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A techno-functional perspective on quartz micro-notches in Sibudu's Howiesons Poort indicates the use of barbs in hunting technology

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ABSTRACT

In this paper we present the results of a use-wear study of quartz micro-notches identified during a technological analysis of lithics from the Howiesons Poort layers of Sibudu Cave. Building on the technological analysis and preliminary functional screening of the archaeological material, a series of experiments was designed to evaluate different hypotheses for notch formation (blank production, intentional notching, hafting, projectile use, and trampling). The experimental reference collection was compared with archaeological micro-notches and a large sample of other archaeological quartz pieces (including bladelets, bipolar blanks, flakes and retouched pieces). This allowed us to evaluate the causes of micro-notch formation in the studied assemblage. Results indicate two novelties in the Howiesons Poort hunting technology at Sibudu: the use of quartz barbs and non-retouched quartz blanks. It seems that in addition to backed pieces (segments, obliquely backed points, etc.), unretouched pieces were mounted as elements in hunting weapons during the Howiesons Poort techno-tradition. Seven probable and 29 tentative barbs were identified. We thus present one of the strongest and oldest bodies of evidence for the use of *barbs* as projectile elements.

1. Introduction

During the technological study of the quartz assemblage of the Howiesons Poort layer Grey Sand (GS) of Sibudu Cave, a new morphotype, the so-called micro-notch, was identified (de la Peña and Wadley, 2014a). These notches measure less than 3 mm in length, and mostly occur on automorphic (crystal) quartz. While some of the notches clearly resemble retouch, other pieces show more irregular macroscopic features, which make them a technologically ambiguous group.

Even though different types of notches have been frequently reported in Howiesons Poort assemblages, their production and/or links to tool use have not been yet examined through systematic experimentation. To shed light on the technological and functional properties of the micro-notched quartz pieces, we developed an extensive experimental and analytical programme focused on the micro-notches first identified in Sibudu's GS layer (de la Peña and Wadley, 2014a) (Fig. 1A–F). On the basis of preliminary functional analysis, we considered different hypotheses for the formation of these micro-notches, taking into account both accidental formation and intentional production. The objective was to discover how the micro-notches were formed, and to evaluate their functional significance. To reach this goal, we analysed a series of quartz micro-notches and other types of blanks with macro-traces from the GS layers (de la Peña and Wadley, 2014a,b), Grey Rocky (GR) (de la Peña, 2015a), Dark Reddish Grey (DRG) and Pinkish Grey Sand (PGS) using microscopes with both oblique and incident light sources.

We offer a variety of microscopic criteria that can help to identify functional and postdepositional causes of micro-notch formation in automorphic (crystal) and xenomorphic (vein) quartz in assemblages of all ages. We also identify two novelties in Sibudu's HP: the use of quartz barbs and the use of unretouched blanks as components of compound weapons. These findings serve as further evidence of the importance of quartz in Sibudu's HP and

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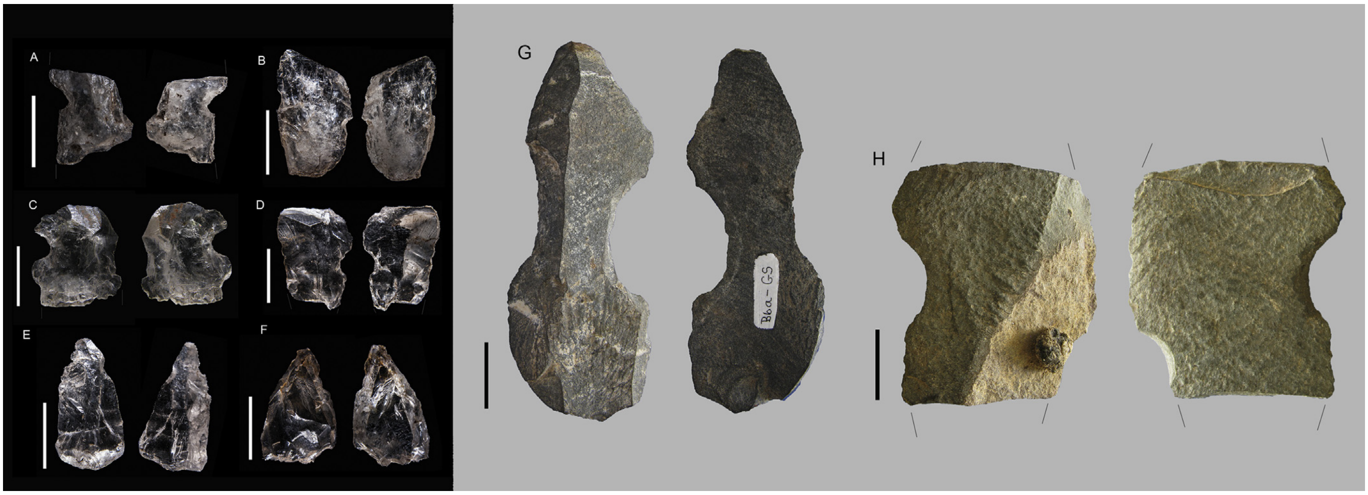

Fig. 1. Different types of notches from Sibudu Cave: A-F micro-notches in quartz. G Strangulated blade in hornfels. H. Notch in dolerite.

highlight the variability within this techno-tradition.

2. Background

2.1. Howiesons Poort

The Howiesons Poort (HP) of southern Africa is a well-known techno-tradition in the Middle Stone Age (MSA). Since its first inception, the HP has been considered unusual because of its so-called 'innovative technologies' reminiscent of the Later Stone Age/Upper Palaeolithic. Furthermore, it was thought to include symbolic implements that seemed out-of-place in MSA techno-traditions. Material culture associated with the HP includes backed stone tools, engraved ochre, bone technology and ostrich eggshell engravings (Singer and Wymer, 1982; Thackeray, 1992; Vogelsang, 1998; d'Errico and Henshilwood, 2007; Wadley, 2008; Backwell et al., 2008; Mackay and Welz, 2008; Texier et al., 2010; d'Errico et al., 2012; Henshilwood et al., 2014). Soon after its first discovery, the HP was relegated to an intermediate phase between the Later Stone Age and MSA, but its autonomous position within the MSA was later established through excavations in Klasies River, Peers Cave, Rose Cottage, Umhlatuzana, Border Cave and Apollo 11 (Wendt, 1976; Beaumont, 1978; Singer and Wymer, 1982; Wadley and Harper, 1989; Kaplan, 1990). For some researchers, the HP still represents an unusual or ephemeral technological development (Villa et al., 2012), whereas for others it is a proxy for complex cognition in the MSA because of the sophistication implied by the multiple action sequences required for processing material culture (Wadley, 2013). The attitudes of some other researchers to the HP are coloured by historiography, in particular a biased view of prehistory, in which European Upper Palaeolithic material culture is held as the standard for advanced culture and technology (Deacon, 1989; Wurz, 1999; McBrearty and Brooks, 2000; Shea, 2009; de la Peña, 2015b).

Even though the HP has received a great deal of attention, its definition still mainly relies on lithic typology. Initially the presence of backed blades was considered the main criterion for placing assemblages in this techno-tradition (Thackeray, 1992). During the last two decades, however, there have been notable efforts to redefine the HP from a technological point of view, using the assemblages from Klasies River (Wurz, 2000; Villa et al., 2010), Diepkloof (Porraz et al., 2013), Rose Cottage (Harper, 1997; Soriano et al., 2007), Pinnacle Point (Wilkins et al., 2017), Klein Kliphuis (Mackay, 2011) and Sibudu (Soriano et al., 2015; de la Peña, 2015a). Some PhD dissertations (for example Minichillo, 2005; Mackay, 2009), as well as southern African syntheses (see for example Mackay et al., 2014) also explore the relationships between MSA typology, environmental conditions and settlement patterns.

Some recent studies have also been dedicated to investigating the functions of backed pieces. They have been considered as versatile tools regardless of the raw material they are made on because they can be rotated and hafted in different ways to serve as elements of composite tools for tasks such as cutting (Wadley and Binneman, 1995; Wadley et al., 2009; Igreja and Porraz, 2013) or piercing when used as weapon tips (McBrearty and Brooks, 2000; Wadley and Mohapi, 2008; Lombard and Pargeter, 2008; Villa et al., 2010; Villa and Soriano, 2010; Lombard, 2011). It has been further suggested that the small quartz segments from Sibudu could have been hafted transversely and that hunting with bow and arrow may have been in use (Pargeter, 2007; Wadley and Mohapi, 2008; Lombard and Phillipson, 2010; Lombard, 2011; Pargeter et al., 2016). The suggestion that hunting with bow and arrow was practised in the HP at Sibudu is supported by the discovery of bone points that could have been arrowheads (Backwell et al., 2008, in press).

2.2. Sibudu and its Howiesons Poort industry

Sibudu Cave is located about 40 km north of Durban, KwaZulu-Natal, and 15 km inland of the Indian Ocean, on a cliff overlooking the uThongathi River. The shelter has a long occupation sequence that is dated by single grain optically stimulated luminescence (OSL) to between 77 ka and 38 ka ago (Jacobs et al., 2008a,b). The HP Industry comes from six square metres (squares B4, B5, B6, C4, C5 and C6) of Wadley's excavations into the deep sounding. The layers associated with the HP followed natural stratigraphy and are (from base to top): loose, pinkish-grey sand, called Pinkish Grey Sand (PGS3, PGS2 and PGS), silty, grey sand called Grey Sand (GS3, GS2 and GS), an ashy layer called Dark Reddish Grey (DRG) and grey sand with rock spalls called Grey Rocky (GR2 and GR) (Fig. 2). The subdivisions within each stratum (for example, GR2 and GR) are mostly based on the z readings of combustion features, but where such features are absent and strata are thicker than 5 cm, the subdivisions are spits. OSL ages for the HP are as follows: 64.7 ± 2.3 (PGS), 63.8 ± 2.8 (GS2) and 61.7 ± 2.0 ka (GR2) (Jacobs et al., 2008a).

As part of an attempt to define the HP, we elsewhere conducted

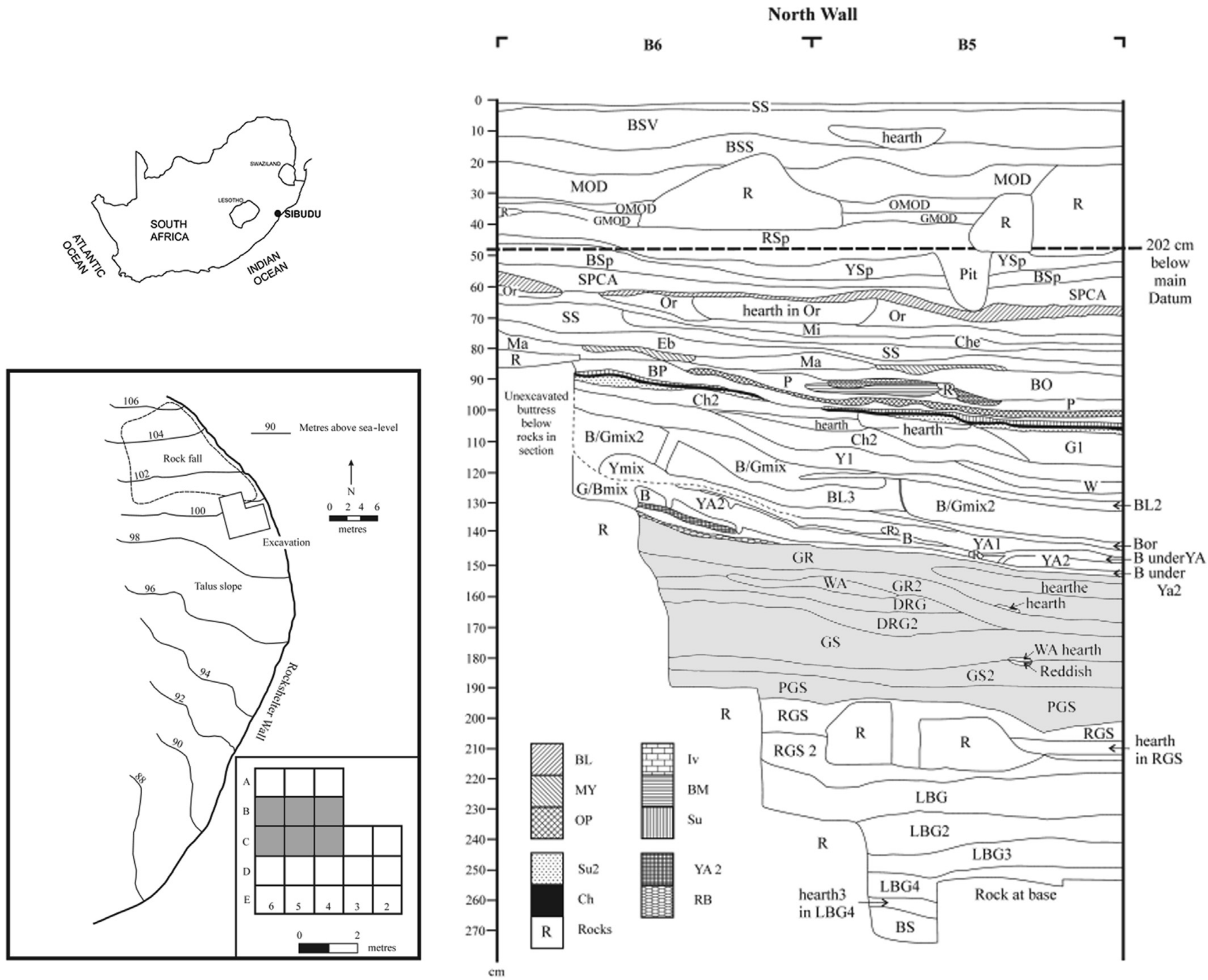

Fig. 2. Location of Sibudu Cave. On the top left, location of Sibudu Cave (29.522627S, 31.085895E). This schematic map was made from a topographic map of southern Africa, source: Maps at the CIA (public domain): https://www.cia.gov/library/publications/the-world-factbook/index.html. On the bottom left is a plan of Sibudu Cave with the excavation grid represented and the square meters included in this study highlighted in grey. On the bottom right, the stratigraphy of the North wall of Sibudu Cave is shown, with the HP layers highlighted in grey.

technological studies on the use of quartz in Sibudu's HP layers (de la Peña et al., 2013; de la Peña and Wadley, 2014a,b; de la Peña, 2015a,b), where this mineral seems to have been particularly favoured. As an example, in layer GR quartz is the most retouched raw material (de la Peña, 2015a). Moreover, new morphotypes in quartz, such as bifacial pieces, have been recognised (de la Peña et al., 2013), together with bipolar knapping (de la Peña, 2015a). Furthermore, it has been proposed that true microlithic strategies were developed during the HP (de la Peña and Wadley, 2014a,b).

2.3. Notched tools in the Howieson poort

Notches have been repeatedly reported on HP lithics, and this raises questions about their potential function. Definitions of notches vary. Volman calls 'notches' formal tools in his dissertation and he identifies them at several MSA sites (Volman, 1980). Singer and Wymer (1982) report 'notched pieces' in the HP of Klasies River and also consider them formal tools. Most of these pieces are made from silcrete with one exception that is made from vein quartz. More recently, Wurz has also described notched pieces from Klasies River, but views the notching and denticulation of edges as the product of use (in particular wood-working) and classifies it as 'informal retouch' (Wurz, 2000:84). She distinguishes among three types of notches in the Klasies's HP lithic assemblage: 'break-out notches', 'complex notches' and 'wood-work notches', and suggests that they might represent different stages in the life cycle of the tools. Igreja and Porraz (2013) note the presence of notches, denticulates and strangulated pieces in the HP of Diepkloof. Strangulated pieces are the most typical formal tool in what has been described as an 'intermediate phase' of the HP at Diepkloof, but unfortunately no use-wear traces were found on them or on denticulates (Igreja and Porraz, 2013). Notches have often been observed on backed tools from the HP, and are in some cases said to resemble intentional retouch (Singer and Wymer, 1982; Wurz, 2000; Lombard and Pargeter, 2008). Lombard and Pargeter (2008) analysed residues on backed hornfels and dolerite pieces with notches from Sibudu and Umhlatuzana, and link them to hunting. Moreover, they suggest that 'smooth' notches could also form inadvertently as a result of impact (Lombard and Pargeter, 2008: 2528).

A variety of notched pieces has been documented in the Sibudu HP assemblage. They can be divided into three main categories: (1) micro-notches on quartz, where the length of the concavity of the putative retouch can vary between 1 and 3 mm; (2) notches usually on hornfels or dolerite, with a much larger concavity, always more than 10 mm in length; and (3) strangulated pieces made on hornfels flakes or blades where two or several large retouched concavities are opposed and may continue in some cases up to the middle part of the blank (see de la Peña and Wadley, 2014b-Table 7 within it, de la Peña, 2015a-Table 14 within it, and Fig. 1 in this article). The present study focuses exclusively on the first category.

3. Quartz technology in the Howiesons Poort layers of Sibudu

Quartz can be divided into two broad categories: crystalline quartz, commonly called macrocrystalline quartz, and the dense and compact forms, which usually are named cryptocrystalline or microcrystalline. The difference between these two categories is simply a consequence of the way they form. Macrocrystalline quartz grows by adding molecules to the crystal's surface, whereas cryptocrystalline forms come from colloidal watery solutions of silica (de Lombera-Hermida, 2008; Mourre, 1996). The mechanical properties of macrocrystalline quartz vary greatly according to the chemical and physical conditions during its formation (de Lombera-Hermida, 2008: 102). It can be divided into two main types, automorphic quartz (commonly called crystal quartz, rock crystal, or hyaline quartz) which consists of rhombohedral crystals of varying sizes, and xenomorphic quartz (commonly called vein quartz or milky quartz) which is an aggregate of small crystals that lack the typical rhombohedral shape (Mourre, 1996; Rodríguez-Rellán, 2016). The knapping qualities of quartz vary both between and within these categories.

In Sibudu's HP layers, cryptocrystalline quartz, such as chalcedony, is extremely rare, whereas macrocrystalline quartz is abundant. Both automorphic (crystal) and xenomorphic (vein) quartz are represented. Vein quartz includes both translucent and white varieties (de la Peña and Wadley, 2014a). The cortex on some Sibudu HP tools demonstrates that both alluvial sources and outcrops were exploited for quartz (Delagnes et al., 2006). Small quartz nodules can be collected from the river and there are conglomerates with clasts of quartzite and vein quartz in the wider area (Clarke et al., 2007).

In the GR, GS, DRG and PGS layers the main knapping methods in quartz are flaking for the production of blanks for bifacial pieces (only in GS and GR), laminar methods for the production of bladelets, and bipolar knapping as a recycling strategy for the waste-products of freehand bladelet production (de la Peña, 2015b). The prismatic freehand cores that come from small river pebbles have either modest preparation or none at all. A simple flake was usually removed to prepare the striking platform, and the longest side of the core was generally chosen to serve as the knapping surface. For freehand cores, the last removals are mostly unifacial and opposed. The most typical morphotypes are pyramidal-unipolar cores and opposed platform prismatic cores. However, it seems that the knapping method of freehand quartz cores was more constrained by the morphological characteristics of the quartz pebbles than by a preconceived design. Most of the laminar freehand cores have plenty of step and hinge accidents. Bipolar cores have quadrangular or rectangular shapes. Both the striking platform and the edge in contact with the anvil are rectilinear and clearly blunted and fissured. The small size (usually under 20 mm) of quartz bipolar cores in these four layers is particularly striking (de la Peña and Wadley, 2014a).

4. Material and methods

4.1. Research design and samples studied

The main objective of the present study was to investigate the possible links between tool use and hafting and the micro-notches on quartz that were discovered during the technological analysis of the lithics from the GS layer (de la Peña and Wadley, 2014a). We examined the remaining quartz material (including chips <10 mm) for micro-notches, which we eventually identified in all HP layers. These micro-notched pieces, 82 in total, form sample 1 that was selected by PdlP using purely technological criteria. It includes all the micro-notched pieces from GS and the other HP layers (Table 1). VR and NT subsequently studied sample 1 to get an overview of main tool uses and the amount of production-related and taphonomic damage present in it. Based on the results of the functional analysis, another archaeological sample (sample 2, $n = 178$) (Table S1 and S2) was selected. Sample 2 was intended to help us further investigate micro-notch formation and the role of the micro-notched pieces in the assemblage. Sample 2 was exclusively collected from layer GS because a detailed technological analysis of the lithic assemblage has been published (de la Peña and Wadley, 2014a). Unlike sample 1, sample 2 does not contain micro-notches. Instead, sample 2 was chosen to examine the artefact types represented in sample 1 independently of the occurrence of micro-notches, and to understand the functions of the artefacts belonging to these technological categories. This was considered necessary for interpreting the different causes of micro-notch formation, including tool use. Only two pieces in sample 2 have damage that can be described as notch-like, but it is subtle and therefore does not meet the criteria used in selecting sample 1. The mean length, width and thickness of the artefacts are summarised in Table S2, and they are described in further detail elsewhere (de la Peña and Wadley, 2014a). Sample 2 covers all the relevant blank types in Sibudu's HP quartz assemblage (backed pieces, bipolar blanks, intact and fragmentary bladelets and flakes). Bifacial pieces were excluded because they have been analysed in depth elsewhere (de la Peña et al., 2013).

All the HP quartz micro-notches (sample 1) are technologically described in Table 1. Most of them are crystal quartz, but also milky and glassy varieties of vein quartz are represented. The micro-notches in sample 1 are typically less than 3 mm in length.

Sample 2 is listed in Table S1, and it consists of 27 backed pieces with macro-traces, 27 bipolar blanks with retouch or macro-traces, 23 intact bladelets with macro-traces, 53 proximal fragments of bladelets, 13 mesial fragments of bladelets, 21 distal fragments of bladelets, and 14 flakes or fragments with macro-traces (Table S1). Table 2 shows the structure of the archaeological samples and the numbers of analysed artefacts per category.

The subsequent experimental programme was designed to identify the most probable processes of micro-notch formation. The interpretations of why notches form rely on the quartz reference collection available at TraceoLab, which covers the most common tool uses, and on our previous experimental and analytical work involving quartz (e.g. Taipale et al., 2014; Knutsson et al., 2015; Rots et al., 2017). In sample 2, only backed pieces, bipolar blanks and intact or nearly intact bladelets display recurring functional wear (cf. Table 2). A total of 50 pieces from these categories – comprising altogether 77 blanks – was therefore subjected to a more detailed low and high magnification analysis aimed at identifying the exact causes of damage formation. The remaining artefacts in sample 2 (see Table 2) show possible functional wear on 30 of the 101 screened blanks, but this wear is not sufficiently diagnostic, and was considered less helpful for addressing the questions at hand.

Table 1
Micro-notched pieces from Sibudu analysed in this study (Sample 1). Layers GR, GS, DRG and PGS. (Abbreviations for blank types: IF: indeterminate fragment; PF: platform flake; BBP: bladelet; BP: bipolar flake; FWP: fragment without platform).

Number	Layer	Square	Subquadrant	Type of blank	Length	Breadth	Thickness	Complete or incomplete	Fragment class	Type of platform	Cortex	Single/double or multiple notch	Position of retouch	Type of retouch	Location
N18	PGS	?	?	BBP	19.6x	10.02	3.68	I	Proximal	Broken	N	Double	Direct + Direct	Simple + Semiabrupt	Distal left + Distal right
N17	PGS	C5	d	PF	13.43	16.97	3.02	C		Lineal	N	Double	Direct + Inverse	Abrupt + Semiabrupt	Proximal left + Proximal right
N16	PGS	C5	d	PF	10.68x	8.97	1.74	C		Broken	N	Double	Direct + Direct	Abrupt + Simple	Distal + Lateral right
N15	PGS	C5	d	BF	15.25x	8.97	3.77	C		Broken	N	Double	Inverse + Direct	Fracture + Simple	Proximal left + Distal right
N14	PGS	C5	d	BF	6.43x	4.81	1.89	C		Linear	N	Single	Inverse	Simple	Lateral right
N13	PGS	C5	b	IF	19.2x	10.58	5.11	I		Deleted	N	Triple	Direct + Direct + Direct	Abrupt + Abrupt + Abrupt	Proximal left + Distal right + Proximal right
N12	PGS	C6	c	BBP	12.93x	10.45	3.82	I	Mesial	No platform	N	Double	Inverse + Inverse	Semiabrupt + Simple	Mesial left + Mesial right
N11	PGS	C4	b	BBP	9.55x	12.01	2.83	I	Mesial	No platform	N	Double	Direct + Inverse	Fracture + Semiabrupt	Mesial left + Mesial right
N10	DRG	B5	d	BBP	13.66x	9.76	2.49	I	Proximal	Plain	N	Double	Edge + Edge	Fracture + Fracture	Proximal left + Mesial right
N9	DRG	B6	a	PF	8.4	7.11	3.82	C		Plain	N	Single	Inverse	Simple	Lateral right
N1	GR	B6	a	Crystal	10.87x	9.09	2.94	I	Distal	No platform	N	Double	Direct + Edge	Semiabrupt + Fracture	
N2	GR2	C5	d	BF	11.65x	8.21	3.12	I	Proximal	Lineal	N	Single	Direct	Semiabrupt	Lateral right
N8	GR	B6	b	BF	15.42	8.51	4.1	C		Punctiform	Y	Single	Edge	Fracture	Lateral right
N7	GR under rock	B4	d	IF	10.55x	20.88	4.6	C		Deleted	N	Double	Direct + Direct	Abrupt + Abrupt	Proximal left + Distal
N6	GR	B6	b	PF	13.37	14.95x	3.58	I	Completed pied except proximal left	Broken	N	Single	Direct	Simple	Lateral right
N4	GR2	B6	a	PF	7.99x	7.24	1.98	I	Proximal	Plain	N	Single	Edge	Fracture	Proximal right
N5	GR2	B5	b	FWP	13.02x	8.8	3.82	I	Completed piece except proximal right	Broken	N	Double	Direct + Direct	Semiabrupt + Semiabrupt	Lateral left + Lateral right
N3	GR	C6	a	PF	26.12x	20.21	7.97	I	Proximal	Broken	N	Triple	Edge + Edge + Edge	Fracture + Fracture + Fracture	Proximal left (2)+ Proximal right
N48	Hearth in GS2	B5	d	BBP	11.1	8.73	3.12	I	Proximal	Plain	N	Single	Direct	Semiabrupt	Lateral right
N47	GS	B6	a	PF	16.52x	9.47	2.52	I	Completed piece except proximal right	Plain	N	Single	Inverse	Semiabrupt	Proximal left
N46	GS2	C4	b	PF	18.58x	13.52	5.18	I	Proximal	Plain	N	Single	Direct	Semiabrupt	Proximal right
N44	GS	C6	c	BBP	11.62x	10.1	2.24	I	Proximal	Plain	N	Double	Direct + Edge	Semiabrupt + Fracture	Proximal left + Proximal right
N43	GS	C6	b	BBP	8.24x	7.78	2.41	I	Mesial	No platform	N	Single	Inverse	Semiabrupt	Lateral right
N42	Hearth in GS2	C5	d	BF	10.13	6.48	3.46	C		Broken	N	Double	Direct + fracture	Semiabrupt	lateral left
N41	GS	B5	a	BBP	10.72	5.87	2.44	C		Plain	N	Double	Direct + Edge	Simple + Fracture	Proximal left + Proximal right
N40	Hearth 1 in GS2	C5	d	FWP	9.86x	7.48	2.71	I	Distal	Broken	N	Single	Direct	Abrupt	Lateral right

N39	GS under hearth	B4	a	BF	9.48x	8.24	2.94	C		Broken	N	Single	Direct	Abrupt	Lateral left
N38	GS3	C4	b	FWP	7.19x	6.02	1.79	I		No platform	N	Single	Direct	Simple	Lateral ?
N37	GS	C6	b	BBP	10.53x	6.3	2.15	I	Proximal	Plain	N	Double	Edge + Inverse	Fracture + Semiabrupt	Lateral left + Lateral right
N36	GS2	B6	a	BBP	17.83	8.77	5.01	C		Faceted	N	Single	Direct	Semiabrupt	Distal right
N35	GS	?	?	BBP	12.65	5.33	2.27	C		Plain	N	Single	Direct	Simple	Lateral left
N34	GS2	C4	a	PF	19.2	19.28	8.74	C		Plain	N	Single	Direct	Simple	Distal right
N33	GS3	C4	b	BBP	9.5x	9.31	3.21	I		Plain	N	Single	Direct	Fracture + Abrupt	Lateral right
N32	GS2	B6	a	PF	9.33	8.09	1.72	C		Deleted	N	Double	Edge + Edge	Fracture + Fracture	Lateral left + Lateral right
N31	GS	B6	b	BBP	7.73x	4.91	1.9	I	Proximal	Faceted	N	Single	Direct	Simple	Proximal left
N30	GS	C5	a	PF	9.03x	18.26x	3.58	I	Proximal	Plain	N	Single	Inverse	Simple	Proximal right
N29	GS	B4	a	IF	11.97	13.49	2.51	I	Proximal	No platform	N	Single	Inverse	Semiabrupt	Proximal
N28	GS2 under hearth	B4	c	PF	14.55	12.5	2.73	C		Linear	N	Single	Inverse	Semiabrupt	Proximal left
N27	GS2	B5	b	BBP	15.73	7.98	3.46	C		plain	N	Double	Direct + Inverse	Abrupt + Semiabrupt	Distal + Distal left
N26	GS under GR2	B5	a	BF	10.27	10.87	6.22	I	Proximal?	Linear	N	Single	Direct	Simple	Proximal right
N25	GS2	B5	a	PF	20.72	15.35	3.68	C		plain	N	Double	Edge + Edge	Fracture + Fracture	Lateral left + Lateral right
N24	GS2	C5	c	IF	13.31x	5.31	3.09	I	Distal	No platform	N	Single	Direct	Simple	Distal
N23	GS	B5	b	BBP	8.26x	6.37	2.46	I	Proximal	Plain	N	Double	Edge + Edge	Fracture + Fracture	Proximal left + Proximal right
N22	GS	C6	d	PF	10.12	8.08	1.85	C		Plain	N	Double	Edge + Edge	Fracture + Fracture	Lateral left + Lateral right
N21	GS	C5	c	PF	9.24	5.76	1.91	C		Broken	N	Double	Edge + Inverse	Fracture + Inverse	Lateral left + Lateral right
N20	GS	C5	c	PF	10.14	5.28	2.46	C		Plain	N	Double	Edge + Edge	Fracture + Fracture	Lateral left + Lateral right
N19	GS2	B5	a	PF	14.75x	9.06	4.32	I	Proximal	Plain	N	Single	Inverse	Simple	Lateral right
N45	GS2	B5	a	PF	10.08	15.85	5.72	I		Plain	N	Double	Inverse + Inverse	Simple + Simple	Proximal left + Distal
N77	PGS	C5	d	FWP	8.66x	7.53	2.58	I	Distal	No platform	Y	Single	Inverse	Fracture	Lateral left
N81	GR2	B6	b	Crystal	9.65	3.72	2.92	C		No platform	Y	Single	Edge	Fracture	
N78	PGS	C5	d	PF	11.14	9.39	2.09	C		Broken	N	Double	Inverse + Inverse	Fracture + Fracture	Lateral left + Lateral right
N79	PGS	C5	d	PF	10.39x	9.97	3.75	I	Proximal	Broken	N	Double	Inverse + Inverse	Fracture + Fracture	Lateral left + Lateral right
N80	GR	B5	b	Crystal	17.22	9.97	4.63	C		No platform	N	Single		Fracture	
N71	GS under hearth	B4	a	FWP	9.44x	6.36	1.84	I	Proximal	No platform	N	Single	Inverse	Semiabrupt	Mesial left
N70	GR under rock	C6	c	IF	18.06	9.79	6.78	I		No platform	N	Double		Fracture + Fracture?	
N69	PGS	C5	d	PF	12	11.79	2.81	C		plain	N	Single	Direct	Simple	Lateral right
N68	GR	B5	a	IF	9.43x	7.18x	3.67	I	Proximal left	Broken	N	Single		Fracture	On fracture?
N67	GR	B4	b	PF	13.22x	10.97	3.87	I	Proximal	Plain	N	Single	Edge	Fracture	Lateral right
N76	GS2	B5	a	PF	12.15	11.51	2.97	C		Plain	N	Single	Edge	Fracture	Distal

(*continued on next page*)

Table 1 (*continued*)

Number	Layer	Square	Subquadrant	Type of blank	Length	Breadth	Thickness	Complete or incomplete	Fragment class	Type of platform	Cortex	Single/double or multiple notch	Position of retouch	Type of retouch	Location
N75	GR2	B5	c	PF	8.37x	13.54	3.8	I	Proximal	Broken	N	Single	Edge	Fracture	Distal
N74	GR	?	?	PF	23.4	11.17	3.94	C		plain	N	Double	Direct + Edge	Fracture + Fracture	Lateral left + Lateral right
N73	PGS	B5	c	FWP	8.04x	8.38	1.92	I		No platform	N	Single	Inverse	Fracture	Lateral left
N72	GR2	C5	b	PF	13.45x	10.53	5.17	I	Proximal	plain	N	Double	Direct + Direct	Fracture + Fracture	Lateral right + Lateral right
N54	PGS3	C4	c	FWP	10.7x	12.69	4.32	I	Distal	No platform	N	Double	Inverse + Direct	Fracture + Simple	Lateral left + Lateral right
N53	GR2	B4	b	FWP	8.3x	9.05	2.9	I	Distal	No platform	N	Single	Direct	Simple	Distal
N52	PGS	C4	d	PF	11.57x	10.9	2.57	I	Proximal	Plain	N	Single	Edge	Fracture	Lateral right
N51	GR under rock	C6	c	BBP	10.1x	8.31	1.78	I	Proximal	Plain	N	Single	Edge	Fracture	Lateral left
N50	GR under rock	C6	c	PF	13.04x	13.57	4.95	I	Proximal	Plain	N	Double	Inverse + Inverse	Fracture + Fracture	Lateral left + Lateral left
N49	GR2	C4	a	BBP	6.88x	5.62	2.08	I	Proximal	Plain	N	Single	Edge	Natural	Lateral right
N65	Hearth B in GS	B5	d	FWP	10.85x	6.89	2.74	I	Distal	No platform	N	Single	Edge	Natural	Lateral right
N64	Heart1 in GS	C5	a	FWP	5.9x	11.35	3.23	I	Distal	No platform	N	Single	Directt	Simple	Distal
N63	GS	B4	b	BBP	12.13x	8.64	3.12	I	Proximal	Plain	N	Single	Inverse	Simple	Lateral left
N62	DRG2	B5	b	BBP	14.91x	8.73	3	I	Proximal	Plain	N	Double	Direct + Direct	Simple + Simple	Lateral left + Lateral right
N66	GR	?	?	BBP	10.22x	8.67	3.23	I	Proximal	Plain	N	Single	Inverse	Simple	Lateral right
N61	GS	C5	b	BBP	15.02x	11	4.06	I	Proximal	Plain	N	Single	Inverse	Simple	Lateral right
N60	GS2	B6	b	BBP	11.47x	12.27	2.39	I	Mesial	No platform	N	Single	Inverse	Simple	Lateral left
N59	GS	C5	d	BBP	9.08x	6.76	2.38	I	Proximal	Plain	N	Single	Inverse	Simple	Lateral left
N58	PGS	C5	c	BBP	11.15x	9.7	2.76	I	Distal	No platform	N	Single	Direct	Simple	Lateral right
N57	Hearth b in GR2	B5	a	BBP	12.99x	9.33	3.46	I	Proximal	Plain	N	Single	Inverse	Simple	Lateral left
N56	DRG2	B5	c	BBP	16.02x	9.56	3.89	I	Distal	No platform	N	Single	Edge	Fracture	Lateral right
N55	GR2	B5	b	BBP	9.81x	6.9	2.12	I	Distal	No platform	N	Double	Edge + Edge	Fracturate + Fracturate	Lateral left + Lateral right
N82	GR2	C6	b	Crystal	30.11	9.51	6.83	c		No platform	Y	Single	Edge	Fracture	

Table 2
Overview of functional screening for sample 1 and sample 2.

	Low magnification screening	Low magnification analysis	Low and high magnification analysis
Sample 1: Notched pieces	82	82	82
Sample 2: Segments and oblique backed points with macrotraces	27	27	27
Sample 2: Potential bipolar blanks with retouch or macrotraces	27	0	0
Sample 2: Intact and nearly intact bladelets with macrotraces	23	23	23
Sample 2: Proximal fragments of bladelets	53	0	0
Sample 2: Mesial fragments of bladelets	13	0	0
Sample 2: Distal fragments of bladelets	21	0	0
Sample 2: Flakes, flake fragments and indeterminate fragments with macrotraces	14	0	0
TOTAL	**260**	**132**	**132**

4.2. Experimental framework

On the basis of the preliminary functional analysis of the archaeological material, we designed an experiment to test three most probable scenarios for micro-notch formation. First, the notches could be accidentally formed either during knapping or trampling. Secondly, the notches could be intentionally shaped to serve different purposes, including hafting or stringing. Thirdly, the notches could form as an unintentional byproduct of hafting, either through pressure from binding stone tools to hafts or through particular type of contact during (hafted) use. We acknowledge that a combination of different actions may have caused the formation of the notches recognized during the techno-typological analysis.

The raw materials selected for the experiment closely resemble the varieties found at Sibudu (see above). Both crystal quartz and vein quartz were used. The knapping and retouching experiments were performed by experienced knappers, Paloma de la Peña (PdlP) at the University of the Witwatersrand and Christian Lepers (CL) at the University of Liège. Trampling and projectile experiments were performed in Liège by CL and Veerle Rots (VR). The experimental reference material produced for this study comprises 166 artefacts and the debitage from five crystal quartz cores that served as a control sample for damage formed during the detachment of blanks (see Table 3). All the experimental pieces in our study fit the measurements and qualitative technological characteristics of the archaeological artefacts. A detailed description and measurements for the blanks from the GS layer can be found in de la Peña and Wadley (2014a) and de la Peña (2015b) (also see Table S2).

4.2.1. Accidental notch formation during knapping

Crystal quartz was used in the knapping experiment, as most of the archaeological micro-notches occur on crystal quartz. We knapped five hyaline quartz cores with the bipolar technique to produce bladelets and small flakes and to evaluate whether notches were accidentally produced.

4.2.2. Accidental notch formation during trampling

A trampling experiment was set up using 28 crystal quartz flakes from one of the experimental cores. Flakes with similar morphologies to sample 1 were chosen and left unmodified to increase the chances of damage formation and to make the identification of possible trampling notches easier. The flakes were painted red to make the scarring produced during trampling easily visible, and placed within a 1 m^2 zone on the surface of an old knapping area covered with mainly flint waste (Fig. 3). Half of the blanks were placed with their dorsal face up, half with their ventral face up. The area was trampled with bare feet wrapped in leather for half an hour a day over a period of two weeks. At the time of the experiment, it rained heavily and the flakes were quickly embedded in the soil, which may have reduced the amount of friction between the blanks. We are aware that our trampling experiments entailed sedimentological and climatic conditions different from the ones in southern Africa. We believe, however, that the differences would mainly affect the frequency of damage, not its general characteristics.

4.2.3. Intentional production of notches using various techniques

PdlP produced notches by percussion with a small quartzite pebble on 15 blanks and by pressure with a small bone compressor on 15 blanks. CL produced notches on 32 blanks by pressure with a bone compressor (10), by percussion with the edge of a dolerite flake (7), by crushing against the edge of a crystal quartz flake (8), and by pressure of the blank against a bone indenter (7) (Fig. 4, Table 4).

4.2.4. Accidental notch formation during hafting

Previous experiments showed that few hafting traces form during the hafting process itself, and that most hafting wear in fact forms during tool use (Rots, 2010). Edge damage is, however, one of the main types of wear that may form during the hafting of the tool. For this reason, it was relevant to test whether the attachment and/

Table 3
Overview of the experiments to explore causes of micro-notch formation.

CATEGORY	CRYSTAL QUARTZ	MILKY QUARTZ	TOTAL
Intentional notches			
by pressure/bone (pressing the flaker against the piece)	25	0	**25**
by pressure/bone (pressing the piece against the flaker)	8	0	**8**
by percussion/dolerite	7	0	**7**
by percussion/quartzite	15	0	**15**
by crushing/crystal quartz	8	0	**8**
Trampling	28	9	**28**
Hafting	9	0	**9**
Barbs	18	27	**45**
Transverse arrowheads	9	12	**21**
TOTAL	**127**	**48**	**166**

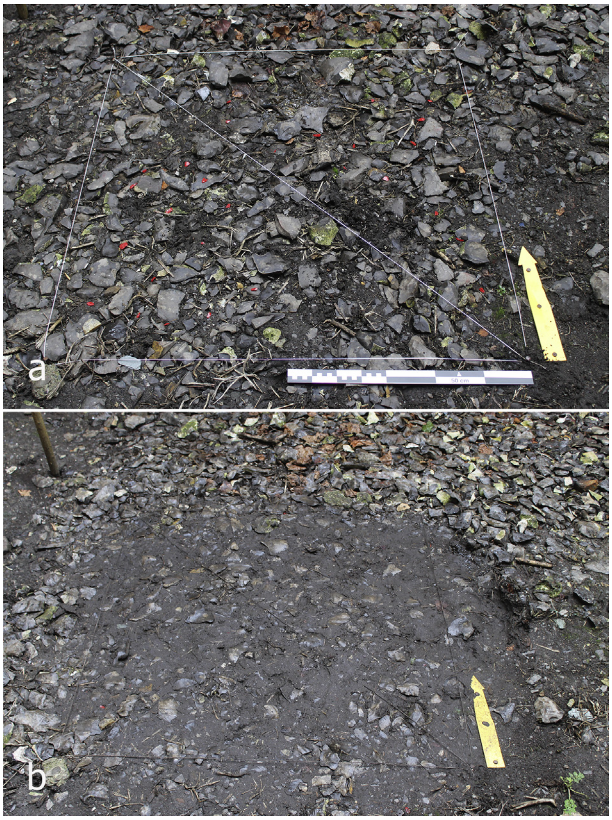

Fig. 3. Trampling experiments. a. situation at the start of the experiment, the red-painted flakes are dispersed over an old knapping surface within 1 m^2; b. situation after a few (rainy) days, all flakes are embedded in the sediment. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

Table 4
Knapping experiments to produce intentional notches.

Knapper	Retouching technique	Total
CL	Pressure with bone	10
	Percussion with dolerite flake	7
	Crushing against crystal quartz indenter	8
	Pressure with crystal quartz indenter	1
	Pressure on dropped bone indenter	7
PP	Percussion with quartzite pebble	15
	Pressure with bone	15
Total	63	

or drying of bindings could lead to the formation of notches on thin quartz edges.

Nine blanks were fixed on wooden shafts with different types of bindings including water-soaked and dry sinew and linen (Table 5). Both thick and fine threads were used to evaluate the differences. Unretouched blanks were mounted on pine shafts without adding adhesive and left to dry (Fig. 5). They were left hafted for a week and were then de-hafted.

4.2.5. Notch formation during hafted use

Certain use activities may result in the formation of micro-notches. Projectile impact is one of the most obvious possibilities and micro-notches have been reported regularly after experimental projectile use (Lombard and Pargeter, 2008; Lombard, 2011; Pétillon et al., 2011; Rots, 2016). The initial screening of the two archaeological samples suggests that projectile use could explain some of the micro-notches, whereas no evidence of other type of use was found. Given the morphology of the archaeological blanks, a transverse end-hafted position and a parallel/oblique lateral position were judged the only possible options for their hafting as hunting weapons. Consequently, both positions were tested experimentally using crystal quartz and vein quartz backed tools (the dimensions of the experimental pieces were taken from the

Fig. 4. Knapping experiments with vein quartz and crystal quartz: a. direct percussion with stone hammer (CL); b. bipolar knapping (PdlP); c. notching by pressure with a bone compressor (CL); d. notching by crushing against a stone edge (PdlP).

Table 5
Materials and techniques used in the hafting experiment.

Knapper	Tool type	Material	Knapping technique	Hafting technique	Number of pieces
PdlP	unretouched flake	crystal quartz	bipolar with stone	binding on a shaft with water-soaked sinew (thick thread)	2
				binding on a shaft with water-soaked sinew (fine thread)	3
				binding on a shaft with dry sinew (thick thread)	1
				binding on a shaft with dry sinew (fine thread)	1
				binding on a shaft with dry thread of linen (thick thread)	1
				binding on a shaft with dry thread of linen (fine thread)	1

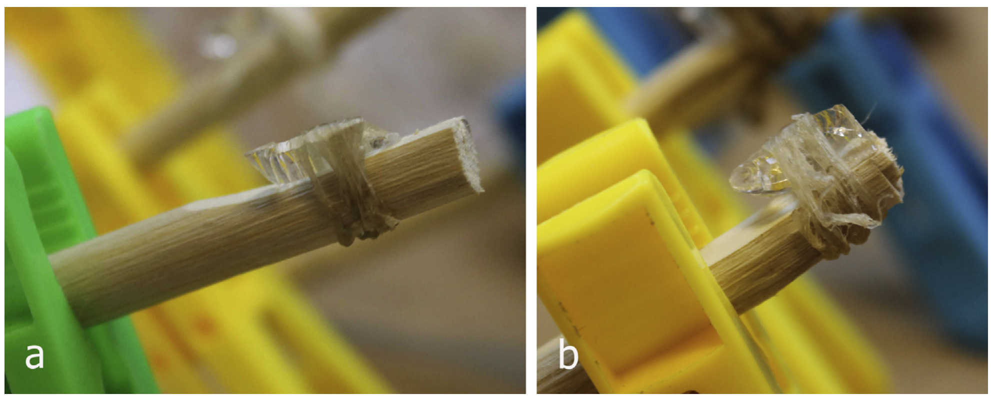

Fig. 5. Flakes hafted with bindings on shafts and left to dry. Flakes remained unused and were de-hafted after a few days.

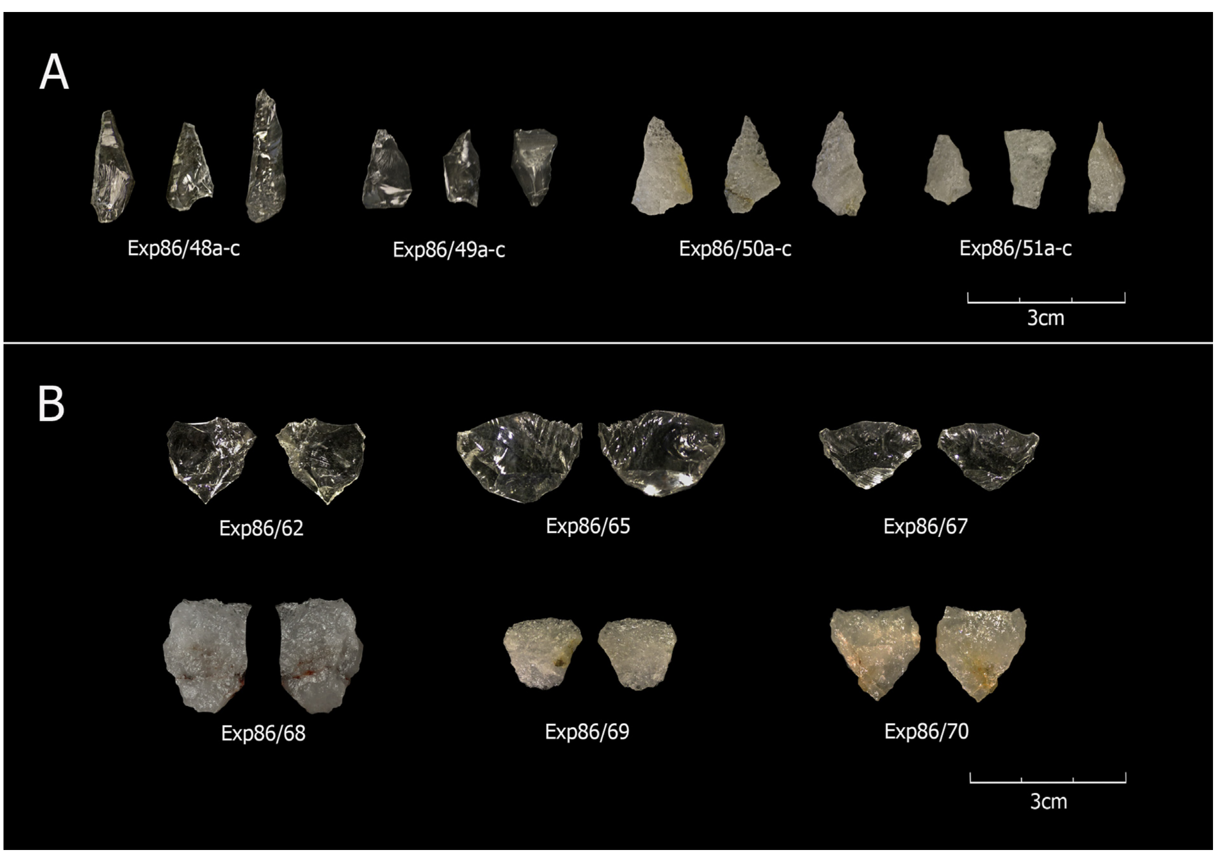

Fig. 6. Examples of experimental blanks used in the study. A: Morphological variability in barbs (Exp. 48 and 49 crystal quartz, Exp. 50 and 51 vein quartz, dorsal view). B: Transversely hafted armatures (top row crystal quartz, bottom row vein quartz, dorsal and ventral view, cutting edge up).

quartz backed pieces from the layer GS, see Tables S1 and S2 and de la Peña, and Wadley, 2014a) were replicated as closely as possible during the experiments (Fig. 6).

First, we examined whether impact with the target alone could result in the formation of micro-notches without being affected by the hafting mode (e.g., resin only, or the addition of bindings). Three hafting techniques were tested, the first one involving sinew only, the second one involving both sinew bindings and an adhesive, and the third one involving an adhesive only. The adhesive was a mixture of 70% natural spruce resin and 30% beeswax. Unretouched (n = 28) and partially retouched (n = 17) armatures made of crystal quartz (n = 18) and vein quartz (n = 27) were mounted as barbs on 13 pine shafts without grooves and two shafts with grooves (Fig. 7).

The absence of grooves may reduce the strength of the attachment between barbs and shafts, and increase the chance of notch formation even though this has not been demonstrated experimentally yet. Three aligned barbs were mounted on each shaft, resulting in a total of six arrows with barbs made of crystal quartz crystal and nine arrows with barbs made of vein quartz. Arrows were shot by CL at a distance of 10 m with a 47 pound flat bow made out of elm wood (29 inch draw distance) at an artificial target consisting of a pony skeleton encased in ballistic gel and covered with a stretched, fresh hide (Fig. 8; for details see Coppe and Rots, 2017). A maximum of three shots was fired, unless the barbs fractured or detached earlier, in which case the experiment was stopped. Two arrows were shot three times and three arrows were shot twice while all others were only shot once (total number of shots = 22).

Secondly, we evaluated whether the damage on the experimental barbs was distinctively different from that on transverse arrowheads. The use of transverse arrowheads has been proposed for the HP at Sibudu (e.g. Lombard and Pargeter, 2008). Twenty-one transverse arrowheads, unretouched and minimally retouched (lateral truncations, n = 13), nine of which were made out of crystal quartz and 12 out of vein quartz, were mounted in split extremities of pine shafts. Three hafting techniques (sinew and resin, sinew only, resin only) were again used (Fig. 9). The experimental set-up and the artificial target were identical to the first phase of the experiment. Again, a maximum of three shots was allowed, unless the transverse arrowheads fractured or detached earlier.

4.3. Analysis

The use-wear analysis of the experimental and archaeological sample involved a low magnification (i.e., microscopic analysis with an oblique shearing light from an external source and more limited magnification) and a high magnification (i.e., microscopic analysis with an incident internal light source and higher magnification) analysis with the aid of different microscopes: a stereoscopic binocular microscope with external light source (Olympus SZX7, magnifications up to 56×), a Zeiss Axiozoom V16 z-motorised microscope with external light source (magnifications up to 180×), and a reflected-light microscope Olympus BX51M (magnifications 50-1000×) equipped with polarizing filters and DIC. Pictures on the Zeiss microscope were taken with a Zeiss AxioCam ICc5 camera and on the Olympus microscopes with an Olympus SC100 camera.

Attention was devoted to scarring, fractures, and microwear, including linear features, surface cracks, and abrasion. The high magnification analysis was based on methodology specifically developed for quartz (Kamminga, 1982; Fullagar, 1986; Knutsson, 1988, Knutsson et al., 2015; Ollé et al., 2016). For linear features, a basic division into striations (brittle fracture wear) and sleeks (plastic deformation wear) (Knutsson, 1988) is used. The appearance of striations on crystal quartz is slightly different from those on vein quartz, and the analysed experimental material suggests that the two are not strictly comparable. Therefore, a simplified description is employed.

While residues are not the focus of this study, they were noted when encountered. Only strongly adhering residues were considered (e.g., black sticky residue that we think is resin, and red residue that may be ochre) because the tools were washed after excavation and no precautions regarding handling were taken.

Use-wear interpretations rely on comparison with the experimental reference material produced specifically for this study and the existing reference collection available at TraceoLab, University of Liège. This collection comprises about 3000 experimental pieces manufactured from various raw materials, including crystal and vein quartz comparable to the types found at Sibudu (e.g., Rots, 2010, 2016, Coppe and Rots, 2017; Rots et al., 2017). The reference

Fig. 7. Examples of experimental hafted barbs before and after use. Left: Exp. 86/47. The barbs attached with sinew moved along the shaft and hit each other upon impact. Right: Exp. 80/48. Only small fragments of the barbs attached with sinew and resin remain on the shaft after the shoot.

Fig. 8. Experimental setting. a: CL with the elm wood flat bow used throughout the projectile experiments. b: Target consisting of a pony skeleton encased in ballistic gel and covered with a stretched fresh hide. c: Example of an experimental arrow in the target where one of the barbs has detached upon impact. d: Wound in the ballistic gel created by an experimental arrow.

Fig. 9. Examples of experimental transversally hafted backed artefacts before and after use. Left: Exp. 86/76. The point fragmented upon impact and only a small fragment remained in the shaft. Right: Exp. 86/82. The point turned in the shaft and shows heavy edge damage in the middle part of its cutting edge (see Fig. 17c).

collection covers a wide range of activities and hafting techniques.

Projectiles are identified based on the co-occurrence of specific forms of scarring and fractures, preferentially in association with microscopic linear impact traces (MLITs) (Moss, 1983; Rots and Plisson, 2014), which further support the attribution of scarring and fractures to impact. While MLITs do not systematically form on each projectile, they should be present on at least some of them (cf. Rots and Plisson, 2014). Determining the position of the point in the shaft (barb, tip, transverse point) is based on the organisation and the orientation of the features (e.g., direction of MLITs) formed during impact (e.g., Rots, 2016, Taipale and Rots, in prep).

All the experimental armatures were analyzed under low magnification before hafting to record the damage that had formed during knapping and possible retouching. Production-related wear features were marked on a photograph of the tool to allow a comparison with wear that would form during subsequent hafting and use. Finished arrows were also photographed in detail both before and after use to record the location of bindings and/or adhesive and the exact position of the barbs and transverse arrowheads in the shafts to make it easier to interpret the use-wear.

5. Results

Out of the 82 micro-notched blanks in Sibudu's archaeological sample 1, 31 are possible tool fragments. Three pieces can be positively identified as projectile components, and a further 12 artefacts have strong indications of projectile use (see below). For all 15 cases, we consider lateral hafting as barbs the most plausible option. An additional 16 pieces display damage that is possibly from impact, but the features are too limited and ambiguous to allow a confident identification. While some of the notches can be indirectly linked to projectile use, the majority of them occur on pieces that show no use-wear. Altogether 47 notches in sample 1 could be attributed to various accidental causes including damage and edge irregularities formed during knapping, trampling, or other post-depositional causes. For four notches, the interpretation is uncertain: they occur on medial or other small fragments with little wear evidence. The results of the low and high magnification analyses are shown in Table 6. Table 7 shows the inferred causes of notch formation within each functional class.

In archaeological sample 2, which contains no micro-notches in the strict sense, four pieces can be confidently identified as parts of hunting weapons, and 17 pieces show more limited evidence for this use. Again, the patterning and orientation of the features matches lateral hafting best. The damage and/or fractures visible under low magnification are sometimes combined with microscopic linear impact traces (MLITs) or other microwear. Several pieces show explicit damage that in two cases resembles micro-notches. The other artefacts in the sample have either minor, ambiguous damage that is possibly functional (five cases) or undefined (15 cases) in origin. The remaining nine pieces do not display any traces of use (Table 8). No evidence of use other than from projectiles was found in the two samples despite the extensive use of high magnifications.

Together with the experimental evidence, these observations from the Sibudu collection support the interpretation that micro-notches may form as a result of projectile use. Detailed examination is, however, necessary before attributing them to this cause given the high frequency of accidental micro-notch formation. Micro-notches form also more frequently on quartz than on other raw materials because of its structural properties. In the following sections we propose a number of diagnostic characteristics that can help to identify the cause(s) of micro-notch formation on quartz blanks in archaeological assemblages by comparing the experimental and archaeological samples. Only sample 1 is discussed here since sample 2 does not have micro-notches that would meet the sampling criteria used in the technological study.

5.1. Accidental micro-notches caused by knapping: characteristics and observations

On the experimental control samples, damage from bipolar knapping is abundant (Fig. 10). It is varied in nature and may occur on both dorsal and ventral surfaces, often at the extremity of the blank (Fig. 10a). There are also dispersed scars along the edges (Fig. 10b), as well as groups of scars forming notches (Fig. 10c–d). Generally, these scars have distinct initiations and/or associated crushing. Small fractures or even burinations may also form at distal extremities (Fig. 10e). A micro-notch on the proximal edge combined with “impact” damage at the distal extremity can be confusing (Fig. 10f) if the analyst is not aware that such damage may result from bipolar knapping. In this case, the micro-notch is part of production damage and the short, crushed burinations on the tip, associated with a ventral step-terminating scar, are a result of contact with the anvil during knapping.

Accidental micro-notches can be formed by a single scar or several scars (Fig. 11b–d). In addition, some micro-notches are not the result of secondary scarring, but are better described as edge irregularities that were created during blank production as the result of internal cracks and flaws in the raw material. They will be referred here as structural micro-notches (Fig. 11a). Roughly similar features may also form as the result of impact, but in this case they are usually accompanied by other wear features that help to attribute the fracture pattern to use instead of production.

Caution is needed when dealing with archaeological assemblages that show evidence of bipolar knapping. A significant amount of damage may occur as the result of friction against the core as well as counter-pressure against the anvil. Very thin, acute-angled edges common in flaked crystal quartz are especially vulnerable to spontaneous retouch and other forms of knapping-

Table 6
Functional interpretations for the micro-notched pieces in sample 1 from Sibudu.

Functional categories	Low magnification	High magnification			
		Convincing microtraces	Possible microtraces	No functional microtraces	Observations limited or impossible
Projectiles	3	2	1	0	0
Possible projectiles	12	0	4	4	4
Possibly functional	16	0	3	11	2
Uncertain	4	0	1	2	1
No functionally relevant traces	47	0	4	31	12
TOTAL	**82**	**2**	**13**	**48**	**19**

Table 7
Suggested causes of micro-notch formation in sample 1 from Sibudu, organised by functional class. Nineteen of the 82 pieces have two notches, resulting in a total of 101 notches in the sample.

Functional class	Notch cause					Total
	Possibly intentional	Structural	Trampling?	Unspecified accidental	NA	
Projectile (n = 3)	0	1	0	3	0	**4**
Possible projectile (n = 28)	4	8	2	16	1	**31**
Uncertain (n = 4)	0	2	0	2	1	**5**
Not used (n = 47)	0	29	4	26	2	**61**
Total (N=82)	**4**	**40**	**6**	**47**	**4**	**101**

Table 8
Functional interpretations for the artefacts in Sibudu's sample 2.

Functional categories	Low magnification analysis	High magnification analysis			
		Convincing microtraces	Possible microtraces	No functional microtraces	Observations limited or impossible
Projectiles	4	2	0	1	1
Possible projectiles	17	0	4	9	4
Possibly functional	5	0	1	2	2
Uncertain	15	0	3	4	8
No functionally relevant traces	9	0	0	7	2
TOTAL	**50**	**2**	**8**	**23**	**17**

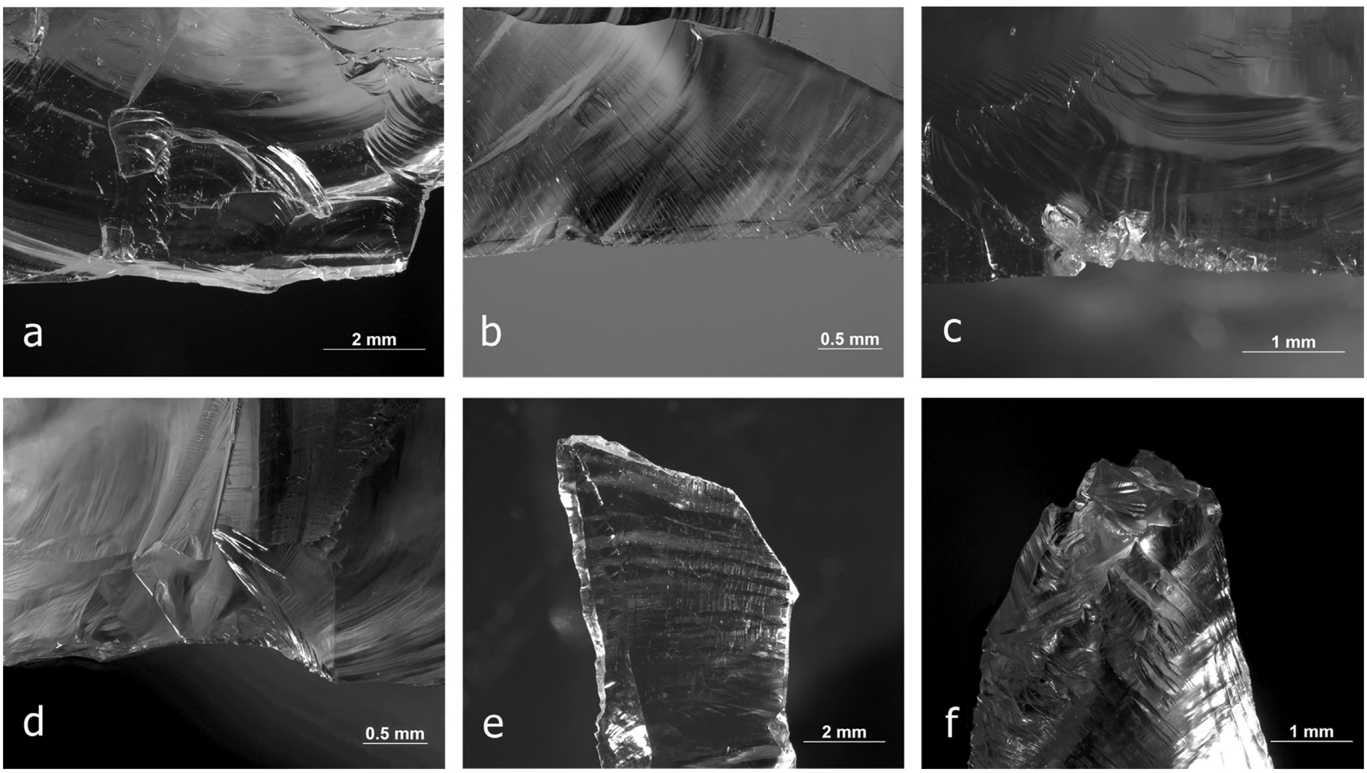

Fig. 10. Accidental damage from bipolar knapping on experimental sample: a. Damage at the extremity of Exp. 86/59-6 (crystal quartz, 25×); b. Dispersed scars on the edge of Exp. 86/59-7 (crystal quartz, 63×); c. Notch formed by several scars on Exp. 86/59-2 (crystal quartz, 50×); d. Notch formed by several scars on Exp. 86/59-5 (crystal quartz, 63×); e: Burination on Exp. 86/59-4 (crystal quartz, 20×); f. Micro-notch combined with "impact" damage at the distal extremity of Exp. 86/59-5 (crystal quartz, 40×).

related damage (Fig. 10). In addition, the structural irregularities in vein quartz often contribute to damage formation during knapping. Broadly speaking, the damage has explicit initiations and associated crushing, which seem to be potentially diagnostic features that can be used in distinguishing production-related features from functional damage.

Accidental damage from knapping is abundant on both archaeological samples. It is responsible for most of the "micro-notches" and for a significant amount of other edge damage observed in Sibudu's sample 1 (no notches were present in sample 2 so this sample is not discussed here). Structural micro-notches alone make up 42 of the micro-notches (observed on 41 pieces) in Sibudu's sample 1. Twenty-nine of these pieces do not bear any evidence of use, and the notch-like features encountered on them can be attributed to irregular fracturing during knapping (Fig. 11i–j). The other 12 pieces show varying amounts of use-wear, but the micro-notches themselves again seem to have formed during knapping. The formation of such micro-notches as the result of taphonomic processes could be studied further in the future, but since structural micro-notches are very common on unused experimental quartz flakes, we consider knapping to be the primary process responsible for them.

Determining the cause of the remaining accidental micro-notches on the Sibudu pieces is not as straightforward. This group comprises 51 micro-notches on 49 pieces, formed by one (Fig. 11k) or several scars (Fig. 11l). Structural micro-notches with subsequent edge damage within them were also observed. Most notches in this group can be attributed to either knapping or taphonomic processes because the characteristics of these two notch types overlap in the experimental material. The origin of three notches could not be identified because the surfaces on these pieces were recrystallized or otherwise problematic for high magnification analysis.

Both intentional and accidental (knapping and trampling) notches in the experimental reference sample commonly show incipient cracks, micro-scarring, crushing and abrasion under high magnification (Fig. 12a–c). Also common are linear features in the area where the removals that form the micro-notch initiate; this is regardless of the cause of notch formation (Fig. 12a–b, 13i-j). Judging from the experimental material produced for this study,

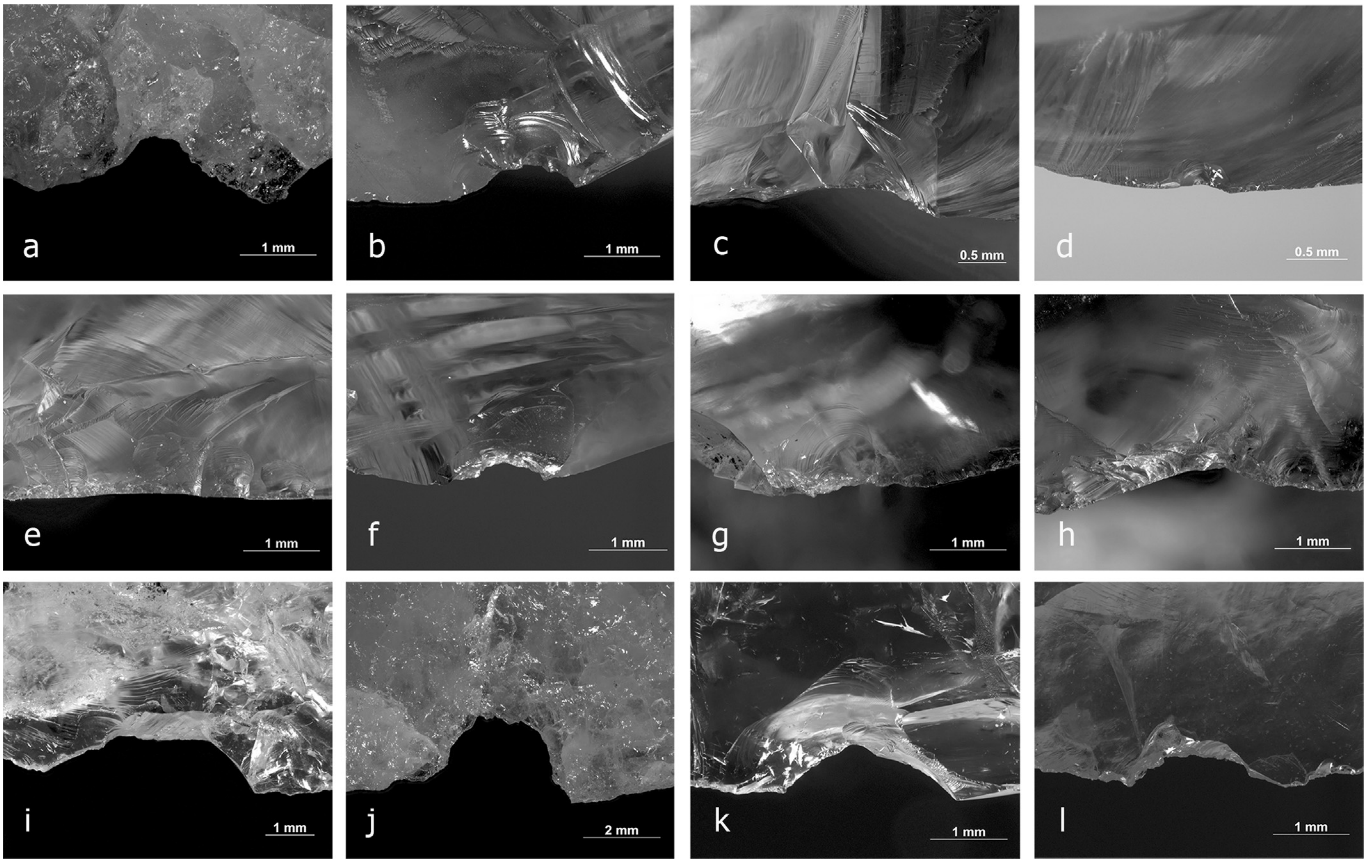

Fig. 11. Structural, production, and trampling micro-notches in the experimental and archaeological samples. a. Structural notch on an experimental bipolar flake from core 9 (vein quartz, 50×); b. Notch formed accidentally during production on experimental barb Exp. 86/47b (crystal quartz, 50×); c. Notch formed accidentally during production on Exp. 86/59-5 (crystal quartz, 80×); d. Notch formed accidentally during production on Exp. 86/59-7 (crystal quartz, 80×); e. Edge damage from trampling on Exp. 86/43-17 (crystal quartz, 50×); f. Trampling notch on Exp. 86/43-15 (crystal quartz, 50×); g. Trampling notch on Exp. 86/43-19 (crystal quartz, 50×); h. Trampling notch on Exp. 86/43-27 (crystal quartz, 50×); i. Structural notch on piece N56 from Sibudu (sample 1) (32×); j. Structural notch on piece N3 from Sibudu (sample 1) (25×); k. Accidental notch formed by a single scar on piece N73 from Sibudu (50×); l. Accidental notch formed by several scars on piece N55 from Sibudu (50×).

the distinction between intentional and accidental micro-notches is best made by looking at the orientation and distribution of the linear features associated with the micro-notch. Although distinguishing between various accidental causes remains difficult, there are certain characteristics that seem diagnostic of trampling (see below).

5.2. Accidental notches caused by trampling: characteristics and observations

Despite the wet conditions and the quick burial of the blanks in the mud during the experiment, scars were observed on several trampled blanks. Given that the paint was not entirely resistant to the humid conditions, it was difficult on some specimens to distinguish between scars resulting from trampling and scars that were present from knapping. In both cases, of course, the scars are accidental and both need to be distinguished from potentially functional or intentional notches.

In most cases, dispersed small scalar scars or limited crushing were observed along the edges, but damage may also be larger and more abundant. Even then, scars are mainly scalar in morphology and have rather explicit initiations even though they are often difficult or impossible to characterise in detail due to superimposed crushing (Fig. 11e). Scars may occur in groups and form micro-notch-like features (Fig. 11f). Also bifacial scarring is present, again with intensively crushed initiations (Fig. 11g). In a few cases, deep scarring was observed, often in a series forming a somewhat triangular notch, again with crushed initiations (Fig. 11h).

While scarring frequently formed during trampling, explicit notches are rare and the crushed component seems to indicate trampling. Even though the area was trampled systematically over the course of two weeks, the rainy conditions sped up the burial of the blanks into the soil, and it is probable that most damage formation took place during the first few days of the experiment when the quartz blanks were in contact with the knapping waste scattered on the surface.

Separating trampling from other accidental causes in the archaeological sample is not straightforward because the damage patterns overlap. Nevertheless, trampling notches can sometimes be identified through high magnification. While linear features (mainly striations) can be found in association with trampling micro-notches, they are generally oblique to the edge and usually form a pattern that is much more chaotic than that observed on intentional micro-notches (Fig. 12). Furthermore, there are certain features that seem diagnostic of trampling and do not occur on any other micro-notches examined in this study. One of these is the association of a large striation or a group of striations (often oblique to the notched edge) with a crushed and/or abraded area, or an area with extensive microscarring, located at the edge of the notch (Fig. 12a–b). This kind of combination never occurs in the context of true retouch, where the edge is generally clear-cut.

Some trampled pieces also show severe surface cracking in the

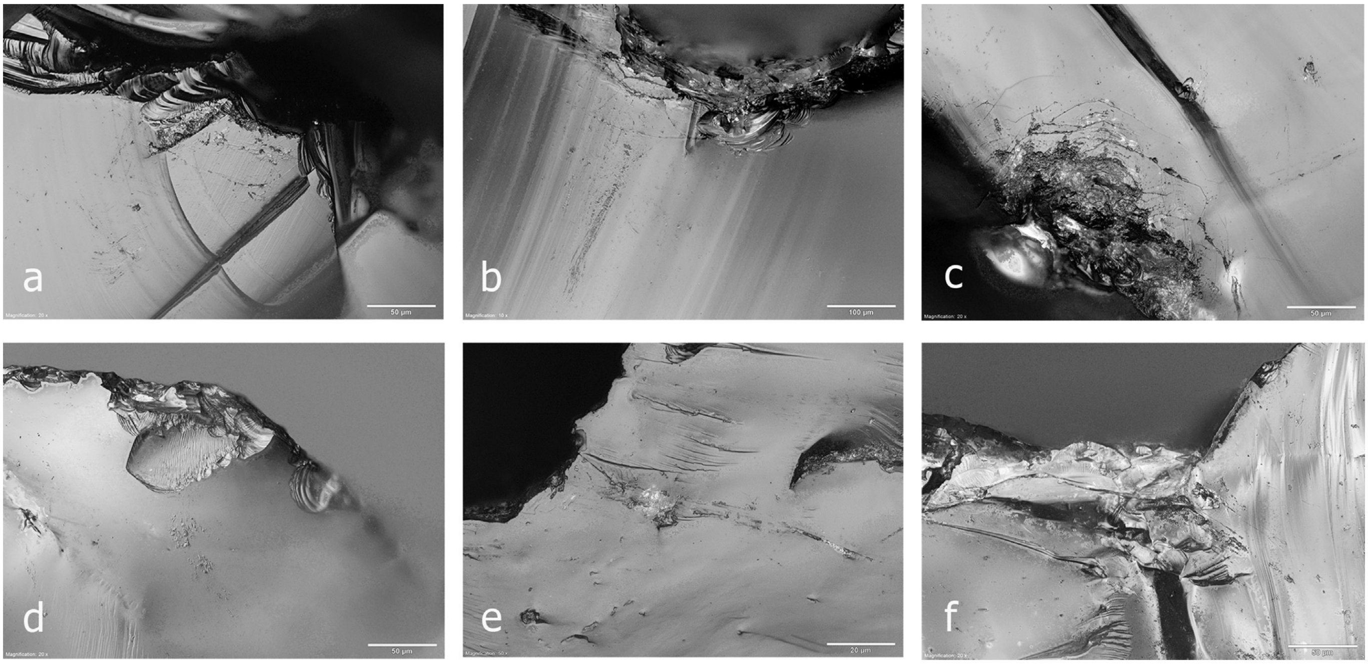

Fig. 12. High magnification features from trampling in experimental and archaeological samples: a. Area of microscarring and incipient cracks associated with striations at the edge of Exp. 86/43-8 (crystal quartz, 200×, scale bar 50 µm); b. Area with incipient cracks, crushing and microscarring associated with striations at the edge of the notch on Exp. 86/43-15 (crystal quartz, 100×, scale bar 100 µm); c. Heavy surface cracking in the vicinity of a notch on Exp. 86/43-20 (crystal quartz, 200×, scale bar 50 µm); d. Microscarring interpreted as evidence of trampling adjacent to the notch on piece N69 from Sibudu (sample 1) (200×, scale bar 50 µm); e. Slightly curved striation oblique to the edge of the notch, associated with deep surface cracking (reflective area) on piece N47 from Sibudu (sample 1) (500×, scale bar 20 µm); f. Heavily cracked area associated with a striation oblique to the notch edge on piece N19 from Sibudu (sample 1) (200×, scale bar 50 µm).

vicinity of the micro-notch (Fig. 12c), another feature that is absent on intentionally notched pieces. The cracking implies that pressure was exerted in the general edge area without the precision that is typical of (successful) retouching. Occasionally, the overall wear pattern helps to identify trampled pieces. The experimental sample contains a number of flakes where occasional retouch-like damage on one edge is coupled with rather heavy damage on other edges and dorsal ridges.

No notches were found in Sibudu sample 2, but in the archaeological sample 1, trampling is a plausible cause for at least six notches. Three of them can be attributed to trampling with a fair degree of confidence thanks to the presence of high magnification features similar to the ones described above (Fig. 12d–f). On many experimental pieces, however, the traces associated with trampling-related edge damage are either scarce or undiagnostic, so the majority of archaeological trampling notches may well go unidentified.

5.3. Intentional notches: characteristics and observations

Notches formed by a bone compressor have intense crushing at the initiation and a marked concavity when the notch is dorsal (Fig. 13a). If the notch is ventral, the crushing seems more limited (Fig. 13b). Bone residue is generally compacted within the notch. Four out of ten experimental micro-notches show linear features, namely striations, coming from the compressor (Fig. 13j), but heavy crushing and cracking (also visible under low magnification) are the most prominent and frequent features in these micro-notches. Three micro-notches, however, do not show any microscopic wear that would help to identify intentional retouch.

Micro-notches formed by percussion with the edge of a dolerite flake have more explicit individual retouch scars. The retouch scars in the centre are generally the largest ones while crushing caused by contact with the edge of the dolerite flake may occur within the initiation of each retouch scar. The five pieces for which high magnification analysis was possible all show linear features (striations, sleeks) (Fig. 13i).

Micro-notches formed by crushing with the edge of a crystal quartz indenter are variable and compare well with ones produced through knapping. Scars can be very regular and equally-sized on thin edges (Fig. 13c), but show a more significant crushing component when the blank edges are steep. Linear features (striations and one sleek) were observed on roughly half of the pieces notched with crystal quartz, but crushing is clearly a more dominant and frequent feature.

When a stone hammer is used as a pressure tool to produce the notch, the notch is formed by explicit retouch scars that are regularly sized. Crushing within the initiation is frequent. It is often extensive and has a strong abrasion component that may also be visible on the opposite surface (Fig. 13d).

When the edge of the blank is pressed against a bone compressor (instead of pressing the compressor against the edge), the notch formed on the quartz blank is either similar to ones formed by pressure with a bone compressor, or the notch comprises one large scar sometimes with additional smaller scars superimposed. Again, half of the micro-notches are associated with linear features (regular and irregular striations). Some of the notch edges are very clear-cut, others show incipient cracks and limited abrasion.

Very few intentional micro-notches were identified in the Sibudu collection. After careful analysis, only three pieces (N1, N4 and N43) show potentially intentional micro-notches. On these three pieces, the type and pattern of removals that form the notches match some of the experimental intentional notches. However, the microwear associated with the micro-notches is either ambiguous or absent, and it is not possible to demonstrate

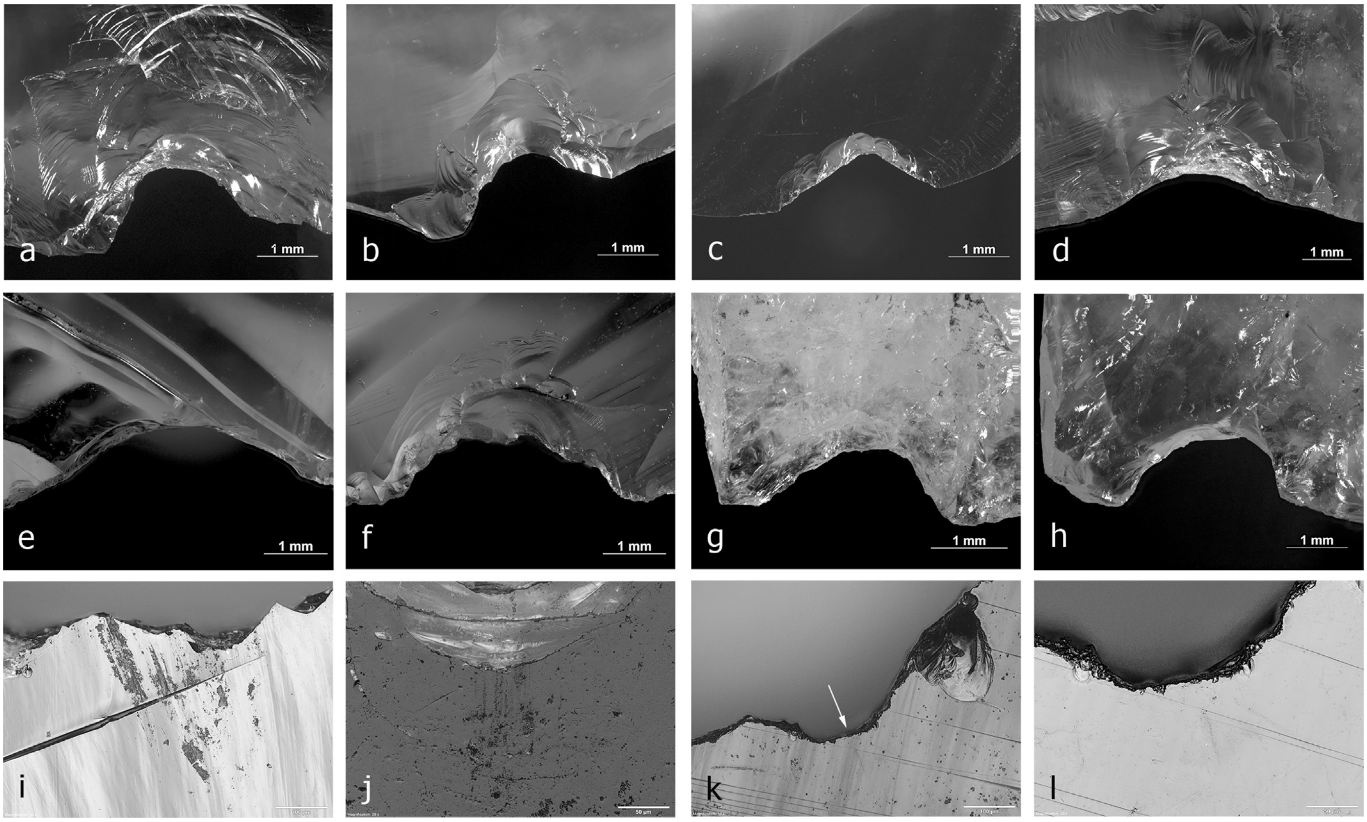

Fig. 13. Intentional notches in the experimental collection and Sibudu sample 1: a. Direct notch made with a bone compressor, showing crushing at the initiation (Exp. 86/16, crystal quartz; 40×); b. Indirect notch made with a bone compressor with more limited crushing at the initiation (Exp. 86/17, crystal quartz; 40×); c. Regular, evenly-sized scars forming a notch on Exp. 86/29, made by crushing the edge against a crystal quartz indenter (crystal quartz, 40×); d. Notch made with a stone hammer, showing heavy crushing and abrasion at the initiations of the scars (Exp. 86/60-5, crystal quartz; 32×); e. Notch on the right edge of piece N1 from Sibudu, formed by a small break and associated secondary scars (crystal quartz, 40×); f. Notch on the left edge of piece N1 from Sibudu, consisting of one large scar and several secondary ones, comparable to experimental notches made with a bone compressor (crystal quartz, 40×); g. Notch on piece N43 from Sibudu, formed by one main removal and possible smaller ones on its both sides (50×); h. A deep notch formed by a single removal on the thin edge of piece N4 from Sibudu (40×); i. Striations at the clear-cut edge of the notch made with a dolerite flake on Exp. 86/21 (100×, scale bar 100 µm); j. Striations and incipient cracks from the bone compressor in the centre of the notch on Exp. 86/13 (crystal quartz, 200×, scale bar 50 µm); k. A weak striation (indicated with an arrow) perpendicular to the edge of the notch located on the left edge of piece N1 from Sibudu (100×, scale bar 100×); l. Close-up of the striation pictured in k (200×, scale bar 50 µm).

deliberate manufacture. We therefore contend that tool use and (in the case of N43) taphonomy are more plausible explanations for the formation of the micro-notches on these three pieces.

N1 is a proximal bladelet fragment on crystal quartz. It has two micro-notches, one per edge at about the same height. The right one (ventral) is a fracture with associated scarring (Fig. 13e), while the left one (dorsal) consists of clear scars, one main one and several secondary ones, which could correspond to pressure against a bone indenter (Fig. 13f). Under high magnification it shows a faint striation with orientation and location comparable to ones coming from the indenter on experimental intentional notches (Fig. 13k–l, compare with Fig. 13i–j), but on the experimental pieces the linear features are much more numerous and/or better-developed. The striation on N1 may well be taphonomic, and its association with the notch coincidental.

N4 has a very thin edge, but the notch is deep and consists of one scar (Fig. 13h). Given the associated damage, it is likely that its origin is functional. It does not seem to show any additional features under high magnification, but part of the notch area is very difficult to observe due to irregular surface topography.

N43 is a proximal bladelet fragment of vein quartz with a notch on the dorsal left edge. No crushing is visible at its initiation and it seems to consist of one main scar similar to what has been observed when an edge is pressed against a bone compressor (Fig. 13g). It is not a convincing example of intentional notching, and the features observed under high magnification in the area of the notch are more consistent with trampling than with intentional manufacture.

5.4. Hafting-related notches: characteristics and observations

Minor scarring was observed on some of the experimental blanks that were fixed on wooden shafts with wet bindings and left to dry. This scarring was produced by the pressure exerted during the attachment of the bindings and not by the drying and shrinking process. This was confirmed by the sound of chips detaching when the tool was attached to its shaft. No damage was observed that could be strictly linked to the drying process. It is reasonable to conclude that the pressure exerted by the drying bindings is too limited to produce notches. The intensity of the damage that is formed during the attachment of the bindings depends on the edge angle and the amount of pressure that is being exerted. Of course, unretouched edges may also cut the bindings.

Under magnification, the damage from the hafting process itself often occurs in patches. On unretouched edges it may consist of small fractures and/or sliced scars (bending initiation, curved profile) (Fig. 14a) that show explicit initiations at the extremities of the patch, or of very small shallow scars if the edge angles are steeper (Fig. 14b). Scars may be alternating, either individually or in patches. Flakes may also break during the attachment of the bindings if a significant amount of pressure is applied, which

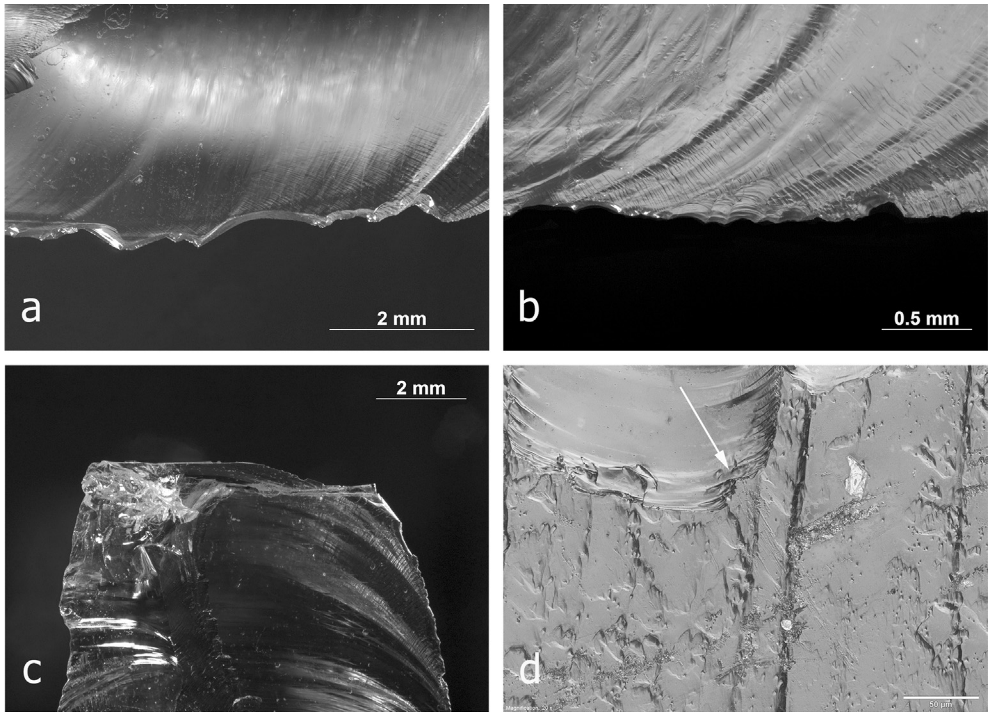

Fig. 14. Experimental micro-notches and associated features formed by the attachment of bindings: a. Sliced scars on the thin edge of Exp. 86/03 (crystal quartz, 32×); b. Small shallow scars on the steep-angled edge of Exp. 86/06 (crystal quartz, 80×); c. Break caused by the attachment of bindings on Exp. 86/06 (crystal quartz, 20×); d. Striations (start point indicated with an arrow) initiating from a scar on Exp. 86/06 (crystal quartz, 200×, scale bar 50 µm).

happened with one of the flakes during the experiment (Fig. 14c). On two pieces, the binding-induced edge damage is at places associated with linear features. This is a diagnostic combination that is also commonly encountered on hafted flint tools (Fig. 14d).

In addition to accidental damage that may occur during the fixing of the tool with bindings, one may also choose to make a notch to facilitate the attachment of the bindings. The possibly intentional micro-notches from Sibudu were evaluated with this in mind, but no conclusive evidence was found.

5.5. Micro-notches formed during use: characteristics and observations

Three barbs could not be recovered from the target and were thus lost during the experiment. Overall, all barbs functioned well, but detachments were frequent in comparison to other weapon components from projectile experiments that we have performed (Rots, 2016; Coppe and Rots, 2017), and this is likely due to the more limited adherence of barbs to shafts (compared to arrowheads), in particular when only bindings are used. Interestingly, barbs were often pushed against each other (see Fig. 7) causing various forms of damage. The outcomes of the projectile experiments are summarised in Table 9.

On the 42 barbs recovered after the experiment, various forms of damage were recorded, including what have been classified as “diagnostic impact fractures” (see Coppe and Rots, 2017 for a discussion) such as “burinations” (5), defined here as elongated bending-initiated fractures starting on one edge and terminating on the opposite edge, and spin-offs (3), defined here as cone-initiated scars starting from an earlier fracture surface and terminating on a ventral or dorsal surface or a lateral edge (Fig. 15c). Several pieces also exploded into fragments, the smallest of which would be difficult to recover archaeologically. Examples of larger fragments of projectiles can be found in both samples from Sibudu (sample 1 with micro-notches and sample 2 without micro-notches) (Fig. 16).

Distinct micro-notches were observed on four pieces (Fig. 15a–b), in two cases in association with a fracture. These micro-notches generally consist of a series of bending-initiated scars that most often have a strongly curved profile (“sliced scars”) and an abrupt termination (Fig. 15a). In two cases, MLITs could be observed, either in direct association with the notch, or elsewhere along the cutting edge (Fig. 15d–f). At least three of the micro-notches were clearly caused by bindings that were used to attach the barbs on the shafts.

Clear zones of edge damage were observed on 23 barbs, in three cases in association with a fracture. In many cases, these zones with edge damage could qualify as notches (Fig. 15b), so it is not always easy to separate the two categories. In most cases the damage is located near the distal or the proximal extremity. Breaks were observed on an additional eight barbs. Only six barbs show no clear damage.

Of the arrows equipped with transverse points, only one could be shot twice and one could be shot three times. In all other cases, a fracture occurred after the first shot. Of the total of 24 shots made with the 21 experimental transverse arrowheads, three points broke after having missed the target and five points broke after a rebound on the skin. Fifteen shots (with 12 arrows) were effective and penetrations from 1 cm up to 19.5 cm into the target were recorded.

The evaluation of the influence of hafting mode on damage formation is complicated by the small sample size and the variation in the ways the projectiles hit the target (contact with skin, ballistic gel, and/or bone). Nevertheless, pieces that broke during use were hafted with sinew and resin, whereas pieces hafted with sinew alone show only edge damage of varying intensities. Sinew hafting is less resistant to impact, and the lithic armature is more likely to simply move within the shaft or detach than to fracture (Fig. 9a vs

Table 9
Experimental details and projectile performance in the projectile experiments. The pieces hafted as armatures were either unretouched, or minimal retouch was applied only to the edge(s) that were in contact with the shaft and had thus no impact on the formation of use-wear.

Type	Knapping technique	Material	Hafting	Nr of shots	Outcome	Exp. ID
barb	unipolar, direct percussion with sandstone	crystal quartz	lateral, resin	1	explosion, barbs lost	Exp. 86/44
			lateral, resin	1	first barb de-hafted	Exp. 86/49
			lateral, sinew	2	one barb de-hafted beforehand, one detached after 2nd shot	Exp. 86/46
			lateral, sinew	1	de-hafted	Exp. 86/47
			lateral, resin + sinew	2	de-hafted	Exp. 86/45
			lateral, resin + sinew	2	de-hafted	Exp. 86/48
		milky quartz	lateral, resin	1	barb fracture in haft	Exp. 86/55
			lateral, resin	1	point broke in haft	Exp. 86/56
			lateral, resin	1	barb fracture in haft	Exp. 86/58
			lateral, sinew	1	two barbs de-hafted	Exp. 86/50
			lateral, in groove, sinew	1	de-hafted	Exp. 86/53
			lateral, in groove, sinew	3	de-hafting and barb fracture in haft	Exp. 86/57
			lateral, resin + sinew	1	one barb de-hafted	Exp. 86/51
			lateral, resin + sinew	1	de-hafted	Exp. 86/52
			lateral, resin + sinew	3	one barb detached before experiment	Exp. 86/54
transverse arrowhead	unipolar, direct percussion with sandstone	crystal quartz	split haft, resin + sinew	1	point broke in haft	Exp. 86/62
			split haft, resin + sinew	1	missed, point broke in haft	Exp. 86/63
			split haft, resin + sinew	1	re-bound on skin, point broke in haft	Exp. 86/66
			split haft, resin + sinew	1	15,5 cm penetration	Exp. 86/80
			split haft, resin + sinew	1	12 cm penetration, point broke in haft	Exp. 86/81
			split haft, resin + sinew	1	15,5 cm penetration, point broke in haft	Exp. 86/82
			split haft, sinew	1	missed, point lost	Exp. 86/64
			split haft, sinew	1	7 cm penetration, point broke in haft	Exp. 86/65
			split haft, sinew	2	shot 1 = 18,5 cm; shot 2 = missed, point broke in haft	Exp. 86/67
		milky quartz	split haft, resin + sinew	1	missed, point broke in haft	Exp. 86/68
			split haft, resin + sinew	1	re-bound in skin, de-hafted	Exp. 86/70
			split haft, resin + sinew	1	9,5 cm penetration, point broke in haft	Exp. 86/73
			split haft, resin + sinew	1	re-bound on skin, point broke in haft	Exp. 86/74
			split haft, resin + sinew	1	skin contact, point broke in haft	Exp. 86/75
			split haft, resin + sinew	1	12 cm penetration, point broke and remained in target	Exp. 86/76
			split haft, resin + sinew	1	13,5 cm penetration, point breakage and de-hafted (in target)	Exp. 86/77
			split haft, resin + sinew	1	15 cm penetration, point broke in haft	Exp. 86/79
			split haft, sinew	3	shot 1 = 19,5 cm; shot 2 = 15,5 cm; shot 3 = 10 cm, point broke in haft	Exp. 86/69
			split haft, sinew	1	19 cm penetration, point broke in haft	Exp. 86/71
			split haft, sinew	1	re-bound on skin, point broke in haft	Exp. 86/72
			flat haft, resin	1	1 cm penetration, de-hafted	Exp. 86/78

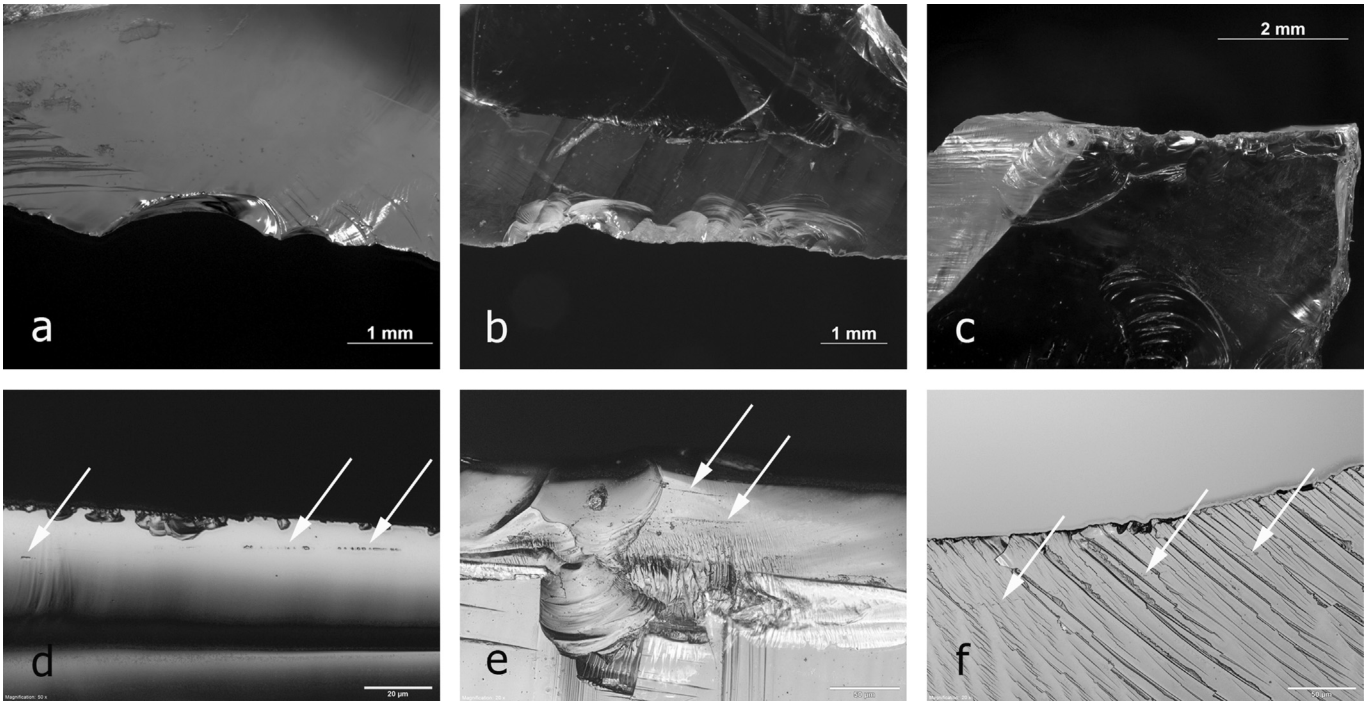

Fig. 15. Wear evidence on experimental barbs: a. Micro-notch formed by a bending-initiated scar caused by impact on Exp. 86/45b (crystal quartz, 40×); b. Stretch of edge damage from impact, partly forming a notch. Exp. 86/48b (crystal quartz, 32×); c. Spin-offs associated with a break on Exp. 86/48a (crystal quartz, 32×); d. MLITs (indicated with arrows) away from the notch on Exp. 86/45b (crystal quartz, 500×, scale bar 20 μm); e. Two MLITs (indicated with arrows) parallel to the edge line initiating from a scar on Exp. 86/46b (crystal quartz, 200×, scale bar 50 μm); f. A long MLIT (indicated with arrows) running parallel to the edge on Exp. 86/48a (crystal quartz, 200×, scale bar 50 μm).

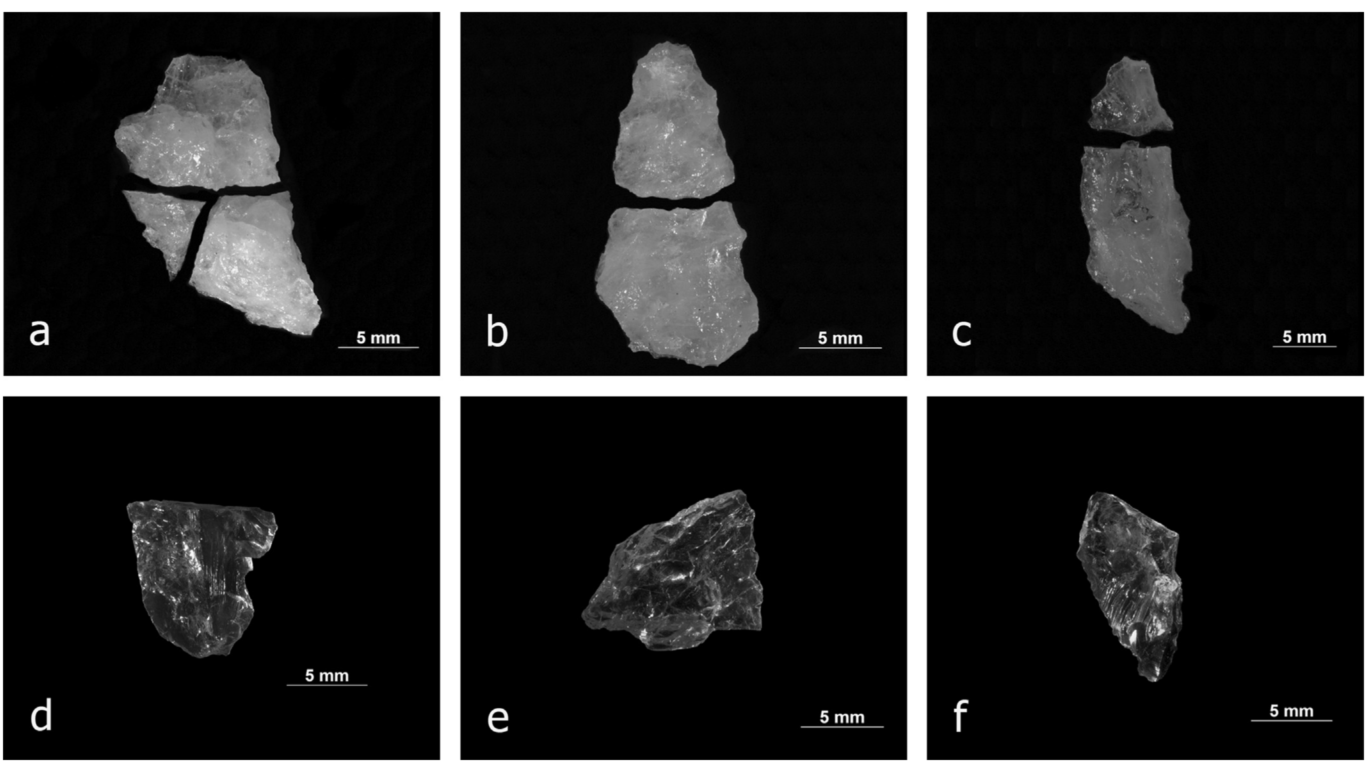

Fig. 16. Fragmentation of experimental barbs and comparable barb fragments identified in the archaeological samples 1 (micro-notches) and 2 (no micro-notches) on the basis of use-wear traces: a. Exp. 86/52a, vein quartz; b. Exp. 86/57a, vein quartz; c. Exp. 86/57b, vein quartz; d. N33, Sibudu (sample 1); e. 64, Sibudu (sample 2); f. 47, Sibudu (sample 2) (see also Fig. 20).

b).

On the transverse arrowheads, the orientation of edge damage and the microscopic features associated with it clearly indicate that the direction of impact was perpendicular to the cutting edge, leaving little doubt about the orientation of the armature in the shaft. The damage to arrowheads, when present, is much heavier than that on the experimental barbs. Notch-like features were observed on four arrowheads (Fig. 17a–c). In three cases, the piece can be identified as transversally hafted thanks to the explicit direction of the features. While the damage can seldom be described as a true notch, a recurrent feature in the sample of transverse points is an area of intense scarring with a roughly concave outline (Fig. 17c) (Taipale and Rots, in prep). On most pieces, however, this type of damage is not very concave (see Fig. 17d for comparison), and even when it is (Fig. 17c), it bears no resemblance to the notches formed through intentional retouching, trampling, or barb use, or to anything encountered in the archaeological samples. Only one piece has confusing features (Fig. 17b). Here, the lack of other wear features makes it impossible to securely identify the cause of notch formation or the position of the point in the shaft.

In sum, ambiguous notch-like damage can occasionally occur on a transverse point that has been shot. However, the more common damage patterns on transverse arrowheads are unequivocal and easy to detect. Judging from the evidence available at the moment, the macroscopic and microscopic wear in the archaeological sample from Sibudu corresponds much better to the wear observed on experimental barbs than to that on experimental transverse points. Since the archaeological samples show no evidence of use involving repetitive movements (such as cutting), barb use is the most likely functional cause for micro-notch formation in the HP of Sibudu.

After careful examination of archaeological sample 1, 31 out of 82 micro-notched pieces could be identified as used with varying degrees of confidence (Fig. 18). All these pieces are fractured and show a combination of a complex break and other damage features (Fig. 19). This does not mean that the micro-notches themselves are necessarily the result of use (see Table 7). For eight pieces, the micro-notches seem to be structural. The other micro-notches (23 pieces) can be classified as broadly "accidental". No microscopic features were found that would suggest they were intentionally made, and the absence or ambiguity of microwear associated with these notches makes it difficult to determine their exact origin.

In 15 out of 31 cases, the artefacts also show use-wear under high magnification. This use-wear consists of striations, abrasion or, most diagnostically, MLITs (i.e., striations clearly associated with a break or a scar that can be attributed to impact). At least two pieces have MLITs associated with other wear (N2 and N11; Fig. 19), and a third one (N33) has other striations that are probably the result of impact (cf. "drag lines" in Knutsson et al., 2016: Fig. 11). These three proximal fragments can be reliably classified as fragments of projectile weaponry. Two of these (N33 and N11) are most likely barbs judging from the fractures and the edge damage patterning, while use as a projectile tip cannot be excluded for N2. In addition to the three certain projectile parts in sample 1, possible use as hunting weaponry can be proposed for at least 12 more fragments even though no explicit MLITs were observed. At least six of these show sticky black residues of (possible) resin. In all cases, use as barbs seems the best supported option. For a further 16 pieces, the interpretation remains uncertain; the breaks and other features are possibly due to use, but are not enough to allow a more specific interpretation. Two of these pieces show possible evidence of resin.

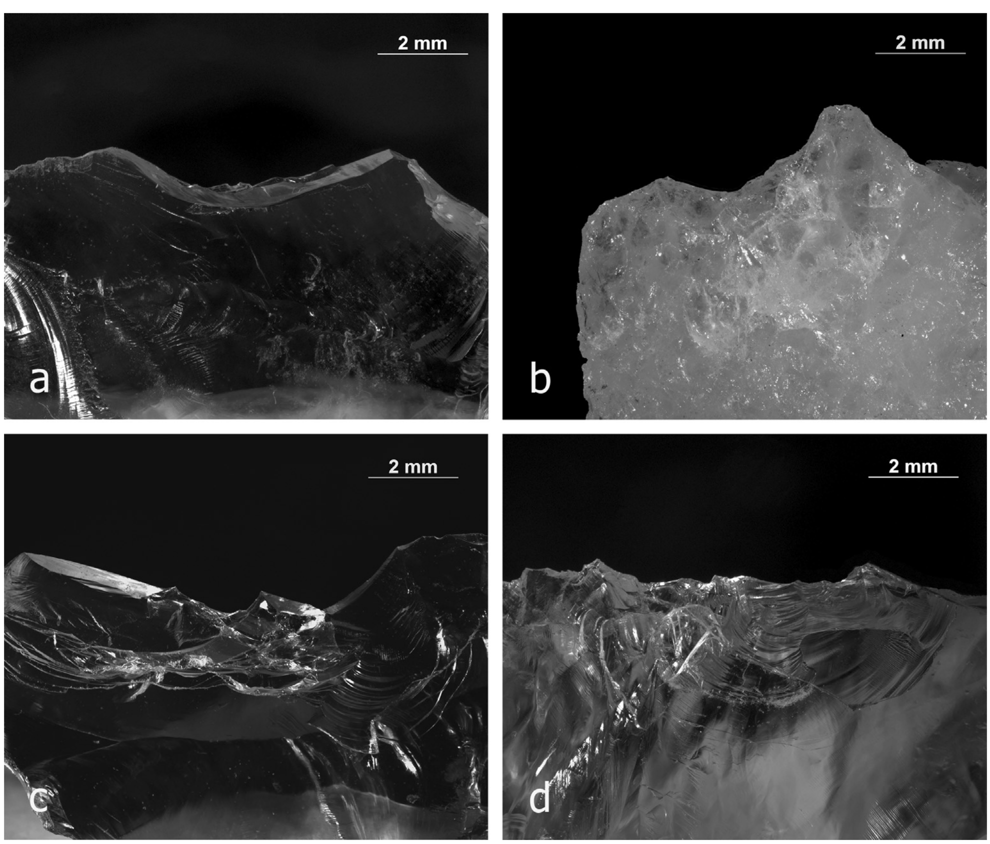

Fig. 17. Notch-like damage and microscopic features from impact on the experimental transverse points: a. Broad shallow notch formed by a bending-initiated scar on Exp. 86/67 (crystal quartz, 20×); b. Notch formed by a single scar on Exp. 86/72 (vein quartz, 20×); c. Stretch of intense edge damage forming a concavity on Exp. 86/82 (crystal quartz, 20×). The wear is comparable to that shown in d; d. Edge damage similar to that shown in c, with a less concave outline. Exp. 86/65 (crystal quartz, 20×).

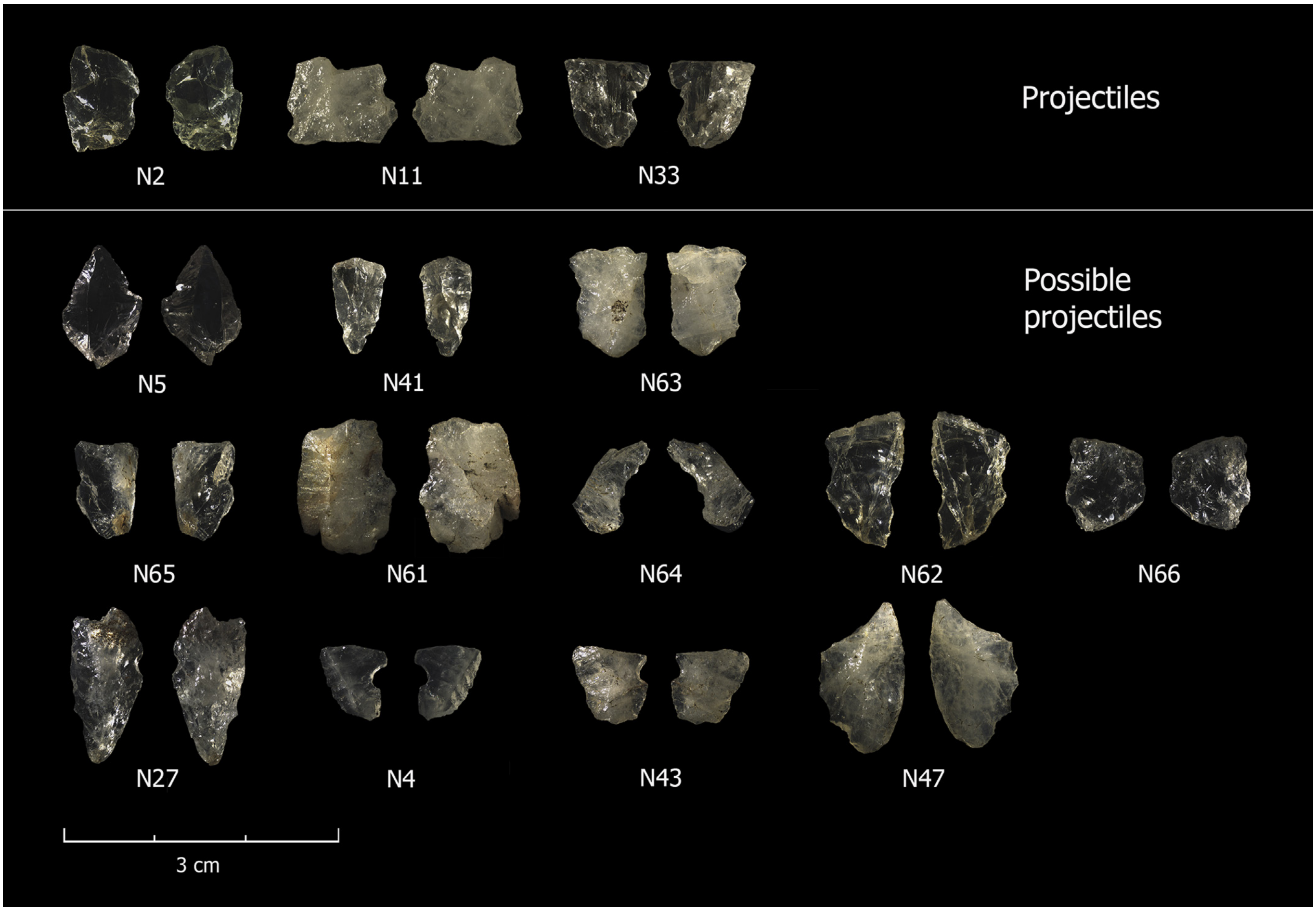

Fig. 18. Pieces identified as barbs and potential barbs in Sibudu sample 1.

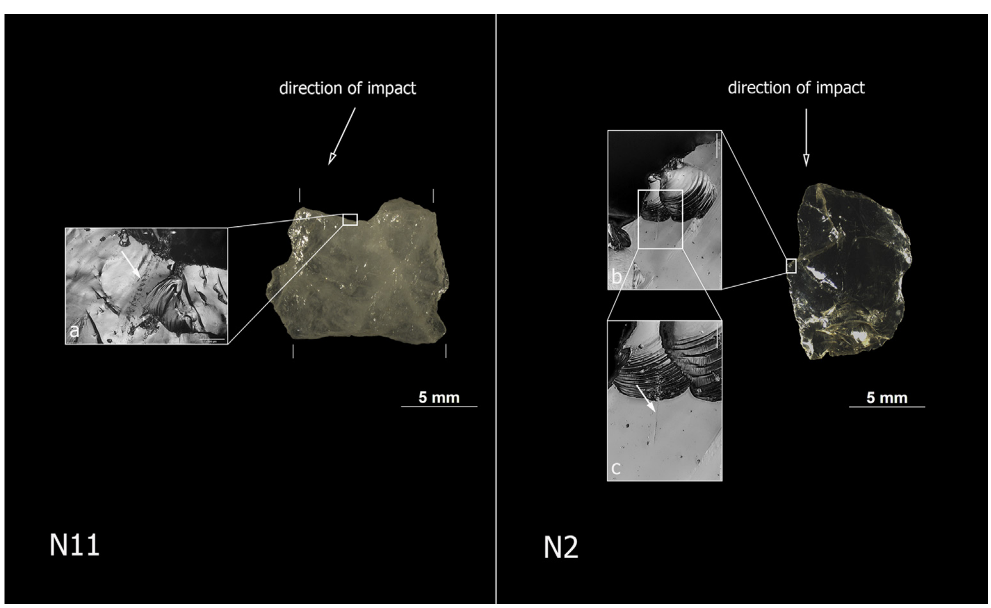

Fig. 19. Wear evidence on Sibudu barbs in sample 1. Left: Impact traces on N11. a. A MLIT (indicated with an arrow) on the ventral surface, associated with the distal break (100×, scale bar 100 μm). Right: Impact traces on N2. b. A MLIT associated with a small scar on the dorsal aspect of the termination of a large secondary removal associated with the break (visible through the translucent piece) (200×, scale bar 50 μm). c. The same MLIT (indicated with an arrow) photographed at 500× (scale bar 20 μm).

The chemical tests required to confirm the presence of resin have not yet been performed on most pieces where putative resin residues have been observed, but preliminary results of Gas Chromatography (GS) confirms that the sticky black film is indeed resin.

These results demonstrate that at least some of the notched fragments were once part of hunting weapons (Tables 6 and 7). It is possible that some are fragments of segments, truncated pieces, intact bladelets and unretouched blanks. Given their fragmented status, the original tool/blank is often not recognisable, but remnants of (possible) retouch are visible on a number of pieces. Moreover, if the wear represented in the two archaeological samples is compared, similarities can be found (Tables 6 and 8).

The 27 segments and truncated pieces in sample 2 (see Table S1) that has no micro-notches include two fragments (Fig. 20a and b) and one intact segment that show wear patterns similar to those observed on the barbs in sample 1. In addition, 11 pieces in this group display damage that is tentative evidence for their use as barbs. Under high magnification, four of them show striations that may be from impact, but they are not MLITs in the strict sense. The remaining 12 segments and truncated pieces do not show signs of use, or the wear is insufficiently developed to allow an interpretation.

Of the 23 intact bladelets of sample 2, six show damage that can be attributed to projectile use, again as barbs, but neither MLITs nor other functional striations were observed on them. Ten further bladelets have use-wear, but it is not diagnostic enough to allow the use to be identified. Four pieces in this group nevertheless show possible evidence of resin, presumably from hafting (e.g. #97). The last seven pieces do not show any convincing use-wear traces. In total 21 pieces in sample 2 are likely to have been barbs. Four of them show explicit evidence, while for 17 the interpretation remains more tentative.

These results support the hypothesis that a variety of tool types was used for hunting weapons, particularly as barbs (Fig. 21). No unequivocal weapon tips were encountered, even though an axial position could not be excluded for one piece (N2) in sample 1 (see above).

5.6. Other observations: residues

Even though residues are not the focus of the analysis here, strongly adhering types of residues such as possible ochre and possible resin were nevertheless observed on a number of pieces (about 10–12), systematically on pieces showing functional wear (Fig. 22). As a test, one piece of sample 1 was submitted to SEM-EDS to confirm its organic nature and GC analysis is still on-going (preliminary results confirm that the residue is indeed resin). Two additional pieces from sample 1, N63 and N65, were submitted to GC analysis. Resin has previously been identified on Sibudu segments (Villa et al., 2015) and some ochre-loaded adhesives have been recognised on other segments from the site (Lombard, 2007, 2008). The preservation of resin on part of the micro-notched pieces that also show functional wear supports their use as hafted elements.

6. Discussion

Our study shows that notches that look similar can be produced by a variety of events, and that the seemingly uniform technological category can in fact be the product of tool use, taphonomic processes, and/or the characteristic behaviour of quartz during knapping. The detailed analysis of micro-notches further led us to discover two novelties in the HP assemblages of Sibudu.

First, the use-wear study demonstrates the inclusion of quartz barbs in the HP hunting kit. They were identified from the co-occurrence of impact breaks, obliquely oriented lateral edge damage, and MLITs. Transverse hafting, the only plausible alternative explanation for the quartz backed pieces in the archaeological sample of notched pieces, could be excluded on the grounds of the orientation of the MLITs parallel to the cutting edges, and the absence of characteristic damage patterns demonstrated on experimental transversely hafted arrowheads.

Secondly, we show the functional importance of some unretouched quartz blanks that were mounted as elements in hunting weapons similarly to their retouched counterparts (e.g. segments and obliquely backed points).

6.1. Processes leading to formation of micro-notches

Intentional manufacture of notches has been discussed in

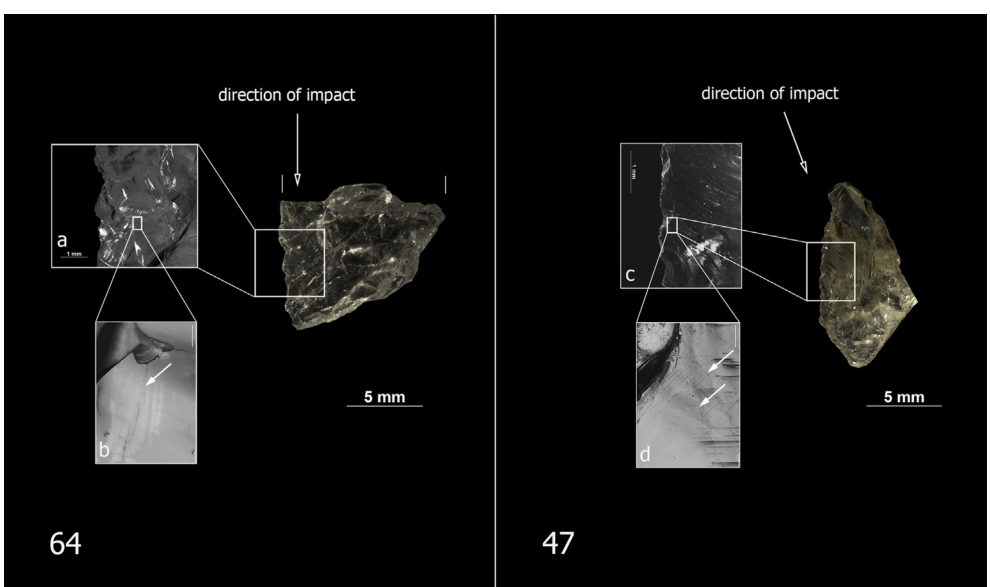

Fig. 20. Wear evidence on putative barbs in sample 2 from Sibudu. Left: Impact traces on 64. a. Scars oblique to the edge (40×). b. A MLIT (indicated with an arrow) starting at the termination of one of the oblique scars (200×, scale bar 50 μm); Right: Impact traces on 47. c. Continuous edge damage with abrupt terminations on the lateral edge (63×). d. MLITs (indicated with arrows) starting at the termination of one of the impact scars, running slightly oblique to the lateral edge (200×, scale bar 50 μm).

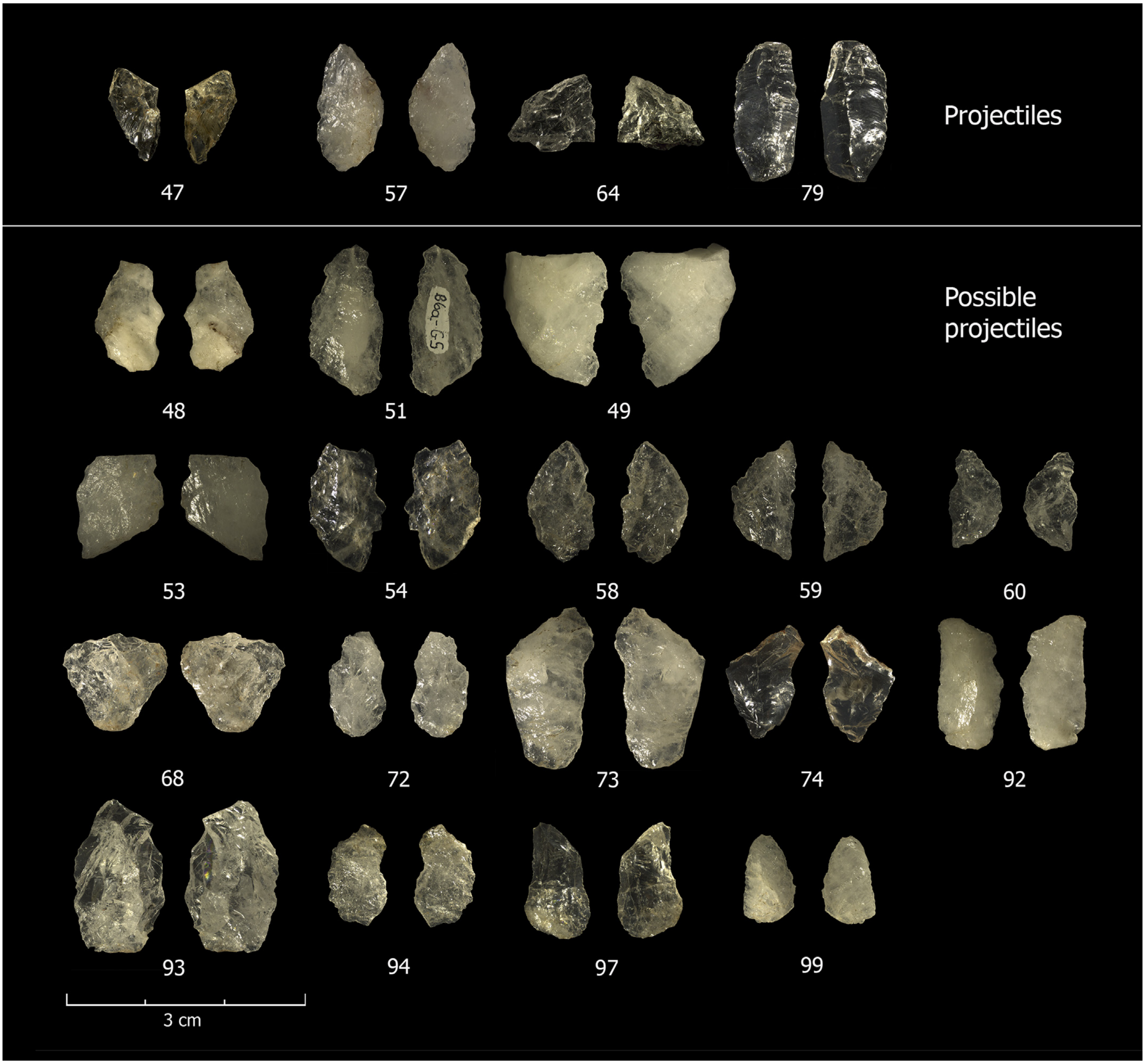

Fig. 21. Pieces identified as barbs and potential barbs in sample 2 from Sibudu.

previous technological studies. These studies have dealt with the Middle Palaeolithic (Holdaway et al., 1996; Hiscock and Clarkson, 2007), the Neolithic (Büller, 1983), and the African Later Stone Age (for example Deacon, 1984). In contrast to the micro-notches discussed here, these earlier studies dealt with larger notches that were retouched to obtain specific shapes necessary for the execution of particular tasks. Furthermore, in these archaeological cases, the notches often represent individual stages in progressive reduction sequences of re-sharpening and recycling. The situation is thus distinctively different at Sibudu where micro-notches occur on small blanks shaped with limited retouch. Only three Sibudu pieces examined in this study have notches with characteristics that overlap with those of the intentionally produced notches in our experiments. Even on these three pieces, the microwear is too ambiguous to allow us to conclude that the notches were deliberately made. Therefore, definite proof of intentional manufacture of micro-notches on quartz in the HP at Sibudu is yet to be found.

Notches have often been assumed to be linked with hafting, generally as a way to facilitate the attachment or securing of bindings (Rots, 2010, 2015), but this issue has never been systematically interrogated at an archaeological site. Ethnographically, the link between notches and hafting is documented (Rule and Evans, 1985; Hall and Fullerton, 1990). Existing evidence mainly concerns larger notches than the ones documented in the analysed assemblage from Sibudu, but for two of the three possibly intentional micro-notches that could be identified, a link with hafting could neither be excluded nor confirmed.

Many quartz micro-notches and other edge damaged pieces in the two archaeological samples from Sibudu could be attributed to accidental causes, mainly knapping. Bipolar knapping in particular seems to produce a variety of macrotraces that can be confused with use-wear.

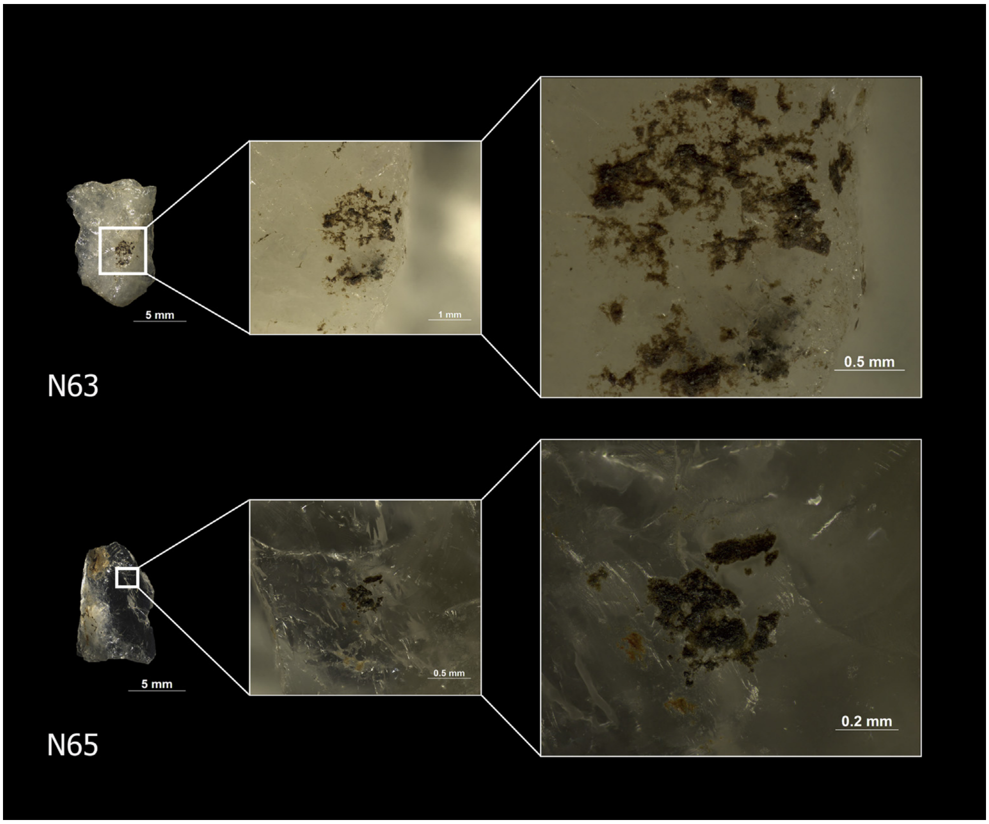

Fig. 22. Resin on archaeological pieces from Sibudu. Top: N63 (sample 1) photographed at 40× and 80×, bottom: N65 (sample 1), photographed at 80× and 180×.

The link between trampling and pseudoretouch, including notches, has been demonstrated in numerous earlier studies (see for example Flenniken and Haggarty, 1977; Vaughan, 1985; Hiscock, 1985; Levi Sala, 1986; McBrearty et al., 1998 among many others). Two recent experiments have involved quartz. Pargeter (2011) reported "smooth semicircular notches" on trampled material but found no knapping-related notches. One of his trampled samples showed notches on 12 out of 50 flakes, whereas the rest of the samples displayed much lower frequencies (Pargeter, 2011: Table 1). Driscoll et al. (2015) did a trampling study involving 386 vein quartz flakes. He noted the difficulty of distinguishing between trampling-related edge damage and flake edge irregularities resulting from knapping. He found edge damage from trampling on 99% of the quartz flakes, but points out that only 1% was truly retouch-like. Interestingly, on this 1% (4 pieces), the pseudoretouch was always notch-like (Driscoll et al., 2015: 7–8). The difference between the frequencies of notches reported in the two studies can probably be at least partly attributed to different definitions of notches. As notches played a minor part in these studies and detailed descriptions or photographs are not provided by the authors, further comparison between their studies and our own is not straightforward. We observed more notches on trampled pieces than Driscoll did. The reason for this may be that our focus was on micro-notches similar to those in the Sibudu material, so we took micro-notches (sometimes formed by a single scar) into consideration. These cannot be mistaken for intentional retouch.

Thanks to the characteristic wear patterns observed in the experimental reference material, we could confidently attribute six of the Sibudu micro-notches to trampling. We consider the combination of heavy crushing or abrasion of the notched edge, randomly oriented linear features, and severe surface cracking in the vicinity of the notch diagnostic of this activity. Also structural notches, which are formed by irregular fracture propagation instead of secondary scarring, form their own distinct group. The rest of the accidental notches, however, are more ambiguous. The experimental material shows that use, knapping, and sometimes trampling can produce notches with overlapping attributes, and in many cases the associated microwear is absent or non-diagnostic. In an attempt to distinguish the different causes it is of crucial importance to pay attention to the overall wear patterns on artefacts.

Finally, some micro-notches proved to be the unintentional result of hafted use, in particular as barbs mounted laterally on the shaft of a hunting weapon. As has been argued elsewhere (Rots and Plisson, 2014), projectiles differ from other tools in that they do not show wear from repeated motions such as scraping or cutting. Wear patterns on projectiles may thus be more variable and consequently difficult to identify. A possible strategy to compensate for this problem is to rely on large samples of tools and to screen them for all possible wear patterns and use activities. In the case of quartz, caution is needed when using micro-scars as functional evidence. Small scars are ubiquitous even on freshly knapped edges due to the brittle nature of quartz (see also Knutsson, 1988). Therefore, archaeological analysis should always be supported by experiments aimed at understanding damage formation processes.

6.2. Barbs mounted on hunting weapons in the HP of Sibudu

Most of previous studies concluded that backed microliths were used to tip HP weaponry (Pargeter, 2007, Pargeter et al., 2016; Lombard and Pargeter, 2008; Wadley and Mohapi, 2008; Villa et al., 2010; Lombard and Phillipson, 2010; Lombard, 2011; but see Villa et al., 2010; Deacon, 1995). Lombard and Pargeter (2008) experimented with replicated segments hafted in four different configurations at the distal extremities of the shafts. Out of 30 experimental segments, one piece developed two 'smooth, semi-circular notches on the cutting edge'. Notches are also mentioned in a use-wear and residue analysis of 16 quartz backed tools from Sibudu's GS layer (Lombard, 2011). Lombard records striations with impact notching on tool 004 where a diagonal orientation is proposed (Lombard, 2011: 1923) and on tool 015, where notching is attributed to the hafting of an armature (Lombard, 2011:1925). The striations are used as evidence that the quartz backed tools from Sibudu were hafted as transverse points at the extremities of shafts. However, the "striations" shown in the pictures and used for arguing the direction of impact are not use-wear, but very common structural features of natural (unused) quartz surfaces that have no bearing on the functional argument (Fig. 23).

In the light of our experimental results, it is worth reassessing the evidence for armature positions and orientations. The quartz tools from Sibudu analysed here show use-wear traces – such as oriented lateral damage associated with MLITs parallel to the cutting edge (Fig. 20b) – which support the interpretation that, perhaps in addition to quartz tips, the HP hunting weapons could have included barbs that were not necessarily always retouched. Sibudu thus provides the earliest evidence for the use of barbs and our argument is supported by a functional experimental programme. The small number of pieces attributed to barb use in our study is in agreement with studies elsewhere (Fullagar, 2016) notwithstanding considerable differences between the sites' components. Experiments involving barbs are limited and they tend to focus on flint (Moss and Newcomer, 1982; Moss, 1983; Crombé et al., 2001; Rots, 2016), or silcrete (Boot, 2005). In several cases, experiments involve barbs mounted on osseous points (e.g., Nuzhnyj, 1989, 2000, Pétillon et al., 2011). Overall, the frequency of impact-related damage on barbs is lower than on tips used in a similar experimental setting (e.g., Crombé et al., 2001; Rots, 2016), and the formation of notches has been reported on some barbs (e.g., Pétillon et al., 2011; Rots, 2016).

Barbs have been identified in more recent European assemblages, made from microliths at Late Palaeolithic sites (Creswellian, Hamburgian, The Netherlands; Rots et al., 2003, 2005) and from geometric microliths at Verrebroek (Mesolithic, Belgium; Crombé et al., 2001). Indubitable evidence for barbs is based on backed blades recovered while still attached to osseous points, such as in a grooved antler point from Pincevent (Magdalenian, France; Leroi-Gourhan, 1983) or various examples from the Mesolithic (see Pétillon et al., 2011 and references therein), or barbs still attached to wooden spears (e.g., Sungir, Russia; Bader and Bader, 2000). The use of retouched bladelets as barbs on osseous points has also been demonstrated through various use-wear studies (e.g., Moss, 1983; Plisson, 1985; Symens, 1986; Keeley, 1988; Geneste and Plisson, 1989; González and Ibáñez, 1993; Ibáñez et al., 1993; Plisson and Vaughan, 2002; Christensen and Valentin, 2004; O'Farrell, 2005; Pelegrin and O'Farrell, 2005; Pétillon et al., 2011). The use of barbs in combination with arrow shafts, osseous points, or wooden spears is thus well demonstrated for the Upper Palaeolithic and the Mesolithic of Europe. Also Australian backed microliths have been interpreted as barbs mounted on spears (Kamminga, 1982; Fullagar, 2016). The use of quartz microliths as barbs has also been proposed, for example, in the Fenno-Scandinavian Mesolithic (Knutsson et al., 2015, 2016).

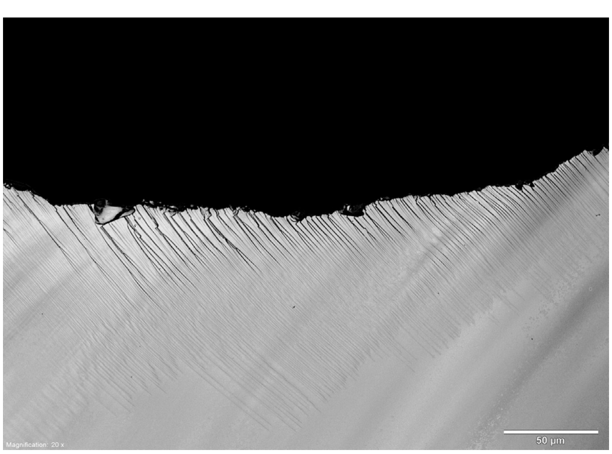

Fig. 23. Natural surface "striations" on an unused and unmodified experimental quartz flake (Exp. 86/59, crystal quartz, 200×, scale bar 50 µm).

The functional relationship between microliths and barbs is a longstanding hypothesis for African Later Stone Age assemblages. Clark proposed it in the light of ethnographical examples from the Kalahari (Clark, 1959: 156) and also archaeological ones from North Africa (Clark, 1975) and these cases are often mentioned in literature on African prehistory (Barham and Mitchell, 2008). However, this hypothesis is rarely evaluated against experimental data. Usually the main argument for the presence of barbs as part of weaponry is the identification of mastic. As examples we mention the Makwe industry from Zambia (Phillipson, 1976), southern African Later Stone Age examples (Deacon, 1966, 1976:70, 61) and early Later Stone Age examples from various sites (Barham and Mitchell, 2008). Southern African Middle Stone Age adhesives are known from Diepkloof (Charrié-Duhaut et al., 2013), Sibudu (for example, Delagnes et al., 2006; Lombard, 2011; Wadley et al., 2009; Villa et al., 2015; Rots et al., 2017) and Apollo 11 (Wendt, 1976), but these are sometimes on tools made from raw materials other than quartz. On the basis of ethnographic analogies (Stow, 1905: 71; Clark et al., 1974; Clark, 1975), the presumption usually is that in most Middle Stone Age and Later Stone Age contexts, microliths tipped arrows (e.g. Brown et al., 2012) or spears (Deacon, 1995; Soriano et al., 2007; Villa et al., 2010), though Villa et al. (2010), and Deacon (1995) mention the possibility of backed tools acting as barbs in the HP at Klasies River. In Middle Stone Age assemblages, there are microlithic backed blades for example in the Lupemban assemblage at Twin Rivers, Zambia (circa 265 Kyr), but these backed tools may not have been hafted (Barham, 2013). Backed flakes and blades are more likely to have been hafted in assemblages of the younger (130-105 Kyr) Mumbwa Caves, Zambia (Barham, 2013). In East Africa, Naisiusiu Beds at Olduvai Gorge (Manega, 1993), Enkapune Ya Muto (Ambrose, 2002) and Mumba rock shelter (Gliganic et al., 2012) have much younger backed microliths. The first two sites have an age of >45 Kyr, whereas for Mumba a 57±5Kyr OSL date has been proposed. Moreover, in Pinnacle Point (PP5-6) backed microliths were recovered from the 71-60 Kyr layer SADBS (Brown et al., 2012). These backed pieces from SADBS were tentatively interpreted as arrow tips or atlatl tips (Brown et al., 2012). However, only typometric comparisons with ethnographical and/or more recent prehistoric examples have been used as an argument until now, and no experimental programmes have been carried out to test the different functional hypotheses. For this reason, we present one of the strongest and oldest bodies of evidence for the use of barbs on projectile weapons, in spite of their scarcity in the analysed sample. Their low frequency should not be taken as an argument for their lack of importance in the archaeological record, because the frequencies are, above all, a consequence of the very specific selection of pieces examined in this study. After all, the study was originally designed to investigate the functional meaning of micro-notches, and potential barbs were not sought during tool selection. Furthermore, if found in isolation, only a small number (9/39, or 23%) of our experimental specimens would be identified as barbs following the criteria for wear patterns used in this study. This suggests that even if barbs are abundantly present, only some of them will be identifiable in an archaeological assemblage. In addition, many may be lost in the carcass during the hunting event or they may explode in several undiagnostic fragments upon impact.

6.3. The use of unretouched blanks

The identification of unretouched blanks as barbs based on use-wear is important. The evidence implies that HP weaponry was much more varied than previously imagined. Backed pieces, which have attracted most attention in the HP technocomplex, may have been used as single weapon elements or in combination with others including unretouched pieces mounted as barbs in a composite weapon. Any unretouched blank, including bladelets, flakes or bipolar blanks (like some from Sibudu's sample 2), could potentially have been used as hunting weapon components by HP people. Unretouched blanks found in early Later Stone Age assemblages in southern Africa were similarly interpreted (Mitchell, 1988). The interpretation is supported by the evidence for death spears in Australia; here various unretouched quartz blanks are hafted as barbs (Roth, 1899; Kamminga, 1982). For the Scandinavian Mesolithic, it has been shown that unmodified quartz flakes produced through simple reduction techniques (such as bipolar knapping) were used instead of, or side by side with, flint blades and microliths produced using more complex methods. This way, the postglacial hunter-gatherers who arrived in areas where easily knappable cryptocrystalline rocks were nearly absent could maintain their slotted bone tool technology simply by adjusting their strategy for producing lithic insets (Knutsson et al., 2016 and references therein). Equally, the convenience of using unretouched blanks as barbs may explain why quartz at Sibudu was so intensely reduced.

It has recently been suggested that bipolar reduction cannot be explained only by a need to recycle cores because the technique was used in environments where quartz was abundant. Other reasons can be suggested: one of these is the possibility of producing high frequencies of thin, intact flakes, and flakes of more even thickness than is possible using platform reduction (Manninen, 2016). Following this reasoning, the explanation for the use of bipolar reduction at Sibudu (de la Peña and Wadley, 2014a,b; de la Peña, 2015b) may be twofold; it served as a strategy to maximise the use of cores on small nodules, and simultaneously allowed the effortless production of evenly thin blanks suitable for implements such as barbs.

Our discovery reinforces the idea that in the Sibudu HP quartz was a highly valued raw material that was intensively exploited for making bifacial quartz pieces (de la Peña et al., 2013), backed pieces (Delagnes et al., 2006; Lombard, 2011) and unretouched blanks (de la Peña, 2015a,b and this study). There may be multiple reasons for choosing quartz: 1) it has the advantage of yielding a considerable amount of high quality cutting edge easily (flaking, bipolar reduction) from small, locally available nodules (Pargeter and de la Peña, 2017); 2) a bipolar strategy is advantageous for the production of small, thin blanks directly usable as barbs; 3) quartz is brittle and sharp (de la Peña et al., 2013); 4) and often shatters upon impact into multiple small fragments that amplify haemorrhaging when used as weapon components.

Barb manufacture is simple; generally, a sharp edge and a relatively thin blank are sufficient to increase bleeding upon prey penetration. It is therefore not unexpected that informal implements as well as formal points or backed artefacts are used for constructing hunting weapons. The selection of quartz for use in composite hunting weapons continued into the recent past and is described, for example, in the South African and Australian ethnographic literature (Goodwin, 1945; Flood, 1980).

7. Conclusion

The functional analysis of the quartz artefacts with micro-notches identified during the technological study of Sibudu's HP assemblage demonstrates that the purely technological category of ‘micro-notch’ is a byproduct of various technological, post-depositional and functional processes. This study showed that at least three and possibly as many as 15 of the micro-notched pieces in Sibudu's sample 1 are implements or fragments that were once hafted as barbs on hunting weapons. None of these pieces can be considered formal tools, but the expansion of the sample also to include segments, oblique backed points, bipolar blanks, bladelets and various fragments (Sibudu sample 2, pieces without micro-notches) allowed us to identify a further four certain and 17 tentative barbs in the assemblage. Therefore, we propose that quartz barbs were part of the HP hunting weaponry. Our findings constitute one of the strongest and oldest bodies of evidence for the use of barbs as projectiles in prehistory. In the future, more attention should be paid to unretouched lithics, because unmodified quartz blanks seem to have played an important role in the HP hunting kit, although they have so far been sidelined by the focus on backed pieces.

Our results also show that it is important to be aware of equifinality in macrotrace formation, especially in the case of quartz, which is characterised by markedly brittle edges and irregular fracture patterns. By incorporating experiments on production, retouching, hafting, use and trampling within a single study, we managed to explain the presence of micro-notches in the Sibudu assemblage. We could also offer macroscopic and microscopic criteria for the interpretation of similar notches in other assemblages despite certain overlap between traces resulting from different activities. This illustrates that an approach which builds on a preliminary functional screening of the archaeological material and subsequent targeted experimentation is a fruitful approach when analysing quartz assemblages.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at https://doi.org/10.1016/j.jas.2018.03.001.

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