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QUATERNARY AND PREHISTORY

Diachronic changes and diversity of quartz microlithism through the Late Holocene at Seal Rock Shelter, Namibia

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Abstract

This study examines the diachronic changes and technological diversity of quartz microlithic lithic at Seal Rock Shelter, located in the Erongo Mountains of Namibia, during the Late Holocene since ca. 4.8 ka. Through a detailed techno-morphological analysis of 573 quartz artifacts—including flakelets, bladelets, retouched tools, and cores—this research identifies significant shifts in raw material selection, techno-morphology category, blank symmetry and morphology type and elongation ratio type, determines the operation chain of the quartz microlithic industry also the core volume management method. These changes reflect alterations in technical practices rather than environmental factors, suggesting possible socio-economic shifts linked to the arrival of pastoralism. The quartz industry at Seal Rock Shelter aligns broadly with the Wilton Industry but exhibits unique characteristics when integrated with the site's concurrent basalt macrolithic tradition. This study underscores the value of techno-morphological approaches in analyzing quartz assemblages and highlights the adaptive flexibility of Holocene lithic technologies in Southern Africa.

Cette étude examine les changements diachroniques et la diversité technologique des microlithes en quartz à Seal Rock Shelter, situé dans les montagnes Erongo en Namibie, au cours de l'Holocène tardif depuis environ *ca.*4.8 ka. Grâce à une analyse technomorphologique détaillée de 573 artefacts en quartz, notamment des éclats, des lames, des outils retouchés et des nucléus, cette recherche identifie des changements significatifs dans la sélection des matières premières, la catégorie technomorphologique, la symétrie et le type de morphologie des supports, ainsi que le type de rapport d'allongement. Elle détermine également la chaîne d'exploitation de l'industrie microlithique du quartz, ainsi que la méthode de gestion du volume des nucléus. Ces changements reflètent des modifications dans les pratiques techniques plutôt que des facteurs environnementaux, suggérant d'éventuels changements socio-économiques liés à l'arrivée du pastoralisme. L'industrie du quartz à Seal Rock Shelter s'aligne globalement avec l'industrie Wilton, mais présente des caractéristiques uniques lorsqu'elle est intégrée à la tradition macrolithique basaltique concomitante du site. Cette étude souligne la valeur des approches technomorphologiques dans l'analyse des assemblages de quartz et met en évidence la flexibilité adaptative des technologies lithiques holocènes en Afrique australe.

Introduction

The Later Stone Age (LSA), following the Middle Stone Age (MSA), is characterized by multiple lithic industries and features items such as ostrich eggshell beads and bone tools. The LSA unfolded at various times and at multiple sites in Africa. In Eastern Africa, the origin of LSA can be traced to the Panga ya Saidi site in Kenya, dating back *ca*.68 ka and several other sites with dates ranging over 50,000 years (Shipton *et al.* 2018, 2021; Faulkner *et al.* 2021). In Southern Africa, one of the earliest sites is Border Cave in South Africa, dating to *ca*. 56ka (Villa et al. 2012), but most of the LSA sites are younger than *ca*. 25 ka (Bousman & Brink, 2018; Will *et al.* 2024). After the Early LSA period, the Robberg and Oakhurst Industries appear in Southern Africa, and then the Holocene period began from *ca*.11.7 ka (Chapter 1.1). The Holocene period is also referred to as the LSA-Holocene period due to the extended period during which microlithic lithic traditions were maintained and various technologies and subsistence strategies were employed (Forssman 2024). Therefore, the Later Stone Age as a chrono-cultural phase, and the Holocene as a chronological period are both very important for understanding the history, culture, evolution, and activities of African hunter-gatherers since the last 60,000 years (Chapter 1.2). In Southern Africa, LSA evidence of ochre, resin, arrowheads, ornaments, and castor beans, such as found in Border Cave since *ca*. 44 ka, is thought to have been left by the San hunter-gatherers (d'Errico *et al.* 2012). These hunter-gatherers in late Pleistocene and Holocene history, in conjunction with the late Holocene Khoe pastoralists, constituted the most substantial and geographically expansive demographic in Southern Africa until they were affected and assimilated by Bantu-speaking farmers around 1800 years ago (Schlebusch & Soodyall 2013; Schlebusch *et al.* 2016).

This thesis studies the Seal Rock Shelter (Figure 1), an archaeological sequence from *ca*.4.8ka, which is located in the Erongo Mountains in Namibia, in Southern Africa. Geographically, Southern Africa refers to the southern region of the African continent. The geographical area encompasses a range of approximately 6° to 35° S and 11° to 41° E. It includes thirteen countries, among which are Botswana, Namibia, Eswatini, South Africa, etc. (Chapter 2.1). The chronological sequence for the Erongo Mountain area has yet to be established, though some scholars (Mauran 2019) have conducted studies on specific regions and divided the occupation phase into four principal stages (Chapter 2.2). During the Holocene period after *ca*. 6 ka, the Namibia region experienced about four thousand years of drought and several wet and dry periods (Bubenzer *et al.* 2007) (Chapter 2.3). Lithic artefacts comprising chert, basalt, and quartz, alongside animal bones and pigments, have been discovered at Seal Rock Shelter (Chapter 2.4).

Around 30,000 years ago, human occupation sequences show that quartz gradually became the primary raw material for the increasing production of microliths. Microliths are considered lithics voluntarily smaller than 30 mm. Common categories include flakelets, bladelets, and geometric microliths (Ossendorf 2017; Forssman 2014). These quartz microliths dominate the LSA and Holocene records, reflecting trends of miniaturization and sometimes standardization in the production. They are also considered a hallmark of the LSA, but very little comparative study of microlithic quartz production exists. (Chapter 1.2)

In addition, the diversity and variability within the microlithic industry are very large, and there are also several non-microlithic industries during the LSA and Holocene periods in sub-Saharan Africa (Orton 2006). Usually, there is a dichotomy in our perception of both types of industry (microlithic / non-microlithic). But at the Seal Rock Shelter site, both types of industry co-occur in a late Holocene-LSA sequence. Therefore, Seal Rock Shelter is a significant site to revisit the diversity and variability of quartz microlithism during the Holocene in Southern Africa, but also its coordination with other types of lithic industries (Chapter 2.4).

The goal of this Master thesis is to analyses the diachronic changes and diversity of lithics in Seal Rock Shelter, reconstruct the operation chain of the quartz microlithic industry, and confirm its type of industry (Chapter 1.3). To this end, an analytical approach based on techno-morphology analysis has been employed (Chapter 2.5).

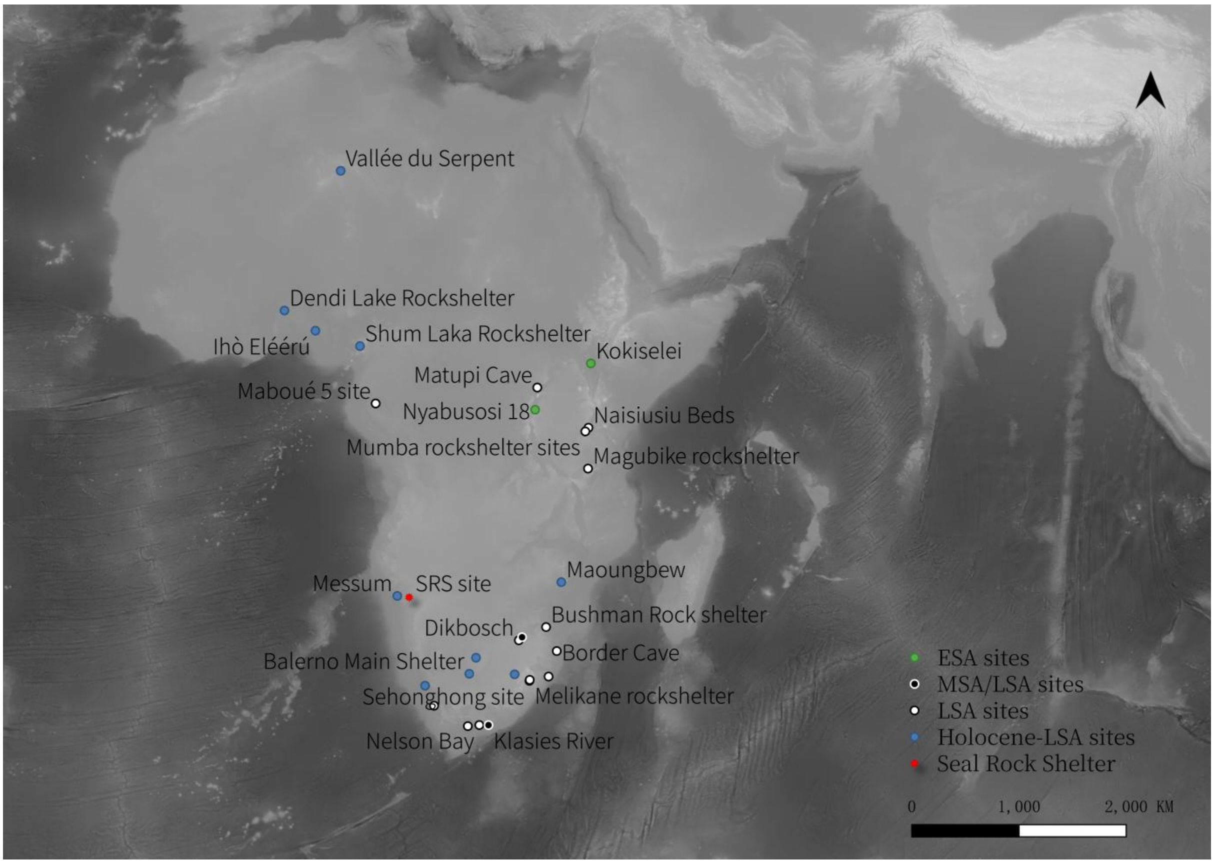


Figure 1 The African archaeological sites mentioned in the thesis

Chapter 1 Contextualization

1. The Late Stone Age and Holocene-LSA in Southern Africa

A. The emergence of the Early Later Stone Age in Africa

Although symbolic and regional behavioral patterns had already begun to emerge in Africa during the Middle Stone Age (MSA) period (Henshilwood 2002,2009; d'Errico & Henshilwood 2007; d'Errico *et al.* 2009; Mauran 2023), more diverse and frequent patterns of behavior were exhibited during the Later Stone Age (LSA) period. The salient differences between LSA and MSA can be enumerated as follows: MSA technologies include "prepared" (e.g. Levallois) cores and flakes, retouched points that may be used as weapons, and side-scrapers that may be hilt-mounted or hand-held (Tryon 2019), and LSA period showed the prevalence of bipolar reduction and quartz provisioning, the trend towards miniaturization of stone tools, and the increase in population size and degree of interaction and mobility (Will *et al.* 2024). These included personal adornment, rock art, bow and arrow techniques, and funerary behavior (Klein 1984).

The emergence of the LSA in Africa occurred at various points in time, the earliest occurrences are dated from Panga ya Saidi site, Kenya (*ca*.68ka, Shipton *et al.* 2018, 2021; Faulkner *et al.* 2021), Border Cave, South Africa (*ca*.56 ka, Villa *et al.* 2012), Magubike Rockshelter, Tanzania (earlier than *ca.* 50 ka, Miller & Willoughby 2014), Mumba Rockshelter, Tanzania (*ca.* 57-49ka, Eren *et al.* 2013), Maboué 5 site, Gabon (*ca*.<44.6 ka, Mesfin *et al.* 2021), Maatupi Cave, Congo (*ca*.41ka, Mesfin 2024) and Sehonghong site, Lesotho (*ca*.31 ka, Pargeter & Redondo 2016). This period is distinguished by the presence of unstandardized lithic assemblages and the incorporation of bifacial technology, by the production of bipolar percussion and blade tools (Jones & Stewart 2016; Lombard *et al.* 2022).

Evidence from Eastern Africa indicates that the MSA/LSA transition may manifest as a mosaic pattern, exhibiting distinct characteristics in the coastal, Rift Valley, and Lake Victoria regions. For example, the correlation between these behavioral changes and climate is less pronounced than the association with heightened population density. The technologies developed by MSA may be completely replaced, gradually replaced, or survive indefinitely (Tryon 2019).

B. Southern African LSA industries in the Late Pleistocene

Upon the development of the LSA, the African lithic record has been found to contain several common trends, including the use of fine-grained materials, the frequent use of quartz as a raw material, the frequent use of bipolar reduction, and miniaturization of blanks and tools (Eren *et al.* 2013; Porraz *et al.* 2016).

Due to the heterogeneity of its internal manifestations of Early LSA, the so-called MSA/LSA transition phase or early LSA does not constitute a distinct cultural entity or Industry (Table 1). Instead, it is better understood as a vast techno-complex wherein a wide array of MSA technology and Robberg Industry technology can be found (Tryon 2019; Blessing *et al.* 2023; Tribolo *et al.* 2024).

Table 1 Description of Culture and techno-complex/industry

	Description
Culture	Typically comprising a range of distinct artefacts, not limited to lithic materials, and regarded as associated with a unique cultural tradition.
Techno-complex/industry	The typological classification of lithic artefacts comprises numerous lithic assemblages, typically encompassing a series of tools of differing types. It can be used by different groups of people for tens of thousands or even hundreds of thousands of years, and its geographical scope can be extremely wide-ranging.

In the Melikane rock shelter, Nelson Bay, and Elands Bay Caves (Bousman & Brink,2018; Pazan *et al.* 2023), there is a gradual emergence of geometric microlithic, prepared cores, and a lack of typical MSA large tools. These phenomena are indicative of the appearance of the first recognizable Robberg Industry (*ca.* 22-12ka) during the LSA period in Southern Africa. The Robberg Industry is distinguished by its emphasis on diminutive blades and cores, accompanied by an array of uncommon trimming techniques, including scrapers and the sporadic use of backed pieces (Jones & Stewart 2016; Lombard *et al.* 2022).

In the classical Southern African LSA sequence, the Robberg Industry is followed by the Oakhurst Industry. The initial manifestation of the Oakhurst Industry is observed in the Dikbosch, Bushman Rock Shelter, Heuningneskrans, and Ntloana Tsoana sites (*ca*.12-11ka Wadley 2000). A comprehensive analysis reveals that tools made of rock, bone, and those employed in hunting and symbolic behaviors are undergoing significant changes. Notably, the use of microlithic tools is declining, indicating a shift towards the lithic industry, which includes medium-sized flakes and macrolithic tools (Thomas 2022). Oakhurst Industry persisted throughout the Early Holocene, the younger occurrence being dated to *ca*. 8.7 ka.

C. Southern African LSA industries in the Holocene

When entering the LSA-Holocene records in Southern Africa, this complexity arises from the progressive co-occurrence of quartz microlithism with other technologies (e.g., iron and ceramic technology) that also evokes co-occurrence/contemporaneity of different types of subsistence strategies (Shipton *et al.* 2016) and different population groups.

For example, Wilton Industry (*ca*.8-2ka) coincides with the first advent of animal husbandry and pottery (Guillemard & Porraz 2022). The tools utilized in this industry were typically no longer than 30 mm in size. The presence of small-sized artifacts and standardized retouched tools, particularly small scarpers and backed elements, is indicative of the industry (Jones & Stewart 2016; Lombard *et al.* 2022). The term "Wilton Industry" was initially employed to denote the “industrial complex” or “culture group”. It has since been utilized to describe a range of small scrapers and microlithic backed tools in various proportions. However, some scholars have argued that the term Wilton Industry is no clearer or more important than the all-encompassing "Later Stone Age" (Deacon 1972). The crux of the issue lies in the observation that, despite the existence of shared cultural practices among individuals, the Wilton Industry offers an excessively comprehensive and grandiose perspective that simplifies numerous human behaviors. The Wilton Industry has been identified through a typological approach on a large geographic scale in Southern Africa, encompassing South Africa, Lesotho, Zambia, Zimbabwe, Botswana, Eswatini, and Namibia (Guillemard 2024). However, concerning non-lithic tools, diet, and ornaments, the "Wilton Industry" exhibited significant regional variation (Radcliffe-Robinson & Cooke, 1950; Cooke 1980; Musonda 1984; Parkington & Sealy, 2007; Miller & Wang 2022).

Starting around *ca.*3ka, numerous settlements and garbage pits containing ceramics and plant remains were discovered in the Congo rainforest. These behaviors and cultures may have accompanied the Bantu people as they expanded from Western Africa to Eastern Africa and Southern Africa (Coutros *et al.* 2025). Approximately 2,000 years ago, a significant transformation occurred in the livelihood strategies and technologies utilized in Southern Africa. This transformation was characterized by the emergence of pastoralism, pottery, metalwork, and agriculture (Figure 2, Lander & Russell 2018).

- ***Pastoralism:*** The introduction of livestock to Southern Africa is estimated to have occurred approximately 2,000 years ago. Archaeological evidence of sheep and cattle bones has been unearthed in various locations, including Leopard Cave in Namibia (cal. 390-40 BC), Spoegrivier and Blombos (cal. 20 BC-AD 240) in South Africa (cal. 350 BC-AD 90), and Toteng 1 in Botswana (170 BC-AD 140). (Pleurdeau *et al.* 2012; Sadr 2015)
- ***Pottery:*** The question of whether pottery was introduced into Southern Africa or invented indigenously is a contentious one. However, the presence of reliable pottery evidence is reported at sites such as Toteng 1 in Botswana (cal. 23 BC–AD 90), Die Kelders and Boundary Shelter (cal. 375–32 BC) in South Africa (cal. 46 BC–AD 221), Oruwanje in Namibia (cal. AD 79–220). (Sadr & Sampson 2006)
- ***Metalwork:*** The introduction of metalwork to Southern Africa coincided with the advent of agriculture. The presence of iron slag in southern Mozambique dates to the cal. AD 200, marking the introduction of iron and copper to Botswana (Miller 2002; Moffett 2020).
- ***Agriculture:*** The first clear evidence for crops was only found at Silver Leaves in South Africa, dated to cal. AD 300 (Klapwijk & Huffman 1996).

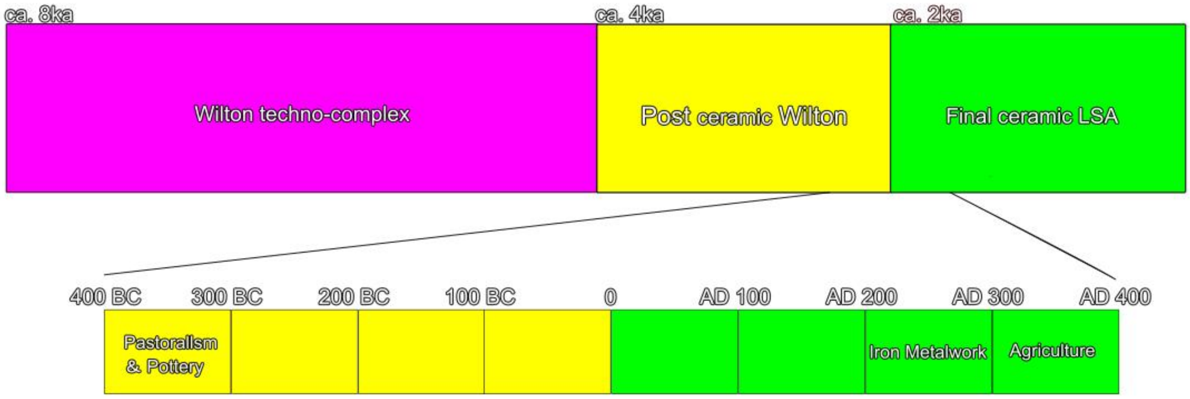


Figure 2 General timeline of animal husbandry, agriculture, pottery, and metalwork in Southern Africa

Interactions between hunter-gatherers and farmers have been barely documented. In Northern Africa, it is estimated to be *ca.*10-8 ka, while in Eastern Africa, it is approximately *ca.*5-2.5 ka, with a later onset observed in Southern Africa. Hunter-gatherers could mitigate contact by concealing themselves in remote locations or by migrating, but in reality, no group could effectively avoid interaction with farmers and later colonizers (Lupo *et al.* 2025). For example, in Southern Africa, following the establishment of the state-level society, the Mapungbwe, around AD 1,220, the hunter-gatherer community, while maintaining their stone age way of life, began to accumulate wealth through interaction with the agricultural community (Forssman 2024).

In this regard, the resilience of the Wilton Industry following the impact of husbandry and pottery serves as an indication of the industry's flexibility and diversity.

2. Lithic technologies in Southern Africa during LSA and Holocene-LSA

A. Diversity and atypicality of lithic technologies

The Later Stone Age technologies of Southern Africa have been notably defined based on Southern African sites, with the development of microlithic technologies among other cultural innovations being a significant contributing factor. The earliest known site in Southern Africa where microlithic production began is the Pinnacle Point site, dated to *ca*. 70 ka (Jacobs & Roberts 2017), and in the Western Cape Province of South Africa, quartz became the principal raw material during the Howiesons Poort Industry, which began from *ca*. 82 ka (Tribolo *et al.* 2009). At approximately *ca.*30ka, one can propose that these two phenomena (quartz-based industry and microlithic production) began to occur simultaneously. The microlithism, which uses quartz as its primary raw material, attained significant importance.

The LSA sequence has been constructed based on the lithics, but there is a possibility that the diversity of local cultures, including microlithic technologies and subsistence practices, is much higher. It should be noted that standardization and miniaturization are not constant features at some LSA sites. For instance, the lithic assemblage of the Early Holocene period at Elands Bay in South Africa lacks backed tools, and larger scrapers are present (Orton 2006). Similarly, the Spoegrivier site in South Africa lacks formally retouched scrapers (*ca*.3.5-1.4ka, Webley 2001). In the Zambezi River Basin, a scraper-rich toolkit occurs only in the upper basin (*ca*.4-2ka, Sadr 2015). These phenomena are also observed in other regions of the African continent. For instance, the Dendi Lake Rockshelter in Ethiopia has been identified as a site with 18 different forms of backed tools, and trapeze and triangle tools (*ca* 7.4-0.25ka, Schepers *et al.* 2020). In contrast, the Shum Laka Rockshelter in Cameroon has been found to contain a minimal percentage of retouched tools (*ca* 10.3-6.2ka, Lavachery 2001). The LSA industry in Southern Africa and the rest of Africa is characterized by a multitude of regional characteristics and diversity. Due to the difficulty in reading quartz crushers and small-sized lithic artifacts, there is a paucity of studies that have employed a comparative technological analysis and diachronic approach to examine these situations.

B. Discussion on microlithic assemblages

During the LSA period, Southern Africa witnessed the emergence of techno-complexes and industries. Early LSA techno-complex represents the hybrid character of MSA technology and Robberg Industry, to the Robberg Industry characterized by diminutive blades and cores and uncommon trimming techniques, the Oakhurst Industry lacking microlithic, and the Wilton Industry characterized by small-sized artifacts and standardized retouched tools but with complex internal diversity.

Common techno-typological types in the Wilton Industry include:

- Flakelet: the products with a length less than 30 mm and the length is shorter than twice of width.
- Bladelet: the products with a length less than 30 mm and the length is equal to or longer than twice of width
- Segment and backed tool: a "backed tool" is defined as a tool that utilizes a flakelet or bladelet as a blank and executes an abrupt retouch on the opposing or adjacent side of a cutting edge to produce a thick back. A "segment" may be a lithic that is intentionally or accidentally broken, and while the underlying cause is often challenging to ascertain, it frequently exhibits a "back" (Deacon 1972).
- Micro-scraper: a type of tool that is made of a small blank (＜30mm）and performs a sharpening retouch on the edge to obtain a sharp or specifically shaped edge. The categories that have been identified include those with a lateral retouch called "woodlot scraper" or "V-Shape" scraper (Guillemard 2024), and those with a straight-convex or convex front and an overall "V-Shape". A "wide" scraper, characterized by a straight-convex or convex front and an overall elongation of approximately 1.2, is designated as a "thumbnail scraper."(Guillemard 2024; Guillemard & Porraz 2024)
- Other tools and heavy-duty tools: including tools like bored stones, points, anvils, hammerstones, grindstones, axes, adzes (Musonda 1984; Guillemard 2024).

In addition to the aforementioned categories, another type is classified as geometric. In certain instances, it is utilized as a category that is independent of the aforementioned categories, referring to tools such as the trapeze, triangle and micro-tranchet (Musonda 1984). In a broad sense, it may be considered a subset of the aforementioned categories. That is to say, it refers to standardized tools that possess particular forms.

C. The concept and reflection of microlithic

A comprehensive examination of the definition of these concepts or groups is imperative to ensure their clarity and precision, especially including the concept of microlithism, back/backing, miniaturization, and standardization.

（1） From flaking to microlithic: foundational concepts and academic controversies

Returning to the fundamental principles of lithic, it is important to first delineate a few basic yet crucial concepts. Firstly, the two most important concepts that are *flaking* and *shaping* (Inizan & Féblot-Augustins 1999): The term "flaking" refers to the process of removing the blank from the core, while "shaping" refers to the carving of any raw material to obtain the desired morphology, and shaping can occur at any stage of the process (Inizan & Féblot-Augustins 1999).

The next stage of the process is the sub-concept of flaking, which comprises two main concepts: the core and the product. The core is the material provider of the removed product, while the product itself can be divided into two main categories: flake and debris. While flake can be classified according to other criteria: if classified according to size, it can be divided into three categories: large size flakes (>10cm), normal size flakes (10-3cm), and small size flakes (<3cm); if classified according to intention, it can be divided into preparation blank and intended blank. The aforementioned concepts can be employed as analytical tools when utilized in their original form or following modification.

The definition of a microlithic piece among the small flakes is a source of confusion for scholars due to the existence of different archaeological materials. Some scholars endorse microlithic in relation to the dimensions of stone tools, encompassing both unretouched and retouched small stone tools (Clark & Prince 1978). This encompasses the process of manufacture (core reduction), which is focused on the production of flakelets and bladelets measuring less than 50 mm in maximum length (Misra et Virendra 1985). In Africa, 30mm seems to be the range (Leplongeon 2014). However, at the Fumane site (Italy), the maximum length of the modified backed tools is 35 mm (Delpiano *et al.* 2024), while at the Ntloana Tšoan site in Lesotho, this maximum is 15 mm (Pargeter 2016; Pargeter & Hampson 2019). It depicts the difficulties in creating a measurement range for microlithic techno-groups, and a statistical analysis reveals the presence of dozens of divergent standards for defining microlithic dimensions (Pargeter & Redondo 2016).

However, some scholars have even proposed that the term 'microlithic' should be understood as referring exclusively to small, retouched stone tools, especially those that use backing to blunt the edge, which is opposite to cutting edge, rather than sharpen cutting edges (Kuhn & Elston 2002). In this definition, a lot of lithic industries focused on variable production of <3cm long products in quartz would be excluded from « **microlithism** ».

Despite disagreements over the definition of the concept, it is clear that the geographic expansion and generalization of microlithic production occurred during the late Pleistocene phase.

（2） Concepts and history of "back"

Backed tools are defined as a tool that utilizes a flakelet or bladelet as a blank and executes an abrupt retouch on the opposing side of a cutting edge to produce a thicker surface.

Pieces with a back and backed tools did not emerge solely in the LSA and Holocene. Obviously, tools with natural back (e.g. repetitive production of core-edge flake) had already appeared in the Oldowan period (Appendix table 1). It is plausible that individuals during that period possessed the capacity to discern the "non-working edge" and deliberately selected or crafted tools that were more ergonomically designed (Weyer 2021), thereby enhancing their ease of grasp; in the Acheulean period, back became more a part of the intention (Mesfin *et al.* 2023); and in the MSA period, standardized backed tools became a distinctive feature (Delpiano *et al.* 2024), as seen in the Lupemban Industry, Zambia (Barham 2002; Delpiano *et al.* 2024).

Backing can be perceived as a 'technical solution' that also occurs in microlithic technology. Small-backed tools are already present in the MSA Lupemban Industry in Central Africa and Porc-Épic MSA site in Ethiopia (Barham 2002; Pleurdeau 2003). The earliest known Southern Africa site location with backed microliths is some Howiesons Poort sites, such as the Pinnacle Point Site (around *ca*.71ka, Brown *et al.* 2012) and Sibudu Cave (around ca.58ka, Backwell *et al.* 2008; Delagnes *et al.* 2006) in South Africa. The Naisiusiu Beds (*ca* ＞42-17ka, Skinner *et al.* 2003) and Mumba Rockshelter sites (Gliganic *et al.* 2012) in Eastern Africa delivered backed microliths around *ca*. 60 ka. The earliest evidence in South Asia occurs in Fa-Hien Lena Cave in Sri Lanka around *ca*. 48-45 ka (Wedage *et al.* 2019) and around *ca*. 40 ka in the Levant (Neeley 2002). In terms of terminology, *abrupt retouch*, *back*, *backed,* and *backing* are four related terms:

- **Abrupt retouch** is used to describe an angular retouch, and it can produce a back.
- **The back** is a morphological term describing a surface that extends along the length of the blank and is more or less perpendicular to both superior and inferior faces (＞80°). Back can be obtained in three ways: natural, unmodified, Such as natural mineral surfaces or naturally occurring fractures; core-edge flakes (*débordant*); post-flaking modification, Such as abrupt retouch or intended fracture.

An edge is considered to be ***backed*** when the continuous regular retouch applied to it is abrupt enough to rule out its being the active part of the tool (i.e., a cutting edge). Backed edge is usually the side that is nearly perpendicular (＞80°) to the surfaces of the flake. In this context, backing refers to the process/action of obtaining a backed edge, which can be done in many different ways (Close & Sampson 1998).

（3） Metrical trends of the flaking: miniaturization and standardization

Lithic miniaturization has been observed to occur with increasing frequency during the Middle and Late Pleistocene periods. It describes the systematic production and use of small stone cutting and piercing tools (Pargeter & Shea 2019). According to Pargeter's statistical analysis on bladelets, which encompasses 29 studies, the microlithic size scale ranges from 20 to 50 mm in length and from 10 to 20 mm in width, which shows a very small size of lithic

(Pargeter & Redondo 2016). Backed tools of this size can be found at several sites in southern Europe (Kuhn 2002), some microlithic in northeast Asia are as small as 9 mm (Kuhn & Elston 2002), while some of the bladelets in the Matupi Cave are only 8mm (Mesfin 2024).

However, lithic miniaturization encompasses more than a mere reduction in size; rather, it may signify alterations in lithic function. For instance, certain Holocene sites in Southern Africa are devoured of formal tools (Orton 2006; Webley 2001). In contrast, the forested sites from the same period, Such as the Dendi Lake Rockshelter in Ethiopia, exhibit a variety of backed tools (Schepers *et al.* 2020). Additionally, the sites of Ihò Eléérú in Nigeria provide a notable example of the use of axes, grooved stones, trapezoid tools, and heavy-duty tools, all utilized in conjunction with microlithic techniques (Cerasoni *et al.* 2023). These site-specific cases demonstrate that microlithic tools serve a distinct function and are supplanted by alternative tools when their use is unnecessary. The most direct evidence for this phenomenon is the association between microlithic and hafting, such as that found at the Sibudu Cave in South Africa, where microlithic can be used as arrowheads (Lombard 2011). It shows the connection between microlithic, hafting, and hunting technologies. Examples of scythes have been found in the Kebaran site in the Levant (Bar-Yosef 1987), and sickles have been found in Lakeshore Village, Italy (Mazzucco *et al.* 2022).

But these general characteristics also hide a high diversity, and differences in lithic size and assemblage combinations can be seen at the previously mentioned archaeological sites. Standardization is when the degree of variation or diversity within a lithic assemblage is low and when methods are repetitive. It can be interpreted through blanks, blank selection, lithic size, morphology, and retouch method, or other relevant factors (Muller & Clarkson 2023). A meticulously regulated and standardized lithic facilitates the fabrication of hafting instruments, or interregional exchange, and may be indicative of the cognitive and symbolic capacities of the maker (Taipale & Rots 2023).

3. Research question

Within the Holocene-LSA framework for southern Africa, numerous questions remain open for discussion: Do standardization and diversity stem from technical, climatic, or cultural factors? Why does microlithism sometimes exhibit standardized characteristics while simultaneously reflecting diverse traits? To what extent can we account for the interplay between microlithism and environmental conditions, subsistence strategies, and other cultural elements? This thesis endeavors to address these questions by examining Seal Rock Shelter during the Late Holocene-LSA period, aiming to resolve four more specific issues:

- What is the operation chain of the microlithic industry in Seal Rock Shelter？
- Have the artifacts in different S.U. undergone significant changes?
- Do the artifacts in each techno-morphology category exhibit diversity?
- Do the technical characteristics reflected in the site belong to the Wilton Industry?

To bring some element of response to this research question, this thesis aims to develop a qualitative technological approach (techno-morphology and technological analysis) to quartz microlithic assemblage and to provide novel insights into the techno-cultural diversity of the Holocene in Southern Africa.

Chapter 2 Materials and Methods

The Seal Rock Shelter has been excavated by the *Mission Archéologique En Namibie* (MANAM) team since 2019. It is part of several ornamented archaeological sites investigated in the North-Eastern part of the Erongo Mountains (central-west of Namibia). The Erongo Mountain, where Seal Rock Shelter is located and known for its rich rock paintings since the 1930s, was surveyed by Henri Breuil for Philip Cave and Omandumba/Anibib (Breuil 1930). Seal Rock Shelter, as well as other sites (like Leopard Cave) located in the Omandumba Farm, and subsequently the site was used as part of the doctoral dissertations of Alma Nankela (2014-2017, Nankela 2017) and Guilhem Mauran (2016-2019, Mauran 2019). The area is known for its rich cave paintings. According to what is currently known, human occupation of the region should have begun during the late Pleistocene and Holocene (Bubenzer *et al.* 2007).

1. Geologic genesis of the Erongo Mountain

At 3.5Ga, the Gondwana continent underwent a southward drift towards the South Pole, resulting in the formation of ice sheets. The subsequent deposition of glacial material led to the formation of the Karoo deposits, which now manifest as protrusions along the margins of the Erongo Mountains. These deposits are further divided into the Krantberg formation and the Lions Head formation (Hegenberger 1988).

As the Gondwana continent moved slowly northward, the climate underwent a gradual transition from glacial to arid tropical, with a significant portion of the continent being covered by vast, shallow post-glacial sedimentary basins. During the Triassic period, these early sediments were gradually elevated and exposed, and the accumulation of dunes persisted. The breakup of the Gondwana continent was triggered by a deep mantle column rising from the core-mantle boundary (1.83 Ga). The separation of Southern Africa and South America was prompted by the formation of the larger Tristan Plume at 1.34 Ga, which manifests itself on the surface as the Etendeka Basalt, while in the interior of the island, there are remnants of several large inland volcanoes, including the Erongo Volcano (Miller 2023).

The pluton in question is one of the largest of its kind, with an average diameter of 35-40 km. Its profile is irregular, reaching a maximum depth of 2305 m. In conjunction with the preceding observations, it is surmounted by a layer of coarse to very coarse sediments and interbedded sandy mudstones, with the primary intrusive rocks comprising granitic diorite and granodiorite (Goudie & Eckardt 1999).

2. Occupation phase of the Erongo Mountain area

Guilhem Mauran (Mauran 2019), based on the mid area of Namibia archaeological discoveries, categorized human occupation into 4 main phases; however, archaeological research and the establishment of chronological sequences at the regional scale of the Erongo Mountains remain relatively scarce.：

Early Stone Age: No evidence of human activity has been found;

Middle Stone Age: Assemblages Such as Fackelträger, Etemba 14, Davib-Ost Shelter, and Cymot Shelter appeared, and lithic industries were represented by pseudo-Levallois points, blades;

Later Stone Age: This period is the most documented by archaeological research in the Erongo Mountain. Based on Richter's summary of archaeological excavations at Brandberg, the LSA was divided into five phases (Richter 1991) :

- ***Phase A (ca. 10-7ka):*** Exists only at Cymot Shelter in the hilly area of Erongo Mountain, where remains are mainly microlithic, bifacial points and ostrich eggshells.
- ***Phase B (ca. 7-5.5ka):*** As with Phase A, archaeological evidence is only found at Cymot Shelter. The remains comprise scrapers, pestles, and bone points. Due to the dry climate, populations of the microlithic industry in Namibia migrated to mountainous areas, such as the Brandberg.
- ***Phase C (ca. 5.5-2ka):*** This is the phase of Erongo Mountain that has produced the largest number of artifacts, including Leopard Cave, Giraffe Shelter, Fackelträger, Etemba 14, Etemba L2, Big Elephant Shelter, and Phillip's Cave. This period, characterized by Wilton Industry, ostrich eggshell beads, and ceramics, is also considered to be the rise of the cave art tradition (Mauran 2019).

- ***Phase D (ca. 2-1ka):*** Pastoralists seem to appear roughly during this phase, with micro point, ceramic, and staining traces unearthed in Etemba 2, Etemba L1, Fackelträger, and Big Elephant Shelter, as well as the most intensive period of cave art production.
- ***Phase E (ca. 1-0.5ka):*** The activities of hunter-gatherer populations declined sharply in favor of pastoralists, and the cave art tradition declined and fell into disappearance.

Iron Age-Brandberg Culture: Little is known about the movement of agri-pastoralist populations into Erongo Mountain during this period. Only at a few site locations, such as Giraffe Shelter, is evidence with pottery and metal occasionally found (Nankela 2017).

3. Holocene Climate of the Erongo Mountain area

For most of the Quaternary period, Namibia was in a period of drought and cold due to the Benguela Cold Stream. During the early Holocene, there were some slight climatic fluctuations, and the climate became slightly wetter and colder in central Namibia, but overall still showed drying *ca.*9.8-8.3ka (Heine 2005; Lancaster 2002). The middle Holocene was marked by global cooling until the late Holocene (Marcott *et al.* 2013). Pollen evidence suggests extreme dryness in this area during *ca.*6-2 ka (Shi *et al.* 1998), but nitrogen isotope records from northwestern Namibia show a recovery in humidity around *ca.*3.8 ka (Chase *et al.* 2010). Since *ca.*2 ka, it has been characterized by wet and dry cycles (Sletten *et al.* 2013), with a short ice period.

4. Information about the Seal Rock Shelter

The Seal Rock Shelter faces east to the Leopard Cave (S 21°34'20"; E 15°33'17", Figure 3), situated 500 meters to the west and in proximity to one of the few perennial sources of water. The Seal Rock Shelter consists of two rooms of approximately 50 square meters each, which contain several colorful rock art depicting people and animals, and a large amount of archaeological material, including bones, ostrich eggshells, stone tools, and ceramics.

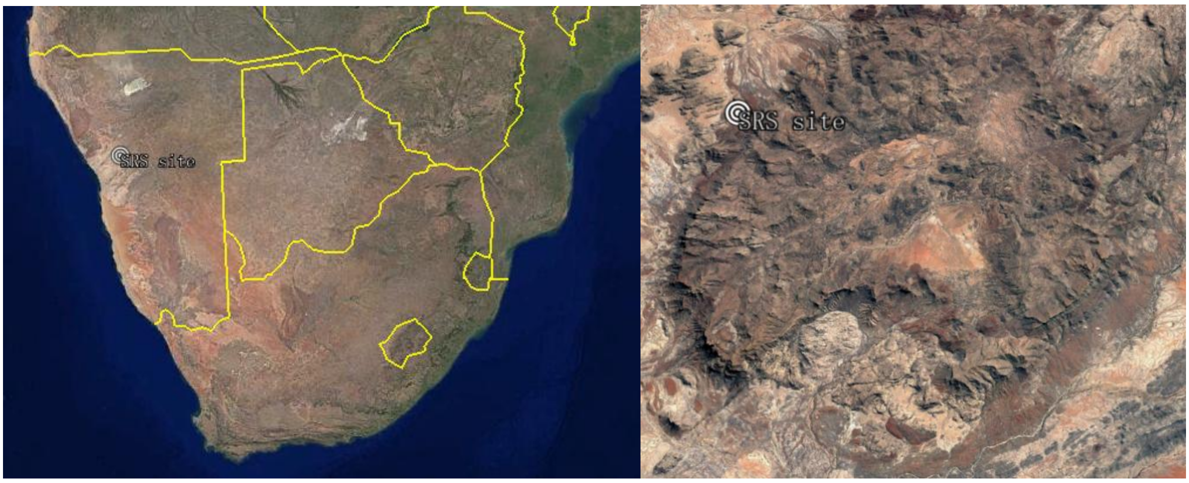


Figure 3 The location of Seal Rock Site in Southern Africa and Erongo Mountain

Until 2024, the Seal Rock Shelter consisted of six squares with sides of 1 meter in length, O11, O12, O13, O14, P12, and P13 (Figure 4), where each square is subdivided into four sub-squares (50 x 50 cm) in length, starting from the north-west clockwise as a, b, c, d. Stratigraphy shows a total of five sub-horizontal sedimentary and archaeological successions. Samples from Layer 1 (144 cm depth), Layer 4 (176 and 191 cm depth), and Layer 4/5 (200 cm depth) were dated at 310-510 cal bp, 4100-4410 cal bp, 3500-3830 cal bp, and 4440-4810 cal bp, respectively. All artefacts are registered in x, y, and z, and the sieving is systematically processed with a grid of 10 cm following a spit of 5cm per sub-square. Due to their small size, a large amount of the quartz that is studied in this thesis comes from the sieving.

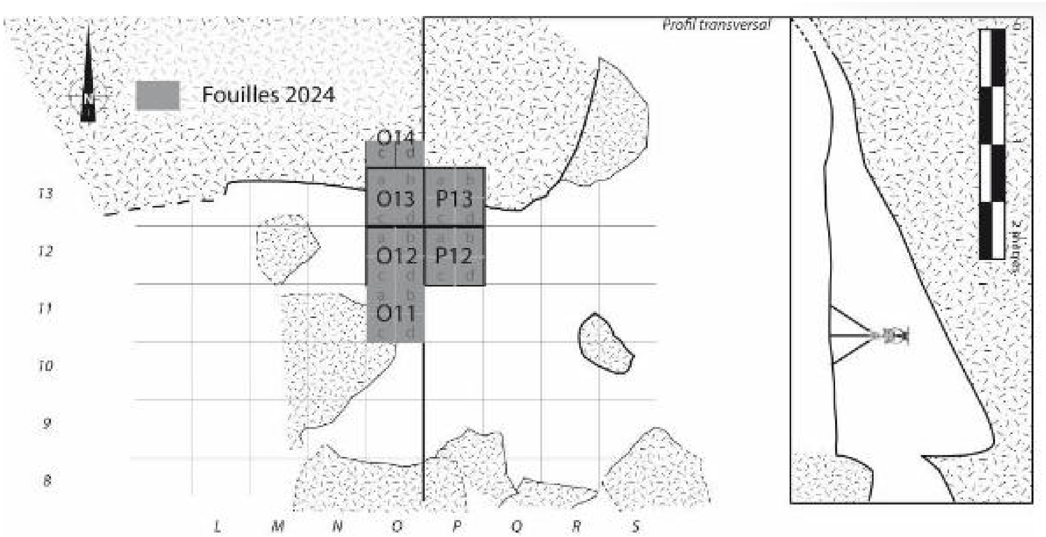


Figure 4 Plan of Seal Rock Shelter, with location of 2024 excavations area

(squares O11, O12, O13, O14, P12 & P13).

Based on the dating results and the artefacts distribution and their obtention in high frequency from, the lithics are divided into three stratigraphic units (S.U.): S.U.1 (0-155cm, ＜*ca.*3.5ka), S.U.2 (155-175cm, *ca.*3.5-3.8ka), and S.U.3 (175-220cm, *ca.*4.4-4.8ka).

The lithic industry at Seal Rock Shelter is a complex industry consisting of quartz microliths (Appendix figure 1-6) and other non-microliths, including a large component of basalt remains. Quartz microlithic tools (n=738) accounted for only 30.5% of all excavated lithic assemblages (n=2,387), and currently, only one possible caprine bone has been discovered (Figure 5). Analysis of animal bones discovered in 2024 shows that the inhabitants of this area may have lived not only by hunting, domestication is still possible (Table 2, Pleurdeau 2025; Shilume 2025).

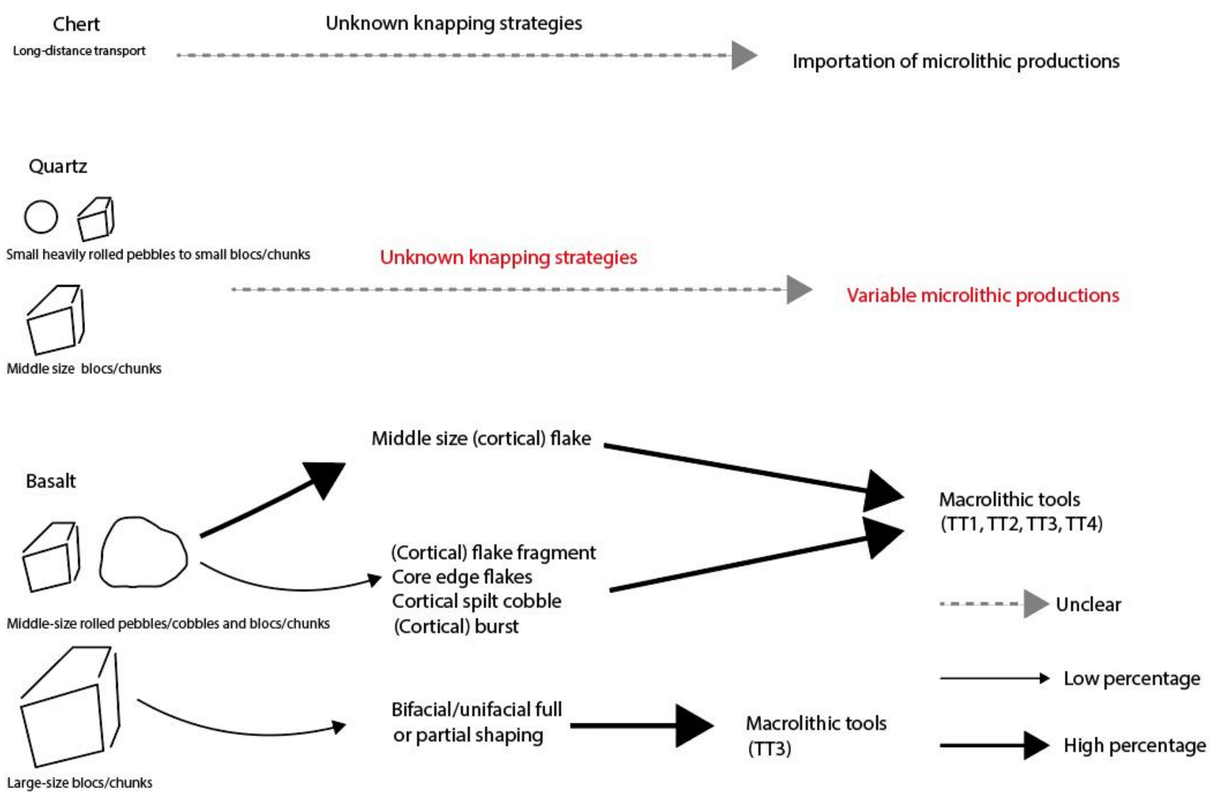


Figure 5 Lithic operation chain in Seal Rock Shelter

Table 2 Remain excavations at Seal Rock Shelter from 2019 to 2024

Categories	Type	Excavation from 2019-2023	Excavation in 2024	Total number
Lithic	Basalt	980	639	1619
	Quartz	363	385	748
	Other volcanic rock	0	1	1
	Pebble	0	1	1
	Sedimentary rock	12	6	18
Total number		1355	1032	2387
Fauna	Animal bones, ostrich eggshells, and other shells	352	193	545

5. Methodologies

This study concerns 470 non-cores lithic and 103 cores, which account for 76.6% of the currently excavated quartz microlithic at Seal Rock Shelter. The studied material is the result of the fieldwork team selection during the 2022, 2023, and 2024 seasons.

A. Technological production analysis

Technology in Stone Age studies initially considers that a technical project involves a combination of conceptual and operational schemes that can vary according to the different cultural backgrounds. A traditional methodological tool in technology is the use of the operation chain (*chaîne opératoire*), which allows for encompassing all the successive processes, from the procurement of raw material until its discard, passing through all the stages of manufacture and use of the different components (Inizan & Féblot-Augustins 1999). Through this lens, technology also studies the relationship between technological systems and socio-economic phenomena, and analyses the management of raw materials and tools from an economic perspective (Inizan & Féblot-Augustins 1999). Five main types have been identified in this thesis: cores, flakes, retouched tools, fragments, and debris. Table 3 presents the definition of 10 categories, based on their position in the operation chain.

Table 3 Types and definitions of artefacts mentioned in the thesis

Main type	Catalogue	Brief description
Flakes	Flake	Entire products removed from the core with a length greater than 30mm but less than twice the width.
	Blade	Entire products removed from the core with a length greater than 30mm and more than twice the width.
	Flakelet	Entire products removed from the core with a length less than 30mm, while less than twice the width.
	Bladelet	Entire products removed from the core with a length less than 30mm but more than twice the width.
Cores	Freehand and/or bipolar cores	Freehand cores are held in the hand when struck, and typically only one strike point is displayed for each negative scar; Bipolar cores are placed on an anvil when struck, and in an ideal state, a single negative scar would display (not systematically) two opposing, shattered impact points (Pargeter & Eren 2017; Pargeter & De La Peña 2017). Freehand and bipolar are techniques that can co-exist even on one core.
Retouched tools	Sharpen edge retouched tool (SERT)	Tools with post-flaking retouch modifications, the cutting edge has been modified to be thinner/sharper.
	Backed tool	A backed tool refers to a tool with a nearly perpendicular edge, which is normally opposite to the active part.
	Double backed tool (DBT)	It exhibits the characteristics of abrupt retouch/fracture on the two opposite sides, with a cutting edge between the two sides.
Fragment		Due to incomplete and difficult-to-distinguish categories of artefacts.
Debris		Unconscious by-products generated during the knapping process.

On all the 'flake' and the 'retouched tool' main types, we recorded the following patterns:

- Technological measurement: the technological orientation is taken as the length and is along the flaking axis for flakes and according to the last removal for cores (Inizan & Féblot-Augustins 1999);
- Potential cutting edge and their types: we recorded if there is only one potential cutting edge, it may be classified by frontal delineation: Straight (S), Curve (C), or Concave Curve (CC). If the edge has been modified or used, add a second characteristic, which is: notched (N), denticulated (D), beak (B), or rostrum (R). When recording, the edge type is written first, followed by the modification/use type, such as SN indicating a straight edge with a notch. If there are two or more potential cutting edges, it is recorded as S+CN (Figure 6).

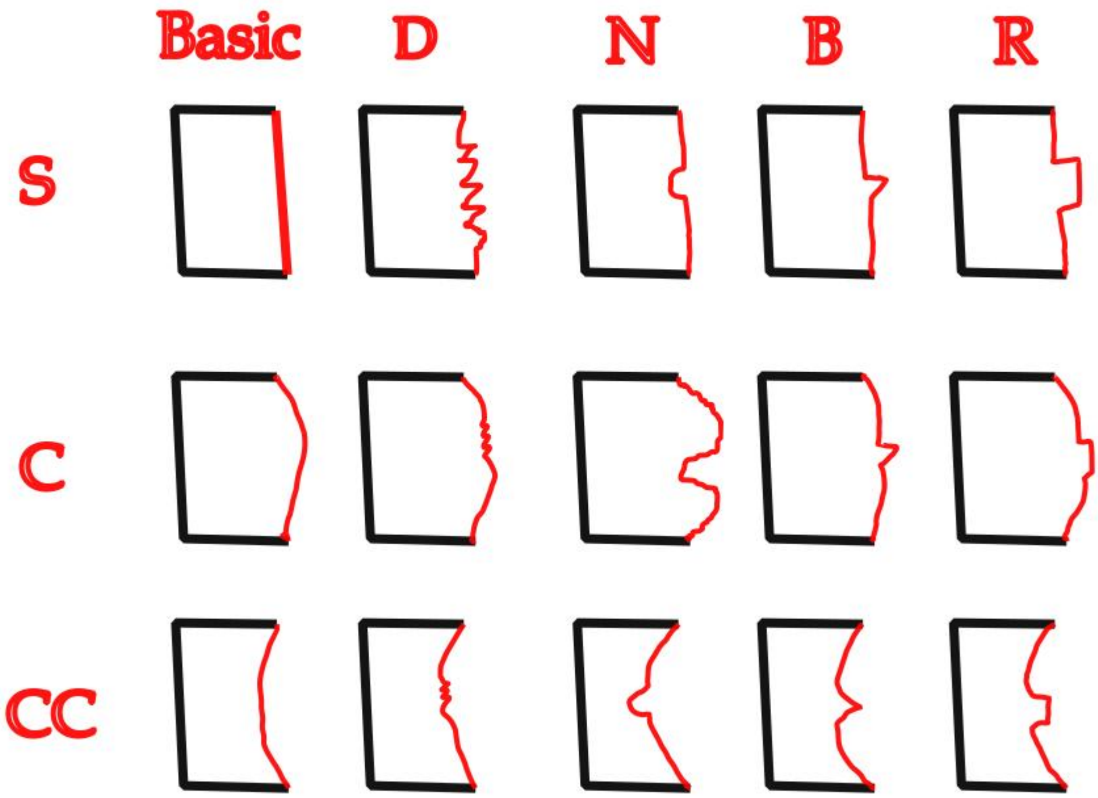


Figure 6 Example of different edge types according to the delineation of the edge: straight (S), convex (C), concave (CC), and the type of edge modification: basic, denticulated, notched, with a beak or a rostrum.

B．Techno-morphology

While quartz fragmentation patterns are not entirely unpredictable (Callahan *et al.* 1992), reading the technical characteristics of quartz microlithic remains a challenge. The special mechanical properties of quartz make it behave differently from other rocks under mechanical stress (Taipale & Rots 2019). In some cases, it is very clear, but in most cases, the fracture, removal, waves or ripples, hackles, etc., are difficult to identify, especially on small artefacts. It would be a very difficult task to perform a detailed technological analysis on every sample. Depending on the quartz 'quality', these microlithic morphologies are also very diverse and hardly predictable; however, these morphologies are well suited to be generalized to the various geometricity categories. This approach facilitates the analysis of their diversity.

Below are some characteristics and data that need to be recorded during the analysis process:

Techno-morphology category: This record is only applicable to 'flakes' main type (including flake, blade, flakelet, and bladelet) and retouched tool (including SERTs, DBTs, and backed tool).

Elongation ratio type: We categorized elongation ≤1 as type 1, elongation between 1 and 2 as type 2, and elongation ≥2 as type 3. Type 1 and type 2 are flakes/flakelets, and type 3 are blades/bladelets; these may reflect their difference in actual functionality. It is our solution to integrate elongation patterns into the types of blank morphology and to deal with the morphometrical continuum of artefact elongation.

Blank symmetry typ*e**: Firstly, we place the ventral face down and the dorsal face up. The platform faces the observer, and the striking direction is vertically forward. Secondly, based on their overall morphology, artefacts are classified into four categories: X, Y, XY, and AS. X is a blank with only symmetrical horizontally; Y is a blank with only symmetrical vertically; XY is a blank which is symmetrical vertically and horizontally, and AS is a blank which is asymmetrical vertically and horizontally. For the ***blank symmetry type, elongation ratio type 1 is referred to as 1 when labelling; elongation ratio type 2 and type 3 are still collectively referred to as 2, for example, X2 and Y2, indicating that the elongation of the blank is greater than 1.

Blank morphology type: We select the geometric shapes that most closely resemble a blank to describe their morphology, such as rectangle, pentagon, flag, triangle, etc. (Figure 7). They are related to ***blank symmetry type*** to some extent, because some geometric figures are symmetrical, while others are not.

Blank type: It can be divided into 3 categories depending on its dorsal face:

- Blank type 1 - Blank with fully cortical dorsal face: this type of blank is not reduced in volume by retouch; the upper face is the natural face of the material.
- Blank type 2 - Blank with “longitudinal removal”: the term "longitudinal removal" is used to describe a kind of scar that appears in the dorsal face of a blank. This term is used to denote a phenomenon where the surface of the blank exhibits visible ridges, often in multiple directions. The number of these longitudinal ridges, designated as "2" or "3," may include some residual natural surfaces of the blank. Their cores are undergoing a process of flaking, which is characterized by the repeated formation of ridges in the same direction.
- Blank type3-Blank with a modified dorsal face: this type of blank can be post-flaking modified through a variety of methods, including unidirectional, bidirectional, centripetal, and other techniques that modify the dorsal surface of the blank.

C. Identifying internal and external changes through a comparative approach

The comparison encompasses a multitude of parameters, including quantity and distribution, raw material, size, bank symmetry and elongation, volume management methods, flaking methods, and edge type. The primary analytical tools employed are SPSS and Excel.

As the recorded variables are predominantly non-numerical text, and the Pearson test is suitable for examining the independence and correlation between two variables (S.U. and other variables and between different variables), it has been adopted as the primary statistical research method. Whereas in comparative technological analysis, different variables will be compared. When the sample size $n \geq 40$ and $T \geq 5$, the asymptotic significance (2-sided) of the Pearson chi-square was used as the p-value. Asymptotic significance (2-sided) with reference to the likelihood ratio as P-value when $n \geq 40$ and at least one $1 \leq T < 5$. If the comparisons are all numeric text, only descriptive analysis is done.

Finally, a more qualitative comparative approach is developed in the discussion section and relies on the literature existing on some typical Wilton Industry assemblages from Southern Africa.

Figure 7 Example of techno-morphology categories (A. S67 rectangle B. 401 isosceles trapezoid C. S38 pentagon D. S30 parallelogram E. S69-1 circular sector F. S62-10 triangle G. S99-1 right trapezoid H. 437 flag I. S80 crescent J. S50-2 maple K. S89-4 hexagon)

Chapter 3 Result

1. Differences and changes of variables in the 3 S.U.

Table 4 demonstrates that the samples of S.U.1 are concentrated in O11, of S.U.2 are mainly distributed in P13, P12, and O12, and of S.U.3 are mainly distributed in P13, O12, and P12. The variation in distribution relates to the deployment of the annual excavation mission.

Table 4 Distribution of lithic samples in different S.U. and square

		Square					Total
		O11	O12	O14	P12	P13	
Unit	S.U.1 0-155cm	129	0	4	0	0	133
	S.U.2 155-175cm	9	26	0	41	51	127
	S.U.3 175-220cm	0	82	0	43	85	210
Total		138	108	4	84	136	470

Table 5 demonstrates that the raw material distribution in each S.U. The microlithic industry at Seal Rock Shelter utilized quartz as its primary raw material, with vein quartz and milky quartz constituting the bulk of the quartz, while rock crystal was comparatively rare.

Table 5 Distribution of raw material in different S.U.

			Raw material			Total
			Rock crystal	Milky quartz	Vein quartz	
Unit	S.U.1 0-155cm	Count	14	110	9	133
		within Unit%	10.53%	82.71%	7.96%	100.00%
	S.U.2 155-175cm	Count	1	48	78	127
		within Unit%	0.01%	37.80%	61.42%	100.00%
	S.U.3 175-220cm	Count	2	92	116	210
		within Unit%	0.95%	43.81%	55.24%	100.00%
Total		Count	17	250	203	470
		within Unit%	3.62%	53.19%	43.19%	100.00%

Table 6 demonstrates the minimum, maximum, average size (length, width and thickness) and their standard deviation. The vast majority of lithic assemblages measure less than 30mm in size, though certain cores and DBTs exceed 30mm. The disparity between length and width is relatively pronounced.

Table 6 Descriptive statistics of size

	N	Minimum	Maximum	Mean	Std. Deviation
Length	467	4.00	38.00	13.96	4.50
Width	467	2.00	36.00	10.55	4.89
Thickness	467	0.50	15.00	3.82	2.11
L/W	467	0.44	6.40	1.50	0.62
Valid N (listwise)	467				

Table 7 demonstrates the distribution of different techno-morphology categories in each S.U. Retouched tools and flakelets/bladelets collectively account for over 95% of the total. The former predominate in S.U.3 and S.U.2, while flakelets and bladelets are more prevalent in S.U.1.

Table 7 Distribution of techno-morphology category in different S.U.

			Techno-morphology category							Total
			Backed tool	Bladelet	Debris	DBTs	Flakelet	Fragment	SERTs	
Unit	S.U.1 0-155cm	Count	12	10	0	10	92	3	6	133
		%within Unit	9.0%	7.5%	0.0%	7.5%	69.2%	2.3%	4.5%	100.0%
	S.U.2 155-175cm	Count	21	3	1	12	54	4	32	127
		%within Unit	16.5%	2.4%	0.8%	9.4%	42.5%	3.1%	25.2%	100.0%
	S.U.3 175-220cm	Count	39	10	1	30	85	5	40	210
		%within Unit	18.6%	4.8%	0.5%	14.3%	40.5%	2.4%	19.0%	100.0%
Total		Count	72	23	2	52	231	12	78	470
		%within Unit	15.3%	4.9%	0.4%	11.1%	49.1%	2.6%	16.6%	100.0%

Table 8 demonstrates the distribution of different blank symmetry types in each S.U. AS2, X2 and Y2 accounted for over half of the amount, yet AS2 consistently maintained a share exceeding 20%. Meanwhile, the proportions of X2 and Y2 decreased within S.U.1, while those of AS1, X1, XY1 and Y1 increased.

Table 8 Distribution of blank symmetry type in different S.U.

			Blank symmetry type									Total
			AS1	AS2	No data	X1	X2	XY1	XY2	Y1	Y2	
Unit	S.U.1 0-155cm	Count	15	32	0	7	20	4	14	18	23	133
		%within Unit	11.3%	24.1%	0.0%	5.3%	15.0%	3.0%	10.5%	13.5%	17.3%	100.0%
	S.U.2 155-175cm	Count	6	26	4	0	36	2	15	6	32	127
		%within Unit	4.7%	20.5%	3.1%	0.0%	28.3%	1.6%	11.8%	4.7%	25.2%	100.0%
	S.U.3 175-220cm	Count	8	45	6	1	62	1	28	13	46	210
		%within Unit	3.8%	21.4%	2.9%	0.5%	29.5%	0.5%	13.3%	6.2%	21.9%	100.0%
Total		Count	29	103	10	8	118	7	57	37	101	470
		%within Unit	6.2%	21.9%	2.1%	1.7%	25.1%	1.5%	12.1%	7.9%	21.5%	100.0%

Table 9 demonstrates the distribution of different blank morphology types in each S.U. The proportions of crescent, isosceles trapezoid and right trapezoid exceed half, but the proportion of crescent decreased in S.U.1 while the latter two increased.

Table 10 demonstrates the distribution of different blank types in each S.U. Type 3 accounted for 45%, reflecting that retouched pieces were the most numerous, particularly in S.U.3 and S.U.2. However, in S.U.1, the proportion of type 3 decreased while that of type 2 increased, indicating a reduction in retouched pieces and a rise in flakelet and bladelet quantities.

Table 9 Distribution of blank morphology type in different S.U.

			S.U.1	S.U.2	S.U.3	Total
Blank morphology type	Circular Sector	Count	2	1	0	3
		%withinUnit	1.5%	0.8%	0.0%	0.6%
	Crescent	Count	12	27	49	88
		%withinUnit	9.0%	21.3%	23.3%	18.7%
	Diamond	Count	0	2	0	2
		%withinUnit	0.0%	1.6%	0.0%	0.4%
	Flag	Count	2	4	5	11
		%withinUnit	1.5%	3.1%	2.4%	2.3%
	Hexagon	Count	6	3	7	16
		%withinUnit	4.5%	2.4%	3.3%	3.4%
	Irregular	Count	9	6	5	20
		%withinUnit	6.8%	4.7%	2.4%	4.3%
	Isosceles trapezoid	Count	31	23	33	87
		%withinUnit	23.3%	18.1%	15.7%	18.5%
	Maple	Count	2	1	1	4
		%withinUnit	1.5%	0.8%	0.5%	0.9%
	Parallelogram	Count	0	4	2	6
		%withinUnit	0.0%	3.1%	1.0%	1.3%
	Pentagon	Count	14	15	19	48
		%withinUnit	10.5%	11.8%	9.0%	10.2%
	Rectangle	Count	14	11	26	51
		%withinUnit	10.5%	8.7%	12.4%	10.9%
	Right trapezoid	Count	28	15	33	76
		%withinUnit	21.1%	11.8%	15.7%	16.2%
	Triangle	Count	13	8	18	39
		%withinUnit	9.8%	6.3%	8.6%	8.3%

Table 10 Distribution of blank type in different S.U.

			Blank type				Total
			Type 1	Type 2	Type 3	indetermined	
Unit	S.U.1 0-155cm	Count	8	60	55	10	133
		%withinUnit	6.0%	45.1%	41.4%	7.5%	100.0%
	S.U.2 155-175cm	Count	7	52	57	11	127
		%withinUnit	5.5%	40.9%	44.9%	8.7%	100.0%
	S.U.3 175-220cm	Count	16	79	100	15	210
		%withinUnit	7.6%	37.6%	47.6%	7.1%	100.0%
Total		Count	31	191	212	36	470
		%withinUnit	6.6%	40.6%	45.1%	7.7%	100.0%

Table 11 demonstrates the distribution of different elongation ratio types in each S.U. Type 3 accounted for 45%, reflecting that retouched pieces were the most numerous, particularly in S.U.3 and S.U.2. However, in S.U.1, the proportion of type 3 decreased while that of type 2 increased, indicating a reduction in retouched pieces and a rise in flakelet and bladelet quantities.

Table 11 Distribution of elongation ratio type in different S.U.

			Elongation ratio type			Total
			Type 1	Type 2	Type 3	
Unit	S.U.1 0-155cm	Count	47	69	17	133
		% within Unit	35.3%	51.9%	12.8%	100.0%
	S.U.2 155-175cm	Count	19	96	12	127
		% within Unit	15.0%	75.6%	9.4%	100.0%
	S.U.3 175-220cm	Count	27	145	38	210
		% within Unit	12.9%	69.0%	18.1%	100.0%
Total		Count	93	310	67	470
		% within Unit	19.8%	66.0%	14.3%	100.0%

2. Diversity within different techno-morphology categories

This section presents a comparison of the aforementioned variables across different techno-morphology categories.

Table 12 demonstrates the raw material choice of different techno-morphology categories. Due to variations in the proportion of raw materials, milky quartz exhibits greater abundance across most techno-morphological categories, with backed tools being the sole exception. Among lithic artefacts utilizing rock crystal as raw material, flakelets constitute the highest proportion.

Table 12 Raw material choice of techno-morphology category

		Raw material			Total
		Rock crystal	Milky quartz	Vein quartz	
Techno-morphology category	Backed tool	2	30	40	72
	Bladelet	1	14	8	23
	Debris	0	2	0	2
	DBTs	0	27	25	52
	Flakelet	11	132	88	231
	Fragment	1	6	5	12
	SERTs	2	39	37	78
	Core	14	62	24	100
Total		31	312	227	570

Table 13 demonstrates the size descriptive statistics of different techno-morphology categories. The mean and variance of assemblage sizes, excluding cores, showed little variation. Bladelets, backed tools and SERTs exhibited relatively high levels of size standardization.

Table 13 Descriptive Statistics of techno-morphology category size

		N	Minimum	Maximum	Mean	Std. Deviation
Backed tool	Long	72	4.0	23.5	13.563	3.9441
	Width		2.0	21.0	8.813	4.2339
	Thickness		1.0	13.0	3.757	1.9929
DBTs	Long	56	8.0	38.0	14.982	5.4987
	Width		3.0	36.0	10.563	5.5293
	Thickness		0.5	15.0	5.116	3.0896
SERTs	Long	78	8.0	28.5	15.494	4.4339
	Width		4.0	21.0	10.872	3.9117
	Thickness		1.5	9.0	3.712	1.6026
Bladelet	Length	23	9.0	23.5	14.217	4.2422
	Width		4.0	10.5	6.109	1.8399
	Thickness		1.0	6.5	2.913	1.3026
Flakelet	Long	231	6.0	31.0	13.342	4.3223
	Width		2.0	30.0	11.368	4.9597
	Thickness		.5	15.0	3.660	1.9788
Core	Length	101	8.0	72.0	24.738	10.7670
	Width		5.0	45.0	19.772	7.8465
	Thickness		1.0	49.0	14.975	7.3822

Table 14 demonstrates the blank symmetry type choice of different techno-morphology categories. Different techno-morphology categories exhibit preferences for specific blank symmetry types; for instance, backed tools predominantly utilize the X2 blank, whilst flakelets favor the AS2, Y2, and XY2 blanks.

Table 14 Blank symmetry type choice of techno-morphology category

		Blank symmetry type									Total
		AS1	AS2	No data	X1	X2	XY1	XY2	Y1	Y2	
Techno-morphology category	Backed tool	2	13	3	1	39	0	2	4	8	72
	Bladelet	0	6	0	0	8	0	2	0	7	23
	Debris	0	0	2	0	0	0	0	0	0	2
	DBTs	3	11	0	2	8	1	8	4	15	52
	Flakelet	21	52	2	5	42	6	33	25	45	231
	Fragment	1	3	1	0	3	0	0	1	3	12
	SERTs	2	18	2	0	18	0	12	3	23	78
Total		29	103	10	8	118	7	57	37	101	470

Table 15 demonstrates the blank morphology type choice of different techno-morphology categories. Blank morphology type and blank symmetry type exhibit a correlation, with distinct techno-morphology categories also displaying preferences. Backed tools predominantly utilize crescent blanks, whilst flakelets primarily employ right trapezoid, isosceles trapezoid, rectangle, and crescent blanks.

Table 15 Blank morphology type choice of techno-morphology category

		Techno-morphology category							Total
		Backed tool	Bladelet	Debris	DBTs	Flakelet	Fragment	SERTs	
Blank morphology type	Circular Sector	1	0	0	1	1	0	0	3
	Crescent	34	5	0	2	30	2	15	88
	Diamond	0	0	0	0	0	0	2	2
	Flag	2	2	0	1	6	0	0	11
	Hexagon	0	1	0	1	12	1	1	16
	Irregular	1	2	0	1	13	0	3	20
	Isosceles trapezoid	7	4	0	18	40	3	15	87
	Maple	0	0	0	0	2	0	2	4
	No data	4	0	2	5	3	3	2	19
	Parallelogram	1	0	0	1	1	0	3	6
	Pentagon	4	4	0	2	29	1	8	48
	Rectangle	2	1	0	8	31	0	9	51
	Right trapezoid	8	2	0	8	44	1	13	76
	Triangle	8	2	0	4	19	1	5	39
Total		72	23	2	52	231	12	78	470

Table 16 demonstrates the blank type choice of different techno-morphology categories. Blank types reveal distinctions between flaking and retouching processes. Type 2 constitutes a significant proportion of bladelets, correlating with core volume management techniques. Conversely, type 3 predominates in flakelets and retouched tools, indicating a higher degree of blank retouching.

Table 16 Blank type choice of techno-morphology category

		Blank type			Total
		Type 1	Type 2	Type 3	
Techno-morphology category	Backed tool	6	29	37	72
	Bladelet	1	21	1	23
	Debris	0	1	1	2
	DBTs	4	16	32	52
	Flakelet	15	88	128	231
	Fragment	0	2	10	12
	SERTs	5	34	39	78
Total		31	191	248	470

Table 17 demonstrates the elongation ratio type choice of different techno-morphology categories. Bladelets are all type 3, while flakelets are all type 2 and type 1, which relates to their definitions. For retouched tools, type 2 is the primary elongation ratio type, indicating that the elongation of most retouched tools is greater than 1 but less than 2.

Table 17 Elongation ratio type of techno-morphology category

		Elongation ratio type			Total
		Type1	Type2	Type3	
Techno-morphology category	Backed tool	6	48	18	72
	Bladelet	0	0	23	23
	DBTS	11	29	12	52
	Flakelet	67	164	0	231
	Fragment	1	7	4	12
	SERTs	8	61	9	78
Total		93	310	65	468

Table 18 demonstrates the edge type choice of different techno-morphology categories. The majority of lithic assemblages are multi-edged, with the remainder comprising straight-edged and curved-edged artefacts. Concave edges and points are comparatively rare.

Table 18 Edge type choice of techno-morphology category

	C	CC	S	P	Multi-edge	Total
Backed tool	15	3	33	2	19	72
Bladelet	5	0	6	0	12	23
DBTs	7	2	16	2	25	52
Flakelet	26	10	33	4	158	231
SERTs	9	3	15	0	51	78

3. Volume management method of cores

Among 103 cores (Appendix figure 6), 56.3% (n=58) have two or more flaking surfaces with flaking directions that are orthogonal, 20.3% (n=21) exhibit single-direction flaking on a single flaking surface, and 11.7% show flaking in opposite directions on a single flaking surface. These three primary methods account for 88.3% of the total. The obvious orthogonal flaking method was observed in the cores numbered 666-4, 121, 667, 806, and 665, which involves flaking around the core's circumference (Table 19).

Table 19 Volume management method of cores

		Frequency
Count	Bidirectional	14
	Irregular	4
	Orthogonal	61
	Undetermined	3
	Unidirectional	21
	Total	103

Based on the preset characteristics of target blanks (such as size, morphology, and edge), the preparation of cores, and their potential for organized recurrence (Boëda & Chazan 2023), the cores from Seal Rock Shelter are classified into three categories:

- ***Method 1- quartz without blank control, preparation, and organized recurrence (n=38):*** most of the unidirectional, bidirectional, and irregular method cores belong to this category. The number of removals ranged from 2 to 10. The flaking process without preset control simply gives the blank a cutting edge, while the blank's morphology and size depend more on the core itself. No different sequences or preparations were observed, and the surface produced by the previous removal was not used as a new platform, such as core 111 in S.U.3 (Figure 8B).

- ***Method 2 - quartz with possible blank control, preparation, and definite organized recurrence (n = 58):*** most of the orthogonal method cores belong to this category. The number of removals ranges from 2 to 11. In certain cores, such as the S68 (Figure 8D), control over blank morphology is employed to achieve the desired bladelet blank. In cores Such as core-489 (Figure 8A), preparation creates a platform for flaking. All cores possess the potential for organized recurrence, meaning that the outcomes of earlier flaking events exert a certain influence on subsequent flaking. Typically, one or two flakes are obtained in one direction first. Then, the newly generated flat surface is used as a new striking platform.

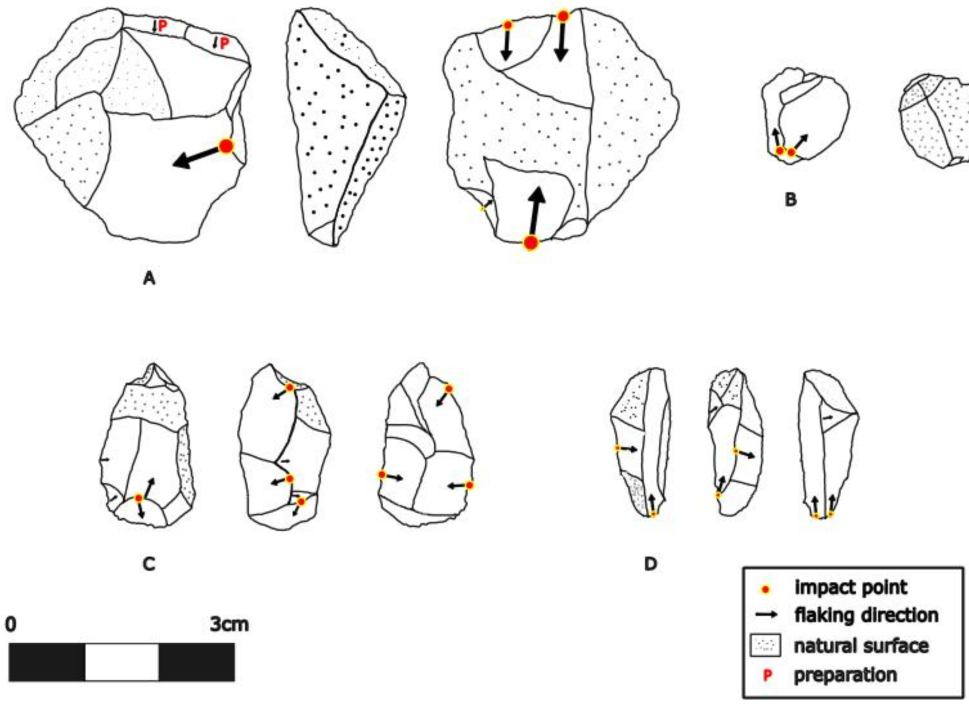


Figure 8 Core samples from S.U.3. A. 489, B.111, C.S89, D.S68.

- ***Method 3 - quartz with possible blank control, definite preparation, and organized recurrence (n = 5)*:** In certain cores, such as core-323 (Figure 9B), acquisition of the bladelet blank can be observed. More significantly, each core acquires the platform through preparation for subsequent flaking, demonstrating clear, organized recurrence. Each flaking sequence is distinct, with subsequent sequences following the same method after completing the initial one, enabling continuous progression. The number of removals ranges from 3 to 13. Examples include cores 323 and 409 from S.U.2 (Figure 9B＆C).

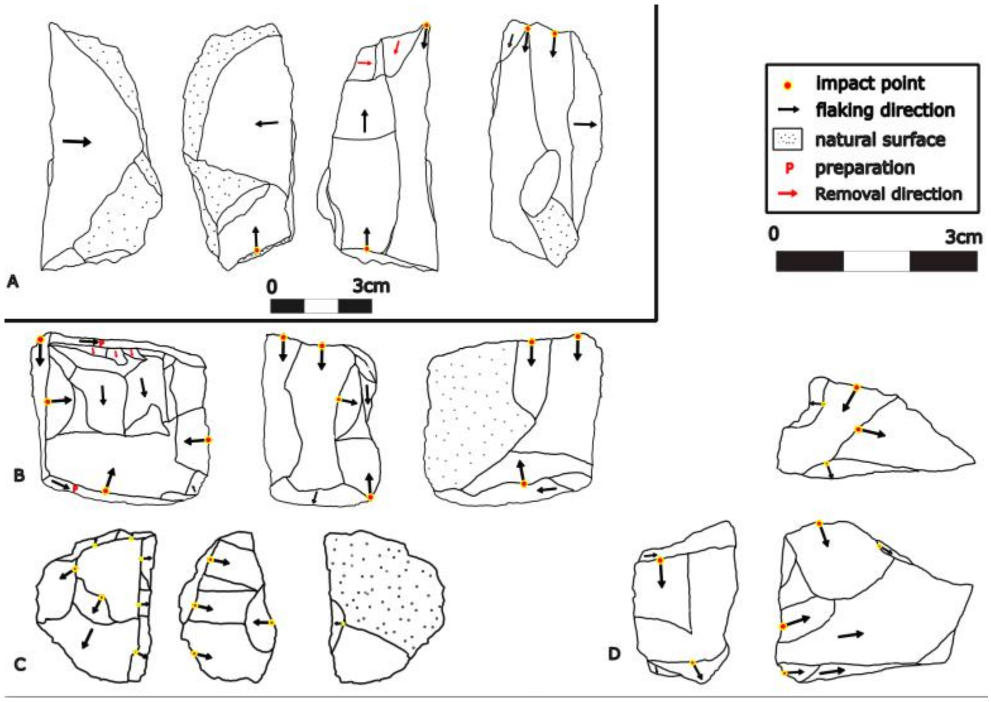


Figure 9 Core samples from S.U.2 and no stratigraphic information,

core A: 577, B: 323, C: 409, D: 280, cores 577 and 280 are without stratigraphic information

Table 20 shows the differences in average size, size variability, and average number of removals among the three types of cores.

Table 20 Comparison of size and removal numbers for three types of cores

	Quartz without preparation and sequence	Quartz with a definite sequence and possible preparation	Quartz with a definite sequence and preparation
Number	38	58	5
Mean length (mm)	24.355	23.614	40.8
Std. Deviation of length	12.0511	9.0751	7.694
Mean width (mm)	19.158	19.263	30.4
Std. Deviation of width	7.5928	7.6951	5.32
Mean thickness (mm)	13.197	15.456	23
Std. Deviation of thickness	6.5528	7.5210	7.714
Mean removals	5.11	5.66	6.8

Chapter 4 Analysis and discussion

1. Diachronic changes in different S.U.

A. Synthetical description of the Seal Rock Shelter quartz industry

The results section provides several elements that allow us to propose the main characteristics for the global description of the quartz industry at Seal Rock Shelter:

- ***Raw material:*** Overall, milky quartz is the primary choice, with vein quartz being secondary.
- ***Techno-morphology category:*** Overall, retouched tools (SERTs, DBTs, and backed tools), along with flakelets and bladelets, account for over 95%.
- ***Size:*** Length and width variance across categories generally exceeds 4, with core length variance reaching up to 10.
- ***Blank symmetry type:*** Different categories exhibit selective preferences—backed tools favor X2 blanks, while flakelets prefer AS2 and X2 blanks, though other symmetry types remain distributed;
- ***Blank morphology type:*** Similar to symmetry type, backed tools favor crescent blanks, while flakelets prefer isosceles trapezoid, crescent, and pentagon blanks, though other types also occur;
- ***Blank type:*** Overall, type 3 is most abundant, followed by type 2, with type 1 being the least common. However, type 2 constitutes a very high proportion among bladelets, reflecting its production method.
- ***Elongation ratio type:*** Overall, type 2 is most abundant, followed by type 1 and type 3.

B. What changes occurred and when ?

Table 21 demonstrates the variation in various elements from S.U.3 to S.U.1 along with their corresponding P-values. We observe these phenomena:

- ***Raw material: A shift from vein quartz to milky quartz***

Vein quartz lithics accounted for 55.24% and 61.42% in S.U.3 and S.U.2 respectively, but decreased to 7.96% in S.U.1, replaced by 82.71% milky quartz lithics.

- ***Techno-morphology category: A shift from retouched tool to flakelet and bladelet;***

Retouched tools accounted for 51.9% and 51.1% of finds in S.U.3 and S.U.2 respectively, but dropped to 21% in S.U.1, replaced by flakelets and bladelets comprising 76.7%.

- ***Blank symmetry type: X2 decreasing while AS2 increasing***

In S.U.3, X2 (29.5%), Y2 (21.9%) and AS2 (21.4%) constitute the primary symmetry types, accounting for 28.3%, 25.2% and 20.5% respectively in S.U.2. However, in S.U.1, X2 and Y2 decreased to 15.0% and 17.3%, respectively, whilst AS2 increased to 24.1%.

- ***Blank morphology type: crescent decreasing while isosceles and right trapezoid increasing***

The proportion of crescent blanks gradually decreased from 23.3% to 9.0%, whilst the proportion of isosceles trapezoids gradually increased from 15.7% to 23.3%, and the proportion of right trapezoids gradually increased from 15.7% to 21.1%.

- ***Elongation ratio type: Type 2 and 3 decreasing while Type 1 increasing***

Type 1 and type 2 accounted for 69% and 12.9% respectively in S.U.3, and 75.6% and 15% respectively in S.U.2. However, in S.U.1, type 2 decreased to 51.9% while type 1 increased to 35.3%, reflecting an overall downward trend in the elongation ratio.

C. How to explain it from a technical perspective ?

The dimensions and blank type of the lithic assemblages represent variables showing no significant variation, suggesting little discernible selection or alteration in core size choice or volume management methods. Nevertheless, despite this lack of significant size variation, the elongation ratio type of the lithic assemblages indicates a transition from slender to flatter forms. Combined with variations in other variables, this may be attributable to technical factors: during the flaking process, there is a gradual tendency to favor blanks with a lower elongation ratio and reduce the proportion of retouching. Consequently, the symmetry type of the blanks exhibits irregularity, with their morphology type progressively dominated by quadrangular forms. Unretouched flakelets and bladelets also become predominant.

Table 21 The summary and description of the change in 3 different S.U.

		P-value	S.U.3	S.U.2	S.U.1	Figure
Raw Material	Milky quartz	<0.05	43.81%	37.80%	82.71%	Appendix figure 7
	Vein quartz		55.24%	61.42%	7.96%	
Techno-morphology category	Flakelet and bladelet	<0.05	45.30%	44.90%	76.70%	Appendix figure 8
	Retouched tool		51.90%	51.10%	21%	
Blank symmetry type		<0.05	X2-29.5%	X2-28.3%	AS2-24.1%	Appendix figure 9
			Y2-21.9%	Y2-25.2%	Y2-17.3%	
Blank morphology type		<0.05	Crescent-18.7%	Crescent-21.3%	Isosceles trapezoid-23.3%	Appendix figure 10
			Isosceles trapezoid-18.5%	Isosceles trapezoid-18.1%	Right trapezoid-21.1%	
Size	Length	0.24				
	Width	0.44				
	Thickness	0.115				
Blank type		0.679	Type3-47.6%	Type3-44.9%	Type2-45.1%	
			Type2-37.6%	Type2-40.9%	Type3-41.4%	
Elongation ratio type		<0.05	Type2-69%	Type2-75.6%	Type2-51.9%	Appendix figure 11
			Type3-18.1%	Type1-15%	Type1-35.3%	

D. Environmental or cultural possibilities?

The Erongo Mountain region experienced an extremely arid climate during approximately *ca.*6–2 ka (Shi *et al.* 1998), but underwent a brief wet period around *ca.*3.8 ka (Chase *et al.* 2010) and subsequently entered a wet-dry climate cycle after approximately 2 ka (Sletten *et al.* 2013). However, no significant changes occurred in S.U.3 (*ca.* 4.4–4.8 ka) and S.U.2 (*ca.* 3.5–3.8 ka), suggesting that climate change may not have been the primary factor causing these differences.

Archaeological evidence from Southern Africa after *ca.*2ka indicates that traditional hunter-gatherer sites feature a relatively high proportion of formal tools, a small amount of pottery, small eggshell beads, and some wild animal remains; in contrast, pastoralist sites have fewer formal tools, larger eggshell beads, and some domesticated animal remains (Mitchell & Whitelaw 2005). Based on the stone tools, fauna, and ceramics found in the Seal Rock Shelter, S.U.3 and S.U.2 seem to represent more traditional hunter-gatherer populations. S.U.1, on the other hand, has fewer formal tools, while no clear evidence of domesticated animals, suggesting that it represents a pastoralist or mixed stage.

2. The global operation chain reconstruction

The quartz microlithic industry at the Seal Rock Shelter exhibits a diverse operational chain (Figure 10). Two primary quartz raw materials and three distinct core volume management methods enable varied possibilities in blank size, symmetry, and morphology. Different edge types enable varied functional requirements. This diversity also correlates with diachronic change, possibly influenced by differing populations and substance strategies.

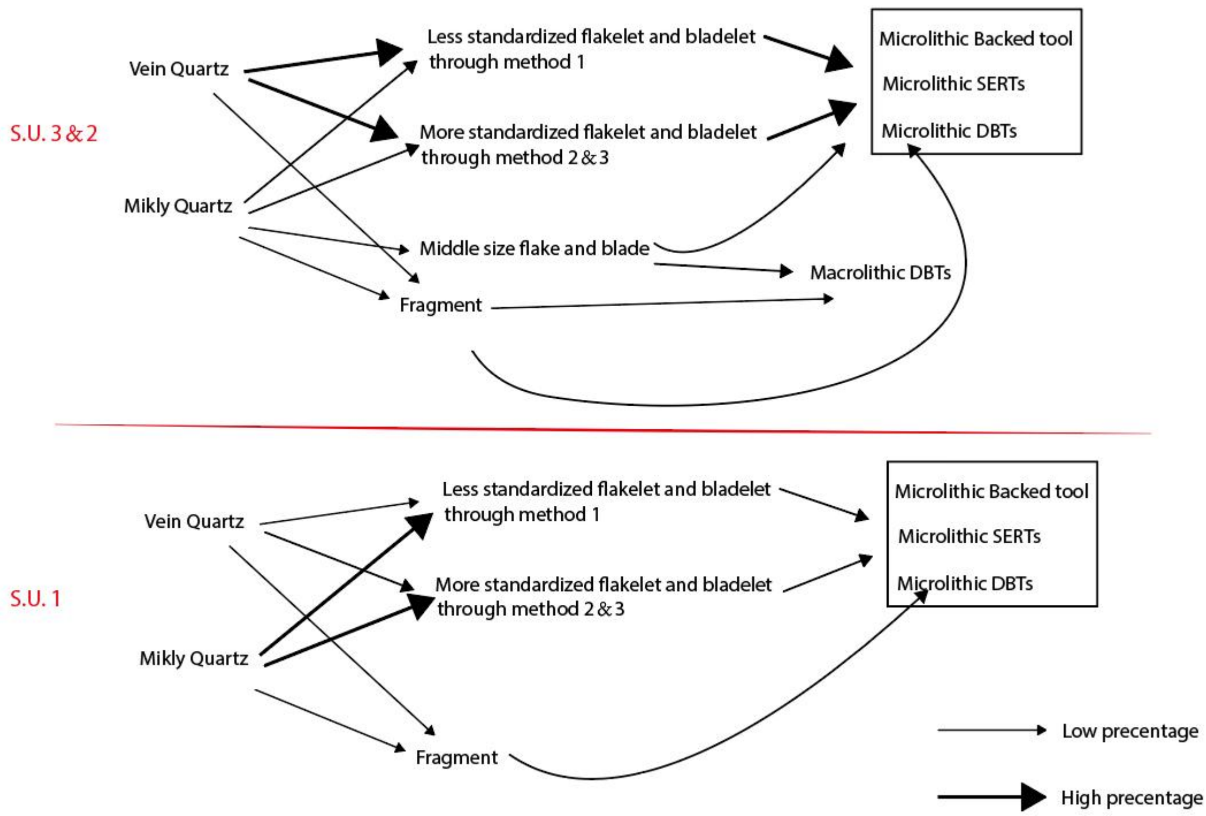


Figure 10 The operation chain in Seal Rock Shelter quartz microlithic industry

The quartz microlithic industry at Seal Rock Shelter may be summarized as assemblages comprising flakelets and bladelets alongside varying proportions of formal tools, consistent with the definition of the Wilton Industry. The Wilton Industry emerged at *ca.*8ka and persisted until *ca.*2ka, coinciding with the advent of sheep and pottery (Guillemard & Porraz 2020). The variability of the lithic assemblage increases after approximately *ca.*4ka, which is referred to as ceramic post-classic Wilton. After *ca.*2 ka is the ceramic final LSA period. The chronological sequence of Seal Rock Shelter is comparable to that of the Wilton Industry. In order to compare the similarities and differences between Seal Rock Shelter and Wilton Industry, Rose Cottage Cave, Elands Bay and Kathu Pan 6 which have been thoroughly researched and confirmed, are used as a comparison object.

3. An attempt at regional comparison

A. Compared with Rose Cottage Cave

Rose Cottage Cave can be traced back to the stratigraphy of the Wilton Industry (PT layer) from around *ca.*7.6 -5.9 ka and the postclassic Wilton stratigraphy (A2 layer) from around *ca.*2.2 ka (Wadley 2000b). There are 1,437 pieces of animal material tools or fragments in the PT layer and 341pieces in the A2 layer.

PT layer contains 11,085 lithic artifacts, including chips (n=6,165), chunks (n=1,889), flakes (n=2,356), blades (n=247), cores (n=105), ground stone(n=15), and retouched tools (n=308). Microlithic materials account for 92%, opaline (67.6%) is the main raw material, while quartz is extremely rare or even absent (Guillemard 2024).

A2 layer contains 14,524 lithic artifacts, including chips (n=6,659), chunks (n=2,416), flakes (n=3,815), blades (n=590), cores (n=218), ground(n=28), and retouched tools (n=798). Among them, opaline (77.4%) is the main material, while quartz is extremely rare or even absent (Wadley 2000b).

Formal tools account for 2.9% of the PT layer (including 55% scrapers, 10.2% adzes, and 17.4% backed tools) and 5.7% of the A2 layer, including 62.7% scrapers, 7.9% adzes, and 12.3% backed tools (Wadley 2000b).

The PT layer and A2 layer at Rose Cottage Cave correspond to the early and late phases of the Wilton Industry respectively (Table 22). Although quartz was not the primary raw material, a microlithic industry comprising flakelets, bladelets and formal tools was developed. Overall, the proportions of flakelet, bladelet, and formal tools within Rose Cottage Cave, along with the proportion of backed tools among formal tools, are lower than those in Seal Rock Shelter. Only the proportion of retouched tools among formal tools is relatively comparable.

Some notable differences are the presence of a significant proportion of heavy-duty tools and debris (chips and chunks) within Rose Cottage Cave, suggesting these locations functioned as a sustained lithic production center. Their diminished presence in later phases implies shifts in technical, demographic, or cultural factors that altered stone production strategies. In contrast, quartz chips and chunks were exceptionally rare at Seal Rock Shelter, indicating distinct site functions and stone production approaches between the two sites.

Table 22 Comparison of Seal Rock Shelter quartz microlithic industry and Rose Cottage Cave

	Rose Cottage Cave		Seal Rock Shelter		
	RCC PT layer	RCC A2 layer	SRS S.U.3	SRS S.U.2	SRS S.U.1
Date	*ca.*7.6 -5.9 ka	*ca.*2.2 ka	*ca.*4.4-4.8 ka	*ca.*3.5-3.8 ka	＜ *ca.*3.5ka
Raw material	Opaline -67.6%	Opaline -77.4%	Quartz		
Percentage of flakelet and bladelet	23.50%	30.30%	45.40%	44.00%	76.70%
Percentage of formal tools	2.90%	5.70%	51.90%	51.40%	21%
Percentage of backed tools in the formal tool	17.40%	12.30%	35.80%	32.10%	42.90%
Percentage of retouched tool in the formal tool	55%	62.70%	64.20%	67.90%	57.10%

B. Compared with Elands Bay

The occupation of Elands Bay spans from the ca. 13.6 ka Robberg Industry to the Late Holocene, encompassing multiple sites including Dunefield Midden 1 and Elands Bay Cave. From mid-Holocene to *ca.*1 ka, this period yielded 14,152 artifacts, primarily crafted from quartz (≈82%) alongside quartzite, silcrete, and other rocks. Among 274 formal tools, quartz constituted 64% and silcrete constituted 18% (Orton 2006).

At **Dunefield Midden 1** (*ca.* 6ka), quartz maintained an 89% share, but silcrete and cryptocrystalline silica comprised 83.3% of the 18 formal tools, with backed tools and scrapers numbering only 12 and 3 pieces, respectively (Orton 2006).

At **Elands Bay Cave** (*ca.* 4.5–3.9 ka), quartz constituted 79–85% of the entire assemblage and 71–75% of formal tools. Scrapers comprised over half of formal tools, adzes were highly prevalent, and backed scrapers and segments were virtually absent (Orton 2006).

The two sites at Elands Bay represent a microlithic industry primarily utilizing quartz as its raw material (Table 23). Despite the absence of data on flakelet and bladelet proportions, comparative metrics indicate that Elands Bay's characteristics more closely align with the trend observed at S.U.1: an increase in flakelet and bladelet proportions alongside a decrease in formal tool proportions. Given the absence of ceramic and livestock domestication in Elands Bay, the observed divergence is more likely indicative of coastal versus inland site differences.

Table 23 Comparison of Seal Rock Shelter and Dunefield Midden 1 and Elands Bay Cave

	Elands Bay		Seal Rock Shelter		
	DFM 1	EBC	S.U.3	S.U.2	S.U.1
Date	*ca.*6 ka	*ca.*4.5-3.9 ka	*ca.*4.4-4.8ka	*ca.*3.5-3.8ka	< *ca.*3.5ka
Raw material	Quartz-89%	Quartz-79-85%	Quartz		
Percentage of flakelet and bladelet			45.40%	44.00%	76.70%
Percentage of formal tools	Nearly absent		51.90%	51.40%	21%
Percentage of backed tools in the formal tool	13.3%	Nearly absent	35.80%	32.10%	42.90%
Percentage of retouched tool in the formal tool	66.6%	> 50%	64.20%	67.90%	57.10%

C. Compared with Kathu Pan 6

Kathu Pan 6 lacks direct radiocarbon dating evidence, but stratigraphic correlation places its age at approximately *ca.*5.7–2.3 ka. A total of 757 lithic artifacts were excavated, with flakes, blades, and bladelets comprising 68% of the finds. Flakes accounted for 97.5% of these, debris constituted 24%, cores represented 6%, and retouched tools made up 2%. The 17 retouched tools comprise 4 backed tools, 8 segments, and 3 scrapers. Raw materials include banded ironstone (over 50%), chert, quartzite, quartz, and other rocks (Black *et al.* 2023).

Kathu Pan 6 exhibits characteristics dominated by unretouched flakes, blades, flakelets and bladelets, accompanied by a small number of formal tools, more closely resembling the situation at S.U.1 (Table 24). Raw materials were diverse, including ironstone, chert, quartz, and other substrates. Although Kathu Pan 6 is also an inland site, its proximity to rivers and seasonal rainfall created a more humid environment than Seal Rock Shelter, potentially supporting large fauna such as hippopotamus (Black *et al.* 2023). Consequently, climatic conditions and faunal assemblages may have influenced the lithic industry at Kathu Pan 6.

Table 24 Comparison of Seal Rock Shelter and Kathu Pan 6

	Kathu Pan 6	Seal rock shelter		
		S.U.3	S.U.2	S.U.1
Date	*ca.*5.7-2.3ka	*ca.*4.4-4.8ka	*ca.*3.5-3.8ka	＜*ca.*3.5ka
Raw material	Ironstone > 50%	Quartz		
Percentage of flakelet and bladelet	68%	45.40%	44.00%	76.70%
Percentage of formal tools	2%	51.90%	51.40%	21%
Percentage of backed tools in the formal tool	23.5%	35.80%	32.10%	42.90%
Percentage of retouched tool in the formal tool	17.6%	64.20%	67.90%	57.10%

By comparing several sites, it can be concluded that the quartz microlithic industry at Seal Rock Shelter bears a strong resemblance to the Wilton Industry. Simultaneously, the Wilton Industry exhibits considerable diversity due to factors such as raw material sources, site types, climate, and cultural influences. However, the quartz microlithic Industry constitutes only 30.5% of the lithic assemblage at Seal Rock Shelter. Therefore, Seal Rock Shelter appears to represent a composite type combining the Wilton Industry with a basalt macrolithic industry.

Chapter 5 Conclusion and perspectives

Given the challenges in conducting technological analysis on quartz microlithic, this thesis employs techno-morphological analysis to systematically document their symmetry, elongation ratio, morphological type, and blank type. This approach facilitates reproducible and quantifiable recording, enabling the extraction of meaningful data. With the aid of this methodology, significant diachronic change and lithic diversity were uncovered in the seal rock shelter microlithic industry: despite the presence of abundant operation chains, the site shifted from being dominated by formal tools to being dominated by flakelet and bladelet production. Compared to other Wilton Industry sites, the microlithic industry at Seal Rock Shelter largely aligns with its characteristics. However, when considered alongside the basalt macrolithic industry, the seal rock shelter site demonstrates a unique adaptive pattern, differing from a typical Wilton Industry site. Considering stratigraphy, climate, and the introduction of ceramics and animal husbandry, the changes observed in S.U.1 likely stem not from technological or climatic shifts, but rather from the adoption of new subsistence strategies.

The quartz microliths from seal rock shelter require further investigation to understand their role and function within the mid-late Holocene lithic industry of Southern Africa. For instance, how did they interact with basalt macrolithic to form the lithic industry, and what distinctions existed in their division? How did their function evolve following the arrival of ceramics and potential pastoralism? Might traceology studies provide insights? The research necessitates collaborative efforts among interdisciplinary archaeologists.

Regarding the study of quartz microliths, various methodologies each possess distinct advantages. The choice depends on the research objectives, the researcher's resources, and the feasibility of establishing a systematic, operational, and reproducible research framework. Crucially, before excavation and research commence, it is essential to clearly define all relevant terms and concepts to facilitate statistical analysis.

APPENDIX

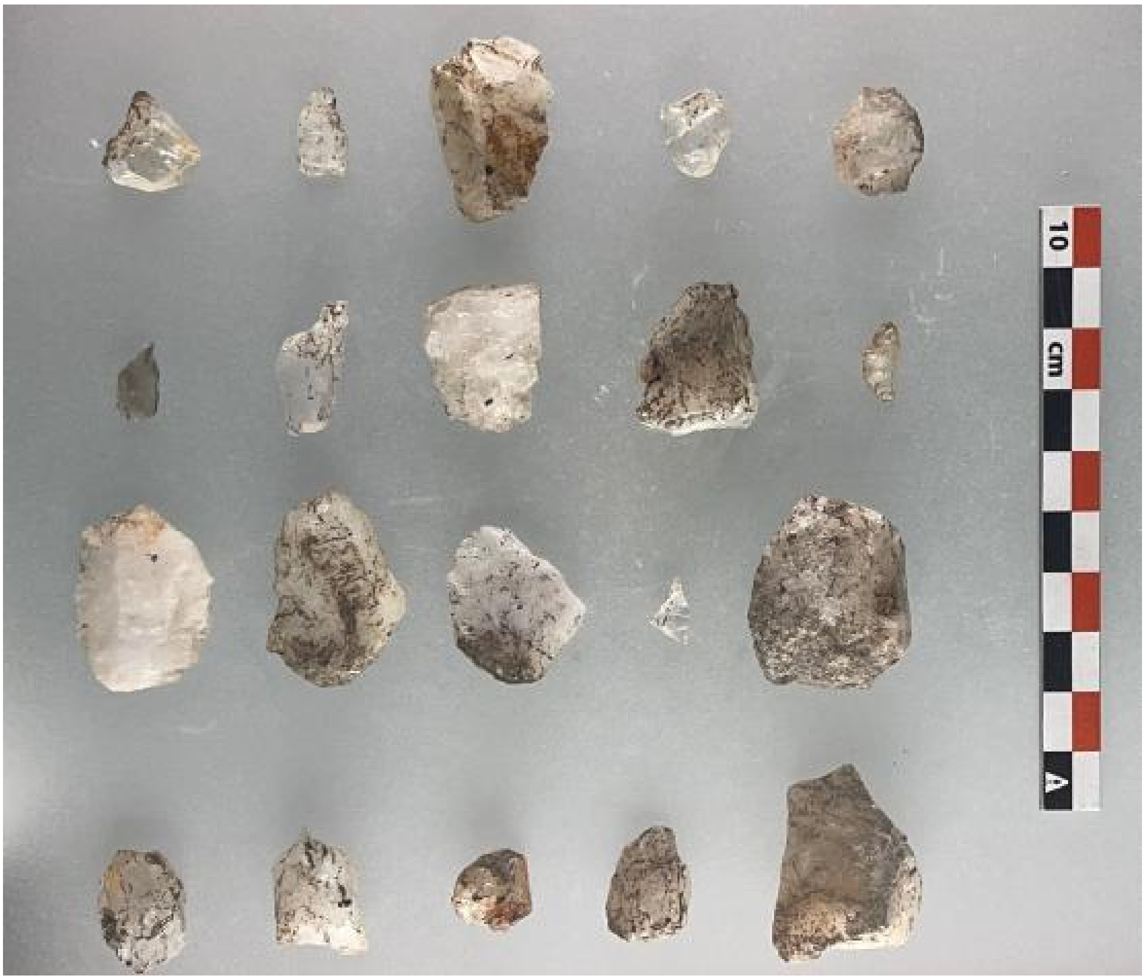
Content of the appendix table

Content of the appendix figure

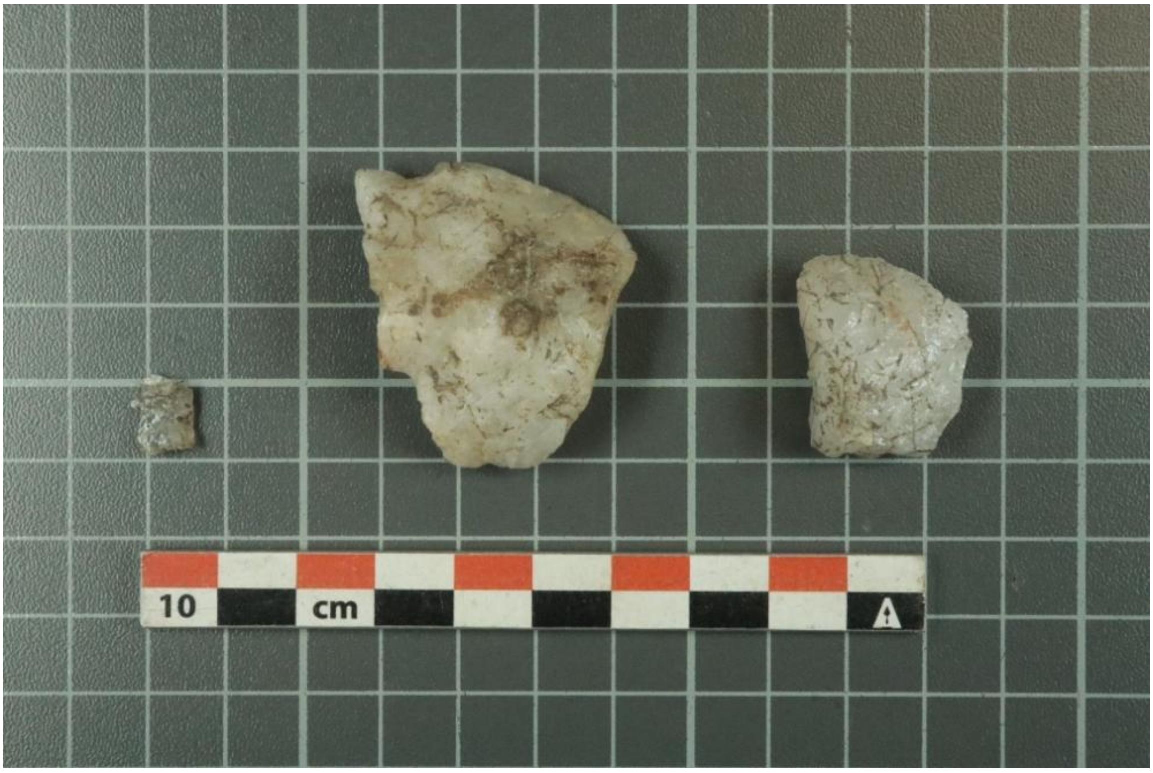
Appendix table 1 “Backed tool” found around the world.

Category	**Artefact name with the earliest site name and dating**	**Explicit description**
Cortical backed tool	Keilmesser (66±14.6—52±6.8Ka, Lichtenberg, Germany)	Defines the tool as a bifacial cutting tool with a working edge opposite an unworked or roughly worked back, a base in the proximal part adjacent to the back, as well as a second, sometimes also sharp edge in the distal part (distal posterior part) that converges with the cutting edge and forms an often pointed distal tip (Weiss 2020).
	Naturally backed tool (Oldowan period, around *ca*. 2.3 Ma)	It is hypothesized that the cortical part of the stone product (natural back) is preferred due to ergonomic reasons and the morphology of the cutting edge, thus rendering the "nonworking edge" redundant (Delpiano *et al.* 2024).
Prepared backed tool	Débordant (core-edge) flakes (*ca*. 1.5Ma, Nyabusosi 18, Uganda)	A class of flakes was obtained using prepared core technology. These prepared cores are required to satisfy five well-defined technical and morphological characteristics. Because the angle between the flaking and striking surfaces is typically between 75° and 90°, flakes will acquire a pre-flaking back (Mesfin & Texier 2022).
	Pseudo-Levallois point (*ca*. 350-300 ka, Orgnac 3, France)	The Pseudo-Levallois point is generally obtained from discoidal flaking, where the desired product is preferably a short and thick flake. And only one ridge from the core flake surfaces, on which the apex of the Pseudo-Levallois point is usually placed (White & Ashton 2003; Goval *et al.* 2016).
	Klasies River (*ca*. 89-60 ka, South Africa)	The lithics that occur in MSA (Mossel Bay) are essentially the same as in the preexisting period, but some backs are covered with cobble cortex, which is because they removed a portion of the distal end of the core. In fact, this is a class of

Category	Artefact name with the earliest site name and dating	Explicit description
		core-edge flakes (Wurz 2002).
Retouch backed tool	Acheulean cleaver (*ca.*1.75 Ma, Kokiselei, Kenya)	Acheulean cleavers are produced on large flakes, characterized by the presence of an unretouched distal cutting edge defined by the intersection of the ventral surface with the cortical surface of the flake, with one or more removals before flaking, or by the intersection of two ventral surfaces. Abrupt modifiers on both sides often give cleavage 'back' (Beyene *et al.* 2013).
	Acheulean backed knives (Acheulean-MSA, Wonderboom, South Africa)	These tools are modularly designed Acheulean LCTs, but are not handaxes or cleavers, and the edges of the back are naturally steep or retouched (angle>75°). The "handle" portion of backed knives potentially increased their efficiency in performing subsistence tasks, Such as animal butchery (Caruana *et al.* 2023).
	Large symmetric backed tool (*ca*. 300-60 ka, Lupemban Industry and Porc-Épic site, Africa)	Large-size (>50mm) backing tools with standardized dimensions and hafting patterns (Barham 2002; Pleurdeau 2003).



Appendix figure 1 Overview of quartz microliths in Seal Rock Shelter

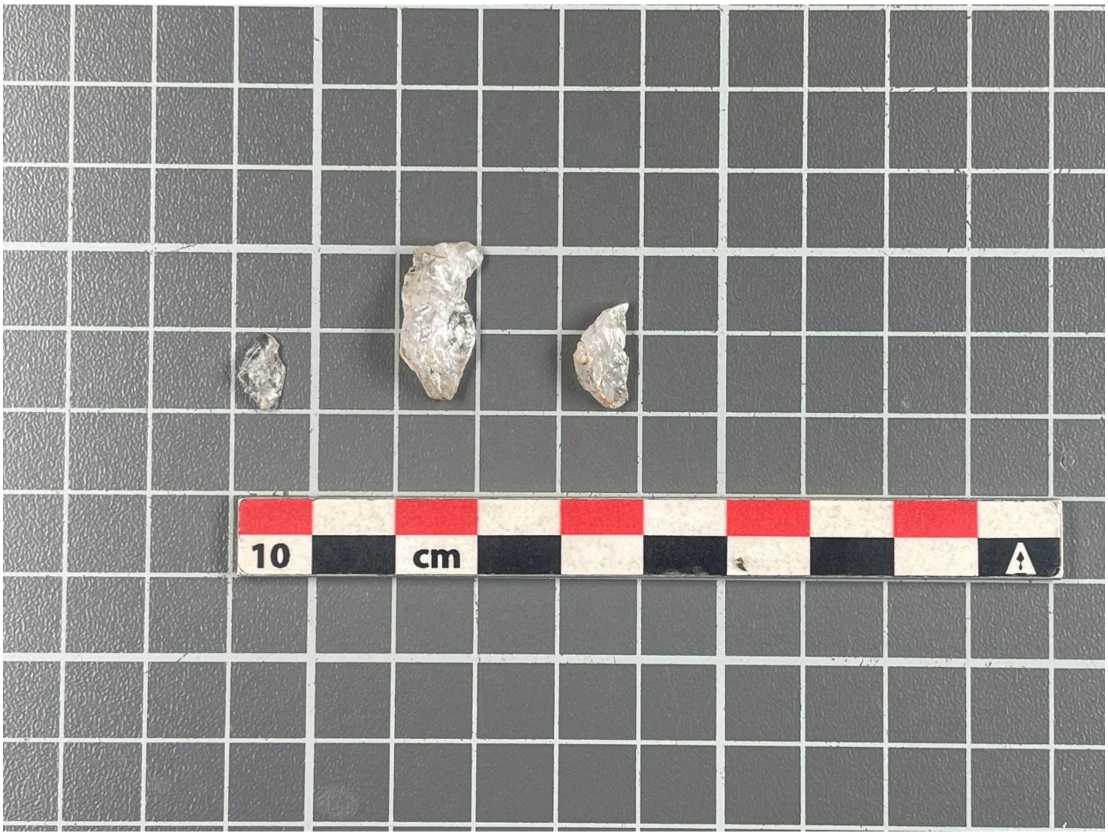


Appendix figure 2 Example of DBTs, from left to right: S126-4, 451, and 464

Appendix figure 3 Example of flakelets and bladelets, from left to right:

bladelet L72, flakelet L131, L132, L136, and 504.

Appendix figure 4 Example of SERTs, from left to right: 433, S82-3, and S70-3.

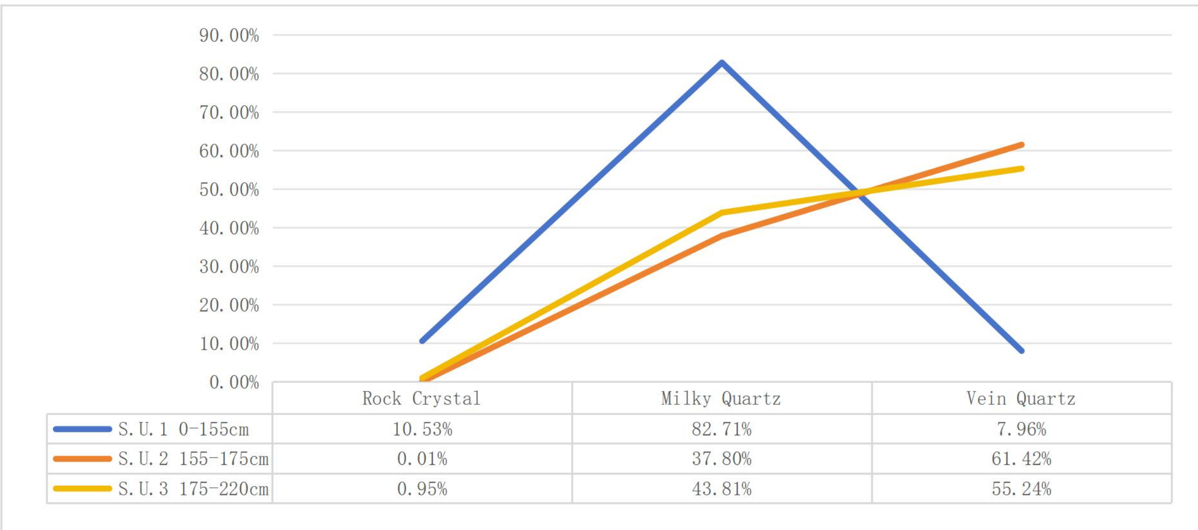


Appendix figure 5 Example of backed tool, from left to right: s16, S87-6, and s62-6.

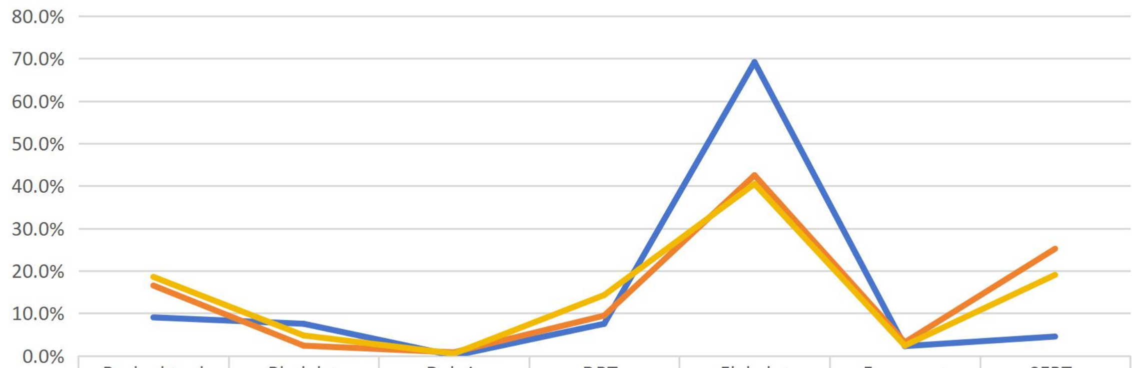
Appendix figure 6 Example of cores, from left to right and up to down:

S.U.3: 433, s177, s66 and s124

S.U.2: s58, 361, s2-1 and 360

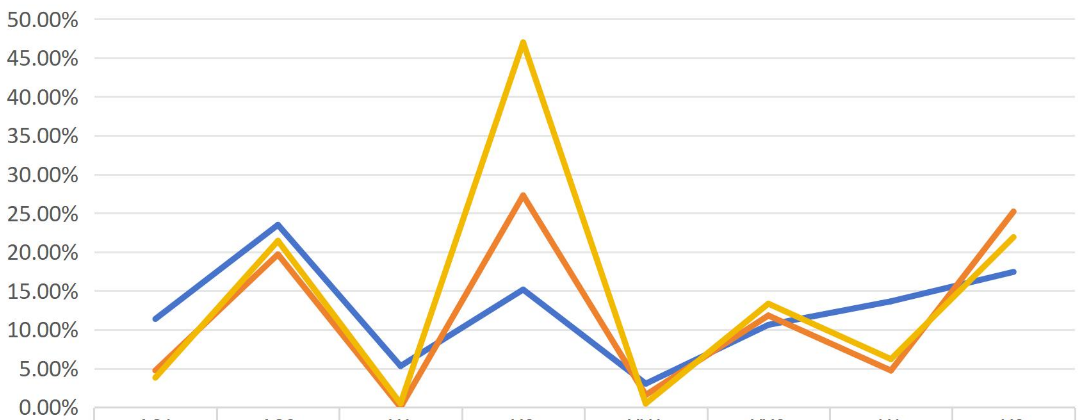


Appendix figure 7 The diachronic change of raw material selection



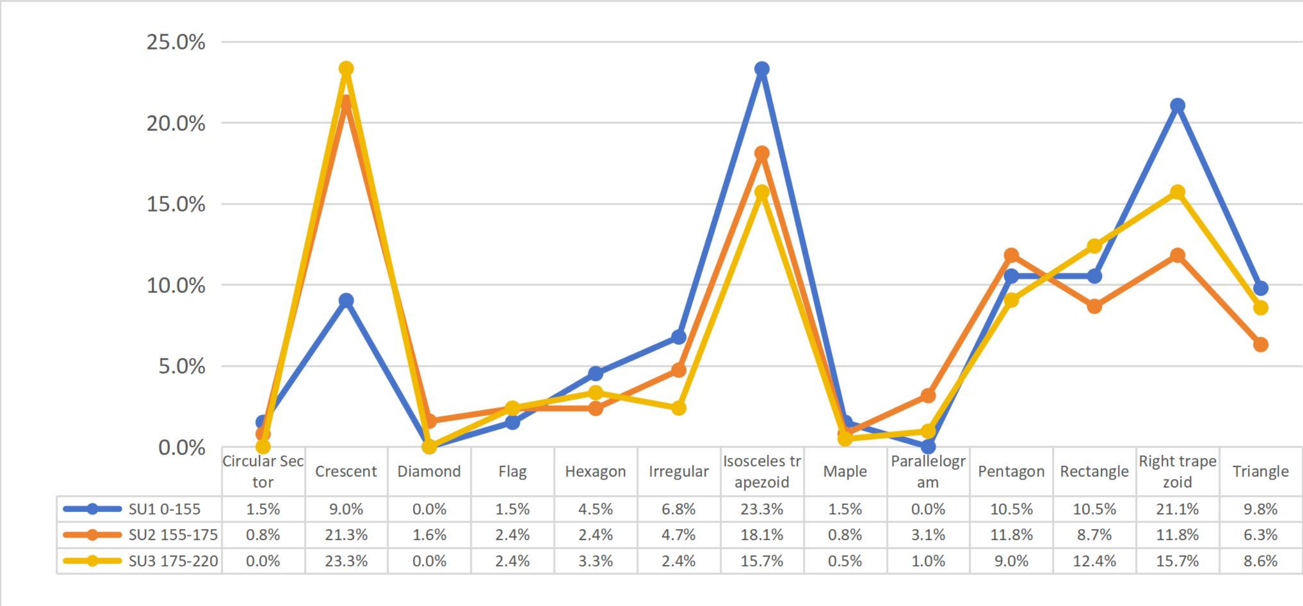
	Backed tool	Bladelet	Debris	DBTs	Flakelet	Fragment	SERTs
S.U.1	9.0%	7.5%	0.0%	7.5%	69.2%	2.3%	4.5%
S.U.2	16.5%	2.4%	0.8%	9.4%	42.5%	3.1%	25.2%
S.U.3	18.6%	4.8%	0.5%	14.3%	40.5%	2.4%	19.0%

Appendix figure 8 The distribution of Seal Rock Shelter lithics in 3 different S.U.



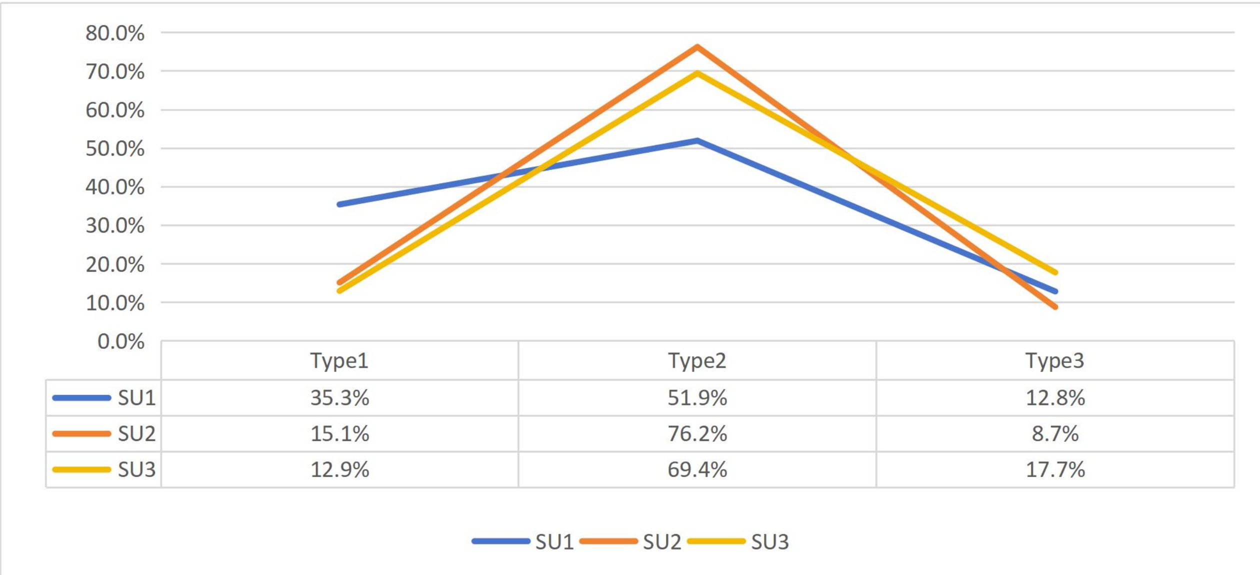
	AS1	AS2	X1	X2	XY1	XY2	Y1	Y2
SU1 0-155	11.36%	23.48%	5.30%	15.15%	3.03%	10.61%	13.64%	17.42%
SU2 155-175	4.72%	19.69%	0.00%	27.27%	1.57%	11.81%	4.72%	25.20%
SU3 175-220	3.81%	21.43%	0.48%	46.97%	0.48%	13.33%	6.19%	21.90%

Appendix figure 9 The change of symmetric morphology type in 3 different S.U.



	Circular Sector	Crescent	Diamond	Flag	Hexagon	Irregular	Isosceles trapezoid	Maple	Parallelogram	Pentagon	Rectangle	Right trapezoid	Triangle
SU1 0-155	1.5%	9.0%	0.0%	1.5%	4.5%	6.8%	23.3%	1.5%	0.0%	10.5%	10.5%	21.1%	9.8%
SU2 155-175	0.8%	21.3%	1.6%	2.4%	2.4%	4.7%	18.1%	0.8%	3.1%	11.8%	8.7%	11.8%	6.3%
SU3 175-220	0.0%	23.3%	0.0%	2.4%	3.3%	2.4%	15.7%	0.5%	1.0%	9.0%	12.4%	15.7%	8.6%

Appendix figure 10 The change of blank morphology type in 3 different S.U.



	Type1	Type2	Type3
SU1	35.3%	51.9%	12.8%
SU2	15.1%	76.2%	8.7%
SU3	12.9%	69.4%	17.7%

Appendix figure 11 The change of elongation ratio type in 3 different S.U.

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