Archaeological and Anthropological Sciences (2022) 14: 93
https://doi.org/10.1007/s12520-022-01559-6

ORIGINAL PAPER

Traceological analysis of lithics from the Camel Site, al-Jawf, Saudi Arabia: an experimental approach to identifying mineral processing activities using silcrete tools

Yamandú H. Hilbert[1,2,3] · **Ignacio Clemente-Conte**[3] · **Rémy Crassard**[4] · **Guillaume Charloux**[5] · **Maria Guagnin**[6] · **Abdullah M. AlSharekh**[7]

Received: 16 December 2021 / Accepted: 8 April 2022 / Published online: 26 April 2022

Abstract

The Camel Site is in the north of Saudi Arabia in the province of al-Jawf. It is characterised by three decaying sandstone hillocks with life-sized 3D engravings (or reliefs) of camels and equids likely carved during later prehistory. A survey in the central area of the site identified clusters of flakes and other flintknapping remains in the lower areas between the sandstone spurs and larger silcrete tools directly underneath the animal depictions. Some of these tools presented abraded edges, possibly from prolonged contact with the soft and abrasive sandstone that constitutes the rock spurs where the animals were carved. Experiments were performed to test this hypothesis and have a reference collection for further traceological analysis. The *chaine opératoire* of the experimental engraving tools, from raw material procurement, tool manufacture and use, reuse and discard, was conducted with locally available materials comparable to the archaeological specimens. Specific experimental variables, including how the force was applied, in what direction the movement took place and the orientation of the stone tool during the experiment, were also recorded. Macro- and microscopic analyses of the experimental collection and a sample of archaeological artefacts seem to show that the ancient tools found on the surface were probably used to make the camelid and equid reliefs at the site.

Keywords Traceology · Experimental replication · Naturalistic animal reliefs · Sandstone · Mineral processing

Introduction

This study describes an exploratory experiment aiming to identify wear traces on different silcrete stone tools used to process sandstone. We will present the results of the subsequent traceological analysis conducted on the experimental tools and compare the traces with an archaeological sample from the Camel Site et al.-Jawf in northern Saudi Arabia. The rationale behind this experiment and subsequent traceological analysis involves the use of stone tools to create rock art engravings. The use of stone tools in the carving of engravings, portable motifs in the form of plaquettes or other symbolic expressions, have been theorised and described (Leroi-Gourhan and Allain 1979; Mélard et al. 2016; Moro Abadía and González Morales 2013; Plisson 2007). We will focus our discussion on the carving of sandstone cliffs and immovable boulders, albeit mobile art made on hard organic and inorganic materials such as antler, bone, clay and ivory along with engravings on schist, jet stone (and other artefacts types), are found throughout prehistory across all continents.

✉ Yamandú H. Hilbert
yamandu.hilbert@uni-tuebingen.de

[1] Paleoanthropology, Senckenberg Centre for Human Evolution and Palaeoenvironment, Institute of Archaeological Sciences, University of Tübingen, Tübingen, Germany

[2] Institut Für Ur- Und Frühgeschichte, Friedrich-Alexander-Universität Erlangen-Nürnberg, Erlangen, Germany

[3] Archeology of Social Dynamics (ASD), Institución Milá y Fontanals de Investigación en Humanidades, CSIC, Barcelona, Spain

[4] UMR 5133 'Archéorient', CNRS, Maison de l'Orient et de la Méditerranée, Lyon, France

[5] UMR 8167 'Orient & Méditerranée', CNRS, Paris, France

[6] Department of Archaeology, Max Planck Institute for the Science of Human History, Jena, Germany

[7] Department of Archaeology, College of Tourism and Antiquities, King Saud University, Riyadh, Saudi Arabia

Analyses designed to identify mineral processing activities have been conducted sporadically since the advent of the traceological methods, and some researchers have included limited numbers of experimental pieces used to modify varying types of minerals in their experimental reference collections (e.g. Clemente-Conte 1997; González-Urquijo and Ibañez-Estéves 1994; Keeley 1980; Mansur-Franchomme 1986). Specific experimental and traceological studies aiming to identify modification caused by mineral processing, however, are rare (Alvarez et al. 2001; Alvarez and Fiore 1995; de Beaune and Pinçon 2001; Hamon et al. 2021; López-Tascón et al. 2018; 2020). These previous studies have focused on either limestone or schist supports transformed by pebbles, quartzite or flint experimental tools. Here, we present the first study concentrated on sandstone carving using tools made from silcretes; two minerals commonly used throughout prehistory across the Arabian Peninsula and beyond. Additionally, our experimental protocol focuses on the use of transverse motions instead of typical longitudinal movements used in classic engraving activities. This focus is a function of the specific archaeological case study addressed herein, namely, the 3D engravings depicting life-size camels and equids from the al-Jawf province in Saudi Arabia.

Background

The al-Jawf province and the immediate surroundings of the Camel Site have undergone surveys and are the subject of different archaeological missions operating in northwestern Saudi Arabia since the second half of the twentieth century (Adams et al., 1977; Parr et al., 1978, for a list see Charloux 2018). The oldest human occupations of the region are attributed to the Lower and Middle Palaeolithic, with some rare occurrences of Upper Palaeolithic materials found throughout the plateaus flanking the Wadi Sirhan fault and even within the fringes of the northern Nafud (Hilbert et al. 2017; Hilbert and Crassard 2020). Neolithic occurrences were found in the vicinity of the Camel Site and throughout the sandstone plateau west of Dumat al-Jandal.

The Camel Site (DAJ155) is characterised by three sandstone spurs that present a series of façades of different magnitudes at varying altitudes upon which zoomorphic reliefs of naturalistic proportions have been carved (Fig. 1); predominantly camels and occasionally wild equids are shown in realistic anatomical proportions with great attention to detail (Charloux et al. 2018; Guagnin et al. 2021). A recent literature review of the still burgeoning field of Arabian rock art study has identified over 50 sites located across the Arabian Peninsula, from Najrân in southern Saudi Arabia, up to Petra in Jordan, that present large-sized camel depictions (Charloux et al. 2020). These sites span a considerable chronological depth as well as a wide geographical area and were recently structured into different traditions of which the reliefs from the Camel Site, which depicts mostly male wild camels, are likely the oldest and possibly of a Late Neolithic age (Andreae et al. 2020; Guagnin et al. 2021).

The geology of the Camel Site and its immediate surroundings within the Sakaka basin is characterised by regolith surfaces, inselbergs and sandstone rock spurs of the late Cretaceous Wasia Group, also known as Sakaka sandstone (Powers et al. 1966; Wallace et al. 1997). The Sakaka sandstone has a primarily marine origin across northwestern Saudi Arabia. It is relatively soft and weathers rapidly by wind abrasion, causing exfoliation, subsequent pitting and the formation of vertical fissures, which instigate the decay of the rock spurs and the reliefs. The sandstone rock spurs on which the camel reliefs and other graphic depictions (encompassing recent graffiti and tribal symbols) have been made are severely deteriorated and eroded by wind abrasion leading to the decay and destruction of the sandstone spurs. The camel reliefs are in most cases only partially preserved, and fragments of the reliefs themselves or even larger blocks that have been carved into near to life-size naturalistic camel reliefs are found collapsed, laying on the low talus slopes; recent bulldozing of the area around the spurs has further deteriorated the archaeological site.

The analysis of the marks of the production of the panels from the Camel Site by Guagnin et al. (2021) indicated the use of percussive and abrasive actions, including scraping and pecking, possibly by using stone tools. The life-sized camel depictions show different preservation conditions, some parts being highly eroded while others maintain some forms of fine details and carvings. The reliefs identified in 30 individual panels found throughout the site were likely made in two separate stages of production: the first stage of manufacture would have encompassed the subtraction of a considerable amount of sandstone volume, particularly around the ventral and dorsal portions of the animals as well as around the extremities. The presence of unfinished reliefs that have been abandoned during the first stage (panel 4) provides a glimpse into how this phase was undertaken. Deep pecked holes have been identified that were likely made using stone tools (Fig. 2). The second phase incorporated the smoothing of the contours on the animal reliefs and the addition of further detail by adding fine lines to the eye, nostrils and mouth.

To shed additional light on the creation of this emblematic site, experimental and traceological analyses were conducted. Here, we report the results of our experiment designed to identify the carving activities using stone tools on sandstone supports. We use this experimental reference collection to identify and classify specific wear patterns of sandstone abrasion to bolster the traceological interpretation of a sample of silcrete artefacts we classify as engraving tools.

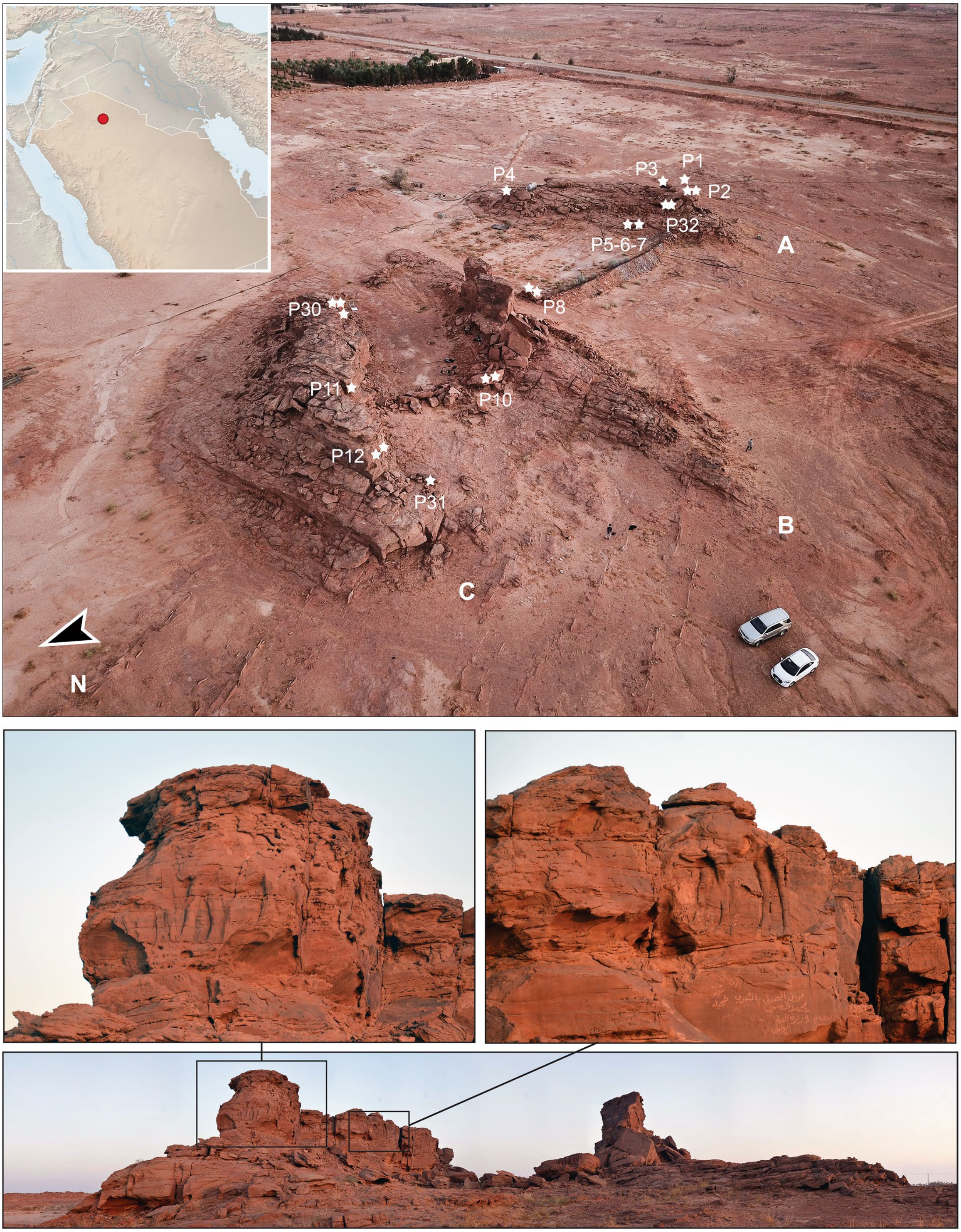


Fig. 1 Map and pictures of the Camel Site. Top, oblique view of a 3D model of the site with the location of the panels (modified after Guagnin et al. 2021); bottom, panoramic photo of the rock spurs with detail of carved camels. (Photo MG and YHH)

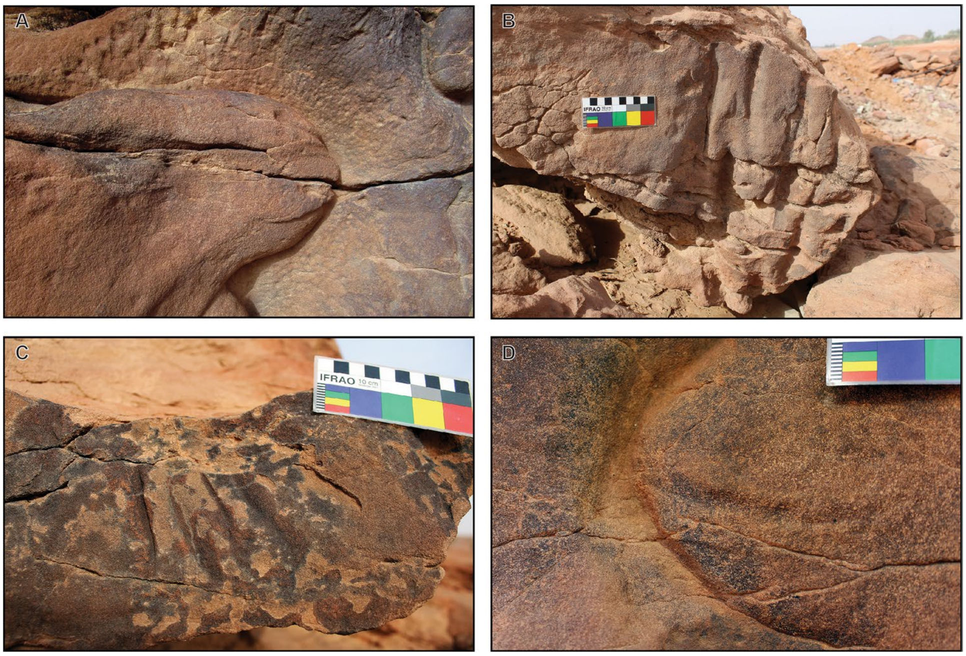


Fig. 2 Tool marks on the camel reliefs. **A** Close up of camel muzzle from panel 2 showing pecking signs in the background as well as smooth surface and thin lines; **B** deep longitudinal grooves and smoother surfaces forming the legs in panel 6; **C** short parallel grooves in panel 3; **D** fine lines forming the mouth and lips in panel 8. (Photographs GC and MG)

Material

A sample of 11 engraving tools found on the talus slope of the sandstone rock spur C that make up the Camel Site was selected for the analysis. These have been collected from the base of panels 11 and 30 and presented bevelled and abraded surfaces indicating their possible use in abrasive work resultant from scraping activities (Fig. 3). In addition to the artefacts collected from the base of the panels, excavations on the talus slope on the southwestern side of rock spurs B were undertaken. A test trench of 5 m^2 (Trench 1) was excavated, and lithics material, faunal remains and stone beads were recovered. Lithic artefacts are diminutive, and to a larger part of flake proportions, tools include different ad hoc retouched implements and a series of pressure-retouched transverse projectile armatures of triangular shape. Used raw materials include different variants of chert, flint and quartz. Based on typology and known parallels from the Levant and Southeastern Jordan, the transverse arrowheads fall between the late sixth to mid-fifth millennium BC (Betts et al. 2013; Rosen 1997). This chronology is supported by three radiocarbon samples taken on bioapatite providing ages falling into the mid-sixth millennium BC (Guagnin et al. 2021). Of the 706 lithic artefacts excavated from trench 1, a single unmodified piece of dark ferruginous sandstone, excavated from square 4 at a depth between 5 and 10 cm, presented what appeared to be lightly abraded edges and was therefore included in the traceological analysis. Archaeological remains from later periods are found in the vicinity of the site, and additional, younger engraved showing light weathered symbols attest to later occupations of the Camel Site.

The lack of suitable raw materials in the direct vicinity of the Camel Site is noteworthy; however, excavations and surveys activities have identified a considerable number of flaking remains, indicating an in situ production and potential use of lithics, that took place at the site (Fig. 4). Raw materials found were therefore brought to the site by human action. The analysed sample consists of three types of raw materials, broadly classified as silcrete, that can be differentiated macro- and microscopically from each other by colour, grains size and sedimentary matrix. Some of the artefacts can be classified as thick discoid cores showing a successive reduction of flakes from either core surface; others bear minimal amounts of modification leading to the formation of what could be interpreted as an active edge, while others were used without any modification.

Method

Excavation and survey methods followed modern standards of archaeological field praxis, excavations were conducted in 5-cm spits, all sediments were sieved, and the piece selected for traceological analysis was briefly rinsed with water and bagged separately. The position of the engraving tools found on the eastern slopes of spur C was recorded by GPS, each artefact was bagged separately to avoid damage, and all artefacts were rinsed with water to remove any loose sediment from their surfaces. Artefacts were exported to Spain with the permission of the local authorities and analysed at the microscopy laboratory of the working group: Archaeology

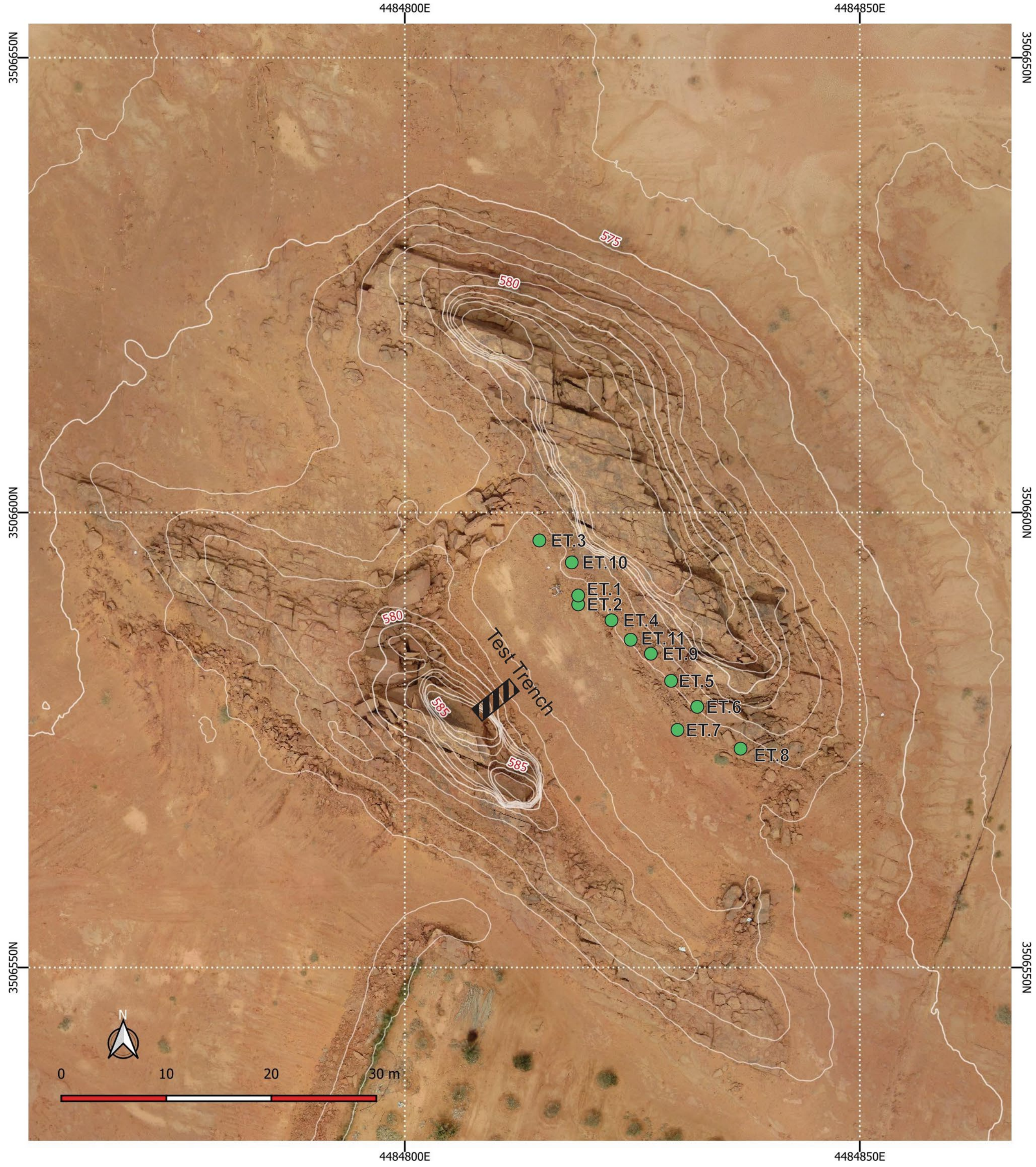


Fig. 3 Map of the Camel Site and location of the engraving tools found under the panel on the C spur of the site. (GC and YHH)

of Social Dynamics hosted at the Mila y Fontanals Institute on Humanities research in Barcelona by ICC and YHH.

An exploratory experiment was conducted to create a frame of reference for the modifications deriving from the transformative actions using specific variations of silcrete raw materials on the Wasia Group sandstone to classify tool motion and narrow the use alterations and exclude taphonomic origins of the observed traces on the archaeological samples. Raw materials used for the experiment were comparable to the archaeological specimens. They included

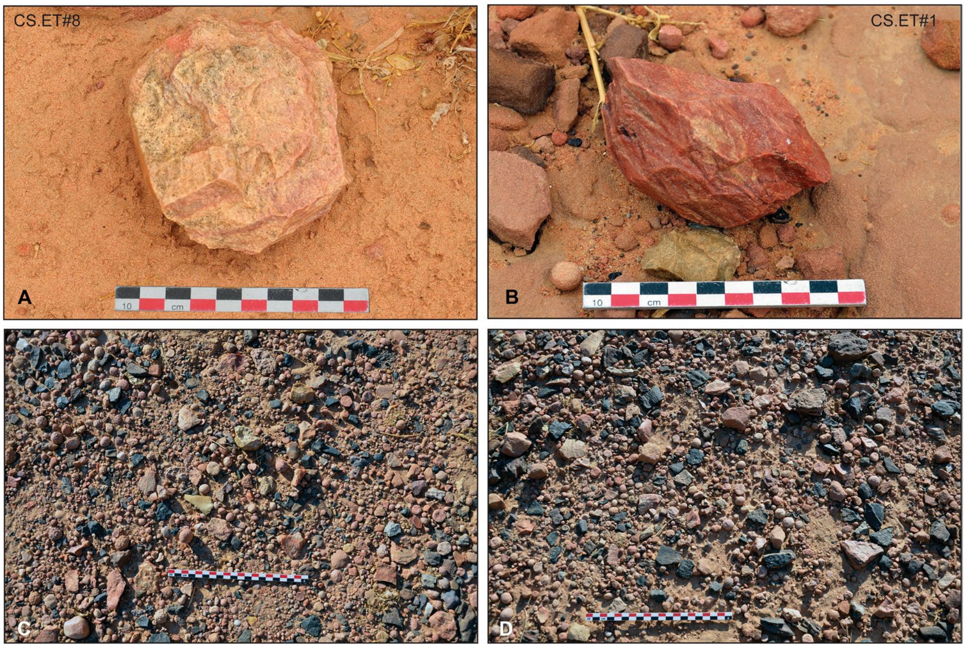


Fig. 4 Lithics on the surface of the site. **A** and **B** Large engraving tools (cores) found underneath the panels; **C** and **D** remnants of flaking activities found between the rock spurs C and B. (Photo YHH)

a dark silicified sandstone (RM1) variation, a red–orange and yellow-banded silcrete variant (RM2) and a dark ferruginous sandstone (RM3). These occur in different outcrops and show different properties. The raw materials for the experiment were collected at specific outcrops found within a 15-km radius of the site. In total, 13 experimental tools were made with the three raw materials using a direct hard hammer knapping technique; the flake and core tools were used during different intervals of either 1, 3 or 5 min averaging between 50 and 70 strokes per minute (Table 1).

The experimental tools were produced by RC and YHH using direct hard hammer percussion and included flakes, cores and natural chunks that were retouched to create a suitable working edge. Two large slabs of Sakaka sandstone collected from the immediate surroundings of the Camel Site were used to conduct the experiment. The specific kinetics of the movements used while wielding the experimental tools are summarised in Fig. 5. The applied force during the experiment was either by pressure or using direct or indirect percussion action using a stone hammer. Movements included transverse and longitudinal motions administered in either unidirectional or bidirectional fashion. All experiments were conducted without the addition of water to the sandstone. The experiment helped to identify abrasive tracks, directional markers, micro-chipping, micro-polish and sandstone residues on the archaeological tools.

Traceology builds on the use of microscopy to identify technological and functional related traces, a principle

Table 1 Metric and information on the experimental sample (*Abraded Edge)

Replica nr	Blank	RM	Length	Width	Thickness	Length AE*	Force	Motion	Time (min)
CS.ET.EXP.1	Flake	RM1	71.97	55.71	25.15	43.74	Pressure	Transverse bidirectional	1′
CS.ET.EXP.2	Flake	RM2	52.85	51.01	17.89	27.15	Pressure	Transverse unidirectional	5′
CS.ET.EXP.3	Flake	RM1	90.45	55.29	20.76	73.09	Pressure	Transverse bidirectional	5′
CS.ET.EXP.4	Flake	RM1	85.79	49.42	18.08	52.27	Pressure	Longitudinal bidirectional	5′
CS.ET.EXP.5	Chunk	RM3	55.51	29.63	15.61	13.24	Pressure	Transverse bidirectional	3′
CS.ET.EXP.6	Core	RM2	91.77	46.11	31.85	23.78	Percussion	Direct	3′
CS.ET.EXP.7	Flake	RM2	79.87	38.4	37.52	53.92	Pressure	Longitudinal bidirectional	5′
CS.ET.EXP.8	Flake	RM1	93.93	65.35	28.41	19.92	Percussion	Direct	3′
CS.ET.EXP.9	Core	RM2	57.11	48.54	21.9	24.11	Pressure	Transverse bidirectional	1′
CS.ET.EXP.10	Core	RM2	69.64	57.38	44.99	32.18	Pressure	Transverse unidirectional	3′
CS.ET.EXP.11	Core	RM2	91.89	54.31	28.5	16.51	Percussion	Indirect with hammerstone	3′
CS.ET.EXP.12	Flake	RM2	54.45	39.77	14.25	31.87	Pressure	Transverse unidirectional	5′
CS.ET.EXP.13	Core	RM2	64.62	60.83	34.82	35.61	Pressure	Transverse bidirectional	3′

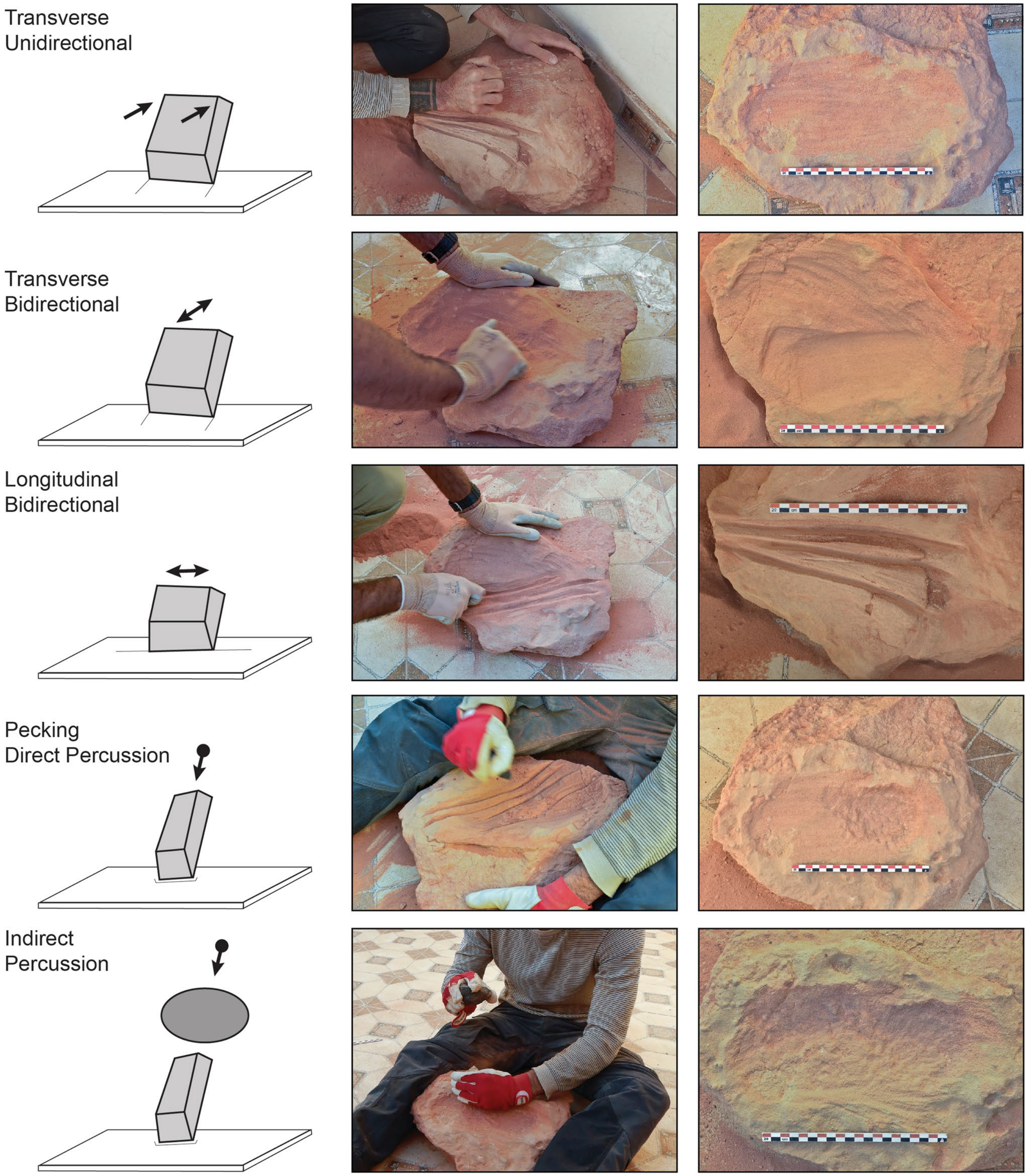
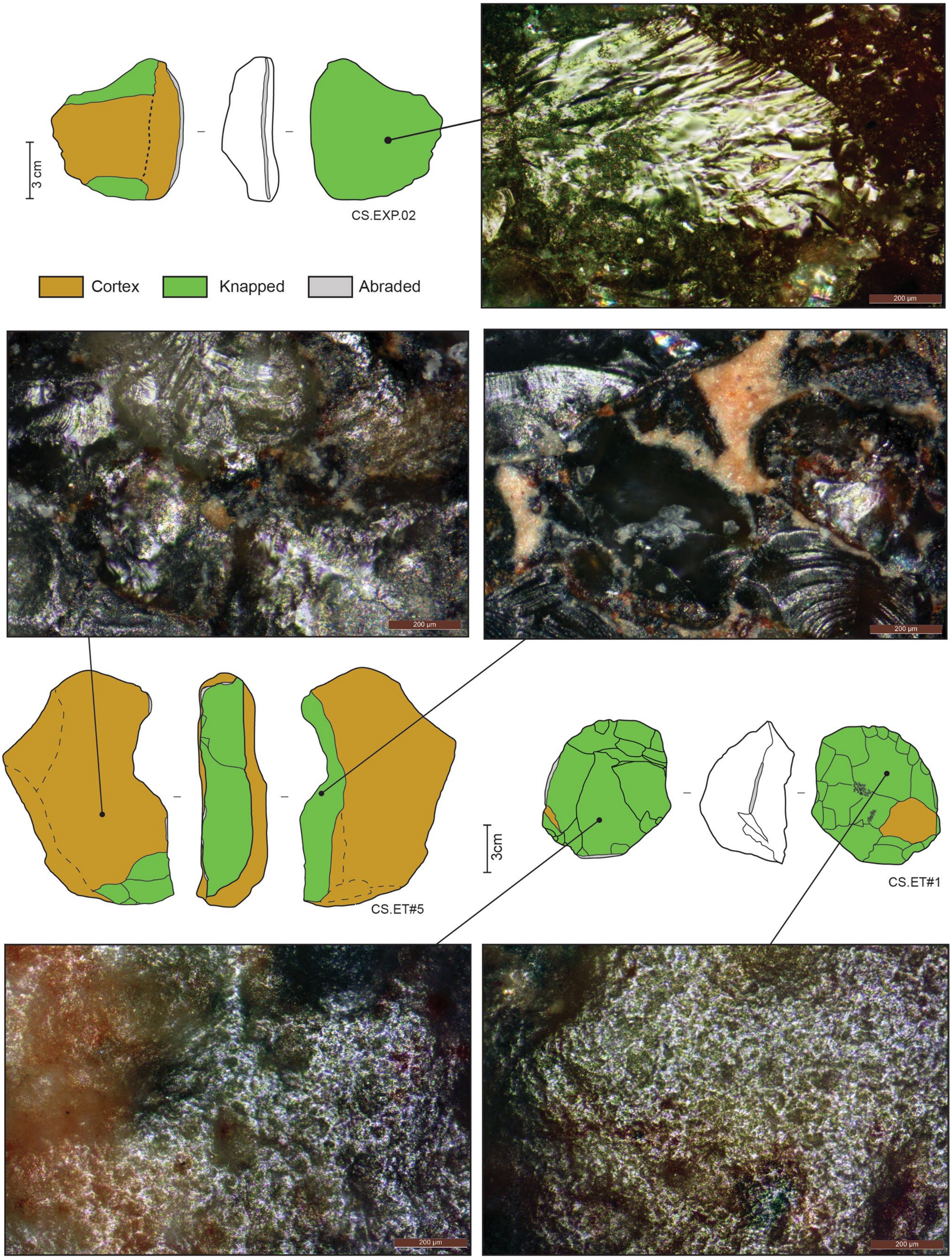


Fig. 5 Experimental protocol for the creation of traces related to sandstone processing. (Image YHH, photos GC and YHH)

established by S. E. Semenov, who applied it to archaeological remains from the Stone Age (Semenov 1964). With the incorporation of an experimental component to validate the interpretations regarding past prehistoric technologies, traceology gained additional importance (e.g. Clemente-Conte 1997; González-Urquijo and Ibañez-Estéves 1994; Keeley 1980; Mansur-Franchomme 1986; Moss 1983; Plisson 1985; Van Gijn 2014; Vaughan 1985). Currently,


3 cm
CS.EXP.02
Cortex
Knapped
Abraded
200 µm
200 µm
200 µm
CS.ET#5
3cm
CS.ET#1
200 µm
200 µm

◀**Fig. 6** Micrograph of the alterations caused by taphonomy located on the cortical portions of the tools and located in the knapped surfaces of the archaeological samples, as well as unmodified areas on the experimental reference sample. (Image YHH, photos ICC and YHH)

quantitative methods of functional analysis are being explored (Caux et al. 2018; Galland et al. 2019; Ibáñez and Mazzucco 2021; Pedergnana et al. 2020). By examining the surfaces and edges on prehistoric stone tools using different magnifications, micro-negatives, striations, micro-polishes and other traces of abrasion are plotted on the artefacts. The different roughness of the surfaces, regularisation of surfaces by abrasion and their intensity are the function of time, materials transformed and specific kinetics of the productive activities undertaken. The use of different ways to apply force with the wielded tool, either by percussion or by pressure, leads to different patterns of micro- and macro-chipping on the active tool edges; here, specific working angles play a considerable role. For this particular study, low power magnification analyses were conducted using an Olympus SZX7 stereomicroscope to scan the edges and surfaces of the tool while micrographs were taken using a HIROX digital microscope. High power analysis was performed using an Olympus BH50 metallurgical upright microscope equipped with Nomarski prisms, and photographs were taken with a Canon EOS camera; micrographs were then combined using HeliconFocus software.

Results

Taphonomic alterations of archaeological remains

Taphonomy greatly influences the quality and reliability of the identified functional patterns that lead to the interpretation of tool function and consequently play an essential role in the traceological analysis of archaeological samples (Levi Sala 1986; Levi-Sala 1988; Mansur-Franchomme 1986; Schiffer 1983). It particularly affects the quality of the results from lithics that have suffered from prolonged exposure to wind and sand abrasion while resting on exposed and deflated surfaces across arid to semi-arid environments. The most common alteration observed on lithic artefacts from such contexts is labelled ‘desert varnish’ (Hunt 1954; Perry et al. 2005), which can be differentiated from gloss patination, dark gloss patination and so-called river patina (Howard 2002; Vaughan 1985). Different theories have been postulated as to the nature of these alterations (adsorption theory vs dissolution theory), incidentally, however, as Rottländer (1975) pointed out, the difficulties in experimentally replicating these alterations and the lack of a unified terminology of ‘patination’, hamper understanding the origins of these alterations. Recently, Schmidt et al. (2020) demonstrated using reflectance infrared microscopy that use-wear polish on chert has its origins in a physical process (abrasion), making it possible to infer a similar origin for the formation of taphonomic surface modifications; nonetheless, additional research into the subject remains to be undertaken.

Artefacts from the Camel Site collected from the surface underneath the panels found on rock spur C show an ephemeral polish that coats all surfaces, possibly due to the mechanical abrasion of wind-born particles on all surfaces. These alterations form indiscriminately over the entirety of the surfaces of the lithics. They are seen on the elevated portions of the microtopography of the surfaces and within the depressions forming an evenly distributed light polish that covers both surfaces and edges. The primary source of taphonomic alteration is sand and wind; the productive properties this study focuses on are the transformation of a sandstone surface by extracting material using different modalities of abrasion and percussion. The experimental sample used to work and modify the sandstone surface allows us to better discriminate between the taphonomic alterations and the use related to modifications of the active edges of the tools (Fig. 6).

Due to the natural origin of these alterations, a chaotic distribution of both polished surfaces, scars and scratches can be differentiated from the traces (striations, polish micro-negatives, etc.) on the controlled and deliberately conducted anthropogenic actions of productive and transformative activities associated with tool use. This is seen when the alterations on the interior portions of the tools, namely, the ventral or dorsal surfaces of CS.ET#1 in Fig. 6. The taphonomic action upon the degradation of the crystals is seen on the unmodified natural surface and knapped surfaces of CS.ET#5 is evident by the damage and scarring on the micro-surfaces showing the different levels of alteration (see unaltered crystal grains on the fresh knapped surface of experimental tool CS.EXP.2 for comparison) (Fig. 6 top).

The experimental reference collection

The patterns of alteration on the experimental collection show a specific characteristic that makes it possible to distinguish the use-wear from the taphonomic alterations. The type of motion and kinetics used during the experiment, including percussion force and pressure, transverse and longitudinal movements, serve different purposes and show other various traces on both the worked material and the tools themselves. The main characteristic of all experimental tools used in the reference collections is the widening and abrasion of the working edges, which becomes highly regularised as work duration advances (Figs. 7, 8 and 9). The abrasive nature of the worked material (sandstone) causes a relatively fast regularisation of the working edges,

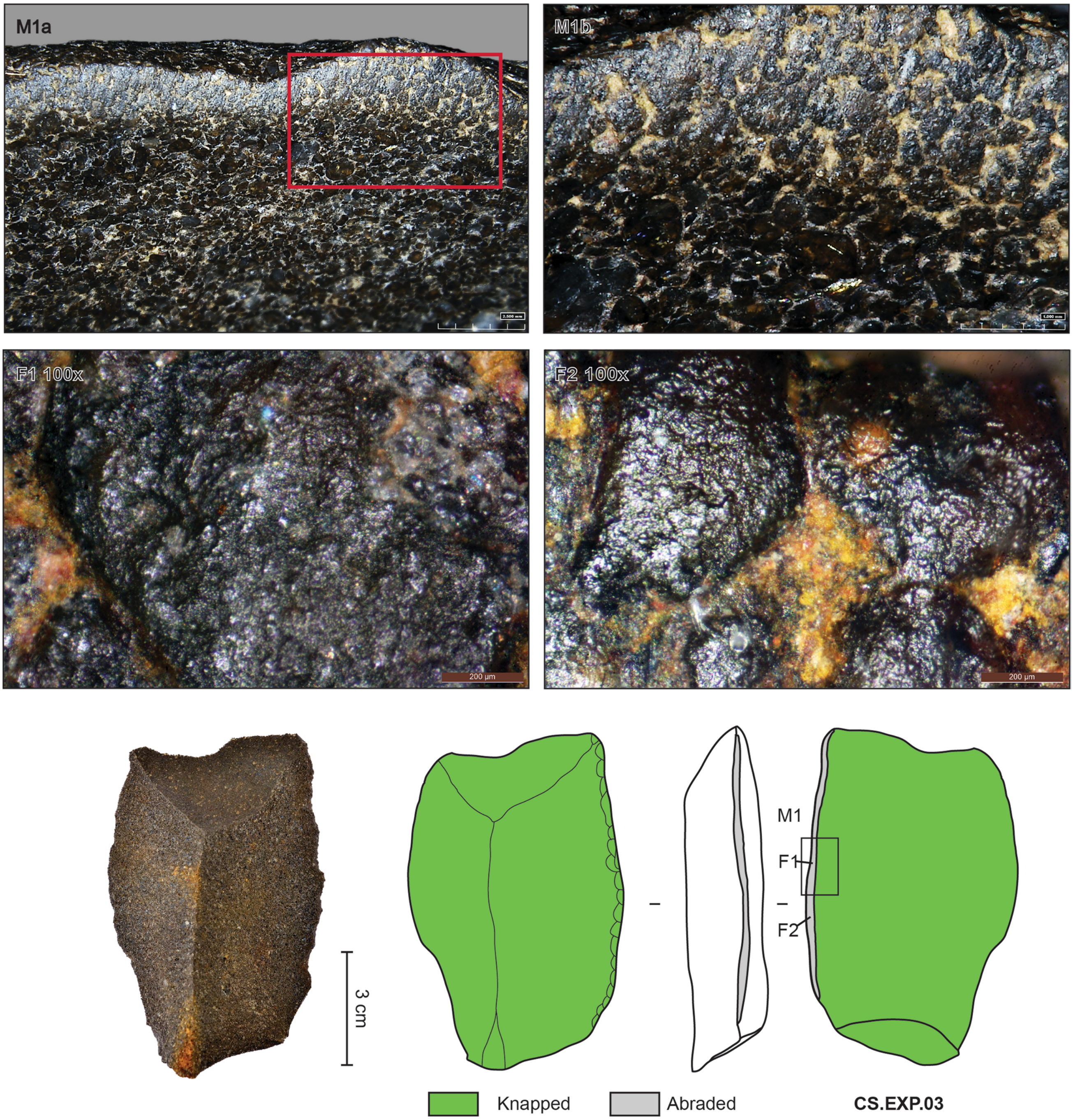


Fig. 7 CS.EXP.03. Flake tool used in transverse bidirectional motion during a 5-min interval on Sakaka sandstone. M1 showing the bevelled and regularised working edge of the tool with the crushed grains and the depressions filled-in with mineral residues. F1 micrograph showing the light developed polish on the eminences of the grains and parallel striations; F2 flat mineral polish on the higher areas of the microtopography and the red iron oxide-rich dust residue between the grains. (Image YHH, photos ICC and YHH)

followed by a widening and broadening of the same edge. Additionally, damage by crushing the elevated areas and the eminences of the grains of all three types of raw materials has been observed.

Specifically, in transverse motions, a bevelled surface is quickly established on the working edge face that makes contact with the sandstone. On the other hand, longitudinal motions caused the rounding of the working edge and wider distribution, generally across both faces of the active working edge. Percussive actions (direct or indirect) caused a highly localised distribution of the abrasion on the working edge, generally located on the face with the highest amount

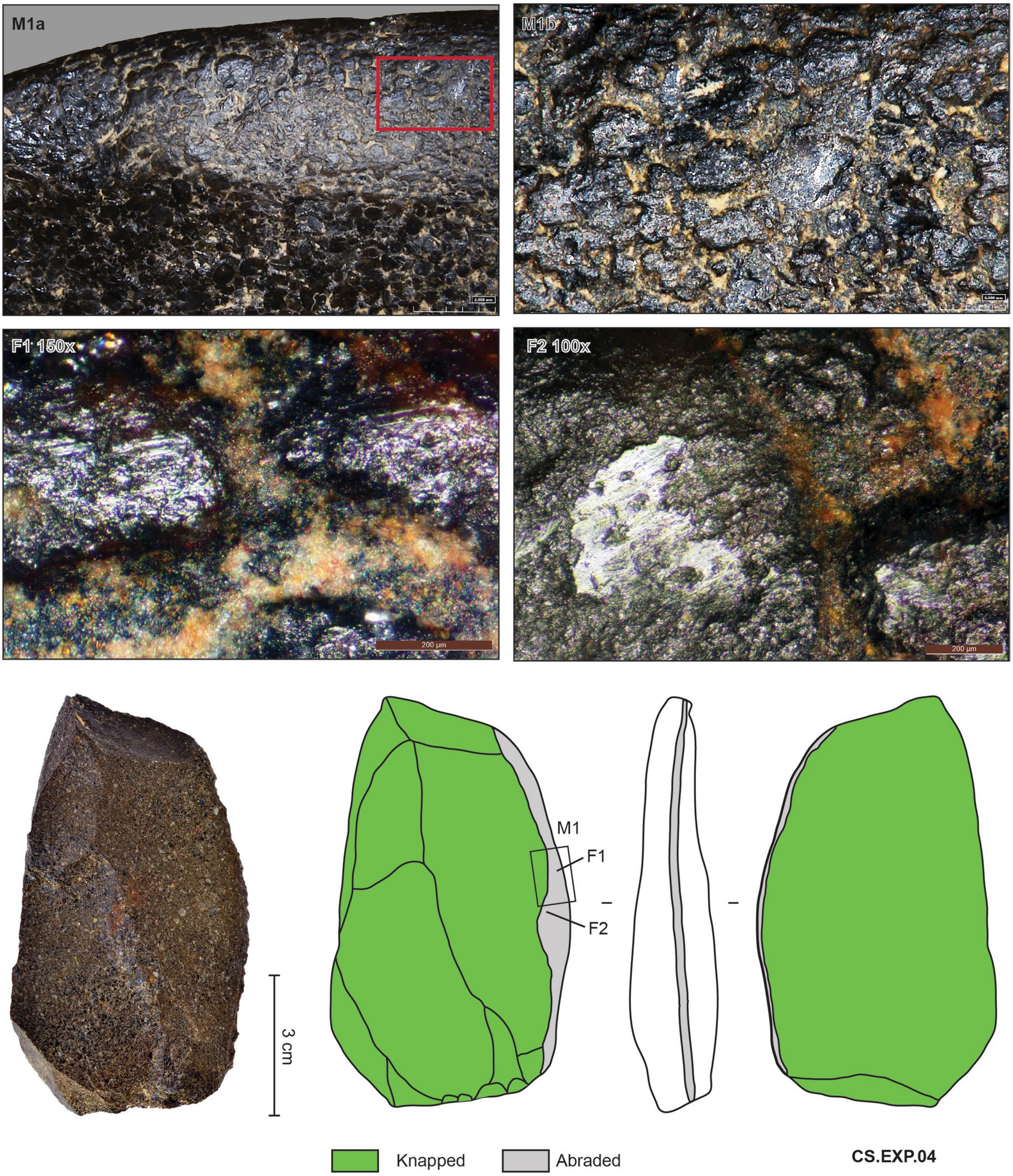


Fig. 8 CS.EXP.04. Flake tool used in longitudinal bidirectional motion during a 5-min interval on Sakaka sandstone. M1 showing the rounded and regularised working edge of the tool. F1 abrasive tracks on the eminences of the microtopography and the depressions filled with mineral residue; F2 oriented flat mineral polish and striations. (Image YHH, photos ICC and YHH)

of contact with the sandstone. All types of motion and delivered force led to the fast development of these specific regularisations and broadening of the working edges on the tools. The formation of typical flat mineral polish, striations and abrasive tracks associated with the contact with the mineral material, however, was rare and related to elevated portions of the tools' working edge topography, as these can be best observed on the CS.EXP.04 F1 and CS.EXP.04 F2 in Fig. 8. While the used edges of the experimental samples are quickly abraded, specific micro-polish are mostly constrained to the eminences on the peripheries of the working edges' microtopography and rarely reach high levels of development due to the continuous abrasion. This, however, remains to be tested by prolonging the duration of use of the experimental specimens.

In addition to the mechanically induced wear traces on the tools' working edge, the depressions between the individual quartz crystal grains exhibited a high amount of mineral residues associated with the abrasive nature of the task performed. The red iron oxide-stained powder became adhered to the working edge and further catalysed the abrasion of the edges of the tools. These were found concentrated in the areas that functioned as working edges or active edges.

Traceological results of the archaeological material

Most engraving tools collected from the surface below rock spur C of the Camel Site have been classified as cores, which is to say that these served a different purpose at some stage and have been reused at different times leading to different weathering patterns on the assemblage. The engraving tools classified as cores, however, show different levels of development, some showing multiple centripetal removals on both dorsal and ventral faces, while other show minimal removal of flakes and appear to be specially manufactured to be used as tools. Some pieces showed only limited or no removals and were used without considerable modification. Except for two pieces that may have been used in percussive activities, longitudinal and transverse motions by the use of pressure prevail. Of the 12 analysed engraving tools, four presented macroscopic modifications comparable to the traces found on the experimental tools, by either transverse or longitudinal abrasion; the dimensions and specific traits of the archaeological engraving tools are summarised in Table 2. The four archaeological pieces presenting wear traces will be briefly discussed.

CS.ET#1 is made of red and yellow-banded silcrete (RM2) and shows a highly elaborated centripetal scar pattern, suggesting that the tool was used as a core to produce normalised flakes with predetermined shapes and sturdy straight edges. Pecking marks on the ventral convex surface may indicate the expedient use of the core in percussive activities; the low incidence of this feature, however,

Table 2 Specific traits and results of the functional analysis of the engraving tools from the Camel Site

Artefact	Blank	RM	Provenance	Dimensions	# abraded edge	Length of abraded edges	Working angle	Force	Motion	Wear
CS.ET#1	Core	RM2	Surface	84.4×77×51.08	2	24.58, 27.31	80°, 80°	Pressure	Transverse	Abrasion/polish
CS.ET#2	Core	RM2	Surface	70.85×56.66×22.96	–	–	–	–	–	–
CS.ET#3	Core	RM2	Surface	96.81×97.35×62.44	–	–	–	–	–	–
CS.ET#4	Chunk	RM1	Surface	50.45×65.11×24.03	2	17.28, 16.68	70°, 35°	Pressure	Longitudinal	Abrasion/striations
CS.ET#5	Core	RM1	Surface	131.07×76.97×42.08	2	18.12, 29.23	60°, 60°	Pressure	Longitudinal	Abrasion/polish
CS.ET#6	Core	RM1	Surface	101.27×71.47×38.12	–	–	–	–	–	–
CS.ET#7	Core	RM2	Surface	123.87. 47.63×36.54	–	–	–	Percussion?	–	–
CS.ET#8	Core	RM2	Surface	98.13×80.44×39	–	–	–	–	–	–
CS.ET#9	Core	RM2	Surface	119.48×71×55.73	–	–	–	–	–	–
CS.ET#10	Flake	RM2	Surface	70.34×61.08×20.41	–	–	–	Percussion?	–	–
CS.ET#11	Flake	RM2	Surface	77.83×56.42×17.95	–	–	–	–	–	–
CS.SQ4.5-10 cm	Chunk	RM3	Excavation	57.92×31×23.18	1	24.4	35°	Pressure	Longitudinal	Abrasion/polish

may also suggest that the core was set on some form of anvil during its knapping. The artefact shows two abraded flat surfaces on the dorsal face, indicating that this particular face was facing the contacted material during the use of the tool (Fig. 9). A series of longitudinal striations on the active portion of the tool on the left side indicates a combination of longitudinal and transverse motions. The exertion of pressure during the work is evident by the presence of micro-negatives seen on the bottom of micrograph F2 in Fig. 10, located at the bottom of the image, while parallel scars are evident on the macro-images.

Tool CS.ET#5 is made on a thick brick-shaped piece of coarse-grained dark ferruginous sandstone (RM1) that shows two removals that formed the active edge. Additional removals are seen on the bottom part of the tool, but no use traces were identified in this area. Macroscopic abrasions are seen on different portions of the active edge, which has become broader where the tool made contact with the worked material. The rounded morphology of the abraded

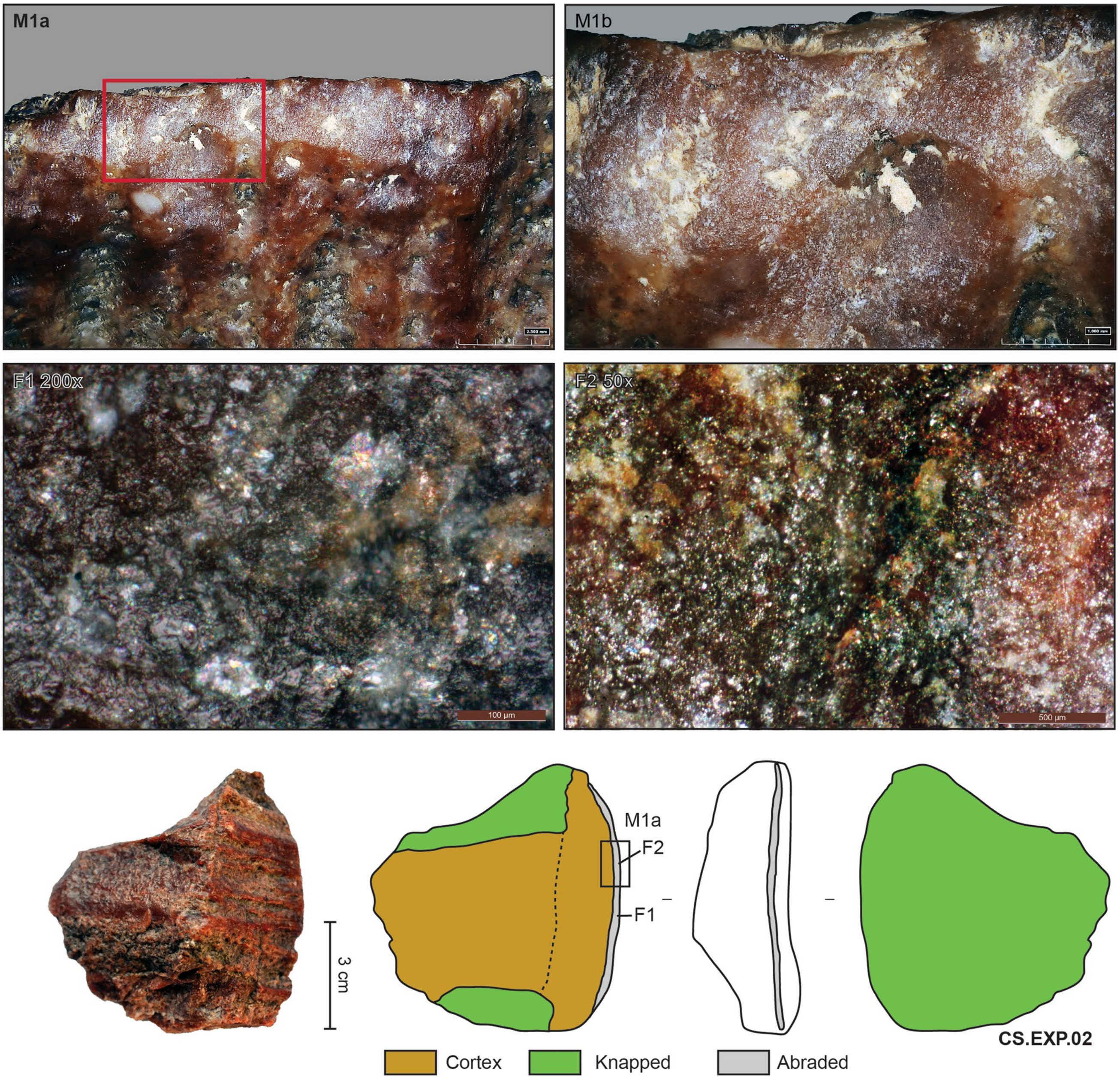
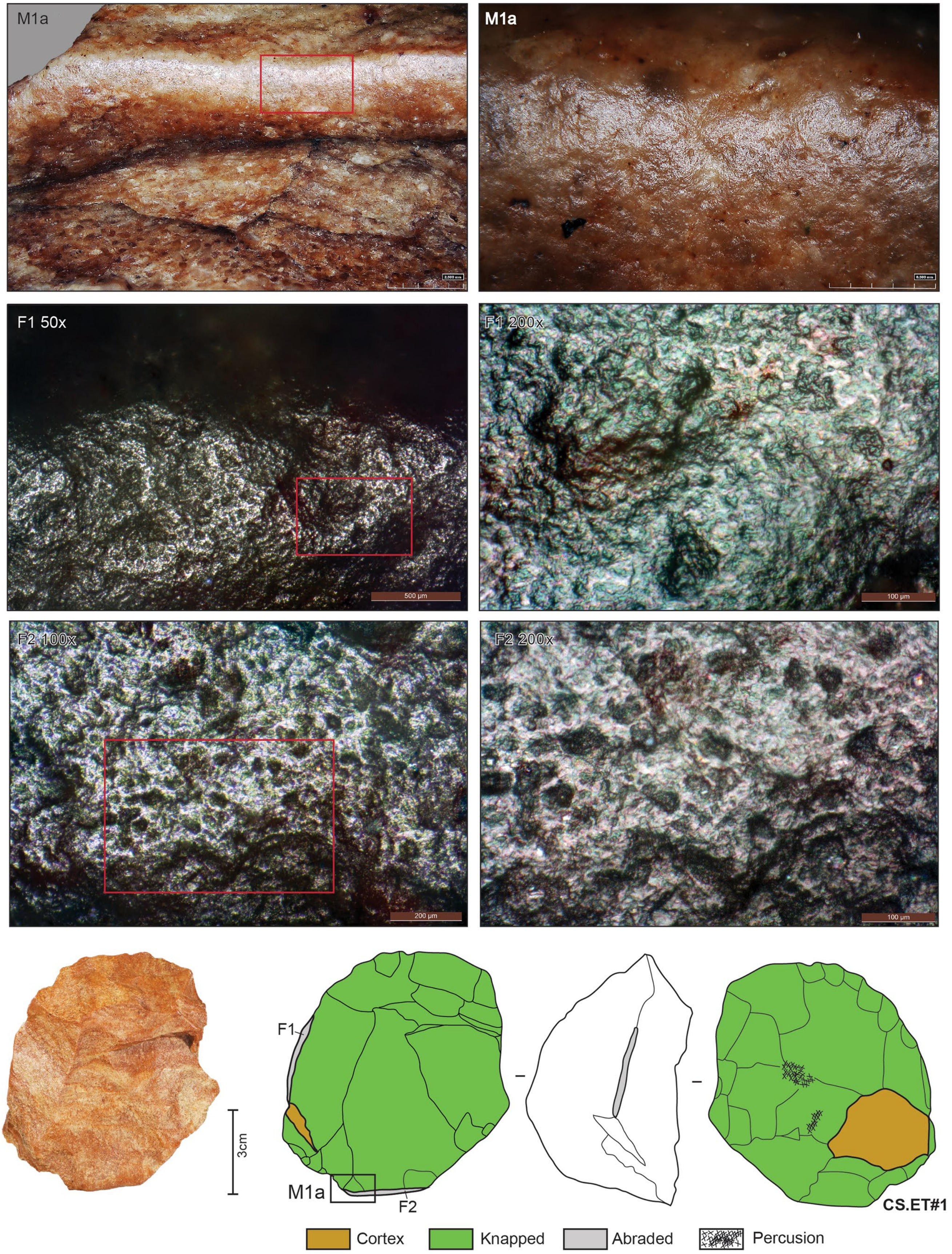


Fig. 9 CS.EXP.02. Flake tool used in transverse unidirectional motion during a 5-min interval on Sakaka sandstone. M1 regularised and bevelled working edge with parallel transverse scratches. F1 light developed flat polish oriented in transverse fashion; F2 transverse scratches. (Image YHH, photos ICC and YHH)


M1a
M1a
F1 50x
500 µm
F1 200x
100 µm
F2 100x
200 µm
F2 200x
100 µm
3cm
F1
M1a
F2
CS.ET#1
Cortex
Knapped
Abraded
Percusion

◂**Fig. 10** CS.ET#1. Schematic drawing and photo of the tool showing the location of the abraded edges and the position where the individual micrographs showing the traces resultant from the use were taken. M1a and M1b show the abraded area with the parallel striations indicating the transverse motion during use. F1 showing the distribution of the polish and striations on the eminences of the microtopography at magnifications 50×and 200×; F2 micrograph showing the abraded and rounded topography and the micro-negatives resultant from the pressure exerted during the abrasive task at magnifications 100×and 200×. (Image YHH, photos ICC and YHH)

areas is comparable to the abrasion observed on the experimental pieces used in bidirectional and longitudinal motions, only much less developed. Signs of damage and crushing can be observed on the macro-image M1b in Fig. 11 that can be distinguished from the non-altered quartz grains found away from the active edge of the tool. Additional weakly developed flat micro-polish and orientation markers are observed on the high areas of the microtopography, while red iron oxide-rich dust residues are found in the depressions. Further flat polished areas are seen on the surfaces of the quartz crystals in micrograph F3.

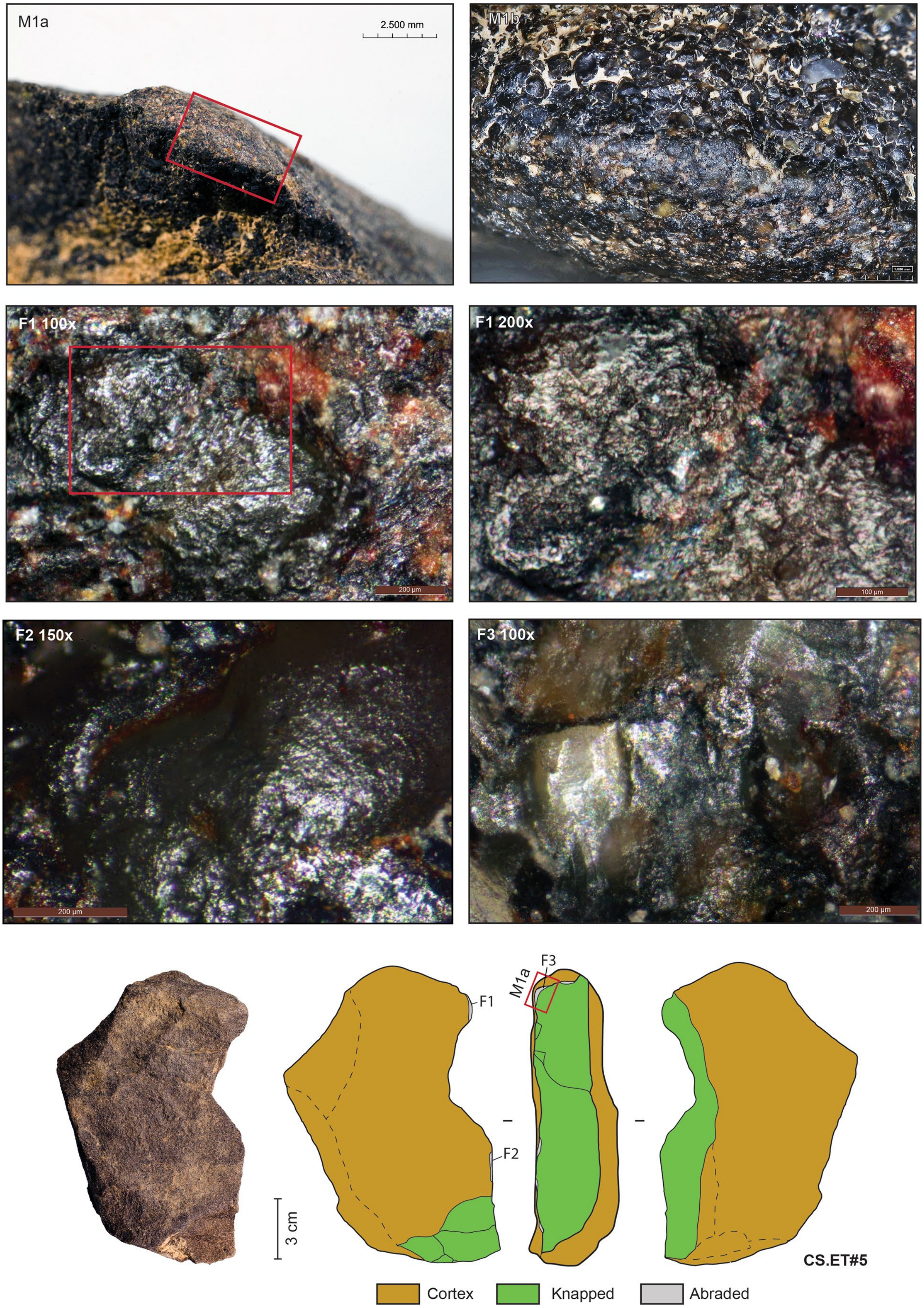
CS.ET#4 is made on a dark ferruginous sandstone chunk, attributed to the RM1 type, that shows minimal modifications by direct percussion on one side. The active working edge is evident in two separate areas that show abrasion on both ventral and dorsal sides of the tool. The difference between the unmodified wind-abraded and rounded quartz grains and the crushed and damaged grains resultant from the abrasive work is visible in the M1a and M1b macro-images in Fig. 12. Similar to the other engraving tools that show traces of use, notably abrasive tracks, orientation markers indicating a longitudinal motion and mineral polish is seen on the elevated areas of the heavily regularised microtopography of the active edge, while the depressions tend to be filed with the mineral residues as seen in F1.

The only artefact from the excavated test trench that presented possible use-wear resultant from the contact with an abrasive mineral material was CS.ET.SQ4.5-10 cm, which incidentally would not be considered an artefact if it was not for the abraded area on the distal portion of an unmodified chunk of fine-grained dark ferruginous sandstone (RM3). Compared to the other engraving tools found on the surface, the piece is relatively small and has been used without any modification to its natural shape by either percussion, abrasion or any other form of force. Yet, as can be seen on the macro-images showing the detail of the crushed and abraded portion of the active edge in Fig. 13, the piece shows traces that suggest its use in longitudinal movements on an abrasive mineral material. Similar to the experimental tools, regularisation and broadening of the otherwise tapered working edge can be observed in M2 and the crushed surfaces of the quartz grains and the presence of striations. Additional traces supporting the interpretation of the tool as being used in mineral processing activities are the abrasive tracks, striations and flat polished eminences on the microtopography of the tool's working edge, seen in F1 and F2 of Fig. 13.

Discussion

The combined results from the traceological analysis of the experimental and archaeological tools from the Camel Site provide additional data on this important and iconic archaeological site in northern Saudi Arabia. The identified patterns on the experimental tools indicate that the abrasive nature of the Sakaka sandstone impends the development of large areas of flat regular polish, with homogenous distributions due to the granular properties of the raw materials used by the makers of the archaeological tools and the experimental replicas. However, the relatively rapid development of the abraded working edge indicates that even a few strokes are sufficient to leave characteristic macro-traces on the working edges. Unfortunately, the preservation of the polished areas on the archaeological samples is additionally impeded by the severe taphonomic modifications resulting from the suspension of sand grains and particles by wind and weather on the tools and panels themselves. Albeit a high amount of debitage attributed to the RM2 has been identified at the site, it is currently difficult to establish whether the human groups that used the tools to process the sandstone were the same that created, quarried and knapped them. This is especially difficult for the pieces that display a high amount of elaboration in the form of prepared core reduction (e.g. CS.ET#1, CS.ET#3 and CS.ET#8). Additionally, we cannot rule out the possibility that the engraving tools found on the surface were used to create some of the more recent petroglyphs. However, the taphonomic modifications that formed on the abraded edges of the tools may indicate that these have been exposed on the surface for a considerable amount of time.

Despite these limitations, the following interpretations can be made regarding the tools found at the Camel Site concerning their possible function and association with the carving activities, which took place at the site. No modification made by retouch to the active edges of the tools was identified, suggesting that the tools have not been resharpened, which is remarkable given the relatively fast regularisation of the used edges. Furthermore, the lack of distinctive wear traces and scaring associated with the implementation of hafting technology (e.g. Moss 1987; Rots 2010) indicates the engraving tools were likely handheld. The limited sample size and taphonomic constraints acting on the material, however, imped a conclusive statement on the subject. The prevalence of traces associated with the longitudinal motion and the weak development of the abrasions on the active edges of the tools may be indicative that these were used during the second stage of the production of the


M1a
2.500 mm
M1b
1.000 mm
F1 100x
200 µm
F1 200x
100 µm
F2 150x
200 µm
F3 100x
200 µm
F1
F2
F3
M1a
3 cm
CS.ET#5
Cortex
Knapped
Abraded

◂**Fig. 11** CS.ET#5. Photograph and schematic illustration of the tool showing the position of macro- and micro-traces. M1a and M1b show the abraded and churched working surface that became abraded through contact with an abrasive mineral material during longitudinal motion. F1 micrograph was taken at 100× showing the rounded and abraded higher areas of the microtopography and the striations, while red iron oxide dust residues are seen on the depressions; detail micrograph magnification 200× showing the orientation markers; F2 polished and abraded areas on the elevated areas of the crystals and additional residues in the depressions at magnification 150×; F3 flat polished areas resultant from contact with abrasive mineral material at 100×. (Image YHH, photos ICC and YHH)

reliefs, namely, the making of the fine details on the head of the animals and the sharpening of the outlines. Alternatively, these were used to carve out the deep wedges seen on some of the panels; unfortunately, it is difficult to positively correlate individual tools with specific panels. What can be said with some certainty is that the engraving tools were used to process abrasive mineral materials, likely sandstone and that their location underneath the panels on rock spur C may hint at a possible correlation.

The majority of the graphic activities known throughout the Arabian Peninsula, North Africa and the greater Middle East are characterised by engravings using distinctive techniques including pecking, engraving and smoothing or polishing large surfaces delimited by linear carvings. These extractive modifications are conducted by using friction as the main force, pecking either with direct or indirect percussion or drilling. These different techniques appear in different constellations throughout the known ensembles of prehistoric rock art sites across Arabia (e.g. Angás et al. 2021; Guagnin et al. 2015; Jennings et al. 2013; Khan 2013; Zerboni et al. 2021; Ziolkowski 2007). The large carved 3D engravings from the Camel Site, however, have, so far, no known equivalent throughout the Neolithic of the Arabian Peninsula, making a comparison of both carving techniques and the characteristics of stone tools used difficult.

A comparison with traceological studies conducted on Palaeolithic sites in Western Europe, however, may present some, albeit tenuous comparison. Of specific interest is the study conducted by López-Tascón et al. (2020), who have conducted experiments with the friction of stone against stone. The focus of their experimental protocol has been laid on the longitudinal engraving motions, a specific function of the archaeological case study addressed by the authors, the Palaeolithic site of La Viña Rockshelter in central Asturias (Spain). López-Tascón et al. report regularisation, rounding and abrasion of the active edges after only a short period. The authors, however, uphold that the essential characteristic of the mineral processing activities is the formation of the distinctive smooth and flat micro-polish; incidentally, due to the abrasive nature of its origin, the polish appears cracked with fissures resulting from material fatigue. A characteristic lacking in the experimental collection and archaeological assemblage is presented here. This may have different reasons including the variance in mineral processed (Carboniferous period limestone and Sakaka sandstone), and differences in use intervals (López-Tascón et al. experiments used intervals of 60 and 120 min), and tool raw materials (flint) come to mind.

Furthermore, the La Viña Rockshelter parietal ensembles are composed of engravings instead of large 3D carvings of natural proportions. Such occurrences are known from France, most notably at the Solutrean site of Roc-de-Sers (Delport 1984) located in the Charant, the Middle Magdalenian sites of Cap Blanc in the Dordogne and the site of Le Roc-Aux-Sorciers (Rousseau 1929) located in the Vienne. The study of the lithic material from Le Roc-Aux-Sorciers provides essential information on the techniques used to manufacture the panels. The site is located in the Anglin valley and is characterised by a 50-m long rock shelter composed of soft Jurassic bioclastic limestone. Excavations at the base of the panels have exposed occupation layers dating to 14,500 BP. The initial investigation on the techniques used to create the murals depicting animal reliefs with naturalistic anatomical proportions conducted by de Beaune and Pinçon (2001) has established seven phases of production identifiable by specific traces: (a) the regularisation of the limestone surface by percussion; (b) extraction of mineral material to create the outline (or preform) of the animal by pecking using a pointed tool; (c) trimming of the animal's silhouette by transverse scraping action; (d) shaping the surface of the sculpture by additional subtraction of mineral material by transverse scraping action; (e) regularisation of the surface of the sculpted parts of the animal by abrasion or polish; (f) engraving of anatomical details by incision and longitudinal action and finally (g) painting of the sculpted animals by using red and dark pigments.

The main categories of tools found in the excavations at the base of the murals included massive quartz pebbles with traces of violent impact and negatives, pick shaped flint nodules with traces of impacts and crushing at the pointed end, split quartz pebbles with traces of crushing on the active edge and sandstone pebbles with polished surfaces. The experimental reconstruction of the panels undertaken by the authors mainly using pebbles and split cobles included the regularisation of the carved area by percussive action, the creation of an outline, the reduction of volume by scraping and the addition of fine anatomical details. Traces on the experimental tools included battered surfaces and abraded edges, which have been found analogous to the archaeological material by the authors; they conclude that mostly pebbles and cobbles have been used to fashion the panels (de Beaune and Pinçon 2001: 74). In a later study of 300 multicomponent lithic tools from the Le Roc-Aux-Sorciers assemblage excavated from the domestic layers found underneath the panels of the rock shelter, Beyries and Cattin (2015)

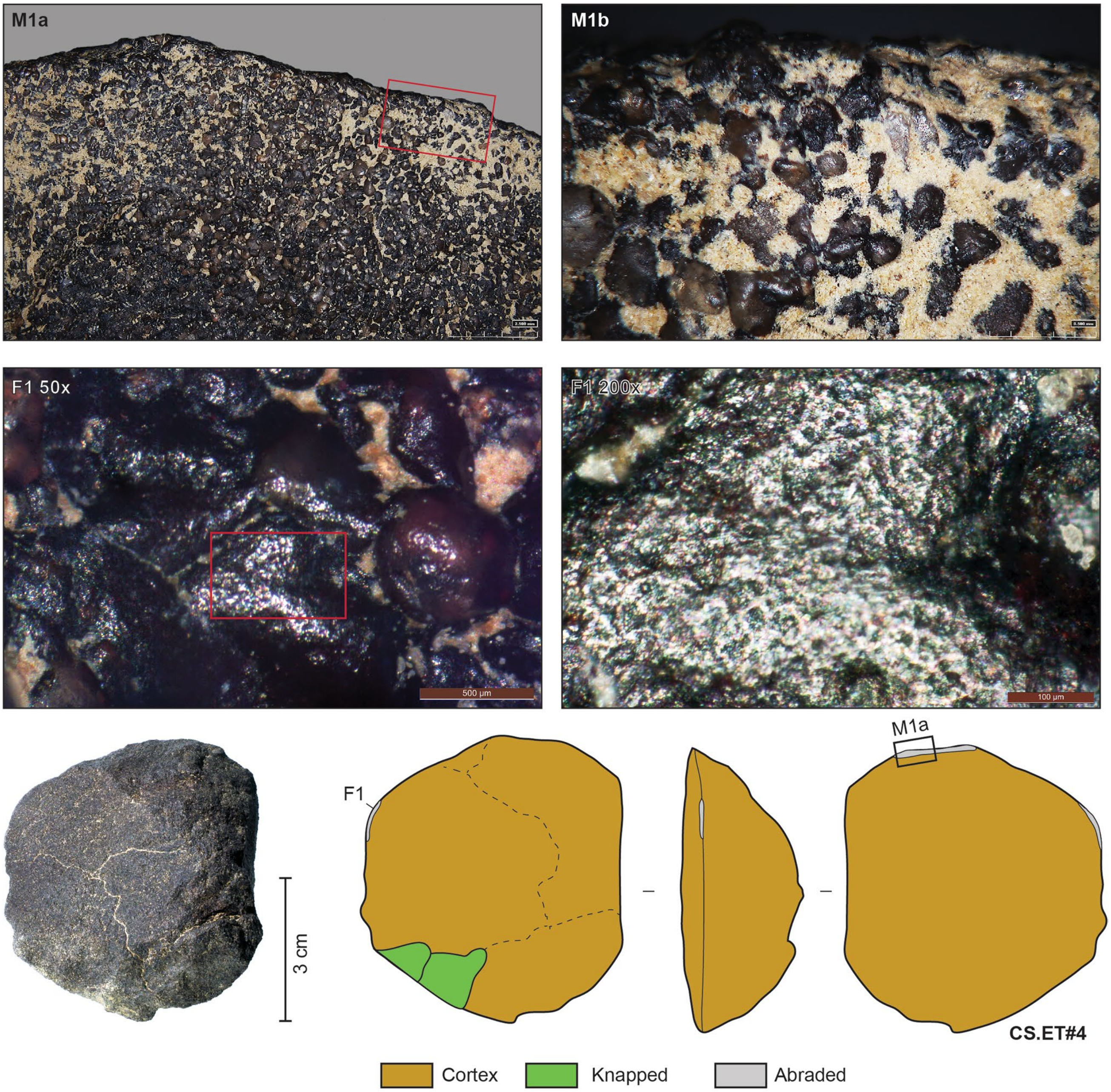


Fig. 12 CS.ET#4. Photograph and schematic illustration of the tool showing the position of macro- and micro-traces. M1 shows the active edge on the ventral surface. F1 shows the polish and striations on the top of the grains and the mineral residues in between on the lateral dorsal working edge of the tool at 50× and 200× magnification. (Image YHH, photos ICC and YHH)

conclude that part of the tools were used in other domestic activities such as hide working prior to the mineral processing activities. They note the low incidence of retouching on the tools that show traces of mineral processing. The use of unmodified or only slightly modified blocks of raw material in abrasive mineral activities was observed at the lithic assemblage found at the base of the panels from the Camel Site. The low incidence of artefacts with traces resulting from percussive actions, however, stands out especially given the tool marks seen on panel 2 (Fig. 2). The low incidence of retouch after use on the engraving tools from the Camel Site is also noted.

The complex and long-lasting development of the Camel Site, attested by multiple surface lithic scatters attributed to different chronologies, the stratified occupation and the carving activities, are being revealed by scientific research. The significance of the Camel Site for the al-Jawf province during the end of the Neolithic as a unique landmark and point

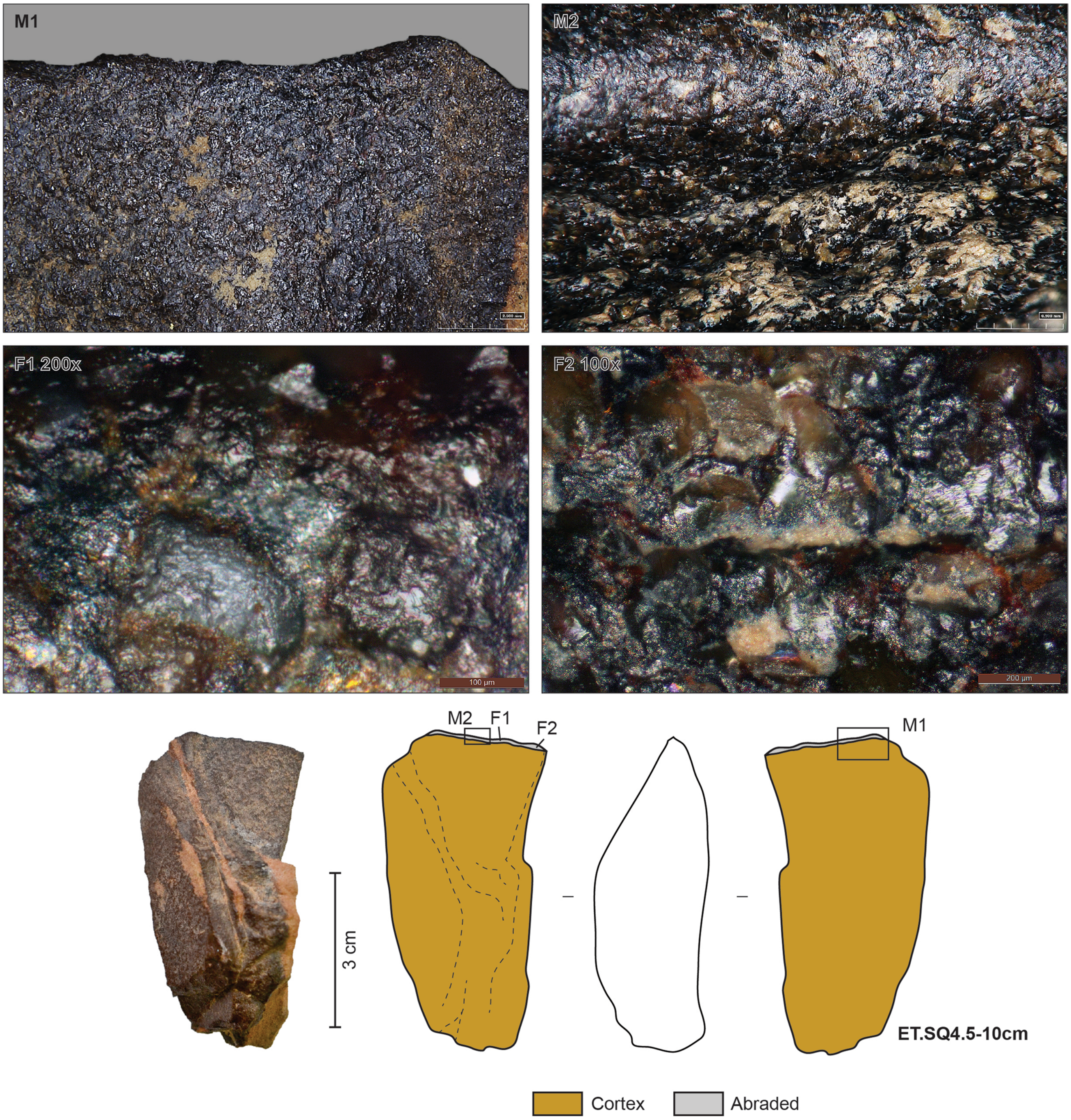


Fig. 13 CS.SQ4.5-10 cm. Photograph and schematic illustration of the tool showing the position of macro- and micro-traces. M1 macro-image on the dorsal side of the active edge of the tool; M2 macro-image of the top view of the working edge showing the crushed and abraded grains and crystals. F1 flat mineral polish on the top of the grains and mineral residues in the depressions at 200×; F2 abrasive wear and flat polish with striations indicate the tool motion's longitudinal character at 100×. (Image YHH, photos ICC and YHH)

of congregation for hunter, herder and gatherer communities across the millennia may be inferred. The Wadi Sirhan fault connects the Sakaka basin with the southern Levant and Jordan towards the northwest. The eastward draining wadis of which Wadi Badana is the most prominent connect the area to ancient Mesopotamia (Charloux et al. 2018).

Conclusions

Here, we have presented the results of the traceological analysis of a sample of stone tools coming from surface and stratified contexts, used to process highly abrasive mineral substances, most likely Sakaka sandstone. We have bolstered our analysis by incorporating an experimental reference collection, used to process this specific raw material, and found a positive correlation between the traces observed on the archaeological material and the replicas. These traces have been associated with both transverse and longitudinal motions. The low levels of trace development, particularly on the specimen from the stratified context, indicate that stone tools were possibly used to create the delicate outlines and details on the animal reliefs during the final stages of manufacture of the panels at the Camel Site. The rapid development of the traces of mineral processing on the tools, the lack of tool curation and the fast reduction of sandstone mass by the scraping activities on the panels themselves may indicate that the carving activities were conducted by a small number of specialists in relatively short period of time. The amount of planning including raw material acquisition and the likely construction of scaffoldings to reach some of the engraved panes testifies for high level of foresight and determination of the prehistoric artisans responsible for the graphic activities at the site.

Acknowledgements We would also like to warmly thank the Heritage Commission from the Saudi Ministry of Culture for permitting to carry out research at the Camel Site, especially the General Director for Archaeological Excavations Dr Abdullah al-Zahrani. Local support in Jawf province was provided by Mr Yasser al-Ali and Mr Ahmed al-Qaeed from the Jawf Department of the Heritage Commission. We are in debt to Dr Patrick Schmidt, Dr Aitor Ruiz Redondo and Dr George Nash for their comments and suggestions that have greatly increased the quality of this manuscript. Finally, we thank the anonymous reviewers for their efforts and constructive comments.

Funding Open Access funding enabled and organized by Projekt DEAL. YHH is grateful to the German Academic exchange program (DAAD) for financial support in the form of a P.R.I.M.E. fellowship for the project 'How did Human Behaviour change During the Terminal Pleistocene and Early Holocene in South Arabia?'. The Camel Site archaeological project (2018–2022) is directed by GC, MG and AS. Fieldwork and research were funded by a grant from the Gerda Henkel Foundation (Grant No AZ 43_V_18, to MG and GC), the CNRS (to GC), Labex Resmed ANR-10-LABX-72/ANR-11-IDEX-0004–02 (to GC), the French Ministry of Foreign Affairs and the French embassy in Riyadh (to GC), the Cefrepa (to RC and GC), the Dahlem Research School at Freie Universität Berlin (to MG) and the Max Planck Society (to MG).

Declarations

Conflict of interest The authors declare no competing interests.

References

Adams RMcC, Parr PJ, Ibrahim M, Al-Mughannum AS (1977) Saudi Arabian archaeological reconnaissance 1976; the preliminary report on the first phase of the comprehensive archaeological survey program. Atlal 1:21–40

Alvarez M, Fiore D (1995) Recreando imágenes: diseño de experimentación acerca de las técnicas y los artefactos para realizar grabados de arte rupestre. Cuad Inst Nac Antropol Pensam Latinoam 16:215–239

Alvarez M, Fiore D, Favret E, Guerra RC (2001) The use of lithic artefacts for making rock art engravings: observation and analysis of use-wear traces in experimental tools through optical microscopy and SEM. J Archaeol Sci 28(5):457–464

Andreae MO, Al-Amri A, Andreae CM, Guagnin M, Jochum KP, Stoll B, Weis U (2020) Archaeometric studies on the petroglyphs and rock varnish at Kilwa and Sakaka, northern Saudi Arabia. Arab Archaeol Epigr 31(2):219–244

Angás J, Bea M, Jasim SA, Uribe P, Farjas M (2021) New insights into human occupation through rock art at Khatm al Melaha archaeological site (Sharjah, United Arab Emirates). J Archaeol Sci Rep 39:103147

Betts AVG, Cropper D, Martin L, McCartney C (2013) The later prehistory of the Badia: excavations and surveys in eastern Jordan. Oxbow Books, Oxford

Beyries S, Cattin MI (2015) Resharpening and recycling: different conceptions of the Magdalenian tools. Quat Int 361:260–268

Caux S, Galland A, Queffelec A, Bordes JG (2018) Aspects and characterization of chert alteration in an archaeological context: a qualitative to quantitative pilot study. J Archaeol Sci Rep 20:210–219

Charloux GH, Al-Khalifah T, Al-Malki R, Mensan R (2018) The art of rock relief in ancient Arabia: new evidence from the Jawf Province. Antiquity 92(361):f1–f6

Charloux G, Guagnin M, Norris J (2020) Large-sized camel depictions in western Arabia: a characterization across time and space. Proc Semin Arab Stud 50:85–108

Clemente-Conte I (1997) Los instrumentos líticos del Túnel VII: una aproximación etnoarqueológica. C.S.I.C U.A.B, Barcelona

Crassard R, Hilbert YH (2020) Bidirectional blade technology on naviform cores from northern Arabia: new evidence of Arabian-Levantine interactions in the Neolithic. Arab Archaeol Epigr 31(1):93–104

de Beaune SA, Pinçon G (2001) Approche expérimentale des techniques magdaléniennes de sculpture pariétale. In Bourguignon L Ortega I and Frère-Sautou M-C (eds) Préhistoire et approche expérimentale Préhistoire. Montagnac: éditions Monique Mergoil 67–75

Delport H (1984) Abri du Roc-de-Sers. Atlas Des Grottes Ornées Paléolithiques Françaises. Imprimerie Nationale, Paris 578–582

Galland A, Queffelec A, Caux S, Bordes J-G (2019) Quantifying lithic surface alterations using confocal microscopy and its relevance for exploring the Châtelperronian at La Roche-à-Pierrot (Saint-Césaire, France). J Archaeol Sci 104:45–55

González-Urquijo JE, Ibañez-Estéves JJ (1994) Metodología de análise funcional de instruentos tallados en sílex. Universidad de Duesto, Bilbao

Guagnin M, Charloux G, AlSharekh AM, Crassard R, Hilbert YH, Andreae MO, AlAmri A, Preusser F, Dubois F, Burgos F, Flohr P, Mora P, AlQaeed A, AlAli Y (2021) Life-sized Neolithic camel sculptures in Arabia: a scientific assessment of the craftsmanship and age of the Camel Site reliefs. J Archaeol Sci Rep 103165

Guagnin M, Jennings RP, Clark-Balzan L, Groucutt HS, Parton A, Petraglia MD (2015) Hunters and herders: exploring the Neolithic transition in the rock art of Shuwaymis. Saudi Arabia Archaeol Res Asia 4:3–16

Hamon C, Fromont N, Gaumé E, Germain-Vallée C (2021) From the quarry to the village: usewear analysis of the manufacture of schist bracelengraving tools in the Early Neolithic of north-western Europe. In Beyries S Hamon C and Maigrot Y (eds) Beyond use-wear traces: going from tools to people by means of archaeological wear and residue analyses. Association of Archaeological Wear and Residue Analysts. Leiden: Sidestone Press, 185–198

Hilbert YH, Crassard R (2020) Middle and Late Pleistocene lithic technology from the region of Dûmat al-Jandal, northern Saudi Arabia. In Bretzke K Crassard R and Hilbert YH (eds) Stone tools of prehistoric Arabia: papers from the special session of the seminar for Arabian studies held in July 2019 in Leiden. Oxford: Archaeopress 27–42

Hilbert YH, Crassard R, Charloux G, Loreto R (2017) Nubian technology in northern Arabia: impact on interregional variability of Middle Paleolithic industries. Quat Int 435:77–93

Howard CD (2002) The gloss patination of flint artifacts. Plains Anthropol 47(182):283–287

Hunt CB (1954) Desert Varnish. Science 120(3109):183–184

Ibáñez JJ, Mazzucco N (2021) Quantitative use-wear analysis of stone tools: measuring how the intensity of use affects the identification of the worked material. PLOS ONE 16(9):e0257266

Jennings RP, Shipton C, Al-Omari A, Alsharekh AM, Crassard R, Groucutt H, Petraglia MD (2013) Rock art landscapes beside the Jubbah palaeolake. Saudi Arabia Antiquity 87(337):666–683

Keeley LH (1980) Experimental determination of stone tool uses: a microwear analysis. University of Chicago Press, Chicago

M Khan (2013) Rock Art of Saudi Arabia Arts 2(4):447-475

Leroi-Gourhan A, Allain J (1979) Lascaux inconnu. CNRS, Paris

Levi Sala I (1986) Use wear and post-depositional surface modification: a word of caution. J Archaeol Sci 13(3):229–244

Levi-Sala I (1988) Processes of polish formation on flint tool surface. Ind Lithiques Tracéologie Technol 83–98

López-Tascón C, Mazo C, Rasilla M de la (2018) Experimentación y huellas de uso, una relación indisociable: Aplicación de un programa experimental sobre diferentes variedades silíceas. In Actas de Las IX Jornadas de Jóvenes En Investigación Arqueológica, Santander 8–11 Junio 2016. Santander: Instituto Internacional de Investigaciones Prehistóricas de Cantabria, IIIPC, 119–127

López-Tascón C, Pedergnana A, Ollé A, de la Rasilla M, Mazo C (2020) Characterization of the use-wear and residues resulting from limestone working. Experimental approach to the parietal art of La Viña rock shelter (La Manzaneda, Asturias, Spain). Quat Int 569–570:212–227

Loreto R (2013) New Neolithic evidence from the al-Jawf region: an outline of the historical development of Dūmat al-Jandal. Proc Semin Arab Stud 43:213–224

Mansur-Franchomme ME (1986) Microscopie du matériel lithique préhistorique: traces d'utilisation, altérations naturelles, accidentelles et technologiques: exemples de Patagonie. Éditions du Centre national de la recherche scientifique

Mélard N, Boust C, Cogné G, Maigret A (2016) Comparison of imaging techniques used in the microanalysis of Paleolithic mobiliary art. J Archaeol Sci Rep 10:903–909

Moro Abadía O, González Morales MR (2013) Paleolithic art: a cultural history. J Archaeol Res 21(3):269–306

Moss E (1987) Polish G and the question of hafting. In La Main et l'outil: Manches et Emmanchements Préhistoriques Table ronde C.N.R.S. Tenue à Lyon du 26 au 29 novembre 1984. Lyon: G.S. Maison de l'Orient 97–102.

Moss EH (1983) The functional analysis of flint implements: Pincevent and Pont d'Ambon: two case studies from the French final palaeolithic. Archaeopress, Oxford

Parr PJ, Zarins J, Ibrahim M, Waechter J, Garrard A, Clarke C, Bidmead M, Al-Badr H (1978) Preliminary report on the second phase of the northern province survey 1397/1977. Atlal 2:29–50

Pedergnana A, Ollé A, Evans AA (2020) A new combined approach using confocal and scanning electron microscopy to image surface modifications on quartzite. J Archaeol Sci Rep 30:102237

Perry RS, Kolb VM, Lynne BY, Sephton M, McLoughlin N, Engel MH, Olendzenski L, Brasier M, Stanley JT (2005) How desert varnish forms? Proc SPIE 5906:276–287

Plisson H (1985) Etude fonctionnelle d'outillages lithiques préhistoriques par l'analyse des micro-usures:recherche méthodologique et archéologique. Université de Paris I

Plisson H (2007) La fonction des outils de silex dans les grottes ornées paléolithiques. In: Évin J (ed) Congrès Du Centenaire: Un Siècle de Construction Du Discours Scientifique En Préhistoire. Société préhistorique française, Paris 125–142

Powers RW, Ramirez LF, Redmond CD, Elberg EL (1966) Geology of the Arabian Peninsula: sedimentary geology of Saudi Arabia. United States Goverment Printing Office, Washington

Rosen SA (1997) Lithics after the stone age: a handbook of stone tools from the Levant. Altamira Press, Walnut Creek

Rots V (2010) Prehension and hafting traces on flint tools: a methodology. Universitaire Press Leuven, Leuven

Rottländer R (1975) The formation of patina on flint. Archaeometry 17(1):106–110

Rousseau L (1929) Le Magdalenien dans la Vienne. Decouverte et fouille d'un gisement du Magdalenien inferieur a Angles-surL'Anglin (Vienne). Bull Société Préhistorique Fr 26:495–496

Schiffer MB (1983) Toward the identification of formation processes. Am Antiq 48(04):675–706

Schmidt P, Rodriguez A, Yanamandra K, Behera RK, Iovita R (2020) The mineralogy and structure of use-wear polish on chert. Sci Rep 10(1):21512

Semenov SA (1964) Prehistoric technology: an experimental study of the oldest tools and artifacts from traces of manufacture and wear. Barnes and Noble, New York

Van Gijn AL (2014) Science and interpretation in microwear studies. J Archaeol Sci 48:166–169

Vaughan PC (1985) Use-wear analysis of flaked stone tools. University of Arizona Press Tucson, Tucson

Wallace CA, Dini SM, Al-Farasani AA (1997) Explanatory notes to the geological map of the Al Jawf Quadrangle, Kingdom of Saudi Arabia. Saudi Arabia: Deputy Ministry for Mineral Resources, Ministry of Petroleum and Mineral Resources

Zerboni A, Esposti MD, Wu YL, Brandolini F, Mariani GS, Villa F, Lotti P, Cappitelli F, Sasso M, Rizzi A, Gatta GD, Cremaschi M (2021) Age, palaeoenvironment, and preservation of prehistoric petroglyphs on a boulder in the oasis of Salut (northern Sultanate of Oman). Quat Int 572:106–119

Ziolkowski MC (2007) Rock on art: petroglyph sites in the United Arab Emirates. Arab Archaeol Epigr 18(2):208–238