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Old stones' song—second verse: use-wear analysis of rhyolite and fenetized andesite artifacts from the Oldowan lithic industry of Kanjera South, Kenya

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Old stones' song - 2nd verse: Use-wear analysis of rhyolite and fenetized andesite artifacts from the Oldowan lithic industry of Kanjera South, Kenya.

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Abstract

This paper investigates Oldowan hominin behavioral ecology through use-wear analysis of artifacts from Kanjera South, Western Kenya. This paper extends development of our experimental use-wear reference collection and analysis of use wear on the well preserved and unweathered Oldowan tools from this site to include rhyolite, a non-local material of similar durability to previously studied quartz and quartzite tools, and fenetized andesite, a local material with considerably less durability. Variability in rhyolite and fenetized andesite texture, inclusions, and matrix required enhancement of previous methods so we combine the use of stereoscopic, metallographic and scanning electron microscopy in this study. This study allows us to begin exploration of the links between specific artifactual raw materials and the materials they were used to process. Data assembled so far suggest that tools fashioned from non-local and local stone were, with one possible exception, used to process similar materials. Tools made of more durable non-local rhyolite, quartz, and quartzite were used to process wood, but less durable local fenetized andesite was not.

Additionally, experiments carried out with replicas of tools made of rhyolite and fenetized andesite confirm interpretation of reduction sequences that tools made of less durable local material had a shorter use-life and were used expediently compared to the more durable non-local quartz, quartzite, and rhyolite. These new data improve our understanding, of the functional needs, behavioral solutions, and cognitive capacities of Oldowan hominins. Finally, this article shows how use-wear data, combined with data from lithic raw material and lithic technology, can be a powerful means for evaluating two key points for human evolution, long-term memory and planning.

Introduction

Lithic use-wear analysis provides a direct means to document the range of hominin behavior represented by Oldowan tools. The primary depositional context (Ditchfield et al. 1999; Plummer et al. 1999; Ditchfield et al. in press) and excellent tool surface preservation of the Kanjera South Oldowan assemblage (Lemorini et al. 2014) makes it well-suited to use-wear analysis. Additionally, it is the largest known Oldowan lithic assemblage (n = 4474 items), including a greater diversity of materials and lithologies than other assemblages, and includes many non-local materials that were transported at least 10 km to the site from their conglomerate source beyond the Homa Peninsula (Braun et al. 2008; 2009a,b). We can therefore address relationships between raw material type, transport distance, and artifact use. Use-wear analysis of the Kanjera lithic assemblage provides robust data to anchor our understanding of the behavioral ecology and cognitive capabilities of Oldowan hominins. Lemorini et al. (2014) demonstrated that quartz and quartzite tools from Kanjera were used to process of a range of plant materials including wood and underground storage organs (USOs) as well as for animal butchery. Here we expand use-wear analysis of the Kanjera lithic assemblage to include tools manufactured from non-local rhyolite and locally available fenetized andesite.

Experiments demonstrate that rhyolite and fenetized andesite active edges are less durable than those of quartz and quartzite (Braun et al. 2009a). Moreover, fenetized andesite has a variable texture causing it to flake unpredictably (Braun et al. 2009a,b). This use-wear study will investigate a) the extent to which rhyolite and fenetized andesite were used in a similar way to quartz and quartzite, in terms of materials processed and actions carried out, b) the duration of use for local versus transported raw materials to examine the hypothesis that the former were used expediently while the latter tools were used for longer-duration activities, or for specific tasks, and c) whether rhyolite and fenetized andesite were used to process the same range of materials as quartz and quartzite tools or if they were used for narrower or more specific tasks.

It is difficult to detect, describe, and diagnose use traces on rocks with a very heterogeneous texture. Because of their variable texture, matrix, and inclusions, analysis of rhyolite and fenetized andesite presented here required the refinement of the methodology described in Lemorini et al. 2014, which had been designed to examine crystalline and cryptocrystalline materials such as chert, flint, quartz, and quartzite. The observation protocol developed in our previous study was optimized for the examination of the rhyolite and fenetized andesite artifacts. We added SEM observations to the methodology following the results of

Perdegnana and Ollé (2017 and references therein) that demonstrate the benefit of this technique for the characterization of use-wear on non-flint rocks. Moreover, with the aim of standardizing as much as possible the description of use-wear, we integrate in our list the variables and definitions proposed by previous use-wear studies on non-flint materials (Clemente Conte et al. 2015; Perdegnana and Ollé 2017).

Kanjera South: the archaeological context

Kanjera South is being investigated as part of the Homa Peninsula Paleoanthropology Project (HPPP) whose primary goal is to document hominin activities across a range of paleoecological settings. Kanjera South is located on the Homa Peninsula, which is situated between the two branches of the East African Rift Valley, on the southern margin of the Kavirondo Gulf of Lake Victoria, southwestern Kenya (Fig. 1). The peninsula is dominated by the Homa Mountain carbonatite complex, active from the late Miocene into the Pleistocene (Le Bas 1977). Fluvial-lacustrine sediments were deposited on the northern flanks of the mountain from 6 Ma through the Pleistocene (Behrensmeyer et al. 1995; Ditchfield et al. 1999; Plummer et al. 1999; Ditchfield et al. in press). The geological context of the Homa Peninsula is unique, as it encompasses a large carbonatite complex, but the peninsula itself is surrounded by an extremely diverse array of geological provinces. The lithic raw material diversity at archaeological sites on and around the peninsula reflects this context (Plummer 2004; Braun et al. 2008).

Oldowan occurrences at Kanjera South were first recognized in a small (~0.5 km^2) amphitheater in 1995. Abundant artifacts and associated fauna are found within the Southern Member of the Kanjera Formation, which is approximately 12 m thick and comprised of 6 beds, from oldest KS-1 to youngest KS-6 (Behrensmeyer et al. 1995; Ditchfield et al. 1999;

Plummer et al. 1999; Ditchfield et al. in press). Oldowan artifacts and associated fauna were recognized in a 2 m thick sequence in the fine alluvial-colluvial sands and silts of upper KS-1 through KS-3. Particle size analysis of the sediment fine fraction in conjunction with new field analysis indicates that sediments from KS-1 through KS-3 were deposited trough tractional and hyperconcentrated flows unlikely to erode or disturb the underlying surface (Ditchfield et al. in press). These were deposited by sheetwash and ephemerally flowing, low aspect and generally low energy rivulets, draining into a paleolake to the north. The lithics and fossils exhibit little or no weathering or rounding. Instead they testify of well preserved surfaces and edge detail. The specimens show a range of hydraulic potentials, supporting the interpretation that KS-1 through KS- 3 deposits represent a primary accumulation from which behavioral inferences can be reliably drawn. One conglomerate level (KS-2CP) provides evidence of a rare episode of rapid water flow. Given the vertical distribution of materials, deposit depths, and estimated low rates of sedimentation and pedogenesis, the archaeological materials accumulated relatively rapidly over a period of decades to hundreds of years per bed.

The presence of the proboscidean *Deinotherium* sp. and the suid *Metridiochoerus andrewsi* suggest a minimum age of 1.7 Ma for the sediments while evidence of *Equus* provides a maximum age of 2.3 Ma. The presence of the Olduvai subchron (1.77-1.95 Ma) in KS-4 and KS-5 further constrains the archaeological levels to ca. 2.0 Ma (Ditchfield et al. 1999; Plummer et al. 1999; Ditchfield et al. in press). 4474 lithic items comprising 3954 intentionally detached pieces (Lemorini et al. 2014, Table 1) and 5000 fossils, many displaying cut and percussion marks, have been recovered from a 169m^2 area since 1996. Taphonomic and zooarchaeological analyses indicate that, with the exception of a conglomerate sub-unit (KS-2cp), hominins were the primary agent of site formation in all three beds (Plummer et al. 1999; Plummer 2004; Ferraro 2007; Ferraro et al. 2013; Ditchfield et al. in press).

Current results of analysis of Kanjera paleoecological and archaeological records may be summarized as follows:

1) Unlike other Oldowan sites situated in more closed woodland settings, analyses of taxonomic representation, ecomorphology, and stable isotopic chemistry of paleosol carbonates and ungulate teeth demonstrate that Kanjera hominins performed their activities in a grassland-dominated ecosystem (Braun *et al.* 2009a,b).

2) Cut marks distributed across meaty portions of small bovid (size class 1 and 2) and limbs were detected and percussion damage indicative of marrow processing as well. Tooth mark frequencies are consistent with early access models. The relatively even representation of high survivorship parts across the skeleton are consistent with hominins hunting, transporting and butchering complete or nearly complete of small bovid carcasses at Kanjera South (Ferraro et al. 2013; Parkinson 2013). High frequencies of size 3 heads suggest that larger bovids were scavenged (Ferraro, 2007; Ferraro et al. 2013).
3) Bovid mortality analysis indicates a) juveniles comprise 50% of the Kanjera bovid assemblage, b) hominins focused their carcass acquisition efforts – probably through hunting – on juvenile size 1-2 bovids, b) size 3 adult bovids were likely scavenged whereas juvenile size 3 bovids were likely acquired by both hunting and scavenging, d) carcass acquisition strategies employed by Kanjera hominins were adapted to grassland habitats and likely included short chases and long observation of size 1-2 herds to locate vulnerable individuals (Oliver et al. in revision).

4) Contrary for the Oldowan Kanjera hominins habitually transported stone materials (30% of the lithic assemblage) selectively collected from conglomerates, over longer distances (13 km) (Braun et al. 2008a), reflecting their preference for hard, easily-flaked materials unavailable on the northern half of the Homa Peninsula (Braun et al. 2009a,b; Braun and Plummer 2013).
5) Kanjera hominins deployed different technological strategies to more intensively utilize these hard, non-local raw materials, including exploiting multiple core surfaces, removing old platforms to develop new exploitation surfaces (platform rejuvenation flakes), maintaining convex surfaces to allow longer debitage sequences, producing flakes that removed less core volume (flakes with higher edge to mass ratios), and retouching flakes. Local raw materials show far less complex reduction sequences, and no retouching (Braun et al. 2009a,b; Braun and Plummer 2013).
6) Use-wear analysis of tools made of non-local quartz and quartzite demonstrates the processing of a diversity of materials including animals (skin, flesh, and bone), herbaceous plants, USOs, and wood (Lemorini et al. 2014). Traces indicative of wood cutting and scraping suggest that stone tools were likely being used to produce other tools, such as digging sticks and spears.

Rhyolite and fenetized andesite: geology, mineralogy, and reduction modes

The most abundant rock types in this region are extrusive volcanics from the Nyanzian System. These are largely siliceous rocks emplaced over a large area on what was once a flat plain prior to the doming of the Homa Mountain carbonatite edifice (Le Bas 1977). These fine-grained and sometimes glassy rocks with numerous phenocrysts can be found in a relatively unaltered state in a broad arc that has a 9 km radius around the Homa Mountain carbonatite center. Rhyolites can be distinguished by their porphyritic nature set in a finergrained matrix of quartz and orthoclase feldspar (Saggerson 1952; McCall 1958). The Nyanzian rhyolite used for artifact manufacture is very fine grained with some phenocrysts that rarely interrupt flaking and is geochemically similar to the rhyolite found at the southern end of the Samanga Fault where it occurs almost exclusively as rounded river cobbles. This raw material follows many of the flaking patterns described earlier for Bukoban Quartzite (Braun et al. 2009 a,b).

Near the Homa Mountain carbonatite center these siliceous rocks underwent an intense metasomatism process. These metasomatized rocks, termed fenites or fenetized rocks, are largely brecciated and shattered with secondary minerals forming along resulting joint surfaces. As this process becomes more intense, potassium feldspars working out from the veins can wholly replace the largely brownish-black rock resulting in extensive penetration of the rock by amphibole and aegirine (Le Bas 1977). Fenetized rocks have completely different mechanical properties compared to the unaltered rhyolites from which they are derived. They do not break in predictable ways and often shatter along joint surfaces that define this rock type. Additionally, wholesale metasomatic processes replace the majority of minerals making these rocks characteristically weak (Braun et al. 2009b).

Weaknesses created by the high frequency of joints and inclusions in fenetized andesite cause fracture to be unpredictable making them difficult to knap. Consequently, many of tools of this rock type show very short reduction sequences. The intersection of an exploitation surface with an internal joint frequently halted reduction of fenetized rocks; over 75% of the cores made on this raw material were discarded because flaking was interrupted by internal flaws in the rock. The simple exploitation of this rock type is also indicated by a) 23% of the fenetized andesite cores have only one exploitation surface, and b) 62% of these cores have only two unidirectional flake scars. It is very difficult to characterize a modal reduction process on fenetized rocks. The most frequent reduction mode appears to be the use of natural angles produced by joints that are then flaked unidirectionally until flaking is interrupted by the intersection of a flake scar with another joint surface. Unidirectional flaking dominates most debitage surfaces in this raw material, although some cores exhibit orthogonal and opposed reduction methods. In a small number of cores a bipolar strategy was employed.

The most abundant core reduction mode for rhyolite artifacts is almost identical to the “flake-core” reduction mode described for Bukoban Quartzite (Braun et al. 2009a,b). The convexity of the ventral surface is exploited using centripetal flaking patterns to reduce a large flake. The platform of the original flake is rarely exploited. Platforms are quite large (median platform area 31.4 mm^2) suggesting that large flakes were subsequently used as cores. The other quite common reduction mode is the biconvex centripetal. In this mode the core has a lower surface preserving a small portion of cortex that tends to be more convex. The upper surface is more planar and has larger removals, while the lower surface tends to have smaller and more abrupt removals. Like Bukoban Quartzite cores, Nyanzian rhyolite cores are relatively small (median core mass: 51.2 g). Some rhyolite cores made of more porphyritic materials tend to fracture erratically and were consequently reduced less extensively.

Materials and Methods

USE-WEAR ON RHYOLITE AND FENETIZED ANDESITE REPLICAS

Using flakes made of the same rock types in the Kanjera lithic assemblage, the experimental protocol was designed to study the development of use-wear characteristics created in the processing of materials likely to have been processed by Oldowan hominins such as animal carcasses, herbaceous stems, USOs, and wood (see Table 1; see also Lemorini et al. 2014). Carcass processing comprised activities related to butchery (i.e., skinning and defleshing; Fig. 2a), as well as the scraping of fresh and dry hide in order to replicate the cleaning and softening of skin. Use-wear created by working plants in the scope of processing activities such as peeling by scraping or slicing of skin and cutting pulp of tubers and rootstock as well crafting (cutting, sawing, and scraping) other tools from wood branches and grass and reed stems (Fig. 2b). Materials for replication experiments were chosen to elucidate the relationship between use-wear and textural or worked material variables (such as the tissue type, water content, and presence of soil particles). This ensured that tool use would lead to the development of distinct traces useful for diagnosing whether artifacts were used on soft or hard stems, or on denser material such as wood, tubers or roots growing in wet or dry environments, rather than demonstrating a relationship between use-wear and a particular plant species. These foundational experiments allow us to distinguish wear from wide categories of animal tissues, plants and plant parts. HPPP team member Rahab Kinyanjui's ongoing analysis of phytoliths recovered from Kanjera sediments and embedded on artifacts will likely provide additional resolution to plants used by Oldowan hominins at Kanjera.

Rhyolite and fenetized andesite have a similar structure in which quartz crystals are embedded in the matrix. The main difference is the size of the quartz inclusions, larger in rhyolite, and its cementation with matrix, weaker in fenetized andesite. For use-wear on quartz crystals, most descriptions refer to the use-wear developed on rhyolite, since this raw material loses crystals to a lesser extent during use than does fenetized andesite.

Cleaning procedure

Archaeological artifacts were already cleaned from the sediments to allow the analysis of raw material and the typological and technological analyses. We washed again the artefacts with warm running water to eliminate any residues due to the previous manipulation.

Experimental replicas were cleaned at LTFAPA laboratory with a chemical procedure to remove any organic residues from the worked materials that might obscure or blur use-wear. Replica flakes were washed first with water and soap, then in a dilute 3% acetic acid (CH_3COOH) for 15 min, and then in a dilute 3% sodium hydroxide (NaOH) base for 15 min, and finally rinsed with de-mineralized water in an ultrasonic tank. Since that cleaning procedure was less effective in removing residues of fleshy tissues and hide, which adhere strongly to the lithic surface, replicas used in this way were further treated in a bath with a 2% solution of buffered soap Derquim© (Asryan et al. 2014, p.12) in de-mineralized water in an ultrasonic tank for 5 minutes followed by a final rinsing with de-mineralized water in an ultrasonic tank for 5 minutes.

SELECTION OF THE ARCHAEOLOGICAL ARTIFACTS AND OBSERVATION METHODS

The entire lithic assemblage (4474 items) housed in the National Museum of Kenya was evaluated to estimate its inference potential (Lemorini et al. 2014 p. 13). The Kanjera South assemblage is well preserved. It was rarely subject to rolling or fluvial action. Strong chemical dissolution is quite rare although items made of carbonatite, limestone, microijolite, ijolite, phonolite and fenetized andesite were more affected by post-depositional chemical dissolution than the other raw materials.

Three criteria were applied to select artifact for use-wear analysis: completeness (artifacts whiteout potentially functional edges were discarded), surface preservation, presence of edge-removals and/or edge-rounding indicating ancient use (Lemorini et al. 2014, p.14).

Up to now, use-were analysis was applied to the selected artifacts made of quartz, quarzite, rhyolite and fenetized andesite. These four raw materials form the 54% (2136 items) of the entire technocomplex of Kanjera South.

301 rhyolite items comprising 279 detached pieces and 1785 fenetized andesite items comprising 1759 detached pieces were evaluated with our three criteria. Mechanical and chemical post-depositional alterations were observed respectively on the 20% and 40% of the items. Edge-removals and/or edge rounding indicating use were found respectively on 39 (14%) and 32 (2%) detached pieces. The remaining assemblage does not show traces of use or is devoid of potentially functional edges.

Rhyolite and fenetized andesite Kanjera South Oldowan artifacts were selected using a Nikon SMZ stereomicroscope with a magnification range of 0.75X to 7.5X equipped with a 10X ocular, a 1X objective, and a reflected light system. This initial survey aimed to evaluate the quality of edge preservation for each artifact and to esclude from study specimens showing evidence of mechanical alteration, including specimens with surface rounding and abrasion that creates a telltale glossy appearance (for a description of the alteration affecting use-wear see Lemorini 2010, pp. 35-37). Then, following the same observation system, edges were examined for use-related “macro-traces”, i.e. edge-rounding and edge-removals. This *Low-Power approach* (Odell 2004; Thringam et al. 1974; Lemorini 2010, p. 8) provided a general understanding of how the tool was used and the material worked (e.g., cutting soft material or scraping medium hard material). Since archaeological materials are not exportable from Kenya, the edges of selected tools were moulded with Provil Novo Light Fast Heraeus© at the NMK for analysis in Italy (for the proven utility of this moulding technique for use-wear analyses see Asryan et al. 2014; D’Errico and Henshilwood 2007; Dubreuil 2004; Perdegnana and Ollé 2017; Ollé and Vergès 2013; Romagnoli et al. 2015; Santucci et al.

2015; for a first attempt to test this moulding technique for metrological analyses see Mcdonald et al. 2018).

Lemorini et al. (2014) inferred the function of quartzite tools through observing use-wear on both the matrix and embedded quartz crystals. This *High Power Approach* methodology using a metallographic microscope, Differential Interference Contrast (DIC) system, and reflected light system appropriate for heterogeneous rocks followed the protocol used in previous studies (for an overview of the method see Conte 1997, Clemente Conte et al. 2015; Leipus and Mansur 2007). However, this method is less satisfactory when applied to rhyolite and fenetized andesite due to their coarser and less well-cemented high silica matrix compared to quartzite. This required the development of the method as described below, to increase magnifications higher than 600X and a larger field of view.

For detailed observations, the *High-Power approach* was applied at the laboratory LTFAPA at Sapienza University of Rome using higher magnifications and two different observation systems, a metallographic microscope (Keeley 1980; Lemorini 2010, p. 7) and a scanning electron scanning microscope (SEM) (Knutsson 1988).

High-power analysis of micro-traces revealed that active edges suffered severe fragmentation and a high loss of material from use. This appears as a very coarse topography on which diagnostic micro-traces develop, predominantly over very small areas. Focus and depth of field of undulating topographies is compromised at higher magnifications when using traditional metallographic equipment. To facilitate observation and interpretation of wear traces on these surfaces we added the use of a scanning electron microscope to the protocol described in Lemorini *et al.* 2014. SEM observations complement rather than replace observations made with stereomicroscope and metallographic microscope. These latter techniques are essential both to locate and delineate the use-wear on the tool and to provide an overview of its function. The integration of these three techniques allows to optimize the data obtainable for more heterogeneous rock types.

For SEM analysis, resin casts were made from these moulds using the epoxy adhesive Araldite© LY 554 plus hardener HY 956 (see also Backweel and D'Errico 2005, p.244). The resin casts were sputter-coated with a thin layer of gold in the Department of Chemical Engineering at the Sapienza University of Rome to make them conductive for SEM observation. SEM observation was carried out with a Hitachi TM 3000 SEM under total vacuum, at 15 kV accelerating voltage (BSE mode) with an acquisition time of 400 s. and two observation settings, *shadow 2* or *composition*. *Shadow 2 mode*, providing an obliquely-lit visual field, is the most useful for detecting use-wear; in some cases *composition* mode enhanced the ability to observe certain types of wear. SEM observations were carried out at accelerating voltage of 15kV (BSE mode), which obtains the best resolution throughout the magnification range. For the description of the traces observed with the SEM, we used the terminology proposed by Perdegnana and Ollé (2017).

Identification of micro-traces, i.e. micro-edge-rounding, corrosion-like features, polishes, striations was carried out with metallographic microscopes with a reflecting light system, Nikon 15X Optiphot oculars, 10X, 20X, 40X objectives, equipped with a Nikon Digital Camera DMX 1200 and a TV Lenses C-0.6X connection and Nikon Eclypse, 10x oculars, 10x, 20x, 50x objectives, equipped with a ToupView CMOS Camera. Helicon Focus software was used for picture focus staking. Descriptions of macro- and micro-traces observed with stereomicroscope and metallographic microscope follow variable definitions in a previous study (Lemorini et al. 2014). To put the attention on the possible combination of chemical and mechanical formation processes, the term “corrosion-like features” is used here instead of “abrasion” (better related to mechanical processes only) for the description of quartz crystal modification from use (see for the use of the term corrosion, Clemente Conte et al. 2015).

Results

Experimental Artifacts

STEREOMICROSCOPE OBSERVATIONS

Like quartzite replicas, rhyolite and fenetized andesite replicas develop few edge removals distributed in small areas of the active edge (see Table 2 for the macro-traces descriptions). In contrast to quartzite and quartz, edge rounding develops more easily, faster, and over larger sections of the active edge on rhyolite and fenetized andesite. This confirms low-magnification observations of artifacts where edge rounding caused by use is well developed and distinguishable from that caused by sedimentary abrasion because it is exclusively localised on the cutting edge, whereas sedimentary abrasion causes damage to all surfaces of an artifact, particularly on raised edges and ridges.

Use-wear experiments with rhyolite and fenetized andesite tools demonstrate that processing soft materials, such as cutting animal soft tissue or stems of soft herbaceous plants causes a light edge-rounding (Fig. 3a) and small edge-removals with feather terminations (Figs. 3b). Cutting fleshy animal tissues may result in a higher degree of edge rounding than would soft herbaceous plants. Compared with these uses, working fresh or dry hide produces a greater degree of rounding on tool edges (Fig. 3c). Materials of medium hardness that are less abrasive than hide, such as large reeds or wood, tends to cause more edge removals and a higher frequency of feather, hinge, step, and snap terminations (Fig. 3 d). Working hard materials, such as bone, produces very little or no edge rounding, but yields a high degree of large edge-removals (Fig. 3e) with feather, step, and hinge terminations.

Notably, underground storage organs (USOs), if worked for a brief time, behave as a material of medium hardness, probably because they are covered with a tough and resistant skin that comes in contact with the active edge in the early stages of activity. USO-working can result in quite large and well developed edge removals along with a medium to high degree of edge-rounding (Fig.3f).

METALLOGRAPHIC OBSERVATIONS

The structure and texture of the lithic raw material is a key variable for the formation and development of use-wear. The relatively weak cementing matrix of rhyolite and fenetized andesite facilitates the quick removal of grains and crystals, which intensifies with greater hardness of the material being worked. Although Braun *et al.* (2009a,b) characterised rhyolite as a hard, resistant raw material, this relates to the macroscopic scale of observation. Hardness, in a relative sense, does not preclude microscopic removal of grains and crystals, which are relatively weakly cemented in the supporting matrix. Stresses induced by tool use produce the appearance of small 'craters' at a microscopic scale. Developed, diagnostic use-wear traces are visible at relatively low magnifications (10X, 20X) only if soft or medium materials are worked. Hard materials, such as bone and hardwood, cause such a high level of degradation on the active edge that diagnostic use-wear can only be detected using higher magnification (50x) on residual edge portions.

Processing of soft and soft/medium materials tends to slightly modify the raw materials' naturally coarse topography (Fig. 4a), generating rough polishes and granular topographies

(Figs.4b-c). With increasing hardness of the materials being worked, polishes shift to smooth and topographies from domed to flat (Fig.4d-f; Fig.5 a-b) as a result of stronger abrasion, particle re-deposition, and levelling of the natural surface at a microscopic level. The exception to this generalization is found in use-wear created by wetlands rootstocks (cassava *Manihot esculenta* and common arrowheads *Sagittaria latifolia*) in our experiments. Processing these materials causes a strong, microscopic modification of the surface due to continuous microabrasion that prevents the re-deposition of the abraded particles and causes the formation of levelled microscopic areas (hereafter ‘microareas’). The resulting use-wear is a diffuse, well-developed rough and granular polish in which polished areas are linked and shallow striae are visible (See Figs. 5c-d). We tentatively link this microabrasion to damage caused by mud covering the rootstock surface. During the scraping and cleaning of rootstocks’ skin, sticky and difficult to remove mud particles may generate this strong microabrasion, which is missing from use-wear caused by processing dry environment tubers. In fact, use-wear on tools used to process tubers from dry substrates (//ekwa *Vigna frutescens* and shakeako *Vigna macrorhyncha*) is mostly limited to the flakes’ edges, with very small levelled areas (polished smooth and flat plus few striae) developing from a lighter rough and granular polish (Figs. 5e-f).

As Tables 3-4 shows, each worked material creates a distinct combination of traces. Wear on the quartz crystals in rhyolite and fenetized andesite contribute less to the use-wear definition than is the case for quartz and quartzite. This is because the quartz crystals are in many cases missing, lost from wear of the weak rhyolite and fenetized andesite matrix. When present, quartz crystals show distinct use-wear attributes fully compatible with material-dependent attributes created on quartzite and quartz experiments (Lemorini et al. 2014).

SEM OBSERVATIONS

SEM observations allow detailed documentation of the mechanisms that create microscopic traces of wear during the use of rhyolite (see Fig. 6a for an example of un-used surface) and fenetized andesite flakes (see Table 5 for the description of traces). The appearance of surface removals and polish relative to one another differ according to the hardness of the worked material. Processing harder materials creates a greater degree of surface loss, limiting the formation of well-developed polishes to small residual areas. Conversely, processing soft material produces a widespread but poorly developed polish on a scarcely eroded surface. Polished areas are plastic deformations that look like rounded protruding points of the surface or flat "patches" of material removed from one area and spread onto the adjacent one. In general, working soft to hard materials produces progressively greater degrees of edge rounding and surface removal. The relationship between degree and extent of surface removals as well as plastic deformations is a significant factor in distinguishing the material worked.

The working of soft materials such as soft, herbaceous plants (Fig.6b) and animal flesh does not remove lithic raw material from an artifact surface nor does it generate an appreciable degree of plastic deformations. An exception is when bone is occasionally encountered during butchery and surface removals occur. During butchery the contact with muscles and tendons develop smooth polish that gently rounds the outermost edge of a flake yielding a domed topography. Skinning creates a more invasive wear - smooth polish forms over a slightly wider portion of the edge and flat patches can be present producing a flat topography (Figs.6c-d). Working fresh hide leads to a more developed polish and a granular topography with progressive polishing of the protruding points (Fig. 6e). Sleek, shallow striae appear starting from 1000X magnification on the very flat micro-areas where removal stopped. Working dry hide creates higher frequencies of two use-wear indicators: surface removals and flat micro-areas that develop when removal stops. As they get more frequent, these flat micro-areas merge. (Fig. 6f).

Processing of USOs causes appreciable surface removals and development of plastic deformation on very small areas, characterized by smooth polish with flat topography for dry environment tubers (Fig. 7a), and domed-to-flat topography with a higher degree of surface removal for wet environment USOs (Figs. 7b-c). The tools used to process rootstocks collected from wet environment (cassava *Manihot esculenta* and common arrowhead *Sagittaria latifolia*) were used for a longer period of time than tools used to process tubers collected from dry environment (//ekwa *Vigna frutescens* and shakeako *Vigna macrorhyncha*). USOs from wet substrates have greater processing requirements due to their larger size and sediment-covered skin. We suggest that the differences in extent of surface removals encountered between the two plant materials are related to the working time rather than the dry or wet condition of the USOs themselves. Processing wood (Figs. 7d-e) and strong reeds (*Arundo donax*; Figs. 7f) produces wider flat areas of wear due to the development of more invasive and persistent plastic deformations. These create a domed-to-flat topography in which linear features are oriented parallel to tool movement. Tools that processed reeds evince a higher degree of surface removals. The greatest degree of surface removal is created by bone working (Fig. 8a). At a very high magnification, small areas where surface removal obliterated the small flat areas of plastic deformation are observable; these survive and retain some sleek striae (Fig.8b).

Analysis of the archaeological sample

In this paper we present the data inferred from the use-wear analysis of 20 among the 39 rhyolite artifacts and 5 among the 32 fenetized andesite artifacts with macro-traces suggesting their ancient use. The remaining artifacts are under study.

24 of the 25 archaeological tools analysed (Fig. 9; Table 6) show use-wear. In 23 cases the traces of use are sufficiently diagnostic to permit identification of the specific material or hardness of the material processed. In one more case (Table 6, n° 14768) the traces of use are not further interpretable. Regarding the Functional Areas, in two cases, n° 11821 and n° 24782, the archaeological tools show two FA instead of one. Accordingly, the 24 archaeological tools with traces of use own a total of 26 FA (Table 6). Under the metallographic microscope, five artifacts (n° 6448, 24521, 24711, 24782 and 24782) display a glossy appearance at different stages of development (Fig. 10a) (see Lemorini 2000, p. 8). Under the SEM, the most altered surfaces appear as a succession of collapsed areas (Fig.10b) caused by intensive surface removal associated with polished ridges or with wide areas of flat polish. SEM observations suggest that this damage was caused by chemical alteration that resulted in the dissolution of the rock, combined with mechanical abrasion that smoothed protruding portions of the surface. SEM analysis also showed that slight alterations appear in the form of small, collapsed areas that occasionally interrupted otherwise continuous use-wear traces. When observed with both metallographic and SEM systems, non-use related damage is both broadly and chaotically distributed, and it is sufficiently distinct from use-wear to preclude confusion between the two. Indeed, two (n° 24521 and 24768) of the four artifacts with micro-surface alteration have discernible macro-traces allowing confident identification of the motion carried out and the hardness of the material processed (n° 24521) and the generic use of the tool (n° 24768). Another artifact (n° 24782) has a less pronounced glossy appearance that allows interpretation of micro-traces on Functional Area n°2. Unfortunately, Functional Area n°1 was affected by a localized accretion of oxides that

obscured the micro-surface; the interpretation of this functional area was based on macro-traces only.

Use-wear on the Kanjera artifacts is generally well preserved; minimal alteration in the form of occasional slight surface brightness was observed on some tools using the metallographic microscope. Fifty-eight percent (n = 11) of the tools with use-wear diagnostic of the worked material (n = 19) are inferred to have been used for working wood or herbaceous plants with a strong stem (Figs. 11,12a-b). On nine of these tools variable actions are identified, including cutting and sawing (i.e., cutting with a bi-directional movement). In two cases, a mixed action of both cutting and scraping wood was carried out with the same edge. These examples suggest a single activity using two distinct actions, or two distinct activities, one cutting and one scraping were carried out at two different times. Two other artifacts (Figs. 12 c-d) observed with SEM show use-wear interpreted as processing of wood and/or strong herbaceous plants due to the high level of material removal from the active edge. However, comparisons with experimental wood- and reed-related traces do not allow an unequivocal identification of the plant material being processed; further experiments on plants could help to distinguish the types of plant or plant part involved in the working process. Additional experiments could, for example, determine the type or types of herbaceous plant worked with artifact n°24985. Wear on this artifact shows crystal corrosion-like features created by a very soft material animal or vegetal (Fig. 12e) with a high level of material removal (Fig. 12f), suggesting the processing of hard herbaceous plants.

The USO processing inferred from the archaeological material involved cutting, scraping, or a mixed action of scraping plus cutting. Use-wear indicative of USO processing is present on six artifacts (26%; 1 fenetized andesite and 5 rhyolite). The observed micro-trace morphologies are compatible with the processing of USOs from both wet (Figs. 13 a-d) and dry environments (Figs. 13 e-f). One of the USO processing artifacts (n° 25625), was initially used as a core, the percussion surface of which was then successively used for scraping USOs.

Three artifacts (1 fenetized andesite and 2 rhyolite) exhibit use-wear related to butchery (13%) (Figs. 14 a-f). In all three cases the degree of edge-rounding and linkage of polished areas observed using the SEM suggests that contact occurred with skin as well as fleshy tissues. Moreover, SEM examination of artifact n° 24905 (Fig. 14f) evinces a particularly high loss of raw material. This degree of raw material loss was not observed in the experimental replicas that were used to process fleshy animal tissues and may have been caused by contact with bones. All three tools show contact with two or more different parts of the carcass, skin and flesh for n° 5490 and n° 24782 while skin, flesh and bone for n° 24905. This suggests that they were used in all or most processing of a single carcass. No traces indicative of hide treatment have been identified on the archaeological artifacts. As our previous analysis of quartz and quartzite suggested, this activity seems not to be evidenced in the Kanjera South Oldowan artifacts (Lemorini et al. 2014).

Although sample sizes are low, particularly for fenedtized andesite, it appears that both animals and plants were processed with tools made of all raw materials (Table 7). Notably however, plant processing is significantly more well-represented than animal processing: of the 64 active edges examined, 53.1% display use-wear indicative of plant processing, but only 15.6% exhibit traces diagnostic of butchery. The frequency of edges with evidence of plant processing is particularly high for quartzite (52.0%) and rhyolite (80.0%) artifacts, Fisher’s exact test shows that both are significantly different than the low frequency of edges with butchery traces on artifacts made of quartz (21.4%; quartzite vs quartz, $p = 0.03966$;

rhyolite vs. quartz, $p = 0.0013$). Frequencies of fenetized andesite with evidence of plant processing (40.0%) is significantly less than that for rhyolite artifacts (Fisher's exact test, $p = 0.0235$). In contrast, there is no tool material preference indicated for butchery. The number of edges with evidence of butchery wear (excluding contact with bone) is rather evenly distributed across all tool material types.

Again with allowances for small sample size, there seems to be a difference in which rock types were used to process wood. None of the non-local fenetized andesite edges exhibit use-wear indicative of woodworking. However, one fenetized andesite tools display non-diagnostic use-wear related to processing of a medium to hard material. Results also show that the prevailing activity was cutting, suggesting that knapping was dedicated to the production of cutting edges for all materials except for fenetized andesite. The different results obtained for fenetized andesite could be due to the difficulty of producing thin and regular artifacts with this raw material. More data on fenetized andesite use-wear is needed to verify this explanation.

Considering the edge angle of each category of artifacts (Table 8), tools made of rhyolite show the active edges having the most homogeneous edge angles, which range from a mean of 48° for cutting to 60° for scraping and mixed actions. This suggests that rhyolite was the most suitable raw material for controlled production of homogeneous and relatively thin flake edge morphology.

Discussion and Conclusion

This study enlarged our experimental use-wear collection to include tools made of rhyolite and fenetized andesite and extended our analysis of use-wear of Oldowan artifacts from Kanjera to include 25 additional artifacts of the same rock types. This paper explores the functional uses of Oldowan stone tools and, through this, the behavioral ecology of the hominins who used them. There are important methodological and experimental results inferred from use-wear on fenetized andesite and rhyolite tools. These results allowed to characterize the Kanjera Oldowan tools made of this type of rocks. Finally, these data reveal some significant patterns in the use of the quartz, quartzite, rhyolite, and fenetized andesite tools to date.

Important experimental results can be summarized as follows:

Examination using the SEM considerably improved the identification of use-wear on rhyolite and fenetized andesite tools by combining a magnification up to 600X with a wide field of view are essential for perceive important details of the use-wear.

1) Since rhyolite and fenetized andesite quartz crystals are embedded in a weaker matrix than quartz and quartzite, they are frequently missing from working edges. Consequently, use-wear on quartz crystals contribute less to identification of use-wear than with tools made of quartz and quartzite.
2) Experiments demonstrate that edge rounding on rhyolite and fenetized andesite tools develops more rapidly and over large areas than edges of replicas made of other rock types.
3) Hide-working creates greater edge rounding than is created in processing other materials.
4) Due to their tough outer skin and adhering sediment, processing of USOs tends to create large, well developed edge removals and moderate to high edge rounding.
5) Processing of USOs from dry substrates tends to yield smaller areas of polish with fewer striae limited to the flake edge compared to traces produced on tools used to process USOs from wet substrates. This may be due to both the larger size of wet environment USOs and the mud that tends to adhere to their surfaces.
6) Working bone created more edge-removals than any other material. Processing reeds with tenacious stems created more edge removals than the working of softer plant parts and animal flesh.

Significant results from the analysis of use-wear of archaeological tool use-wear demonstrate the following:

1) The enhanced methods (Low and High Power approaches) considerably improved the identification of diagnostic wear traces. The method allowed identification of diagnostic use-wear on 88% of the rhyolite and fenetized andesite Oldowan tools.
2) Both fenetized andestite and rhyolite were used to process USOs.
3) Both fenetized andestite and rhyolite were used to process animal flesh.
4) Both cutting and scraping are indicated by use-wear on rhyolite tools used to work wood.
5) Tools made of both non-local (rhyolite, quartzite, and quartz) and local (fenetized andesite rocks were used by Kanjera Oldowan hominins to process herbaceous plants, USOs, and animal tissue.
6) A significantly greater number of tool edges bear traces of plant processing (53.1%) than animal processing (15.6%).
7) The frequency of quartzite and rhyolite tools exhibiting use-wear diagnostic of plant processing (52.0% and 80.0%, respectively) is significantly greater than that for tools made of fenetized andesite (40.0%) and quartz (21.4%) suggesting they were preferred for plant processing activities.
8) Although the sample size is small, fenetized andesite was not used to process wood.
9) Cutting appears to have been the main activity for all tools with exception of those made of fenetized andesite.
10) Use-wear on tools replicas used to process plants is considerably less developed than plant use-wear traces on Kanjera Oldowan tools perhaps suggesting a greater period of use or processing of different plants.

The high degree of use-wear development indicative of plant working on Kanjera South artifacts, in comparison to that of our experimental tools, suggests that the Oldowan artifacts were used for processing plant for relatively long time intervals. This may suggest that several different plants were processed with a single tool. However, it is likely that our experimental reference collection does not fully represent the total range of plants species worked by Kanjera hominins. Another potential explanation could be that the same tool was used to work different types of woody and hard herbaceous plants. This latter hypothesis needs to be tested with future experiments and opens new possibilities for research on the repeated and different use of the same tool.

Functional inferences from use-wear analysis highlight the conclusion that rhyolite and fenetized andesite tools were used for a similar range of activities noted for tools made of quartz and quartzite (Table 7 and Lemorini et al. 2014, Table 6). Signs of use for butchering have been found in all four categories of raw materials. For each raw material, a greater proportion of artifacts show use-wear related to processing plant material than for processing animal material. This may suggest that butchery was a less frequent activity than processing of plants and plant organs. That said and as with modern chimps (Stanford 2000; Schoeninger et al. 2000), butchery of small prey might have been accomplished hands and teeth so cutting tools may not have been critical.

Use-wear indicating processing of USOs is well-represented in the archaeological sample, confirming that underground storage organs were a key food for Kanjera South hominins. This further suggests that these hominins maximized the exploitation of these resources and likely gathered them in a wide range of environments. Presumably, hominins could improve their exploitation of this critical resource by using lithic artifacts. Additionally, lithic artifacts seem strongly associated with cutting and scraping woody plants and cutting stems of herbaceous plants.

For the rhyolite tools, the scarcity of use-wear related to softer materials, such as animal flesh and soft herbaceous plants, may be seen not as a functional preference but rather as the result of sequential use on different materials. Examination of the experimental replica reference sample shows that processing soft materials generates light use-wear, limited to the outer edge. This initial wear may be removed or obliterated through subsequent activity, particularly if the tool is subsequently used for processing harder materials. Due to the nature of the raw material, quartz and quartzite tools are less vulnerable to this overprinting. Nevertheless, if we take the results of our experiments into consideration, tools made of rhyolite and fenetized andesite become dull much faster because crystalline materials are less cemented than in quartz and quartzite tools, so a functional preference may have existed.

Artifacts' contact with harder animal tissues such as skin and bone and with plant parts such as tubers, roots, the robust stems of herbaceous plants, and wood are clearly identifiable. Moreover, we have noted that morphological details of rhyolite and fenetized andesite use-wear allow identification of very minor differences in the consistency of the material worked. This finding may be attributable to the methodological developments described here – the integration of observations from stereo and metallographic microscopy with scanning electron microscopy. Additional analysis of tools made from both homogeneous and heterogeneous raw materials will enable us to further elucidate the uses to which this artifact assemblage was put. In future we plan to apply this integrated methodology to the whole lithic industry of Kanjera South.

Considering the range of activities identified in these artifacts of the Kanjera South lithic assemblage (Tables 8), tools made of quartzite and rhyolite display the most regular and acute edges, likely indicative of their primary purpose – cutting. However, the cutting power of rhyolite created by their homogenous, more acute edges is reduced by its tendency to dull faster than quarzite which can be used for longer durations. Tools made of quartz and fenetized andesite had a weaker cutting power compared to quartzite and rhyolite tools. This difference could be explained in terms of technology. That is, the extreme hardness of quartz and, conversely, the weakly cemented fenetized andesite makes it very difficult to knap both raw materials in a controlled manner. As a consequence, hominins at Kanjera South may have had less control over the production of thin and regular quartz and fenetized andesite flakes than would have been the case for quartzite and rhyolite.

Results obtained from this analysis open new avenues for the study of the technological behavior of Oldowan hominins in relation to carcass processing and the use of varied plant materials. The use of lithic artifacts for plant processing at Kanjera South certifies the acquisition and extensive processing of plant food and enhances our knowledge on this question. The evidence for wood-working further suggests that hominins were possibly producing tools of organic materials to be used as additional or complementary tools to foraging and for other activities. These new data and interpretations from Kanjera South strengthen our knowledge of the relationship between hominins, their lithic industries and plants and confirm the existence of interactions that have implications for our understanding of hominin cognitive and cultural abilities.

Use-wear data combined with data on raw material acquisition and behaviors indicated by zooarchaeological analyses can open new windows on the capability and capacities of the Oldowan hominins of Kanjera South in terms of memory and planning, two key aspect of human cognition. Kanjera South hominins had memory and knowledge of places from which raw materials could be collected to produce cutting tools for a wide variety of uses. This memory was related to a preconceived awareness of the variety of expected functions to be accomplished upon return to Kanjera South. Use-wear data, will allow us to define the amplitude and complexity of this knowledge. The actual observation of the interaction between memory and forethought through such ancient time intervals is crucial to understanding the evolution of hominin congnitive abilities (see for a general discussion Haidle 2010). Use-wear analysis can elucidate the focus of this forethought and enhance our comprehension of the basis of our cognitive evolution. Notably, use-wear traces indicative of wood processing suggest that tools were being used by Oldowan hominins to manufacture other tools, including perhaps digging sticks and spears.

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Table

Table 1. Number of experiments using rhyolite and fenetized andesite replica flakes for production of use-wear with different motions to process a variety of materials.

N° exp	Raw Material	Activity Carried Out	Material Worked	Action Carried Out	State of the Material	Time
1	Rhyolite	Butchering -	Goat flesh and occasional bone contact	Cutting	Fresh	1000 strokes
2	Rhyolite	Butchering	Goat flesh and occasional bone contact	Cutting	Fresh	30m
3	Rhyolite	Butchering	Goat flesh and occasional bone contact	Cutting	Fresh	1000 strokes
4	Rhyolite	Butchering	Goat flesh and occasional bone contact	Cutting	Fresh	500 strokes
5	Rhyolite	Skinning	Goat flesh	Cutting	Fresh	1h
6	Rhyolite	Skinning	Goat flesh	Cutting	Fresh	500 strokes
7	Fenetized And.	Skinning	Goat flesh	Cutting	Fresh	500 strokes
8	Fenetized And.	Skinning and Butchering	Goat flesh	Cutting	Fresh	40m
9	Fenetized And.	Hide Processing	Goat tissues	Scraping off subcutis	Fresh	30m
10	Fenetized And.	Hide Processing	Goat tissues	Scraping off subcutis	Fresh	30m
11	Fenetized And.	Hide Processing	Goat tissues	Softening by scraping	Dry	30m
12	Rhyolite	Butchering	Juvenile Cow long Bone	Scraping off meat/periostium	Fresh	30m
13	Rhyolite	Gathering	Riparian Grasses	Cutting	Fresh	>30m
14	Rhyolite	Gathering	Riparian Grasses	Cutting	Fresh	>30m
15	Rhyolite	Gathering	Riparian Grasses	Cutting	Fresh	>30m
16	Fenetized And.	Making Tool	Reeds (*Arundo donax* L.)	Cutting	Soaked	30m
17	Fenetized And.	Making Tool	Reeds (Arundo donax L.)	Cutting	Soaked	30m
18	Fenetized And.	Peeling, Slicing	*Manihot esculenta* "Cassava" Rootstock	Scraping, Cutting	Fresh (wet environment)	35m

19	Fenetized And.	Peeling, Slicing	*Manihot esculenta* "Cassava" Rootstock	Scraping, Cutting	Fresh (wet environment)	35m
20	Rhyolite	Peeling, Slicing	*Vigna m. "Shaehako"* ; *Vigna f.*"//Ekwa" Tubers	Scraping, Cutting	Fresh (dry environment)	>30m
21	Rhyolite	Peeling, Slicing	Vigna m. "Shaehako" Tuber; Vigna f."//Ekwa" Tuber	Scraping, Cutting	Fresh (dry environment)	>30m
22	Rhyolite	Peeling, Slicing	Vigna m. "Shaehako" Tuber; Vigna f."//Ekwa" Tuber	Scraping, Cutting	Fresh (dry environment)	>30m
23	Rhyolite	Peeling, Slicing	Vigna m. "Shaehako" Tuber; Vigna f."//Ekwa" Tuber	Scraping, Cutting	Fresh (dry environment)	>30m
24	Rhyolite	Peeling, Slicing	Vigna m. "Shaehako" Tuber; Vigna f."//Ekwa" Tuber	Scraping, Cutting	Fresh (dry environment)	>30m
25	Rhyolite	Peeling, Slicing	Vigna m. "Shaehako" Tuber; Vigna f."//Ekwa" Tuber	Scraping, Cutting	Fresh (dry environment)	>30m
26	Fenetized And.	Making Tool	Wood Chestnut (*Castanea Sativa* Mill.)	Cutting	Fresh	45m
27	Fenetized And.	Making Tool	Wood Quercus	Cutting	Fresh	>30m
28	Fenetized And.	Making Tool	Wood Quercus	Cutting	Soaked	30m
29	Fenetized And.	Making Tool	Wood Quercus	Scraping	Fresh	30m
30	Rhyolite	Making Tool	Wood Chestnut (*Castanea Sativa* Mill.)	Scraping	Fresh	1h
31	Rhyolite	Making Tool	Wood Chestnut (*Castanea Sativa* Mill.)	Scraping, Cutting	Soaked	1h

Table 2. Use-wear variables associated with the materials worked as observed under the stereomicroscope.

Material being processed	Edge Rounding	Edge-Removals
Animal soft tissue	light to medium	feather termination
Skin + soft tissue	light to medium	feather termination
Fresh hide	medium	
Dry hide	medium very localized	
Bone		very large with hinge/step termination
Soft herbaceous plant (riparian grass stems)	light	feather termination
Hard herbaceous plant (*Arundo donax* stems)	light to medium	Half moon-like and step terminations
Wet environment USOs	medium	very large feather-step terminations
Dry environment USOs	light to medium	feather-step terminations
Wood	light to medium	feather-step terminations

Table 3. Use-wear variables of matrix associated with the materials worked as observed under the metallographic microscope.

Processed Material	Matrix Edge Rounding	Matrix Distribution	Matrix Texture	Matrix Striae	Matrix Topography
Animal soft tissue	light to medium	outer edge /protruding points	rough/rough to smooth		granular/granular to flat
Skin + soft tissue	light to medium	outer edge / protruding points	rough/rough to smooth		granular/granular to domed
Fresh hide	medium to high	outer edge/edge	rough/rough to smooth		granular/granular to domed
Dry hide	medium to high	outer edge/edge	rough to smooth		granular to domed
Bone	medium very localized	outer edge/ protruding points	smooth		flat/pitted
Soft herbaceous plant (riparian grass stems)	light	outer edge	rough with some localized smooth		
Hard herbaceous plant (*Arundo donax* L. stems)	medium very localized	protruding points	smooth	few shallow slicks	flat/domed (on areas with higher removal of matrix)
Wet environment USOs	medium to high	edge/surface	rough	few deep furrow striae	granular
Dry environment USOs	medium to high	edge/surface	rough with some localized smooth	few shallow slick striae	granular with some flat spot
Wood	medium	edge/surface	smooth		flat or, more often, domed

Table 4. Use-wear variables of quartz crystals associated with the materials worked as observed under the metallographic microscope.

Processed Material	Corrosion	Striae	Rounding	Polish
Animal soft tissue	widespread lightly developed corrosion-like features			
Skin + soft tissue	widespread lightly developed corrosion-like features			
Fresh hide	widespread lightly developed corrosion-like features			
Dry hide	widespread strongly developed corrosion-like features		yes	pitted melting polish and shallow, narrow striae (slicks) on flat topography
Bone				pitted melting polish and shallow, narrow striae (slicks) on domed topography
Soft herbaceous plant (riparian grass stems)	localized well developed corrosion-like features	deep narrow striae (slicks)	yes	
Hard herbaceous plant (*Arundo donax* L. stems)				
Wet environment USOs	localized well developed corrosion-like features			
Dry environment USOs	localized well developed corrosion-like features	furrow (deep narrow tapering striae)		
Wood		furrow (deep narrow tapering or corrugated striae)	yes	smooth polish on domed topography

Table 5. Use-wear variables associated with the materials worked as observed under the scanning electron microscope.

Processed Material	Material Removal	Edge rounding	Polish	Topography	Striae
Animal soft tissue	none or light	medium on the outer edge	smooth	domed	
Skin + soft tissue	none or light	medium to high on the outer edge/edge	smooth	domed to flat	
Fresh hide	light to medium	medium to high on the outer edge/edge	rough to smooth	granular to flat	few shallow striae (slicks)
Dry hide	medium	high on the edge	smooth	granular	
Bone	high	high on protruding points	smooth	flat	very small narrow striae (slicks)
Soft herbaceous plant (riparian grass stems)	light	medium on the outer edge	smooth	domed	
Hard herbaceous plant (*Arundo donax*) stems	medium to high	high on the outer edge and protruding points	smooth; rough if high removal of material occurs	domed to flat; granular if high removal of material occurs	
Wet environment rootstocks	medium	medium on protruding points	smooth	domed to flat	
Dry environment tubers	medium	light to medium on outer edge	smooth	flat localized	
Wood	medium to high	high on the outer edge/edge	smooth	domed to flat	narrow striae (slicks)

Table 6. Interpretation of the Functional Areas (FA) of the Kanjera South archaeological tools. Two functional areas have been identified on tools n° 11821 and n° 24782; the remaining tools show a single FA. Tool n° 6448 owns traces uninterpretable. For each tool the table shows the lithic raw material, the functional areas, the technological description, active edge angle (in degrees), action, and material processed as determined by this study. In grey artefacts with glossy appearance.

Tool	Material	FA	Description	Edge Angle	Action	Material Processed
93	Rhyolite	1	Flake	55	Indeterminable	Soft Material
1516A	Rhyolite	1	Flake	52	Cutting	USO prob. from wet environment
5369	Rhyolite	1	Flake	72	Bi-directional cutting	USO prob. from dry environment
5490	Rhyolite	1	Flake	32	Cutting	Skin + Animal soft tissues
5806	Rhyolite	1	Flake	40	Cutting	Wood
6448	Rhyolite	1	Flake	35°	Uninterpretable	Uninterpretable
6554	Rhyolite	1	Flake	50	Mixed	Wood
7681	Rhyolite	1	Flake	65	Mixed, specifically scraping	USO prob. from wet environment
10000	Rhyolite	1	Retouched flake	45	Cutting	Wood/hard herbaceous plant
10500	Rhyolite	1	Flake	23	Scraping	Wood
10685	Rhyolite	1	Flake	45	Bi-directional cutting	Wood
11821	Rhyolite	1	Flake	50	Cutting	Wood
11821	Rhyolite	2	Flake	58°	Scraping	Wood
15338	Rhyolite	1	Flake	32	Cutting	Wood/hard herbaceous plant
20464	Rhyolite	1	Flake	54	Scraping	Wood
20961	Rhyolite	1	Flake	95	Scraping	USO
24521	Rhyolite	1	Flake	39	Cutting	Soft Material
24905	Rhyolite	1	Angular flake	48	Cutting	Skin plus animal soft tissues and bone (short contact)
A65 Aar	Rhyolite	1	Retouched flake	65	Mixed	Wood
ArDO5Da	Rhyolite	1	Flake	65	Scraping	Wood
J1724A	Rhyolite	1	Flake	59	Cutting	USO prob. from dry environment
24711	Fenetized	1	Flake	70°	Mixed	Soft material
24768	Fenetized	1	Snapped flake	39°	Used	Used
24782	Fenetized	1	Angular flake	70°	Scraping	Medium Hard material

24782	Fenetized	2	Angular flake	30°	Cutting	Skin + Animal soft tissues
24985	Fenetized	1	Angular flake	40°	Mixed	Soft material/hard herbaceous plants
25625	Fenetized	1	Core	90°	Scraping	USO prob. from dry environment

Table 7. Percentage of edges with use-wear by materials processed, lithic raw material, and inferred actions, for artefacts from Kanjera South, as determined in this study and Lemorini et al. 2014. All blank cells indicate zero values. Total Soft includes flesh, hide, and herbaceous plants. Total Medium Hard includes bone, wood, and USOs.

	Animal									Plant									Material Hardness					
Material / Action	**flesh**	**flesh + fresh hide**	**flesh + fresh hide + bone**	**flesh + bone**	**bone**	**total flesh**	**total hide**	**total bone**	**Total**	**wood**	**herb.**	**USO**	**wood + herb.**	**wood + USO**	**total wood**	**total herb.**	**total USO**	**Total**	**soft**	**med. hard**	**indet.**	**Total Soft**	**Total Med. Hard**	**TOTAL**
Fenetized Andesite																								
cutting		100.0 (1)				100.0 (1)	100.0 (1)		100.0 (1)													100.0 (1)		100.0 (1)
mixed											50.0 (1)					50.0 (1)		50.0 (1)	50.0 (1)			100.0 (2)		100.0 (2)
scraping												50.0 (1)					50.0 (1)	50.0 (1)		50.0 (1)			100.0 (2)	100.0 (2)
indeterminate	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Local Total		20.0 (1)				20.0 (1)	20.0 (1)		20.0 (1)		20.0 (1)	20.0 (1)				20.0 (1)	20.0 (1)	40.0 (2)	20.0 (1)	20.0 (1)		60.0 (3)	40.0 (2)	100.0 (5)
Rhyolite																								
cutting		9.1 (1)	9.1 (1)			18.2 (2)	18.2 (2)	9.1 (1)	18.2 (2)	27.3 (3)		27.3 (3)	18.2 (2)		45.5 (5)	18.2 (2)	27.3 (3)	72.7 (8)	9.1 (1)			45.5 (5)	81.8 (9)	100.0 (11)
mixed										66.7 (2)		33.3 (1)			66.7 (2)		33.3 (1)	100.0 (3)					100.0 (3)	100.0 (3)
scraping										80.0 (4)		20.0 (1)			80.0 (4)		20.0 (1)	100.0 (5)					100.0 (5)	100.0 (5)
indeterminate																			100.0 (1)			100.0 (1)		100.0 (1)
Total		5.0 (1)	5.0 (1)			10.0 (2)	10.0 (2)	5.0 (1)	10.0 (2)	45.0 (9)		25.0 (5)	10.0 (2)		55.0 (11)	10.0 (2)	25.0 (5)	80.0 (16)	10.0 (2)			30.0 (6)	85.0 (17)	100.0 (20)
Quartzite																								
cutting	27.3 (3)					27.3 (3)			27.3 (3)	18.2 (2)	9.1 (1)	9.1 (1)	9.1 (1)		27.3 (3)	18.2 (2)	9.1 (1)	45.5 (5)	9.1 (1)	9.1 (1)	9.1 (1)	54.5 (6)	45.5 (5)	100.0 (11)
mixed				20.0 (1)		20.0 (1)		20.0 (1)	20.0 (1)			60.0 (3)		20.0 (1)	20.0 (1)		80.0 (4)	80.0 (4)				20.0 (1)	100.0 (5)	100.0 (5)
scraping										22.2 (2)		22.2 (2)			22.2 (2)		22.2 (2)	44.4 (4)		55.6 (5)			100.0 (9)	100.0 (9)
indeterminate	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Total	12.0 (3)			4.0 (1)		16.0 (4)		4.0 (1)	16.0 (4)	16.0 (4)	4.0 (1)	24.0 (6)	4.0 (1)	4.0 (1)	24.0 (6)	8.0 (2)	28.0 (7)	52.0 (13)	4.0 (1)	24.0 (6)	4.0 (1)	28.0 (7)	76.0 (19)	100.0 (25)
Quartz																								
cutting	14.3 (1)					14.3 (1)			14.3 (1)	14.3 (1)			14.3 (1)		28.6 (2)	14.3 (1)		28.6 (2)	14.3 (1)	14.3 (1)	28.6 (2)	42.9 (3)	42.9 (3)	100.0 (7)
mixed																					100.0 (1)			100.0 (1)
scraping					25.0 (1)			25.0 (1)	25.0 (1)	25.0 (1)					25.0 (1)			25.0 (1)		50.0 (2)			100.0 (4)	100.0 (4)
indeterminate	50.0 (1)					50.0 (1)			50.0 (1)										50.0 (1)			100.0 (2)		100.0 (2)
Total	14.3 (2)				7.1 (1)	14.3 (2)		7.1 (1)	21.4 (3)	14.3 (2)			7.1 (1)		21.4 (3)	7.1 (1)		21.4 (3)	14.3 (2)	21.4 (3)	21.4 (3)	35.7 (5)	50.0 (7)	100.0 (14)
Sum Non-local																								
cutting	13.8 (4)	3.4 (1)	3.4 (1)			20.7 (6)	6.9 (2)	3.4 (1)	20.7 (6)	20.7 (6)	3.4 (1)	13.8 (4)	13.8 (4)		34.5 (10)	17.2 (5)	13.8 (4)	51.7 (15)	10.3 (3)	6.9 (2)	10.3 (3)	48.3 (14)	58.6 (17)	100.0 (29)
mixed				11.1 (1)		11.1 (1)		11.1 (1)	11.1 (1)	22.2 (2)		44.4 (4)		11.1 (1)	33.3 (3)		55.6 (5)	77.8 (7)			11.1 (1)	11.1 (1)	88.9 (8)	100.0 (9)
scraping					5.6 (1)			5.6 (1)	5.6 (1)	38.9 (7)		16.7 (3)			38.9 (7)		16.7 (3)	55.6 (10)		38.9 (7)			100.0 (18)	100.0 (18)
indeterminate	33.3 (1)					33.3 (1)			33.3 (1)										66.7 (2)			100.0 (3)		100.0 (3)
Non-local Total	8.5 (5)	1.7 (1)	1.7 (1)	1.7 (1)	1.7 (1)	13.6 (8)	3.4 (2)	5.1 (3)	15.3 (9)	25.4 (15)	1.7 (1)	18.6 (11)	6.8 (4)	1.7 (1)	33.9 (20)	8.5 (5)	20.3 (12)	54.2 (32)	8.5 (5)	15.3 (9)	6.8 (4)	30.5 (18)	72.9 (43)	100.0 (59)
TOTAL	7.8 (5)	3.1 (2)	1.6 (1)	1.6 (1)	1.6 (1)	14.1 (9)	4.7 (3)	4.7 (3)	15.6 (10)	23.4 (15)	3.1 (2)	18.8 (12)	6.3 (4)	1.6 (1)	31.3 (20)	9.4 (6)	20.3 (13)	53.1 (34)	9.4 (6)	15.6 (10)	6.3 (4)	32.8 (21)	70.3 (45)	100.0 (64)

Table 8. Actions carried out with rhyolite, fenetized andesite, quartzite, and quartz artefacts and the mean edge angle of the active edges.

Raw Material (n° of artefacts)	Cutting		Scraping		Mixed	
	n	Mean Edge Angle	n	Mean Edge Angle	n	Mean Edge Angle
Rhyolite (20)	11	48°	5	60°	3	60°
Fenetized Andesite (5)	1	30°	2	80°	2	55°
Quartzite (25)	11	58°	9	74°	5	60°
Quartz (14)	6	60°	3	61°	3	59°

Table 1. Number of experiments using fenetized andesite and rhyolite replica flakes for production of use-wear using different motions to process a variety of materials.

Table 2. Use-wear variables associated with the materials worked as observed under the stereomicroscope.

Table 3. Use-wear variables of matrix associated with the materials worked as observed under the metallographic microscope.

Table 4. Use-wear variables of quartz crystals associated with the materials worked as observed under the metallographic microscope.

Table 5. Use-wear variables associated with the materials worked as observed under the scanning electron microscope.

Table 6. Interpretation of the Functional Areas (FA) of the Kanjera South archaeological tools. Two functional areas have been identified on tools n° 11821and n° 24782; the remaining tools show a single FA. Tool n° 6448 own traces uninterpretable. For each tool the table shows the lithic raw material, the functional areas, the technological description, active edge angle (in degrees), action, and material processed as determined by this study. In grey artefacts with glossy appearance.

Table 7. Percentage of edges with use-wear by materials processed, lithic raw material, and inferred actions, for artefacts from Kanjera South, as determined in this study and Lemorini et al. 2014. All blank cells indicate zero values. Total Soft includes flesh, fresh hide and herbaceous plants. Total Medium Hard includes bone, wood and USOs.

Table 8. Actions carried out with rhyolite, fenetized andesite, quartzite, and quartz artefacts and the mean edge angle of the active edges.

Figures captions

Fig. 1 – Placement map showing the location of Kanjera in southwestern Kenya and of the Southern Exposures at Kanjera where the Oldowan occurrences are found. The composite stratigraphic log shows the basal three beds of the Southern Member (KS-1 to KS-3) and the base of KS-4. Spatially associated artifacts and fossils are found as diffuse scatters and also in more vertically discrete concentrations from the top of KS-1 through KS-3, with KS-2 providing the bulk of the archaeological sample.

Fig.2 - Experimental activities with replicas of rhyolite and fenetized andesite tools: a) butchering; b) USO processing.

Fig. 3 – Stereoscopic microscope images of macro-traces on replicas a) light edge-rounding on the active edge of a rhyolite flake used for skinning and butchering; b) small edge-removals with feather terminations on the active edge of a fenetized andesite flake used for skinning and butchering; c) medium edge-rounding on the active edge of a fenetized andesite flake used for scraping dry hide; d) localized edge-removals with feather-step terminations on the active edge of a rhyolite flake used for scraping wood,; e) very large edge-removals with hinge-step terminations on the active edge of a rhyolite flake used for scraping fresh bone; f) medium edge-rounding on the active edge of a fenetized andesite flake used for peeling and cutting rootstocks.

Fig.4 - Metallographic microscope images of micro-traces on replicas a) unused edge of a fenetized andesite; b) rough especially (soft animal tissues) and smooth localized spots (bone contact) with a granular topography on the outer edge aspect of the active edge of a rhyolite flake used for skinning and butchering; c) narrow striae on the crystal (a) and lightly developed rough polish on matrix (b) on the active edge of a fenetized andesite flake used for cutting riparian grasses steams; d) rough to smooth polish with a granular to domed topography on the outer edge aspect of the active edge of fenetized andesite flake used for scraping fresh hide subcutis subcutaneously; e-f) edge-rounding medium and smooth polish with a domed topography on the edge of the active edge of a fenetized andesite flake used for cutting wood.

Fig.5 - Metallographic microscope images of micro-traces on replicas a) smooth polish with a domed topography on the surface of the active edge of a rhyolite flake used for working wood with a mixed action; b) localized medium edge-rounding and smooth polish with a domed topography on the protruding points of the active edge of a fenetized andesite flake used for cutting reeds; c-d) rough polish with granular topography plus shallow sleeks striae (a) on the surface of the active edge of two distinct different fenetized andesite flakes used for peeling and cutting rootstocks from wet environment; e) smooth polish with granular topography on matrix (a) and developed and localized corrosion plus narrow deep tapering (furrow) striae (b) on a crystal on the active edge of a rhyolite used for peeling and cutting tubers from dry environment; f) smooth polish with granular topography on matrix of a fenetized andesite ; used for peeling and cutting tubers from dry environment

Fig. 6 - SEM images of micro-traces on replicas – a) unused edge of a rhyolite flake; b) light material removal, medium edge rounding on the outer edge and a smooth polish with a domed topography on the active edge of a fenetized andesite used for cutting riparian grasses steams; c) light material removal, medium edge-rounding on the outer edge and smooth polish with domed to flat topography on the active edge of a fenetized andesite flake used for skinning and butchering; d) light to medium material removal, high edge-rounding on the outer aspect and smooth polish with domed topography on the active edge of a fenetized andesite flake used for skinning and butchering; e) medium material removal, high degree of rounding on the edge, rough to smooth polish with flat topography on the active edge of a fenetized andesite flake used for scraping fresh hide subcutaneously; f) medium material removal, medium edge-rounding on the edge, smooth polish with a granular topography on the active edge of a fenetized andesite flake used for scraping dry hide

Fig. 7 - SEM images showing micro-traces on replicas — a) medium degree of material removal, medium level of rounding on the outer edge, smooth polish with a flat topography on the active edge of a rhyolite flake used for peeling and cutting dry environment tubers; b-c) medium material removal, medium edge rounding on protruding points, smooth polish with domed to flat topography on the active edge of a fenetized andesite flakes used for peeling and cutting rootstocks from wet environment; d-e) high level of material removal, high degree of rounding on the outer edge, smooth polish with domed topography and sleek striae on the active edge of a rhyolite tool used for scraping wood; f) medium material removal, high edge-rounding on the outer edge and protruding points, rough to smooth polish with domed topography on the active edge of a fenetized flake used to cut reeds

Fig.8 – SEM images showing micro-traces on replicas – a-b) high material removal, high edge-rounding on protruding points, smooth polish with a flat topography and few sleek striae on the active edge of a rhyolite flake used for scraping bone

Fig. 9 – Some example of Kanjera South tools of rhyolite tools presenting use-wear: a) 5490; b) 11821; c) 20961; d) 24521; scale bars equal to 1cm.

Fig. 10 – Post-depositional alteration on archaeological tools – a) Kanjera South 24768 metallographic microscope: developed glossy appearance of the surface ; b) Kanjera South 24711 SEM: collapsed areas caused by an intensive process of surface removal

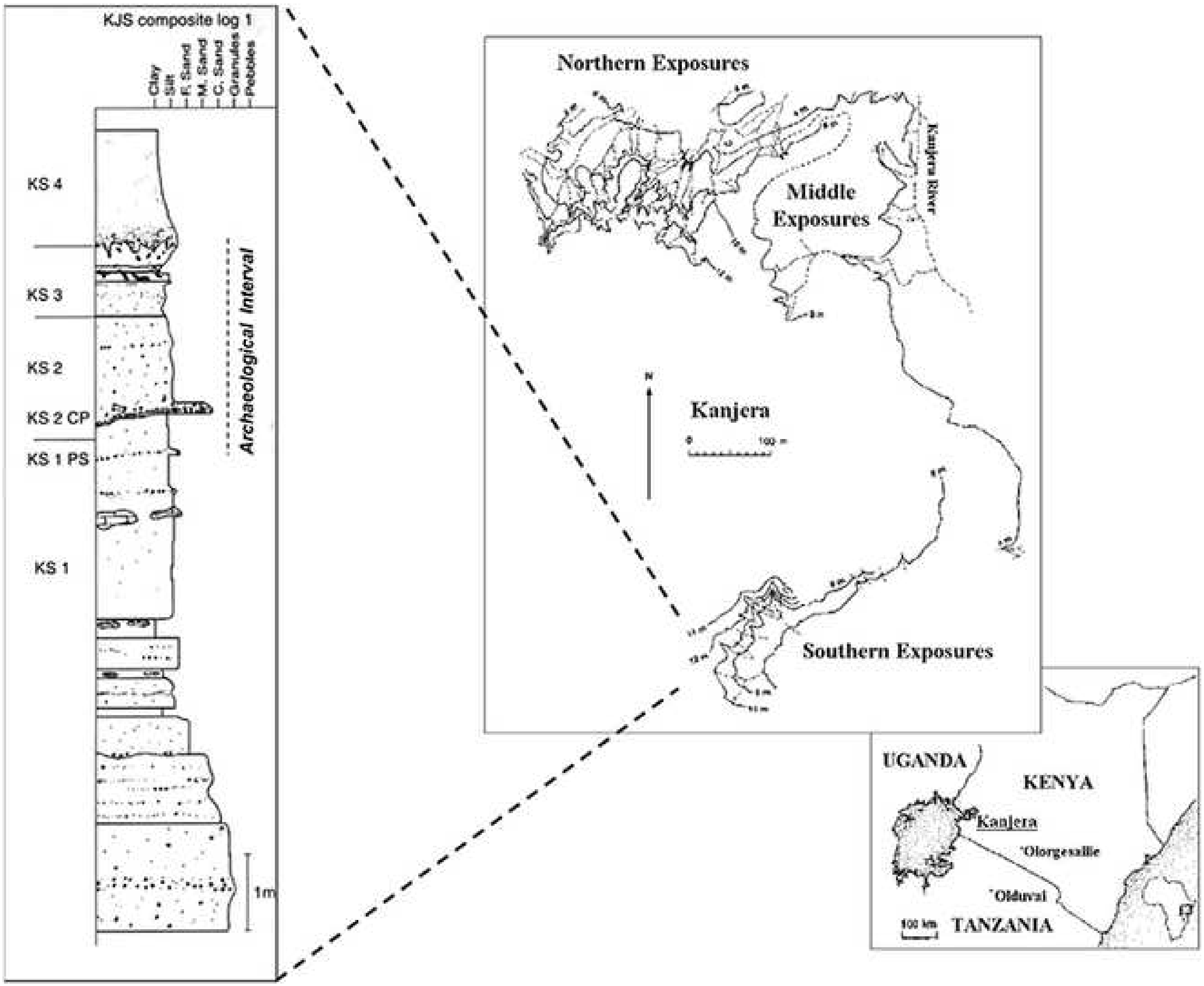
Fig. 11 Archeological inferred activities of wood working – a) Kanjera South 11821 stereo: FA1 light edge-rounding and edge removals with feather-step terminations with a transversal direction interpreted as the result of a scraping action on a medium-hard material; b) Kanjera South 11821 metallographic microscope: rounded crystal with smooth polish and domed topography interpreted as the result of wood working;c) Kanjera South 11821 metallographic microscope: crystal with well-developed deep narrow tapering (furrow) striae interpreted as the result of wood working; d) Kanjera South 20464 stereo: light edge-rounding and edge removals with step terminations with a transversal direction interpreted as the result of a scraping action on a medium-hard material; e) Kanjera South 20464 metallographic microscope: very well developed smooth polish on domed topography plus deep narrow tapering (furrow) striae on crystal interpreted as the result of wood working; f) Kanjera South 20464 SEM: medium material removal and flat on area interpreted as resulting from wood working.

Fig. 12 Archeological inferred activities of wood working and wood or hard herbaceous plants working – a-b) Kanjera South 6554 SEM: medium level of material removal, high degree of rounding on the outer edge, polish smooth with a flat topography interpreted as working wood; c) Kanjera South 15338 metallographic microscope: smooth polish on domed/flat topography plus some striae on the active edge interpreted as the result of working wood or hard herbaceous plants; d) Kanjera South 15338 SEM: high level of material removal, light-medium degree of edge rounding localized on protruding points, smooth polish with granular topography interpreted as the result of working wood/hard herbaceous plantsplantss; e) Kanjera South 24985 metallographic microscope: crystal with a light corrosion interpreted as a result of working soft material; f) Kanjera South 24985 SEM: localized high level of material removal, medium degree of edge-rounding on the outer edge, polish rough with a granular topography interpreted as the result of working hard herbaceous plants.

Fig. 13 Archaeological inferred activities of underground storage organs – a) Kanjera South 7681 stereo: medium edge-rounding and light and edge removals with feather-step terminations with a transversal direction interpreted as the result of a scraping action on a medium-hard material; b) Kanjera South 7681 metallographic microscope: rough polish with granular topography interpreted as the result of working tubers/rootstocks from wet environment; c) Kanjera South 7681 SEM: high level of material removal, high degree of edge-rounding on protruding points, smooth polish with a domed to flat topography interpreted as the result of working wet environment tubers/rootstocks; d) Kanjera South 20961 SEM: medium level of material removal, medium degree of edge-rounding on protruding points/outer edge, smooth polish with a localized domed topography interpreted as the result of working tubers/rootstocks; e-f) Kanjera South 5369 a) developed and localized corrosion plus narrow deep tapering (furrow) striae on a crystal and b) rough to smooth polish with a granular to flat topography interpreted as the result of working tubers/rootstocks from dry environment.

Fig. 14 Archeological inferred activities of butchering–a) Kanjera South 5490 stereo: light edge-rounding and edge removals with feather terminations with a diagonal direction interpreted as the result of a cutting action on a soft material; b) Kanjera South 5490 metallographic microscope: rough to smooth polish with granular to domed topography interpreted as the result of contact with skin and soft animal tissues (butchering); c-d) Kanjera South 5490 SEM: light material removal, light edge-rounding on the outer edge, smooth polish with domed to flat topography interpreted as the result of skinning plus butchering; e) Kanjera South 24905 metallographic microscope: rough to smooth polish with granular topography interpreted as the result of contact with skin and soft animal tissues (butchering); f) Kanjera South 24095 SEM: medium level of material removal, high edge-rounding on the outer edge, smooth polish with domed to flat topography interpreted as the result of skinning plus butchering.

Figure

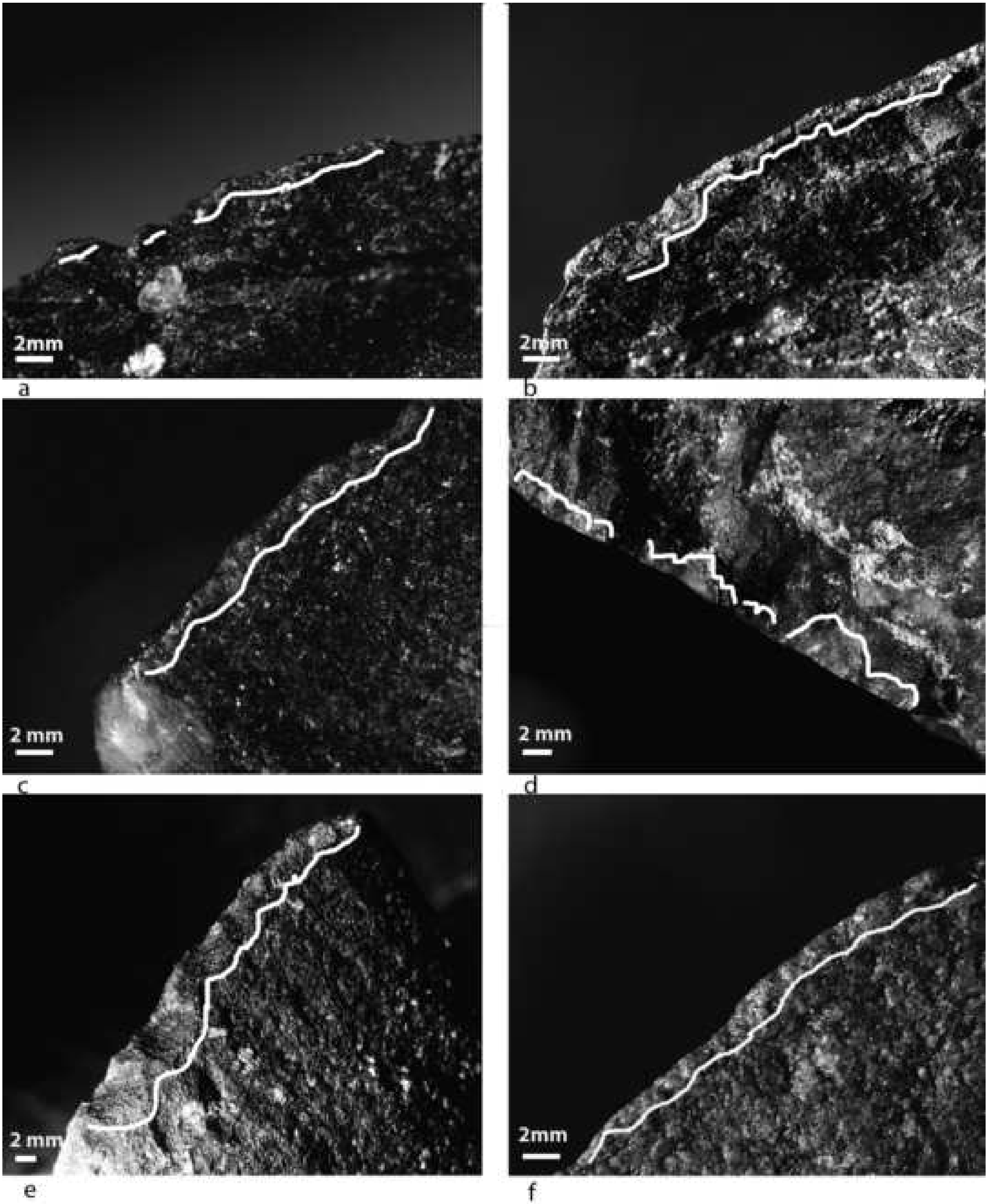


KJS composite log 1
Clay
Silt
F. Sand
M. Sand
C. Sand
Granules
Pebbles
KS 4
KS 3
KS 2
KS 2 CP
KS 1 PS
KS 1
Archaeological Interval
1m
Northern Exposures
Middle Exposures
Kanjera River
Kanjera
N
Southern Exposures
UGANDA
KENYA
Kanjera
Olorgesailie
Olduvai
TANZANIA
100 km

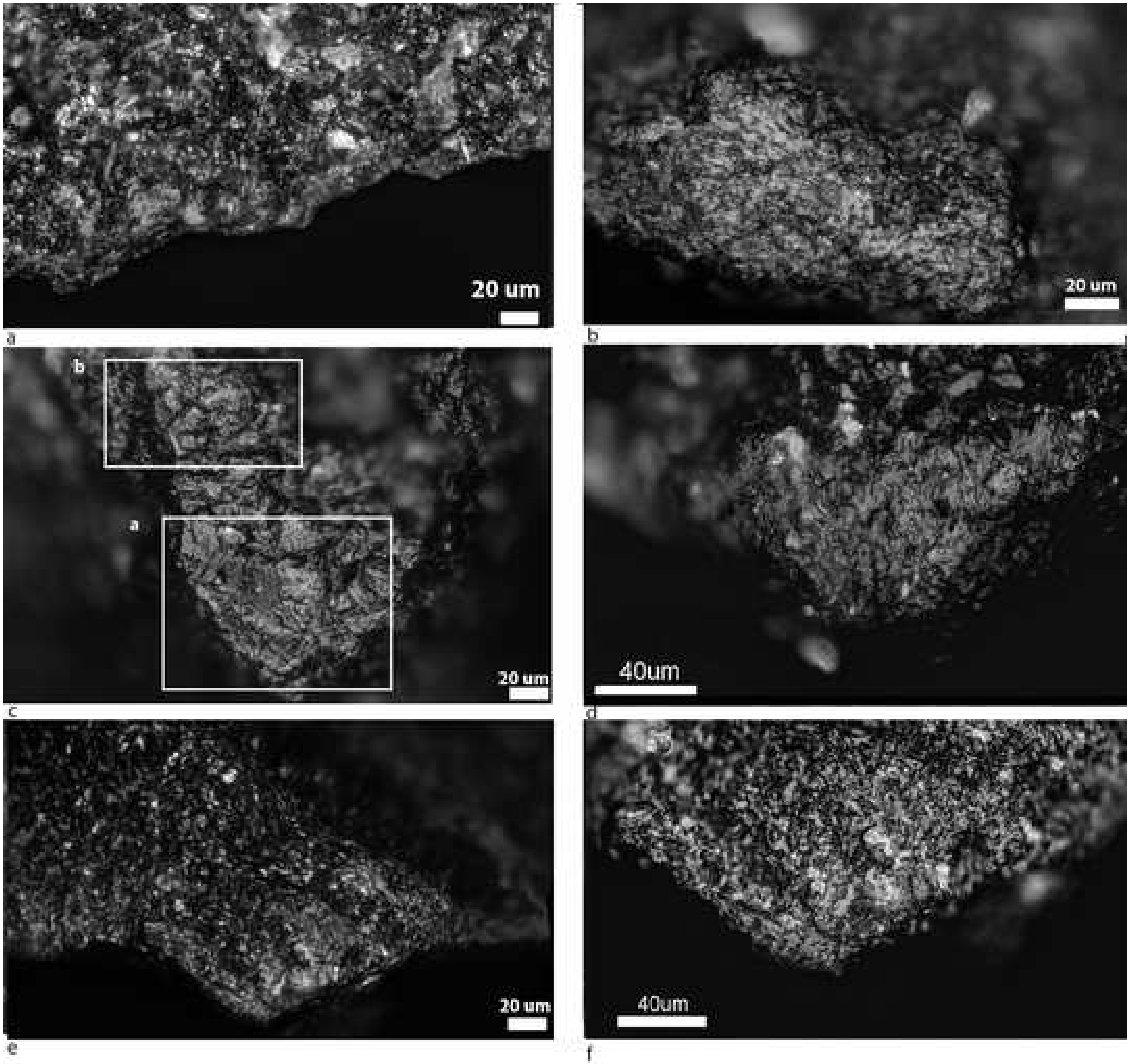
Figure

a b

Figure



Figure



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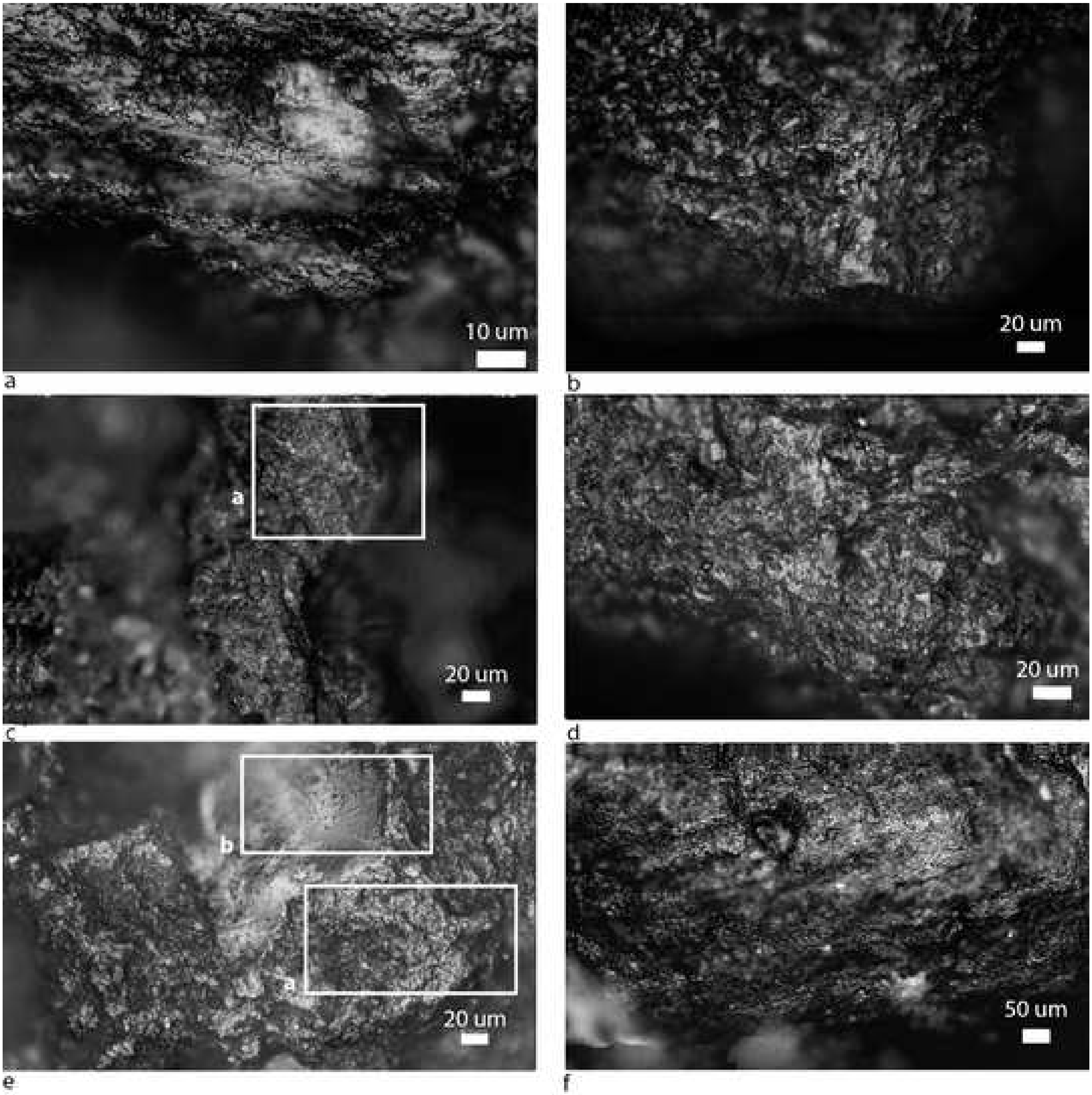

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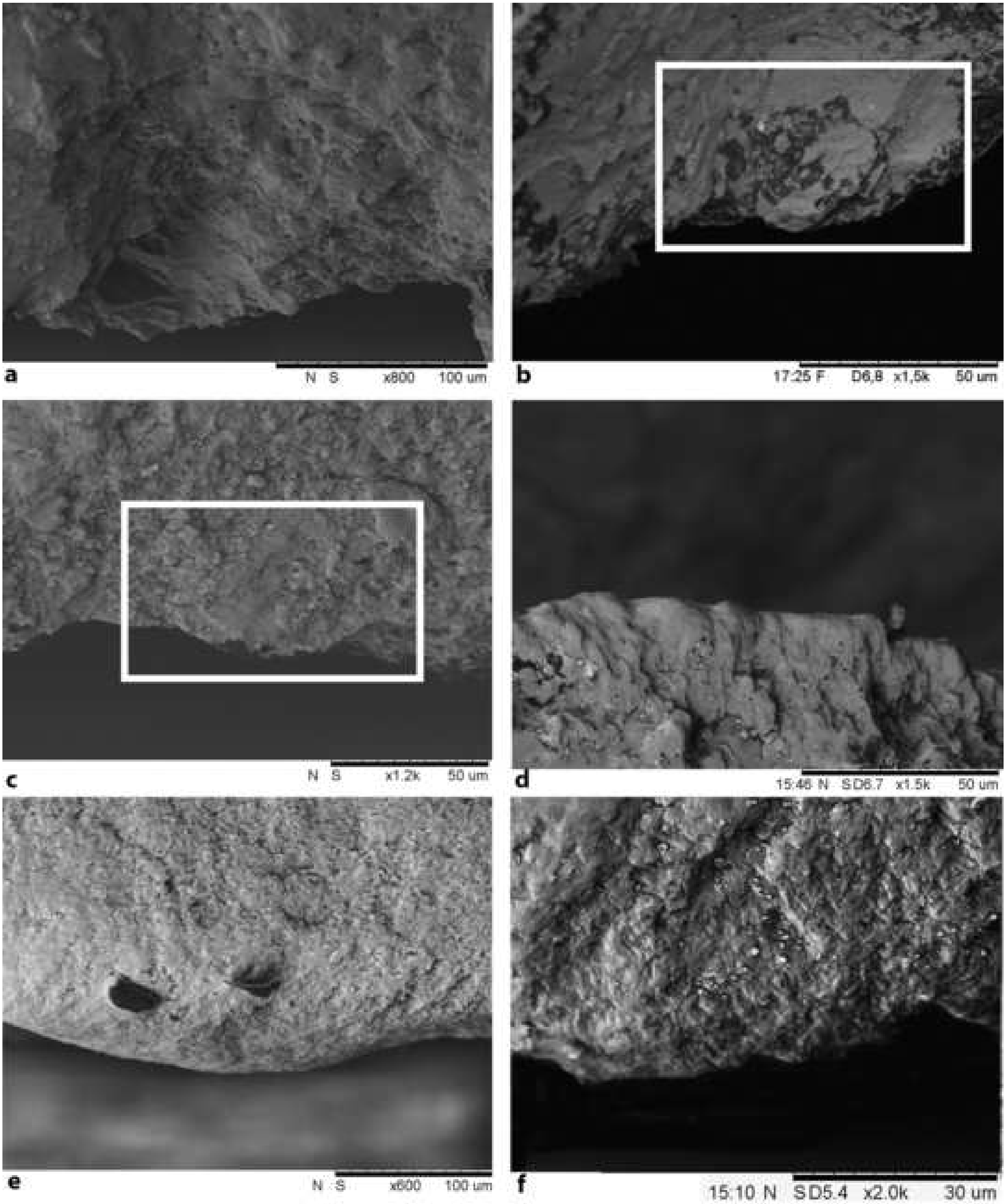
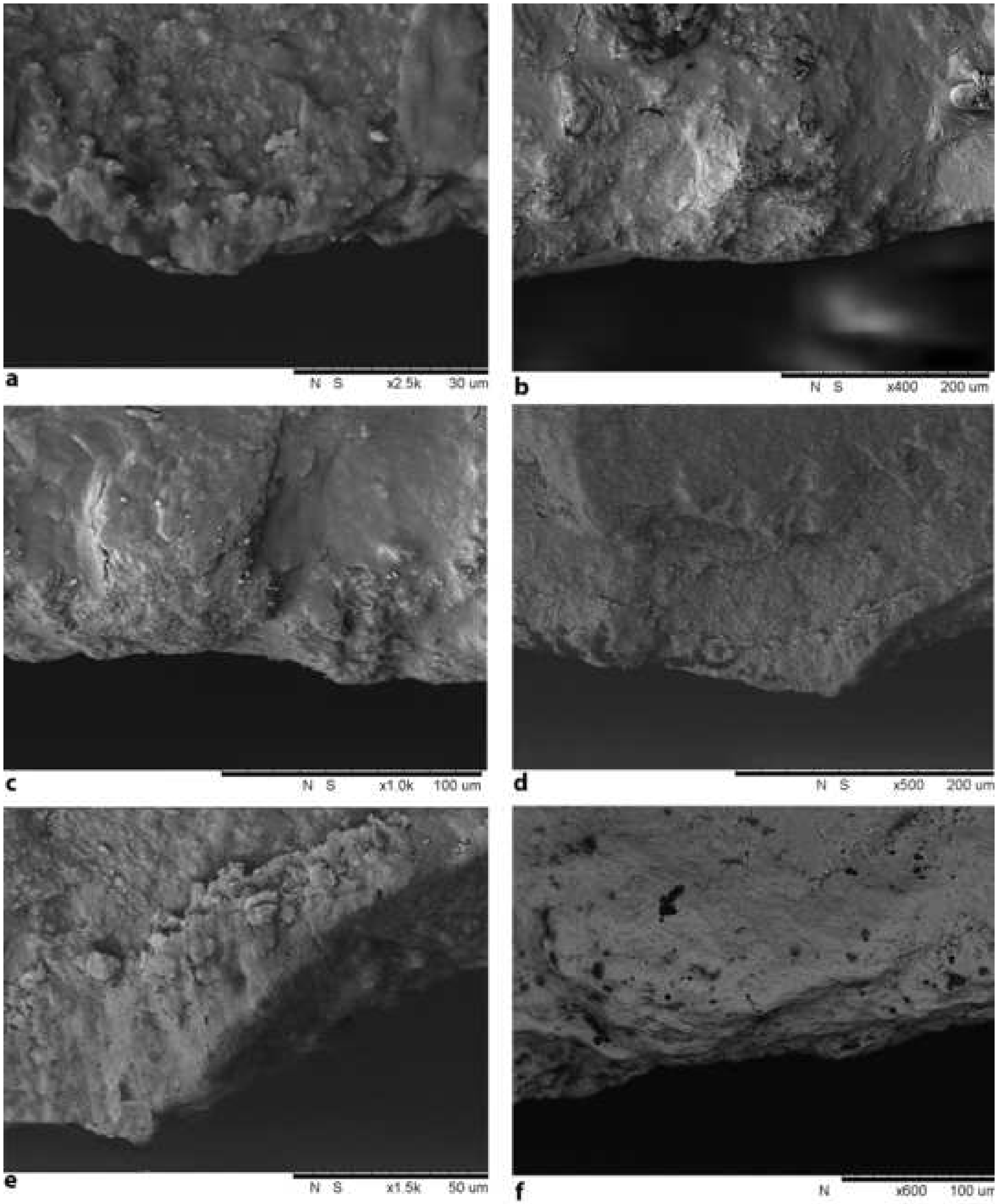
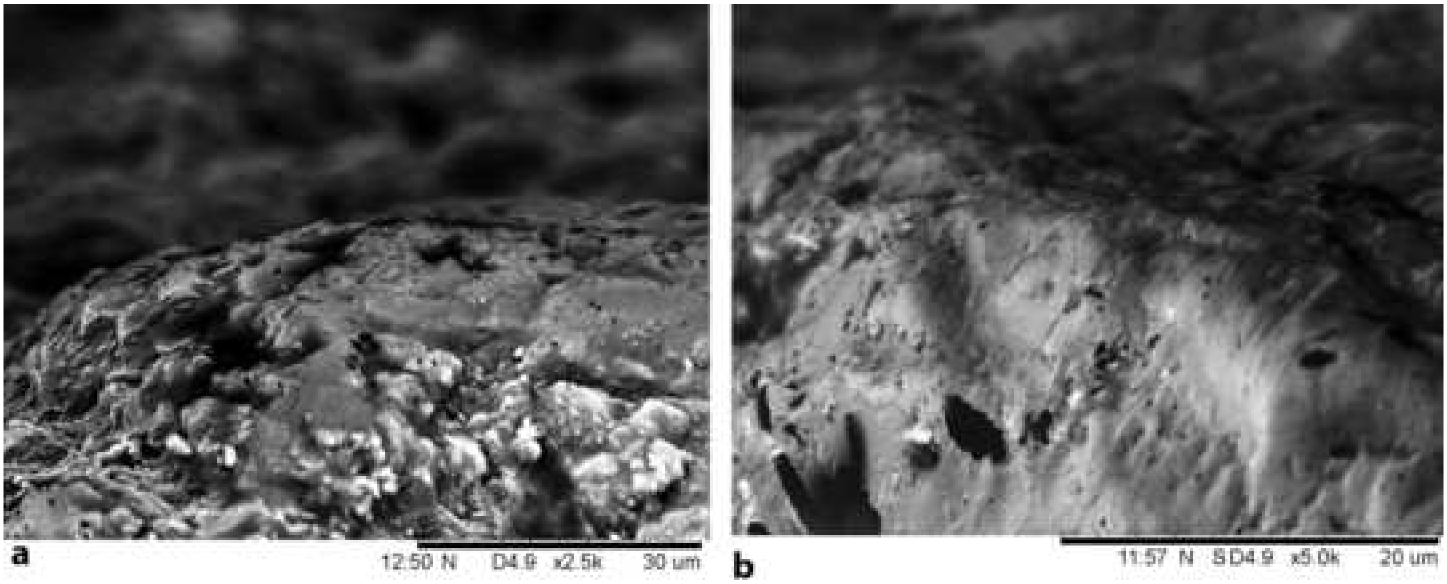

a
N S x800 100 um
b
17:25 F D6,8 x1,5k 50 um
c
N S x1.2k 50 um
d
15:46 N SD6.7 x1.5k 50 um
e
N S x600 100 um
f
15:10 N SD5.4 x2.0k 30 um

Figure



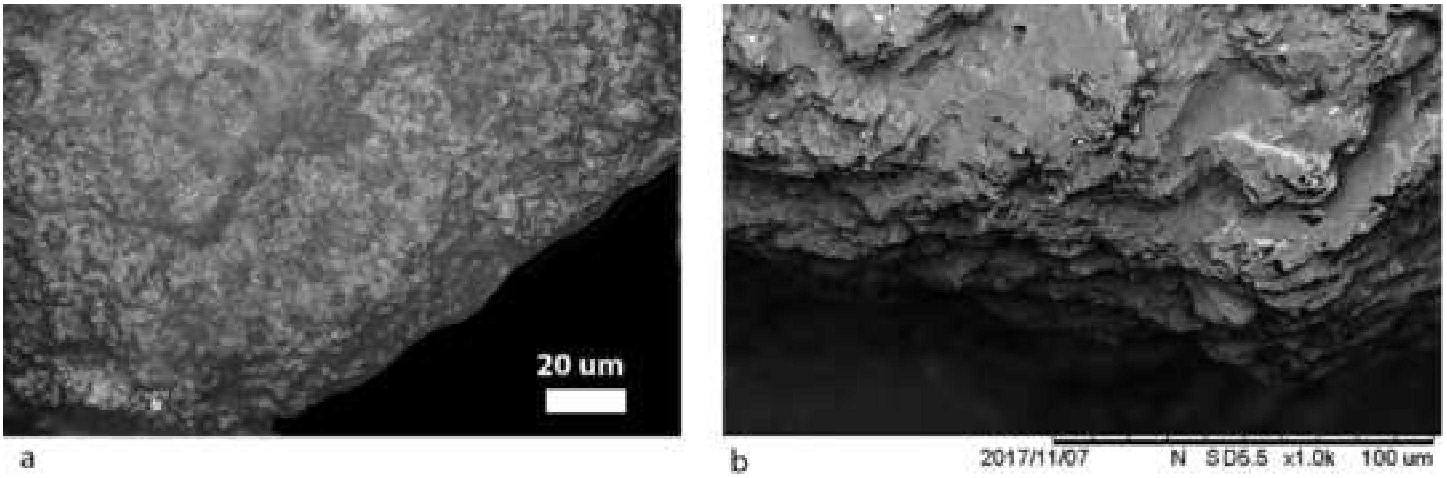
a
N S x2.5k 30 um
b
N S x400 200 um
c
N S x1.0k 100 um
d
N S x500 200 um
e
N S x1.5k 50 um
f
N x600 100 um

Figure



Figure

Figure



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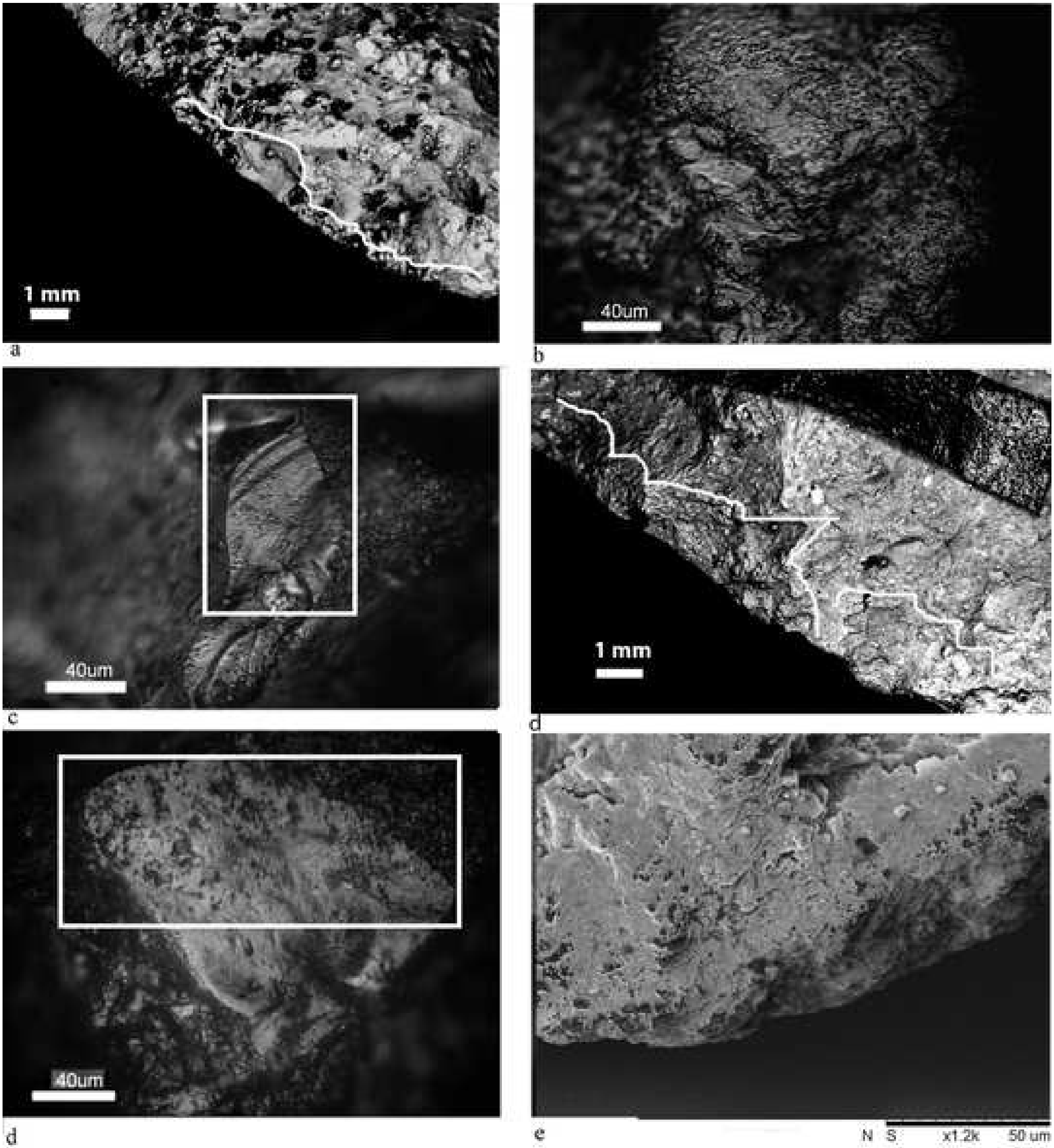

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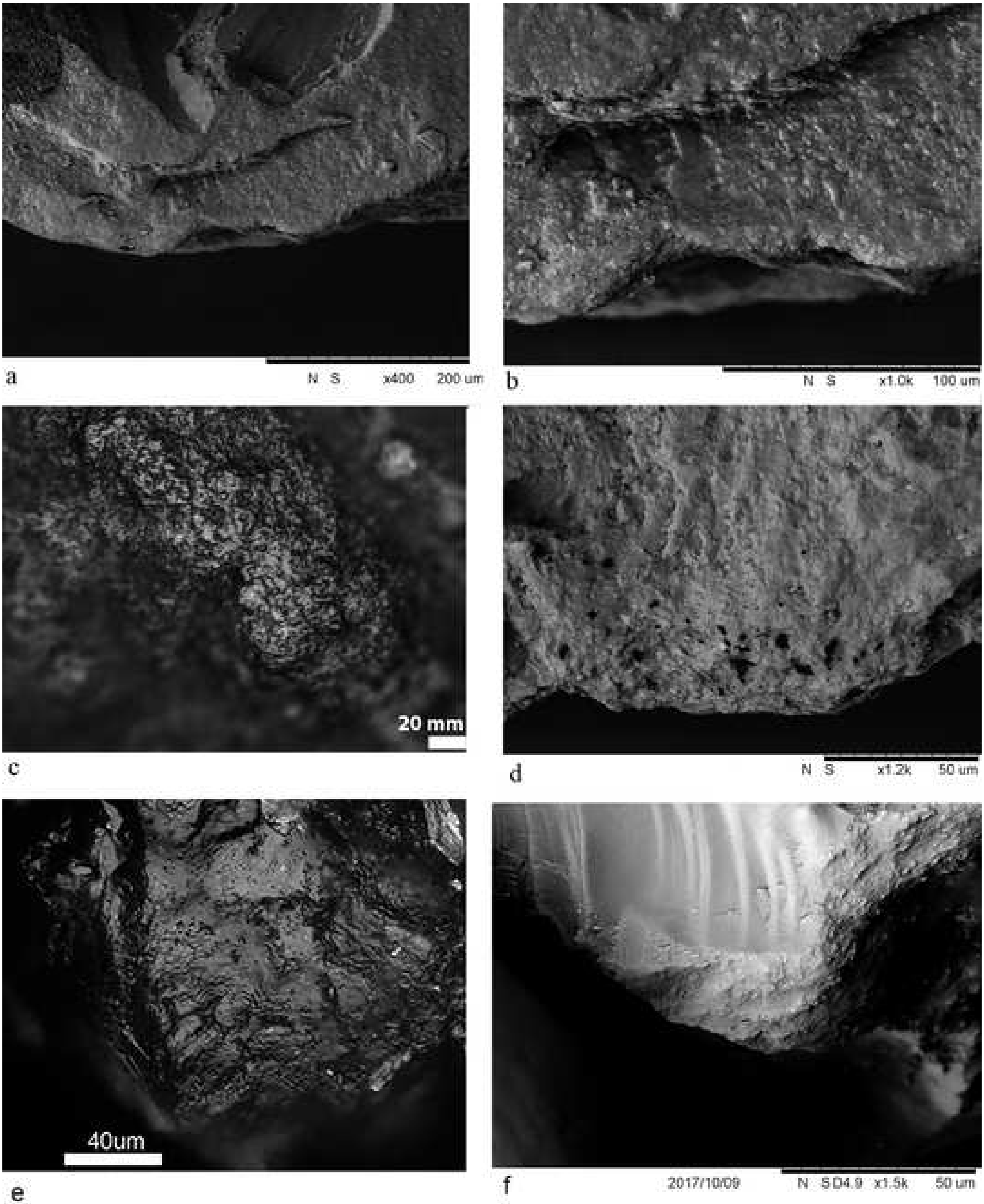
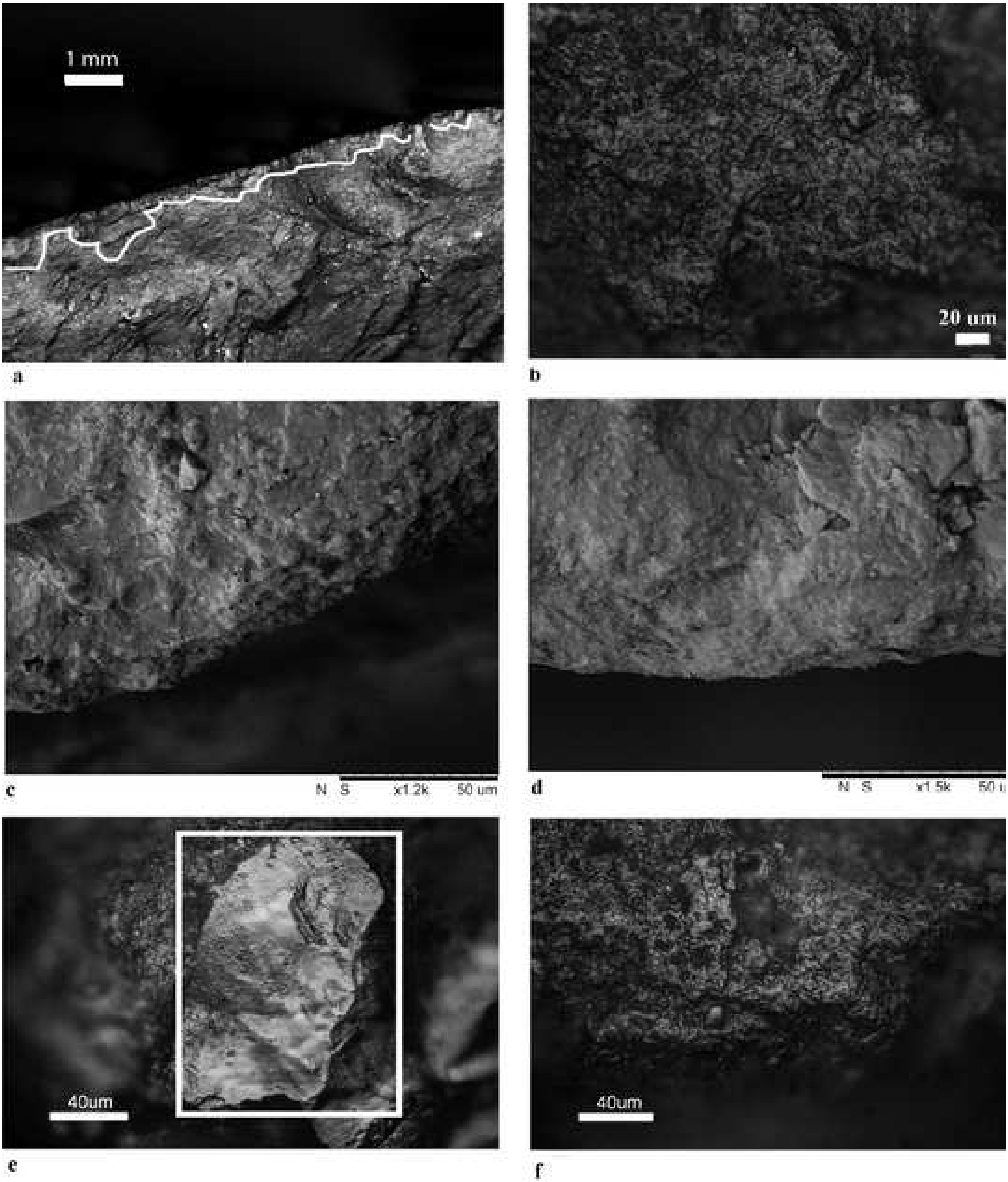

a
N S x400 200 um
b
N S x1.0k 100 um
20 mm
c
d
N S x1.2k 50 um
40um
e
f
2017/10/09
N SD4.9 x1.5k 50 um

Figure



Figure