The cause of the pinched appearance of some beads is not definitively known, but I think use wear is the most plausible candidate for its creation. One potential non-use wear explanation is that the pinching is a random phenomenon arising from either the production or use of beads. For example, during the trimming stage of bead manufacture a larger than intended piece of shell may detach, leaving an indented flake scar near the perimeter of the bead or preform. This indent could later smooth out through normal use, resulting in the smoothed indents in the edge of the bead. However, this occurance would be unlikely to create indents in opposing surfaces by chance, and there would be far more beads with randomly placed, single surface indentations. Further, the presence of the pinching trait is not randomly distributed amongst the beads analyzed, and has only been identified on completed and worn beads, not on preforms.

If pinching is the result of use wear caused by a specific display pattern, then the next step in this issue is to link stringing patterns to use wear. Intuitively, OES beads that are strung back-to-back, so that the resulting sequence resembles a roll of pennies (Figure 23), should not develop pinching. In this configuration, use wear should be concentrated evenly around the perimeter of the bead, and on the cuticle and mammillary surfaces. This formation should enhance circularity, increase outer rim patina, and influence the Outer Rim Donut Index towards a 0 rating (90° angle between outer rim and shell surface). The pinched use wear likely results from sewing or otherwise fastening a bead across one edge. While a simple thought experiment is useful to predict roll of pennies pattern use wear or the attachment of a pinched bead, the ethnographic record documents many alternative patterns that are not straightforward to predict (see Figure 24 for examples). These variations should be examined in the future by experimentally stringing modern OES beads in ethnographically-documented patterns.

OD3 beads and preforms

The production of OES beads spans the transition from stone and bone to metal implements, and it makes sense that the production techniques would have evolved as

Figure 23. Modern OES bracelet in a roll-of-pennies configuration; photo by S. Halmhofer.


Figure 24. Examples of variation in OES stringing patterns; adapted from Wilmsen 2015, p. 97.

well. Previously, the only production variants to be recorded were the manufacturing Pathways. In my study of OES beads, I observed a variant of the manufacture sequence while experimenting with OES bead drilling techniques (see results in Werner and Miller 2018), we found that breaking OES into polygonal pieces can be achieved with accuracy and ease. However, finer trimming around the edges of the beads was impossible without the aid of tools. Rough shaping was achieved by grasping a fragment between the thumb and forefinger of each hand, and applying a moderate amount of force. It seems to work equally well from the inner or outer surfaces of the shell, and I used the edge of my thumbnail as a pivot point to help direct force.

Methods for trimming OES preforms are mentioned only casually in ethnographic literature. Some accounts noted preforms being trimmed with a piece of horn, bone, or stone (Bleek 1928, p. 9; Schapera 1930, p. 66; van der Post and Taylor 1984, p. 88). They do not describe whether the action takes place with free hand percussion, indirect percussion, or pressure flaking. A more recent ethnography (Wingfield 2003) describes OES trimming taking place with nail clippers. Each of these techniques could theoretically create a slightly different pattern on OES preforms, and these patterns may be discernable in the archaeological record. Some ethnographic accounts describe that fine trimming took place while a number of beads were strung together (Hahn et al. 1966; Schapera 1930; Wingfield 2003). In these cases, the direction of trimming (from the cuticle or mammillary surface) would be random, unless care was taken to thread every preform in the same direction. As unlikely as this seems, it procedure may have unintentionally happened, as in practice it is slightly easier to thread preforms from the side with the larger cup perimeter. This is the inner surface of the shell, almost without exception.

In practice, OES bead trimming typically appears as tiny, irregular-looking flake scars, somewhat similar to those observed on lithics. They are most visible on the outer surface, as the thin glossy cuticle becomes jagged when the shell is broken, exposing the palisade layer underneath. The outer rim of the trimmed bead is roughly perpendicular to the surface of the shell, at roughly a 90° angle.

The shape of the outer edges of a preform appears to relate to some aspect of bead manufacture. If the resulting OD3 variable were a natural result of shell fracture, then it should be randomly distributed amongst all sites, which it was not. I suggest that it is the result of a specific trimming technique. The unsystematic distribution of OD3 preforms suggests that the trimming technique that produced it probably arose independently in several regions.

Future experimental work could be used to reconstruct the techniques responsible for this trait. In Plug's 1982 article, she implies that it is possible to determine whether a bead preform was trimmed by striking the inner or outer surface of the shell, and she further suggests that beads trimmed from alternating surfaces are only found in levels 12-15 of Bushman Rockshelter, indicating that this could be a culturally specific practice. Unfortunately, Plug does not write how she assessed trimming direction, although I suspect that it involved examining flake scars on the cuticle surface. The act of shaping an OES preform leaves behind traces which may have culturally encoded components, and these should be explored in the future.

Recycling in the Stone Age

The decorated OES preforms presented in Chapter 4 appear to be fragments of OES containers that were subsequently used for beadmaking. The practice of recycling broken OES containers into beads was briefly documented in ethnographic accounts, but to my knowledge it has not been recognized in the archaeological record.

Ostrich eggs were a valued item, both for their ability to hold liquid, but also as a material to make durable beads. At least two ethnographic accounts note that when accidentally broken, an OES container may be repurposed into bead-making material (Shostack 1976; Silberbauer 1981). As mentioned in Chapter 1, the use of OES containers may date back to the MSA, as incised fragments were recovered from Diepkloof Rockshelter. Since both OES beads and containers have been produced for tens of thousands of years, it seems probable that the practice of recycling broken containers into beads also existed over this same stretch of time.

Identifying proof that OES containers were recycled into OES bead making material requires very specific evidence. OES beads would have to fall out of the manufacture sequence at exactly the right stage to be both identifiable as a decorated shell and as a bead preform. Finding decorated fragments of OES would not be sufficient. There must be some evidence these pieces were being transformed into beads, otherwise they may just represent a broken OES container. In pictures of archaeological and ethnographic examples, decorations on OES appear to encircle the circumference of the egg in one or more bands of décor, so not all broken pieces from an egg with decoration will show evidence of it. Further, intensive manufacture or wear on the cuticle surface of a bead may obscure decoration marks. Evidence of ancient recycling of a container into beads would then exist only in a very small percentage of OES preforms, and possibly some completed beads.

The specimens described in Chapter 4 are to my knowledge the first archaeological OES preforms to be asserted as container fragments. As all three are from museum collections, I suspect the excavators were probably aware of their existence. It seems unlikely, however that they appreciated their rarity or potential significance. Future analysis should try to document this trait when present to help assess the distribution of OES container use and recycling in the Stone Age.

What other collections should be examined?

The assemblages of OES artifacts in my dissertation are dominated by southern and eastern African sites, however this is not the full geographic distribution of OES bead assemblages in sub-Saharan Africa. The abundance of palaeoanthropological research into eastern and especially southern African sites has likely contributed to profusion of well-dated and well-published examples in these areas. Intuitively, there should be early LSA OES assemblages that span the region between my eastern and southern collections. Through my graduate research I have come across references to OES beads that are significant because of their age or location. Table 6 is a list of OES bead collections that merit further study, and their approximate locations are shown in Figure 25. This is not a comprehensive list of sites with OES beads, rather this table highlights some special cases in Africa that could be considered in future research.

Table 6. Other OES bead collections; numbers correspond to Figure 25.

Site	Country	Age	Reference(s)
1.Wakrita	Djibouti	Neolithic	Gutherz et al. 2015, p. 62
2.Asa Koma	Djibouti	Neolithic	Gutherz et al. 2015, p. 56
3.Lake Besaka	Ethiopia	19-22 kya	Brandt 1986, p. 71; Clark and Williams 1978, pp. 27, 35
4.Goda Buticha	Ethiopia	5.5-7 kya	(Pleurdeau et al. 2014, p. 119)
5.Matupi Cave	Democratic Rep. of Congo	2-12 kya	Brooks and Robertshaw 1990, p. 155; van Noten 1977, p. 36
6.Panga Ya Saidi	Kenya	20-45 kya	Shipton et al. 2018, pp. SI11, SI31
7.Hora 1 & Mazinga 1	Malawi	9.5-30 kya	J. Thompson (pers. comm.)
8.Txina-Txina	Mozambique	25-34 kya	Bicho et al. 2018, p. 6
9.Duncombe Farm	Zimbabwe	LSA	Brooks and Robertshaw 1990, p. 144; Walker and Wadley 1984
10.Pomongwe	Zimbabwe	11-15 kya	Brooks and Robertshaw 1990, p. 141
11.Mirabib Hill Rockshelter	Namibia	5-6 kya	Sandelowsky 1974, p. 71
12.Byneskranskop	South Africa	12-14 kya	Deacon 1990, p. 180
13.Die Kelders	South Africa	LSA	Avery et al. 1997, p. 271
14.Elands Bay Cave	South Africa	11 kya	Mitchell et al. 1998, p. 106; Parkington 1990, p. 219
15.Heuningneskrans	South Africa	Early LSA	Deacon 1990, p. 172
16.Kangkara	South Africa	12-14 kya	Deacon 1990, p. 180
17.Rose Cottage Cave	South Africa	6-13 kya	Wadley 2000, p. 98, 2001, p. 214
18.Varsche Rivier 003	South Africa	42 kya	Steele et al. 2016, p. 117

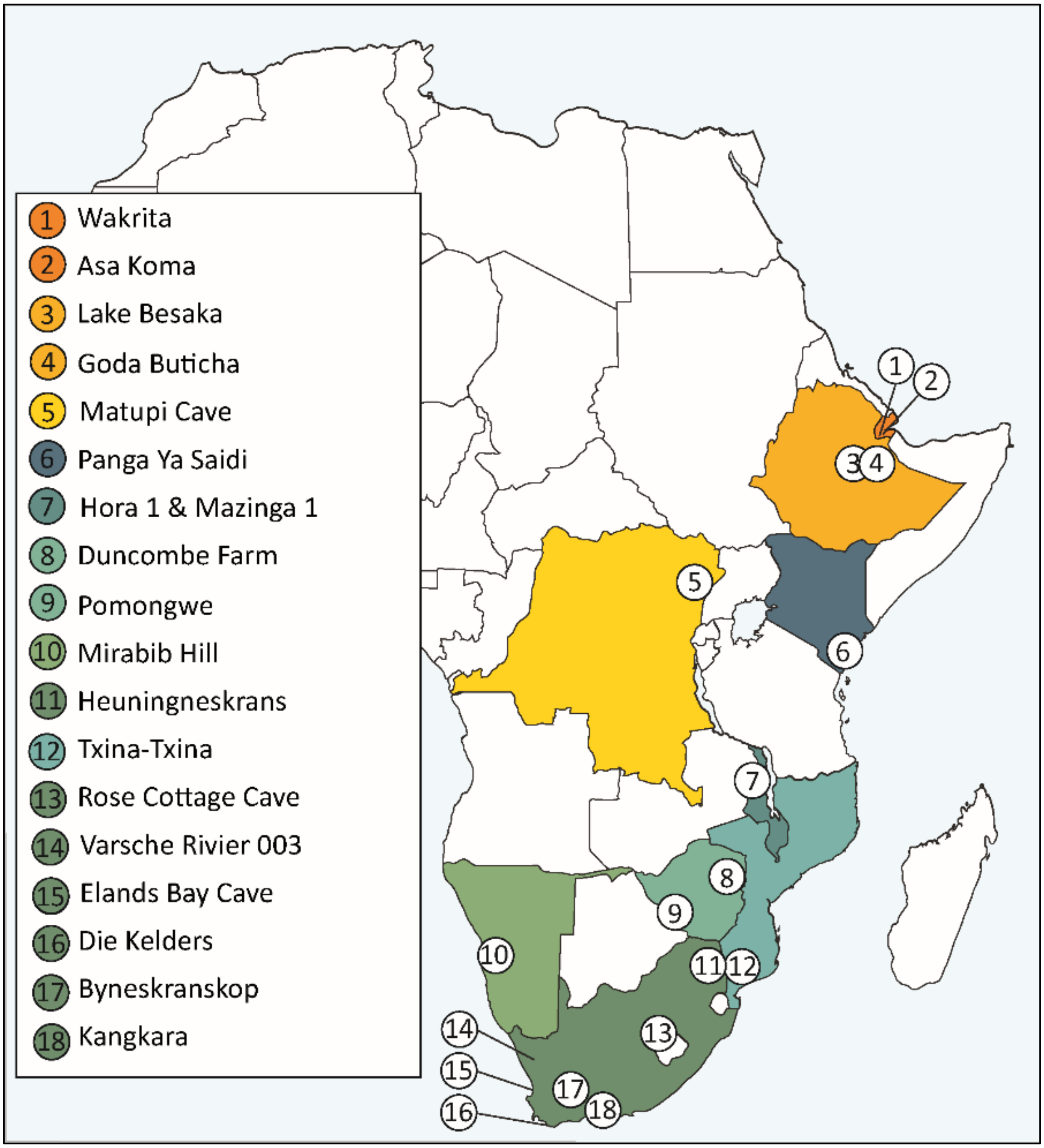

Figure 25. Map showing approximate locations of other OES bead collections.

Chapter 6 - Conclusions

OES beads are powerful symbols that can provide insight into ancient human relationships. Beads are among the first symbolic ornaments to appear in the archaeological record, and they document that important societal changes are taking place during the MSA. In this dissertation, I systematically analyzed OES beads from eleven archaeological assemblages for variation in form. The results are not only unexpected, but expose provocative questions that can be examined in future studies.

Symbolic artifacts appear relatively late, when considering the time depth of the hominin lineage and material culture. The earliest members of the Tribe Homimni lived in Africa between 4.3 and 7 Mya (Wood and Lonergan 2008), and while there is no evidence of tools from this time, this observation may be a preservation issue rather than actual evidence of absence. The oldest stone tools date to approximately 3.3 Mya, and can be found in eastern Africa (Harmand et al. 2015). Several fossil species lived in Africa during this time, so it is unclear which of these may be responsible for making these tools but they predate the genus *Homo*. It is not until millions of years later that symbolic artifacts become evident in the archaeological record.

Subsequent technological advancements often coincided with the appearance of new fossil hominin species, indicating a possible connection between biological and cultural evolution. This relationship is most apparently during the MSA / MP, when hominin species that had been producing comparable technology begin to show divergent behaviour. *H. sapiens* in Africa show bursts of technological and cultural innovation beginning approximately 100 kya that are unparalleled among contemporary hominins, and include advanced lithic technology and personal ornaments. Neanderthals may have been developing similar advances, although the evidence for this hypothesis is less robust, and appears much later than it does in humans, approximately 50 kya. It is also possible that other contemporary species, such as Denisovans (Reich et al. 2010), *H. floresiensis* (Sutikna et al. 2016), or *H. naledi* (Dirks et al. 2017) were producing LSA / UP culture, but not enough is known about their material culture, and signs of innovation are typically assigned to human occupation. We are the only hominin species remaining, a situation that suggests some biological or cultural trait(s) conferred an advantage that other species didn't have.

The earliest symbolic artifacts are beads. These first appear in the MSA / MP of the Near East and Africa, often in the form of unmodified marine shells (e.g., Bouzouggar et al. 2007; d'Errico et al. 2005; Vanhaeren et al. 2006). Sometimes an aperture was created, at other times a naturally perforated shell was collected, but these earliest beads all retain the appearance of the original shell. Some thousands of years later people began manufacturing beads made from OES. These are not as ancient as the marine shell beads, but they are the first to have a fully imposed shape, meaning the resulting bead does not resemble the original ostrich egg. They are also the first mass-produced ornaments and have a high degree of standardization. OES beads have always tended to be round discs, less than a centimeter in diameter, with a central perforation. This feature is true of the earliest examples of OES beads at 40-50 kya, and also true of the modern OES beads produced and sold in tourist shops today.

Scholars have examined the utility of symbolic communication in attempt to reveal the driving force behind its evolution. A challenge of using this kind of communication is that the sender and receiver must have a shared framework for interpretation, otherwise the message will not be understood. One suggestion is that wearing symbols developed as an effective way to convey information in a large community in which not everyone directly knows one another. This system would efficiently balance the costs of ornament production with the benefits of conveying information to culturally similar strangers (Wobst 1977; Kuhn and Stiner 2007a), although social niceties do not need to be efficient. Another hypothesis is that symbols developed to indicate ownership or commodification of resources. An example of this explanation may be the engraved OES containers that are used in the present to store liquids in the Kalahari Desert (Dunn 1931; Humphreys 1974a; Marshall 1976). Similar fragments of engraved OES have been recovered from MSA levels at Diepkloop Rockshelter, South Africa (Texier et al. 2010), suggesting that this practice has ancient roots. The emergence of social stratification or increased dependence on group affiliation may also have contributed to the development of symbolic communication. These artifacts that appear during a crucial stage of human evolution can reveal insights into the minds and lives of Palaeolithic people.

Previous research into OES beads has focused on diameter. Initial work by Jacobson (1987a,b) observed a shift in bead sizes when migrating herders entered Namibia approximately 2500 years ago. Specifically, he observed that mean diameters of beads older than 2500 years (up to 4800 years BP) were smaller, while those younger than 2500 years were larger. Over the next 20 years, subsequent studies by Smith et al. (1991, 1995, 2001), Sadr et al. (2003), and Orton et al. (2005) generally confirmed the diameters change with the introduction of herding. This shift to larger bead diameter has informally come to represent the migration of herders into southern Africa.

OES beads are constrained very little by function, so the majority of their form is the result of stylistic variation. These subtle bead traits are cultural encoded, meaning that people of the same culture will tend to do things in similar ways. A theoretical framework that describes this element of culture is Social Network Analysis. It explains the flow of information, resources, and influence within populations by explaining that those with shared relationship ties will homogenize their behaviour and styles under the weight of social influence (Otte and Rousseau 2002; Borgatti et al. 2009). SNA also suggests that people from different populations, who have no shared relationships, will become increasingly different as the new cultural norms shape in isolation (Neiman 1995). This hypothesis is similar to how projectile points or pottery décor are emblematic of particular cultures. OES beads also retain stylistic variation.

Today it is relatively easy to maintain ties across distances, however geographic distance would have restricted the range of social relationships in the past. In the Stone Age, then, the potential to transmit social information in the Stone Age should decay with distance, as proposed by the Isolation by Distance model (Wright 1943). Barring cases of convergent evolution which should affect only functional variation, stylistic variation that spans large distances is likely the result of a shared social network.

OES bead characteristics then can be a proxy for the shifting structures within ancient populations. While the previous studies have confirmed a change in size over time, these were all geographically restricted to the western part of southern Africa, and temporally limited to the last 5000 years. The use of OES beads, however extends at least 50,000 years into the past and spreads over diverse regions. In addition, diameter was the first characteristic to be identified, but other variables may exist. My research is the first multi-component analysis to examine OES beads from the Middle and Later Stone Age across eastern and southern Africa.

My dissertation data consisted of 2570 OES artifacts (1566 beads and 1004 preforms), from eleven collections in Kenya, Tanzania, Botswana, Namibia, and South Africa. No single collection spans the entire history of OES bead use, but together the eleven assemblages span modern times to 50,000 years ago. At the outset of my research, I sought to examine three questions, which I will summarize here:

- What happens to the size of southern Africa OES beads older than 5000 years?

The negative correlation between size and time identified in previous research actually reverses. My data show that beads older than 5000 years have a positive, moderately correlated, and highly significant relationship between age and size. A scatter-plot of bead diameters through time resembles a check mark, in which the two peaks of large diameters are the most recent period (0-2500 years ago) and the oldest period (40-50 kya).

- Does this trend of diameter change also exist in other regions of Africa?

No, OES bead sizes through time are not mirrored between eastern and southern Africa. While southern African beads go through periods of fluctuation, eastern beads retain a relatively consistent range through the entire history of OES bead use (0-50 kya). Further, the eastern African beads show no statistically significant change between pre and post herding periods. However, these results should be interpreted cautiously, given the patchy introduction of herding into eastern Africa.

- Are there other bead characteristics that may have regional or temporal signatures, which may symbolize Stone Age cultures / ethnic identities?

Yes, I observed two previously undocumented traits that appear to vary with region or time. The first trait (OD3) is visible as a considerable rounding or slanting of the outer edges of a preform or bead towards the mammillary surface. It is present on both preforms and some completed beads, and appears to result from a specific manufacture technique. OD3 beads and preforms are mostly in southern African sites (with the highest numbers at Apollo 11 Cave, Namibia), although smaller numbers of these can be found in eastern Africa assemblages, and based on published photos they also present at the SDG2 site in China. The second trait (pinching) occurs when the opposing mammillary and cuticle surfaces have matching, smoothed indentations, as if they had been pinched together. This trait is only on beads, not on preforms, an observation which suggests that it is a use wear pattern occurring only after completion. The pinched bead trait and the angled rim preform traits (OD3) should both be assessed in future work through a review of ethnographic research and experimental replication.

While previous research into OES beads examined the variation in diameters from 0-5 kya around a limited region, my dissertation expands this knowledge to encompass beads from 0-50 kya throughout southern and eastern Africa. This tenfold increase in time depth revealed that the previous understanding of bead size and its link to the first herders was incomplete. My research demonstrates that the question of bead size is not as simple as linking herders with larger beads, but rather suggests that bead diameters represent long-standing traditions of continuity.

This dissertation has only scratched the surface of the potential for OES bead analysis, but has demonstrated that these decorative handicrafts are more than mere ephemera. OES beads are physical evidence of past technology, but also a window into the social lives of Palaeolithic people. The emergence of beads in the Palaeolithic is a tangible record of the increasing complexity of social interactions, and rising importance of symbolic communication. These issues are at the core of human evolution research, and show that even something as trivial as an OES bead can contribute to the understanding of ourselves.

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Appendix A

List of traits for OES bead data collection

Percent Cemented:
Visual estimation of bead surface covered in hardened sediment which cannot be removed through dry brushing, given as a percentage.

Minimum Diameter:
Smallest external diameter, given in millimetres to two decimal places.

Maximum Diameter:
Largest external diameter, given in millimetres to two decimal places.

Average Diameter:
Calculated as (minimum.diameter * maximum.diameter) / 2, given in millimetres to two decimal places.

Min / Max Diameter Ratio:
Calculated as minimum.diameter / maximum.diameter.

Minimum Aperture Diameter:
Smallest aperture width, measured at the position of restriction, given in millimetres to two decimal places.

Maximum Aperture Diameter:
Largest aperture width, measured at the position of restriction, given in millimetres to two decimal places.

Aperture to Diameter Ratio:
Calculated as aperture diameter / average diameter.

Aperture Cup Diameter:
Largest measurement across aperture cup, given in millimetres to two decimal places.

Minimum Thickness:
Smallest measurement from mammillary to cuticle surface, given in millimetres to two decimal places.

Maximum Thickness:
Largest measurement from mammillary to cuticle surface, given in millimetres to two decimal places.

Average Thickness:
Calculated as (minimum.thickness * maximum.thickness) / 2, given in millimetres to two decimal places.

Bead Shape:
Visually estimated external shape of bead or preform.
1 – Circular
2 – Roughly circular (rounded edges but not circular)
3 – Oval
4 – Polygon
5 – Unable to determine (due to delamination / wear / breakage / cementing)
9 – No outer shaping

Interior Surface Patina:
Visually estimated, gloss or slick sheen on the inner surface (mammillary layer) of OES.
0 – No surface patina
1 – Slight surface patina (glossy to the naked eye, but not consistent under microscope)
2 – Surface patina (glossy even under magnification)
5 – Unable to determine (due to delamination or cementing)

Exterior Surface Patina:
Visually estimated, gloss or slick sheen on the outer surface (cuticle layer) of OES.
0 – No surface patina
1 – Slight surface patina (glossy to the naked eye, but not consistent under microscope)
2 – Surface patina (glossy even under magnification)
5 – Unable to determine (due to delamination or cementing)

Aperture Shape:
Visually estimated, shape of aperture in cross-section.
1 – Conical
2 – Biconical (if appears due to use wear, do not record as biconical)
3 – Cylindrical
5 – Unable to determine (due to delamination / wear / breakage / cementing)
9 – No aperture

Location of Position of Restriction:
Visual estimate of the location of narrowest point of aperture.

1 – Significantly towards outer surface
2 – Significantly towards inner surface
3 – Approximately equidistant between surfaces
5 – Unable to determine (due to delamination / wear / breakage / cementing)
9 – No aperture

Aperture Centered:
Visual estimate of whether aperture is in general center of bead's outer rim.

0 – Not centered (significant bulk of bead to one side)
1 – Centered
5 – Unable to determine (due to delamination / wear / breakage / cementing)
9 – No aperture

Aperture Chipped:
Visual inspection of cuticle / palisade damage around aperture edges.

0 – No chipping
1 – Smoothed dents, edges of cuticle not visible
2 – Edges of cuticle somewhat defined
3 – Edges of cuticle sharply defined and jagged
5 – Unable to determine (due to delamination)
9 – No aperture

Aperture Consistent:
Visual estimate of whether the position of restriction has a consistent arc for at least 75% of aperture circumference.

0 – Aperture not smooth / consistent
1 – Aperture consistent
5 – Unable to determine (due to delamination / wear / breakage / cementing)
9 – No aperture

Aperture Striae:
Visual inspection for linear grooving or scratching within the aperture cup.

0 – No aperture striae
1 – Aperture striae
5 – Unable to determine (due to delamination)
9 – No aperture

Aperture Patina:
Visual inspection for a gloss or slick sheen on position of restriction.

0 – No aperture patina
1 – Slight aperture patina (glossy to the naked eye, but not consistent under microscope)
2 – Significant aperture patina (glossy even under magnification)
5 – Unable to determine (due to delamination or cementing)

Aperture Donut Index:
Visual inspection for the shape of the aperture in relation to the shell surfaces (similar to Aperture Shape).

0 – 90° angle between aperture position of restriction and shell surfaces
1 – Slight rounding / slanting between position of restriction and shell surfaces
2 – Significant rounding / slanting towards external shell surface
3 – Significant rounding / slanting towards internal shell surface
4 – Significant rounding / slanting towards both shell surfaces (like a donut)
5 – Unable to determine (due to breakage / delamination / cementing)
9 – No aperture

Outer Rim Donut Index:
Visual inspection for the shape of the outer rim in relation to the shell surfaces.

0 – 90° angle between outer rim and shell surfaces
1 – Slight rounding / slanting between outer rim and shell surfaces
2 – Significant rounding / slanting towards external shell surface
3 – Significant rounding / slanting towards internal shell surface
4 – Significant rounding / slanting towards both shell surfaces (like a donut)
5 – Unable to determine (due to breakage / delamination / cementing)

Outer Rim Chip:
Visual inspection of cuticle / palisade damage around outer rim.

0 – No outer rim chipping
1 – Smoothed dents, edges of cuticle not visible
2 – Edges of cuticle somewhat visible
3 – Edges of cuticle sharply visible
5 – Unable to determine (due to delamination / wear / breakage / cementing)
9 – No outer rim shaping

Outer Rim Striae:
Visual inspection for linear grooving or scratching around the outer rim.

0 – No outer rim striae
1 – Vertical outer rim striae (perpendicular to cuticle layer)
2 – Horizontal outer rim striae (parallel to cuticle layer)
3 – Both vertical and horizontal (or diagonal) outer rim striae
5 – Unable to determine (due to delamination / wear / breakage / cementing)
9 – No outer rim shaping

Outer Rim Patina:
Visual inspection for a gloss or slick sheen around outer rim.

0 – No outer rim patina
1 – Slight outer rim patina (glossy to the naked eye, but not consistent under microscope)
2 – Significant outer rim patina (glossy even under magnification)
5 – Unable to determine (due to delamination or cementing)

Heating:
Visual estimate if surface colour appears significantly different from natural OES colour, as seen in experimental thermal alteration.

0 – Not significantly different from natural OES colour
1 – Light heating, somewhat different from natural OES colour (tan, yellow, orange)
2 – Intense heating, significantly different from natural OES colour (brown, gray, black)
5 – Unable to determine (due to delamination or sediment coating)

Layers:
Visual assessment of how distinguishable the constituent OES layers are, specifically the edges of the cuticle layer, and the delineation of the mammillary cones.

0 – Constituent parts easily distinguishable
1 – Constituent parts somewhat distinguishable
2 – Constituent parts largely indistinguishable
5 – Unable to determine (due to breakage / delamination / cementation)

Staining:
Visual inspection for surface residue.

0 – No surface staining
1 – Ochre powder present
2 – Other residue present
3 – Both ochre powder and other residue

5 – Unable to determine (due to breakage / delamination / cementation)

Delamination:
Visual assessment of the degree of surface degradation.

0 – No delamination (cuticle and mammillary surfaces intact)
1 – Partial delamination of one or both surfaces
2 – Complete delamination of one surface (usually the mammillary surface)
3 – Complete delamination of one surface, partial delamination of second surface
4 – Complete delamination of both surfaces
5 – Unable to determine (due to breakage / cementation)

Orton:
Visual assessment of production value, as outlined by Orton (2008). Orton's stages use roman numerals, entered as digits for SPSS.

Pathway 1:

1a – Polygonal fragment of OES
1b – Broken, polygonal fragment of OES
2a – Signs of drilling, no perforation
2b – Broken, signs of drilling, no perforation
3a – Complete perforation, no outer shaping
3b – Broken, complete perforation, no outer shaping
4a – Complete perforation, outer edges partially trimmed
4b – Broken, complete perforation, outer edges partially trimmed
5a – Outer edges fully trimmed
5b – Broken, outer edges fully trimmed
6a – Main protrusions ground off, no use polish
6b – Broken, main protrusions ground off, no use polish
7a – Completed bead
7b – Broken, completed bead

Pathway 2:

2.1a – Polygonal fragment of OES, no drilling
2.1b – Broken polygonal fragment of OES, no drilling
2.2a – Partially trimmed edges, no signs of drilling
2.2b – Broken, partially trimmed edges, no signs of drilling
2.3a – Completely trimmed edges, circular shape, no signs of drilling
2.3b – Broken, completely trimmed edges, circular shape, no signs of drilling
2.4a – Circular shape, signs of drilling, no perforation
2.4b – Broken, circular shape, signs of drilling, no perforation
After this point it is no longer possible to distinguish between pathways, so revert to designations for Pathway 1

Kandel and Conard:
Visual assessment of production value, as outlined by Kandel and Conard (2005).

0 – Indeterminate
1 – Angular blank
2 – Rounded blank
3 – Complete, partially drilled blank
4 – Broken, partially drilled blank
5 – Complete, perforated blank
6 – Broken, perforated blank
7 – Complete, perforated, slightly formed bead
8 – Broken, perforated, slightly formed bead
9 – Complete, perforated, almost bead form
10 – Broken, perforated, almost bead form
11 – Complete, finished bead
12 – Broken, finished bead

Munsell:
Visual assessment, matching OES outer surface colour to Munsell Soil Colour book (*Munsell Soil Color Charts* 2000) in daylight or under full spectrum bulb.

Notes:
Record any other observations.

Photographic record
With a digital microscope, take a minimum of 3 photos, with a scale wherever possible:

#1 – cuticle surface
#2 – mammillary surface
#3 – profile