



Exploring use-wear on Wommersom quartzite: petrographic, experimental and archaeological perspectives[☆]

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ABSTRACT

Wommersom quartzite (WSQ) is a distinctive lithic raw material from a single geological source in Belgium that was widely distributed across northwest Europe during the Mesolithic. Although its procurement, typology and circulation have been extensively studied, the functional role of WSQ tools has remained largely unexplored, and no use-wear reference framework exists for this raw material. This study began with observations made during functional screening of the Mesolithic site of Diepenbeek-Molenstraat: the macroscopic edge damage and impact-related fractures on some of the WSQ artefacts closely resembled wear documented on flint. This raised the methodological question that frames the paper: can the attribute systems used to identify use-wear and projectile damage on flint be useful in the study of WSQ, and if so, what material-specific adjustments are needed? Because no reference existed, an exploratory experiment was needed to assess how WSQ responds to use. WSQ and Harmignies flint flakes were used with similar gestures to process bramble (*Rubus fruticosus*), chosen for its potential to produce macroscopic edge damage and microwear. Analysis began with low-magnification stereo-microscopy, matching the original archaeological observation, and was extended to incident-light and SEM microwear characterisation, with petrographic analysis providing an explanatory basis for the observed wear. The study establishes that flint attribute systems can be applied to WSQ macroscopically with only minor adjustments, whereas microwear characterisation requires a framework closer to that used for macrocrystalline quartz. These preliminary results provide a first methodological basis to be tested and refined through further functional studies of WSQ assemblages.

1. Introduction

Wommersom quartzite (WSQ) has attracted archaeological interest for more than a century due to its distinctive geological provenance and widespread use during the Mesolithic in northwest Europe (de Loë & Raeymaekers, 1902). WSQ originates from the early Eocene Tienen Formation and is macroscopically distinct from other locally available lithic resources (Goemaere et al., 2024), including Campinian and Maastrichtian flint. In petrographic terms, WSQ is a pedogenetic silcrete assimilable to an orthoquartzite (Cnudde et al., 2013; Goemaere et al., 2024), and is referred to throughout this paper by its traditional

archaeological designation *Wommersom quartzite*.

The material derives from a single known outcrop at the Steenberg in Wommersom, central Belgium, where fine-grained orthoquartzite occurs in the form of flattened slabs or plaquettes, typically not exceeding 10 cm in thickness (Fig. 1) (Goffin-Cabodi, 1985, cited in Di Modica, 2011). When first scientifically described, WSQ was reported as nodules enclosed within sandstone since at least the 20th century (de Loë & Raeymaekers, 1902). However, the in-situ outcrop is no longer exposed, and the raw material is currently recoverable only as individual fragments brought to the surface by ploughing in the immediate vicinity of the Steenberg (Blomme et al., 2012). Mesolithic procurement is

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generally considered to have taken place directly at the Steenberg, where plaquettes were collected from surface or near-surface exposures, and is therefore treated as primary in the present study (Cnudde et al., 2013; Noens & Van Baelen, 2019; Goemaere et al., 2024). Although additional sources have occasionally been hypothesised, none have yet been archaeologically confirmed (Blomme et al., 2012; Cnudde et al., 2013; Noens & Van Baelen, 2019; Goemaere et al., 2024). The occurrence of WSQ in secondary contexts, such as the gravel beds of the Meuse, has been debated and is not generally considered to reflect natural redeposition (Noens & Van Baelen, 2019, with references therein).

Because of its restricted provenance and wide spatial distribution, WSQ has long been regarded as a key diagnostic raw material, sometimes described as a Mesolithic “chrono-cultural marker” in Belgium and adjacent regions (Veldeman et al., 2012; Noens & Van Baelen, 2019). From the Early Mesolithic onward, WSQ was increasingly exploited and circulated across a vast territory across present-day Belgium, the Netherlands, central and northern France, Luxembourg, and western Germany (Rozoy, 1978; Gendel, 1984; Crombé, 1996; Robinson et al., 2010; Noens & Van Baelen, 2019). While the Rhine appears to delimit its eastern distribution, major river systems such as the Scheldt and the Meuse likely facilitated its movement (Perdaen et al., 2009; Robinson et al., 2013). This extensive circulation has frequently been interpreted as evidence for regional mobility, long-distance transfer networks, and sustained social connectivity among Mesolithic groups (Gendel, 1984; Amkreutz, 2013; Robinson et al., 2010).

Typological and technological studies have documented consistent patterns in WSQ use across sites and time periods. Huyge (1987) identified a clear chronological shift in exploitation patterns: during the Early Mesolithic, intensive WSQ use remained concentrated within approximately 25 km of the source, while Middle and Late Mesolithic assemblages show substantial WSQ frequencies at distances exceeding 60 km. Sites with exceptionally high WSQ content consistently exhibit overwhelming dominance of microlithic elements in their tool assemblages, interpreted as specialised workshops for hunting armature production (Huyge, 1987; Gendel et al., 1985; Lauwers et al., 1986). Systematic analysis reveals differential raw material selection for specific armature types, with certain trapeze forms showing markedly higher WSQ frequencies than others within the same assemblages (Huyge & Vermeersch, 1982). For the Early Mesolithic, Crombé et al. (2003) documented similarly structured patterns in the Scheldt basin, with WSQ predominantly employed in assemblages dominated by obliquely truncated points and segments but occurring less frequently in scalene triangle assemblages. While assemblage composition and technological characteristics suggest intensive WSQ use for projectile manufacture, direct functional evidence to support this interpretation

remains lacking.

Research on WSQ has focused primarily on procurement strategies, typology, and distribution patterns, while its functional role in Mesolithic toolkits remains unexplored. To date, no dedicated use-wear studies have been conducted on WSQ artefacts, and no experimental reference framework exists for characterising wear formation on this material. The applicability of functional analysis methods, including attribute-based fracture identification for projectile armatures, has not been systematically tested on WSQ. Although WSQ is recognised as a high-quality knappable stone with mechanical properties often considered broadly comparable to flint (Di Modica, 2011), the lack of understanding regarding wear formation has practical consequences. During screening of large archaeological assemblages predominantly composed of flint, the relatively few WSQ tools present are often excluded from detailed functional analysis. This highlights the need to better understand how use-wear develops on fine-grained quartzite materials such as WSQ, and how wear formation differs from that observed on flint when tools are used under comparable conditions.

Addressing this gap requires establishing whether analytical frameworks developed for other materials can be effectively adapted to WSQ. The need for raw material-specific reference frameworks is well-established in use-wear research. Wear formation is strongly conditioned by physical and mechanical properties including mineral composition, grain size, cementation, and fracture behaviour (e.g. Clemente Conte, 1997; Astruc et al., 2001), requiring tailored analytical strategies for quartz-rich materials (e.g. Knutsson, 1988; Fernández-Marchena & Ollé 2016; Pedergrana & Ollé 2017; Pedergrana et al., 2020; Pedergrana et al., 2016, 2018; Ollé et al., 2016; Taipale & Rots 2019; Lundin et al., 2025). Recent systematic experimental work has demonstrated that while analytical frameworks developed for flint can be adapted to quartzite, material-specific considerations remain essential. Pedergrana et al. (2016) established that quartzite surfaces develop polish and striations at different rates than flint, and that continued use may progressively obliterate earlier wear through cumulative micro-chipping. Ollé and Vergès (2014) demonstrated through extensive experimentation that quartzite preserves diagnostic use-wear traces, though preservation trajectories differ from those observed on fine-grained flint. These studies emphasize that successful functional analysis requires understanding material-specific wear development patterns rather than assuming direct transferability from flint-based frameworks.

The present study originated from an empirical observation made during functional screening of the Mesolithic site of Diepenbeek-Molenstraat. The macroscopic edge damage and impact-related fractures on some WSQ artefacts appeared to closely resemble those on the flint elements from the same assemblage, raising the methodological



Fig. 1. Two pieces of Wommersom quartzite (WSQ) collected at the source area in central Belgium, approximately 10 cm in maximum dimension.

question that frames this paper: can the attribute-based use-wear and projectile damage frameworks developed for flint (e.g. Tringham et al., 1974; Keeley and Newcomer 1977; Hayden 1979; Keeley 1980; Moss and Newcomer 1982; Plisson 1985; Jensen, 1994; Coppe and Rots, 2017) and macrocrystalline quartz (e.g. Knutsson, 1988; Knutsson et al., 2015, Taipale & Rots 2019) be employed to characterise wear on WSQ, and what material-specific adjustments are required to reach reliable results?

To this end, geological samples of Wommersom quartzite (WSQ) were characterised petrographically in order to contextualise observed patterns of wear development and to explore the potential influence of microstructural properties on use-wear formation. In parallel, a small experimental programme was conducted in which WSQ and flint flakes were used to process *Rubus fruticosus* (bramble). The paper follows the actual research workflow. It opens with the first observations on the Diepenbeek-Molenstraat assemblage that motivated the study, then sets out the rationale of the experimental programme. Plant processing was selected as a well-documented activity that allows close observation of early-stage wear development and facilitates detailed comparison of edge damage and scar formation across raw materials, together with an assessment of microwear formation. Flint was included not as a normative reference, but as a point of comparison to contextualise material-specific differences in wear formation. Further parallels were drawn from published results on microwear on quartz and quartzite (e.g. Knutsson 1988, Ollé & Vergès 2014, Knutsson et al., 2015, Pedergrnana & Ollé 2017, Pedergrnana et al., 2017a). The dataset presented here is exploratory in scope, limited in worked-material range, use durations, and gestures. A broader programme, covering additional contact materials, longer use durations, and dedicated projectile experiments on WSQ, is discussed in the final section of the manuscript as the necessary next step.

Together with these preliminary results, the study aims to lay the groundwork for future functional analysis of WSQ assemblages, clarifying both the potential and the limits of applying established analytical frameworks to this archaeologically significant but functionally

underexplored raw material.

2. Archaeological context

The Mesolithic site of Diepenbeek-Molenstraat, located in the Demer basin (Belgium) (Fig. 2), represents a key archaeological context for investigating lithic technology and raw material use in the region. It is the only large Mesolithic site identified in the basin, with more than 20,000 lithic artefacts recovered across five excavation areas, covering a total surface area of 373.5 m² (see Fig. 3). Excavations were conducted under the framework of preventive archaeology and revealed a substantial prehistoric occupation, although much of the site had been disturbed by Iron Age and later agricultural activity (Devriendt and De Herdt, 2024).

From a typo-technological perspective, the assemblage is heterogeneous and reflects a multiphase occupation. Flint is the dominant raw material (~83%), followed by WSQ (WSQ, ~16%) and Tienen quartzite (TQ, ~1%) (see Table 1) (Devriendt and De Herdt, 2024).

The tool component accounts for 2.39% of the total assemblage (n = 499) and includes a wide range of artefact types. As is typical of Mesolithic sites, potential projectile armatures represent a significant portion of the tool inventory (33%), dominated by microliths, especially micropoints. Notably, approximately one-third of these microliths were made from WSQ, while TQ was not used for microlith production (see Table 2). The remaining tools categories (e.g., scrapers, borers, burins, retouched flakes and blades) show a slightly lower frequency of WSQ use (~23%), possibly reflecting different functional or chronological associations (see Table 3). A small number of tools may date to the Neolithic, as suggested by diagnostic artefacts such as polished axe fragments and bipolar pieces.

The chronological span of the Diepenbeek assemblage adds further complexity. Based on microlith typology, elements from the Early, Middle, and Late Mesolithic are all present. Key Early Mesolithic groups such as Neerharen, Verrebroek, and Ourlaine are identified based on dominant microlith types (e.g., points with unretouched bases, triangles,

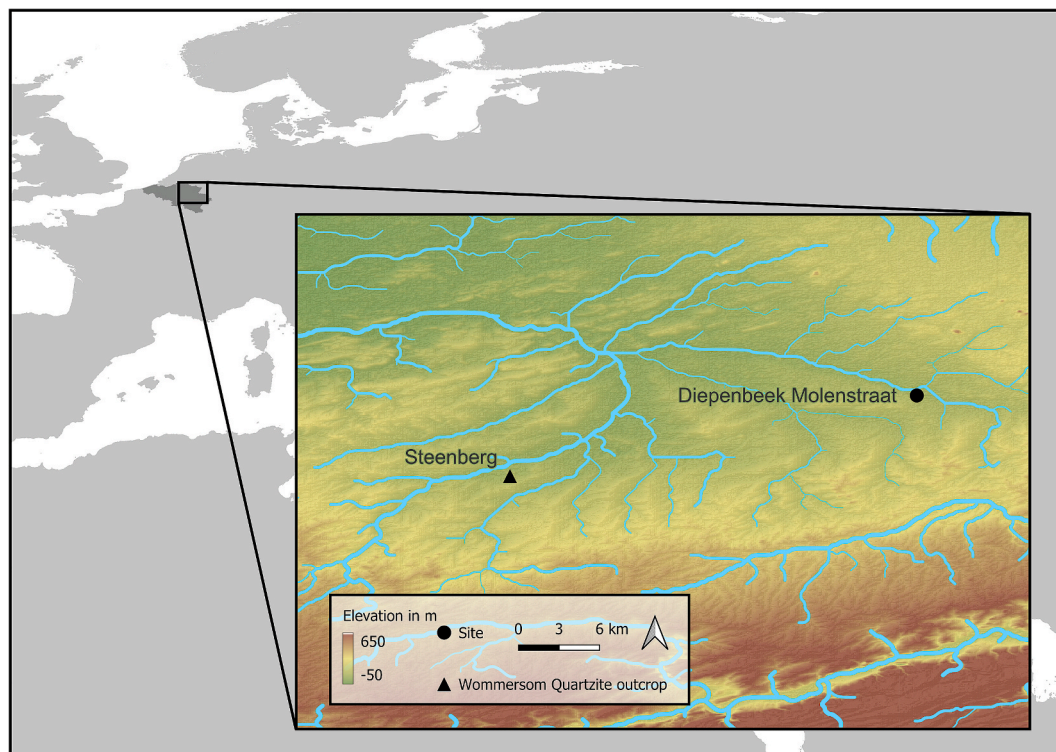


Fig. 2. Map showing the location of the Mesolithic site of Diepenbeek Molenstraat within the Demer Basin (eastern Flanders), in relation to the known WSQ outcrop at Steenberg (© Marcel Schemmel).

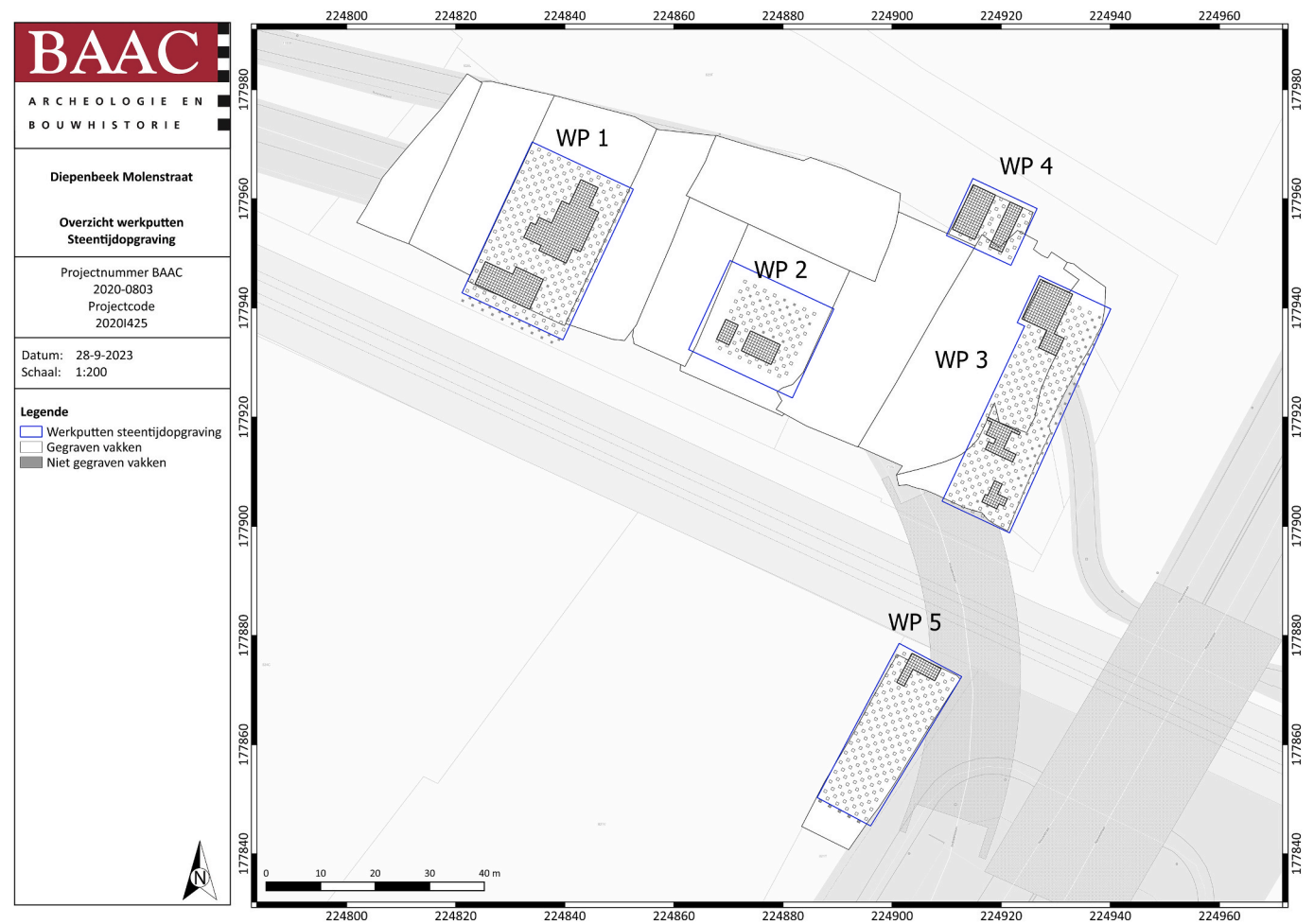


Fig. 3. Location of the excavation trenches at Diepenbeek Molenstraat.

Table 1
Composition of the archaeological assemblage according to raw material.

Artefact category	Flint	Flint %	WSQ	WSQ %	TQ	TQ %	Total	Total %
Chips	12.735	73,3%	2.110	64,5%	120	60,6%	14.965	71,8%
Flakes	2.747	15,8%	499	15,3%	46	23,2%	3.292	15,8%
(Micro)blades	869	5,0%	401	12,3%	25	12,6%	1.295	6,2%
Cores	34	0,2%	8	0,2%	1	0,5%	43	0,2%
Core rejuvenation	122	0,7%	68	2,1%	5	2,5%	195	0,9%
Fragments	257	1,5%	12	0,4%	0	0,0%	269	1,3%
Potlids	165	0,9%	0	0,0%	0	0,0%	165	0,8%
Tools	359	2,1%	114	3,5%	1	0,5%	474	2,3%
Tool production waste	61	0,4%	57	1,7%	0	0,0%	118	0,6%
Nodules/frost flakes	25	0,1%	0	0,0%	0	0,0%	25	0,1%
TOTAL	17.374	100,0%	3.269	100,0%	198	100,0%	20.841	100,0%
% of assemblage	83,36%		15,69%		0,95%			

segments). These correspond to calibrated dates ranging from ca. 8700/8500 to 7500 cal BC, spanning the Late Preboreal to the Boreal. Middle Mesolithic elements, such as narrow microblades with blunted edges, are common across the site and could belong to typological groups such as Sonnissee Heide or Gelderhorsten. Although these types are usually associated with Middle Mesolithic contexts, their presence in Early Mesolithic clusters elsewhere (e.g., Beveren LPWW) raises the possibility that they appeared earlier and are not necessarily intrusive.

Overall, the assemblage is best placed within a Mesolithic framework based on raw material use and techno-typological composition. Early Mesolithic microlith types occur in varying proportions across all excavated zones, while narrow backed microblades, typically attributed

to the Middle Mesolithic, likely have an earlier appearance as well. Indications of Late Mesolithic activity are also present, including a trapeze and several large, regularly produced (micro)blades. However, this blade production technique continued into the Neolithic, from which several index artefacts are also documented at the site. As a result, it remains difficult to assign individual finds securely to specific occupational or use phases (Devriendt and De Herdt, 2024).

This interpretative uncertainty is further compounded by the significant mixing of materials in the upper layers, which prevents secure stratigraphic attribution of individual artefacts to discrete occupation phases and hampers efforts to identify activity areas or temporal changes in site use (Devriendt and De Herdt, 2024).

Table 2
Microliths according to raw material.

Microlith category	Flint	Flint %	WSQ	WSQ %	Total	Total %
MICROLITHS/MICROPOINTS						
Point with backed edge (A point)	9	8,0%	2	4,1%	11	6,8%
Point with oblique truncation (B point)	11	9,7%	2	4,1%	13	8,0%
Point with retouched base (C point)	8	7,1%	0	0,0%	8	4,9%
Triangle	16	14,2%	13	26,5%	29	17,9%
Segment	7	6,2%	0	0,0%	7	4,3%
Sauveterre point	1	0,9%	0	0,0%	1	0,6%
Trapezoidal point	1	0,9%	0	0,0%	1	0,6%
Narrow microblade with backed edge	5	4,4%	14	28,6%	19	11,7%
Triangular narrow microblade	1	0,9%	1	2,0%	2	1,2%
Trapeze	1	0,9%	0	0,0%	1	0,6%
Undetermined microlith type	4	3,5%	1	2,0%	5	3,1%
Undetermined microlith fragment	45	39,8%	16	32,7%	61	37,7%
OTHERS						
Tanged arrowhead	3	2,7%	0	0,0%	3	1,9%
Undetermined fragment	1	0,9%	0	0,0%	1	0,6%
TOTAL	113	100,0%	49	100,0%	162	100,0%
% of microlith assemblage	69,75%		30%			

Table 3
Typological composition by raw material type.

Tool type	Flint	Flint %	Wommersom	Wommersom %	Total	Total %
SCRAPERS						
Endscraper	16	6,5%	2	3%	18	5,8%
Scraper fragment	4	1,6%	0	0,0%	4	1,3%
BURINS & BORERS						
Burin	1	0,4%	1	1,5%	2	0,6%
Multiple burin	2	0,8%	0	0,0%	2	0,6%
Borer	4	1,6%	2	3,1%	6	1,9%
TOOLS ON FLAKE, (MICRO)BLADE & REJUVENATION FLAKE						
Retouched flake	32	13,0%	0	0,0%	32	10,3%
Denticulated flake	1	0,4%	0	0,0%	1	0,3%
Notched flake	3	1,2%	1	1,5%	4	1,3%
Truncated flake	4	1,6%	0	0,0%	4	1,3%
Retouched (micro)blade	22	8,9%	7	10,8%	29	9,3%
Notched (micro)blade	3	1,2%	2	3,1%	5	1,6%
Truncated (micro)blade	9	3,7%	1	1,5%	10	3,2%
(Micro)blade broken above notch	6	2,4%	3	4,6%	9	2,9%
(Micro)blade broken in notch	8	3,3%	4	6,2%	12	3,9%
Retouched rejuvenation piece	5	2,0%	5	7,7%	10	3,2%
Truncated rejuvenation piece	2	0,8%	0	0,0%	2	0,6%
Modified core	0	0,0%	3	4,6%	3	1,0%
Modified fragment	0	0,0%	1	1,5%	1	0,3%
VARIOUS						
Polished axe fragment & polished flake	12	4,9%	0	0,0%	12	3,9%
Blade point	1	0,4%	0	0,0%	1	0,3%
Bipolar piece	3	1,2%	0	0,0%	3	1,0%
Rounded piece	1	0,4%	0	0,0%	1	0,3%
Hammerstone	1	0,4%	0	0,0%	1	0,3%
Undetermined tool fragment	64	26,0%	11	16,9%	75	24,1%
TOTAL	204	100,0%	43	100,0%	247	100,0%

3. First observations on the Diepenbeek-Molenstraat assemblage

Functional study of the Diepenbeek-Molenstraat lithic assemblage was initially approached by macroscopic screening of all artefact categories, with particular attention to the projectile component. During this screening phase, a striking observation was made: the macroscopic edge damage and impact-related fractures observed on the WSQ projectile elements appeared to closely resemble those observed on the flint projectile elements from the same assemblage. Bending breaks with long propagation phases, oriented lateral scarring, and secondary damage

were present on both raw materials, with broadly similar morphology and distribution. This empirical observation raised a methodological question that motivated the present study: can the attribute systems used to identify projectile damage on flint be adapted to WSQ, and if so, are there material-specific adjustments to make?

A parallel observation concerned the broader assemblage. A subset of artefacts in both flint and WSQ presented edge damage suggestive of a range of domestic activities involving different worked materials and gestures. The macroscopic appearance of this damage on WSQ was, again, comparable to that observed on flint tools used for similar tasks.

This suggested that the convergence in damage formation between the two raw materials was not specific to projectile use, but extended also to tools used in repetitive motion on different contact materials. Together, these observations defined the empirical baseline against which the present study was designed: WSQ and flint appear macroscopically to develop similar wear, but no controlled reference exists for WSQ on which to base this interpretation.

4. Methods and materials

4.1. Geological characterisation

Geological characterisation of Wommersom quartzite (WSQ) from archaeological artefacts and geological samples was carried out using SEM–EDS following the methodology described by Blomme (2012), complemented by high-magnification binocular stereomicroscopy under water ($\times 100$). Mineralogical and microfacies features were examined with SEM using low-voltage secondary electron detection, with particular focus on the diagnostic matrix of WSQ, characterised by larger mineral grains embedded within a fine-grained silica matrix. In addition, mineral inclusions such as rutile (titanium oxide) and zirconium were identified in accordance with the analytical approach outlined by Blomme. These analyses were undertaken to improve understanding of the fracture behaviour of the rocks, and the observations largely confirmed the results of the multi-proxy petrographic study by Cnudde et al. (2013), which suggested a pedogenetic origin for these orthoquartzites.

4.2. Archaeological sample selected for functional analysis

The functional analysis was carried out on a sample, representative of the entire Diepenbeek-Molenstraat assemblage. Following the macroscopic screening described above, a first selection of 419 potentially used tools was retained for use-wear analysis. This selection comprised both unretouched artefacts (flakes, blades, and microblades) and retouched tools, and was drawn from across the raw material spectrum of the site, with 75 pieces made from Wommersom quartzite (WSQ) (see Table 4). Artefacts were selected on the basis of macroscopically observable edge damage. Because the WSQ component of the assemblage is comparatively small, all WSQ artefacts displaying potential use traces were included, allowing a direct comparison with the more numerous flint tools processed under the same analytical protocol.

4.3. Experimental programme

An exploratory experimental programme was designed to examine how use-wear develops on WSQ during plant-processing activities. Bramble (*Rubus fruticosus*) was selected as a worked material because its use in experimental studies is well documented and its mechanical and mineralogical properties have been investigated previously (e.g. Tomasso et al., 2024), allowing a clearer assessment of early-stage wear development. As a woody plant, *Rubus fruticosus* exhibits structural characteristics typical of relatively hard plant materials and forms part of the botanical spectrum documented for the Mesolithic in Belgium (Deforce et al., 2014). Previous analyses have shown that this species does not contain silica minerals; instead, it is characterised by the presence of calcium oxalate crystals (COCs) in the phloem, although

their overall abundance is very low (Tomasso et al., 2024) (see Fig. 4). These properties provide a well-defined basis for assessing the influence of plant structure and mineral content on wear formation.

Within this framework, a total of 13 experimental tools were employed to investigate the development of use-wear traces (see Tables 7 and 8), thereby including both WSQ (Table 5) and Harmignies flint (Table 6). The flint flakes were included in the experimental programme to provide a comparative reference for the visual assessment of wear development and to examine differences in wear formation between two raw materials that co-occur in the studied archaeological assemblages. The experimental activities were designed to replicate realistic tool use and plant-working motions and included transversal motions mainly. For WSQ, five tools were used in activities ranging from 25 to 66 min (see Table 5, Fig. 6), predominantly to remove the thorns or to debark the stems. The WSQ used for the experimental programme was provided by Nick Van Lieferringe (Studiebureau Archeologie) and originates from the immediate vicinity of the Steenberg outcrop in Wommersom, i.e. from the primary source area itself. As the in-situ outcrop is no longer exposed (Blomme et al., 2012), the material was collected as surface fragments brought up by ploughing in the fields surrounding the Steenberg. Blanks were produced by direct percussion with a sandstone hammer from plaquettes with a maximum thickness of 10 cm (see Fig. 5), reflecting the constraints on blank size that characterise WSQ throughout its prehistoric exploitation.

The Harmignies flint used as a comparative reference was obtained from the Harmignies quarry (Hainaut, Belgium), a well-documented Late Cretaceous flint source widely used as an experimental reference at TraceoLab. Eleven Harmignies flint tools were employed for transversal and longitudinal motions, with use durations ranging from 20 to 60 min (Table 6) (Fig. 7). This variation in duration and motion aimed to permit recording the development and variation of microscopic wear patterns relative to both activity type and raw material. Tool motions and working angles were recorded using established terminologies defined in previous experimental and functional studies (Gassin 1994, 1996; Guéret, 2013b; Guéret et al., 2014; Mazzucco et al., 2016).

4.4. Analytical protocol

After use, all experimental tools were carefully cleaned using an ultrasonic bath for 10 min with a neutral, phosphate-free detergent to remove the plant residues adhering to the surface, followed by treatment with a 3% hydrochloric acid (HCl) solution to eliminate the remaining residues. The artefacts were then thoroughly rinsed with tap water to remove any residual deposits (e.g., Evans and Donahue 2005; Jensen 1994; Ollé and Vergès 2008; Asryan and Rots 2024).

The archaeological artefacts from the wetland site of Diepenbeek were not yet subjected to any cleaning procedures, as organic residues were exceptionally well preserved due to the waterlogged conditions. These residues are being directly studied on the artefact surfaces to ensure the integrity of the preserved material. As attention was only focused on the macroscopic component here for the part of the use-wear analysis, no intensive cleaning was required.

The difference in cleaning protocols between the experimental and archaeological components is not considered to affect the present analysis. Identification of impact-related fractures relies on macroscopic and low-magnification stereoscopic observation of fracture morphology (initiation, propagation, termination, fissuring), features which are not obscured by the residues preserved on the archaeological artefacts. Polish development and microwear, which are more sensitive to surface contamination, were the focus of the experimental analysis and were therefore systematically observed only on cleaned experimental tools. A comparable cleaning protocol will be required for any future microwear analysis of the Diepenbeek artefacts beyond the projectile component reported here.

To document the formation of wear traces on both the experimental and archaeological artefacts, a combination of stereomicroscopic

Table 4
Use-wear analysis of the Diepenbeek-Molenstraat assemblage: selection and attribution.

Analytical stage	Flint	WSQ	Total
Tools selected for analysis	344	75	419
Tools displaying functional use-wear traces	60	21	81
Tools with a functional attribution	45	10	55

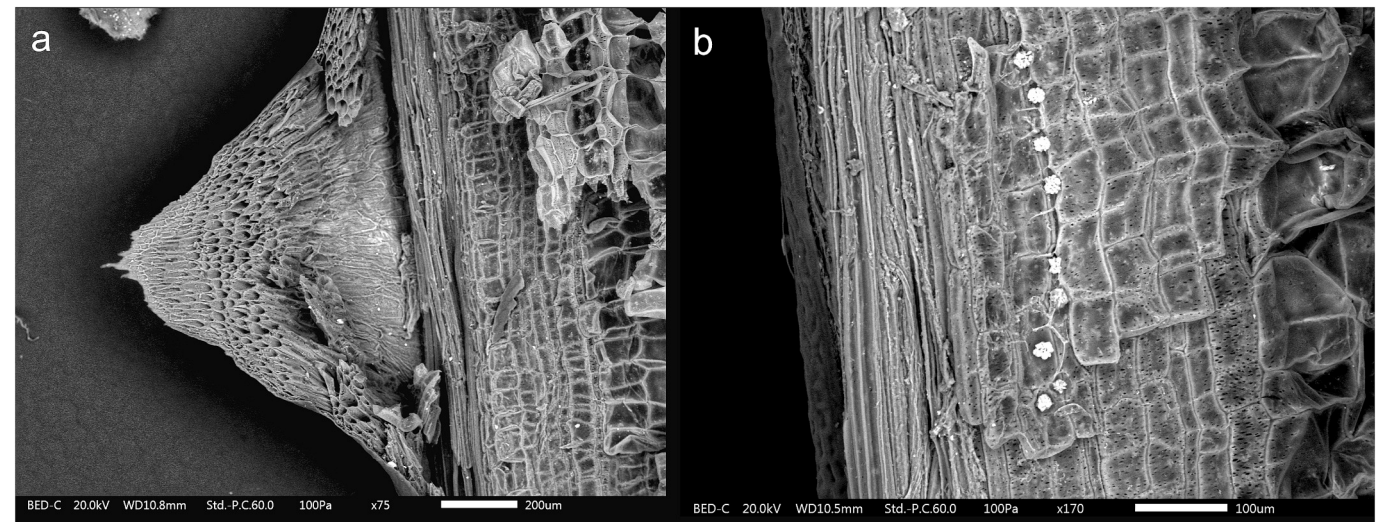


Fig. 4. Location of calcium oxalate crystals in a and b in the phloem of *Rubus fruticosus*.

Table 5
Experimental setup for the Wommersom quartzite (WSQ) tools (n = 5). For each tool, the table indicates the contact area on the tool, the working angle, the worked material, the use motion, the task performed, the use duration in minutes,

Raw material	Wommersom quartzite				
Tool ID	110/173	110/174	110/175	110/176	110/180
Worked material	<i>Rubus fruticosus</i>				
Contact area	left edge	right edge	right edge	right edge	left edge
Working angle	20–35°	45–90°	20–35°	20–35°	90°
Use motion	transverse	transverse, longitudinal	transverse	transverse	transverse
Task	removing thorns	removing thorns, debarking, splitting, cutting	removing thorns	removing thorns	removing thorns, debarking
Use duration	28'	66'	25'	32'	25'
Prehensile mode	hafted	hafted	hafted	hafted	hand-held

Table 6
Experimental setup for the Wommersom quartzite (WSQ) tools (n = 5) used on bramble stems (*Rubus fruticosus*). Working angles are measured relative to the worked surface. Use duration in minutes.

Raw material	<i>Harmignies flint</i>							
Tool ID	110/91	110/92	110/131	110/134	110/135	110/136	110/137	110/138
Worked material	<i>Rubus fruticosus</i>							
Contact area	right edge	left edge	left edge	right edge	distal part	right edge	distal and right edge	distal and right edge
Working angle	90°	90°	20–35°	20–35°	20–35°	20–35°	20–35°	20–35°
Use motion	transverse	transverse, longitudinal	transverse, longitudinal	transverse	transverse	transverse, longitudinal	transverse	transverse
Task	removing thorns	splitting	splitting	debarking	removing thorns, debarking	removing thorns, debarking, cutting	removing thorns, debarking	removing thorns, debarking
Use duration	60'	60'	20'	25'	24'	29'	36'	40'

observation (Zeiss Discovery V12 with an oblique external light source, magnifications up to $\times 100$) and incident light microscopy (Zeiss Axio Imager.M2m metallurgical microscope, magnifications $\times 50$ – $\times 1000$) was used to examine microscopic wear (e.g., Knutsson, 1988; Keeley, 1980; Odell & Odell-Vereecken, 1980; Tringham et al., 1974). Further, some of the observed wear was examined with a JEOL IT300 scanning electron microscope (SEM).

Edge damage was documented using standard damage attributes, such as initiation, propagation and termination derived from experimental edge-damage studies (e.g. Hayden, 1979). Microwear analysis on the experimental tools was conducted following frameworks developed for flint (after Jensen, 1994) and quartz (after Knutsson, 1988). Due to

differences in raw material properties, the recorded features and their attributes vary slightly between the two datasets. For flint artefacts, wear was documented through detailed observations of polish development, including its degree, texture, topography, and distribution, alongside striations, edge rounding, and scar characteristics. In contrast, for WSQ artefacts, attributes related to polish development were not applicable due to the lack of optical contrast with the unworn surface and therefore excluded apart from estimation of the relative degree of development. The analysis additionally focused on edge damage, rounding, fracture patterns, and the presence and orientation of linear features, which are considered more diagnostic for use-wear on macrocrystalline quartz (see Knutsson, 1988).

Table 7
Experimental details and wear attributes recorded for the experimental flint artefacts.

ID	Polish	Development	Symmetrical	110/91	110/92	110/131	110/134	110/135	110/136	110/137	110/138
		Polish distribution: location/ extent (following Jensen, 1994)	Ventral more polished dorsal more polished	Moderate	Low	/					
		only ventral	x								
		only dorsal									
		marginal									
		degree of intrusion (following Jensen, 1994)									
		dorsal									
		ventral									
		dorsal									
		ventral									
		dorsal									
		ventral									
		dorsal									
		ventral									
		linear depressions									
		Scarring									
		presence initiation									
		termination									
		orientation									
		intensity									
		Edge rounding									
		presence intensity									

For the archaeological microliths examined for possible projectile use, fractures were recorded and described following the terminology proposed by Coppe and Rots (2017). Analysis concentrated on fracture occurrence and damage patterns, with particular attention to the association between individual traces and their spatial patterning across the tool surface (Rots and Plisson, 2014). Three fracture categories were identified: bending breaks, secondary damage, and lateral scars. Bending breaks are fractures initiated in bending from a surface or edge and terminating on a surface or opposite edge. They were interpreted as evidence of a compressive stress component upon breakage when associated with long propagation, fissured terminations, and secondary damage. Secondary damage consists of scars initiated on bending break surfaces as a result of secondary fracture formation on impact. Their diagnostic value increases when multiple scars occur simultaneously and display destroyed initiations, fissured terminations, and/or long propagations (see Coppe and Rots, 2017; 2025). Lateral scars are located on the lateral (cutting) edges of the artefact and initiate and terminate on a surface. They can be oriented obliquely or perpendicularly to the point axis and are considered indicative of compressive stress when multiple scars with oblique orientations, damaged initiations, fissured terminations, or secondary damage occur.

5. Results

5.1. Microstructural basis: petrographic characterisation of WSQ

In what follows, the terms matrix and cement are used in the strict sense applicable to silcretes (Blomme et al., 2012; Goemaere et al., 2024), referring respectively to the fine-grained siliceous binding phase and to the diagenetic silicification process, and not to the recrystallised groundmass of a metaquartzite. Geological characterisation by SEM-EDS, focusing on the mineral composition of the WSQ using low-voltage secondary electron detection, revealed the presence of accessory minerals (particularly rutile, zircon, and detrital quartz) that are poorly rounded and larger than 50 µm (Fig. 8). These minerals are loosely distributed within a siliceous matrix composed of mesocrystalline quartz crystallites (≈15 µm) cemented by microcrystalline spheroids (5–10 µm) of fibrous silica.

The origin of the detrital material is most likely related to erosion of the Ardennes Massif during the Paleocene and Eocene. The bimodal structure of the silica crystals forming the rock is characteristic of WSQ and allows it to be distinguished relatively easily from Tienen (ortho) quartzite.

In addition to the mineralogical approach, the microfacies analysis (Fernandes et al., 2024) revealed the pseudo-brecciated character of the WSQ (Fig. 9), resulting from the presence of numerous illuviation conduits developed along former root channels. Their brown coloration is related to impregnation by very small amounts of ferric minerals (goethite, limonite), which stain the intergranular porosity. Where this porosity remains unfilled, it appears lighter in colour. With the exception of root ghosts (see above), no plant or faunal fossils were identified. The rock is therefore entirely composed of terrigenous detrital elements, later cemented by a hypersiliceous binding phase emplaced along a root network that has since disappeared. All these features indicate a pedogenetic origin for the rock, which we interpret as a silcrete (Thierry & Milot, 1987). From a petrofacies perspective, such a silcrete can be assimilated to an orthoquartzite (or quartzitic sandstone), thereby validating the term *Wommersom Quartzite*.

Owing to the nature of its protolith and the homogeneity of the binding phase related to diagenetic processes, the WSQ exhibits an isotropy comparable to that of marine flints, such as those from the Campanian of Mons basin. WSQ is a pedogenetic silcrete. In Belgium, other siliceous rocks of the “silcrete” family (e.g. the Tienen quartzite and the Brussels Sandstone) are better regarded as phreatic silcretes. The size difference between the binding phase and the grains, as well as their much higher proportion, leads to discontinuities in shock-wave

Table 8
Experimental details and wear attributes recorded for the experimental WSQ artefacts.

ID				110/173	110/174	110/175	110/176	110/180	
Polish	(following Knutsson, 1988)	dorsal					x		
		ventral					x		
Striations		straight-sided	dorsal						x
		irregular	ventral		x		x		
			dorsal						
			ventral		x		x		
		discontinuous	dorsal						
			ventral				x		
Impact pits		dorsal							
		ventral			x		x		
Plastic deformation		dorsal							
		ventral							
Scarring	presence			x	x	x	x	x	
	initiation			bending, dorsal and ventral	bending, cone, dorsal and ventral	bending, ventral feather	bending, cone, dorsal and ventral feather	bending, cone, dorsal	
	termination			feather, step, hinge to step	feather, hinge to step			dorsal feather, step, hinge to step	
	orientation			oblique	perpendicular	perpendicular	perpendicular	perpendicular	
	intensity			moderate	high	moderate	moderate	high	
Microscopic edge rounding	presence			x	x		x		
	intensity			low	medium		low		



Fig. 6. Experimental tool 110/173 made from WSQ, hafted in a bone handle using a beeswax-resin adhesive and additional leather bindings. The tool was used in a transverse motion to clean bramble branches by removing thorns.

propagation at the moment of fracturing that are not comparable to those observed in the Wommersom silcrete. In addition, the relative contribution of grain detachment to overall wear formation is higher in phreatic silcretes than in marine flints and in WSQ, where conchoidal fracture dominates at the macroscopic scale. Through-the-grain fracture and grain detachment are not necessarily mutually exclusive processes; some quartzite varieties present a combination of fracturing through and around the grain (Pedernana et al., 2017b; Pedernana and Ollé, 2017) and the relative contributions of these two phenomena to fracture formation on WSQ remain to be evaluated through a sequential experimental programme.

5.2. Experimental wear formation on Harmignies flint

The experimental tools in Harmignies flint presented three main

forms of wear: edge scarring, rounding, and polish (see Table 7). Edge scarring was recorded on all Harmignies flint tools and represents one of the most consistently observed wear features within the experimental sample. Scars were present across the entire range of use durations, while rounding was identified on three tools and was present only on those used for longer durations. Polish varied in degree and distribution depending on the use duration and performed tasks.

All the use-related scars recorded on the flint tools were bending-initiated (Fig. 10), while terminations varied considerably, with different morphologies frequently occurring together on individual tools. Scar orientation relative to the working edge was predominantly perpendicular (seven tools), with three tools showing oblique orientations.

Scarring intensity varied considerably, independent of use duration, with five tools exhibiting high intensities, three showing low intensities,

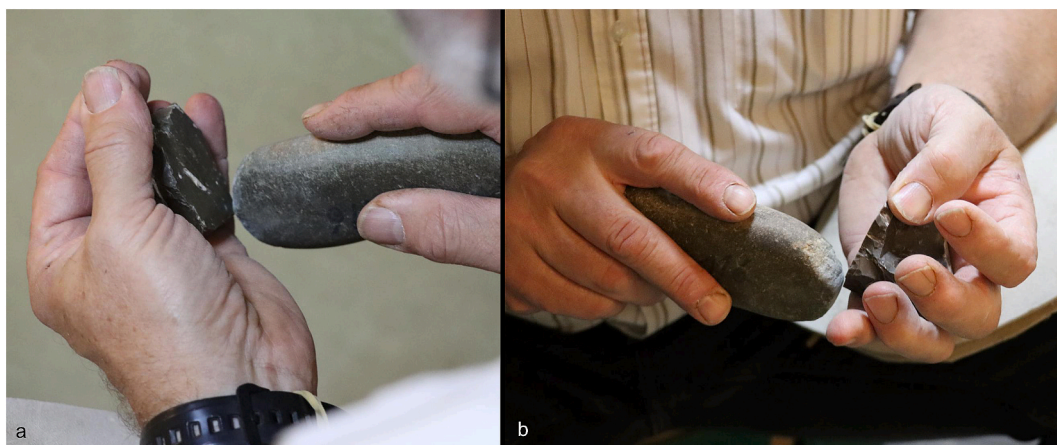


Fig. 5. (a) and (b) Knapping of experimental tools made from Wommersom quartzite. Blanks were produced by direct percussion with sandstone hammer, using raw material collected from surface deposits with a maximum thickness of 10 cm.

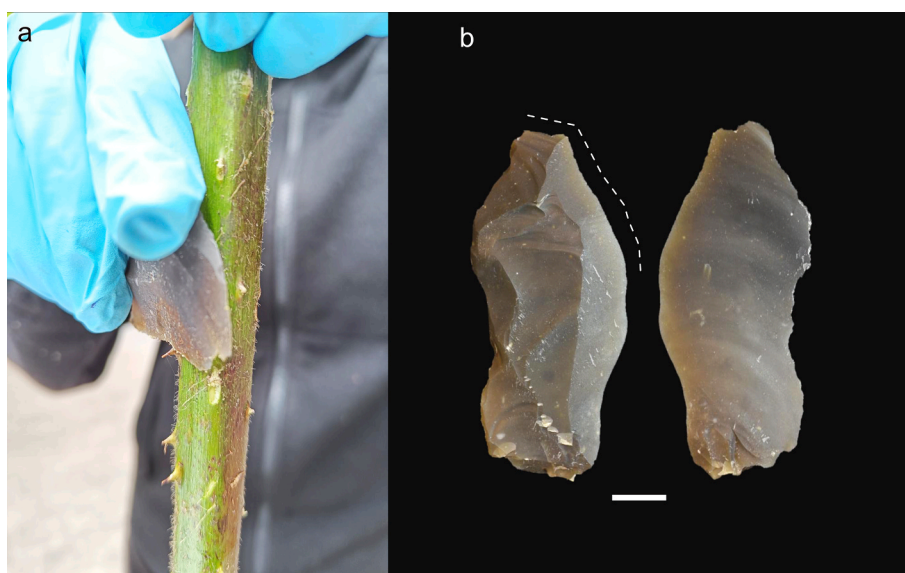


Fig. 7. Experimental tool 110/137 made from Harmignies flint, used without haft in a transversal motion to clean bramble branches by removing thorns.

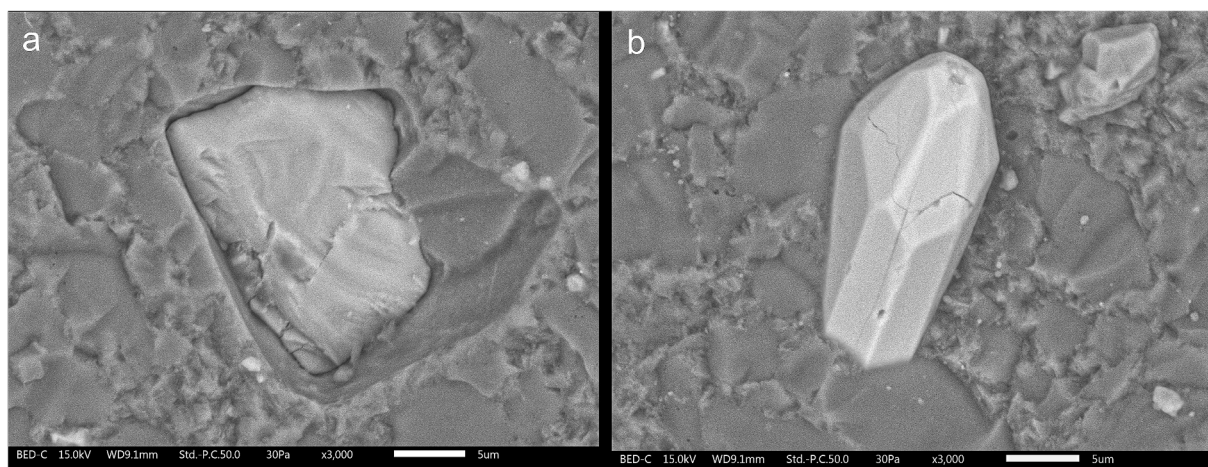


Fig. 8. Scanning electron microscope (SEM) images of (a) Titanium oxide (rutile) mineral inclusion ($\times 3000$); (b) Zirconium mineral inclusion ($\times 3000$).

and two displaying moderate intensities. This indicates that multiple variables contribute to scar formation, including working angle, applied

force and edge morphology. Notably, all tools were used with untouched edges.

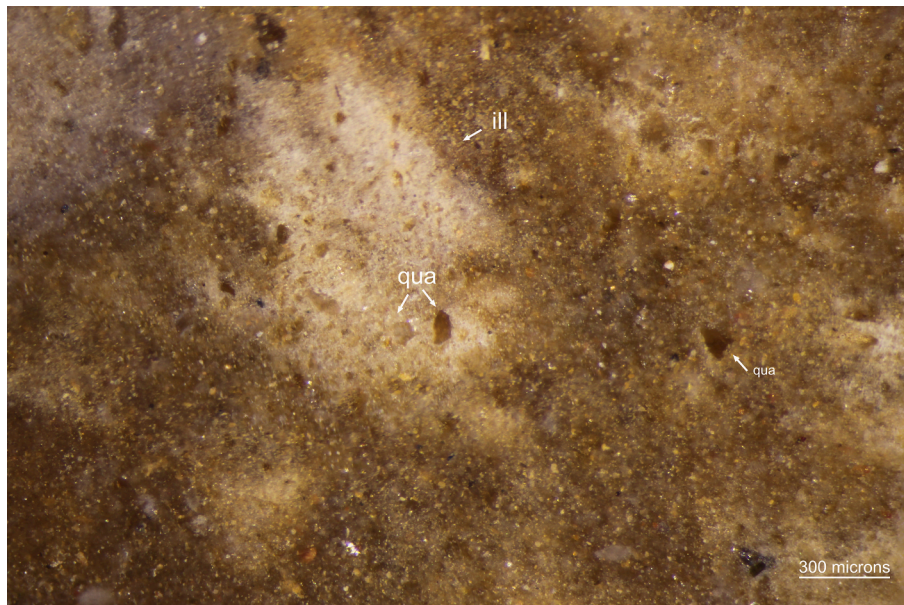


Fig. 9. Microfacies view of the Wommersom Quartzite.

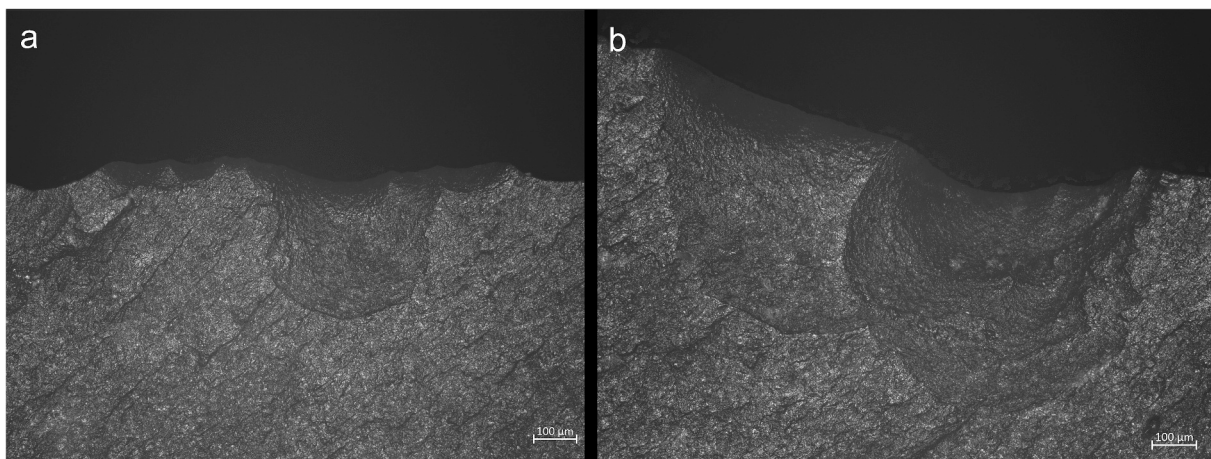


Fig. 10. Details of characteristic edge scarring on flint tool 110/137. Both images were taken using incident-light optical microscopy at $\times 100$ magnification and show bending-initiated scars: a) the largest scar in the image shows a distinct bending initiation, partly cut by a smaller removal, and a shallow hinge termination; b) two overlapping bending-initiated scars showing shallow hinge (left) and a feather-and-hinge (right) terminations.

Most tools exhibited only lightly developed polish, attributable to repeated contact with the harder structural components of the plant tissue, including calcium oxalate crystals. Although these crystals are less frequent in bramble than in other woody plants (Tomasso et al., 2024), their presence likely enhanced surface abrasion and may have contributed to the more pronounced polish development observed on tools used for longer durations (Tomasso et al., 2024).

A comparison between tools used for debarking and those used for splitting bramble stems shows that the debarking tools display slightly more pronounced edge rounding and somewhat better-developed polish than the splitting tools. This indicates that polish intensity on flint does not correlate strictly with use duration, but rather reflects the combined effects of activity type and the mechanical properties of the worked material.

Polishes were predominantly distributed asymmetrically over both tool surfaces. Two tools exhibited a mainly ventral polish distribution, while three showed a polish that was predominantly distributed over the dorsal surface. This asymmetry reflects the contact mechanics during use, which are significantly influenced by working angle and edge

geometry.

5.3. Experimental wear formation on Wommersom quartzite

Five experimental tools manufactured from WSQ were used during the experiment in scraping, removing thorns, splitting, debarking and shaving activities, with durations ranging from 25 to 66 min. Four main forms of wear were recorded: scars, linear features, impact pits, and polish. Macroscopic edge rounding was absent.

Edge scarring was observed on all WSQ tools included in the experimental reference set (see Table 8). Scars were predominantly initiated in bending, but some scars displayed cone-like initiations (Fig. 11). In certain cases, initiations could not be characterised due to fracture propagation affected by grain boundaries or preferential cleavage within larger quartz grains. This kind of fracturing was, however, infrequent, and while the fracture surfaces are somewhat rough when viewed under high ($\sim \times 500$) magnification, the relative (compensatory) isotropy of the material (Mourre, 1996; Rodríguez-Rellán, 2016), identified during petrographic analysis, is visible in the

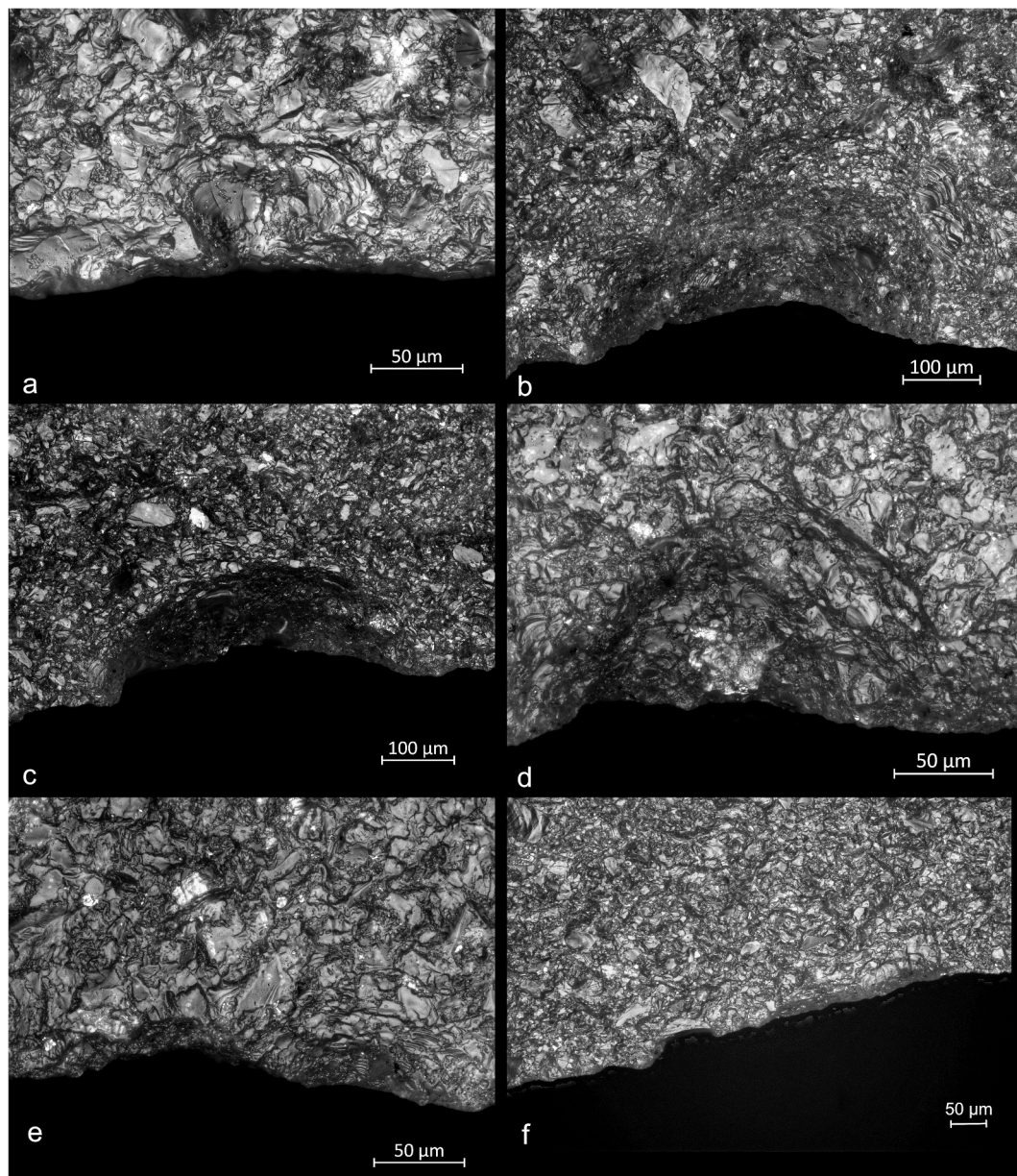


Fig. 11. Use-related scars on experimental WSQ tools. (a) Cone-like scar initiation and complex (feather and hinge) termination ($\times 500$) (b) Bending initiation and feather termination, with possible small conchoidal secondary scars on the right side of the scar ($\times 200$) (c–d) Two scars with slightly irregular, potentially multiple initiations and feather and hinge terminations ($\times 200$ and $\times 500$) (e) Scars with irregular and cone-like initiations and abrupt terminations ($\times 500$) (f) Small scar propagated following natural structural weaknesses of the WSQ ($\times 200$).

overall appearance of the scars. Scar terminations were often composite, showing combinations of feather, hinge, and step terminations, which may also relate to the slightly uneven nature of the material. Scar orientations were mainly perpendicular to the tool edge, although oblique orientations were also recorded on some tools. Overall scar intensity ranged from moderate to high across the used tools.

Surface polish from use was recorded on only a limited number of WSQ tools and was generally weakly developed. This probably relates to the low silica content of the plant (cf. Knutsson et al., 2015). Throughout the manuscript, “polish” on WSQ tools is used to denote weakly developed surface modification observed on a minority of tools, in line with the criteria for quartz established by Knutsson (1988); it should not be read as comparable in extent or diagnostic value to polish development on flint, which is described separately for the experimental flint tools. Where polish is described as “absent” on WSQ tools elsewhere in the text, the difficulties of detecting lightly developed polish in the absence

of clear optical contrast typical of flint must be kept in mind. Sequential documentation (e.g. Ollé and Vergès, 2014; Pedergrana and Ollé, 2017) could help resolve such issues in future experimental programmes.

Linear features (discontinuous, straight-sided, and irregular striations; see Knutsson 1988) and impact pits were the most frequently documented microwear features on the WSQ tools. Striations were the most easily visible on the largest quartz crystals (Fig. 12) where they occurred in clusters or as isolated features, but they were also occasionally recorded on smaller grains (see Fig. 12). Their more frequent occurrence on large grains is consistent with previous results on other quartzites, as is their interrupted appearance on grain fracture surfaces with uneven topographies (Fig. 12a, compare Pedergrana et al., 2017a). The striations were in most cases associated with numerous impact pits. Certain worn fractured quartz grains may present sleeks, or narrow plastic deformations (Knutsson, 1988) (Fig. 12a–b), but this remains to be investigated through closer analysis. In terms of the presence/

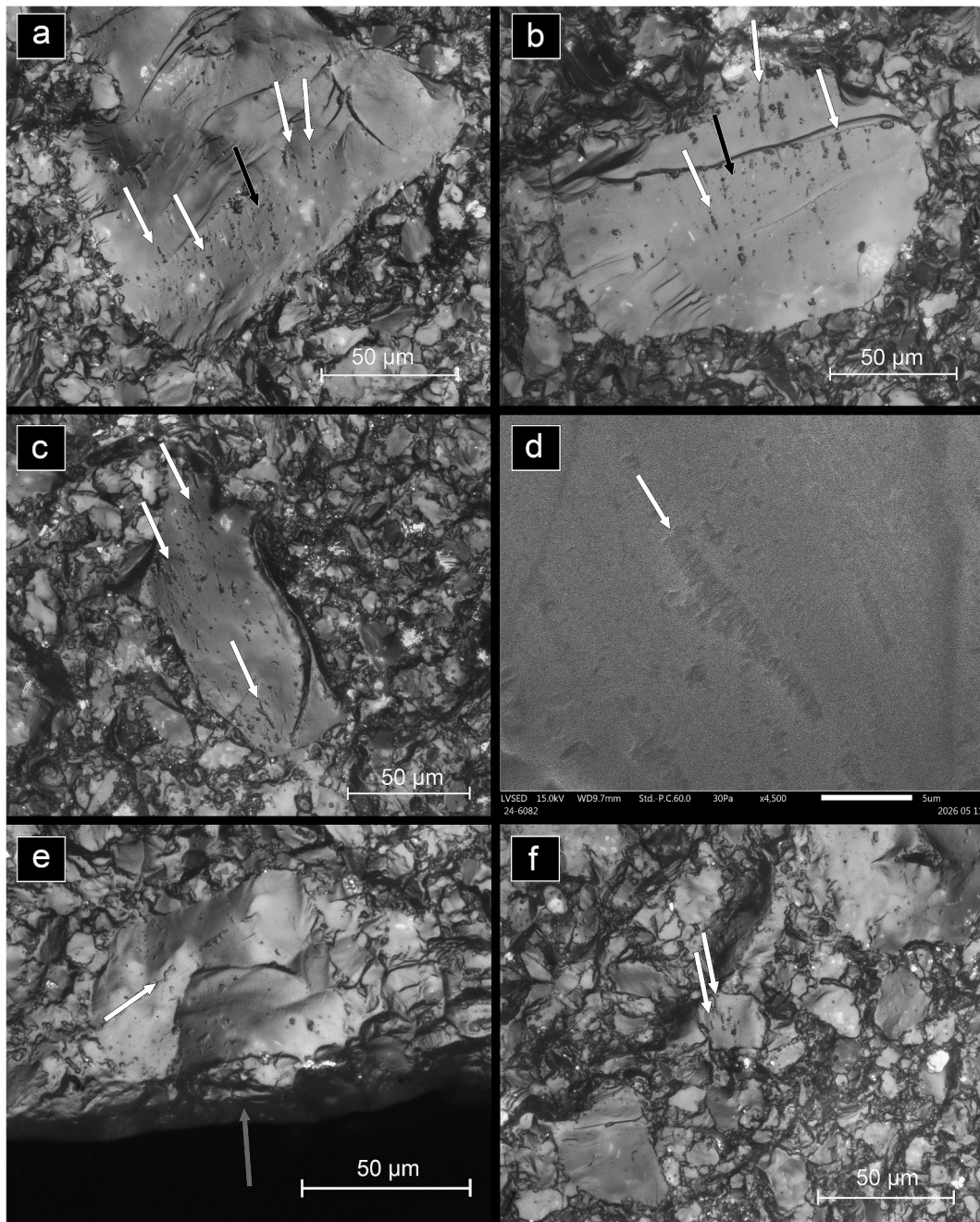


Fig. 12. Microwear features on experimental WSQ tools. Microwear on experimental tools used for processing bramble. (a) Discontinuous, straight-sided, and irregular striations (white arrows) and impact pits, with a possible minor contribution of plastic deformation (sleeks; black arrows), on a large quartz crystal on Exp. 110/176 used for removing thorns. The striations are confined to the elevated lower part of the fractured grain (cf. Pedergrnana et al., 2017) (close-up of image captured at $\times 500$) (b) Discontinuous and straight-sided striations (white arrows) and a possible sleek (black arrow) on Exp. 110/176 (close-up of image captured at $\times 500$) (c) Discontinuous and irregular striations (arrows) and impact pits on Exp. 110/176 (close-up of image captured at $\times 500$) (d) SEM view of an irregular striation (arrow) shown in (c) on Exp. 110/176 ($\times 4500$) (e) A hinge and feather-terminated scar (grey arrow) with a removed initiation within the boundaries of a single large crystal co-occurring with obliquely oriented, straight-sided and discontinuous striations (white arrow) on Exp. 110/174, used for scraping bark ($\times 500$) (f) Straight-sided striations and impact pits on a small quartz grain (circle) on Exp. 110/176 (close-up of image captured at $\times 500$).

absence of different linear features, the wear on the bramble-processing tools comes close to the wear recorded on flake knives used on fresh wood in previous experiments on quartz, with partial overlap with feature combinations documented for softer plants (Knutsson, 1988 Fig. 54). This highlights the broad applicability of previously developed methods in the microwear analysis of WSQ, particularly for the wear forming on its larger crystals.

5.4. Comparative analysis: material-specific differences in wear formation

The pilot experimental study on WSQ, focused on plant-processing activities that are well documented for the Mesolithic, demonstrated relative convergence in edge damage formation that stems from the isotropy of both raw materials. While the isotropy of flint relates to its cryptocrystalline character, WSQ is composed of crystals readily visible with optical microscopes and sometimes with the naked eye. Its response

to stress is determined by the properties of these larger grains and their binding phase (cf. Tsirk, 2014) and it presents a case of ‘isotropy by compensation’ previously described for polycrystalline aggregates of quartz (Mourre, 1996; Rodríguez-Rellán, 2016). These differences between flint and WSQ result in a slight divergence in their fracture mechanical properties. This can be illustrated through comparisons between tools employed with comparable gestures and similar use durations. Under these conditions, edge scarring was observed on all tools in both assemblages, whereas microwear development varied according to tool use details and lithic raw material properties.

Due to the structure of the raw materials, scars were typically more easily visible on Harmignies flint and displayed clearly identifiable (bending) initiations, and well-visible terminations. On WSQ tools, scar initiation and termination were sometimes less clearly expressed. Importantly, however, the overall frequency and distribution of edge scars on WSQ tools were comparable to those observed on flint (see Fig. 13). A notable difference lies in scar propagation length and overall dimensions, which are typically larger in flint tools than in WSQ. These may relate to the bimodal crystal structure of the latter material.

Fracture surfaces produced during knapping show that when the fracture front propagates through the smaller grains present in WSQ, the microroughness of the resulting surface resembles that seen on coarser varieties of flint. When it encounters large quartz grains, it does not significantly deviate from its original path due to the strong cohesion of the material. This results in relatively flat surfaces. Nevertheless, minor effects of the internal structure of the individual quartz grains and their interfaces on fracture propagation can be detected, resulting in a more complex and, at places, slightly stepped relief compared to cryptocrystalline rocks (observe various slopes evidenced by shadow effects in Fig. 12).

These observations indicate that standard fracture attributes are partly applicable in the description of edge damage on WSQ tools, but that raw material-specific differences in fracture propagation and scar expression should be further explored to refine attribute systems. The smaller size of scars on WSQ needs to be taken into consideration when examining and comparing wear features and further development of dedicated reference collections in WSQ is recommended to ensure the reliability of interpretations. Based on our preliminary observations, we can hypothesise that shorter fracture propagations may relate to the loss of energy of the propagating crack when it reorients itself in the heterogeneous material to find paths of least resistance, as opposed to more straightforward propagation trajectories characteristic of isotropic cryptocrystalline or amorphous materials. While we limited our documentation here to 2D imaging of worn areas, future work employing surface metrology could shed further light on the effects of the crystal

structure on fracture expression.

Judging from the first experimental observations, microwear on WSQ is at least partly describable using the analytical framework developed for quartz and other quartzites (Knutsson, 1988; Knutsson et al., 2015; Ollé et al., 2016; Pedergrana and Ollé, 2017; Pedergrana et al., 2017b; Pedergrana, 2019), and combinations of wear features documented here for the plant-processing tools are within the range recorded previously for woody plants (Knutsson, 1988). However, the bimodal crystal structure results in discontinuous wear patterns, with the characteristic linear features mostly occurring on the largest grains, where they can further be confined to only an elevated part of the fracture surface as a result of its uneven topography (Fig. 12a). This is in line with previous observations on other quartzites (Pedergrana et al., 2017a). Notably on WQS, feature combinations can be best evaluated when they occur on large quartz grains, which allow detecting high enough numbers of features to estimate their relative portions. The scattered distribution of such large crystals presents some limitations to observation when the wear is weakly developed (i.e. linear features infrequent) compared to macrocrystalline quartz. On the other hand, the high degree of cementation/silicification of the rock, and the resulting relative isotropy, yields macroscopically smooth, regular fracture surfaces that allow easy observation of microwear with incident-light microscopes compared to quartzites that present rougher surface textures. Therefore the wear, even though discontinuous, allows gaining an overview and estimating attributes such as extension with relative ease. We want to highlight here that our approach to microwear on WSQ relies on the method developed for quartz (Knutsson, 1988); potential responses of the smallest crystals to wear remain to be explored.

In sum, while flint and WSQ present overlap in the formation of macroscopic damage, slight differences emerge that are consistent with the mesocrystalline character of the latter material that should be kept in mind in designing reference collections. Microwear analysis of WSQ should be developed starting from the framework developed for macrocrystalline quartz, consistent with earlier observations on wear formation on quartzites (e.g. Pedergrana et al., 2017b).

5.5. Application of the framework to the WSQ tools of the Diepenbeek-Molenstraat assemblage

Out of the 81 artefacts which displayed functional use-wear traces (60 in flint and 21 in WSQ), 55 exhibited diagnostic wear patterns. For these 55 artefacts a functional attribution could be proposed: 27 were identified as projectile elements and 28 as domestic tools (tools used in activities other than hunting armature functions) (see Table 9). Flint dominates both functional categories, accounting for 45 of the 55



Fig. 13. Comparison of edge damage on a Harmignies flint tool (110/137) and a WSQ tool (110/176) used for processing bramble. Both tools exhibit comparable frequencies and distributions of edge scarring under similar use gestures and durations, while scars on the WSQ tool tend to have shorter propagation lengths.

Table 9
Functional distribution of artefacts by raw material.

	Flint	Wommersom Quartzite	Total
Projectile	20	7	27
Domestic	25	3	28
Total	45	10	55

artefacts, while Wommersom quartzite (WSQ) is represented by only 10 pieces. Within the WSQ subset, projectile elements (n = 7) are more frequent than domestic tools (n = 3). Among the WSQ domestic tools, one scraper, one notched tool and one perforator showed use. Their macro-wear is comparable to that on the flint artefacts: the scraper shows slight rounding on the scraper front, while the perforator displays tip wear combining edge rounding with alternating dorsal and ventral scarring (scraper and perforator illustrated in Figs. 14 and 15).

Twenty-seven artefacts that showed diagnostic combinations of damage features (bending breaks, obliquely oriented lateral scarring, and secondary damage; see Figs. 16 and 17) could be confidently identified as projectile elements (Coppe and Rots 2017). While a tailored

projectile reference collection in WSQ is not yet available, we consider these interpretations (n = 7) conservative given that our initial use-wear tests demonstrate that fracture dimensions are downplayed in WSQ compared to flint. This implies that attributes characteristic of compressive stress related to high-energy impact (e.g. long fracture propagations; multiple occurrences of secondary damage) should be less frequent and explicit in WSQ than in flint. Our flint-based reference collection therefore underestimates rather than overestimates the number of projectiles in the archaeological sample.

The attributes recorded for each fracture on these projectile elements (n = 27) are summarised in Table 10. Comparison of wear patterns on flint and WSQ projectile elements reveals that the three considered classes of fractures, bending breaks, lateral scars, and secondary damage, occur for both raw materials. However, closer comparison of fracture attributes indicates a higher frequency of fissured terminations among WSQ projectile elements, pointing to material-specific differences in fracture behaviour that need to be taken into account, even though the overall categories of damage are shared across raw materials. Future analyses should further explore these differences through systematic comparison of scar length and fracture propagation.

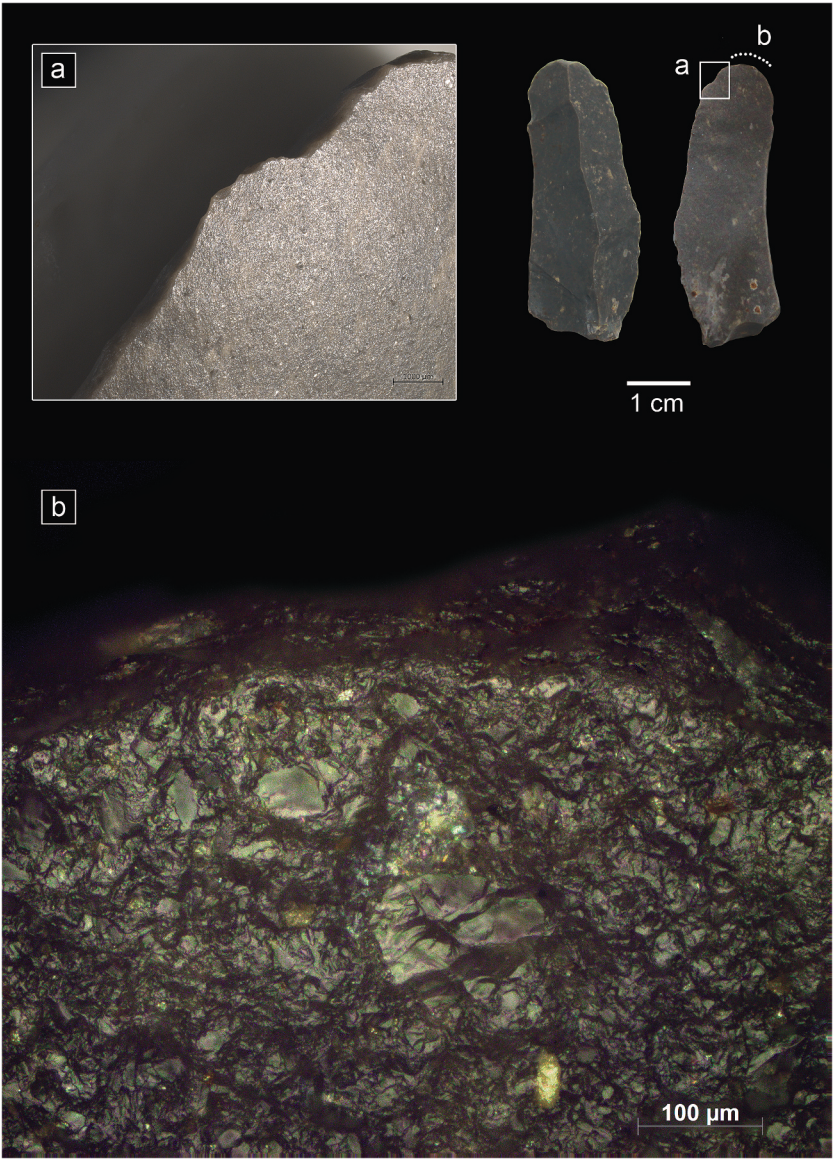


Fig. 14. Overview of the use traces observed on scraper 102500407: (a) edge rounding cut by removals from resharpening (x25), (b) microscopic details of the functional edge rounding of the ventral distal left surface of the scraper (x100).

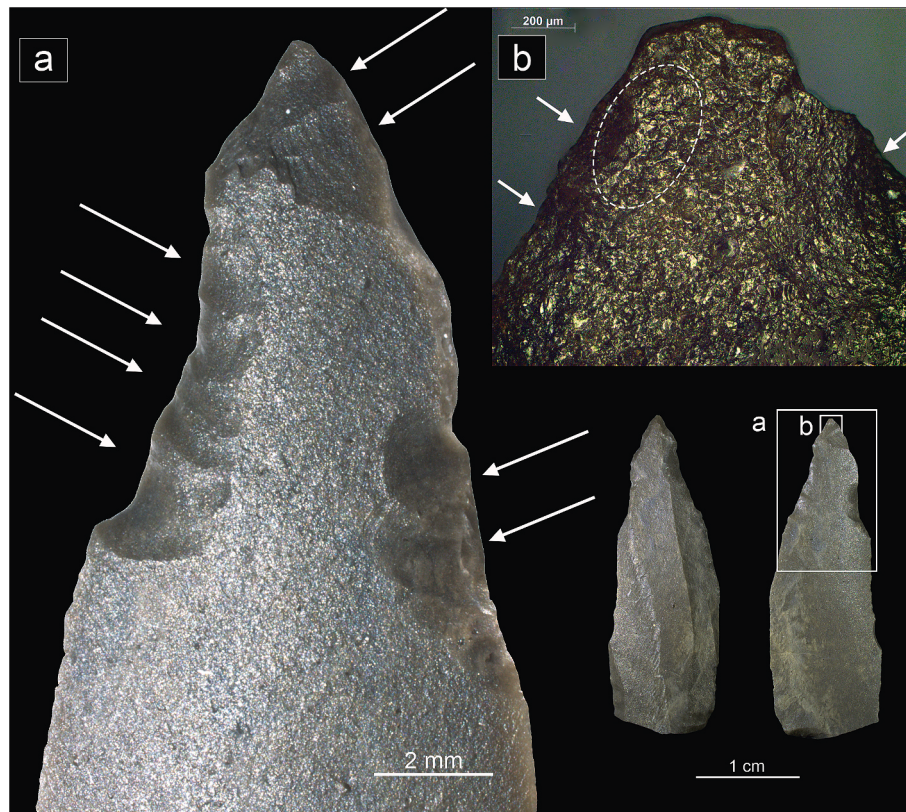


Fig. 15. A) macroscopic view of the tip of the wsq tool ($\times 12.5$) showing alternating removals on both the left and right edges; b) microscopic detail of scars (arrows) and edge rounding or smoothing (ellipse) on the tip ($\times 100$).

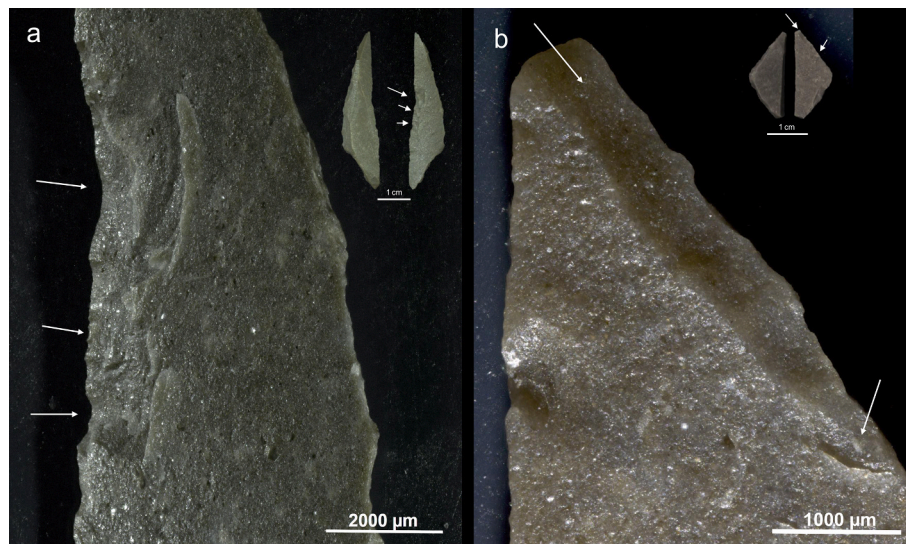


Fig. 16. Macroscopic details of the impact damage present on two of the WSQ archaeological microliths from Diepenbeek identified as projectiles. (a) Piece 300,108,001 presents oriented lateral scarring with bending initiations and fissured step terminations; (b) Artefact 300,800,907 showing a bending break with a long propagation on the ventral aspect of left lateral edge, associated with secondary damage with a fissured termination.

6. Discussion

Wommersom quartzite (WSQ) has remained functionally underexplored despite its archaeological prominence in Mesolithic northwest Europe. Our study addressed this gap by establishing that systematic functional analysis of WSQ is feasible, but that it requires dedicated reference collections to further explore how wear formation differs from previously studied siliceous rocks and what this implies for

archaeological analysis.

The experimental programme revealed that edge damage formation generally shows similar patterning between WSQ and flint, even though scarring on WSQ tools displayed more cone-like initiations than on flint, and some scars could not be fully characterised due to fracture propagation along crystal grain boundaries or preferential cleavage plains in quartz grains. Scar terminations tended to be more complex on WSQ and presented combinations of multiple termination types, including

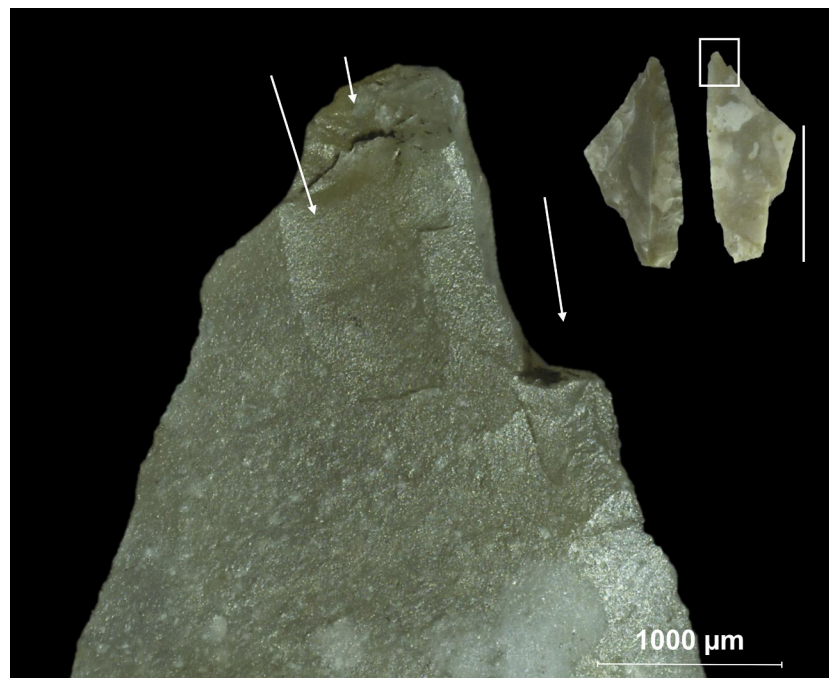


Fig. 17. Macroscopic detail ($\times 40$) of the edge damage recorded on the tip of a flint projectile from Diepenbeek (30090330301) presenting a combination of damage features, including obliquely oriented edge damage with long propagations and terminations on the ventral surface and the left lateral edge.

feather, hinge, and step terminations. The most notable difference between the raw materials related to scar dimensions, with scars on flint generally showing longer propagations than those observed on WSQ, even when tool use gestures and duration of use were comparable.

These material-specific differences in fracture propagation can be understood through WSQ's distinctive microstructure. Petrographic analysis reveals a bimodal crystal structure in which mesocrystalline quartz grains ($\approx 15 \mu\text{m}$) are cemented by microcrystalline spheroids ($5\text{--}10 \mu\text{m}$) of fibrous silica. This size difference between the binding phase and larger grains creates discontinuities in crack propagation that differ fundamentally from the more homogeneous structure of marine, including Campanian, flints, despite both materials exhibiting comparable isotropy at the macroscopic level (Goemaere et al., 2024). The pedogenetic origin of WSQ as a silcrete, combined with its relatively uniform cementation along former root channels, produces a material that fractures through edge chipping like marine flint but with material-specific constraints on crack propagation length. This microstructure also distinguishes WSQ from phreatic silcretes such as Tienen quartzite, where wear formation proceeds primarily through grain plucking rather than edge chipping (Goemaere et al., 2024). The observed shorter scar propagation and occasional fracture termination at grain boundaries in WSQ experimental tools thus reflect intrinsic mechanical properties resulting from this specific diagenetic history rather than representing analytical limitations. Although initiation characteristics appear more variable across WSQ tools, the limited size of the sample means that these observations must be regarded as preliminary and do not yet allow final conclusions. Further, the relative contributions of microchipping and grain detachment to wear formation on WSQ and how they evolve with use duration could also be investigated through a sequential experimental design, in which the same tool is observed at successive intervals during use (e.g. Ollé and Vergès, 2014; Pedergrana and Ollé, 2017), which could be among the strategies to pursue in future.

Attribute-based fracture analysis (Coppe & Rots 2017, 2025), originally developed for flint, proved effective when applied to the WSQ armatures from Diepenbeek. The impact-related fracture patterns were broadly similar between the two raw materials with high-energy impact fractures being readily observable and reliably interpretable. Nevertheless, differences in certain attributes could be noted that require

recalibration of the attribute system to accommodate WSQ's distinct fracture properties. This finding contributes new elements to the discussion on inter-raw material variability in impact fracture expression (e.g. Pargeter, 2011, 2013; Taipale and Rots, 2019; Neill et al., 2022) that can be tested through future projectile experiments involving WSQ.

These first results indicate that while high-energy activities such as projectile use can produce edge damage reminiscent of features documented for flint, it may be premature to conclude that flint would constitute a sufficient reference for interpreting wear on WSQ at this scale of analysis beyond the category of projectiles. The smaller size of scars on WSQ documented through the bramble-processing experiments suggests that the force applied during tool use may be underestimated if the reference collection consists of cryptocrystalline rocks. It is worth noting, however, that we have not carried out a formal analysis of scar volume that would incorporate the aspect of depth, which would be necessary to better correlate stress during tool use with scar dimensions. Even so, the slight differences in scar attributes (initiations, propagation trajectories, terminations) between flint and WSQ we documented advice against attempts to directly transfer analytical criteria from flint to WSQ without further experimental investigation and validation.

The results of the preliminary evaluation of microwear formation on WSQ were encouraging, suggesting that methods developed previously for macrocrystalline quartz will be valuable for increasing the resolution of functional interpretations and expanding the scope of research to domestic tool use in future studies. A comparison of microwear on the experimental bramble-processing tools with previously published data on wear from working woody plants (Knutsson, 1988) demonstrated that all relevant microwear features reported for quartz can be observed on WSQ. However, due to the minute size of the linear features and their frequent overlap on worn surfaces, future SEM analyses can be recommended to increase the resolution of wear description overall and to examine the relative proportions of different wear features that worked material identification builds on in quartz studies (Knutsson, 1988). The discontinuous nature of microwear on WSQ brought on by its bimodal crystal structure and the near lack of wear on the smaller grains that could be identified using existing quartz-based frameworks call for further investigation and potential methodological adjustment, in line with previous observations for other quartzites (Pedergrana et al.,

Table 10

Fracture attributes on the archaeological WSQ and flint projectiles from Diepenbeek.

			Pieces identified as projectile elements (N = 27)	Flint (N = 20)	WSQ (N = 7)
			N fractures		
<i>Bending Breaks</i>	<i>Termination morphology</i>	<i>Snap</i>	7	5	2
		<i>Abrupt (step or hinge)</i>	10	6	4
		<i>Feather</i>	5	4	1
	<i>Fissured termination</i>	<i>Yes</i>	7	2	5
		<i>No</i>	20		2
Total Bending breaks			22	18	2
<i>Secondary damage</i>	<i>Fracture composition</i>	<i>Simple</i>	0	0	0
		<i>Multiple</i>	4	2	2
	<i>Initiation conservation</i>	<i>Absent</i>	2	1	1
		<i>Present</i>	2	1	1
	<i>Initiation morphology</i>	<i>Cone</i>	0	0	0
		<i>Bending</i>	2	1	1
		<i>Mixed</i>	0	0	0
	<i>Fissured termination</i>	<i>Yes</i>	2	1	1
		<i>No</i>	2	2	0
	<i>Location of termination</i>	<i>Same as bending break</i>	3	2	1
		<i>Opposite to bending break</i>	1	1	0
Total Secondary damage			4		
<i>Lateral scars</i>	<i>Fracture composition</i>	<i>Simple</i>	5	2	3
		<i>Multiple</i>	4	2	2
	<i>Initiation conservation</i>	<i>Absent</i>	5	2	3
		<i>Present</i>	4	2	2
	<i>Initiation morphology</i>	<i>Cone</i>	1	0	1
		<i>Bending</i>	1	0	1
		<i>Intermediate</i>	2	2	0
	<i>Fissured termination</i>	<i>Yes</i>	4	1	3
		<i>No</i>	5	3	2
	<i>General direction with regard to the axis of the piece</i>	<i>Oblique</i>	2	1	1
		<i>Variable</i>	5	2	3
		<i>Perpendicular</i>	2	1	1
Total Lateral scars			9		

2017a). Compared to quartz, microwear patterns on WSQ are interrupted and constrained by grain size. Further and more diverse experiments involving contact materials of varying mechanical and chemical properties will be needed, as worked material hardness and other properties influence the nature of contact between the worked material and the quartzite surface, leading to differences in wear distribution (Pedernana et al., 2018). Such tests will permit evaluating whether the application of a quartz-based method would be appropriate or whether a method fully tailored to WSQ should preferably be developed. The conclusions of previous investigations on wear formation on different varieties of quartzite (e.g. Pedernana et al., 2017b, 2018) predict that the latter strategy might be advisable.

The Diepenbeek assemblage shows typological differentiation between WSQ and flint, with WSQ more commonly represented among microliths and smaller tools. This pattern reflects remarkably consistent associations documented throughout the Mesolithic of northwest Europe (Huyge, 1987; Crombé et al., 2003; Noens & Van Baelen, 2019). The association persists independent of the expansion of the WSQ circulation from localised exploitation within 25 km of the Wommersom outcrop during the Early Mesolithic to ranges exceeding 80,000 km² by the Late Mesolithic, with documented occurrences extending more than 90 km from source. It represents one of the most consistent trends in Mesolithic lithic technology in the region.

While the relative performance of WSQ and flint armatures remains to be investigated through projectile experiments, a possible explanation for the archaeological pattern emerges from a consideration of raw material availability and form. WSQ derives from a single known outcrop at the Steenberg in Wommersom, central Belgium, where fine-grained orthoquartzite occurs at the surface in the form of flattened slabs or plaquettes, typically not exceeding 10 cm in thickness (Goffin-Cabodi, 1985, cited in Di Modica, 2011). This outcrop, no longer exposed today (Blomme et al., 2012), represents the sole documented source of WSQ exploited during the Mesolithic. In contrast, flint was available as larger nodules in multiple source areas across the southern Netherlands and northeastern and southern Belgium, including the extensive chalk deposits of Belgian and Dutch Limburg. This fundamental difference in raw material availability constrained blank production. WSQ plaquettes with maximum thickness of 10 cm (Huyge, 1987) probably limited core volumes and opportunities for the preparation and maintenance of large cores. In such a setting, production sequences geared towards the detachment of small, thin blanks (suitable for microlith production) to make the most of the high-quality raw material may well have been favoured, which is supported by the small size of exhausted cores (Devriendt and De Herdt, 2024). Larger flint nodules, in contrast, enabled the production of more diverse blank sizes including those appropriate for scrapers, burins, and other tool types requiring greater volume or thickness. The predominant association of WSQ with microlithic armatures may therefore reflect morphological constraints imposed by the plaquette form rather than deliberate selection for specific mechanical properties, although the latter aspect remains to be investigated through functional testing.

While the weaponry-oriented role of WSQ in lithic toolkits at Diepenbeek is obvious, our experimental results indicate that macrowear from non-projectile use develops differently on WSQ than on flint, with WSQ presenting smaller and sometimes less distinct scars. The use of WSQ artefacts in domestic activities may therefore be more difficult to identify than equivalent use of flint tools on the basis of stereomicroscopic screening. Multi-scale analytical approaches that take into account the lower visibility of subtle macrowear on WSQ tools are therefore recommendable for future research programmes to guarantee a balanced view of the roles of these raw materials in Mesolithic toolkits.

The persistent WSQ-microlith association observed at Diepenbeek and throughout northwest Europe requires consideration of multiple interacting factors: raw material form and availability, technological traditions adapted to plaquette morphology, and potentially subtle performance characteristics not yet identified through experimentation. Future research should involve dedicated experimental programmes, building on models developed for other quartzites and quartz (Pedernana et al., 2017a, b, 2020; Ollé & Vergès, 2014; Knutsson, 1988; Clemente Conte & Gibaja Bao, 2009; Taipale and Rots, 2019; Lundin et al., 2025). Such approaches will allow a more refined understanding of the functional factors underlying one of the most distinctive and well-documented non-flint raw material circulation patterns in the Mesolithic archaeological record.

7. Conclusion

This study represents a first experimental exploration of use-wear formation on WSQ, a raw material that is central to northwest European Mesolithic assemblages but that has been overlooked in previous functional studies. By combining actualistic experiments, petrographic characterisation, macro- and microscopic observations and a small-scale archaeological application to the Mesolithic site of Diepenbeek-Molenstraat, this paper provides an initial foundation and working hypotheses for a more elaborate reference framework that needs to be developed in order to understand in full detail how use-wear develops on this quartz-rich material. The first results demonstrate that systematic functional analysis of WSQ is feasible.

The experimental programme revealed that WSQ and flint present

broadly similar scar patterns that can be described using the same attribute system, but that the fracture mechanical properties of WSQ influence the way fracture attributes are expressed. Differences were visible in scar initiations as well as in propagation length and overall dimensions, with less pronounced differences observed in termination attributes. Petrographic analysis provided an explanatory framework for these differences, showing that WSQ's geological origin as a pedogenetic silcrete results in fracture behaviour distinct from both flint and other quartzite varieties. The development of more comprehensive reference sets in WSQ is advisable to guarantee reliable functional interpretations.

Fracture attribute systems used in projectile identification can be used for analysing armatures in WSQ, but differences in propagation length and frequency of fissured terminations can be expected, together with added variability in fracture initiations introduced by the grain structure. The archaeological application of the flint-based projectile attribute system to a set of armatures from Diepenbeek consisting of both flint and WSQ permitted confirming their use in hunting technology. This adds a functional confirmation to the long-documented association between WSQ and microliths throughout Mesolithic northwest Europe. This persistent pattern may reflect both the natural constraints of WSQ's plaque form, which favours production of smaller blanks suitable for microliths, and the mechanical properties of the raw material. The latter hypothesis remains to be tested through further functional experiments.

The high magnification optical analysis of experimental plant-working tools in WSQ points to the applicability of the interpretative framework developed previously for other quartzites and macro-crystalline quartz. Wear features defined in earlier studies for experimental wood and plant-working tools are present and easily identifiable on WSQ, although extended datasets are needed to investigate possible subtle differences in microwear formation and to optimise analytical approaches. Closely matching the raw material of the experimental reference collection with the archaeological assemblage provides the safest way forward and ensures that the particular challenges and opportunities related to the functional analysis of WSQ are sufficiently explored in future work. This is in line with previous recommendations for various quartzites.

Our exploratory study provides an initial basis for the functional analysis of WSQ artefacts. Future work should expand the experimental reference set to include a broader range of worked materials, longer use durations, and more varied gestures to develop a more comprehensive framework. Since use-wear traces on WSQ are often more subtle than on flint and are more comparable to quartz and other quartzites, multi-scale analytical approaches are essential to ensure a balanced interpretation of assemblages containing multiple raw materials. In future, such studies could permit better understanding of how these two raw materials functioned as complementary elements within Mesolithic toolkits.

CRedit authorship contribution statement

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Data availability

Data will be made available on request.

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