What do spatial data from Sibhudu tell us about life in the Middle Stone Age?

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Abstract

For the last 10 years, we have been carefully excavating rich, well-stratified Middle Stone Age (MSA) horizons from Sibhudu in KwaZulu-Natal, South Africa. This work has provided a great abundance of numerous classes of cultural material from well-controlled contexts dating to between >90 and 36 ka that is relevant for documenting the Late Pleistocene cultural evolution of \textit{Homo sapiens} in Africa. In this paper, we look more closely at intra-site spatial relationships between the finds and critically examine their context to determine what has been learned through such careful excavation. The effort is justified because through excavation we destroy sites, necessitating the recovery of as much relevant information as is possible and practicable, for ourselves and for future generations. This paper focuses on the high-resolution Sibhudan sequence at Sibhudu (~58 ka) which features high sedimentation rates and abundant finds, with people performing multiple activities in different parts of the site over time. The analyses present examples of how quantitative, 3D spatial data and statistical analyses open new paths of inquiry that advance our understanding of the lifeways of MSA peoples on spatial and temporal scales that have yet to attract much attention by researchers in Africa. Our analyses find intra-site patterning both within and across layers that is indicative of structured spatial use even in small areas of excavation. We identify potential knapping and dumping areas that change their position through time and connect these observations with rich techno-typological and techno-functional information. This work points to future directions, such as refitting and related contextual studies that are rarely used in Late Pleistocene archaeology of southern Africa, but will ultimately provide new insights into MSA lifeways.

Keywords Middle Stone Age · Southern Africa · Intra-site spatial analysis · Settlement dynamics · Cultural stratigraphy · Spatial organization

Introduction

Studying the cultural evolution and Paleolithic lifeways of hominins can operate on multiple scales of analysis, including spatial, temporal, demographic, and behavioral dimensions (Fig. 1; Conard 2001a; Bailey 2007; Kuhn 2013). Archaeologists can examine the actions of hominins on scales from molecular to continental, and from seconds to many hundreds of thousands of years. From a demographic perspective, the individual is the smallest unit of analysis, while other studies might be interested in the population dynamics of entire species. Finally, the behavior scale spans the range of hominin experience from the fulfillment of essential biological needs for food, drink, sleep, and shelter to a wide range of practical activities and into the symbolic areas of beliefs, abstract thought and communication.

The topic of high-resolution temporal and spatial studies, often supported by refitting studies of lithic artifacts and faunal remains, has long been a focus of Paleolithic archaeology and ethnoarchaeology in Europe and the Near East (e.g. articles in Conard 2001b; 2005; Gamble and Porr 2005; Gaudzinski-Windheuser et al. 2012). Well-known sites for such studies include among many
others Pincevent (Leroi-Gourhan 1984; Karlin and Julien 2019), Verberie (Audouze and Enloe 1997), Abric Romani (Chacón et al. 2012; Romagnoli and Vaquero 2016; Vaquero et al. 2017; articles in Carbonell i Roura 2012), Maastricht-Belvédère (Roebroeks 1988), Wallertheim (Conard and Adler 1997; Adler et al. 2003), and Gesher Benot Ya’aqov (Alperson-Afil et al. 2009). Yet, this line of research on fine spatial and temporal scales has typically not received much attention in the southern African MSA where issues related to establishing broad cultural stratigraphic and chronostratigraphic sequences have been the mainstay of research (Sampson 1974; Singer and Wymer 1982; Volman 1984; Lombard et al. 2012; Porraz et al. 2013; Wadley 2015). Additionally, with the realization that modern humans originated in Africa, recent decades have seen a shift of attention toward the MSA and a wide array of topics related to the cultural and cognitive evolution of our species (Henshilwood et al. 2001; 2004; Conard 2008; Wadley et al. 2009, Texier et al. 2010; Marean 2010; 2011; Henshilwood 2012; Wadley 2015; d’Errico et al. 2012; Will et al. 2019; Lombard and Högbåck 2021). An underlying theme has been the demonstration of innovative technologies and cultural behaviors that are argued to have provided early modern humans with an evolutionary advantage in comparison with archaic hominins outside of Africa.

Although intra-site spatial analysis has not been a focus of recent research on the MSA of southern Africa, there are exceptions. These include, among others, Bernatchez’s (2010) analysis of intra-site spatial patterning at Pinnacle Point, Wadley’s (2001, 2010, 2012) discussion of specific features and the activities of individuals and groups at Rose Cottage Cave and Sibhudu, and Henshilwood et al.’s (2011) identification of a highly localized cluster of symbolic objects at Blombos. Most recently, Haaland et al. (2020) published a detailed geoarchaeological study of the Blombos deposits with an explicit focus on diachronic trends in spatial site use. None of these studies have changed the overall emphasis on more large-scale patterns of cultural change and behavioral evolution, but they do help to illustrate the potential importance of intra-site spatial patterning and a change of perspective toward more fine-grained scales of analyses.

This paper reports research at Sibhudu, where on the invitation of the previous excavator of the site, Lyn Wadley, a team from the University of Tübingen under Conard’s direction began excavation at Sibhudu in 2011. On a formal note, at the request of multiple Zulu tribal authorities, starting in 2020, we have updated the spelling of Sibhudu to include an ‘h’. During the first season and subsequently, Wadley’s and Conard’s teams worked together to ensure a fluid transition between the excavations. This approach allowed the current team to profit from Wadley’s 25 seasons of work at the site between 1998 and 2011. One of the many topics guiding the research design of the new phase of excavation at Sibhudu was the desire to study patterns of intra-site variation in the spatial distributions of cultural materials. The hope is that these kinds of data will provide new insights into the behavior of people during the MSA while informing us on how people lived their daily lives, took care of their needs, and interacted with each other.

Here we examine the spatial patterning of multiple classes of artifacts from the high-resolution stratigraphic sequence at Sibhudu combining piece-plotted finds together and other field data with multiple analytical methods to see if such an approach provides useful new insights into how MSA peoples lived and organized their activities in the uThongathi Valley of KwaZulu-Natal. We apply expectations from ethnoarchaeological and experimental studies to help interpret the quantitative spatial patterns of artifacts. Given the great effort required to obtain high-quality intra-site data, this paper also represents a critical assessment of our excavation techniques and research questions that may have implications for how we excavate sites and collect data in the future.

**Sibhudu and its stratigraphic units**

Sibhudu is a large rockshelter within the Natal Sandstone group overlooking the uThongathi River in KwaZulu-Natal, South Africa, about 40 km north of Durban and...
The site is located 15 km from the Indian Ocean (Fig. 2). The site is located in southern Africa’s summer rainfall zone and today lies ecologically within the Indian Ocean Coastal Belt. In terms of its archaeological content, the site features Iron Age deposits directly overlying MSA strata. Wadley’s team excavated the MSA deposits over an area of 21 m² to a depth of nearly 3 m. This sequence, dating between > 77 and 38 ka, includes Wadley’s designation of pre-Still Bay, Still Bay (SB), Howiesons Poort (HP), “post-HP”, late MSA, and final MSA strata (Jacobs et al. 2008; Wadley 2006, 2013; Wadley and Jacobs 2006). The current excavations have focused on re-excavating the upper portion of the site beginning at the top of the “post-HP” and continuing into deposits below the “pre-SB” where Wadley stopped in 2011 (Conard et al. 2012; Will et al. 2014; Conard and Will 2015; Rots et al. 2017; Schmid et al. 2019; Will and Conard 2020). Today, Sibhudu is one of the key archaeological sites in Africa for studying the cultural evolution of *Homo sapiens*. Within its thick and high-resolution archaeological sequence, the site shows excellent organic preservation and high densities of archaeological remains, including lithic artifacts, faunal and botanical remains, ochre, and organic tools.

Sibhudu preserves a long and complex stratigraphy comprised of more than 50 distinct MSA layers (Wadley and Jacobs 2006; Goldberg et al. 2009; Rots et al. 2017). The deposits overlying the HP are mostly anthropogenic and exhibit little indication of vertical mixing. These deposits are characterized by dozens of intact, often finely laminated strata. The HP and deeper horizons differ from the upper deposits in appearing relatively homogenous in color and texture, although isolated features such as ash lenses occur and define surfaces, allowing for stratigraphic distinctions between excavated units (Goldberg et al. 2009; Miller 2015). Of particular interest in the context of this study is the “post-HP”, which we refer to with the working term “Sibhudan” (Conard et al. 2012; Will et al. 2014, see also Lombard et al. 2012). This well-stratified sequence lies on top of the HP and below Wadley’s (2006) “late MSA”. It is one of the thickest and richest deposits of this period in southern Africa. The depositional sequence of 1.2 m thickness includes a succession of 23 layers often containing finely laminated find...
horizons and features. These 23 layers are further subdivided into 72 finer stratigraphic units or Abträge (see below). These deposits are almost entirely of anthropogenic origin, although some strata have undergone diagenic alternations (Fig. 3; Goldberg et al. 2009; Miller 2015; Will and Conard 2018). This sequence has an extraordinarily high temporal resolution, with occupations at the base, middle, and top of the deposits dated by Jacobs et al. (2008) indistinguishably to \( \sim 58 \text{ ka} \) by optically stimulated luminescence (weighted mean age of \( \sim 58.4 \pm 1.4 \text{ ka} \); Table 1). Combined, these observations attest to numerous intense and repeated occupations by MSA hunter-gatherers over the course of somewhere between only centuries to at most a few millennia (Jacobs et al. 2008; Wadley 2013; Wadley and Jacobs 2006; Will and Conard 2018). Assuming the deposition of the entire Sibhudan sequence took place over one or two millennia, individual Abträge would approach the temporal resolution of the lifetime of individuals.

The Sibhudan was initially defined based on techno-typological and techno-functional analyses of stone artifacts from six stratigraphic layers from the uppermost part of the “post-HP” excavated over a surface of 6 m\(^2\) in 2011 and 2012 (Conard et al. 2012: Table 1). As excavations progressed, the definition was expanded on a preliminary basis to include an additional 17 layers with diverse cultural and technological signals (Table 1; Conard and Will 2015; Will and Conard 2018; Will et al. 2014; Will 2019). The Sibhudan sequence from the Tübingen excavation encompasses 5 m\(^3\) sediments, close to 200,000 lithic artifacts with high densities per layer (5000–90,000 n/m\(^3\) lithics), frequent fauna, ochre, charcoal, and bone tools. Data and observations from all of these classes of finds provide a strong starting point for spatial analyses.

### Excavation methods and data collection

The new phase of excavations at Sibhudu used techniques employed by the Department of Early Prehistory and Quaternary Ecology on its digs around the world. In short, the approach has similarities with the methods pioneered by Leroi-Gourhan, Bosinski, and Hahn at sites including Pincevent, Gömmersdorf, and Geissenklösterle (Leroi-Gourhan and Brézillon 1966; Bosinski 1969; Hahn 1988) except for the use of modern measuring and imaging techniques together with more quantitative methods. The system is based on the excavation of Abträge (singular Abtrag) that closely follow the stratigraphy and never crosscut geological layers in an attempt to approximate the chronostratigraphic units. This approach to excavation is similar to the décapage approach used in many French Paleolithic studies (e.g. Leroi-Gourhan and Brézillon 1966). Abträge are usually 1–3 cm thick depending on find densities, the presence of stratigraphic markers, anthropogenic features, and other variables. In contrast to horizontal spits with a fixed thickness, Abträge follow natural and irregular surfaces such as inclinations,
and crew members measure sediment volumes collected in every bucket and all classes of materials quantitatively. At Sibhudu, we began digging surfaces of 6 m² in the Sibhudan layers, which we viewed as a size that enabled us excellent stratigraphic control. Fortunately, the upper ~1.5 m of MSA deposits preserve many stratigraphic markers that typically allow for the definition of reliable chronostratigraphic units. This being said, the site has undergone considerable diagenesis, which along with many other geoarchaeological topics has been the focus of recent research (Schiegl and Conard 2006; Goldberg et al. 2009; Miller 2015).

Since Sibhudu is so rich in finds, we measure all lithic artifacts larger than 3 cm in three dimensions—as well as all cores, tools, and fragments of tools regardless of size—together with the slope and orientation of elongated finds. Visible botanical remains, charcoal, and pieces of ochre are piece-plotted as are larger (typically >3 cm) and identifiable bones. The size cut-off for bones varies and is lowered in layers with fewer bones or worse faunal preservation. In the field, we perform 3D piece-plotting with a Leica Total Station with help of the EDM program (Dibble and McPherron 1996) and Microsoft Access to store all data. The top and base of every Abtrag are photographed (Fig. 4), and each variety of sediment is sampled. We also hand pick botanical material from the sediments. The excavation team dry-screens sediments from each quarter meter through 5- and 1-mm mesh at the site. We subsequently sort all of the materials from the coarse screen and sample columns from the fine screens for different find categories which are then bagged separately for further analyses. In the coarse screen, lithic finds are categorized by different size types including 5–10 mm, 10–20 mm, and 20–30 mm, and their number is entered in the database for each bucket. Finds found during sorting including bone tools, faunal remains, ochre, shells, charcoal, botanical remains, and unidentified materials are also recovered systematically and archived.

Using the combined information from the piece-plotted finds and finds from the screened buckets of sediment, we command a wealth of spatial data and quantitative information on the abundances of many classes of material in a continuous record for the entire volume excavated at Sibhudu. Tables 1 and 2 provide an overview of the total numbers of piece-plotted lithics (n = 10,882) and faunal remains (n = 1444) from the Sibhudan, as well as over

| Layer | Abträge (n)* | Lithics (>30 mm) | Faunal remains | Ochre | Charcoal | Chronometric ages b |
|-------|--------------|------------------|----------------|-------|----------|-------------------|
| BSP   | 6            | 822              | 179            | 13    | 40       | 57.6 ± 2.1 ka     |
| SPCA  | 5            | 580              | 142            | 33    | 68       |                   |
| CHE   | 3            | 133              | 42             | 9     | 18       |                   |
| MA    | 2            | 178              | 54             | 14    | 26       |                   |
| IV    | 4            | 676              | 152            | 12    | 27       |                   |
| BM    | 2            | 262              | 35             | 2     | 1        | 59.6 ± 2.3 ka     |
| POX   | 5            | 2192             | 155            | 14    | 4        | 59.0 ± 2.2 ka     |
| BP    | 3            | 261              | 9              | 0     | 0        |                   |
| SU    | 7            | 1624             | 69             | 10    | 0        |                   |
| SP    | 3            | 705              | 33             | 5     | 0        |                   |
| WOG1  | 3            | 368              | 12             | 2     | 0        |                   |
| G1    | 5            | 185              | 6              | 1     | 1        |                   |
| CH2   | 2            | 109              | 5              | 0     | 0        | 58.3 ± 2.0 ka     |
| Y1    | 2            | 279              | 35             | 11    | 0        | 58.6 ± 2.1 ka     |
| BG MIX | 3           | 487              | 60             | 11    | 4        | 58.2 ± 2.4 ka     |
| BBGM  | 2            | 260              | 39             | 6     | 1        |                   |
| YA    | 2            | 247              | 37             | 8     | 5        |                   |
| YA2   | 2            | 224              | 47             | 4     | 11       |                   |
| GM    | 1            | 133              | 24             | 1     | 3        |                   |
| YA2i  | 1            | 164              | 27             | 0     | 1        |                   |
| BYA2i | 3            | 310              | 88             | 10    | 2        |                   |
| LBYA  | 3            | 451              | 96             | 15    | 1        |                   |
| RB    | 3            | 232              | 98             | 5     | 25       |                   |
| Total | 72           | 10,882           | 1444           | 186   | 238      |                   |

*aNot all layers are continuously found throughout the excavated surface, but rather as pockets (e.g. layer BP)*

*bAbsolute ages are OSL dates (in ka) from Jacobs et al. (2008)
160,000 lithic artifacts < 3 cm recovered from the sorting of the buckets, > 142 kg of faunal remains, and > 3000 pieces of ochre and ochre-like material. We can assign all finds from excavated buckets to one of the 24 quadrants within the six squares and a thickness of 1–3 cm, providing coarser-grained but reliable spatial information for large numbers of small finds. The average thickness of the 72 Abträge is about 1.5 cm. All 1140 excavated buckets of sediment from the Sibhudan layers have been sorted, providing a complete picture of all archaeological finds in these sediments.

**Analytical methods**

A study of the spatial distributions at Sibhudu suffers from a number of weaknesses that should be mentioned from the start. First, the size of the excavation is never more than 6 m². In the lower part of the Sibhudan sequence, we reduced the area to 4 m². While in theory it could be possible to combine the areas of the Wadley and Conard excavations, in practice the different nature of the data collection and the possibility of stratigraphic inconsistencies due to the complexity of sequence makes this difficult. Clearly, 6 m² is far too small an area to reconstruct fully how the inhabitants used the space available at a site, particularly given the large size of the Sibhudu rockshelter that provides a usable space of several hundreds of square meters (Fig. 2). Still, as we will see, this window into the MSA past does give us a meaningful look into how the site was used, and at present, there is no pressing reason to destroy additional parts of the site through excavation to gain a larger sample.

Another factor that brings both advantages and disadvantages for spatial analysis is the lack of clear stratigraphic separation between adjacent find horizons. Ideally, we would like to have discrete layers that represent separate chronological entities. Even if these cultural stratigraphic units represent palimpsests, as is normally the case, and bring along problems such as time averaging (see in more detail Shott 1998; Bailey 2007), they can be compared to each other with reliable separation between the occupations. An example of this would be some of the archaeological layers at Abri Romaní which form discrete assemblages sandwiched between geogenic horizons (Carbonell i Roura 2012; Romagnoli and Vaquero 2016; Vaquero et al. 2017). Sibhudu is extremely rich, and all the deposits of the Sibhudan sequence are of anthropogenic origin, without sterile geogenic horizons separating them. Despite the clear stratigraphy seen in many parts of the profile (Fig. 3), it is impossible to separate the artifacts from adjacent find horizons perfectly. The same applies to the many anthropogenic features. These are so numerous that they cannot always be reliably separated from each other (Fig. 4). We do the best we can to dig the site optimally, but it would be naïve to think that the cultural stratigraphic units that we define are completely separated from each other. In theory, we could check the integrity of the layers by systematic refitting or other techniques, but in practice, the sheer amount of cultural material and the homogeneity in raw materials has made systematic refitting
an unobtainable goal for the present. Nonetheless, individual layers could be distinguished in the field based on composition, texture, and color (Figs. 3 and 4). Many of these layers are highly distinctive.

Other than the minor disturbances from occasional roots or rare small biogalleries left by animals or insects, the finely laminated layers, while at times having undergone strong diagenesis, have not experienced postdepositional reworking. Anthropogenic processes at this intensely occupied site appear to be the strongest taphonomic agents affecting the spatial distribution of finds. In most settings at Sibhudu, it appears that the distribution of finds corresponds closely to the pattern left behind when the occupants abandoned the site and the find horizons were eventually buried. This claim is supported by the orientation and dip of finds (Fig. 5), which are distributed in all directions, though with a preferred inclination along the natural sloping of the sediments. Goldberg et al. (2009) also demonstrate the limited impact of trampling in this part of the sequence. Work by Bailey and Galanidou (2009) and more recently Reeves et al. (2019) likewise suggests that, even if not always straightforward, meaningful spatial patterning can be preserved in both Upper and Middle Paleolithic caves where horizons clearly represent large numbers of occupations preserved in palimpsests.

Fortunately, we can test these claims. Our null hypothesis for this study is based on the idea that we would expect a random distribution of finds within and across layers as a result of the taphonomic mixing of materials that were exposed to the surface. Alternatively, distinct patterns in the distribution of finds between deposits would reflect largely undisturbed sediments. In the case of Sibhudu and its mostly anthropogenic sediments, we hypothesize that such patterns most likely result from patterned human activity. If we can reject our null hypothesis, we can begin to examine potential explanations for the observed distributions of archaeological material. In this study, we examine both intra- and inter-assemblage spatial data to test these two hypotheses and to develop inferences about activities at Sibhudu using expectations derived from ethnographic studies of hunter-gatherers and experimental archaeology.

Ethnoarchaeological studies have often documented how hunters and gatherers perform spatially discrete activities that lead to a patterned record of refuse (e.g. Binford 1978; 1996; Fisher and Strickland 1989; Kent 1984, 1991; Yellen 1977).

| Layer  | Sediment volume (m³) | Buckets (n) | Lithics (<30 mm) | Fauna (g) | Ochre (n) | Lithic density (n/m³) |
|-------|----------------------|------------|------------------|-----------|----------|----------------------|
| BSP   | 0.387                | 102        | 13,644           | 199,667   | 287      | 37,360               |
| SPCA  | 0.300                | 85         | 10,019           | 16,732    | 138      | 35,330               |
| CHE   | 0.090                | 26         | 2792             | 4716      | 44       | 32,500               |
| MA    | 0.136                | 44         | 4421             | 4378      | 31       | 33,816               |
| IV    | 0.424                | 95         | 20,389           | 15,988    | 121      | 49,682               |
| BM    | 0.142                | 28         | 5694             | 4127      | 28       | 41,945               |
| POX   | 0.575                | 114        | 43,418           | 14,142    | 301      | 79,391               |
| BP    | 0.048                | 16         | 4039             | 10,978    | 93       | 89,583               |
| SU    | 0.400                | 89         | 26,816           | 8357      | 789      | 71,189               |
| SP    | 0.232                | 47         | 5060             | 3872      | 159      | 24,904               |
| WOG   | 0.188                | 39         | 2210             | 1468      | 76       | 1335                 |
| G1    | 0.334                | 56         | 1505             | 1679      | 85       | 5060                 |
| CH2   | 0.189                | 34         | 971              | 1355      | 63       | 5714                 |
| Y1    | 0.194                | 43         | 1794             | 2493      | 304      | 10,701               |
| BG M  | 0.262                | 48         | 4063             | 6775      | 345      | 17,366               |
| BBGM  | 0.162                | 32         | 2020             | 7024      | 154      | 14,074               |
| YA    | 0.131                | 32         | 2288             | 4488      | 137      | 19,351               |
| YA2   | 0.125                | 32         | 2291             | 3105      | 91       | 20,120               |
| GM    | 0.096                | 16         | 1285             | 3105      | 38       | 14,771               |
| YA2i  | 0.097                | 16         | 1043             | 1856      | 12       | 12,443               |
| BYA2i | 0.192                | 48         | 1457             | 5262      | 85       | 9203                 |
| LBYA  | 0.188                | 48         | 2299             | 5844      | 142      | 14,628               |
| RB    | 0.064                | 50         | 1969             | 4717      | 95       | 34,391               |
| Total | 4.954                | 1140       | 161,847          | 142,552   | 3618     | 34,790               |
Although many methodical advances have been made in recent decades through experimental archaeology (e.g. Newcomer and Sieveking 1980; Johansen and Stapert 1998; de la Torre et al. 2019) and analytical methods (e.g. Lloyd and Atkinson 2004; Katsianis et al. 2008; Clark 2017), difficulties remain in linking such behaviors to the archaeological record. Research on the spatial organization of stone knapping is particularly relevant for the study of the dispersion of lithic artifacts in the MSA layers of Sibhudu. Here we use an experimental study by Johansen and Stapert (1998) that provides expectations on how knapping and dumping shape the spatial distribution of...
lithic artifacts and connect them with further ethnographical work.

According to Johanson and Stapert’s experimental work, a knapping spot exhibits distinct patterns of artifacts which accumulate around the knapper. During knapping, small flakes accumulate right by the knapper’s feet in concise and roughly circular concentrations, mostly within 1 m of the knapper (see also Newcomer and Sieveking 1980). A little further away from the knapper, the blanks are often collected during the flaking process. Since not all artifacts produced are used and transported away, a portion of the blanks tends to stay in or near the knocking area. Following Johansen and Stapert (1998), such patterns can be differentiated by analyzing the spatial heterogeneity of assemblages. For lithic assemblages, they defined heterogeneity as the presence of both positive and negative correlations among the different size classes of lithic artifacts. An artifact accumulation featuring a heterogeneous pattern can be linked to knapping, while positive correlations among the size classes indicate dumping. To test the presence and directions of correlations among the different size classes following Johansen and Stapert (1998), we distinguish large artifacts (> 3 cm), flakes (1–3 cm), and small and micro-debitage (< 1 cm). We use the frequencies of these classes of artifacts within identified density peaks (see below) to calculate Spearman’s correlation coefficient, which expresses the degree and direction of a potential correlation between two classes. Additionally, based on ethnographic studies and general expectations of waste accumulation and management in domestic areas on sites that were used over longer periods (see Binford 1978; Schiffer 1983; 1987; O’Connell 1987; Brooks and Yellen 1987; Simms and Heath 1990; O’Connell et al. 1991; Bamforth et al. 2005), we expect dumping areas to exhibit lower concentrations of small debris, since small and micro-fabrics are often lost in the sediment. Conversely, more larger lithic items are expected to occur in dumps, because they are more likely to be picked up during the cleaning and maintenance of surfaces. Dumping areas should also contain higher numbers of broken tools and more frequent burnt faunal remains. Within dumps, artifacts are expected to show a wide range of dips that result from secondary discard in bulk.

To examine questions regarding spatial patterning, we used 3D spatial data collected in the field and stored in a Microsoft Access database. We used a range of indices to test whether the find distributions observed in our excavation are random, grouped, or homogenous. Calculations included the index of dispersion, Morasita’s index (Morisita 1959), and the index of patchiness (Lloyd 1967). We used routines implemented in the open access software PASSaGE, as well as the global Moran’s I using the functionality of version 5.5 of the R package “ape”. We further employed ESRI ArcGIS to plot kernel density estimations (e.g. Baxter et al. 1997) in order to visualize patterns in the spatial distribution. We also performed a Cluster and Outlier Analysis (Anselin Local Morans I) to define “hot spots”, which represent statistically significant clusters of finds. Localizing the hotspots and voids can help to identify features, which can be interpreted further by looking at the positions of different categories of material. We added other parameters, such as single-find plots of different artifact types or sizes, as needed, using 3D data from all categories of finds (e.g. Lloyd and Atkinson 2004; Conolly and Lake 2006).

For the current study, we will focus on kernel density plots, basic geo-statistical analyses, models from experimental archaeology for distinguishing in situ knapping scatters (Johansen and Stapert 1998), and the broader ethnoarchaeological literature (Binford 1978; 1996; Fisher and Strickland 1989; Kent 1984, 1991; Simms and Heath 1990; O’Connell et al. 1991; Yellen 1977) to consider the potential usefulness of the high-resolution spatial data from Sibhudu. To illustrate these points, we will start by looking at the distributions of cultural material in the layer Ivory dated Using OSL to ca. 58 ka (Jacobs et al. 2008). The assemblage from Ivory is a typical expression of the “classic Sibhudan” (Conard et al. 2012; Will et al. 2014; Will and Conard 2018) with high find densities and a great diversity in lithic artifacts, lending itself as a showcase for this analysis. We can break down the deposit into the three Abträge from the layer and then combine them for comparison with other layers (Fig. 4).

While we illustrate the approach with the layer Ivory, we could easily perform similar analyses using the data from any of the layers we have excavated at Sibhudu. The technologically analyses of the Sibhudan sequence (Conard et al. 2012; Will et al. 2014; Conard and Will 2015; Will and Conard 2018) allow for a more detailed assessment of spatial patterns than distributions of size classes or simple categories of stone tools. A second analysis evaluates diachronic patterns of spatial data across the 23 layers of the Sibhudan based on established findings from Ivory, examining whether the use of space was similar or different over time.

**Spatial distributions within layers: the case of Ivory**

Ivory yielded a total of 21,065 chipped lithic artifacts in a complex find situation with several potential combustion features (Fig. 4). The spatial distribution of 18,733 artifacts recovered from the screened buckets is shown in the kernel density plot of Fig. 6a, while Fig. 6b is a kernel density plot of the distribution of the 9948 micro-artifacts < 10 mm in maximum dimension. These plots clearly deviate from a uniform or random distribution and reveal two areas of increased find densities. The first one, which we call Ivory density peak 1 (IDP1), is located in the northwestern part...
of the excavation covering the entire square C3 as well as the northern quadrants of square D3. The second, Ivory density peak 2 (IDP2), is located in the southwestern part of the excavation covering square E3 and extending into the southern two quadrants of square D3. Subtle differences are seen in the two plots, which suggest differences in how micro-artifacts enter into the archaeological record. The index of dispersion with a value over 1 ($ID = 169$) and Moran’s $I$ with a value of 0.15 ($p < 0.01$) confirm a non-random and non-homogenous spatial distribution of artifacts for the entire surface. Morisita’s index ($MI = 1.2$) and the index of patchiness ($IP = 1.2$) indicate a high intensity of grouping. The results from the Cluster and Outlier Analysis support this conclusion by indicating that IDP2 is a hot spot (Fig. 6a). Superimposed on Fig. 6b is the position of the 14 cores recovered in Ivory. The cores broadly follow the pattern of the rest of the artifacts, except for the two cores near the eastern limit of the excavation. When comparing the distribution of micro- and small debitage to the distribution of lithics $> 3$ cm, IDP2 is dominated by micro- and small debitage, while IDP1 shows a high concentration of all sizes of lithics. For IDP2, correlations of the frequencies of the different size classes of lithic artifacts used here show a combination of positive and negative correlations, while IDP1 is characterized by exclusively positive correlations (Table 3). In addition, there is a prevalence of cores, one hammerstone, and an increased number of unretouched blanks in IDP2. The combination of these observed patterns and statistical results in layer Ivory fits the expectation of a knapping spot for IDP2 and a dumping area for IDP1 following Johansen and Stapert (1998).

Figure 7 shows the distributions of piece-plotted finds from the two most abundant raw materials, dolerite ($n = 410$) and hornfels ($n = 238$). The kernel density estimation for dolerite is highest in the western part of the distribution,

**Table 3** Spearman’s correlation coefficients for frequencies of large flakes tested against small flakes (LF vs SF), large flakes tested against micro-debitage (LF vs MD), and small flakes tested against micro-debitage (SF vs MD) for two Ivory density peaks (IDP)

|       | LF vs SF | LF vs MD | SF vs MD |
|-------|----------|----------|----------|
| IPD1  | 0.94     | 1.00     | 0.94     |
| IDP2  | −0.60    | −0.83    | 0.26     |

Fig. 6 Sibhudu. Kernel density plot of layer Ivory for all lithics $< 30$ mm (left) and micro-artifacts $< 10$ mm and location of cores (right)
while hornfels is more heavily concentrated in the west and southwestern part of the excavated area. This again demonstrates that the distribution of finds has not been homogenized and most likely reflects the results of human activities rather than geo- and biogenic agents of re-deposition. Figure 8 shows the location of 152 piece-plotted bones and 33 charcoal pieces over the general kernel density plot of lithic artifacts < 3 cm. As mentioned above, time constraints have not yet made the refitting of lithic artifacts or faunal remains practicable. The distribution of bones corresponds broadly to that seen in the lithic artifacts, although the concentration is denser in D3, compared to E3 in the south. This pattern could be the result of the much lower number of piece-plotted faunal finds, but viewed in combination with other findings, this pattern could relate to a dumping area in IDP1, which extends into square D3. Improved contextualization of the faunal remains as research continues should contribute to refining hypotheses based on lithic distributions.

Turning to the distribution of particular tool groups, Fig. 9 depicts the distribution of the main classes of tools from Ivory that are integral to the definition of the Sibhudan, most notably Tongati \((n = 74)\) and Ndwedwe \((n = 29)\) tools (Conard et al. 2012) that both fall into the more general class of unifacial points. As is the case with the bones, both of these tool types show a slightly broader scatter than the plot of all lithic artifacts. Although space constraints limit the number of examples we can mention in the present context, we could choose the number or weights of bones, ochre, burnt material, lithic or bone artifacts, or many other kinds of data in distributions. The selection presented here represents only a small range of the possibilities available with regard to classes of materials, their forms, slopes, orientations, and associations. This approach raises a wide range of potential exploratory analyses.

![Kernel density plot of layer Ivory for lithic artifacts > 30 mm of dolerite (left) and hornfels (right)](image-url)
Spatial distributions between layers: patterns and diachronic comparisons

The Sibhudan encompasses a total of 23 layers, with studied lithic remains and the full recovery of small finds from a total of 1140 excavated buckets of sediments. Our database contains quantitative data on sediment volumes and all classes of organic and inorganic finds (see Tables 1 and 2). As such, the site lends itself to the diachronic comparison of spatial patterns of artifacts within the area of excavation. Here we follow Brenner’s (2015) work to see if the distributions of finds stay constant or change between the layers. Given the size of Sibhudu with several hundred square meters of relatively unrestricted sheltered space available, we would not expect constraints to force similar activities to happen repeatedly in the same positions. Also given that we are able to identify activity zones within layers, we would expect to see changing spatial distributions between cultural stratigraphic units. This expectation is realized when we consider the data from

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adjacent find layers, from top to bottom, BSP, Chestnut, Mahogany, Ivory and Black Magic, Pox Abträge 1–2, Pox Abtrag 3, Pox Abtrag 4, Sulphur, and Speckled (Figs. 10 and 11). The distributions of artifacts are based on sample sizes ranging from $n = 2792$ in Chestnut to $n = 27,716$ in Sulphur. When we consider the find densities, the range is less extreme with values varying between ~22,000 n/m$^3$ and 84,000 n/m$^3$. In all cases, the sample sizes are large enough to be meaningful and reflect the entirety of lithic remains deposited in these sediments.

In the upper layers of the so-called “classic Sibhudan” (BSP to Ivory), potential dumping areas—based on the same observations as spelled out in detail for layer Ivory above—change between a northern and southern position consecutively (Fig. 10). The situation is similar in the so-called “Middle Sibhudan” of layers Sulphur and Speckled (Fig. 11) where the knapping areas are in different parts of the excavation grid than the dumping areas. Interestingly, neither the positions of the hypothesized dumping and knapping areas show any continuities from one layer to the next within this part of the deposits. These observations indicate no long-term consistency in the spatial use of the site but also no homogenization or randomization effects by taphonomic processes.

We can also compare further aspects of spatial patterns across the sequence, and here we show the example for raw materials. The distribution of raw materials among each of the layers shows a heterogeneous picture. Hornfels is the second most frequent raw material in the upper layers including Ivory, and its distribution is always different from that of dolerite in the classic Sibhudan (Fig. 7). This lends further contextual information to the techno-typological data for the different treatments of these lithic raw materials (Will et al. 2014; Conard and Will 2015). The same pattern is seen in the lower layers, but here, hornfels is almost absent and the more frequent material is quartz. Dolerite and quartz artifacts > 3 cm nearly exclude each other in their spatial distribution, indicating that knappers used different areas for reducing these materials (Fig. 12).

To broaden these analyses, we can directly contrast spatial patterns with our techno-typological data, here exemplified by the layers Mahagony (classic Sibhudan; Fig. 13) and Sulphur (middle Sibhudan, Fig. 14). In Mahagony, there is a strong emphasis on the use of non-local hornfels, combined...
Fig. 10 Sibhudu. Kernel density plots of all lithics < 30 mm and interpretation of potential dumping and knapping areas from left to right: Brown Speckled, Chestnut, Mahogany, and Ivory.

Fig. 11 Sibhudu. Kernel density plots of all lithics < 30 mm and interpretation of potential dumping and knapping areas from left to right: Black Magic, POX1-2, POX5, Sulphur, Speckled.
Fig. 12 Sibhudu. Raw material distributions in layer Y1, depicting kernel density plots of dolerite (left) and quartz (right) artifacts > 30 mm

Fig. 13 Sibhudu. Kernel density distributions for layer Mahogany of all lithics < 30 mm with interpretations of potential dumping and knapping areas (left), micro-debitage < 10 mm (middle), and all tools with the most common techno-functional classes plotted individually (right)
with a high proportion of retouch and a diverse tool kit that most frequently features various forms of finely made unifacial points. Cores document frequent preparation, and the resulting assemblages show comparatively low reduction intensity and a lower lithic density compared to Sulphur (Conard and Will 2015). In Mahagony, hornfels and dolerite show different distributions and mostly broken tools show a concentration in the eastern parts. Interestingly, the distribution of the unifacial points typical for this assemblage shows no conclusive patterning and likely reflects their discard after use rather than area of their production (Fig. 13). Dipped artifacts show no clear pattern, although more of them are found in the northern half of the area of excavation. The concentration of the mostly broken tools and the abundance of charcoal suggests a dumping area here. Based on the distribution of bones, another dumping area could be located in the northwestern corner. A concentration of small and micro-debitage is found in the middle of the excavation grid, differing slightly from the concentration of lithics > 3 cm, which is typical for all classic Sibhudan layers. The concentration of micro-debitage adjacent to the concentration of larger artifacts points toward a knapping area (Fig. 13). The interpretation of activity zones is difficult since activity zones lie right next to each other, which likely weakens the signal of distinct activities like dumping and knapping. This pattern potentially results from episodes of less intense knapping or the performance of more mixed activities that created a palimpsest.

In contrast to Mahogany, Sulphur is characterized by predominant and intense reduction of dolerite mostly by an inclined method with a high output of small blanks. Tool frequencies are low, with fewer unifacial points but more notched and denticulated implements than Mahagony. Knockers reduced their raw materials intensely, which resulted in the highest lithic densities we have excavated. In terms of spatial patterns, retouched pieces in Sulphur are concentrated in the north and northwestern area, and tools like scrapers, denticulates, and unifacial points are mostly positioned in the north and northeast (Fig. 14). In conjunction with the observation that lithic artifacts with a strong dip are found only in the northeastern corner, these patterns are indicative of one or two dumping areas in the northern part of Sulphur. Small and micro-debitage (< 1 cm) and lithics > 3 cm show a distinct distribution. Micro-debitage is found in the south (E-squares) and in part of the D2, while larger lithics are concentrated in the northern area (Fig. 14). Combined with the position of cores and the presence of blanks, the distribution may reflect a knapping spot stretching over the southern portion of the excavated area and, possibly, the western middle part (D3). Importantly, Cluster and Outlier analyses find these spatial clusters as significantly different from a statistical perspective (see Fig. 14d). In sum, these observations suggest distinct artifact concentrations in Sulphur that can be related to separated activity zones in contrast to the more continuous distributions found in Mahagony. The analysis of intra-site spatial patterns thus shows that Mahagony and Sulphur differ not just in their techno-typological characteristics but also in the spatial organization of knapping and dumping behaviors. This pattern appears not to be due solely to the selection and use of distinct raw materials and different organization of mobility, but also may reflect changes in the frequency of various activities of daily life performed at the site (Conard and Will 2015).

**Discussion and future perspectives**

What have we learned from following this approach in analysis and excavation? How do our observations relate to our initial hypotheses for the spatial patterning of stone artifacts at Sibhudu? The identification of intra-site patterning and distinct spatial structures both within and across layers at Sibhudu from 10,882 lithics > 3 cm and more than 160,000 lithics < 3 cm across 23 layers constitutes the main findings of our study. These results run counter to a null hypothesis of taphonomic processes randomizing any originally present spatial structure. As such, the Sibhudan sequence at Sibhudu preserves much spatial integrity in a palimpsest context (see also Bailey and Galanidou 2009; Reeves et al. 2019 for different Paleolithic periods) and allows inferences to be made on the use of space by early *Homo sapiens* during the MSA at ~ 58 ka.

What do these spatial patterns mean in behavioral terms? Regarding synchronic observations, distinct distributions of raw materials and lithic size classes within layers support the interpretation that the finds have not been disturbed significantly or randomized by taphonomic processes. Based on links to observations from experimental knapping (e.g. Newcomer and Sieveking 1980; Johansen and Stapert 1998), the identified patterns often reflect debris from on-site knapping testified by non-random clustering of small and microdebitage. The presence of all classes of lithic debris is also consistent with on-site knapping. In contrast, blanks > 3 cm and retouched tools follow more diffuse patterns of distribution, likely resulting from their biographies of production, use, curation, resharpening, and ultimate discard (Conard and Adler 1997). Our previous analyses have shown that two-thirds of the modified blanks at the site are broken, suggesting that most of these patterns reflect discard and
potentially failed resharpeming, perhaps augmented by damage from thermal alteration and heavy diagenesis that is well documented at Sibhudu (Schlegel and Conard 2006; Goldberg et al. 2009; Miller 2015). The observations from artifacts > 3 cm appear to match the findings by Johansen and Stapert (1998) that dumping and maintenance more greatly affect the deposition of larger artifacts than micro-artifacts that fall to the ground and tend to stay on the spot they fall. In sum, both potential knapping and dumping spots of stone tools can be inferred within the MSA at Sibhudu across the 23 layers studies, also fitting with previous geoarchaeological work on the existence of spatially distinct site maintenance behavior (Goldberg et al. 2009).

Our initial results also show the potential for connecting abundant 3D point data to the rich raw material and technotypological data from previous studies (Conard et al. 2012; Will et al. 2014; Conard and Will 2015; Will and Conard 2018), here exemplified by the detailed spatial comparison of two layers Sulphur and Mahagony. The evidence presented in this paper, combined with geoarchaeological work on the construction of hearths and bedding in specific areas (Goldberg et al. 2009; Wadley et al. 2011), maintenance of occupational surfaces through sweeping (Goldberg et al. 2009), and clustering of shell beads (Wadley 2012; Vanhaeren et al. 2019), provide firm evidence of internal partitioning and intentional structuring of domestic space at Sibhudu, behaviors well-known from the broader ethnographic literature of recent hunter-gatherers (Binford 1978; 1996; Fisher and Strickland 1989; Kent 1984, 1991; O’Connell 1987; O’Connell et al. 1991; Yellen 1977) and indicative of complex social organization already in the MSA.

We were also able to track changes in spatial distributions and hence spatial behaviors across the finely stratified MSA sequence of Sibhudu. Some recent diachronic studies have found evidence for the spatial structure of earlier occupations dictating that of later occupations, such as the positioning of hearths or dumping areas (e.g. Bamforth et al. 2005; Holdaway and Wandsnider 2006; Bailey and Gallandou 2009). At Sibhudu, subsequent occupations by social units did not necessarily re-use the same areas in the same ways, as is seen, for example in the classic Sibhudan, even though these assemblages are similar with regard to raw material use and techno-typological characteristics (Will et al. 2014). This might point to frequent re-organization of domestic space within the shelter, which is consistent with the abundant geoarchaeological evidence for site maintenance. A more consistent patterning is seen in the lower layers, showing that within one site and a short period of time there can be fluctuations in spatial and technological signals (Conard and Will 2015).

Regarding future perspectives, it is clear that many Palaeolithic sites, including those from the MSA of southern Africa such as Pinnacle Point (Bernatchez 2010; Wilkins et al. 2017), Diepkloof (Porraz et al. 2013), and Blombos (Haaland et al. 2020), have gathered large amounts of reliable 3D information on the spatial distribution of all classes of archaeological materials. Yet, at Sibhudu, like at many other sites, we have until now scarcely begun to analyse these data. Clearly, this “collect first and analyse later” approach is preferable to destroying sites and their contexts without gathering reliable spatial information. This being said, the scales of excavations at Sibhudu and many other MSA sites are too small to follow approaches pioneered at much larger excavations in shelters like Abric Romani (Chacón et al. 2012; Romagnoli and Vaquero 2016; Vaquero et al. 2017; articles in Carbonell i Roura 2012) or at numerous open-air sites like Pincevent (Leroi-Gourhan 1984; Karlin and Julien 2019), Maastricht-Belvédère (Roebroeks 1988), Wallertheim (Conard and Adler 1997; Adler et al. 2003), Schöningen (Conard et al. 2015), and Gesher Benot Ya’aqov (Alperson-Afil et al. 2009). Excavations at these localities have uncovered spatial scales more in keeping with the scale of hominin activities documented ethnographically and in ethnological studies of non-human primates (Binford 1978; O’Connell 1987, O’Connell et al. 1991; Yellen 1977). Yet, experimental and ethnearchaeological work has also shown that some of the daily tasks—such as activities around hearths or individual knapping spots—could be recognizable in such limited spaces (e.g. Newcomer and Sieveking 1980; Binford 1978, 1996; Johansen and Stapert 1998).

Notwithstanding these challenges, we advocate following this line of work in the future, even if it is time-consuming. Ideally, these techniques would have been used from the beginning of the work at Sibhudu. This would have greatly expanded the scope of spatial analysis possible at the site. The more excavations that collect these kinds of data, the better researchers will be able to make comparisons at the intra- and intersite scales as has long been done in European contexts and in rare cases like Parkington’s work in LSA settings at Dune Field Midden, where his team excavated an area of > 800 m² (Parkington 2013). Research at the deflated sites in the Geelbek Dune system and at Anyskop (Dietl et al. 2005; Kandel and Conard 2012) similarly reflects efforts at large spatial scales in southern Africa. However, as is nearly always the case, one has either large areas of excavation or long temporal sequences. Rarely do archaeological sites provide both, and we are not aware of such excavations in the Stone Age of Africa. Thus far we have only begun to address the questions and implications that these methods bring to the archaeology of the MSA.

Our excavations at Sibbudu so far have collected these kinds of data from a surface of 4–6 m² (Eastern Excavation) and 4 m² (Deep Sounding), now totaling > 55 layers and > 130 Abträge with over 37,000 measured lithics, 7500 faunal remains, 1700 charcoal pieces, and 350 ocher pieces that reflect the signatures of repeated occupations over more
than 50,000 years. Finds recovered by screening with information on sub-square origin are more numerous (Table 2). This publication provides only a first glimpse into the potential of such spatial data from diverse classes of archaeological material. Independent of the large amounts of high-quality data we are collecting from the sites we destroy through excavation, we also need more experimental and ethnoarchaeological work in small spaces, which correspond more closely to the small areas that are excavated in high-density sites like Sibhudu. Reports from MSA sites often mention collecting 3D data, but rarely publish the detailed vertical and horizontal distributions of archaeological materials needed to facilitate spatial analyses. This criticism can certainly be directed at our team’s work, which represents one reason to publish this paper. By building on this research, we hope in the coming years to establish a stronger research program for studying the spatial behavioral patterns of early modern humans during the MSA.

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Declarations

Conflict of interest The authors declare no competing interests.

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