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From excavation to analysis: Experimental insights on the impact of wet sieving processes on lithic use-wear traces

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ABSTRACT

Lithic microscopic use-wear analysis plays a crucial role in reconstructing past human behaviour, offering insights into tool use, site function, and subsistence strategies. However, its reliability depends greatly on the identification of genuine use traces and is therefore continuously challenged by contamination, either in post-depositional conditions or in handling post-recovery. This study aims to investigate the impact of a common procedure in archaeological excavation – wet sieving – on the preservation of use-wear on flint tools, through experimentation and controlled field simulations conducted at the site of Pirro Nord 13. Results of the microscopic analysis indicate that wet sieving, despite concerning mechanics similar to specific abrasive weathering processes, does not significantly alter use-wear patterns. These findings reaffirm the resilience of functional traces and highlight the reliability of use-wear analysis in archaeological research when accompanied by rigorous protocols both in the field and in the laboratory.

1. Introduction

Microscopic use-wear analysis is a fundamental approach in archaeology for reconstructing past human behaviour through the study of lithic tool use. Also known as functional analysis, it operates on the principle that different activities leave distinct wear patterns on the working edges and surfaces of tools, enabling the archaeologist, through the observation of traces under different microscopes and their direct comparison with experimental reference collections, to infer the types of tasks/actions the tools were used for and the worked materials (e.g., meat, plant, wood, bone) (Keeley & Newcomer, 1977; Odell, 1981; Semenov, 1964; Tringham et al., 1974). By providing evidence of prehistoric activities, this type of analysis has proven to offer insights into site use, technological practices, economic systems, subsistence strategies, and human-environment interactions (the examples are too many, here we cite only some recent works: Berruti et al., 2022, 2023, 2024; Carpentieri et al., 2023; Daffara et al., 2021; Fasser et al., 2022; Groman-Yaroslavski et al., 2022; Hilbert et al., 2023; Taipale et al., 2022; Xhauflair et al., 2020). Use-wear analysis may also include the study of residues left on tools, such as plant fibres, animal tissues, or pigments (Fullagar & Matheson, 2014; Grace, 1996; Hayes & Rots, 2019; Marreiros et al., 2015; Perrault et al., 2016; Rots et al., 2015). Advances in microscopy, such as the use of scanning electron microscopy (SEM) and 3D imaging technologies, can enhance the precision of use-wear and residue identification, enabling researchers to more confidently attribute specific traces to prehistoric human activity.

The reliability of this type of analysis, however, is inherently dependent on the accurate identification of genuine use traces, which can be complicated by various factors. One of the main challenges is distinguishing use-wear from traces produced by natural post-depositional processes and those that may be caused by modern handling during excavation and post-excavation activities. It has already been established that taphonomic factors can alter or obscure original wear: mechanical processes such as sediment consolidation and soil pressure, trampling, water movement, and bioturbation may cause microfractures, edge damage, polish, striations, and even embed organic residues on lithic artefacts (Asryan et al., 2014; Balirán, 2014; Berruti & Arzarello, 2020; Eren et al., 2011; Levi-Sala, 1986; Werner, 2018), while chemical processes such as diagenesis and weathering from groundwater percolation, soil acidity or exposure to atmospheric agents and decomposing plant matter may cause differential surface pitting, contribute to surface roughness or create patinas that affect the visibility of diagnostic microwear features by masking, modifying or even removing them (Burroni et al., 2002; Carranza and Alberti, 2018; Keeley

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and Newcomer, 1977; Ollé and Vergès, 2014). Similarly, modern contamination from the recovery, packaging, or cleaning of artefacts can introduce new marks or residues that may mimic or confound ancient use-wear patterns, potentially leading to misinterpretation (e.g., Cnuts et al., 2021; Frahm et al., 2022; Gero, 1978; Pedergnana et al., 2016; Rots et al., 2015; Xhauflair et al., 2017). The development of standardised methods for identification and distinction of traces, more rigorous experimental protocols (e.g., Evans, 2014; Evans et al., 2014; McPherron et al., 2014; Perrault et al., 2016), the application of quantitative techniques together with microscopic imaging technology (e.g., Borel et al., 2014; Cnuts and Rots, 2018; Evans and Donahue, 2008; Galland et al., 2019; Ibáñez and Mazzucco, 2021; Ollé and Vergès, 2014), and revisiting potentialities and constraints both in theory and method (e.g. Akoshima & Kanomata, 2015; Anderson et al., 2014; Calandra et al., 2019; Marreiros et al., 2015; Rodriguez et al., 2022) have helped address some of these issues, but the field remains complex and interpretive.

A significant yet potentially overlooked source of possible contamination concerns lithic artefacts contained in archaeological sediments that are subjected to the sieving process (also see Cnuts et al., 2021). It is common if not standard practice in excavating Palaeolithic sites (but not only) to conduct sieving and flotation to improve the recovery of remains, such as of small mammals, micro-shells, and seeds, as well as artefacts, such as micro-lithics and beads, that may otherwise be missed or are impossible to be hand-collected during excavation (Cnuts et al., 2021; Hosch & Zibulski, 2003; Reitz & Shackley, 2012; Sapir-Hen et al., 2017). The sieving process is also referred to as 'washing' because the artefacts are washed off of sediments to facilitate identification and recovery. Often, sieves with mesh that are either plastic or metal are used for this process (see Lembo et al., 2019).

The Mohs scale of mineral hardness provides a useful framework for comparing the hardness of different materials and understanding their potential to cause abrasion. Flint, a form of microcrystalline quartz, has a Mohs hardness of approximately 7 (Brandl, 2014; Luedtke, 1992). This means that it is relatively resistant to scratching and abrasion by softer materials. In contrast, the metal commonly used for sieve meshes, such as brass and stainless steel, typically has a hardness on the Mohs scale ranging from 3 to 6, depending on the specific alloy and manufacturing process (Brandl, 2014; Kooyman, 2000). Given this disparity, flint is significantly harder than the metal mesh, making it theoretically unlikely for the mesh to cause substantial wear on the surfaces of flint artefacts. However, it has been reported that abrasion may cause the deposition of metal residues on a stone tool's surface (Donahue & Burroni, 2004; also see Fullagar & Matheson, 2014), although intense traces are mostly associated with contact with excavation tools (Cnuts et al., 2021; Rots et al., 2015). It remains that the hardness of materials alone does not account for the complete dynamics involved in the sieving process: flint artefacts may come into repeated and forceful contact with the sieve mesh, the sieve matrix that may contain particles of varying hardness, or other artefacts that could act as intermediaries. More importantly, although theoretical considerations suggest minimal risk of alteration, real-world excavation scenarios involve numerous uncontrolled variables. Experimental validation ensures that the assumptions about material interactions and potential contamination risks are supported by empirical evidence, strengthening the reliability of use-wear analysis (Fullagar & Matheson, 2014; Gero, 1978; Marreiros et al., 2020a, 2020b; Mazzucco et al., 2013; Venditti et al., 2016).

As such, our aim in this work is to investigate whether such process, i.e., subjecting lithic materials to contact with sediments and other archaeological materials, water, and sieve mesh, poses a genuine risk in inadvertently introducing, obscuring, or altering traces on the edges/surfaces of lithic artefacts that may affect the interpretation of use traces in microscopic analysis. This study was motivated by and is created in the context of archaeological work conducted in the site of Pirro Nord in Puglia, Italy (Arzarello et al., 2007, 2012, 2015). Specifically, the objectives are: 1) to test and qualitatively assess, by experimentation, the presence and extent to which the wet sieving process may introduce or modify traces on lithic artefacts, 2) to understand the nature of any such potential alterations and whether they may be a legitimate concern in use-wear analysis, and if necessary, 3) to develop protocols for distinguishing between use-wear and modern, post-excavation/post-recovery-related contamination traces. Ultimately, this distinction is critical for ensuring the reliability of traces identification and the validity of interpretations drawn from lithic functional analysis.

2. Materials and methods

2.1. The archaeological context: Pirro Nord 13

The archaeological site of Pirro Nord 13 is located at the foothills of the Gargano region in Puglia, Italy, and is characterised by a Pleistocene deposit within a vertical fracture of a karst formation (Fig. 1). Dated to approximately 1.3 million years ago, it represents one of the oldest sites in Europe (Arzarello et al., 2007, 2012; Duval et al., 2024).

The site is situated in a homogeneous sedimentary matrix, formed by chaotic depositional events, including debris flows and collapse phases, indicative of repeated alluvial processes over time (Giusti and Arzarello, 2016; Karampatsou, 2017). The four stratigraphic units that comprise the site's stratigraphy exhibit significant differences in sediment granulometry. *Unit A*, primarily composed of very fine mud with poorly sorted grains and no apparent structure, is the thinnest layer, ranging between 20 and 30 cm. Its granulometry is characterised by the predominance of small particles, and its boundary between the unit below, *Unit B*, is easily distinguishable due to the chromatic variation and differences in grain sizes. *Unit B*, with a thickness between 60 and 100 cm, consists of a gravel and mud matrix with calcareous pebbles ranging from 1 to 10 cm. This unit is characterised by a chaotic structure with no preferential orientation of clasts and a higher proportion of gravel compared to *Unit A*. *Unit C*, with a thickness of approximately 100 cm, consists of a gravel and mud matrix with progressively larger clasts, including limestone boulders. The decrease in calcite content and the increase in plagioclase minerals, such as anorthite and albite, indicate a change in mineral composition relative to the upper units. Finally, *Unit D*, with a thickness of at least 100 cm and is still under excavation, is composed of a gravel and muddy sand matrix, with a higher density of limestone boulders and an increased presence of kaolinite in the muddy sands. The granulometry of the units tends to increase with depth, with larger particles more prevalent in the deeper units (Fig. 1).

Pirro Nord 13 provides crucial evidence of the technological and environmental situation of early humans in southern Europe (Arzarello et al., 2007, 2012, 2015; Duval et al., 2024; López-García et al., 2015). The archaeological evidence includes lithic artefacts made exclusively from locally sourced Gargano flint, attributed to the Lower Palaeolithic. Use-wear analysis indicates their function for meat processing, which is further supported by faunal remains, including fragments of large mammals such as deer and probable bovids, that were found to show reliable evidence of butchering and bone marrow extraction, suggesting hunting and consumption activities (Cheheb et al., 2019). The faunal assemblage reflects a significant dietary component, highlighting the site's role in understanding prehistoric subsistence strategies and the interaction between early humans and their environment.

2.2. Experimentation

The experimentation was conducted in two phases. During the initial phase, in the lithics laboratory at the University of Ferrara, 12 unretouched flakes were produced using direct percussion with a hard hammerstone, following an opportunistic method and employing a distinctive type of flint from the Scaglia Rossa formation (Fig. 2*a*). The choice of Scaglia Rossa flint, typical of formations in the Veneto region, was deliberate as it is a raw material frequently utilised in prehistory, as documented at numerous archaeological sites, such as Riparo Tagliente,

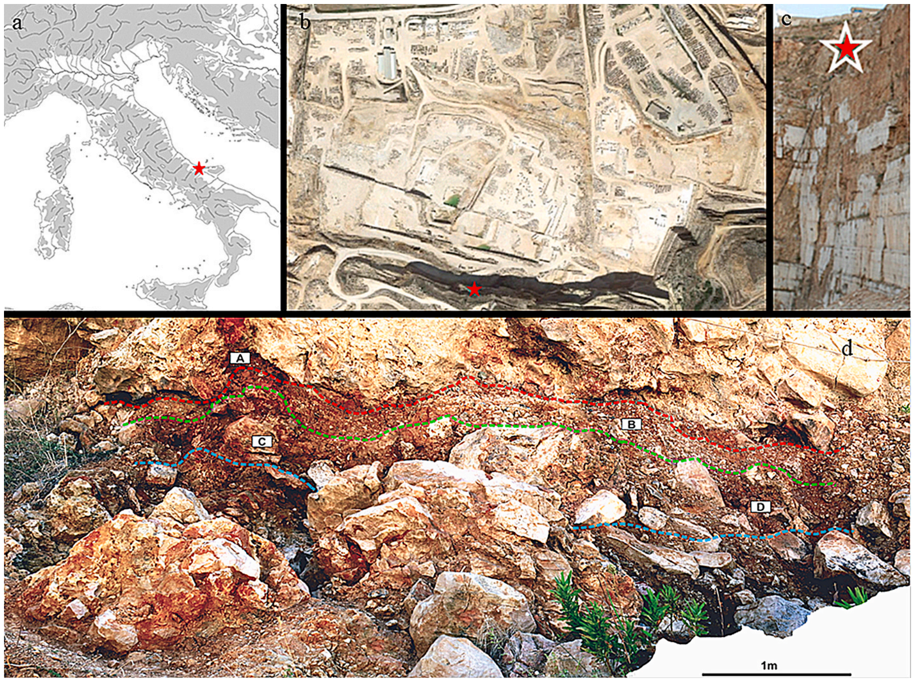

Fig. 1. Site location: (a) Location of the Pirro Nord fossiliferous area. (b) Aerial view of the PN13 fissure within the quarry. (c) Position of the site on the quarry wall. (d) PN13, stratigraphic layout across squares 1 and 6. Labels indicate the stratigraphic units (SUs), and lines mark their bases. Modified from Cheheb et al., 2019).

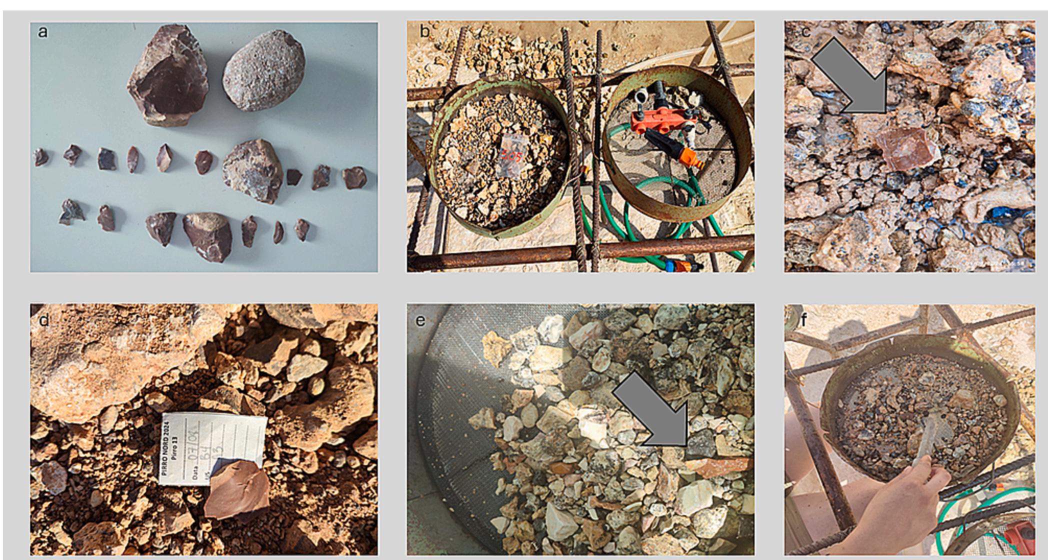

Fig. 2. Experimentation. (a) Experimental assemblage. (b) Flake S05 introduced into the metal sieves at the site of Pirro Nord. (c) Detail of a flake, indicated by grey arrow, mixed within sediments in a sieve before wet sieving. (d) Detail of a flake mixed within sediments with the label containing its archaeological provenance at Pirro Nord. (e) Flake contained in a sieve after the wet sieving process, indicated by the grey arrow. (f) Wet sieving at Pirro Nord.

Broion, and Grotta di Fumane, spanning a broad diachronic period from the Lower Palaeolithic to the Mesolithic (e.g. Arzarello, 2004; Berruti et al., 2020; Bertola et al., 2013; Fontana et al., 2019; Peresani, 2019; Peresani et al., 2019; Romandini & Peresani, 2019). Moreover, the Scaglia Rossa flint allowed for an unmistakable distinction from the local lithic materials at the Pirro Nord 13 site. Only flint of Gargano origin, sourced from Puglia, is documented in the assemblage at this site (Arzarello et al., 2007), making it impossible to confuse with the Scaglia Rossa from Veneto, sourced approximately 800 km away. The red colour of the Scaglia Rossa flint also visually facilitated the differentiation between experimental and archaeological materials, preventing any potential contamination with artefacts from Pirro Nord (Fig. 2c). After production, each flake was assigned a unique identification number. Ten of the twelve flakes were then used to process two different materials of medium to high hardness (fresh wood and deer antler) with an arbitrary active edge selected for each flake. A fixed use time of 10 min per flake was established (Table 1), creating a controlled variable to facilitate the consistent formation of use-wear traces.

The second phase of the experimentation entailed the transportation of the flakes to the site of Pirro Nord, where they were introduced into the sieves containing sediment procured from the actual excavation (Fig. 2c-e). The standard operating procedure for the sieving process in Pirro Nord involves submerging sediment-filled fine-mesh (5 mm) metal sieves in water and subjecting them to rigorous shaking to facilitate the

Table 1
Experimental flakes with worked materials, time of use, type of movement employed, and dimensions.

Flake ID	Worked materials	Time of use	Type of movement	Length (mm)	Width (mm)	Thickness (mm)
S01	Antler	10 min	Transversal	30	17	7
S02	Antler	10 min	Transversal	29	10	3
S03	Antler	10 min	Longitudinal	28	18	4
S04	Antler	10 min	Mixed	27	18	5
S05	Antler	10 min	Mixed	31	28	9
S06	Fresh Wood	10 min	Longitudinal	39	16	7
S07	Fresh Wood	10 min	Longitudinal	30	25	4
S08	Fresh Wood	10 min	Transversal	31	19	4
S09	Fresh Wood	10 min	Transversal	27	18	5
S10	Fresh Wood	10 min	Mixed	31	20	6

separation of artefacts from sedimentary residues. Additionally or alternatively, the sieves are positioned under low-pressure, continuous water flow, enabling manual sediment removal through gentle agitation. Each sieve comes with a label containing the sediment matrix's corresponding stratigraphic unit and square, which was also noted for each flake introduced into the sieves to ensure accurate provenance tracking and material characterisation. For the experiment, both metal mesh and plastic mesh sieves were used, and the duration of the sediment cleaning process was recorded based on actual operator effort rather than adhering to fixed time intervals, providing a more realistic representation of field conditions (Table 2). To bolster the reliability of the experimental results, two unused flakes were also incorporated into the same procedure, to make it possible to identify alterations unrelated to the 'original' use of the flakes.

2.3. Microscopic analysis

The analysis of the experimental flakes under the microscope was conducted three times: 1) before use, 2) after use on fresh wood and antler, and finally 3) after being subjected to sieving alongside sediments from the site of Pirro Nord. Except for the first time, the flakes were subjected to a cleaning protocol before microscopic analysis: each flake was placed in small individual plastic bags with a mild solution of common anionic surfactant and distilled water (<2% (v/v) concentration or about 10 mL of liquid detergent per 500 mL of water), left in an ultrasonic cleaner for not more than 180 s, and then air-dried. This gentle cleaning process is purposely designed and has been found by the authors to effectively dislodge and remove dirt and oils that may hinder clear observation of edges and traces under the microscope, without potentially over-cleaning or producing either a gloss enhancement or matte effect on the lithic surface.

Table 2
Experimental flakes with type of sieve, time of sieving, and sediment matrix within which they were incorporated (archaeological provenance: stratigraphic unit – artificial cut – square).

Flake ID	Type of sieve	Time in sieving	Sediment matrix
S01	Metal	05:44	D21 A05
S02	Metal	10:00	D24 C7
S03	Metal	01:38	D4 A3
S04	Metal	10:13	B4 A3
S05	Metal	06:39	D41 D3
S06	Plastic	06:30	D41 D3
S07	Plastic	05:00	D41 D3
S08	Plastic	06:10	D41 D3
S09	Plastic	06:11	D41 D3
S10	Plastic	06:12	D41 D3
SN01	Metal	05:00	B4 A3
SN02	Plastic	05:30	D27 C7

The flakes were analysed using a Leica Ez4 HD stereomicroscope at magnifications ranging from 8x to 10x. Further detailed imaging was conducted using an Optika B-600Met metallographic microscope equipped with five PLAN IOS MET objectives (5x, 10x, 20x, 50x, and 100x) and two digital cameras, an Optika B3 and an Optika B5. This combined use of low-power and high-power instruments has proven to be highly effective for use-wear analysis, as demonstrated by numerous studies (e.g., Berruti et al., 2023, 2024; Claud et al., 2019; Cruz et al., 2016; Fasser et al., 2022; Pawlik, 2001; Venditti et al., 2016). On one hand, the low-power approach allows for the observation of edge scars, rounding, microfractures, and striations, providing insights into potential activities performed (e.g., cutting, scraping, piercing) and helps determine the hardness of the materials worked. On the other, the high-power approach enables a more detailed examination of these traces and improves the visibility of polish and bright spots, contributing to a more precise understanding of the activities performed and the materials processed (Fullagar & Matheson, 2014; Keeley & Newcomer, 1977; Odell, 1981; Semenov, 1964; Tringham et al., 1974). For a systematic identification and comparison of wear traces before and after sieving, the following parameters were used, qualitatively and depending on applicability: position, organisation, distribution, morphology, dimensions, degree of development or intensity, density, coalescence, texture, depth, and micro-topography (e.g., Berruti et al., 2024; Claud et al., 2019; Ibáñez and Mazzucco, 2021; Keeley, 1980; Odell, 1981; Pawlik, 2001; Tringham et al., 1974; van Gijn, 1989; Vaughan, 1985).

Each artefact was examined and micro-photographed at both high and low magnifications before use, after use, and after contact with sieves. Capturing the images and merging them using Adobe Photoshop allowed for precise alignment of the areas on the surface and edges of the artefacts with different depths of field. This integration process improved visual continuity, resulting in a detailed and uniform representation of the surfaces, which facilitated the careful examination, description, and interpretation of traces. By comparing the condition of the edges and surfaces in a sequential basis, it was possible to assess the extent of any production of new traces or alteration of existing use traces caused by sieving.

3. Results

The results obtained from this study are highly encouraging. As demonstrated by the analyses conducted, the surfaces of the flakes did not exhibit significant structural alterations following their incorporation into the sediments from the site of Pirro Nord and eventual wet sieving, and that the experimental use traces produced by material processing remained unaltered. No significant differences in terms of trace preservation, edge attributes, or polish development were found between those that had contact with metal mesh sieves and those with plastic mesh sieves, also regardless of the duration of the process.

The flakes used on working antler (flakes S01–S05) exhibit particularly evident traces of working hard material, including numerous, aligned, deep edge removals, polish with high brilliance but discontinuous and marginal in extent, and occasional, wide and deep striations (Figs. 3 and 4). These traces were not altered by the wet sieving process and remained fully readable, without the emergence of new, potentially misleading ones. An interesting case concerns flake S02 (Fig. 3), which suffered a fracture during wet sieving, likely due to its thinness (under 3 mm thick) and/or the presence of a pre-existing latent fracture. While this did not negatively affect the interpretation of use traces on the flake, in the absence of proper technological study and refitting, this fragmentation could artificially augment the number of identifiable tools in

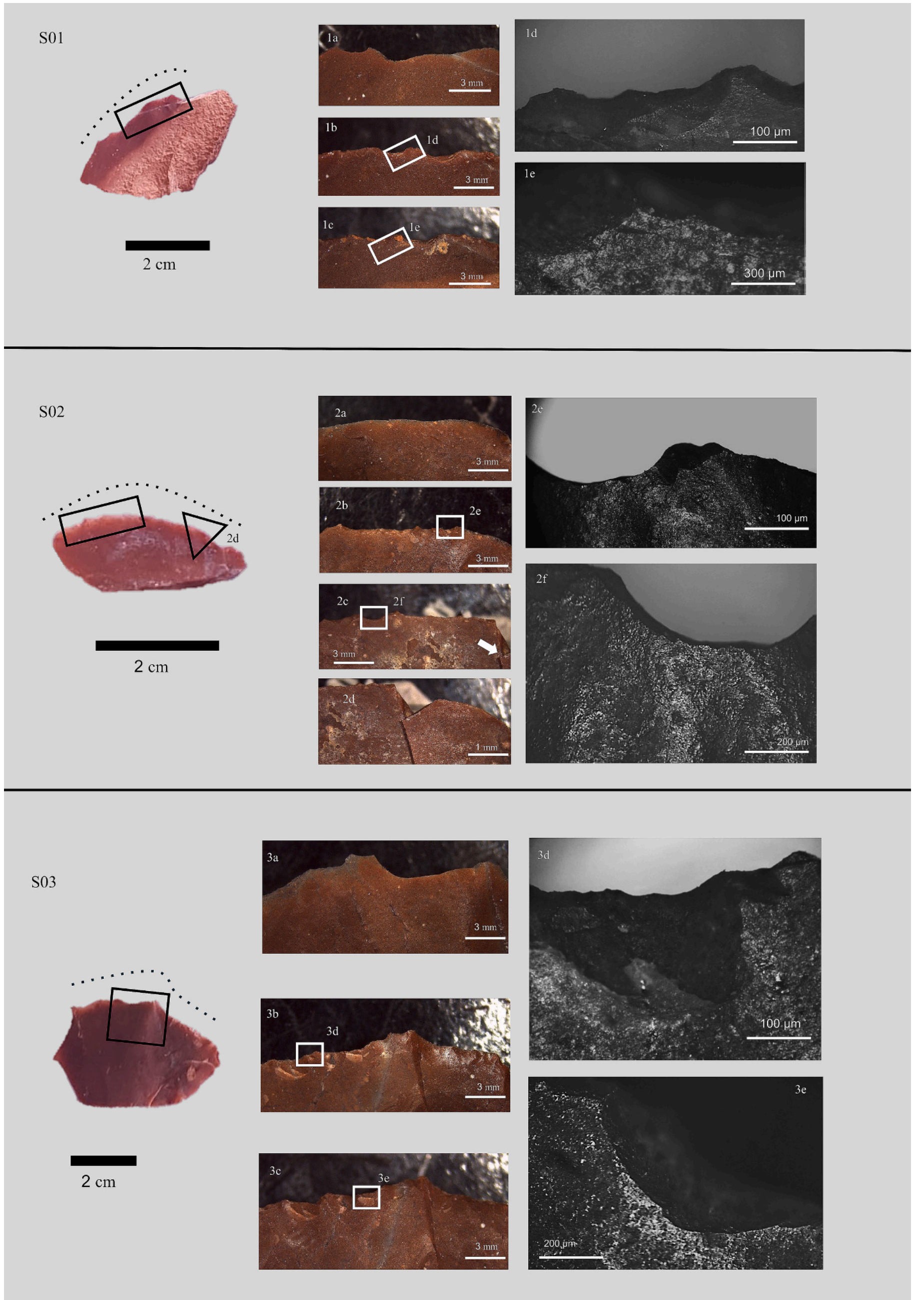

Fig. 3. *S01*: (*1a*) Edge before use. (*1b*) Edge after use showing edge removals linked to transversal work on medium-hard materials. (*1c*) Edge after use and wet sieving, exhibiting blunting but retaining original traces. (*1d*) Magnified view of *1b*, small and continuous areas of smooth and flat polish (contact with antler). (*1e*) Magnified view of original polish in *1c*, unaltered after wet sieving. *S02*: (*2a*) Edge before use. (*2b*) Edge after use (dorsal), showing frequent, ridged edge removals linked to transversal work on medium-hard materials. (*2c*) Edge after use and wet sieving (ventral), showing less frequent, edge-directed removals. White arrow indicates fracturing. (*2d*) Detail of the fracture. Position in the flake indicated by triangle. (*2e*) Magnified view of *2b*, small and continuous areas of smooth and flat polish (contact with antler). (*2f*) Magnified view of original polish in *2c*, unaltered after wet sieving. *S03*: (*3a*) Edge before use. (*3b*) Edge after use, showing edge removals linked to longitudinal work on medium-hard materials. (*3c*) Edge after use and wet sieving, exhibiting some micro-chipping on the ridges but retaining original, readable use traces. (*3d*) Magnified view of *3b,* small and continuous areas of smooth and flat polish (contact with antler). (*3e)* Magnified view of original polish in *3c*, unaltered after wet sieving.

the assemblage with use-wear traces.

In flakes S04 and S05 (Fig. 4) used on antler, pre- and post-sieving observations show consistent edge removals linked to mixed action on hard material, regardless of the superficial adherence of some sediment residue on a high ridge in flake S04 (Fig. 4*c*). High-magnification views (Fig. 4*d–f*) reveal traces of compact, smooth polish typical of antler processing. Although polish brightness and continuity appear slightly diminished after sieving, the diagnostic features remain discernible and functionally interpretable (cf. Grace, 1996; Keeley, 1980; Rots et al., 2015).

Flakes S06 to S10, used for working fresh wood, exhibit less evident edge removals compared to the flakes used on harder material. High-magnification observation allowed for a clear distinction of the traces that are characteristic of wood working, which were in no way altered or obliterated by wet sieving: relatively shallow edge removals, blunting of working edge, and polish moderate in extent and with a hard domed

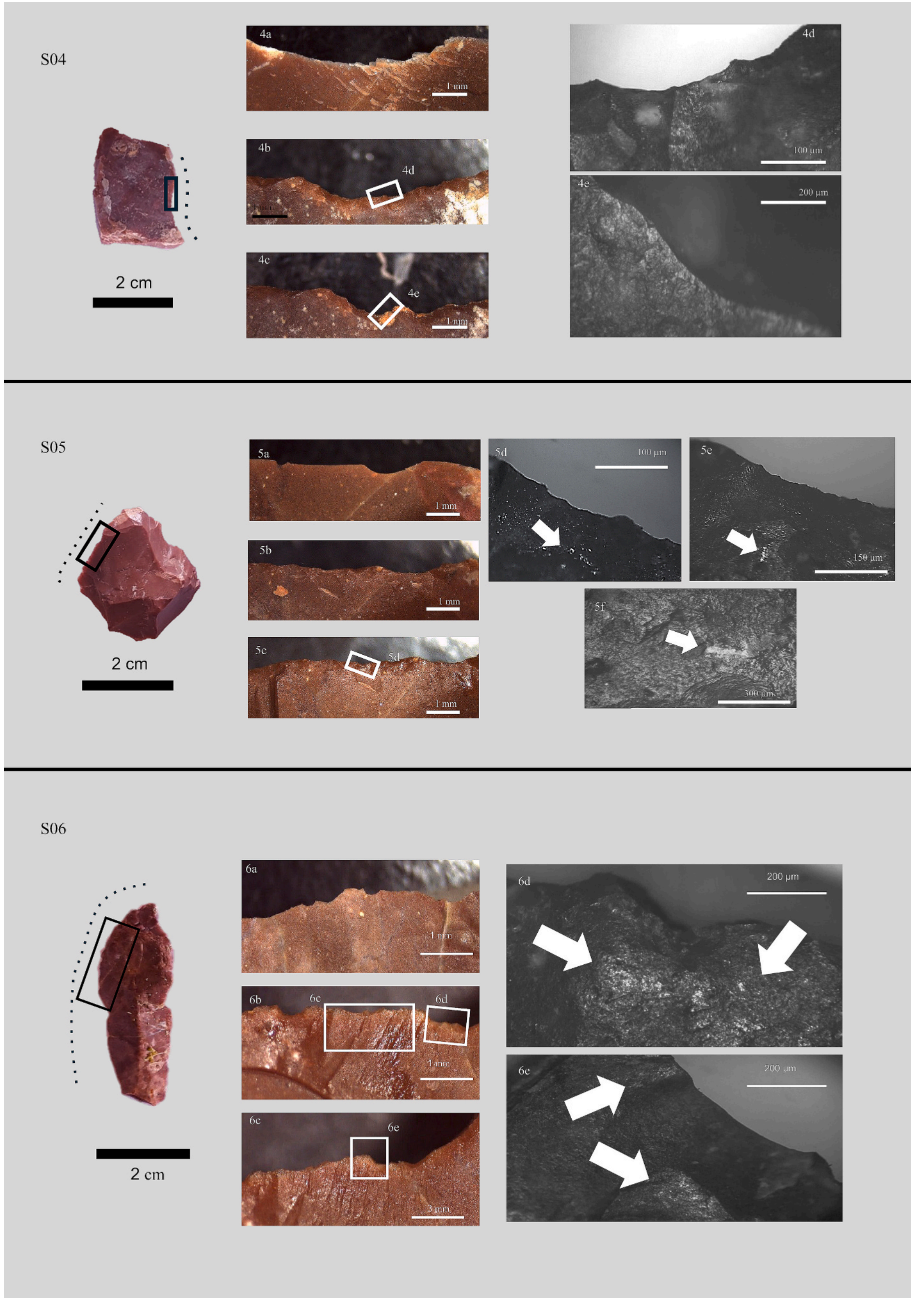

Fig. 4. *S04*: (*4a)* Edge before use. (*4b*) Edge after use, showing edge removals typical of mixed actions on hard material. (*4c*) Edge after use and wet sieving, showing some sediment grains adhering on a ridge, but retaining original traces. (*4d*) Magnified view of *4b* showing micro-polish from antler processing, although not well developed. (*4e*) Magnified view of original polish in *4c*, unaltered after wet sieving. *S05*: (*5a*) Edge before use. (*5b*) Edge after use, showing continuous, superimposed edge removals. (*5c*) Edge after use and wet sieving, retaining original traces. (*5d*) Magnified view of *5c* showing light polish formed during antler processing; the arrow indicates the position of a deep striation better seen at higher magnifications in *5e* and *5f*. *S06*: (*6a*) Edge before use. (*6b*) Edge after use, showing edge removals typical of longitudinal work on soft-to-medium-hard material. (*6c*) Magnified edge indicated in *6b,* after use and wet sieving, demonstrating no significant changes. (*6d*) Magnified view of *6b* showing clear polish with domed topography and wide spacing, typical of wood processing; arrows indicate specific contact points. (*6e*) Magnified view of original polish in *6c*; arrows indicate specific contact points, unaltered after wet sieving.

coalescence (Fig. 5).

Typical traces observed for flakes S06–S09 (Fig. 5), were longitudinal or transversal edge removals, wide-spaced polish, and domed topography—attributes consistently linked to wood processing (Ibáñez and Mazzucco, 2021; Rodriguez et al., 2022; Van Gijn, 1989). Despite minor modifications in edge clarity, the topography and distribution of the polish remained unaffected by the sieving process. For instance, the polish observed on flake S09 (Fig. 5*d–f*) retained its domed structure and spacing, indicating functional continuity. Thus, in all cases analysed, the traces remained easily identifiable through both low power and high power analysis.

Furthermore, a close inspection of unused flakes SN01 and SN02 (Fig. 6) revealed isolated point removals likely caused by contact with sediment or mesh. These modifications are morphologically distinct from intentional use-wear and lacked any organized spatial distribution or polish, reinforcing their classification as post-depositional (Levi-Sala, 1986; McPherron et al., 2014; Venditti et al., 2016). Altogether, even subtle changes induced by the sieving process—such as minor dulling or

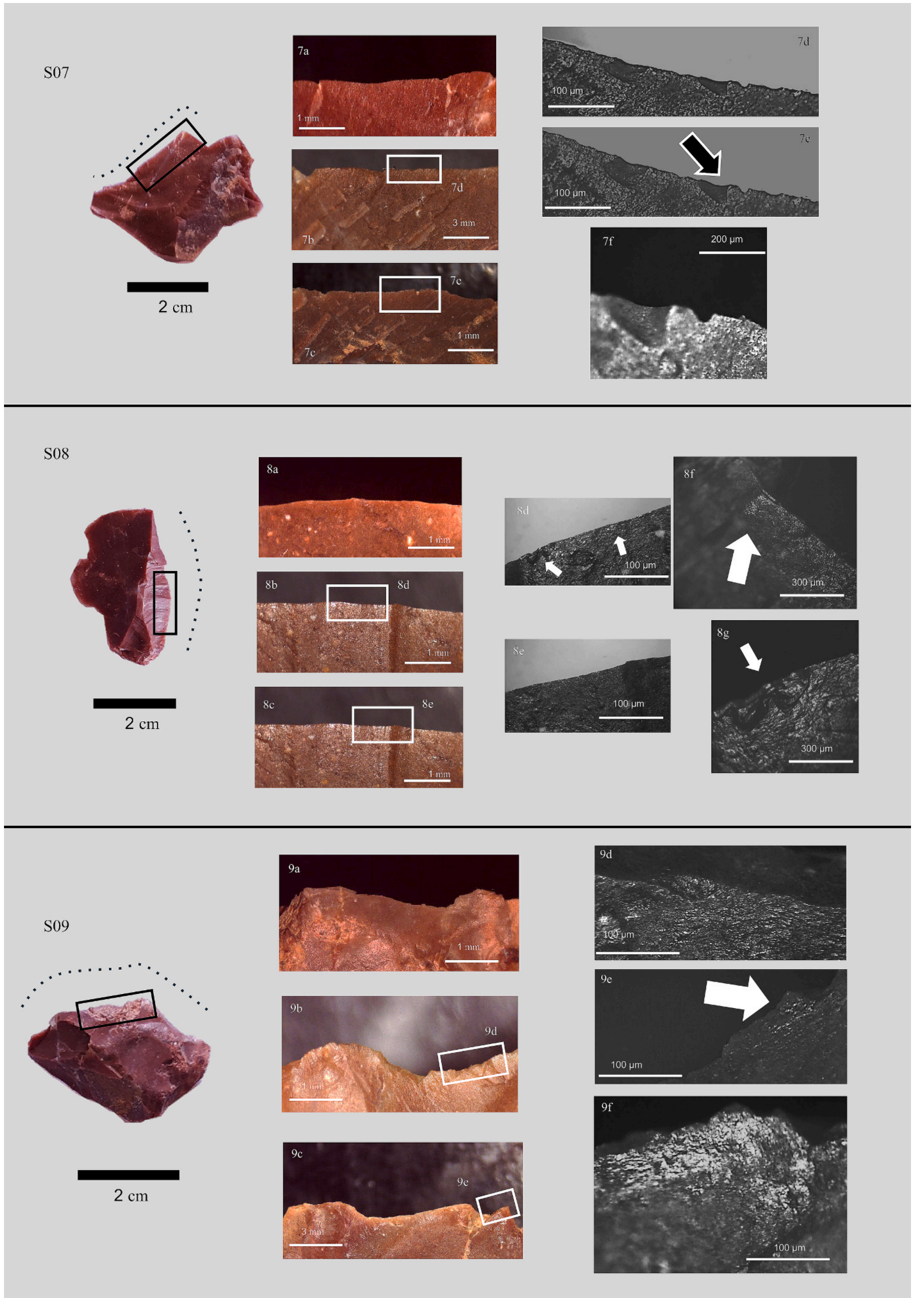

Fig. 5. *S07*: (*7a*) Edge before use. (*7b*) Edge after use, showing edge removals typical of longitudinal light work on soft-to-medium-hard material. (*7c*) Edge after use and wet sieving, demonstrating no significant changes. (*7d*) Edge removals of *7b* at higher magnification, showing contour with polish of wide spacing and relatively doomed topography, typical of wood processing. (*7e*) Magnified view of original polish in *7c*, unaltered after wet sieving, shown at higher magnification in *7f*. *S08*: (*8a*) Edge before use. (*8b*) Edge after use, showing small edge removals typical of work on soft-to-medium material. (*8c*) Edge after use and wet sieving, demonstrating no significant changes. (*8d*) Magnified view of *8b* showing small edge removals typical of transversal work on soft-to-medium material. (*8e*) Sparse and unclear polish traces on the edge; magnified of *8c*. (*8f*) Magnification of *8d* showing edge with wide-spaced, relatively compact polish on the upper section, indicating wood processing. (*8 g*) Magnification of two edge removals with morphologies typical of transversal actions in *8d*. *S09*: (*9a*) Edge before use. (*9b*) Edge after use, showing edge removals typical of transversal working on soft-to-medium material. (*9c*) Edge after use and wet sieving, demonstrating some blunting but retaining original traces. (*9d*) Magnified view of *9b* showing polish with a wide-spaced, compact, and domed topography, typical of wood working. (*9e*) Magnified view of polish in *9c* retained after sieving; arrow indicates latent fractures and evidence of wood polish, characterised by semi-open polish with domed topography, shown in higher magnification in *9f*.

microfracturing—did not compromise the visibility or interpretability of functional traces.

4. Discussion

The results of this study highlight the resilience of use-wear traces on lithics under post-recovery procedures, despite concerns about contamination of traces through sieving processes. Wet sieving entails the contact of lithic artefacts with: 1) other elements of the archaeological matrix within which they are contained, 2) stagnant to low pressure water flow, and 3) plastic or metal sieve mesh. This contact, facilitated by the controlled shaking or rotating of the sieve in a circular

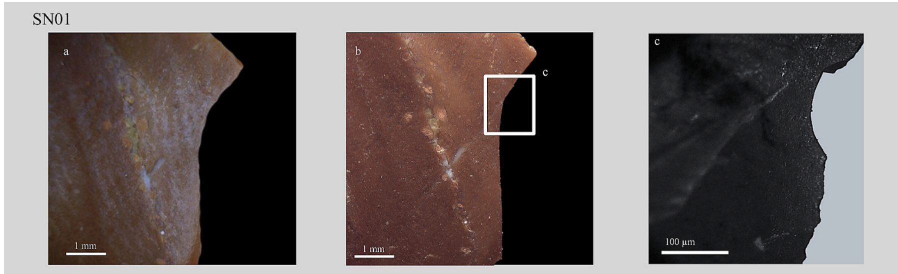

Fig. 6. Macro and micro-images of unused, control flake *SN01*. (*a*) Edge prior to wet sieving. (*b*) Edge after wet sieving, displaying small, point-like edge removals usually attributable to trampling, movement, or contact with coarse-grained sediment. (*c*) Edge after wet sieving, under the metallographic microscope, showing no evidence of polish or any other kind of use-wear trace.

or back-and-forth motion under shallow water, pertains to mechanics that are in a way similar to that of natural abrasion processes seen in environments like rivers or windblown sand, which potentially cause post-depositional modifications on lithic edges and surfaces such as rounding, striations, and polish. The experimental protocol adopted, which simulated realistic excavation scenarios using sediments from actual archaeological deposits, provide insights into the overall preservation of use-wear traces.

All lithics subjected to experimental use followed by wet sieving retained their original traces, regardless of their characteristics based on the worked material (wood or antler) and the type of sieve used (metal or plastic mesh). The few observable changes that were present, including blunting of higher ridges and some micro-chipping along thinner margins, were minimal and too subtle to affect the readability of use traces. The inclusion of two unused flakes as controls further validated that alterations introduced during sieving did not replicate the distinctive features of functional wear: faint and unstructured polish, where present, were morphologically distinct, lacked any functional organisation, and did not resemble intentional use-wear patterns. Indeterminate traces as such may be more attributable either to taphonomic events or to knapping activity (e.g. Bird et al., 2007; Healan, 2019; Thiébaut, 2007). These results align with earlier work underlining the stability of use-wear features under moderate post-recovery processes (Fullagar & Matheson, 2014; Marreiros et al., 2020a; Mazzucco et al., 2013). However, the unused flakes exhibiting chipping on thinner margins, along with the flake that fractured during sieving, may serve as cautionary examples that certain fragile pieces may be at risk of damage. Whenever possible, prior manual sorting may be carried out as a preemptive assessment to determine what archaeological materials should or should not undergo the process, although since wet sieving is an indiscriminate approach as far as maximum recovery is concerned, this may be impractical at times. Awareness and careful handling by archaeologists conducting the sieving may minimise this risk, and if inevitable, receptiveness of use-wear analysts to consider such mechanisms in their analysis.

In the context of Pirro Nord 13, within which the methodology of this investigation was developed, the study contributes to the understanding of the lithic assemblage and the integrity of corresponding analysis in a substantial way. Functional studies previously conducted for the site identified use-wear traces on only 5 out of 360 artefacts (less than 2 % turnout), a result largely attributed to the presence of extensive post-depositional alterations—such as edge damage, rounding, concretion, patina—caused by the antiquity of the deposits and their accumulation conditions (Berruti & Arzarello, 2020; Cheheb et al., 2019; Lemorini et al., 2014). The possibility of contamination by activities linked to excavation and post-excavation could not be completely ruled out, but thanks to the results of this experimentation, we are now able to exclude wet sieving as a contributing factor to the low turnout of identifiable use traces on artefacts from the site.

Furthermore, the experimental approach used in this study is aimed at the validation of and advancement in archaeological practice by addressing the direct impact of excavation and recovery methodologies on the integrity of lithic functional traces. We have seen earlier studies that examined post-depositional alterations by replicating taphonomic processes in controlled settings, such as sediment consolidation, trampling, and transport of sediment-embedded lithic artefacts in tumbling machines and similar devices (Asryan et al., 2014; Eren et al., 2011; Levi-Sala, 1986; Venditti et al., 2016; Mazzucco et al., 2013). For modern contamination, insights have been provided by experimental duplication of edge damage from cleaning and brushing, dry sieving, and bagging together of artefacts (Gero, 1978), by comparative studies of the effects of various sieving and excavation techniques (Cnuts et al., 2021), as well as by determining some common contaminants encountered in residue analysis related to the handling of artefacts (human skin, modelling clay commonly used for different purposes in the lithics laboratory, pencil marks) and to the cleaning of artefacts (water or acetone, fibres from paper towels used to dry specimens after cleaning) (Pedergnana et al., 2016), including "invisible" contaminants such as the release agent in zip-top bags (Frahm et al., 2022). The research presented here, specifically focused on the effects of wet sieving, demonstrates that this washing and recovery technique has negligible contaminating impact on lithic artefacts as it allows for the preservation and readability of the original use-wear traces, and is therefore a reliable field practice.

Taken with other studies (especially Cnuts et al., 2021; Pedergnana et al., 2016), moreover, it becomes apparent that the specified *gentle* cleaning protocol employed in the laboratory by the authors proves effective and may be crucial in the washing off of potential metal residues (and possibly other contaminants) so that they are no longer observable on the lithic surface by the time the artefacts are subjected to microscopic analysis. At any rate, while many modern contaminants are reported to endure even extensive cleaning procedures (Frahm et al., 2022; Pedergnana et al., 2016), the risk that ancient wear and residue are eliminated prior to or along with the washing off of contaminants during a cleaning protocol cannot be completely dismissed and therefore requires careful consideration. As in this case, however, even with the wet sieving process entailing a washing of artefacts at the recovery stage and prior still to any laboratory protocol, the original use-wear on the experimental flakes could remain intact.

The study presents a huge potential for further research, as it was developed with a scope specific to conditions at the site of Pirro Nord, and in its current state has a number of limitations. The sample size (12 experimental flakes), for instance, was here deliberately small and intended for in-depth, systematic observation rather than statistical analysis, whereas a similar experiment with a larger sample size could benefit from the application of quantitative measures, such as percentages or edge damage metrics (Cnuts et al., 2021; also see Galland et al., 2019; Ibáñez and Mazzucco, 2021; McPherron et al., 2014; Werner, 2018). Certain potential variables were also here not tested, such as other sets of use traces and residues, different sediment matrices, raw materials other than flint, sieving procedures entailing different parameters (e.g., in terms of duration and water pressure), and variations in or the complete absence of cleaning protocols prior to microscopic analysis. Future research could build on these results by expanding the experimental database of use traces, conducting the sieving with stratigraphic matrices from other archaeological sites, and examining a wider range of lithic materials, such as quartz and quartzite which were already seen to demonstrate a different behaviour in terms of taphonomy (Venditti et al., 2016), basalt (see Asryan et al., 2014), and obsidian (see Emery & Aoyama, 2007) to evaluate their response to excavation and post-recovery-induced alterations. Additionally, further investigations into the effects of dry sieving and other sediment processing techniques that do not include washing or cleaning the artefacts would provide a more comprehensive understanding of contamination risks. We would like to build on and support the already encouraged case-by-case approach and the development of specific protocols per site also in terms of recovery and cleaning protocols (Frahm et al., 2022; Pedergnana et al., 2016), acknowledging that procedures may differ depending on certain conditions and limitations in an archaeological project. Nevertheless, long-term experimental studies focusing on the cumulative impacts of prolonged excavation activities would further enhance methodological rigour.

5. Conclusion

This study demonstrates that wet sieving, a common practice in archaeological fieldwork, does not significantly alter use-wear traces on lithic artefacts, and therefore does not compromise the interpretive reliability of functional analyses. This reinforces the methodological robustness of use-wear studies while underscoring the importance of rigorous experimental and analytical approaches to ensure the integrity of interpretations for distinguishing authentic use-wear from post-depositional and other types of modifications and contamination (e.g. Asryan et al., 2014; Asryan, 2015; Balirán, 2014; Burroni et al., 2002; Caricola et al., 2018; Carranza and Alberti, 2018; Cnuts et al., 2021; Eren et al., 2011; Frahm et al., 2022; Gero, 1978; Levi-Sala, 1986; Mazzucco et al., 2013; McPherron et al., 2014; Pedergnana et al., 2016; Venditti et al., 2016; Werner, 2018). This work also wishes to contribute to archaeological practice by building upon the previous ones in highlighting the need to assess the various protocols carried out in the archaeological site up to the laboratory and to reflect on how they influence the empirical evidence that in turn dictate our results and interpretations. Continued refinement of excavation and analytical protocols is essential to maintaining the integrity of functional analyses in archaeological research.

Declaration of Generative AI and AI-assisted technologies in the writing process

The authors used [e.g., ChatGPT by OpenAI] for language refinement. After using this tool, authors reviewed and edited the content, taking full responsibility for the final version of the manuscript.

CRediT authorship contribution statement

Trishia Gayle R. Palconit: Writing – review & editing, Writing – original draft, Investigation, Formal analysis, Data curation. **Lorenzo Testi:** Writing – original draft, Investigation, Formal analysis, Data curation, Conceptualization. **Marta Arzarello:** Supervision. **Gabriele L. F. Berruti:** Writing – original draft, Supervision, Methodology, Investigation, Formal analysis, Data curation.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data availability

Data will be made available on request.

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