Journal of Archaeological Science: Reports 65 (2025) 105197

Contents lists available at ScienceDirect

Journal of Archaeological Science: Reports

journal homepage: www.elsevier.com/locate/jasrep

Use-wear analyses of macro-lithic artefacts from the Early Bronze Age site of Dhaskalio, central Aegean, unveil their use as tools for metalworking☆

Diego Capra[a,b,*], Isabella Caricola[c], Giulio Lucarini[d,g], Giuseppina Mutri[e,f,g], Myrto Georgakopoulou[h], Michael J. Boyd[h,i,j], Evi Margaritis[h], Colin Renfrew[i]

[a] Universitat Rovira i Virgili (URV), Departament d'Història i Història de l'Art, Avinguda de Catalunya 35, 43002 Tarragona, Spain
[b] Institut Català de Paleoecologia Humana i Evolució Social (IPHES-CERCA), Zona Educacional 4, Campus Sescelades URV (Edifici W3), 43007 Tarragona, Spain
[c] Zinman Institute of Archaeology, Haifa, Israel
[d] National Research Council of Italy, Institute of Heritage Science (CNR-ISPC), Rome, Italy
[e] Università degli Studi di Firenze, Dipartimento di Storia, Archeologia, Geografia, Arte e Spettacolo (SAGAS), Florence, Italy
[f] University of Connecticut, Department of Anthropology, Lab of Deep History, Mansfield,CT,USA
[g] The International Association for Mediterranean and Oriental Studies, Rome, Italy
[h] Science and Technology in Archaeology and Culture Research Center, The Cyprus Institute, Nicosia, Cyprus
[i] McDonald Institute for Archaeological Research, University of Cambridge, UK
[j] British School at Athens, Greece

A R T I C L E I N F O

Keywords:
Dhaskalio
Macro-lithic tools
Metalworking
Use-wear analysis
pXRF analysis

A B S T R A C T

The site of Dhaskalio is located on an islet at the western end of the island of Keros in the central Aegean. Excavations brought to light the remains of an extended building complex on Dhaskalio and a ritual centre in the Kavos area of Keros, dated to the Early Bronze Age (EBA), ca. 2750–2250 BCE. Finds on Dhaskalio include an abundant assemblage of macro-lithic tools. Use-wear analysis allows us to define them as grinding, casting, hammering and abrading or polishing tools. The preliminary results of an ongoing use-wear study combining low and high-power approaches suggest that the examined items were utilised in different phases of metal object manufacture. Additionally, lead residues have been found using X-ray fluorescence spectroscopy (pXRF) analysis on a grinding slab. Our research provides preliminary results concerning this craft activity undertaken at Dhaskalio, supporting the hypothesis that the site may have acted as a centre for specialised artisans within a broad regional network.

1. Introduction

The earliest evidence of metallurgical production in Greece, dating to the 5th millennium BCE, has been found at a number of northern settlements such as Promachon-Topolnica, Sitagroi or Dikili Tash (Zachos, 2007) and is considered a phenomenon connected to the Balkan region (Radivojević et al., 2010; Radivojević and Rehren, 2016); copper objects were distributed widely in Greece in the Neolithic (Zachos, 2007). It is attested in the northern Aegean during the Early Bronze Age at Thassos (Nerantzis et al., 2016), whereas, in the southern Aegean at Kephala, it is dated to the Final Neolithic (Coleman, 1977: pp. 3-4).

So far, only Early Bronze Age mining and smelting sites have been investigated in the western Cycladic islands of Siphnos (Wagner and Weisgerber 1985), Kythnos (Bassiakos and Philaniotou, 2007) and Seriphos (Georgakopoulou et al., 2011); for a comprehensive overview of metal production during the Early Bronze Age, refer to Georgakopoulou (2016) and the references therein. The archaeological studies highlighted a similar pattern of spatial organisation of sites consisting of settlements located far from ore sources (Broodbank, 1993; Nakou, 1995), supporting the hypothesis that large-scale metal production was performed close to sources (Georgakopoulou, 2007); however, there are important exceptions to this (Catapotis, 2007); not least Kavos and Dhaskalio themselves (Ioannidis et al., in press). Keros (Fig. 1) stands out as one of these locations, presenting a unique opportunity to delve into the primary and secondary phases of metal processes in a settlement located next to a smelting area during the Early Bronze Age in the central Cyclades (Georgakopoulou, 2023).

☆ This article is part of a special issue entitled: 'Proceedings of ICAS-EMME 4' published in Journal of Archaeological Science: Reports.

* Corresponding author at: E. Montale street 2, Castel Mella, 25030, Brescia, Italy.
E-mail address: capra.die@gmail.com (D. Capra).

https://doi.org/10.1016/j.jasrep.2025.105197
Received 31 October 2024; Received in revised form 14 April 2025; Accepted 8 May 2025
Available online 22 May 2025

Fig. 1. Map showing the location of Keros in the central Aegean.

The set of stone items analysed for this study is part of an ongoing use-wear research project that attempts to detect possible craft or daily activities at the site of Dhaskalio, where a rich macro-lithic assemblage has been recovered.

Following the translation of Semenov's (1964) work, several research studies have been carried out to understand the use of macro-lithic tools, also referred to as ground stone tools or non-flaked stones. This category of stone tools includes grinding equipment, pounding, percussive, abrading and polishing stone artefacts involved in craft activities (Adams, 2014; Delgado-Raack, 2008; Dubreuil et al., 2024; Hamon, 2006) along with perforated or worked stones such as weight and stone vessels (Adams, 2014; Stroulia et al. 2022). Macro-lithic tools have been used in different geographic areas from the African Middle Stone Age (Henshilwood et al., 2011) to more recent times (De Angelis and Lemorini, 2024; Kufel-Diakowska et al., 2020; Lucarini et al., 2023). For a comprehensive list of references, see Dubreuil and Savage (2014) and Hayes et al. (2018).

Ethnographic accounts have shown that macro-lithic tool types were utilised in different phases of metallurgical work processes, in addition to other craft activities and foodstuff processing. Grinding devices can be used for crushing and grinding ores (Greener and Ben-Yosef, 2016; Yamasue et al., 2010) or metal slags (David, 1998; Stahl, 2015; Webb, 2015). Stone blocks are commonly used as anvils (Bocoum, 2004: p. 79, Figs. 29 and 30; Haaland, 2004; Stahl, 2015) and pebbles as hammerstones for forging metal objects (Grillo, 2012: p. 235; Haaland, 2004). Furthermore, worked stone slabs (Thiébaux et al., 2016) or natural slabs, stone blocks, or boulders can be used as whetstones for sharpening metal objects such as knives, spears and needles (Delgado-Raack and

Fig. 2. The Dhaskalio islet is located west of Keros island, as shown in the Google Earth image.

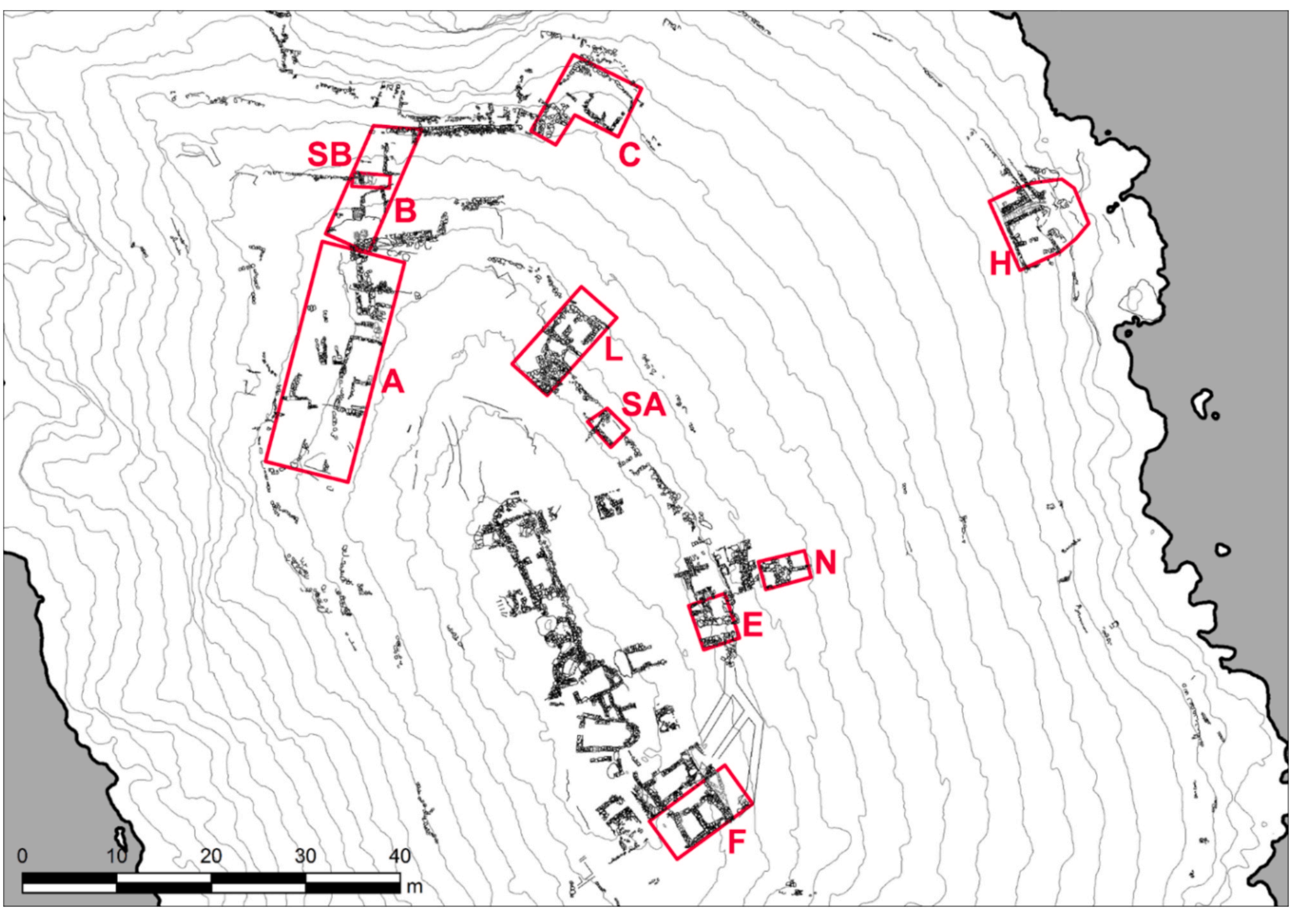

Fig. 3. In red is the location of the trenches excavated in 2016–2018.

Risch, 2008; Fendin, 2006; Grillo, 2012: pp. 235-236); pebbles or cobbles can also be used in this way (Tsegaye, 2019).

The discovery of macro-lithic tools related to the manufacture of metal objects from Bronze Age ritual contexts and hoards (Batora, 2002; Boutoille, 2019; Butler and van der Waals, 1966; Drenth et al., 2016) led to their identification also in residential contexts in different regions of Europe (Belgiorno et al., 2009; Delgado-Raack et al., 2020; Hamon et al., 2020).

Archaeological and experimental works concerning macro-lithic tools utilised in metal production have mainly addressed understanding the primary phase of the metallurgical process. It includes different activities such as mining (Caricola et al., 2020; Dimic, 2019), grinding

Fig. 4. Metal workshop in trench H. It includes two rooms and the drainage system indicated by the black arrow. The yellow arrow indicates the position of one of the hearths.

ores (Abar, 2023; Carey et al., 2023; Hamon et al., 2009; Nodin and Nerantzis, 2024) and smelting (Bassiakos and Philaniotou, 2007; Doonan and Marks, 2021; Nerantzis et al., 2017).

The second phase of the metallurgical process, the production of metal artefacts, is less represented in scientific research. It encompasses casting (Armbruster et al., 2019; Barbieri et al., 2015), forging (Boutoille, 2015; Delgado-Raack et al., 2016; Drenth et al., 2014) and abrading of the surface to remove the irregularities left during the casting (Hamon et al., 2024), as well as surface polishing (Crellin et al., 2023; Hamon et al., 2020) and edge sharpening.

This paper aims to present the results of a use-wear and hand-held X-ray fluorescence spectroscopy (pXRF) analysis of a set of macro-lithic artefacts utilised in different steps of the metallurgical chaîne opératoire at Dhaskalio, from the grinding of ore to the finishing of metal objects.

2. The archaeological context

2.1. The building complex on Dhaskalio

The islet of Dhaskalio (Fig. 2), today located some 90 m west of the western end of Keros, was in the Early Bronze Age a promontory linked to the main island by a causeway which formed a natural harbour (Dixon and Kinnaird, 2013).

Excavations took place on Dhaskalio in 1963 (Doumas, 2013), 2007–2008 (Renfrew et al., 2013) and 2016–2018 (Renfrew et al., 2022). Earlier excavations concentrated on the summit area and revealed densely packed architecture, mainly dating to the final phase of the site (ca. 2400–2250 BCE, Dhaskalio Phase C). Recent excavations on the slopes (Fig. 3), however, have revealed that the architecture extends across the north, east and south part of the promontory with a system of terraces to produce flat spaces for building, and buildings set on those terraces built with marble imported from Naxos. The terracing system dates to the early phase of use of the site (Phase A, 2750–2550 BCE) and was maintained and reused during Phase B (2550–2400 BCE). While a range of activities has been detected on the site, not least metalworking (see further below), domestic activities seem less well represented than might be expected for a settlement (Margaritis et al., 2024), meaning that the purpose of the site appears more specialised than quotidian. This is further borne out by the study of the macro-lithic tool assemblage, where domestic tools seem under-represented.

On Keros itself, north of the zone of the so-called special deposits, on the Kavos Promontory, a place for the smelting of copper ore was located (Georgakopoulou, 2007; 2016), remarkable for the distance of the site from the ore sources in the western Cyclades. Two types of slag from the resulting analyses suggest two processes, one involving pure copper production and the other the production of lead-rich arsenical copper (Georgakopoulou, 2018; Ioannidis et al., in press). One piece of litharge was also noted.

On Dhaskalio, the full spectrum of metalworking processes has been located in several workshops (Fig. 4) and other finds, with the evidence indicating that metalworking was widespread at the site (Renfrew et al., 2022; Georgakopoulou, 2023). Recent research has suggested that smelting may also have taken place on Dhaskalio (Ioannides et al., in press). Workshops seem mainly to have been dedicated to the production of metal artefacts and, perhaps, in the case of a lead workshop, to the repair of pottery. Both open-air and enclosed workshop spaces have been identified, and different processes were used in Phase A and Phase B. Gold and silver working has been identified in addition to copper, lead, and (to a limited extent) tin bronze. Several factors allowed for the identification of workshops, but each workshop also has unique characteristics, related to process (e.g. leadworking in Trench A, and different copper melting process in Trenches L and H) and perhaps to chronology (Phase A for Trench H, and Phase B for Trenches A and L). Common features include significantly enhanced soil chemistry reading for lead, copper and arsenic (a comprehensive soil chemistry programme including sampling of all excavated contexts: Boyd et al., 2021), installations and tools (Trench H), and significant concentrations of metallurgical ceramics (Trench L).

A hoard of stone tools under a pithos found in the metal workshop

Table 1
Summary table of the analysed macro-lithic artefacts from Trench A, B, H and N. L = length; W = width; T = thickness and We = weight. The symbol > indicates the actual measurements of a broken item.

ID and Raw material	TRENCH, PHASE and CONTEXT	TOOLS TYPE	SHAPE	LONGITUDINAL and TRANSVERSAL SECTION	ACTIVE SURFACES SHAPE	L (cm)	W (cm)	T (cm)	We (gr)
SF 1675 Mica-schist	A B Occupation	Grinding slab	Sub-rectangular	Slightly biconcave and bi-plano	S1 slightly concave S2 slightly concave	>175	158	37.9	>1699
SF 1499 Hematite	A B Natural erosion or deposit	Multiple-use tool (anvil and hammer-stone	Irregular	Wedge and irregular-irregular	S1 irregular S2 irregular S5 irregular S6 irregular	160	120	104	3413
SF 12,002 Marble	A B Collapse	Multiple-use tool (whetstone and anvil)	Sub-rectangular	Bi-plano and bi-plano	S1 flat S2 flat	183	86	40	1211
SF 2123 Kouphonisi limestone	B Uncertain Natural erosion or deposit	Multiple-use tool (polisher and pestle)	Sub-rectangular	Bi-plano and plano-convex	S1flat S2 flat S6 Flat	125	58	41	460
SF 4860 Amphibolite	H B III-C	Multiple-use tool (hammer and pecking tool)	Irregular	Convex-slightly convex and plano-convex	S5 convex S6 flat	103.3	69.3	53.4	585
SF 4885 Emery	H Uncertain Uncertain	Multiple-use tool (hammer and polisher or abrader	Sub-rectangular	Slightly bi-convex and slightly bi-convex	S1 Slightly convex S2 Slightly convex S3 Slightly convex S5 flat S6 convex	115	54	33	512
SF 4925 Marble	H B	Anvil	Sub-oval	Bi-plano and bi-plano	S1 flat S2 flat	>115	127	41	>1209
SF 16,059 Hematite	H Uncertain A I-B	Handstone (Polisher)	Irregular	Bi-plano and bi-plano	S1 flat S2 unidentifiable S3 flat S6 flat	87	78	24	>391
SF 16,061 Uncertain hornfels	H Uncertain A I-B	Multiple-use tool (polisher and pecking tool)	Irregular	Plano-convex and plano-convex	S1 flat S2 convex S3 flat S4 irregular S5 irregular S6 convex	>78	56	44	>207
SF 16,131 Uncertain hornfels	H Uncertain A I-D	Handstone (polisher)	Sub-square	Wedge Bi-plano	S1 flat	49	48	31	113

unearthed in Trench H room 1 (Supplementary materials, Fig. 1) includes a two-sided mould (Supplementary materials, Fig. 2) for spear-head points and perhaps small chisels (or ingots), two pestles, four grinders, two stone discs, two other worked stones, pumice, a complete conch shell and an intact spherical pyxis (Renfrew et al., 2022). Elsewhere, two moulds, SF 1639 and SF 5713, come from trenches A and L. These latter are valves of bi-valve moulds used in dagger production (Supplementary materials, Fig. 3).

3. Material and methods

3.1. Macro-lithic items and their classification

The description of macro use-wear for macro-lithic tools follows Adams et al. (2009) in general, with a modification, and de la Torre and Mora (2009–2010) for hammerstones. The modification entails the use of the term “homogenous surface” for the description of an active face showing the complete levelling of the surface, similar to the “homogenous zone” proposed by Adams et al. (2009) for large levelled areas.

The terminology employed in this paper for the techno-typological description of macro-lithic tools was based on the classification proposed by Adams (2014) and Wright (1992). The stone artefacts studied for this work include passive and active tools. Among the passive tools, there is a grinding slab (SF 1675) and an anvil (SF 4925), whereas among the second group, there are two handstones used as polishers (SF 16,059 and SF 16131), and six multiple-use tools (SF 1499, SF 2123, SF 4860, SF 4885, SF 12002 and SF 16061). They come from Trench A (n = 3), B (n = 1) and H (n = 6). Their main characteristics are summarised in Table 1. The passive stone items were made from mica-schist and marble slabs. In contrast, very fine sedimentary and metamorphic pebbles and cobbles of various shapes and sizes were used as active tools. The raw material classification was based on the prior study of Dhaskalio macro-lithic tools from 2007 to 08, which demonstrated that most stone artefacts were made from non-local rocks (Rowan et al., 2013).

3.2. Cleaning and procedure for use-wear analysis

Before processing for use-wear analysis, stone artefacts were cleaned by gently brushing their surfaces with a soft toothbrush using water and dish detergent. After the first cleaning, they were rinsed for about two minutes with tap water to remove any possible detergent residue and were left to dry. The macro use-wear observation was carried out using the naked eye and a Dino-Lite USB microscope with extended depth of field (EDOF) and external polarised light ranging from 20x to 50x. Macro use-wear was photographed with a Canon EOS 750D camera, a macro lens EF 100 mm f/2.8L IS, lens Case LP1219 and lens Hood ET-73. Macro-use wear was described using the terminology known in the literature (Adams et al., 2009; Dubreuil et al., 2015). After macro-use wear analysis, pure acetone 99 % was applied with another soft toothbrush to remove any modern finger contamination (Dubreuil et al., 2015; Pedergnana et al., 2016). Once the acetone had dried, Provil Novo ® Light Fast (Adams et al., 2009; Dubreuil et al., 2015) was applied with a Kulzer dispensing gun directly on the area of the stone artefact surface showing macro use-wear. After ten minutes, the mould was removed

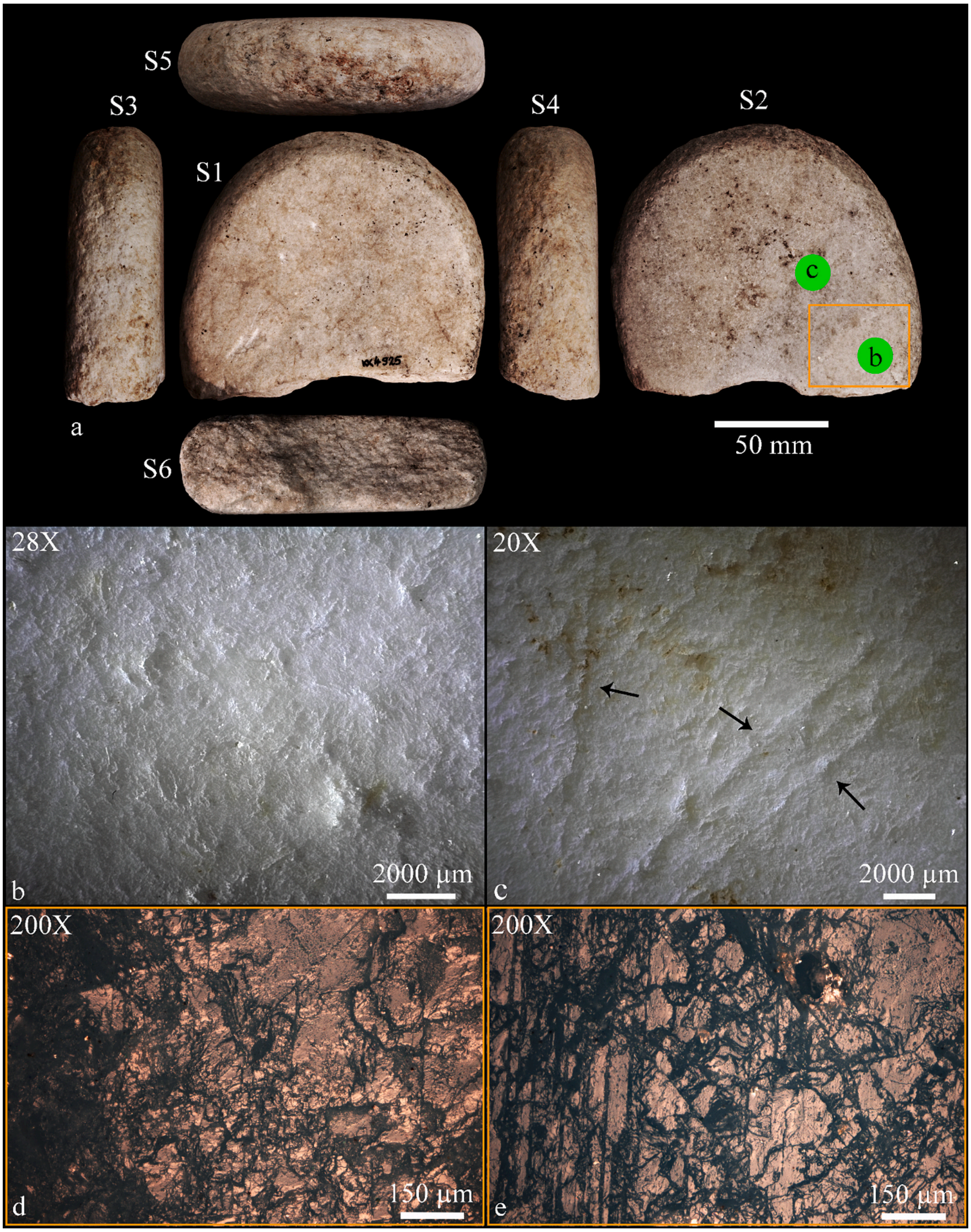

Fig. 5. SF 4925, marble anvil: a) general view of the stone artefact, b) highly levelled homogeneous surface, c) highly levelled homogeneous surface associated with longitudinal and oblique parallel long scratches indicated by black arrows and d) micro traces on crystals (i.e., micro-polishes on the top of the crystals (d)); orientated deep striae (e). The micro traces have been observed on S2.

and put in a zipped plastic bag, ensuring the cleanliness and integrity of the mould for the analysis. High magnification analyses of the Provil Novo ® Light Fast moulds were carried out at the Cyprus Institute in Nicosia, the Zinman Institute of Archaeology in Haifa and the Institut Català de Paleoecologia Humana I Evolució Social (IPHES-CERCA) in Tarragona. The moulds were examined at high magnification, ranging from 50x to 500x, employing several microscopes, including a Zeiss Axio Imager 2 polarised light microscope in Nicosia, a Leica DM1750 metallographic microscope in reflected light in Haifa, and a Zeiss Axioscope A1 reflected light metallographic microscope in Tarragona. Helicon Focus 8.0 stacking software was used to obtain focused images. Micro-wear descriptions followed the terminology generally used (Adams et al., 2009; Dubreuil et al., 2015; Caricola et al., 2020). The functional interpretations of the stone artefacts were based on experimental hammering and polishing of a copper wire performed by one of the authors, a reference collection (Caricola, 2017) and recently published research studies (Crellin et al., 2023; Delgado-Raack et al., 2016, 2020; Hamon et al., 2020, 2024; Muller et al., 2023).

3.3. X-ray fluorescence spectrometry analysis

Previous studies have shown that X-ray fluorescence (XRF) spectrometry can detect tin, copper, gold and silver residues (Carey et al., 2023; Delgado-Raack et al., 2016; Hamon et al., 2009, 2020; Muller et al., 2023). In an attempt to identify the potential concentration and distribution of elements such as copper, gold, silver and lead that could

Table 2
Summary table of the analysed macro-lithic artefacts from Trench A, B, and H indicating the types of macro- and micro-traces and their interpretation.

ID Raw material	Tool types	Naked-eyed and Dino-Lite macro-use wear	Micro-polish and striation description	Use interpretation
SF 4925 Marble (Fig. 6)	Anvil	S1 highly levelled and moderately polished homogenous surface; S2 highly levelled and moderately polished homogenous surface associated with concentrated close pits in the centre and loose separated oblique transversal short and long superficial scratches; S3, S4 and S5 covering close deep pecking pits.	S2 very high density; very high development; very high reflectiveness; bi-directionality. The micro-polish is associated with bidirectional micro-striations.	S2 passive forging tool for metal objects or foil.
SF 1499 Hematite (Supplementary materials Fig. 4)	Multiple-use tool (anvil and hammerstone)	S1 and S2 covering close, random, short superficial striations; S5 concentrated separated random short superficial striations in the centre and concentrated connected superficial and deep battering pits associated with fracture angles close to S3; S6 concentrated connected superficial and deep battering pits.	S1 very high density; high reflectiveness; highly developed micro-polish associated with parallel longitudinal and oblique deep micro-striations	S1 passive forging tool for metal objects or foil.
SF 4860 Amphibolite (Fig. 6)	Multiple-use tool (hammer and pecking tool)	S5 concentrated connected superficial pits; S6 highly levelled and moderately reflective polished central homogenous surface associated with covering close random short superficial striations and concentrated connected superficial and deep battering pits surrounding the polished surface.	S6 very high density; very high reflectiveness; unidirectional and differently oriented polishing band associated with concentrated loose parallel short micro-striations following the same direction of the polish	S6 Possible forging metal foil.
SF 12,002 Marble (Fig. 7)	Multiple-use tool (whetstone and anvil)	S1 highly levelled homogenous surface associated with concentrated close parallel longitudinal long deep scratches; S2 moderately smoothed homogenous surface associated with covering close superficial and deep pits.	S1 high density; highly reflective polishing bands associated with short and long micro-striations.	S1 abrading metal objects.
SF 2123 Kouphonisi limestone (Fig. 8)	Multiple-use tool (abrader and pounding tool)	S1 slightly polished homogenous surface associated with concentrated close parallel transversal short deep scratches close to S3 and S5; S2 concentrated close parallel transversal short deep scratches close to S4; S6 covering close deep pits and fracture angles.	S1 medium density; long micro-striations with various orientations can be observed on crystals. S2 highly reflective polishing bands associated with parallel oblique short and long micro-striations.	S1 and S2 abrading metal objects.
SF 4885 Emery (Supplementary materials Fig. 5)	Multiple-use tool (hammer and polisher or abrader	S1 highly reflective polished sub-oval homogenous zone measuring 68x35 mm associated with loose close transversal random short superficial striations; S2 slightly reflective polished central homogenous zone, measuring 88x43 mm, associated with concentrated close superficial pits and loose close transversal random short superficial striations; S3 concentrated connected superficial pits; S5 and S6 covering connected superficial and deep battering pits and concentrated connected moderately levelled and slightly reflective polished surface asperities in the central part.	S1 low density; medium development; medium reflectiveness and bidirectional. The micro-polish is associated with bidirectional striations.	S1 polishing or abrading and hammering metal objects.
SF 16,059 Hematite (Supplementary materials Fig. 8)	Handstone (polisher)	S1 and S2 highly reflective polished homogenous surfaces associated with covering separated random superficial striations; S3 highly levelled and reflective polished homogenous surface associated with covering close parallel longitudinal long superficial striations; S6 highly levelled and reflective polished homogenous surface associated with covering close oblique parallel transversal short and long superficial striations.	S3 low density; medium development; medium reflectiveness and bidirectional. The micro-polish is associated with bidirectional micro-striations and micro-pitting.	S3 and S6 polishing metal objects.
SF 16,061 hornfels (Fig. 9)	Multiple-use tool (polisher and pecking tool)	S1, S2 and S3 slightly reflective polished homogenous surfaces associated with covering close random short superficial striations; S2 also shows flake scars removed from S5; S4 concentrated connected superficial pits and fracture angles and covering close random short superficial striations; S5 shows covering connected superficial and deep battering pits associated with fracture angles and flake scars;	S4 low density; medium development; medium reflectiveness and bidirectional. The micro-polish is associated with bidirectional micro-striations and micro-pitting	S4 polishing metal objects.

(*continued on next page*)

Table 2 (*continued*)

ID Raw material	Tool types	Naked-eyed and Dino-Lite macro-use wear	Micro-polish and striation description	Use interpretation
		S6 concentrated connected superficial and deep pits.		
SF 16,131 Hornfels	Handstone (polisher)	S1 slightly reflective polished homogenous zone in the centre associated with covering loose random short superficial striations.	S1 low density; medium development; medium reflectiveness and bidirectional. The micro-polish is associated with bidirectional micro-striations and micro-pitting	S1 polishing metal objects.

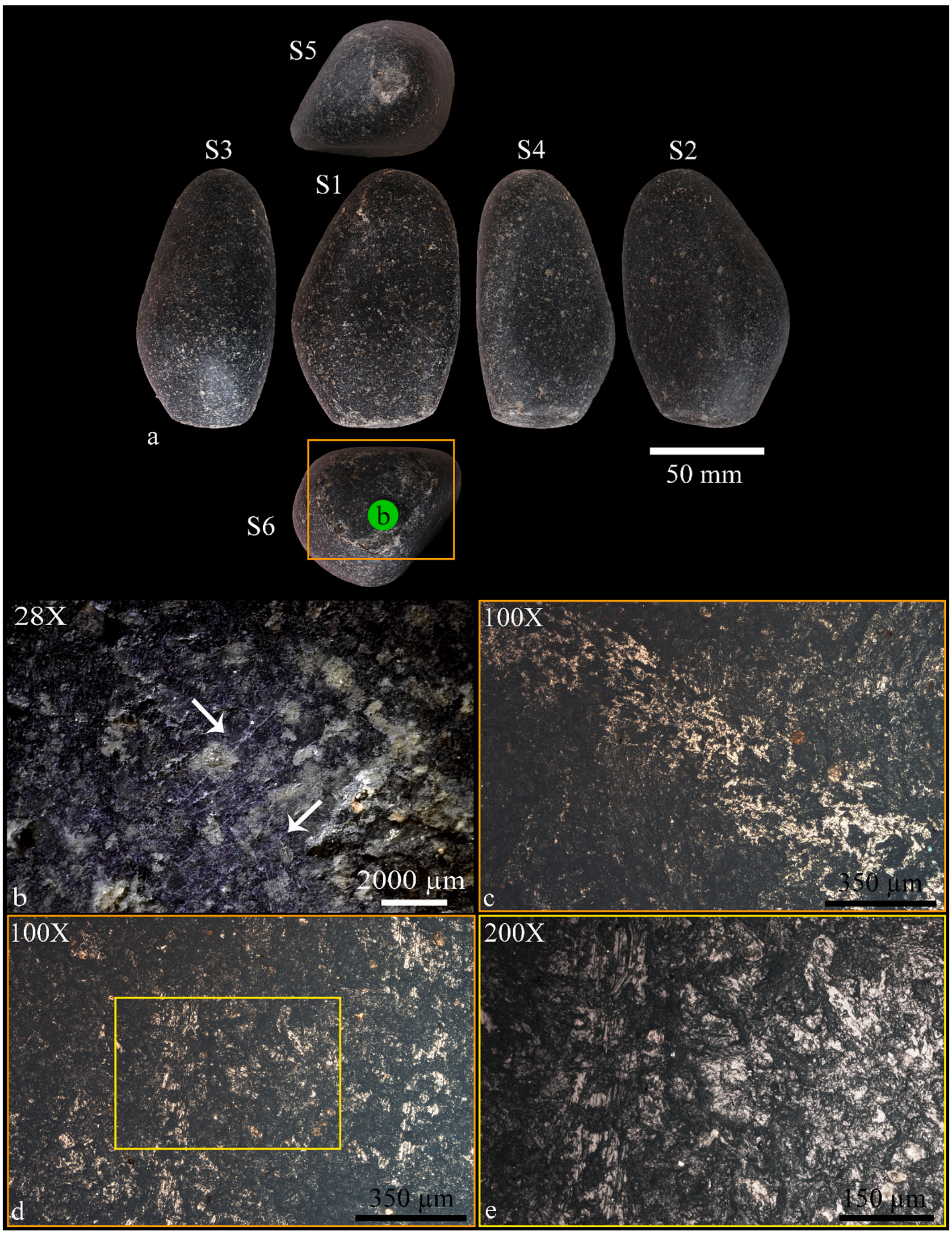

Fig. 6. SF 4860, amphibolite multiple-use tool: a) general view of the stone artefact; b) highly levelled and moderately reflective polished homogenous surface associated with covering close random short striations surrounded by concentrated connected superficial and deep impact pits; c) unidirectional highly reflective polishing band associated with concentrated loose parallel short striations following the same direction of the polish; d) differently oriented highly reflective polishing bands associated with short and long parallel striations following the direction of the polishes and e) detail of d. White arrows indicate striations.

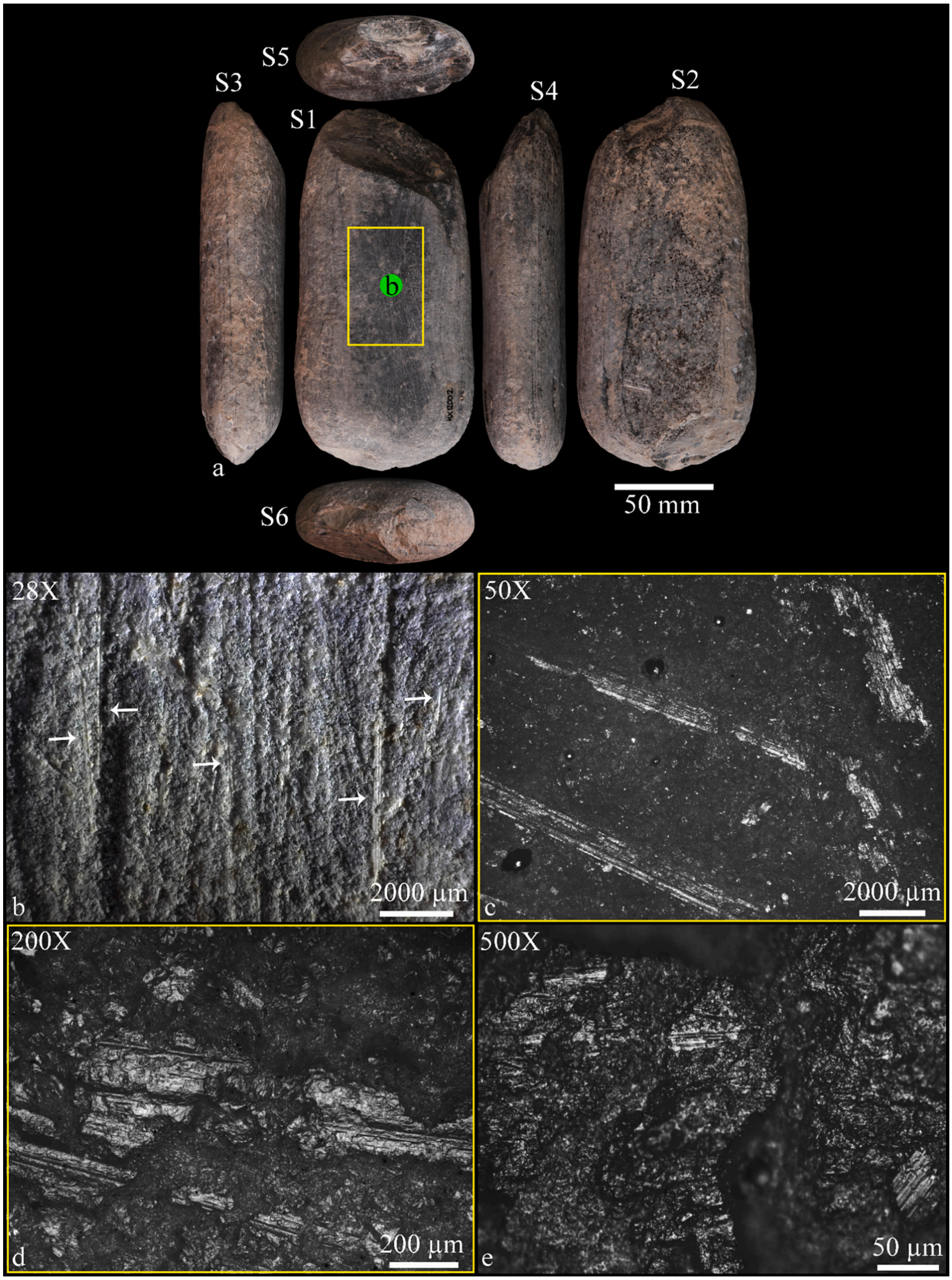

Fig. 7. SF 12002, marble multiple-use tool: a) general view of the stone artefact; b) highly levelled homogenous surface associated with covering close parallel longitudinal long scratches and concentrated close parallel longitudinal short striations indicated by the white arrows; c-d) differently oriented highly reflective polishing bands associated with short and long parallel striations on S1 and e) image of modern experimental abrading of a bronze knife with a sandstone slab, showing highly reflective polishing bands with varying orientations, associated with short parallel striations.

suggest the use of stone artefacts in different stages of the *chaîne opératoire* for metal processing, a preliminary pXRF analysis was performed using a Hitachi handheld instrument using the Mining Method. After the stone items were cleaned, two points were taken on the used and non-used surfaces. The time per reading was 30 s, whilst the voltage of the two successive phases of the Mining Method was 45 kV and 8 kV.

4. Results of use-wear and pXRF analysis

4.1. Macro and micro-use wear

Based on macroscopic observation, a fragmented marble anvil (SF 4925) shows preparation traces such as pecked edges and intentional high levelling of surfaces characterised by regular relief (Fig. 5). Adhesive wear occurs on a lower grinding slab (SF 1675). The other stone artefacts are unmodified waterworn pebbles and cobbles exhibiting

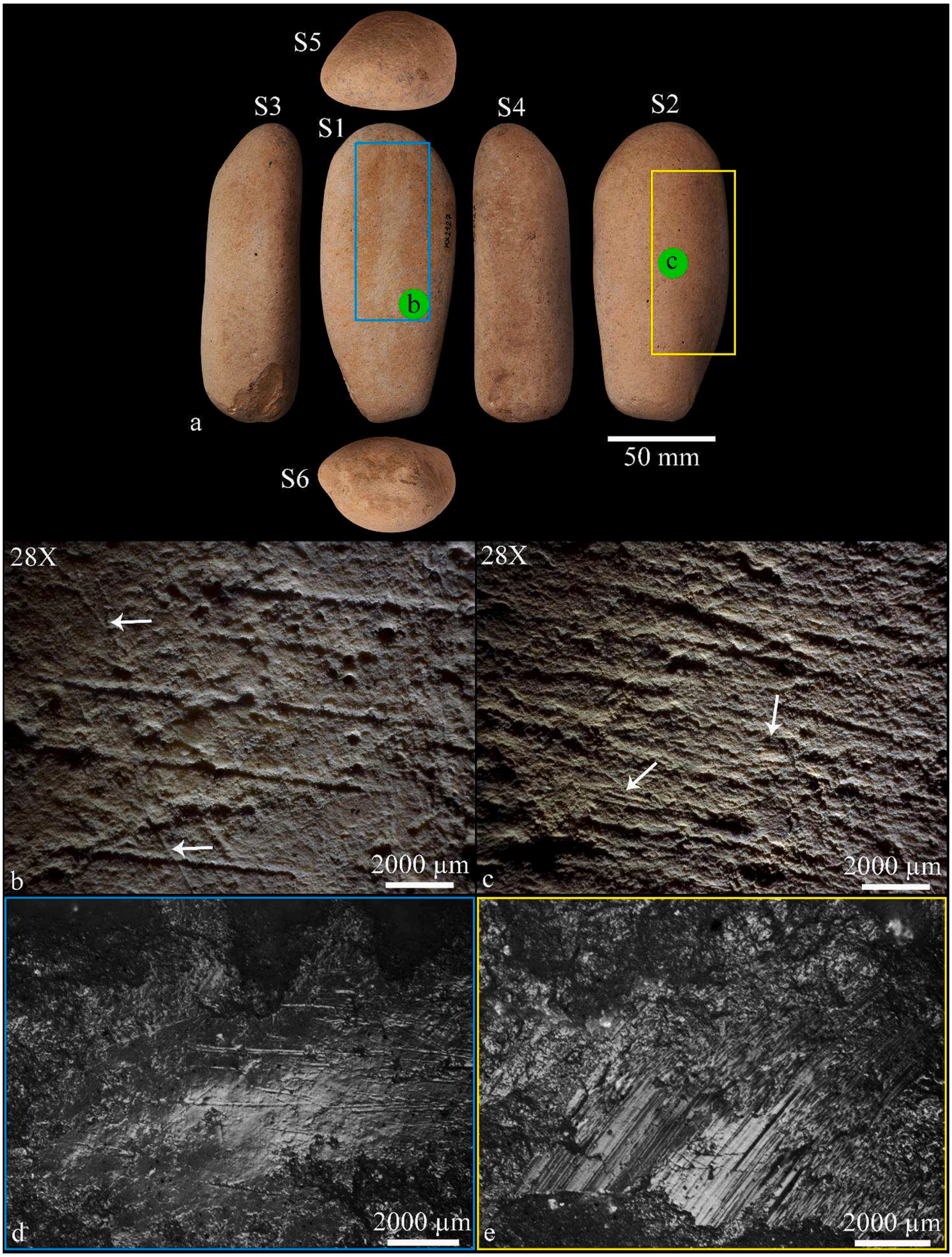

Fig. 8. SF 2123, Kouphonisi limestone multiple-use tool: a) general view of all the stone artefact surfaces; b) concentrated close parallel transversal short scratches and differently oriented, separated loose superficial short striations on S2; c) covering close parallel transversal deep short scratches and separated loose short superficial striations; d) differently oriented short and long parallel superficial striations observed on levelled crystals of S1 and e) highly reflective polishing band associated with parallel oblique short superficial striations on S2. White arrows indicate striations.

fatigue wear (pits and fracture angles) and abrasion wear (levelling, striations and scratches), resulting in a significant modification of the used surfaces (SF 4860 and SF 16059). Six stone tools combine different macro use-wear traces, suggesting they were used or reused to accomplish different or complementary activities.

Based on microscopic observation, all the stone items analysed show tribochemical wear (polish and sheen). The description of the macro- and micro-traces is summarised in Table 2.

The working of different metals or different actions on a metal object can also be inferred from the forging tools, as shown by a levelled and polished end (S6) of a hammer (SF 4860) and the ends of one multiple-use tool (SF 4885) used as a hammer (S5 and S6) and a polisher (S1).

The type of active surface noted on SF 4860, probably prepared before its use, and the use-wear traces allow us to interpret it as an active forging stone tool, possibly used for soft metal foil, potentially gold or silver. Muller and colleagues created a similar, even if smaller, flattened and levelled end surface for experimental gold nugget hammering in gold foil manufacture (Muller et al., 2023). In contrast, both ends of SF 4885 (Supplementary materials, Fig. 5) show covering connected superficial and deep impact pits derived from hammering harder metal

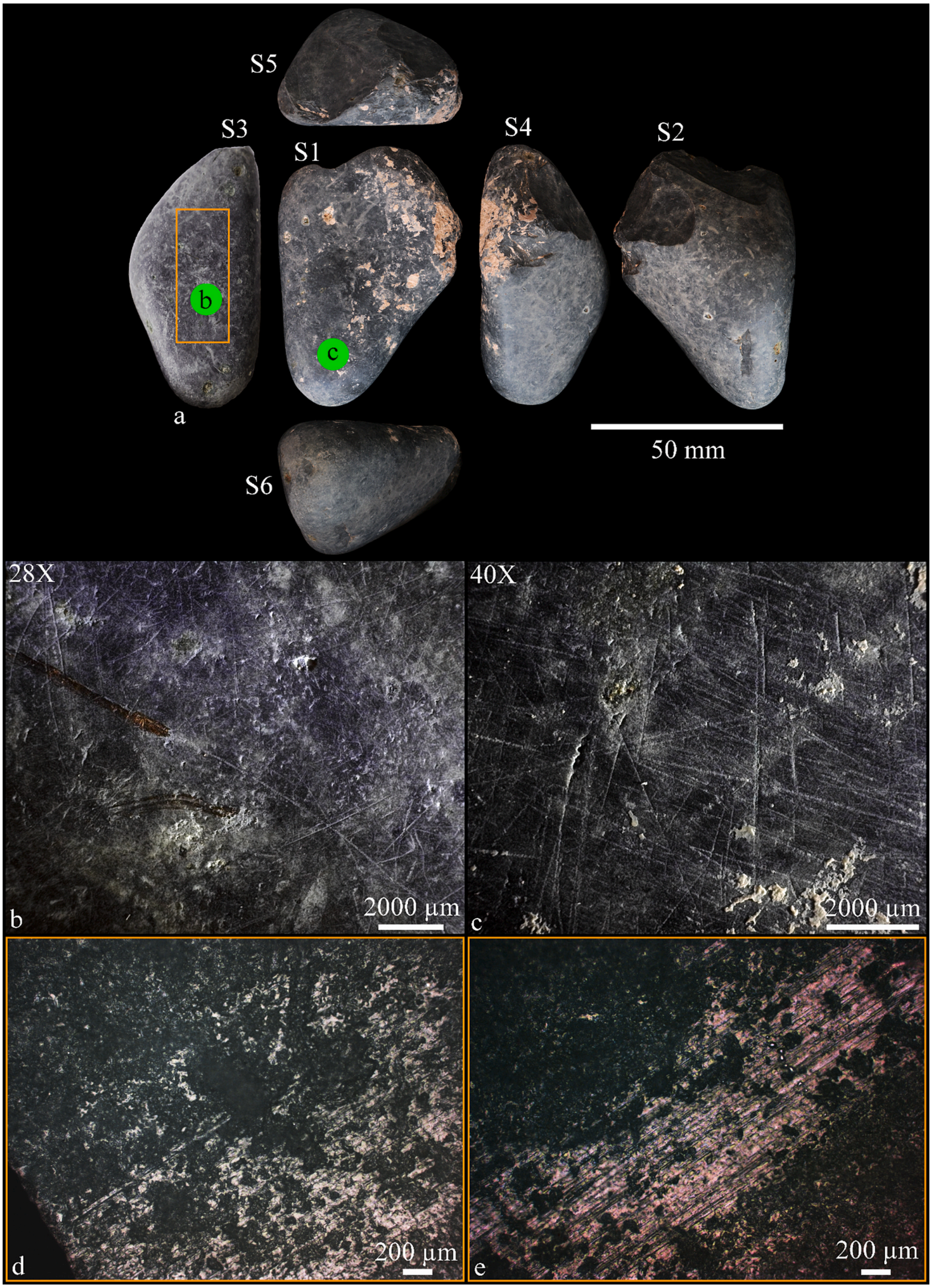

Fig. 9. SF 16061. Hornfels multiple-use tool: a) general view of all the stone artefact surfaces; b) covering close random short and long striations on S3; c) covering close random long striations on S1 and d-e) rough micro-polish associated with bidirectional micro-striations and micro-pitting.

objects, such as copper, as demonstrated by experimental limestone and amphibolite (Supplementary materials, Fig. 6) hammers used for flattening a copper wire and by comparing our results with other experimental work (Hamon et al., 2024). Non-compact rough polishing bands associated with parallel micro-striations were recorded on SF 4860.

Polishing the flattened copper wire tip immediately produced a highly reflective surface and concentrated connected longitudinal parallel long superficial striations (Supplementary materials, Fig. 7). These striations are located on the residue left from the limestone hammer that adhered to the surface of the copper wire tip during its hammering. Subsequently, during the copper wire tip polishing, the back-and-forth movement created the striations on the limestone residue bonded on the amphibolite polisher's active surface. Again, Hamon and colleagues observed a similar macro-wear trace on an experimental schist slab used for polishing a copper flat axe (Hamon et al., 2024).

Two types of micro-polish have been identified on the analysed surfaces of active metal working stone artefacts. The first type is a compact polishing band associated with short or long parallel or random

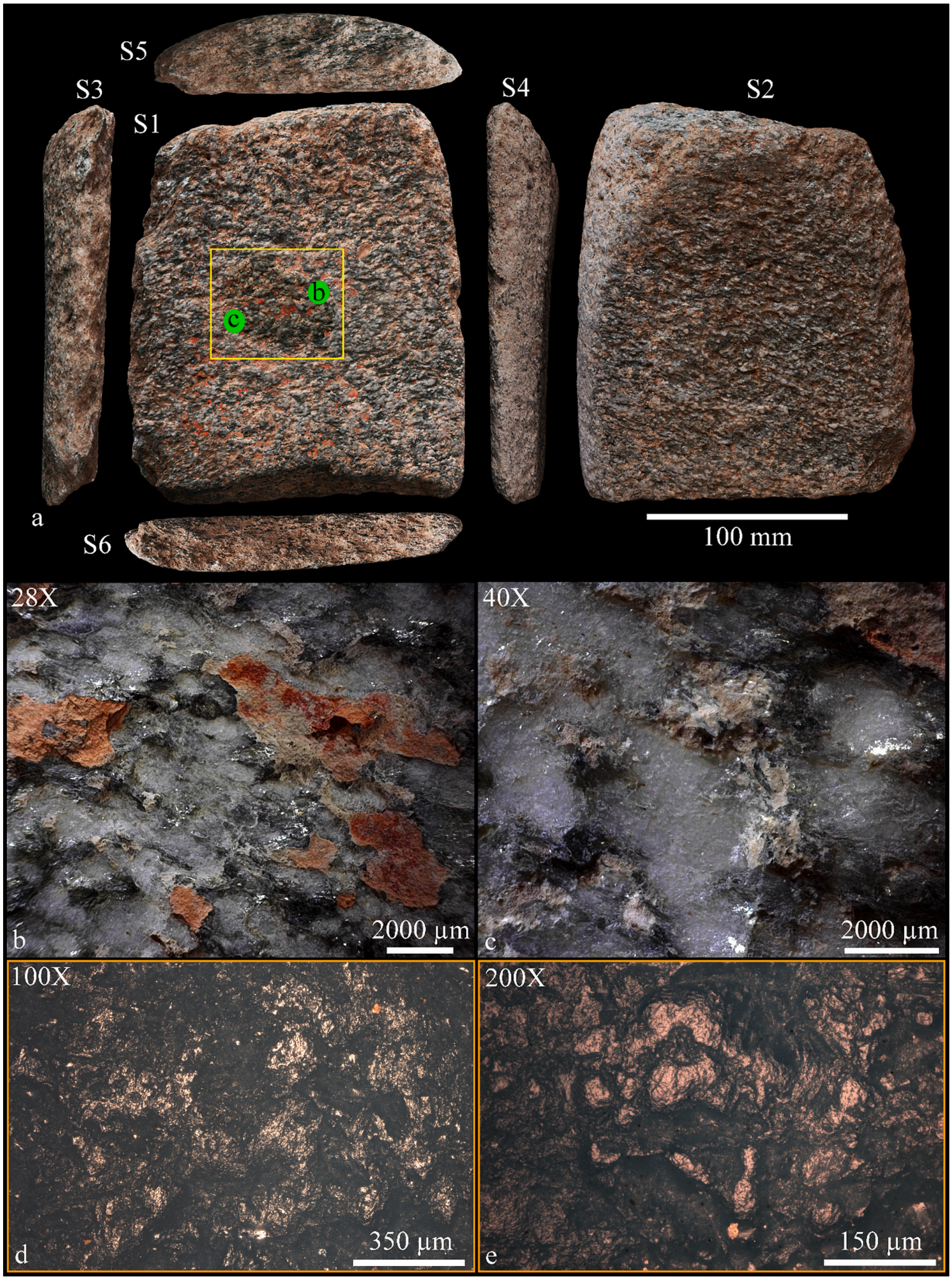

Fig. 10. SF 1675 – Trench A, fragmented mica-schist grinding slab: a) general view of the stone artefact; b) pink residues and grains rounding on S1; c) grains rounding on S1; d) and e) rough to smooth/domed polish developed on the high part of the crystals, medium development, reflectivity and density. Some not-polished striae are also present, with the same directionality of the polish.

striations without micro-pits. This kind of micro-trace has been detected on SF 12002 and SF 2127, allowing us to interpret them as abrading tools. The same use-wear was detected on an experimental sandstone item for abrading a copper blade (Caricola, 2017). The second type consists of a compact, rough and highly reflective micropolish, displaying superficial micro-pits and micro-striations (Hamon et al., 2024), and it has been detected on two polishing tools, SF 16059 (Supplementary materials, Fig. 8) and SF 16061.

Additionally, two stone artefacts from Trench C and Trench N, which are yet to undergo use-wear analyses, are made from waterworn pebbles of basalt and Kouphonisi limestone (Supplementary materials Fig. 9). The basalt multiple-use stone item shows covering close, short, deep and parallel transversal V-shaped in-profile scratches on S3 and S4. The Kouphonisi limestone sharpener exhibits concentrated, close, short, superficial and deep random and parallel transversal U-shaped in-profile scratches on S1-S4. These deep scratches suggest their use in sharpening metal tooltips or edges to prevent their dullness; this hypothesis needs to be confirmed by use-wear analysis.

Passive metalworking stone items show different kinds of surfaces and micro-use wear. In the case of SF 4925, an intentionally

Table 3
Results of the pXRF analysis on the S1 of SF 1625.

Chemical elements	Used surface		Residue		Natural surface	
	1st point	2nd point	1st point	2nd point	1st point	2nd point
Pb	0.83	0.01	12.81	13.11	0.01	–
Ag	–	–	–	0.02	–	–
Cu	–	–	–	–	0.01	–
As	0.02	–	–	–	–	–
Sn	–	–	0.05	0.05	0.02	–
Sb	0.02	0.01	–	–	0.01	–
Zn	0.01	0.01	0.01	–	0.01	0.01
Bi	–	–	–	0.3	–	–
Si	29.23	31.18	24.10	20.27	24.07	29.06
Al	8.32	7.36	5.18	6.13	8.17	7.69
Ca	2.87	2.84	5.20	8.93	8.78	3.51
Fe	2.47	1.97	1.41	1.88	4.30	3.26
K	3.68	3.18	1.34	1.97	3.39	3.95
Mg	1.44	1.40	2.37	2.12	2.37	1.56
Ba	0.10	0.10	0.25	0.25	0.11	0.12
P	0.30	0.20	1.48	1.35	0.16	3.39
Mn	–	–	–	0.07	0.05	–

manufactured anvil, the careful levelling of the asperities of its surfaces required a great deal of investment, suggesting that it may have been used for working precious metal objects, possibly made in gold or silver. Drenth et al. (2014) have stated that this type of preparation would be due to the least possible loss of metal during the processing of metal objects. In contrast, SF 1499, a hematite natural water-worn cobble was has been interpreted as an anvil and hammerstone (Supplementary materials, Fig. 4). Micro-use wear analysis on it revealed a similar pattern of polishing traces and striations found on a stone anvil used for manufacturing gold objects from the Early Bronze Age site of Bruszczewo in Poland (Muller et al., 2023). The analysed stone anvils would suggest working with objects made from different metals, requiring different surface types.

4.2. X-ray fluorescence (XRF) spectroscopy analysis results

The X-ray fluorescence spectroscopy (pXRF) analysis of pink residues filling the topographic lows of one active surface (S1) of SF 1675, a fragmented mica-schist bifacial lower grinding slab (Fig. 10), revealed increased Pb contents compared to the used (S1) and the natural surface indicating it was used for processing lead-related material (Table 3).

Si, Al, Ca, Fe and K are among the main elements present in micaceous schist. Ag can be present within Pb, whereas Cu, Zn, As, Sn, Sb, and Bi can be related to metallurgy in general and have been detected in slags or artefacts from Daskalio and Kavos (Georgakopoulou, 2013, 2018). The remaining elements, such as P, Mn, Ba and Mg, are linked to the composition of the rock.

5. Discussion

Different rock types were used for several tasks with varying kinematics and actions on the material, showcasing their versatility in metalworking. Softer, fine-textured stones such as marble and limestone were used for abrading metal objects (mobile element) and forging (static element). Harder, very fine textured rocks, including emery, hematite and hornfels, were used for polishing (mobile element), while emery and amphibolite were used as handheld hammers (forging mobile element). In one case, a hematite multiple-use tool has been interpreted as both anvil and hammerstone.

The small dimensions of the anvils and the absence of hafting traces on the hammers would suggest their use in the working of pliable metals (Boutoille, 2015) or small objects, such as copper-based needles and fishhooks or lead rivets that have been recovered from the settlement (Georgakopoulou, 2013). Examples of the use of handheld hammers are found in painted tombs in Egypt (Guerra, 2023; Scheel, 1989: pp. 28-31).

The detection of lead residues solely in the topography lows of S1 of SF 1675 and the absence of residues on the analysed spots of the stone items used in the second phase of the metallurgical process would corroborate the results of previous research involving elemental chemical analysis, such as pXRF and EDS (Carey et al., 2023; Delgado-Raack and Risch, 2008; Delgado-Raack et al., 2014; Drenth et al., 2014; Hamon et al., 2009, 2020; Martin, 2014).

These studies demonstrated the rarity of detecting residues of copper, tin, silver, and gold on stone artefacts compared to the number of stone items analysed. However, experimental hammers, abraders (Hamon et al., 2024), and an anvil (Fig. 11) have demonstrated that copper residues rapidly adhere to their surfaces.

According to Hamon et al. (2024) and Boutoille (2015), the disappearance of copper residues is likely to be due to varied taphonomical processes. Another reason is that maintaining the working surface of the stone tool prevents the risk of damaging the worked metal, particularly for gold processing, which can erase residues and micro-use traces (Boutoille, 2015). Furthermore, we observed in our experiment that the copper residues adhered quickly to the active surface of the hammers.

Continuing the thinning of the copper wire, the fatigue wear, in this case impact pitting, removed the adhering copper residues from the hammers' active surface, leaving only a minimal part of the initial residues (Fig. 12).

At this stage of analysis, we cannot exclude the possibility that the macro-lithic tools were multifunctional. More recently developed polishes may have overwritten previous stages of tool usage. However, literature and contextual information suggest contact with metals. The use-wear analysis of this set of macro-lithic tools has permitted us to confirm that in Trench A and H, where metal workshops have been identified based on metallurgical evidence such as furnaces, metallurgical ceramics, soil chemistry and metal slags (Renfrew et al., 2022), the working and finishing of metal objects were also performed. Metalworking at Dhaskalio included the production of daggers, spearheads, and other small objects (Georgakopoulou, 2013; Renfrew et al., 2022).

6. Conclusion

Through the use-wear and preliminary residues pXRF analyses of stone artefacts from Dhaskalio, we were able to investigate the various activities associated with the metallurgical processes carried out at this site. We demonstrated that lead-related material was processed in Trench A, and all the secondary activities of the metallurgical process, including casting, working (hammering and abrading) and finishing (polishing) of metal objects, were accomplished in Trench H.

We provided certain macro and micro-use traces related to metalworking that may be helpful for other researchers. Our work has demonstrated that analysing the use-wear on stone items may offer valuable new insights into their use in metallurgical activities that are otherwise unavailable.

This approach also offers new data on metal crafting. It enhances our understating of the spatial organisation of working areas at Dhaskalio, attesting to the use of stone tools in metallurgical processes within a settlement for the first time in the central Aegean.

While metalworking has been detected in other sites in the Cyclades, no other site has such intense, widespread and varied evidence as Dhaskalio. This has allowed for a detailed study of the worked stone tools used in the metalworking process, as well as a focus on metal artefacts production (rather than on smelting). Other aspects of the metalworking process evidenced at Dhaskalion are still under study (Georgakopoulou 2023; Ioannides et al. in press) but ultimately promise the possibility of understanding the site as a significant production centre operating in the wider region.

The settlement's location within the Cyclades, distant from ore resources, along with its small size and exceptional architectural organisation, and plentiful evidence for far-flung contacts, offers an

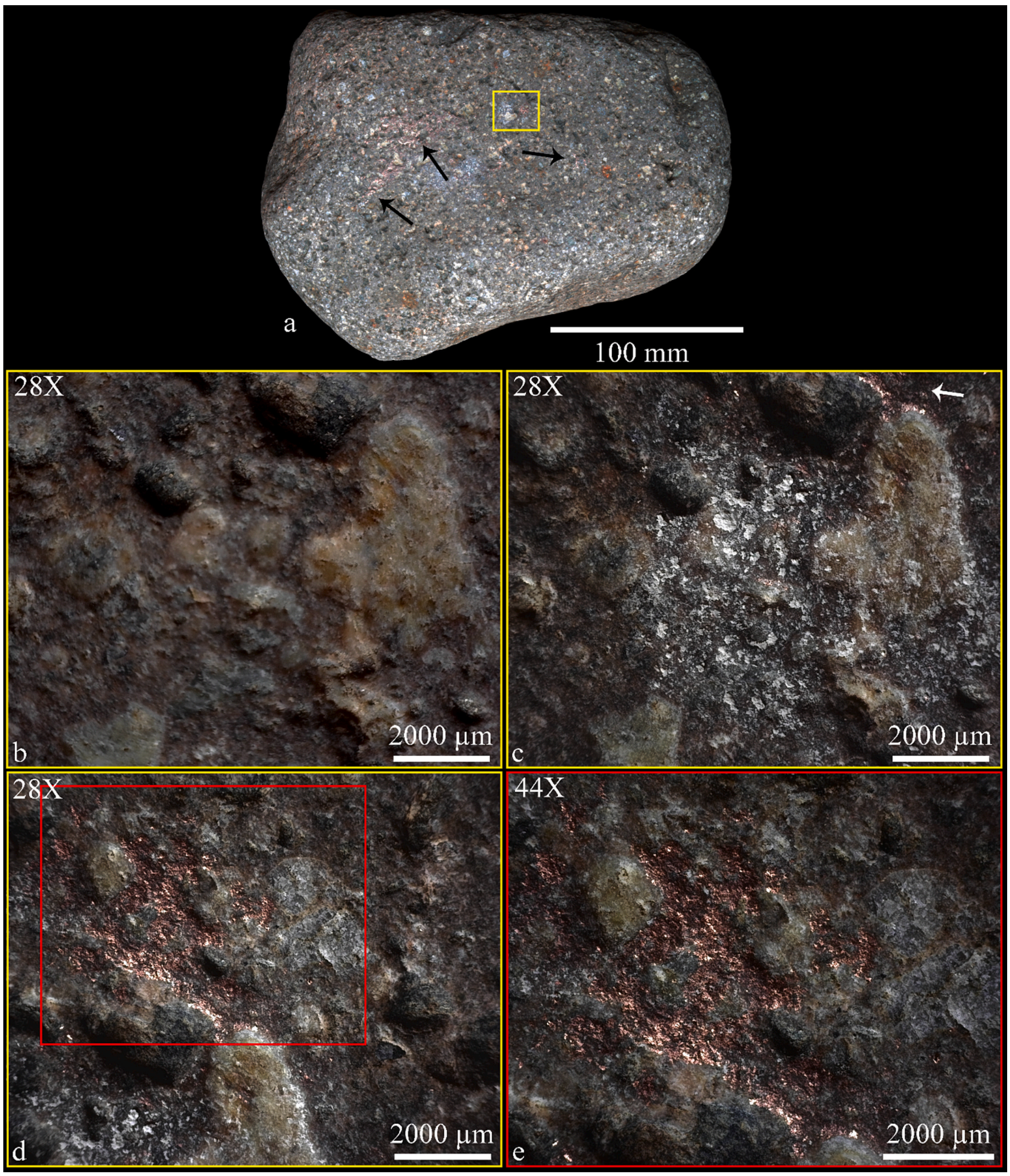

Fig. 11. Experimental effusive rock used as an anvil for flattening a copper wire: a) active surface; b) unused surface; c) same area of b showing residues of limestone hammer and copper residue indicated by the withe arrow, after being used for 5 min; d) copper residue within the red frame; e) detail of d. Black arrows indicate where copper residues adhered to the surface of the anvil.

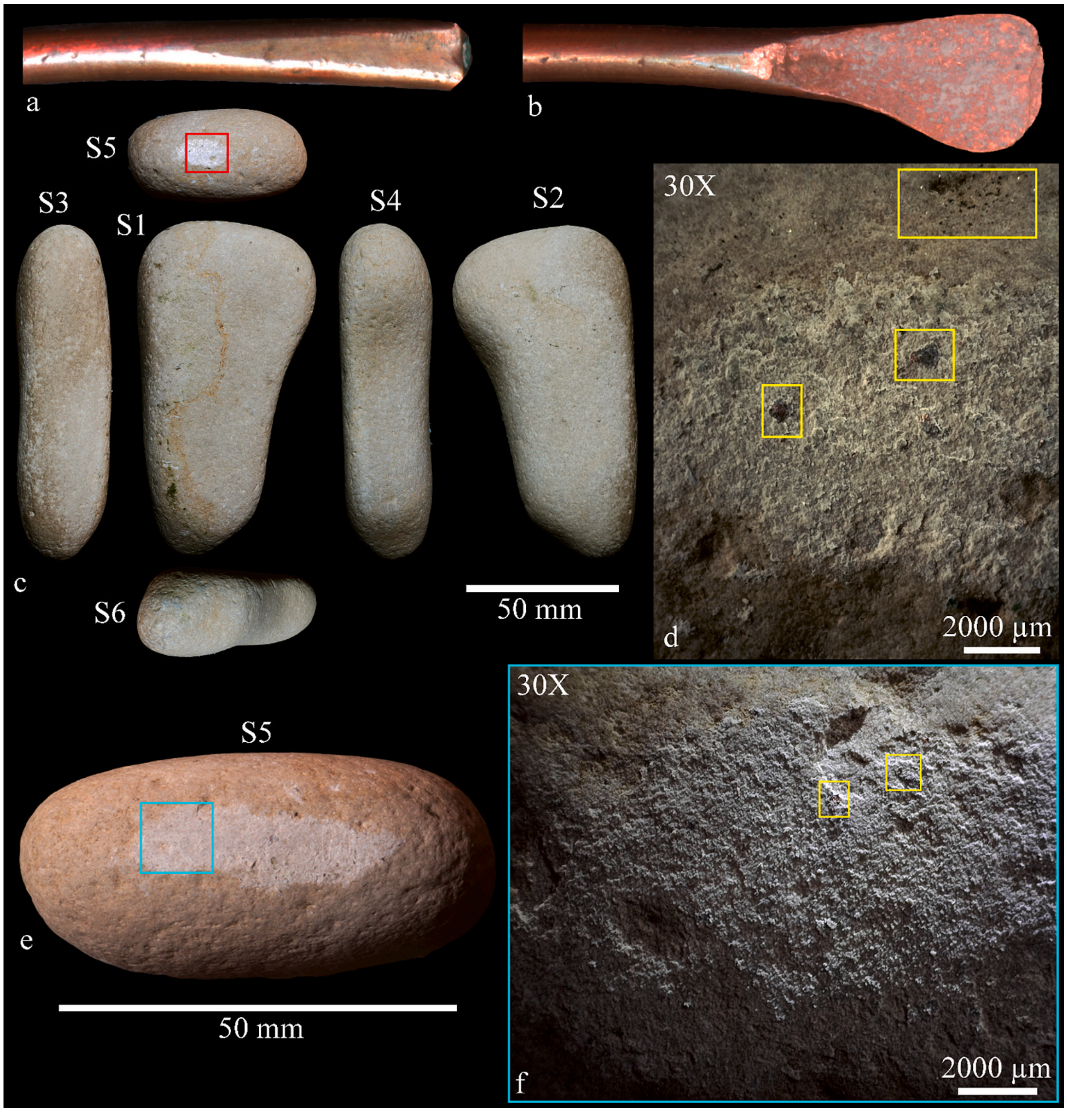

Fig. 12. Experimental hammering of a thick copper wire: a) copper wire before hammering; b) copper wire after hammering for 3 min, showing limestone residue on the flattened tip; c) view of the hammerstone surfaces with S5 after use for 1 min; d) concentrated connected superficial impact pits after 1 min associated with copper residues located on the top of the surface in the yellow rectangles; e) S5 after hammering for 3 min and f) concentrated connected superficial impact pits after hammering for 3 min and copper residues on the top of the surface in the yellow rectangles.

unparalleled opportunity to investigate developing forms of social organisation, including perhaps a form of centralised political control over metallurgy during the Early Bronze Age in the central Aegean.

Ongoing use-wear research will further enhance our understanding of the internal organisation of various craft activities at Dhaskalio, refining our knowledge of the site, which may have acted as a specialised centre for metallurgical production in the region during the Early Bronze Age.

Funding

This work was supported by the A. G. Leventis Foundation, the Stavros Niarchos Foundation, the Institute for Aegean Prehistory, the Balzan Foundation, the Packard Humanities Institute, the McDonald Institute for Archaeological Research, the Research and Innovation Foundation of Cyprus (EXCELLENCE/1216/0463), the Cyprus Institute, the British Academy, the Leverhulme Trust, the National Geographic Society, the Society of Antiquaries of London, the Gerda Henkel Stiftung, Cosmote, EZ-dot, Blue Star Ferries, Creta Farms, and private donors.

Declaration of Competing Interest

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

Acknowledgements

The Keros-Naxos Seaways Project was directed by Colin Renfrew and Michael Boyd for the British School at Athens, with associate director Irini Legaki. The fieldwork was conducted with the permission of the Hellenic Ministry of Culture and thanks are due to Ephorate of Antiquities of Cyclades director, Demetris Athanasoulis, and his many colleagues. We wish to thank Magda Giannakopoulou for carrying out the pXRF analysis.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jasrep.2025.105197.

References

Abar, A., 2023. Same same, or very different? Comparing grindstones from Late/Final Bronze Age settlements and a mining/ore beneficiation site in the Southern Alps. J. Archaeol. Sci.: Rep. 48, 103886. https://doi.org/10.1016/j.jasrep.2023.103886.

Adams, J., 2014. Ground stone tool analysis. A technological approach, second ed. The University of Utah Press and American Southwest, Salt Lake City.

Adams, J.L., Delgado, S., Dubreuil, L., Hamon, C., Plisson, H., Risch, R., 2009. Functional analysis of macro-lithic artefacts: a focus on working surfaces. In: Sternke, I., Eigeland, F., Costa, L. (Eds.), The Non-Flint Raw Material Use in Prehistory. Archaeopress, Oxford, pp. 43–66.

Armbruster, B., Jockenhövel, A., Kapuran, A., Ramadanski, R., 2019. The moulds from Velebit and European Bronze Afe metal anvils. Starinar 69, 139–182. https://doi.org/10.2298/STA1969139A.

Barbieri, M., Cavazzuti, C., Pellegrini L., Scacchetti F., 2015. Experiencing visible and invisible metal casting techniques in the Bronze Age Italy, in: Kelm, R. (Ed.), Archaeology and Crafts. Experiences and Experiments on traditional Skills and Handicrafts in Archaeological Oper-Air Museums in Europe, Proceeding of the VI. OpenArch-Conference in Albersdort, Germany, 23-27 September 2013. AÖZA, Husum, pp. 94-102.

Bassiakos, Y., Philaniotou, O., 2007. Early copper production on Kythnos: archaeological evidence and analytical approaches to the reconstruction of the metallurgical process. In: Day, P.M., Doonan, R.C.P. (Eds.), Metallurgy in the Early Bronze Age Aegean (Sheffield Studies in Aegean Archaeology 7). Oxbow, Oxford, pp. 19–56.

Bátora, J., 2002. Contribution to the problem of 'craftsmen' graves at the End of Aeneolithic and in the Early Bronze Age in Central, Western and Eastern Europe. Slov. Archeol. 50, 179–228. https://archeol.sav.sk/index.php/en/publications/the-slovenska-archeologia-journal-2/.

Belgiorno, M.R., Ferro, D., Loepp, D.V., 2009. Pyros-Mavrorachi in Cypriot metallurgy, in: Kassianidou, V., Papasavvas, G. (Eds.), Eastern Mediterranean Metallurgy and Metalwork in the Second Millennium BC. A conference in honour of Muhly J.D., Nicosia, 10th-11th October 2009. Oxbow Books, Oxford, pp. 26-34. DOI: 10.2307/j.ctvh1dvpm.9.

Bocoum, H., 2004. The origins of iron metallurgy in Africa: new light on its antiquity, West and Central Africa, Unesco publishing. (accessed 9 September 2024).

Boutoille, L., 2015. Les techniques du dinandier : formes et fonction des outils lithiques spécifiques à la déformation plastique des métaux, in: Boulud-Gazo, S., Nicolas, T. (Eds.), Artisanats et productions de l'âge du bronze, Actes de la journée de la Société préhistorique française à Nantes le 8 octobre 2011. Association pour la promotion des recherches sur l'âge du Bronze et Société préhistorique française (Séances 4), Paris, pp. 83-96.

Boutoille, L., 2019. Cushion stones and company: British and Irish finds of stone metalworking implements from the Bell Beaker period to the Late Bronze Age, in: Brandherm, D. (Ed.), Aspects of the Bronze Age in the Atlantic Archipelago and Beyond. Proceedings from the Belfast Bronze Age Forum 9-10 November 2013. Curach Bhán Publications, Hagen, pp. 203-217.

Boyd, M., Campbell, R., Doonan, R., Douglas, C., Gavalas, G., Gkouma, M., Halley, C., Hartzler, B., Herbst, J., Indgjerd, H., Krijnen, A., Legaki, I., Margaritis, E., Meyer, N., Moutafi, I., Iliou, N., Wylie, D., Renfrew, C., 2021. Open Area, Open Data: Advances in Reflexive Archaeological Practice. J. Field Archaeol. 46 (2), 62–80. https://doi.org/10.1080/00934690.2020.1859780.

Broodbank, C., 1993. Ulysses without sails: Trade, distance, knowledge and power in the early Cyclades. World Archaeol. 3, 315–331. https://doi.org/10.1080/00438243.1993.9980211.

Butler, J., Van der Waals, J., 1966. Bell Beakers and Early Metalworking in the Netherlands. Palaeohistoria 12, 41–139.

Carey, C., Tsoraki, C., Jones, A., M., Harris, O.J.T., Crellin, R.J., Lyons, P, 2023. Beaker and Early Bronze Age Tin Exploitation in Cornwall: Cassiterite Processing Identified through Microwear and pXRF Analyses. Eur. J. Archaeol. 26 (2), 147–167. https://doi.org/10.1017/eaa.2022.30.

Caricola, I., 2017. La funzione Dei macro-lithic tools e lo sfruttamento delle risorse minerarie durante la Preistoria recente nel Mediterraneo Occidentale. Tesi di PhD, Sapienza Università di Roma.

Caricola, I., Breglia, F., Larocca, F., Hamon, C., Lemorini, C., Giligny, F., 2020. Prehistoric exploitation of minerals resources. Experimentation and use-wear analysis of grooved stone tools from Grotta della Monaca (Calabria, Italy). Archaeol. Anthropol. Sci. 12, 259. https://doi.org/10.1007/s12520-020-01219-7.

Catapotis, M., 2007. On the Spatial Organisation of Copper Smelting Activities in the Southern Aegean during the Early Bronze Age. In: Day, P.M., Doonan, R.C.P. (Eds.), Metallurgy in the Early Bronze Age Aegean (sheffield Studies in Aegean Archaeology 7). Oxbow, Oxford, pp. 207–223.

Coleman, J.E., 1977. Kephala: A Late Neolithic Settlement and Cemetery (Keos 1). American School of Classical Studies, Princeton.

Crellin, R.J., Tsoraki, C., Standish, C., Pearce, R., Morriss, S., Barton, H., Harris, O.J.T., 2023. Materials in movement: gold and stone in process in the Upton Lovell G2a burial. Antiquity 97 (391), 86–103. https://doi.org/10.15184/aqy.2022.162.

David, N., 1998. The ethnoarchaeology and field archaeology of grinding at Sukur, Adamawa State, Nigeria. Afr. Archaeol. Rev. 15 (1), 13–63. https://doi.org/10.1023/A:1022270208256.

De Angelis, A., Lemorini, C., 2024. Space inside the wall, space outside the wall. The contribution of the macro-lithic and chipped stone tools use-wear analysis to disclose the role of the monumental wall in the EBA village of Arslantepe (Malatya, Turkey). J. Archaeol. Sci.: Rep. 57, 104665. https://doi.org/10.1016/j.jasrep.2024.104665.

de la Torre, I., Mora, R., 2009-2010. A technological analysis of non-flaked stone tools in Olduvai Beds I & II. Stressing the relevance of percussion activities in the African Lower Pleistocene, PALEO, Numéro special, 13-34. DOI: 10.4000/paleo.1877.

Delgado-Raack, S., 2008. Prácticas Económicas y Gestión Social de Recursos (Macro) líticos en la Prehistoria Reciente (III-I milenios AC) del Mediterráneo Occidental. At the Department of Prehistory. Universitat Autònoma de Barcelona, Bellaterra.

Delgado-Raack, S., Kneisel, J., Czebreszuk, J., Müller, J., 2020. Manufacture, use and management of macro-lithic resources in the Bronze Age settlement of Bruszczewo (Poland). J. Lithic Stud. 7(3), 1-26.

Delgado-Raack, S., Lull, V., Martin, K., Micó, R., Rihuete Herrada, C., Risch, R., 2014. Die Silberschmiede von Tira del Lienzo, Totana, Prov. Murcia im Kontext der El Argar Metallurgie, in: Meller, H., Risch, R., Pernicka, E. (Eds.), Metals of power, Early gold and silver, 6th Archaeological Conference of Central Germany (Halle, October 17-19, 2013), Landesamt für Denkmalpflege und Archäologie Sachsen-Anhalt. Landesmuseum für Vorgeschichte, Halle, pp. 577-591.

Delgado-Raack, S., Lull, V., Martin, K., Micó, R., Herrada, C.R., Risch, R., 2016. The Silversmith's Workshop of Tira del Lienzo (Totana, Murcia) in the Context of Iberian Bronze Age Metallurgy. Archaeometry 58 (5), 779–795. https://doi.org/10.1111/arcm.12198.

Delgado-Raack, S., Risch, R., 2008. Lithic perspectives on metallurgy: An example from Copper and Bronze Age south-east Iberia, in: Longo, L., Skakun, N. (Eds.), "Prehistoric technology" 40 years later: Functional studies and the Russian legacy. Proceeding of the International Congress, Verona (20th-23rd April 2025). B.A.R-, IS 1783, Archeopress, Oxford, pp. 235-252.

Dimic, V.B., 2019. Hammering the past: the experimental (re)construction and usage of the prehistoric mining hammerstones from the Prljuša-Mali Šturac site, Rudnik mountain. Starinar 69, 85–112. https://doi.org/10.2298/STA1969085D.

Dixon, J., Kinnaird, T., 2013. Sea-level change and the early bronze age topography, in: Renfrew, C., Philaniotou, O., Brodie, N., Gavalas, G. and Boyd, M.J. (Eds.), The Sanctuary on Keros and the Origins of Aegean Ritual Practice, Vol. I: The Settlement at Dhaskalio. McDonald Institute for Archaeological Research, Cambridge, pp. 45-55.

Doumas, C., 2013. The Dhaskalio Excavations of 1963, in: Renfrew, C., Philaniotou, O., Brodie, N., Gavalas, G. and Boyd, M.J. (Eds.), The Sanctuary on Keros and the Origins of Aegean Ritual Practice, Vol. I: The Settlement at Dhaskalio. McDonald Institute for Archaeological Research, Cambridge, pp. 79-86.

Doonan, R.C.P., Marks, Y.A., 2022. Blowin' in the wind: The beginning of primary metallurgy in the Early Bronze Age Aegean. Archaeometry 64, 161–176. https://doi.org/10.1111/arcm.12689.

Drenth, E., Freudenberg, M., van Os, B., 2014. Prehistoric stone tools for metalworking from the Netherlands: an overview, in: Bartelheim, M., Peska, J., Turek, J. (Eds.), From copper to bronze. Cultural and social transformations at the turn of the 2rd/3nd milennnia B.C. in Central Europe. Gewidmet PhDr. Václav Moucha, CSc, anlässlich seines 80. Geburtstages Beair & Beran, Archäeologische Fachliteratur, pp. 41-51.

Drenth, E., Freudenberg, M., Williams, G.V., 2016. The belongings of a Bell Beaker smith? A stone hoard from Hengelo, province of Gelderland, the Netherlands. Musaica Archaeologica 1, 37–58.

Dubreuil, L., Savage, D., 2014. Ground stones: A synthesis of the use-wear approach. J. Archaeol. Sci. 48, 139–153. https://doi.org/10.1016/j.jas.2013.06.023.

Dubreuil, L., Savage, D., Delgado-Raack, S., Plisson, H., Stephenson, B., de la Torre, I., 2015. Current Analytical Frameworks for Studies of Use–Wear on Ground Stone Tools. In: Marreiros, J., Gibaja Bao, J., Ferreira Bicho, N. (Eds.), Use-Wear and Residue Analysis in Archaeology. Manuals in Archaeological Method, Theory and Technique. Springer, Cham, pp. 105–158. https://doi.org/10.1007/978-3-319-08257-8_7.

Dubreuil, L., Robitaille, J., Gonzalez-Urquijo, J., Marreiros, J., Stroulia, A., 2024. A 'Family of Wear': traceological patterns on pebbles used for burnishing pots and processing other plastic mineral matters. J. Archaeol. Method Theory 31 (1), 144–201. https://doi.org/10.1007/s10816-022-09597-z.

Fendin, T., 2006. Grinding processes and reproductive metaphors. In: Andrén, A., Jennbert, K., Raudvere, C. (Eds.), *Old Norse Religion in Long-Term Perspective*. Nordic Academic Press, Lund.

Georgakopoulou, M., 2007. The Metallurgical Remains. In: Renfrew, C., Doumas, C., Marangou, L., Gavalas, G. (Eds.), Keros Dhaskalio Kavos, the Investigations of 1987-88. McDonald Institute for Archaeological Research, Cambridge, pp. 382–403.

Georgakopoulou, M., 2013. Metal Artefacts and Metallurgy, in: Renfrew, C., Philaniotou, O., Brondie, N., Gavalas, G., Boyd, M.J. (Eds.), The Settlement at Dhaskalio: The sanctuary on Keros and the origins of Aegean ritual practice: the excavations of 2006-2008. Volume I. McDonald Institute Monographies. Oxbow Books, Oxford, pp. 667-692.

Georgakopoulou, M., 2016. Mobility and Early Bronze Age Southern Aegean Metal Production. In: Kiriatzi, E., Knappett, C. (Eds.), Human Mobility and Technological Transfer in the Prehistoric Mediterranean. Cambridge University Press, Cambridge, pp. 46–67.

Georgakopoulou, M., 2018. Metal production, working and consumption across the sites at Dhaskalio and Kavos, in: Renfrew, C., Philaniotou, O., Brondie, N., Gavalas, G., Boyd, M.J. (Eds.), The Sanctuary on Keros and the Origins of Aegean Ritual Practice, Vol. II: The Marble Finds from Kavos and the Archaeology of Ritual. McDonald Institute for Archaeological Research, Cambridge, pp. 501-32.

Georgakopoulou, M., 2023. Different scales of archaeometallurgical research at the sites of Dhaskalio Metals Technologies in the Aegean and Beyond from the 4th to the 1st Millennium BCE. CReA-Patrimonie, Brussels, pp. 23-39.

Georgakopoulou, M., Bassiakos, Y., Philaniotou, O., 2011. Seriphos Surfaces: A Study of Copper Slag Heaps and Copper Sources in the Context of Early Bronze Age Aegean Metal Production. Archaeometry 53 (1), 123–145. https://doi.org/10.1111/j.1475-4754.2010.00529.x.

Greener, A., Ben-Yosef, E., 2016. The ground stone assemblage of a metal workers community: an unexplored dimension of Iron Age copper production at Timna. J. Lithic Stud. 3 (3), 191–220. https://doi.org/10.2218/jls.v3i3.1678.

Grillo, K.M., 2012. "The materiality of mobile pastoralism: ethnoarchaeological perspectives from Samburu, Kenya". PhD thesis, Washington University in St. Louis.

Guerra, M.F., 2023. Gold an exceptional material, in: Guerra, M.F., Martinón-Torres, M., Quirke, S. (Eds.), Ancient Egyptian gold Archaeology and science in jewellery (3500-1000 BC). McDonald Institute Monographs, Cambridge, pp. 3-25.

Haaland, R., 2004. Iron smelting - a vanishing tradition: ethnographic study of this craft in south-west Ethiopia. J. Afr. Archaeol. 2 (1), 65–79. https://doi.org/10.3213/1612-1651-10019.

Hamon, C., 2006. Broyage et abrasion au Néolitique ancien. Caractérisation technique et fonctionnelle des outillages en grès du Bassin parisien, BAR international Series 1551. DOI: 10.30861/9781841719801.

Hamon, C., Ambert, P., Laroche, M., Guendon, J.L., Rovira, S., Bouquet, L., 2009. Les outils à cupules, marqueurs de la métallurgie du district de Cabrières-Péret (Hérault) au Chalcolithique. Gall. Préhistoire 51, 179–212. https://doi.org/10.3406/galip.2009.2478.

Hamon, C., Gandois, H., Reguer, S., 2024. Identifying the stone toolkit of Copper Age and Bronze Age metallurgists: A new contribution from use-wear and XRF analysis carried out on experimental tests. J. Archaeol. Sci.: Rep. 55, 104512. https://doi.org/10.1016/j.jasrep.2024.104512.

Hamon, C., Reguer, S., Bellot-Gurlet, L., Pailler, Y., 2020. Tracking the first bronze metallurgists of Western Europe: combined use-wear analysis and X-ray fluorescence synchrotron spectroscopy of a stone toolkit from Ploneour-Lanvern (Brittany). Archaeol. Anthropol. Sci. 12, 14. https://doi.org/10.1007/s12520-019-00999-x.

Hayes, E., Pardoe, C., Fullagar, R., 2018. Sandstone grinding/pounding tools: use-trace reference libraries and Australian archaeological applications. J. Archaeol. Sci.: Rep. 20, 97–114. https://doi.org/10.1016/j.jasrep.2018.04.021.

Henshilwood, C.S., d'Errico, F., van Niekerk, K.L., Coquinot, Y., Jacobs, Z., Lauritzen, S., Menu, M., García-Moreno, R., 2011. A 100,000-Year-Old Ochre-Processing Workshop at Blombos Cave, South Africa. Science 334 (6053), 219–222. https://doi.org/10.1126/science.1211535.

Ioannides, D., Boyd M.J., Rehren T., Georgakopoulou M., Renfrew, C., in press. Dhaskalio, Keros: New insights from a major Early Cycladic metalworking centre. J. Archaeol. Sci: Rep.

Kufel-Diakowska, B., J., Buchner, A., Lipert, M., Ziewiecka, I., 2020. Functions of early Iron Age handstones. Experimental and Traceological Approach. Praehistorische Zeitschrift 95 (1), 267–289. https://doi.org/10.1515/pz-2020-0012.

Lucarini, G., Guagnin, M., Shipton, C., Radini, A., Alsharekh, A.M., Petraglia, M., 2023. Plant, pigment, and bone processing in the Neolithic of northern Arabia–New evidence from Use-wear analysis of grinding tools at Jebel Oraf. PLoS ONE 18 (10), e0291085. https://doi.org/10.1371/journal.pone.0291085.

Margaritis, E., Boyd, M.J., Renfrew, C., 2024. Being an Islander in the 3rd millennium BC Small Cyclades in the central Aegean: Connectivity, food networks, and sustainability of resources. In: Christophilopoulou, A. (Ed.), Islands and Communities: Perspectives on Insularity, Connectivity, and Belonging. Oxbow, Oxford, pp. 117–135.

Martin, K., 2014. Was bleibt… Der Metallurg und sein Handwerk im archäologischen Befund, in Metalle der Macht – Frühes Gold und Silber, in: Meller, H., Risch, R., Pernicka, E. (Eds.), Tagungen des Landesmuseums für Vorgeschichte, 11/I, Halle, pp. 309-319.

Müller, J., Delgado-Raack, S., Escanilla, N., Kienle, L., Kneisel, J., Czebreszuk, J., Jaeger, M., Szmyt, M., Schürmann, U., 2023. First evidence for the forging of gold in an Early Bronze Age Site of Central Europe (2200-1800 BCE). J. Archaeol. Sci.: Rep. 47, 103748. https://doi.org/10.1016/j.jasrep.2022.103748.

Nakou, G., 1995. The cutting edge. A new look at Early Aegean Metallurgy. J. Mediterr. Archaeol. 8 (2), 1–32. https://doi.org/10.1558/jmea.v8i2.1.

Nerantzis, N., Bassiakos, Y., Papadopoulos, S., 2016. Copper metallurgy of the Early Bronze Age in Thassos, north Aegean. J. Archaeol. Sci.: Rep. 7, 574–580. https://doi.org/10.1016/j.jasrep.2015.08.008.

Nerantzis, N., Bassiakos, Y., Georgakopoulou, M., Filippaki, E., Mastrothedororos, G., 2017. Copper production in early Bronze Age Thassos: new finds and experimental simulation in the context of contemporaneous Aegean metallurgical practices, in: Montero Ruiz, I., Perea, Al. (Eds.), Archaeometallurgy in Europe IV. Bibliotheca Praehistorica Hispana XXXIII, Consejo Superior de Investigaciones Científicas, Madrid, pp. 115-125.

Nodin, S., Nerantzis, N., 2023. Processing of Mineral Resources and the Organization of Metal Production in Thasos during the Early Bronze Age, in: Filippaki, E. (Ed.), Proceedings of the 7th Symposium of the Hellenic Society for Archaeometry. Archaeology Archaeometry: 30 years. Archeopress Publishing LTD, Oxford, pp. 45-57.la.

Pedergnana, A., Asryan, L., Fernández-Marchena, J.L., Ollé, A., 2016. Modern contaminants affecting microscopic residue analysis on stone tools: A word of caution. Micron 86, 1–21. https://doi.org/10.1016/j.micron.2016.04.003.

Radivojević, M., Rehren, T., Pernicka, E., Sljivar, D., Brauns, M., Boric, D., 2010. On the origins of extractive metallurgy: new evidence from Europe. J. Archaeol. Sci. 37, 2775–2787. https://doi.org/10.1016/j.jas.2010.06.012.

Radivojević, M., Rehren, T., 2016. Paint It Black: The Rise of Metallurgy in the Balkans. J. Archaeol. Method Theory 23, 200–237. https://doi.org/10.1007/s10816-014-9238-3.

Renfrew, C., Boyd, M.J., Athanasoulis, D., Brodie, N., Carter, T., Dellaporta, K., Floquet, M., Gavalas, G., Georgakopoulou, M., Gkouma, M., Hilditch, J., Krijnen, A., Legaki, I., Margaritis, E., Marthari, M., Moutafi, I., Philaniotou, O., Sotirakopoulou, P., Wright, J., 2022. The sanctuary at Keros in the Aegean Early Bronze Age: From centre of congregation to centre of power. J. Greek Archaeol. 7, 1–36. https://doi.org/10.32028/jga.v7i.1709.

Renfrew, C., Philaniotou, O., Brodie, N., Gavalas, G., Boyd, M.J., 2013 (Eds.). The Sanctuary on Keros and the Origins of Aegean Ritual Practice, Vol. I: The Settlement at Dhaskalio. McDonald Institute for Archaeological Research, Cambridge.

Rowan, Y., Dixon, J., Dubicz, R., 2013. The Ground Stone Assemblage from Dhaskalio, in: Renfrew, C., Philaniotou, O., Brondie, N., Gavalas, G., Boyd, M.J. (Eds.), The Settlement at Dhaskalio: The sanctuary on Keros and the origins of Aegean ritual practice: the excavations of 2006-2008. Volume I. McDonald Institute Monographies. Oxbow Books, Oxford, pp. 557-595.

Scheel, B., 1989. Egyptian Metalworking and Tools. Shire Egyptology 13. Shire Publications Ltd, Bucks.

Semenov, S.A., 1964. Prehistoric technology: An experimental study of the oldest tools and artefacts from traces of manufacture and wear. Cory, Adams and Mackay Ltd, London.

Stahl, A.B., 2015. Metalworking and ritualization: negotiating change through improvisational practice in Banda, Ghana. Archaeological Papers of the American Anthropological Association 26 (1), 53–71. https://doi.org/10.1111/apaa.12059.

Stroulia, A., Tounas, P., Robitaille, J., Hondroyanni-Metoki, A., Kouziakis, Z., Wardle, K. A., Theodoropoulou, T., 2022. Fishing, weaving, matting: Debating the function of notched cobbles in Neolithic Greece. JNA 24, 15–46. https://doi.org/10.12766/jna.2022.2.

Thiébaux, A., Feller, M., Duchêne, B., Goemaere, E., 2016. Roman whetstone production in northern Gaul (Belgium and northern France). J. Lithic Stud. 3 (3), 565–587. https://doi.org/10.2218/jls.v3i3.1672.

Tsegaye, T.W., 2019. An ethnoarchaeological study of hide working with iron scrapers in East Gojjam, northwestern Ethiopia. Ethnoarchaeology 11, 61–79. https://doi.org/10.1080/19442890.2019.1573290.

Wagner, G.A., Weisgerber, G., 1985. *Silber, Blei und Gold auf Sifnos*, Der Anschnitt, Beiheft 3. Deutsches Bergbau-Museum, Bochum.

Webb, J.M., 2015. Identifying stone tools used in mining, smelting, and casting in middle bronze age Cyprus. J. Field. Archaeol. 40 (1), 22–36. https://doi.org/10.1179/0093469014Z.000000000108.

Wright, K., 1992. A Classification System for Ground Stone Tools from the Prehistoric Levant. Paleorient 18 (2), 53–81. https://doi.org/10.3406/paleo.1992.4573.

Yamasue, E., Murahashi, I., Ishihara, K.N., 2010. Traditional steelmaking in Southwestern Ethiopia: A Metallurgical Analysis. Nilo-Ethiopian Studies 14, 1–18. https://doi.org/10.11198/niloethiopian.2010.14_1.

Zachos, K., 2007. The Neolithic Background: A Reassessment. In: Day, P.M., Doonan, R. C.P. (Eds.), Metallurgy in the Early Bronze Age Aegean. Oxbow Books, Oxford.