Technological and functional analysis of Upper Palaeolithic backed micro-blades from southern Oman

Technologische und funktionale Analyse jungpaläolithischer Mikroklingen aus dem südlichen Oman

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Abstract - While a considerable amount of information on the Pleistocene human occupation of South Arabia has been gathered by archaeologists over the course of the last decades, little is known about the Upper Palaeolithic period and its local specificities. This is evidently a function of the still poor archaeological record for this period and the difficulties in finding stratified and therefore datable occurrences in general. Here, we present the traceological and technological analysis of the stone tools from one of the few archaeological sites in Oman dating between 33,000 to 30,000 years ago, which has yielded a small but important assemblage of backed tools initially suggested to be projectiles. The bi-pointed backed micro-blades from Mutafah 1 share specific technological and morphological features making it germane to suggest comparable operational sequences for the manufacture of these pieces. Our analysis, which identified specific traces of use related to both hunting and domestic activities, as well as microscopic residues on the backed micro-blades, indicates that the Mutafah 1 tools were part of a toolkit with wide applications reflecting the highly opportunistic nature of the Upper Palaeolithic human occupation of South Arabia.

Zusammenfassung - *Während Archäologen im Laufe der letzten Jahrzehnte eine beträchtliche Menge an Informationen über die pleistozäne menschliche Besiedlung Südarabiens zusammengetragen haben, ist über das Jungpaläolithikum und seine lokalen Besonderheiten nur wenig bekannt. Dies ist offensichtlich eine Folge der immer noch dürftigen archäologischen Überlieferung für diesen Zeitraum und der Schwierigkeiten, stratifizierte und damit datierbare Vorkommen im Allgemeinen zu finden. Hier stellen wir die Spurenanalyse und technologische Analyse von Steinwerkzeugen aus einer der wenigen archäologischen Stätten im Oman vor, die auf die Zeit vor 33.000 bis 30.000 Jahren datiert werden können und eine kleine, aber wichtige Ansammlung von Rücken-gestumpften Werkzeugen hervorgebracht haben, die ursprünglich als Projektile gedeutet wurden. Die doppelspitzigen Mikro-klingen aus Mutafah 1 weisen spezifische technologische und morphologische Merkmale auf, die es erlauben, vergleichbare Arbeitsabläufe für die Herstellung dieser Stücke zu vermuten. Unsere Analyse, bei der spezifische Gebrauchsspuren sowohl für die Jagd als auch für häusliche Aktivitäten identifiziert wurden, sowie mikroskopische Rückstände, zeigt, dass die Werkzeuge aus Mutafah 1 Teil eines Werkzeugsatzes mit breitem Verwendungsspektrum waren, was den hochgradig opportunistischen Charakter der lokalen jungpaläolithischen Besiedlung Südarabiens widerspiegelt.*

Keywords - Stone tools, hunting, technology, traceology, South Arabia
Silex Werkzeuge, Jagd, Technologie, Spurenanalyse, Südarabien

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Pleistocene human occupation of South Arabia

Prehistoric human occupations of the territories south of the Rub' al Khali have been tied to specific periods of congenial climatic conditions throughout the Pleistocene, associated with the northward migration of the Intertropical Convergent Zone (ITCZ) and the associated intensification of the Indian Ocean Monsoon. Paleoclimatic investigations of hydrogen and oxygen isotopes in stalagmite fluid inclusion from caves in Oman and Yemen, have identified 21 South Arabian pluvial phases that occurred over the course of the last 1.1 million years (Burns et al. 1998; Fleitmann et al. 2011; Nicholson et al. 2020). Additional paleoclimatic data have been gathered from lacustrine sequences and deep sea cores (Matter et al. 2015; Parker & Rose 2008; Parton et al. 2015; Schulz et al. 1998). These periods characterized by wet summers and dry winters are thought to have facilitated human demographic movements, while acting as "windows of opportunity for human expansions" (Parton et al. 2015; Rosenberg et al. 2012, 2011). Little is known about the human occupation between these pluvial phases, albeit considerable amounts of prehistoric archaeological sites have been reported across South Arabia over the course of the last decades (Amirkhanov 2006; Bretzke et al. 2020; Crassard 2008; Crassard et al. 2013; Delagnes et al. 2012; Newton & Zarins 2019; Rose et al. 2019a). The majority of the South Arabian Palaeolithic occurrences reported by the end of the 20th century were the result of large scale survey activities aiming at mapping and classifying prehistoric sites (Albright 1982; Amirkhanov 1994; Parr et al. 1978; Pullar 1974).

As a result of recent fieldwork across South Arabia, with its heterogeneous and at times remote landscapes, additional sites and data on the different stone tool (lithic) industries and their potential for providing insights to the behavioural adaptations of prehistoric human populations has been gathered (Armitage et al. 2011; Bretzke & Conard 2017; Delagnes et al. 2013, 2012; Rose & Hilbert, 2014). Lower Palaeolithic occurrences were generally associated with a plethora of handaxes types, large flake production, cleavers and choppers (Amirkhanov 2018; Beshkani et al. 2017; Bretzke et al. 2017; Whalen et al. 2002), while associated with warm and wetter climatic conditions. The subsequent Middle Palaeolithic technocomplexes show a great variety in knapping strategies aiming at the production of predetermined and standardised blanks by means of the Levallois technique (Amirkhanov 2006; Beshkani et al. 2017; Bretzke 2020; Crassard et al. 2013; Crassard et al. 2011; Petraglia et al. 2012; Usik et al. 2013).

The nature of the Upper Palaeolithic of Arabia, which falls chronologically within a highly volatile global climatic period, has remained elusive save for the occasional report of undated surface occurrences tentatively associated to either MIS 3 or MIS 2 ages based on techno-typological similarities with better known regions (e.g. Edens 2001; Hilbert 2020; Hilbert & Crassard 2020). Archaeologist have argued that the difficulties in establishing the emergence and characteristics of the Upper Palaeolithic in South Arabia relate to the possible differences in lithic production methods and tool forms adopted by humans inhabiting the region in contrast to the well-established archaeological record of Europe, North Africa and the eastern Mediterranean (Amirkhanov 1994; Inizan & Ortlieb 1987; Maher 2009; Rose & Usik 2009). And yet, genetic and paleoanthropological data argued in favour of a significant human migration event occurring between 60 to 40 ka years ago (Černý et al. 2016; Fernandes et al. 2015; Mellars 2006; Mellars et al. 2013).

This article focuses on the Upper Palaeolithic assemblage of backed micro-blades from Mutafah 1 in southern Oman, to reconstruct the production techniques used in their manufacture and assess tool function. Given the small number of sites and limited artefact sample sizes for the archaeological material from this period currently available for South Arabia we hope to make a contribution by providing a comprehensive study of the collection of Upper Palaeolithic backed micro-blades from Mutafah 1.

Material and methods

The Upper Palaeolithic assemblage from Mutafah 1

The site of Mutafah 1 (N 17.671110° E 53.561180°) is characterized by a deep chronology and stratigraphy with archaeological layers dating to 32,000, 14,000 and 10,000 years BP (Hilbert et al. 2018; Rose et al. 2019b). The site is located within a shallowly incised box canyon situation found along Wadi Ghadun on the central Nejd Plateau (Fig. 1). As Wadi Ghadun meanders across deeply incised limestone plateaus, forming a distinctive canyon landscape with steep erosional terraces on either side, where short tributaries like that at Mutafah 1 would have facilitated access to the riparian system and its resources. A series of test-pits have been made in different areas of the sedimentary terraces of which locality 1, 4 and 5 have yielded Upper Palaeolithic finds.

The stratigraphic succession found at locality 1, excavated as a 1 x 2 m test-pit, is described as horizontal beds of variable slope waste, alluvial, and aeolian sediments. The uppermost archaeological level at Mutafah 1 occurs within an ebulis layer found below a sandy horizon of probable aeolian origin, some 15 cm below the surface. The archaeological horizon I (AH-I) comprised 63 stone tools, including denticulated side scrapers, a small biconvex foliate and a leaf-shaped arrowhead. Below layer AH-I is a mostly sterile, 50 cm thick deposit of fine sand and silt with no gravel inclusions. At the base of this horizon, two blades have been excavated (AH-II). Two OSL dates are available for this level, placing its deposition

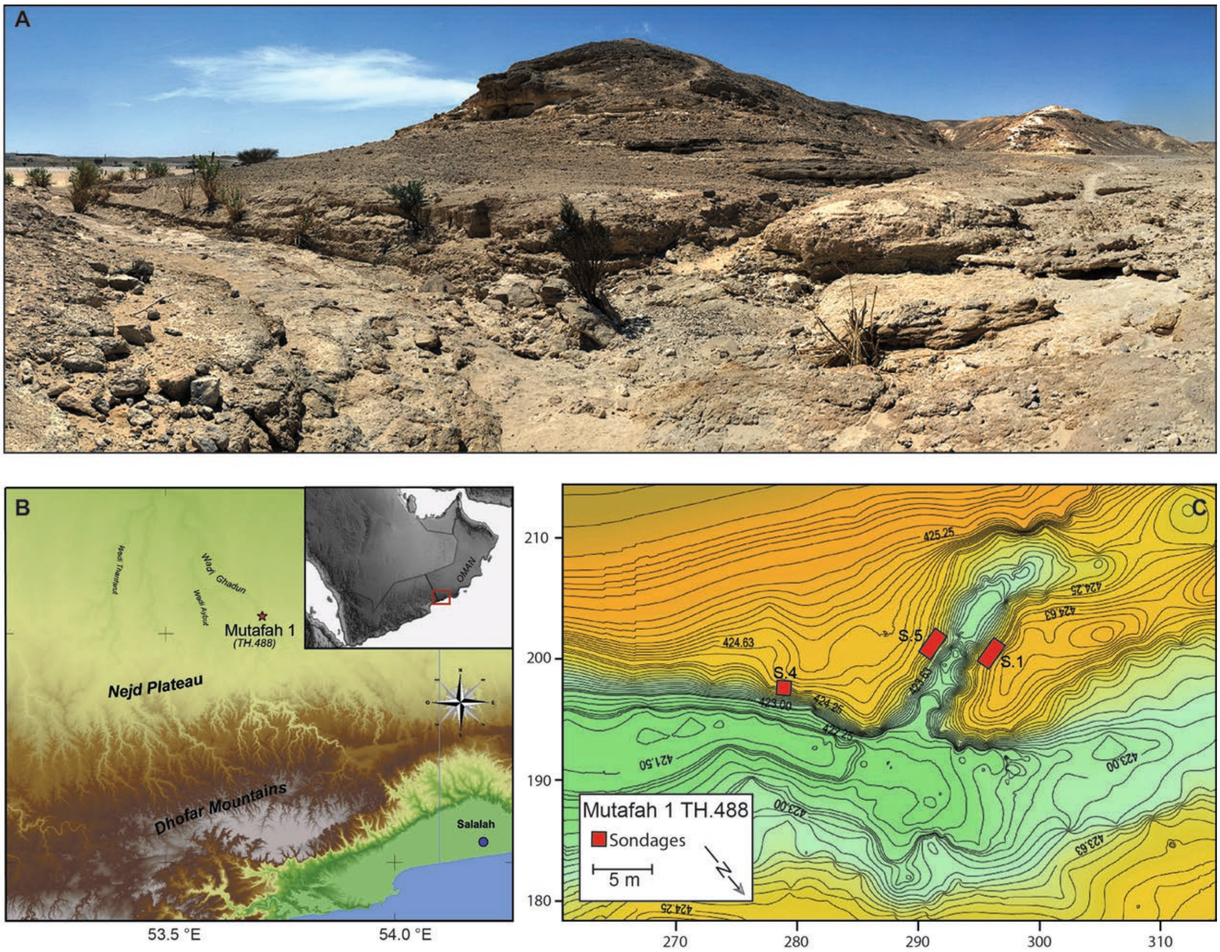

Fig. 1. Map showing the location of the site. A) Photograph of the fluvial terrace; B) Map showing the location of Mutafah 1 in southern Oman; C) Plan of the site showing the location of the test excavations.

Abb. 1. *Karte mit der Lage der Fundstelle. A) Foto der Flussterrasse; B) Karte mit der Lage von Mutafah 1 im südlichen Oman; C) Plan des Geländes mit der Lage der Testgrabungen.*

at ap. 10,000 years before present, well within the time range of the Early Holocene wet phase for the region (Cremaschi & Negrino 2005; Fleitmann et al. 2007; Gennari et al. 2011).

The Upper Palaeolithic find horizon AH-III was excavated from a moderately cemented sedimentary unit with poorly sorted small to medium sized angular limestone inclusions. AH-III is found between 125 to 135 cm below the surface and dated by OSL to 30,300 ± 2,000 and 33,300 ± 2,100 years ago. In total 159 artefacts were excavated. The majority of the artefacts are chips, flakes, blades and bladelets (Fig. 2). The limited tool sample comprises two burins, two limestone hammerstones as well as a series of retouched and backed micro-blades (Fig. 3). The limited tool sample size and the lack of cores certainly places considerable constrains on interregional comparisons, making it paramount to obtain as much information from the available material as possible. To address the production techniques used by the Upper Palaeolithic hunter-gatherers to manufacture the backed implements, their hafting mechanisms and to provide insights into tool function a technological and traceological analysis of 11 artefacts was conducted at the microscopy laboratory of the *CSIC-IMF Archaeology of social dynamics* group in Barcelona and at the Institute of Prehistoric Archaeology of the Friedrich-Alexander-University Erlangen-Nürnberg.

Traceological analysis

Given their pointy morphology, Rose and colleagues (2019b) have argued that the Mutafah 1 microliths were projectiles. The interpretation of a given artefact as part of a prehistoric hunting equipment, however, should be based on the traceological methods (Iovita et al. 2016; Knecht 1997). Which is to say that the interpretation needs to be based on the comparison of specific traces and the results of empirical evidence drawn from systematic experimentation using different interchangeable variables (Coppe & Rots 2017; Fischer et al. 1984; Geneste & Maury 1997; Rots & Plisson 2014). The formation of diagnostic macroscopic impact fractures on either apex or base of the lithic armatures has been repeatedly associated with percussive activities related to high velocity impact connected with either thrown or trusted propulsion

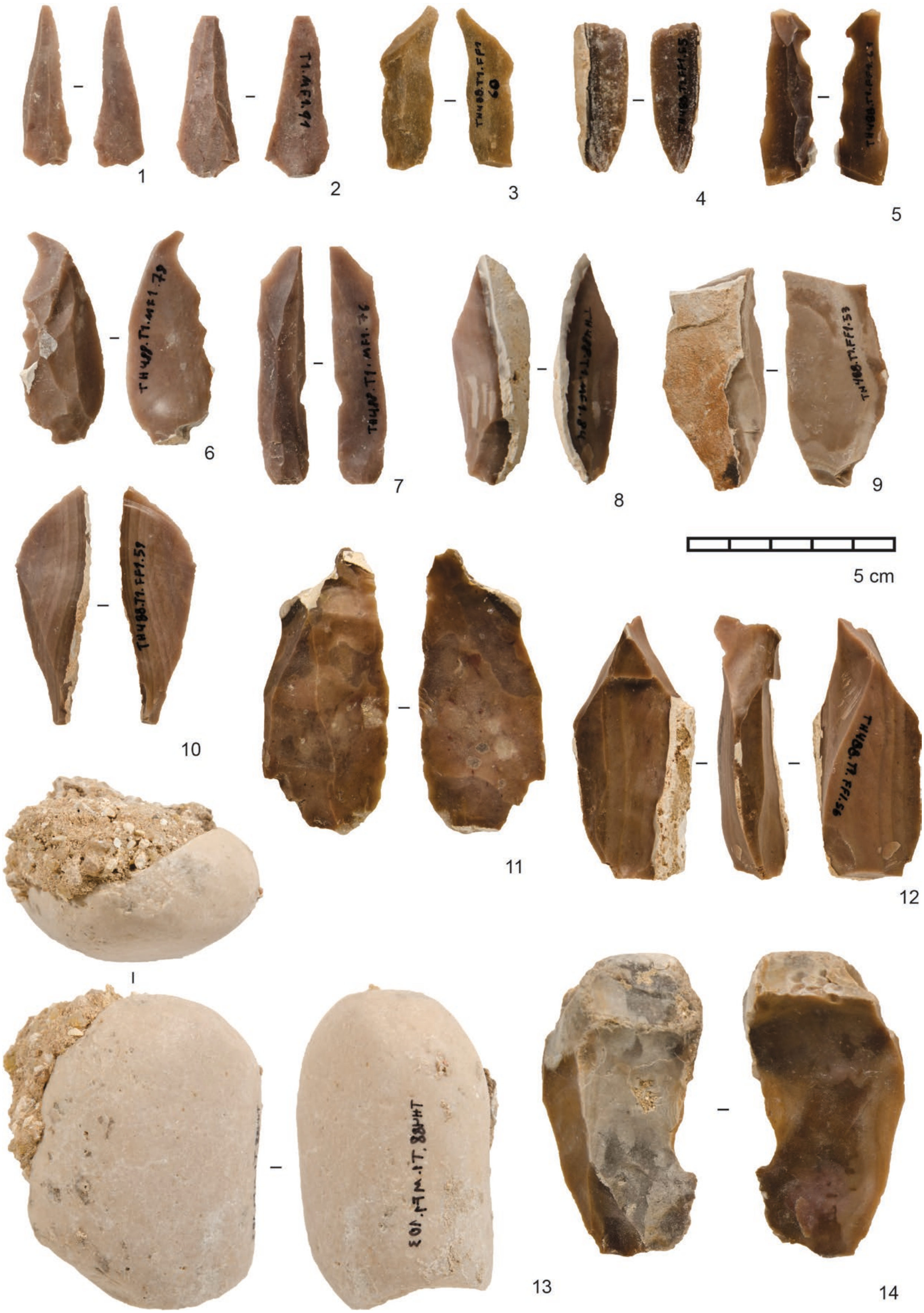

Fig. 2. Artefacts form the Upper Palaeolithic assemblage AH-III.

Abb. 2. *Artefakte des Jungpaläolithischen Inventars aus AH-III.*

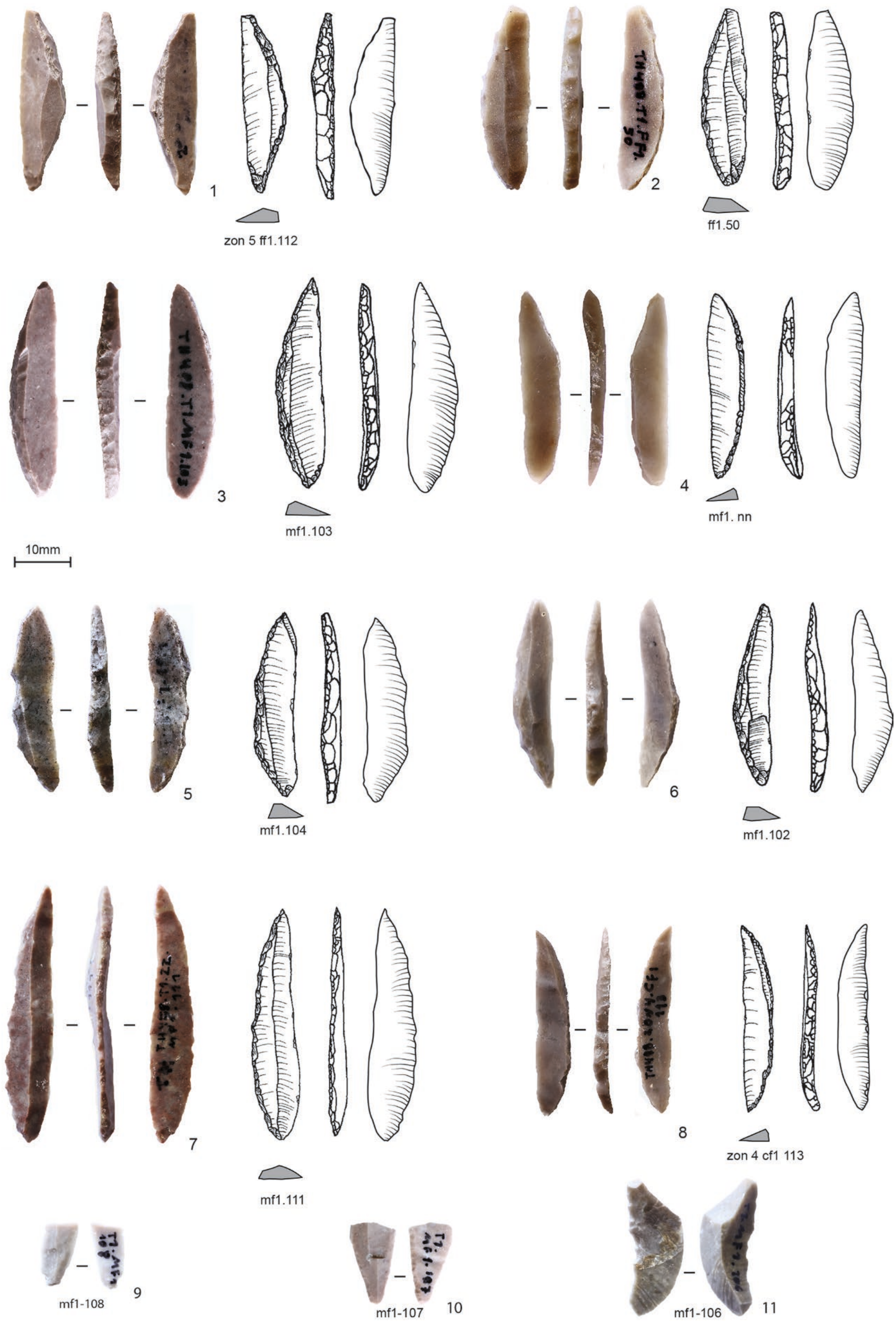

Fig. 3. Bi-pointed backed micro-blades from Mutafah 1 and other analysed tools from AH-III.

Abb. 3. *Doppelspitzen mit rückenretuschierte Mikroklingen aus Mutafah 1 und weitere analysierte Werkzeuge.*

mechanisms (Calvo Gómez et al. 2021; Dockall 1997; Iovita et al. 2014; Lombard 2005; Rots et al. 2014). Repeated experimental replication has led to the formation of a comprehensive reference consortium from which traces and specific actions associated with projectile technology can be drawn (Carrère 1990; Coppe et al. 2017; Sano et al. 2016). However, diagnostic impact fractures, edge damage and even striations have been associated with different activities owing to the complexity of the subject and as a warning to those in search for impact as highlighted by Rots and Plison (2014).

With these limitations in mind we applied the traceological method, which makes use of different microscopy methods and experimental comparative collections to understand prehistoric technologies (Keeley 1980; Semenov 1964). We use high and low powered approaches to detect wear traces resulting from mechanical stress during use (e.g. Clemente-Conte 1997; González-Urquijo et al. 1994; Levi-Sala 1988; Mansur-Franchomme 1986; Moss 1983; Odell et al. 1980; Plisson 1985; Rots 2010; Tringham et al. 1974; Van Gijn 2014). Special attention was given to the identification of potential impact fractures, striations, microscopic polish and micro-chipping. An Olympus BH50 metallographic upright microscope equipped with Nomarski prisms, an Olympus BMX digital camera and a Carl Zeiss Stemi 508 microscope with an Axiocam ERc 5s digital camera were used to conduct the traceological analysis. Artefacts were gently washed with warm water and soap before they were inspected under the optical microscope in order to observe the condition of the edges, ridges, surfaces and negatives. Possible micro-polish distributions along active edges, the degree of rounding on the ridges that belong to the negatives from re-sharpening or blunting activities were recorded and plotted.

Residue analysis

In addition to these aforementioned traces of mechanical stress on the lithic artefacts the potential of both microscopic and macroscopic organic residues for the holistic interpretation of the tool's functions have been recurrently explored by different researchers (e.g. Hardy & Garufi 1998; Lombard 2008; Rots et al. 2016). The artefact surfaces were scanned (after washing) using an Olympus BH50 metallurgical upright microscope equipped with Nomarski prisms at the Archaeology of social dynamics lab in Barcelona and a ZEISS-Axio Vision v16 microscope at the GeoZentrum Nordbayern (GZN) of the University of Erlangen-Nuremberg in Germany. We used the multifocal function under reflected light, to show surface morphology of the attached residue and for the positioning of later micro-Raman-spectroscopic measurements. For non-destructive compositional analyses we used a micro-Raman Spectroscope (µRaman) at the University of Padova in the Department of Organic Chemistry. The Thermo Scientific micro-Raman Spectroscope is equipped with a monochromatic 532 nm DXR laser and was run at 3 mW laser power, applied with a 25 µm pinhole and a 50x long-working distance (LWD) objective. Collection exposure time was 60 s per sampling spot and reported spectra represent averages from four repeated sample exposures. The Raman-shift was recorded from 100 to 3,500 cm^{-1} with relative intensities measured in counts per second (cps). Acquired spectra were processed with the Omnic software. Mineralogical reference spectra were sourced from the RRUFF-database (http://rruff.info/) and in-house standards. Comparison spectra for recent and mid-Holocene blood components were sourced from Atkins et al. (2017) and Janko et al. (2012), respectively.

Attribute analysis

In order to further describe and classify the small assemblage of bi-pointed micro-blades, additional metric and qualitative data were gathered. The artefacts were classified in terms of their state of preservation, whether complete or fractured, and where possible a distinction between proximal and distal fragments was attempted based on the morphology of the fragments. The dorsal scar pattern on the tools was recorded, edge and back angles were recorded using a goniometer along different landmarks on the tools. Additional metric data including maximal length, max. width and max. thickness have been recorded with a digital calliper.

Results

Technology, manufacture and raw material

The analysed sample from Mutafah 1 included eleven backed micro- and nano-blades, as well as two specimens from the undated sondages 4 and 5, which presented backing and a series of blades and bladelets (Tab. 1). Raw material provenance and acquisition strategies across southern Oman remain largely understudied. Throughout Dhofar, a great variety of chert bearing Eocene limestone strata (Platel et al. 1992; Platel & Roger 1989) have been identified and the majority of the lithic raw material outcrops are associated with prehistoric primary workshop sites. The artefacts from AH-III that present cortical cover provide some insights on the provenance of the raw material used at the site. While the majority of primary blades and flakes show a thin and coarse cortex (Fig. 2: 4-9), which indicates that the nodules have been collected from secondary deposits, thick and chalky cortex, indicative of an acquisition from primary outcrops (Fig. 2: 8-12) are also observed. Artefact 14 on figure 2, on the other hand, presents a high amount of rounding and edge rolling, as well as the distinctive chemical weathering associated to the formation of a alluvial type neocortex (Fernandes et al. 2007), indicating that the nodule from which the blank was struck likely came from a wadi or stream bed.

Artefact Number (#)	Sondage	Profile	Length (mm)	Max Width (mm)	Max Thickness (mm)	Weight (g)	State
50	1	straight	30.98	8.36	2.58	0.8	complete
102	1	slightly twisted	32.12	6.84	3.15	0.7	complete
103	1	straight	36.72	8.14	3.15	1.1	complete
104	1	slightly twisted	30.44	6.67	2.89	0.7	complete
107	1	straight	15.37	8.41	1.41	0.3	fractured
108	1	straight	12.18	6.38	1.53	0.1	fractured
109	1	straight	11.22	2.24	1.52	0.1	fractured
111	1	straight	44.28	8.19	3.19	1.2	complete
112	5	straight	31.06	8.38	4.27	0.9	complete
113	4	slightly twisted	35.60	6.56	2.60	0.6	complete
115	1	straight	32.28	6.67	3.27	0.6	complete

Tab. 1. Metric and qualitative data from Mutafah 1 micro-blades.

Tab. 1. *Metrische und qualitative Merkmale der Mutafah 1 Mikroklingen.*

Metrically, the Mutafah 1 bi-pointed backed micro-blades show some variability with respect to their maximum length, which averages 34.19 mm, while width and thickness are similar for the rest of the tools. Both width and thickness vary considerably within each piece as well as between pieces, this is particularly evident when focusing on the dimensions along specifically set points (Fig. 4). While measurements taken along the set landmarks on the apex of the artefacts are thin, the measurements on the base show thicker and wider configurations, possibly due to the morphology of the initial blanks used. Edge and back angles show some variability; generally, the distal extremities show more acute angles while the mesial portion of the pieces show the steepest angles. Exceptions to this pattern are artefacts #112, #113 and #115, which present a different method of backing then for the remaining pieces.

The majority of the micro-blades show continuous abrupt retouch from tip to bottom along one side. The backing follows the negative ridge on the dorsal face of the bladelet. Seven out of the eight complete backed pieces show continuous short abrupt to semi-abrupt retouch along one edge circumventing both proximal and distal extremities. The micro-negatives that form the back of these tools are irregular in shape and run parallel to one another. In some cases, notably #50, #103 and #113, additional minute negatives shape

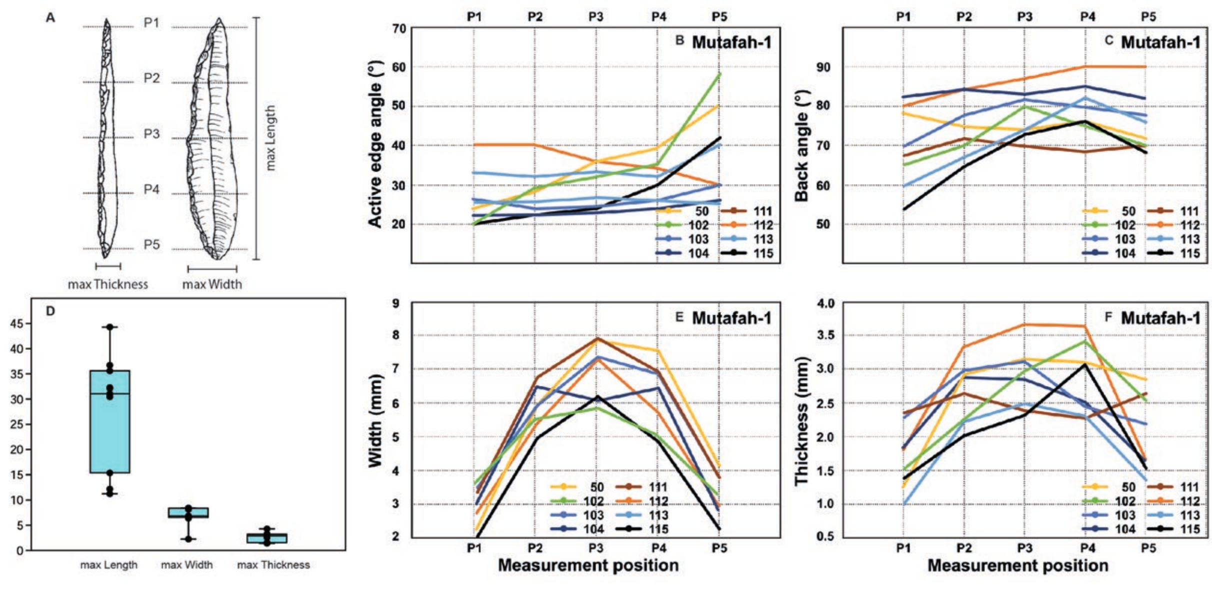

Fig. 4. Mutafah 1 bi-pointed backed micro-blades metrics. A) measurements taken; B) active edge angle measured at each landmark; C) back angle measured at each landmark; D) boxplot showing max length, max width and thickness; E) bi-pointed backed micro-blades width; F) 1 bi-pointed backed micro-blades thickness.

Abb. 4. *Metrik der Mikroklingen von Mutafah 1. A) Messstrecken; B) Winkel der aktiven Kante, gemessen an den jeweiligen Orientierungspunkten; C) Winkel des Rückens, gemessen an den jeweiligen Orientierungspunkten; D) Boxplot mit maximaler Länge, maximaler Breite und Dicke der Artefakten; E) Breite der Mikroklingen; F) Dicke der Mikroklingen.*

the extremities to form the typical bi-pointed configuration, which characterizes the baked implements from the site. The negatives on the backs of the tools are short and show high incidence of hinge and step fractures on the proximal/mesial section of the tools (Fig. 5). Specimen #113 from sondage 5 and #112 from sondage 5 show two different types of negative orientation and morphology. While the proximal termination shows abrupt micro-negatives coming from both ventral and dorsal faces the distal section shows unidirectional negatives. Tool #115 from AH-III, shows bidirectional micro-negatives on the distal section of the back while the proximal portion, which is thicker due to the removed bulb of percussion, shows regular shapes and parallel unidirectional negatives. The blanks were retouched in such a way that the bulbs of percussion were removed and are no longer visible on all artefacts. Generally, this is the thickest portion of the blanks, resulting in a specific profile, where the thinner distal and thicker proximal zones of the backed micro-blades hint at a different functionality of these elements.

Traceology and taphonomy

The taphonomic alterations on the lithics from Mutafah 1 show differences across the stratigraphic sequence, soil polish and edge damage from trampling are evident on artefacts from AH-II (Fig. 6). The soil polish presents itself as a generic weak polish, which is dull and yet brighter than the naturally reflective background of the raw material, and is evenly distributed on the complete surface of the artefacts (Clemente-Conte et al. 2005; Glauberman et al. 2012; Levi-Sala 1988).

Soil polish was less pronounced on the AH-III artefacts making the identification of microscopic polish on some of the bi-pointed micro-blades possible; nonetheless, out of the eleven pieces analysed from AH-III six were to altered to identify any traces. The nano-blades from Mutafah 1 are fractured while the remaining eight micro-blades are in complete states. The fragments are considerably smaller than the rest of the baked micro-blades; two are elongated triangular fragments with semi-abrupt retouch running continuously along the edges of the fragments.

The results from the traceological analysis of the bi-pointed micro-blades are summarized in table 2. Given the sample size constrains and preservation of traces on the material some of the results for the artefacts will be presented and discussed individually.

Artefact #111, the largest specimen, presents micro-negatives and >2 mm negatives on both dorsal and ventral surfaces along the edge of the tool, similar to specimens #104, #103 and #112 (Fig. 7). Under the metallurgical microscope these micro-negatives show the lightly developed soil polish, which homogenously covers the interior of the negatives indicating their cohesive taphonomic origin. These are of triangular,

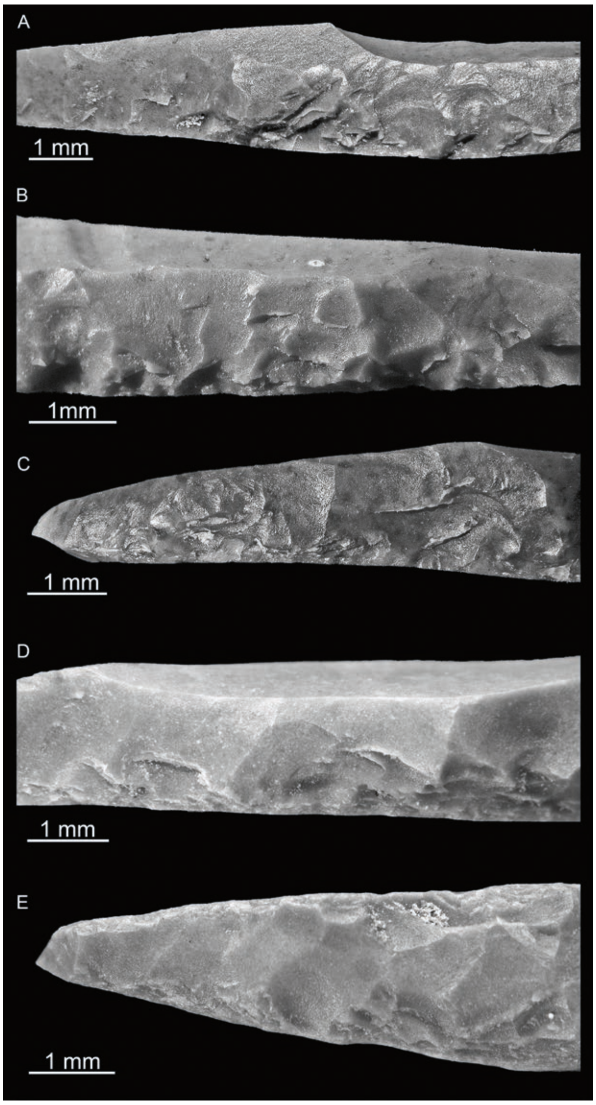

Fig. 5. Mutafah 1 bi-pointed backed micro-blades backs.
Abb. 5. *Rückansicht der doppelspitzigen Mikroklingen von Mutafah 1.*

circular and rectangular shapes, and show different orientation. On specimen #115 these negatives are smaller than on the other specimens and cluster on both proximal and distal portions of the dorsal face, while in medial section of the tool only microscopic scars where observed. Scars have been observed on the proximal termination, which display a large rectangular negative with step termination. Additional fractures, observed on both the distal and proximal extremities of the bi-pointed backed micro-blades have been observed on the majority of the pieces. On specimen #104 both terminations show signs of damage (Fig. 8: A & B).

Specimen #111 shows additional wear and damage traces on both extremities, the tip of the distal termination is rounded, possibly from the contacts with a soft organic abrasive material. Specimens #111 and #50 show a series of circular and semi-circular shaped micro-negatives with feathered terminations that show slightly rounded edges, which are associated to

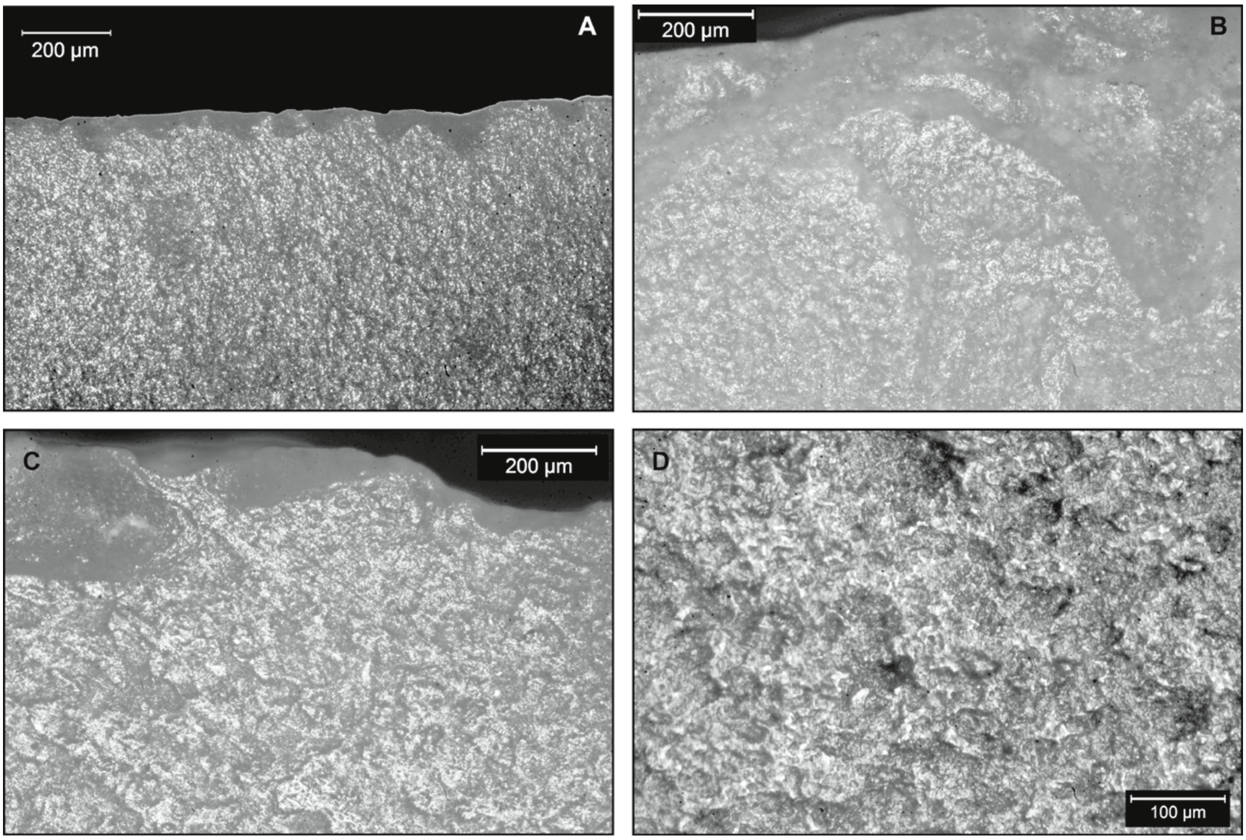

Fig. 6. Different types of taphonomic alterations on the surfaces of the lithics form AH-II and AH-III. A) series of semi-circular, rectangular and triangular micro-negatives on a blade from AH-III; B) Rounded negative edges on a bi-pointed backed micro blade from sondage 4; C) and D) soil polish on a blade from AH-II.

Abb. 6. *Verschiedene Arten von taphonomischen Veränderungen auf den Oberflächen der Artefakte aus AH-II und AH-III. A) Serie von halbkreisförmigen, rechteckigen und dreieckigen Mikro-Negativen auf einer Klinge aus AH-III; B) Abgerundete Negativ-Kanten auf einer Mikroklinge mit zweiseitigem Rücken aus Sondage 4; C) und D) Bodenpolitur auf einer Klinge aus AH-II.*

a lightly developed smooth pitted polish with a mat sheen and undulating morphology (Fig. 9). Striations are missing, however micro-negatives on both faces of the active edge and their orientation hint at the longitudinal and possibly also transverse kinetic of these tools. A cutting and possibly piercing activity of soft

Artefact Number (#)	Classification	Backing	Hafting Traces	Residue	Use traces	Type of traces	Material used	Motion
50	Bi-pointed bladelet	obverse unilateral	yes	yes	yes	polish and micro negatives	soft organic	longitudinal
102	Bi-pointed bladelet	obverse unilateral	no	no	no	na	na	na
103	Bi-pointed bladelet	obverse unilateral	yes	no	no	na	na	na
104	Bi-pointed bladelet	obverse unilateral	no	no	yes	MILT	na	percussion
107	Distal Fragment	bi lateral inverse and obverse	no	no	no	na	na	na
108	Distal Fragment	obverse unilateral	no	no	no	na	na	na
109	Backed Fragment	obverse unilateral	no	no	no	na	na	na
111	Bi-pointed bladelet	obverse unilateral	yes	no	yes	polish and micro negatives	soft organic	longitudinal and transverse
112	Bi-pointed bladelet	unilateral/bilateral on tip	no	no	no	na	na	na
113	Bi-pointed bladelet	unilateral/bilateral on base	yes	no	yes	micro negatives and striations	hard	longitudinal
115	Bi-pointed bladelet	obverse unilateral	no	no	no	na	na	na

Tab. 2. Summary of the traceological study from Mutafah 1.

Tab. 2. *Ergebnis-Zusammenfassung der Gebrauchsspuren Analysen für die Artefakte aus Mutafah 1.*

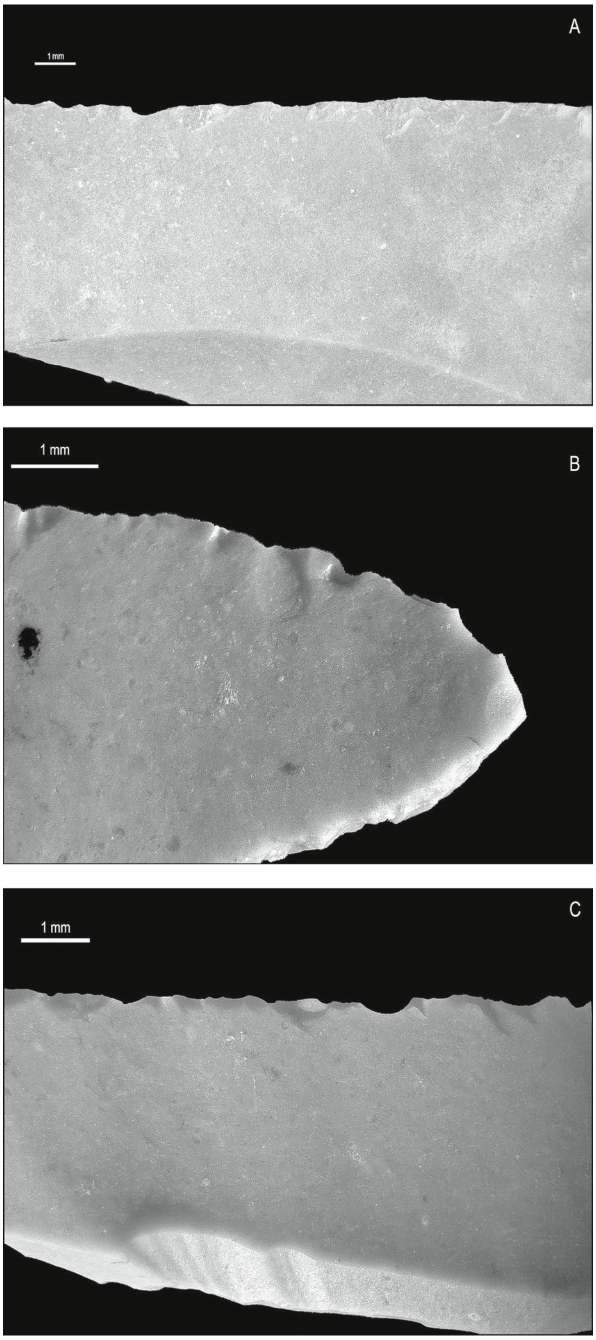

Fig. 7. Mutafah 1 bi-pointed backed micro-blades edges.
Abb. 7. *Aktive Kanten der Mikroklingen von Mutafah 1.*

organic material is suggested based on the microscopic wear traces.

A series of deep parallel striations have been identified on the dorsal side of the proximal portion on artefact #104 running slightly parallel with the edge of the artefact (Fig. 10). These traces are somewhat similar with Microscopic Linear Impact Traces (MLIT) as described by different authors (Fischer et al. 1984; Moss 1983). MLIT are, however, commonly found in association with spinoff fractures, which have not been identified on the specimen making a secure attribution of the identified striations as resultant form of an impact problematic.

Edge rounding caused by abrasion on the salient portions of the negative that form the backing on the micro-blades were identified on four of the analysed artefacts. These were found spread across the majority medial section of the backed edge, the base and apex portions of the tools, however, showed no such traces. Negative edge abrasion was found associated with weakly developed flat bright micro-polish on specimens # 50, #103, #111 and #113 (Fig. 11). Comparable polish was neither observed on the base or the apex of the bi-pointed micro-blades, nor on the active portion of the tools. Together these traces may indicate that these artefacts were hafted along the backed edge.

µRaman-spectroscopy

In addition to the different macro- and micro-negatives, polish and abrasions the majority of the bi-pointed micro-blades present a variety of microscopic residues attached to either the interior zones of the negatives that occur on the backing portion of the tool or on the surface of negatives on the opposite side. Generally, sand grains have been noticed adhering to the back of the tools possibly fixed to the artefacts by a calcium carbonated crust. Specimen #50 shows a reflective residue adherent to the active portion of the implement and showing a mud-cracked aspect (Fig. 12). This residue was analysed with µRaman-spectroscopy as well as the artefact itself. The average of 11 spectra from the lithic portion next to the site of the polygonal residue all showed the characteristic peaks for quartz from the underlying silica artefact surface, centred at 1,871.13, 1,162.48, 465.15, 394.53, 355.50, 206.59 and 128.67 cm^{-1}. The µRaman-spectra from the polygonally-cracked residue, which is suspected to be a remnant of blood, showed coherent spectra and the averaged spectrum of 9 spot measurements is shown in figure 13. Expected peaks from blood and blood components, sourced from Janko et al. (2012) show peaks centred at 1,586, ~1,450, 1,395, 1,308, ~1,240, ~1,130, and 747 cm^{-1}. These find a correspondence in our spectra in the form of broad peaks and slope shoulders in steep segments of the spectra.

The spectrum recorded between 3,200 to 1,400 cm^{-1} shows relatively high absorbance and broad peak areas, and a less strong overall signal between 1,400 and 100 cm^{-1}. Janko et al. (2012) reported peaks for the mid-Holocene icemen from the Italian Alps, dated to 5,300 yrs BP, with Raman spectra reported between 1,700 and 700 cm^{-1}, that convincingly coincide with modern blood or blood component spectra, as later for instance also shown in Atkins et al. (2017). Our data show a correspondence at the same positions, but the peaks are much wider. Based on the position of the 300 x 250 µm large residue on the artefact, its presumable use, as well as the morphological residue appearance would suggest a remnant of blood. Considering the good correspondence for 5 of the peaks and a weak correspondence at 2 peaks,

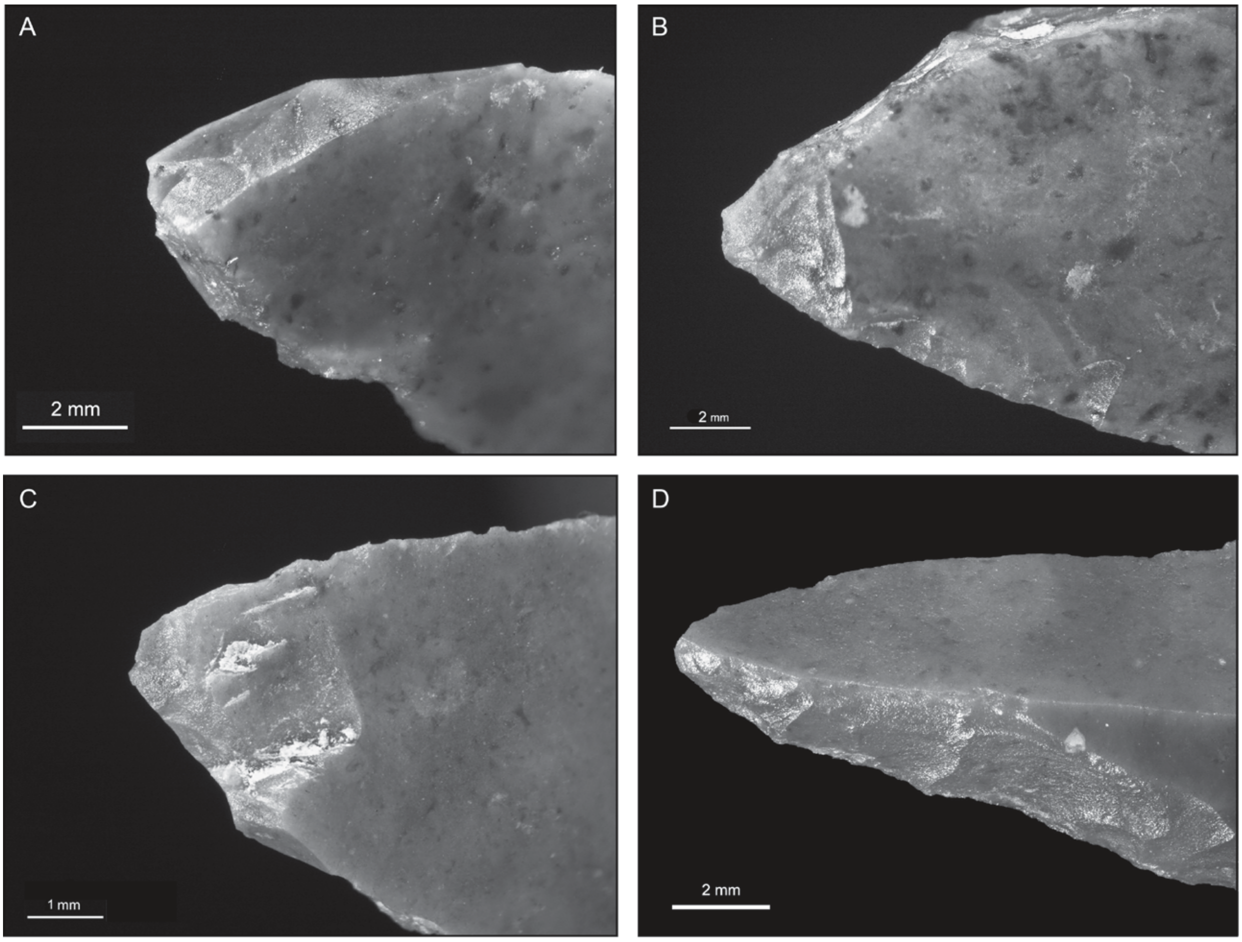

Fig. 8. Mutafah 1 bi-pointed backed micro-blades distal and proximal terminations. A) burin damage on distal portion of #104; B) impact damage on proximal portion of #104; C) step fracture on proximal termination of #111; D) distal portion of #111.

Abb. 8. *Distale und proximale Enden der Mutafah 1 Mikroklingen mit Doppelspitze und Rücken. A) Stichelschaden am distalen Teil von #104; B) Schlagschaden am proximalen Teil von #104; C) Stufenfraktur am proximalen Ende von #111; D) distaler Teil von #111.*

we are optimistic that the Raman signal can be taken as further evidence for fossil blood. Considering the different storage of the Iceman's Holocene blood in a glacier, while our sample was preserved in a dry desert rubble under high ambient temperatures (modern average 25 °C), blood may show different degradational changes and hence modified Raman signals. In the absence of other Raman spectra of presumable blood residues at 30 ka from the Arabian Peninsula, we provide the data as a reference for eventual future finds.

Discussion

Manufacture technology, hafting options and function of the Mutafah 1 backed micro-blades

The chaine operatoire of the Mutafah 1 backed micro-blades starts with the acquisition of suitable raw material. Based on the different characteristics of the cortex on both primary flakes and blades from AH-III, which show different morphologies, it is likely that different sources including primary and secondary deposits have been exploited indicating a flexible acquisition system. The occurrence of primary flakes, core tables, debordant blades as well as chips, bladelets and flakes speaks in favour of an on-site manufacture of the micro-blades that have been retouched into the bi-pointed backed artefacts. Experimental reconstruction of backing techniques have been conducted by a variety of scholars for the European Upper Palaeolithic, predominantly to investigate Gravettian, Epigravettian and Magdalenian backing technology (e.g. Duches et al. 2018; Pelegrin 2004). Based on these experiments a differentiation between direct hard hammer percussion, percussion on anvil, soft hammer percussion, pressure retouch and pressure by stone (*l'égrisage* sensu Pelegrin 2004) can be differentiated. The irregular negatives and high incidence of hinge and step fracture terminations on the majority of the mesial sections of the Mutafah 1 bi-pointed micro-blades may indicate that direct percussion using a mineral hammerstone was employed. The lack of abrasions and micro-scaring on the dorsal surfaces of the artefacts speaks against the use of a mineral anvil (sandstone or limestone); the use of an organic anvil, however, cannot be ruled out. The thinner distal portions of the tools, show a low incidence of hinge and step fractures, while being

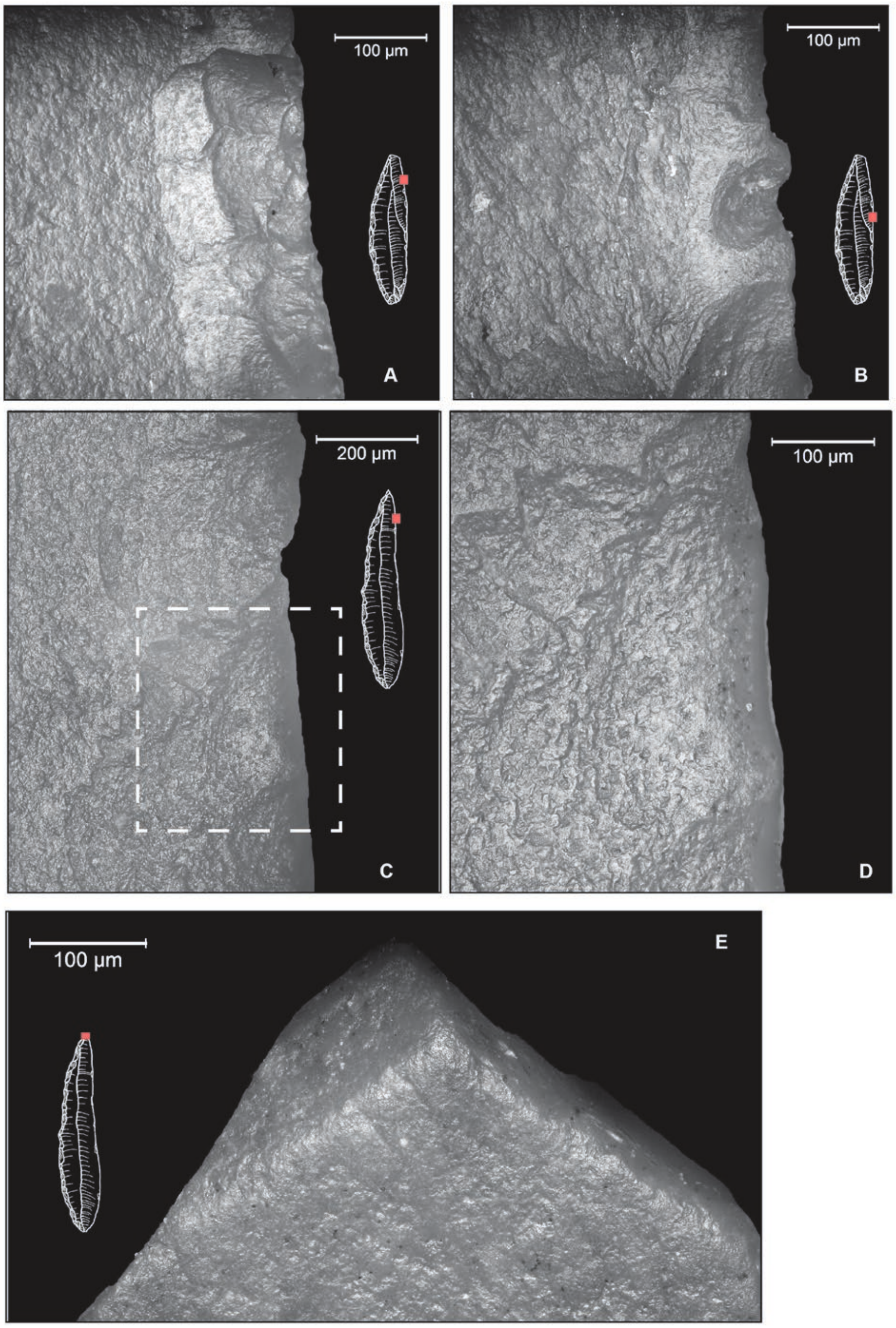

Fig. 9. Micro-polish on artefacts #50 and #111 from AH-III. A) bright undulating micro-polish and micro-negatives on the dorsal side of the active edge of artefact #50 at 200 x; B) bright undulating micro-polish and micro-negatives on the dorsal side of the active edge of artefact #50 at 200x; C) mat weakly developed undulating polish located on the dorsal side of the active edge of #111 at 100x; D) the same polish at 200 x; E) rounding and week developed polish on distal portion of the tip on artefact #111 at 100x.

Abb. 9. *Mikropolitur an den Artefakten #50 und #111 aus AH-III. A) helle wellenförmige Mikropolitur und Mikronegative auf der dorsalen Seite der aktiven Kante von Artefakt #50 bei 200x; B) helle wellenförmige Mikropolitur und Mikronegative auf der dorsalen Seite der aktiven Kante von Artefakt #50 bei 200x; C) matte, schwach entwickelte, wellenförmige Politur auf der dorsalen Seite der aktiven Kante von #111 bei 100x; D) dieselbe Politur bei 200x; E) Abrundung und schwach entwickelte Politur auf dem distalen Teil der Spitze von Artefakt #111 bei 100x.*

generally semi-abrupt and regular in shape. These patterns may indicate the use of pressure by stone for the shaping of the more fragile tips. Three of the bi-pointed backed micro-blades show bidirectional backing, which indicates the use of a stone anvil for the manufacture of these implements. The variable use of different techniques, the morphological homogeneity of the backed implements, and the low incidence of

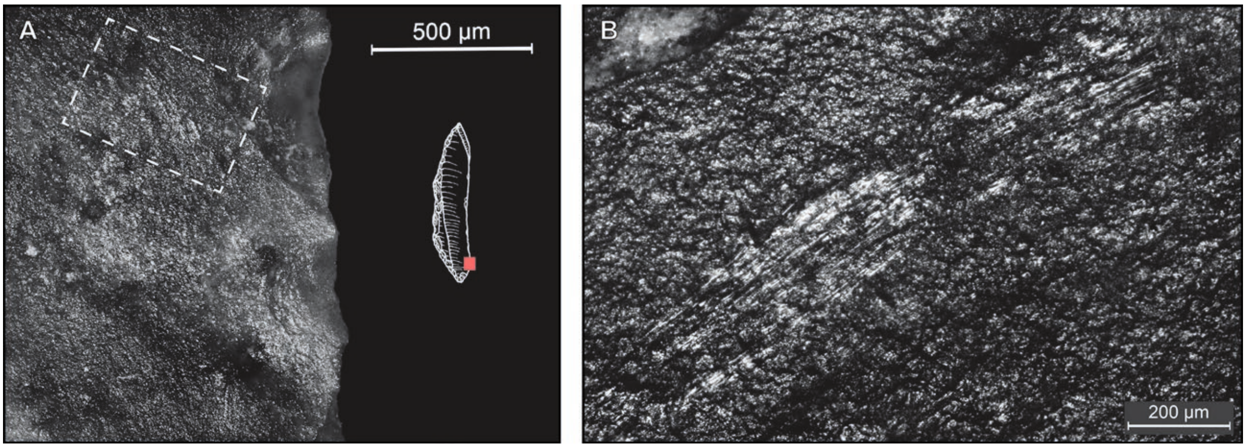

Fig. 10. Microscopic Linear Impact Traces (MLIT) on artefact #104. A) micrograph at 50 x; B) micrograph at 200x.

Abb. 10. *Mikroskopische lineare Aufprallspuren auf Artefakt #104. A) Bild bei 50x; B) Bild bei 200x.*

accidental manufacturing fractures, such as Krukowski micro-burins, cone fractures or overpassed fractures, are noted.

While local differences and chronological specificities have been recorded, backed implements were used to achieve a variety of tasks throughout the Palaeolithic, including the use as projectiles in composite long range weaponry, cutting implements or craft related utilities (Fano et al. 2020; Pelegrin 2004; Taipale et al. 2021; Taller et al. 2012).

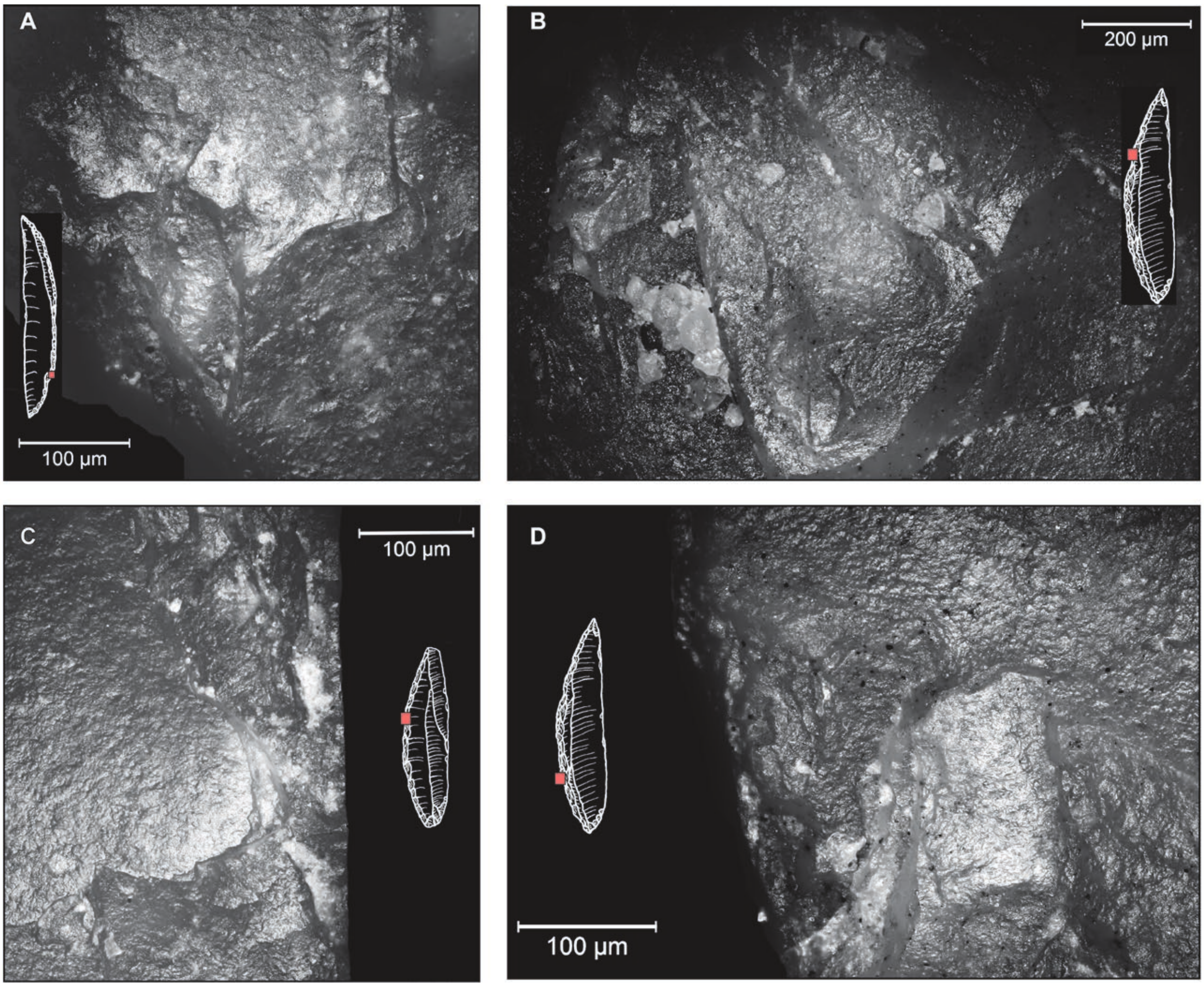

Fig. 11. *Hafting traces on Mutafah 1 bi-pointed backed micro-blades. A) artefact #113; B) artefact #103; C) artefact #50; D) artefact #103.*

Abb. 11. *Haftspuren an den Mikroklingen von Mutafah 1 mit zweizinkigem Rücken. A) Artefakt #113; B) Artefakt #103; C) Artefakt #50; D) Artefakt #103.*

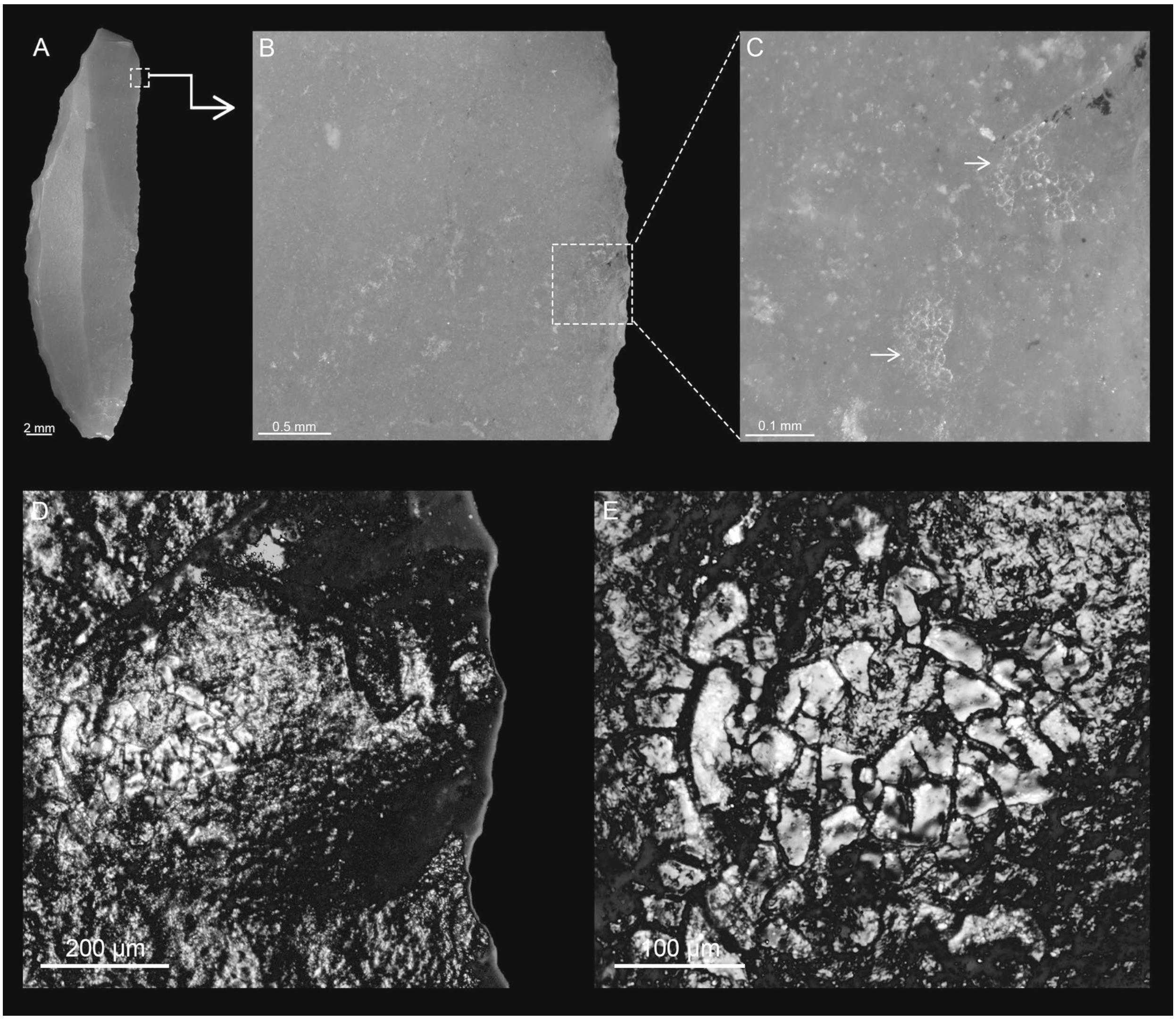

Fig. 12. Location of residue on artefact #50, showing polygonal shrinkage cracks.
Abb. 12. *Residuen an Artefakt #50, mit charakteristischen polygonalen Trocknungsrissen.*

The traceological analysis of the Mutafah 1 artefacts has reviled a variety of traces that, together, provide some information on the possible function of these artefacts. The use of some of these morphologically homogenous tools as projectiles is tempting, however, given the limited sample size available for analysis and uncertainty in the attribution of diagnostic impact fractures currently difficult to address. The possibly MLIT identified on artefact #104 may be indicative of a fired projectile that has missed its target and struck the ground, however, given the general scarcity of additional diagnostic traces a definitive assessment on tool function remains complicated. Additional uses in possible cutting or piercing activities conducted on soft and abrasive organic materials, possibly the slitting of an animal carcase by longitudinal motion or the perforation of hides in a punctuated motion are suggested for artefacts #50 and #111. The residues found on #50 are preliminary interpretation as organic and possibly blood, however, they neither revokes nor confirms the functional interpretation. We hope to conduct additional SEM analysis of these tool in the future.

The identification of hafting traces on four of the specimens indicates that these bi-pointed micro-blades were mounted on a shaft along their abrupt to semi-abrupt backs. The bi-pointed backed micro-blades where likely hafted in a slightly oblique fashion leaving a small portion of the apex and the proximal points salient. In case these tools were indeed part of composite weapon technology the distal tip would function as the apex of the projectile while the proximal end of the bi-pointed artefacts would serve as a barb (Fig. 14). Weather the backed micro-blades were mounted individually or if multiple elements have been hafted to each shaft remains difficult to ascertain given the limited sample size.

Recent focus of investigations have been places in determining the diversity of the Arabian Palaeolithic record, its chronological and geographical pattering based on stone tool manufacturing techniques (Bretzke et al. 2020). Currently, only a handful of

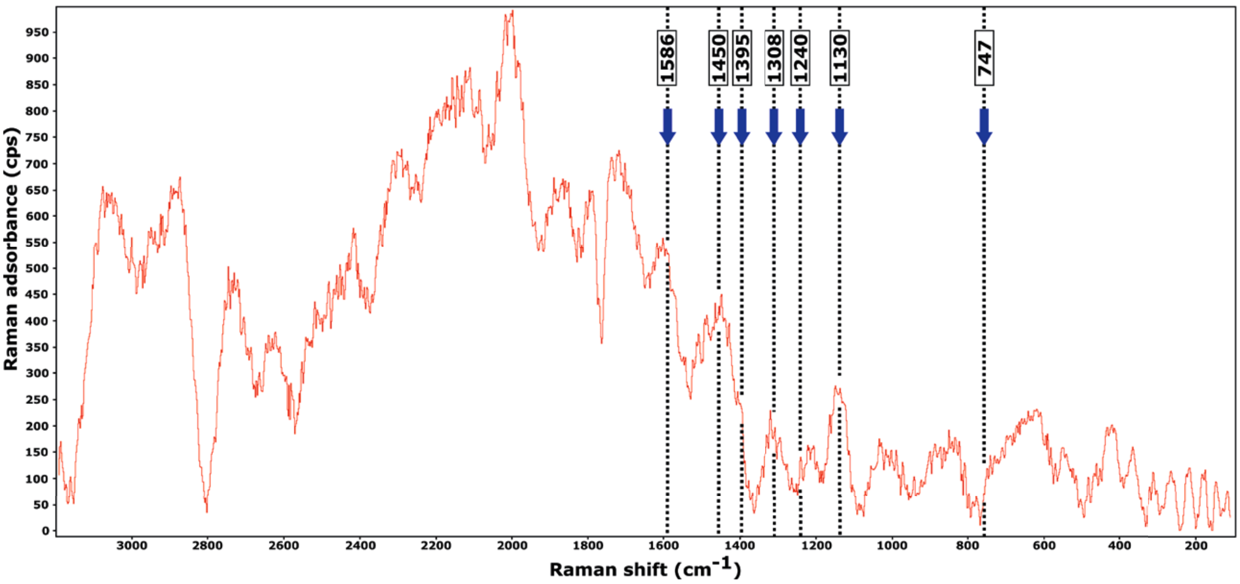

Fig. 13. Micro-Raman spectrum from artefact #50 of the mud-cracked residue (red curve), which is suspected to be a remnant of blood, shown as average from 9 spectra. Expected Raman peaks for blood or blood components, based on Janko et al. (2012), are marked with blue arrows and stippled lines.

Abb. 13. *Mikro-Raman-Spektrum des Rückstands an Artefakts Nr. 50 (rote Kurve), bei dem es sich vermutlich um einen Blutrest handelt, dargestellt als Mittelwert aus 9 Spektren. Erwartete Raman-Peaks für Blut oder Blutbestandteile, basierend auf Janko et al. (2012), sind mit blauen Pfeilen und gestrichelten Linien markiert.*

sites are attributed to the Upper Palaeolithic based on absolute dates and the presence of blade and bladelet production, burins and endscrapers. Sites falling chronological within the MIS 3 to late MIS 2 are known from the Jebel Faya and Jebel Buhais escarpments in the UAE and from Mutafah 1 in the Dhofar region in the south of the Sultanate of Oman. Additional sites were also reported in Yemen by the Soviet Expedition to the Hadramawt (Amirkhanov 2006). Comparable finds to the Mutafah 1 bi-pointed micro-blades are rare and have been excavated from Buhais Rockshelter (BHS-84) in the Emirate of Sharjah by Bretzke (2020, 2018). The artefacts from BHS-84 AH-I show comparable morphologies and size as well as the characteristic bi-pointed articulation of the ends by very fine backing. Preliminary OSL ages place the deposition of the find bearing sediments to the second half of MIS 2 and therefore younger than the Mutafah 1 lithics.

The spread and distribution of micro-blade bearing inventories and the emergence of backing/microlithic technology have seen some attention, particularly their interpretation as part of complex hunting equipment, has brought forth poignant arguments and discussion over the past decades (Basak & Srivastava 2017; Clarkson et al. 2018; Lewis

Fig. 14. Reconstruction of hafting options based on the traceological analysis.

Abb. 14. *Rekonstruktion der Schäftungsmöglichkeiten auf Grundlage der Spurenanalyse.*

2015; Petraglia et al. 2009; Sisk & Shea 2011). While backed implements have been observed at a variety of surface sites in southern Oman, including TH.68 at Jebel Kareem (Hilbert 2020), site RK.2a in the southern most margins of the Rub' al Khali near Ramlat Fasad (Rose & Hilbert 2014) and the Faw Well site (Edens 2001) in Saudi Arabia, stratified occurrences instead have mainly been reported from early Holocene site KR213 in the Jebel Qara escarpment of the Governorate of Dhofar in southern Oman (Cremaschi & Negrino 2002). Across South Arabia during the Holocene backing technology and especially microlithic technology intermittently appear from the Neolithic onward to the Proto-Historic periods (Khalidi et al. 2013; Maiorano et al. 2018; Moore et al. 2020; Zarins 2001).

Evidently, very different scenarios may explain these geographically separate technological patterns of which technological convergence is currently *en vogue* (see Clarkson et al. 2018 and reference therein), as opposed to the migration or diffusion arguments proposed by others (Mellars et al. 2013). Similarities in stone tool technology may also hint at a common root from a technical background shared by populations across the Indian Ocean rim, an argument raised by Delagnes and colleagues (2012) for the Late Middle Palaeolithic, and supported by the heterogeneity between the south Arabian and Levantine records. Incidentally, this latter argument may hold some form of validity if the genetic data on the divergence between the Asian and European lineages is added to the discussion, which states a separation between these populations at some point between 80 and 40 ka years ago (Yang & Fu 2018).

The current rudimentary MIS 3 and MIS 2 archaeological record of South Arabia is inconsistent with the current notions of a restricted climatic window that allows for a sustained human occupation or migration and diffusion into the territories south of the Rub' al-Khali. The multifunctional aspect of the backed micro-blades may be interpreted as a specific adaptation to an increasingly mobile population, which was forced to increase their range of action due to the adverse climatic conditions during the younger half of MIS 3. While the current archaeological data for South Arabia impede weighing the local development of these technical elements, by which we mean backing technology and associated complex multi-component equipment, versus their introduction by a highly mobile and arid-adapted population from outside of southern Arabia. Whatever the case, the Mutafah 1 data adds a direly needed layer of information to a complex development of human prehistory. Incidentally additional research on the subject and particularly more sites from the MIS 3 and 2 are required to further elaborate on the nature of human subsistence technologies of the South Arabian Upper Palaeolithic.

From a paleoclimatic point of view continuous records are still lacking for the Last Glacial and the Holocene and the existing records comprise still a patchwork of different archives from speleothems (Fleitmann et al. 2011; Nicholson et al. 2020), fluvio-lacustrine deposits (Hoffmann et al. 2015) and marine records (Schulz et al. 1998). In the modern-day desert climate of Oman it seems perceivable that prolonged pluvial phases would be required to facilitate human migration. This might however be in part oversimplistic, as already in the modern desert environment, suitable sites for human persistence occur in a mosaic like shape offering connectivity, for instance in the form of adjacent wadis hosting strong karstic springs along the Hadramawd and Al Hajar mountains. Cave systems in the Dhofar area and in the Hajar mountains host large deposits of inactive speleothems, that herald pluvial periods, of which most still require radiometric dating and geochemical analyses. The MIS 3 comprises a strong climatic variability from Dansgaard-Oeschger cycles and shorter-term variability, which may indicate repeated "windows of opportunity" for human dispersal. Along this line Hoffman et al. (2015) reported fluvial episodes from a rock-fall dammed lake in Wadi Mistal in the Hajar mountains for the earlier half of MIS 3. The fine-grained sediments there were OSL dated to between 55 and 40 ka BP, spanning a 5 to 15 ka long record, with a 50 to 150 years recurrence rate of major pluvial events. The latter may indicate repeated northward shifts of the Inner Tropical Convergence Zone (ITCZ). Based on marine and ice-core records the second half of MIS 3 with the 30 ka archaeological material from Mutafah 1, may have seen overall similar conditions. Southern Oman, with the sites in Dhofar were likely also during MIS 3 more prone to receive pluvial events. From this point of view the wadi systems in the Hadramawd area in Yemen were probably at least seasonally active during northern hemisphere summer, facilitating human presence.

Conclusion

Paleoanthropological and genetic research have demonstrated how a series of human population diffusion, admixture and retracting events occurred throughout the Quaternary from Africa into Arabia (and back) leading to a complex archaeological record (Černý et al. 2016; Gandini et al. 2016; Hilbert et al. 2018; Musilová et al. 2011). That Arabia played an important role in contributing to the understanding prehistoric human environmental interactions has been evident since the earliest explorations of the Arabian Peninsula (Tosi 1986; Zarins 1990). Geography, climate and biodiversity are major agents responsible for human cultural and behavioural diversity, as well as demographic variability. These factors deeply affect subsistence strategies, which in turn govern human mobility, resource exploitation patterns and ultimately lead to the survival of populations. Diachronic variability in Palaeolithic tool kits may be seen as an example of the wide range and plasticity of survival strategies developed by our ancestors to cope with specific challenges and constrains. Although additional research on larger samples remains to be conducted once found and excavated, the analysis of the Mutafah 1 bi-pointed backed micro-blades indicates that these tools were used in cutting and piercing activities and possibly as projectile heads. These activities are associated with subsistence practices and represent general human adaptations that cannot be associated with any specific type of landscape or climate. Thus, environmental deterministic associations between arid phases and presence/absence of human occupation fail to accommodate the cultural variability expressed by the still limited Upper Palaeolithic archaeological record of South Arabia.

Funding: YHH is grateful for the financial support for the International Foundation for the Study of Arabian (IFSA) in the form of a Research Grant as well as 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?'.

Acknowledgements: We thank Sultan al-Bakri, Khamis Al-Asmi, Khalid al Nadabi and Said al Jadidi of the Ministry of heritage and tourism of the Sultanate of Oman for making the traceological analyse of the Mutafah 1 assemblage possible. We are in depth to Dr. George Nash and Dr. Radu Iovita for proofreading our article and providing important feedback. We are grateful for the comments of two anonymous reviewers that greatly enhanced the scientific quality of our manuscript. This is CNR-ISMAR Bologna scientific publication n. 2059.

Contributor roles: Conceptualization. YHH, ICC, MLC, NF, CM; Data Curation YHH, ICC, MLC, NF, CM; Formal analysis – YHH, ICC, MLC, NF, CM; Funding acquisition – YHH, MLC, CM.; Investigation – YHH, ICC, MLC, NF, CM; Methodology – YHH, ICC, MLC, NF, CM; Project administration – YHH; Resources – YHH, ICC, MLC, NF, CM; Supervision YHH, ICC, MLC, CM; Validation – YHH, ICC, MLC, NF, CM; Visualization – YHH, ICC, NF; Writing – original draft – YHH and MLC; Writing – review & editing YHH and MLC

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