Bone Tool Functionality in the Bronze Age Copper Mines of Great Orme (UK): preliminary results

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Research Article

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Abstract

This pilot study examines 150 bone tool samples from the Bronze Age copper mines at Great Orme, Wales, one of Europe's most extensive prehistoric mining complexes. Through combined morphological, technological, and use-wear analyses – including scanning electron microscopy – the research investigates the manufacture and functional roles of bone implements in mining and possibly ore-processing. The assemblage includes wedges made from tubular bones, scoops fashioned from scapulae and pelvic bones, and rib tools, reflecting targeted selection of bone materials suited to specific tasks. Use-wear traces suggest these tools were used for splitting soft copper-bearing rock, scraping ore, and raking finely ground ore fractions. Comparative insights with contemporaneous Eurasian mining sites reveal both shared traditions and local adaptations. Despite the limited sample size, the study highlights the important contribution of organic tools in Bronze Age mining technologies and provides a foundation for further, more extensive research.

Introduction

Copper ore exploitation during the European Bronze Age was a technologically and economically complex process that required specialised knowledge, tools, and labour (e.g. see O'Brien, 2013; 2015). While considerable attention has been given to stone and metal implements used in prehistoric mining, bone tools remain significantly underrepresented in the literature. Their organic composition contributes to poor preservation and limited recognition, yet they offer critical insights into the material strategies of Bronze Age mining communities.

Bone tools are frequently found in direct association with mineral extraction contexts such as mine shafts, spoil heaps, and ore-processing areas, and are often interpreted as functional complements or analogues to bronze tools like chisels and wedges. Their consistent presence at mining sites, particularly those associated with softer mineral matrices (e.g., copper-rich sandstones and carbonates), suggests a deliberate and specialised role in extraction and processing tasks.

This study presents a comprehensive analysis of 150 bone tools recovered from surface and underground contexts at the Great Orme copper mine in North Wales. Although over 30,000 bone fragments have been documented at the site, this subset was selected for its archaeological integrity and contextual relevance. The analysis builds on the foundational work of James (2011), who first identified use-wear and technological features on a small number of specimens, but did not systematically examine typologies, manufacturing techniques, or functional variation.

Through an integrated approach combining morphological classification, technological analysis, and microscopic examination (including scanning electron microscopy) this study aims to reconstruct the manufacture, use, and functional roles of bone tools in Bronze Age mining. The assemblage is also considered within a broader Eurasian context, through comparison with similar finds from contemporaneous prehistoric mining sites.

Despite increasing recognition of organic materials in prehistoric mining economies, bone tools remain largely overlooked compared to their metal counterparts, and their functions are often assumed rather than empirically demonstrated. This research addresses that gap by offering a detailed, evidence-based assessment of bone tools from Great Orme, contributing to broader discussions on prehistoric mining technologies, resource exploitation, and labour organisation.

Background and context

The copper mines are located in the Pyllau Valley area of Great Orme, the limestone headland tipping the Creuddyn Peninsula on the north coast of Wales (Fig. 1). Copper mineralisation there occurred in some 40 north-south trending vertical veins in bands of dolomite. The primary ore is recorded as chalcopyrite ($CuFeS_2$) and is present to a depth of c. 200 m. Supergene weathering, occurring largely in the upper bands of mineralisation, caused the conversion of chalcopyrite to secondary ores including intermixed malachite ($Cu_2CO_3(OH)_2$) and goethite ($Fe^{3+}O(OH)$) hosted in soft, 'rotted' dolomite; and lesser amounts of azurite($Cu_3(CO_3)_2(OH)_2$) associated with bands of shales/mudstones. It is considered most likely that the intermixed malachite and goethite was exploited during the Bronze Age (Dutton et al., 1994; Ixer and Davies, 1996; Lewis, 1997; Williams, 2023). Underground surveys indicate the presence of up to 6000 m of often narrow, interconnecting Bronze Age mine workings. These cover an area of approximately 24,000 m^2 and reach a depth of 55 m relative to the current ground level (Dutton et al., 1994; Williams, 1995; Lewis, 1997; Williams, 2023). Landscaping work at the site to create an archaeological park, coupled with nearly two decades of archaeological excavations exposed trench workings and an extensive opencast mine with numerous entrances leading underground (Dutton et al., 1994; David, 1994; 1995; 1996; 1997; 1998; 1999; 2000; 2001; 2002; 2003; 2004; 2005). Radiocarbon dates obtained from 24 samples of wood charcoal and bone collagen from locations in surface and underground workings indicate that mining activities occurred at the site for an eight-century span, between *c.* 1700 and 900 BC (Williams, 2023, 80–83). There is currently no archaeological evidence to suggest that copper ore extraction occurred in Pyllau Valley between the end of the Bronze Age and the start of the second phase of mining there during the last decade of the 17th century AD. This second phase, intermittent initially, then continuous for nearly a century until the second half of the 19th century AD, resulted in the cumulation of thousands of tonnes of mine waste which was discarded at the surface, infilling Pyllau Valley and covering the early mine and its surrounding landscape.

The excavations at the site have led to the recovery of thousands of Bronze Age artefacts. Despite the large quantity, they are limited to four primary types, an influence of the specialist nature of the activities carried out there. These are: charcoal fragments residual from fire-setting; stone implements including mauls, pounders and mortars representing mining and ore processing activities; copper alloy fragments spalled from metal mining tools during their use; and faunal remains (Dutton et al., 1994; Lewis, 1997; James, 2011; Jowett, 2017). The faunal remains are by far the largest artefact class with over 30,000 bone pieces recovered. They were primarily intermixed with mining spoil but also occurred as *in-situ* finds in worked-out veins. Most were well preserved and more than half of them have been subject to zooarchaeological analysis (see Hunt, 1993; Hamilton-Dyer in Dutton et al., 1994; James, 2011). The studies have drawn similar conclusions. Cattle dominate the assemblage (over half) followed by sheep/goat and pig. Red deer, roe deer, horse and hare are also are present but rare. A bias of elements present in the assemblage was identified: ribs and limb bones (especially tibia) are overrepresented compared to pelvis and scapulae, while skull, limb extremities and vertebrae are underrepresented. James (2011, 182) calculated over 75% of the assemblage shows less than 25% completeness revealing the highly fragmented nature of the remains.

James’ (2011) work was the first to include a study of those faunal remains she identified as tools. She focused primarily on their technological characteristics. Through detailed examination of surface modifications and use-wear traces, including rounded edges, extensive polish, and striations, James proposed that many of the implements had been used in mining-related activities. She suggested specifically their functions included scraping dolomitized limestone to expose ore-bearing veins. This interpretation was supported by both contextual evidence and the consistent patterns of polish and edge rounding indicative of abrasive contact with mineral surfaces. The work presented below adds to James’ research by extending tool categories analysed and employing high-powered microscopy to identify diagnostic features created by tool use.

Material and Methods

Sampling

The bone samples analysed derived from underground mine workings (Locations 18 and 37, and East 3 Vein (40' Level)), as well as from surface deposits (the Opencast, Location 7C (surface), West 6 Vein (North), Central Vein, and East 3 and 6 Veins (North). A total of 150 relatively well-preserved specimens were subjected to structural, technological, and traceological analyses. Of these, 78 bones recovered during the 1991 excavations had previously been identified to species level (Hunt, 1993), revealing a predominance of cattle, alongside remains of pig, sheep, goat, red deer, and horse.

Preservation quality is attributed to the site's limestone-dolomite geology, which produces neutral to slightly alkaline conditions (pH 7–8) that buffer acidity resulting from ore oxidation (Lewis, 1996). Over 95% of the specimens exhibit green staining attributable to copper (0.9%) and iron (0.5%), with some also showing manganese deposits (1.6%) (Jenkins and Lewis, 1991).

Methods

Traceological analysis of osseous materials is a well-established field, building on the foundational work of Semenov on prehistoric technologies (Semenov, 1957). Since bone and antler were often used with little or no modification, wear traces frequently provide the primary evidence for inferring tool function (e.g. Binford, 1981; Bonnichsen and Sorg, 1989; Fernandez-Jalvo and Andrews, 2016; Fisher, 1995; Maigrot, 2003; and Luik et al., 2005).

This study aims to identify diagnostic wear traces on bone tools and, where possible, associate them with mining activities. The analytical framework is grounded in the kinematics of manual labour, with particular emphasis on both linear striations and volumetric surface alterations as indicators of tool movement and contact (Semenov, 1957). Many of the tools retained their natural anatomical form with minimal shaping, reflecting prehistoric manufacturing methods such as splitting, chopping, and sawing. The analysis also considered the physical and structural responses of bone and antler to mechanical stress, focusing on features such as striations, micro-chipping, cracking, smoothing of protrusions, and polish.

A comprehensive, multi-scalar approach was employed, combining macroscopic and microscopic observations. Initial assessments were conducted with the naked eye and under low magnification (up to ×20) using a stereoscopic microscope. Low-magnification optical microscopy was used to differentiate natural surface alterations (e.g., root etching, microbial activity, post-depositional damage) from human modifications (e.g., striations, smoothing, impact marks, polish, and hafting traces). Detailed documentation was achieved through macrophotography using a Canon EOS 60D camera equipped with EF-S 60 mm and MP-E 65 mm macro lenses. Image clarity and depth of field were enhanced using focus stacking via Helicon Focus software. Image post-processing was conducted using ACDSee Canon Professional and Adobe Photoshop. Representative specimens were selected for high-magnification analysis.

Microwear analysis was carried out using scanning electron microscopy (SEM) (Hitachi S-3700N) at the Department of Scientific Research, British Museum. SEM imaging provided high-resolution views of fine striations and surface topographies, using both backscattered and secondary electron signals.

In certain cases, wear traces were interpreted by comparison with an experimental reference collection derived from prior replication studies (Zagorodnia, 2014a), thereby increasing the reliability of functional attributions.

This integrated methodology effectively balances macro- and micro-scale observations, facilitating robust and replicable interpretations of bone tool use. The full range of wear patterns is presented in the accompanying visual materials, supporting the functional conclusions of the study.

Results

Within the assemblage, a few functional categories of tools were identified, including mining implements (wedges, scoops, and scraping (*and/or* stirring) tools) and domestic utensils (Table 1).

Larger bones, primarily ribs and limb bones (tibia, femur, humerus), were preferred for tool production, although scapulae and pelvic fragments were also occasionally utilised. Many specimens exhibit substantial damage consistent with both intensive use and manufacturing processes. Others represent technological waste with no evidence of post-production use.

Both human and non-human modifications were recorded. Human modification includes impact marks, flake scars, cut marks, polish, striations and grooves. Natural modifications comprise evidence of microbial activity, as well as root etching and post-depositional abrasion, which resulted in superficial, multidirectional scratches likely caused by sediment contact.

Two primary types of human bone modification were identified: fracture patterns associated with hammerstone use and cut marks.

A number of limb bones display distinct impact points, diagnosed by internal and external flaking (Fig. 2c). Among these, several show evidence of hammerstone use, while one specimen features chop marks adjacent to the impact site. There is also evidence for the use of metal tools in the manufacture of some items.

Seven cattle femora and tibia were broken near the midshaft, with at least five showing signs of impact near the proximal epiphysis (Fig. 2a). Another technique involved longitudinal splitting initiated by striking one of the epiphyseal ends.

Ribs and scapulae were often only minimally modified; in many instances, their natural morphology suited specific tasks, requiring little or no additional shaping.

Other fragments represent technological waste, showing no evidence of post-production use. Notably, 22 small central diaphysis fragments were produced by direct impact with a blunt object during the fracturing process. Interestingly, these fragments were recovered both from excavations in underground workings, often found alongside finished tools, and from redeposited surface spoil heaps in equal measure. This suggests that the manufacturing technology was simple enough to allow tool production directly at the worksite. It is also possible that these materials had a dual function: waste from food consumption (such as meat processing and marrow extraction) may have simultaneously provided suitably shaped blanks for tool making by the ancient miners.

The bones consistently exhibit a greenish staining, resulting from prolonged exposure, over 3,000 years, to a copper-rich environment. This coloration, along with the presence of copper micro-inclusions, is interpreted as environmental in origin, as the bones were embedded in a layer of crushed, copper-bearing limestone.

Additionally, numerous specimens show cut marks consistent with butchery processes. Cut marks on bones have characteristic narrow, V-shaped sections (Fig. 2b).

Wedges

A distinct type of wedge made from limb bones was identified (26 specimen) (Figs. 2a, 2e and 3a), along with a single, rare sample fashioned from deer antler. These tools exhibit clear traces of use, particularly at the pointed ends, where chipping and deep striations are consistent with repeated impact against mineral surfaces (Figs. 2d, 3b, 3c, 4d, 4f and 4g).

At the opposite ends of the two tools, typically corresponding to the epiphyses, distinct percussion marks were observed (Fig. 3d), suggesting that these areas were struck with hammerstones to drive the tools into the rock (Fig. 3e). This interpretation is supported by the presence of stone pebbles within the assemblage that show concentrated wear on their working surfaces, indicative of use as hammerstones.

Some bone tools may have been hafted, much like their metal counterparts (Fig. 4c). Based on tool morphology and the distribution of wear patterns, 18 specimens appear to have been used as handheld implements, while 9 show indications of having been hafted. Technological modifications, such as flake scars, deliberate chipping, or thinning near the proximal end, likely served to facilitate insertion into a handle. Notably, these modified areas lack direct use-wear, reinforcing the interpretation that they were prepared for hafting rather than direct contact with worked materials (Fig. 4e).

A substantial number of fragmented bone wedges were also recovered, indicating frequent breakage and disposal.

Based on the observed tool forms and wear patterns, it is possible to propose a hypothetical reconstruction of Bronze Age ore extraction methods at Great Orme (Figs. 2f, 3e and 4c). Although bone wedges were less robust than their metal counterparts, they may have been equally effective in softer lithological contexts, such as copper-bearing dolomitised limestone. Experimental replication using bone tools is recommended to further test this hypothesis.

Scraping (and/or Stirring) Tools Made from Ribs and Other Bones

The largest category of tools consists of implements made primarily from rib bones (28 specimens) (Fig. 5) and, to a lesser extent, tubular limb bones (2 specimens). This group includes tools with single working edges (Figs. 5a, 5f and 5j), double opposing edges (Fig. 5e), and fragmented pieces exhibiting identifiable wear traces.

Macroscopic analysis indicates that the morphology of the working edge was influenced by two main factors: either the natural sternal end of the rib was utilised, or the rib was split prior to use. In the first case, the working edge developed a rounded or slightly sharpened form, either symmetrical or asymmetrical, through repeated use. Straight or bevelled edges were also observed, particularly on specimens that show evidence of prior shaping by cutting or sawing.

Microscopic analysis recorded use-wear traces on both the working edge and the longitudinal margins. These include edge rounding, surface smoothing, bright polish, and striations (Fig. 5c). On the longitudinal edges, grouped scratches, either perpendicular or oblique to the edge, were commonly observed (Fig. 5i). Similar striations were noted on the sternal or vertebral working ends (Fig. 5h), often appearing as grouped or isolated linear marks of varying length and texture, located on both the medial and lateral planes (Figs. 5b, 5d and 5f). These were typically oriented perpendicularly or at a low angle to the main axis of the rib.

The limb bone specimens were produced by longitudinally splitting the diaphysis after the removal of one or both epiphyses. The resulting tools display use-wear patterns comparable to those observed on rib implements, including working edge rounding and polishing across the surface relief.

The presence of deep grooves alongside superficial striations on the working edges suggests repeated contact with abrasive, fine-grained materials. The combination of edge rounding and bright polishing suggests use on soft but textured materials, such as leather or wood. Notably, consistent contact with a sandy substrate could also produce similar polish.

Scoops

A recognisable category of scooping tools was identified, primarily manufactured from animal scapulae (10 specimens) (Figs. 6a and 6c) and, less frequently, from pelvic bones (2 specimens) (Fig. 6e). The working edge is located along the dorsal margin of the bone (Figs. 6b and 6f). While these edges do not exhibit pronounced rounding, they do show surface smoothing that conforms to the natural topography of the bone.

Deep linear grooves extend from the working edge into the blade, typically aligned along the longitudinal axis and occasionally intersecting with each other. These striations are consistent with repeated use in a scooping or scraping motion. In addition, areas of bright polish and smoothing on the proximal ends (interpreted as handles) suggest prolonged and repetitive contact with the hand during use (Fig. 6d).

Awls and Other Non-Mining Objects

Four tools from the assemblage (three made from tubular bone blades and one from a scapula) (Fig. 7a) were not directly associated with mining or ore-processing activities. These implements have been identified as awls. While not used for mineral extraction, they may have played a supporting role in the underground environment, possibly employed by Bronze Age miners for repairing leather items such as bags, mittens, or other forms of protective gear or wooden containers.

Use-wear analysis indicates concentrated wear approximately 2.5–3 cm from the tool tip (Figs. 7b, 7c and 7d). Observed traces include bright polish and fine surface striations oriented in both longitudinal and angular directions (Fig. 7b). These wear patterns suggest rotational kinematics during use, consistent with piercing or puncturing motions (Fig. 7d), particularly through soft materials such as leather or wood. Based on this evidence, it is reasonable to interpret these objects as leatherworking tools, most likely used for piercing hides.

Awls of this kind are widespread across different archaeological contexts and periods. However, the Great Orme example displays an unusually broad working edge, distinguishing it from more typical awl forms. At present, this is the only example of such a morphology identified at the site. Nonetheless, ongoing study of the assemblage may reveal additional specimens of this unique type.

Table 1 Bone samples from Great Orme Mines analysed in this paper

Type	Species/ elements								Human modifications				Working edge				Wear traces						Total	Fig.
													single							striations, location				
	limb bones	rib	scapulae	pelvic	mandible	astragalus	antler/ horn	unidentified	cut marks	fracturing	splitting	cut/ broken	distal	proximal	two	no preserved	smoothness	polish	grooves	tip	sides	flat surface		
Wedge	26						1		+	+	+								+	+			**27**	2-4
Scraper/ stirrer (?)	2	28							+			+	12	4	5	9	+	+		+	+	+	**30**	5
Scoop			10	2					+										+			+	**12**	6
Awl	3		1								+	+					+	+		+			**4**	7
Fragments with use-wear	21			2		3					+	+						+	+				**26**	
Fragments/ technological wastes	39		1	3	4		2	2	+	+	+	+											**51**	
Total	**91**	**28**	**12**	**7**	**4**	**3**	**3**	**2**															**150**	

Discussion

The bone tool assemblage from Great Orme exhibits strong technological and functional parallels with those from other Bronze Age mining sites across Eurasia. Comparable implements have been identified at Kartamysh (Ukraine) (Zagorodnia, 2014a, 2014b), Kargaly (Antipina, 2004) and Mikhailo-Ovsyanka (Russia) (Gorashchuk and Kolev, 2004), Schwaz/Brixlegg (Austria) (Gale, 1995; Rieser & Schrattenthaler, 2004; Staudt et al., 2019), and Ross Island (Ireland) (O'Brien, 2004), where they have similarly been interpreted as components of the prehistoric mining toolkit. These tools were likely used for a range of tasks, including splitting and scraping ore-bearing rock (Lewis, 1996; James, 2011), sorting mineral fragments, and manipulating processed material during beneficiation (Zagorodnia, 2014a; 2021). The recurrence of similar forms and wear patterns across geographically dispersed sites suggests the existence of a broadly shared technological tradition in Bronze Age mining practices.

At Great Orme, wedge-shaped tools primarily made from limb bones, and in one case, deer antler display use-wear and impact-related damage consistent with soft-rock mining. Pointed working ends, combined with percussion marks on proximal surfaces, suggest they were used to apply controlled force against copper-bearing limestone. Frequent breakage and a high number of fragmented specimens support their interpretation as heavily used, expendable tools within a demanding work environment.

Equally significant is the presence of scoop-like implements fashioned from scapulae and pelvic bones. These forms are well documented at Bronze Age mining sites in Eastern Europe and Central Asia (e.g. Ukraine, Kazakhstan, Uzbekistan) (Zagorodnia, 2014a; Margulan, 1966; Doll, 2003), where they are associated with ore collection rather than extraction. Use-wear features, such as longitudinal striations and smoothing from handling, indicate their use in raking or collecting loose ore or ground material, suggesting a degree of task specialization within the operational sequence.

Also noteworthy is the identification of bone awls, interpreted as ancillary tools likely used for piercing leather or wooden equipment. Though not directly related to ore extraction, their contextual association with mining areas points to a supporting role, possibly in the maintenance of gear such as bags or protective clothing. One unusually wide awl tip at Great Orme may represent a local morphological variant or tool re-purposing, reflecting adaptive responses to specific functional needs or raw material availability.

Although experimental studies on bone tools in mining contexts have been sporadically undertaken, most results remain unpublished or inaccessible. The only documented experiment is from Kargaly (Russia), where long bone fragments were used to split rock, but no detailed microwear data or illustrations were made available (Chernykh, 2004).

The author’s own experimental work, using rib bones as stirring implements in wet ore beneficiation processes, facilitated the identification of similar tools at Kartamysh (Ukraine) (Zagorodnia, 2014a; 2014b; 2021). Initially, this seemed to offer a model for interpreting the rib tools from Great Orme. However, detailed microwear analysis suggests that, despite typological similarity, the Great Orme specimens may have functioned as versatile, multi-use implements. These rib tools may have been used both as scrapers in mining activities and as stirrers or rakes during wet ore beneficiation.

The widespread occurrence of rib tools at Bronze Age mining sites across Europe underscores both their practicality and adaptability. Their simplicity, availability, and effectiveness likely made them expedient tools for a range of extractive and processing tasks. In pastoral societies with abundant faunal resources, such tools would have represented a readily accessible and efficient technological solution.

This pilot study highlights the need for dedicated experimental replication and the development of a robust reference collection under site-specific geological conditions. Such work is essential for refining functional interpretations of bone tools and assessing their performance in ore extraction and processing tasks at Great Orme.

Overall, the data from Great Orme support and extend previous interpretations of bone tool use in prehistoric mining. The manufacturing simplicity, functional versatility, and strategic selection of bone as a material point to a pragmatic approach to tool production in Bronze Age extractive industries. Rather than being marginal, bone tools formed an integral part of the technological repertoire, particularly in contexts involving softer geological matrices where lightweight, disposable tools were advantageous.

These findings contribute to a growing recognition of the technological sophistication and adaptability of Bronze Age mining communities. The integration of functional, technological, and contextual analyses in this study demonstrates the value of systematic, multi-scalar approaches in reconstructing ancient labour organization and technological innovation. Future research including experimental archaeology and broader inter-regional comparison will be essential in exploring cultural transmission, technological convergence, and local adaptation across Eurasian mining landscapes.

Conclusions

This study has analysed a selected assemblage of bone tools from the Great Orme Bronze Age copper mine, focusing on those associated with mining and ore-processing activities. Several distinct tool types were identified, including limb bone wedges, likely used for splitting soft, copper-bearing rock; rib tools, likely used for scraping sandy dolomitized limestone or/and stirring and scraping copper ore concentrate during wet ore processing; and scapula- or pelvis-based scoops, possibly for raking or handling loose ore. These tools appear to have required minimal modification, reflecting both the ready availability of raw materials, primarily cattle bones, and the limitations imposed by bone’s mechanical properties.

The evidence indicates that bone was not a marginal or opportunistic material but was deliberately and systematically selected for specific tasks within the mining sequence. Its light weight, workability, and suitability for tasks involving scraping or abrasion made it a functional complement to stone and bronze implements. Technological modifications and use-wear traces (such as edge rounding, polish, striations, and percussion marks) demonstrate that these tools were subject to heavy use and were integral to the extractive process.

The widespread presence of such tools at Great Orme, especially wedge-like forms, underscores their importance within the prehistoric mining toolkit. Comparative findings from sites such as Kartamysh (Ukraine), Mikhailo-Ovsyanka and Gorny (Russia), Schwaz/Brixlegg (Austria), and Ross Island (Ireland) further support the use of bone in extractive technologies across Eurasia. In these contexts, bones appear to have been selected for their accessibility, malleability, and ability to withstand mechanical stress in ways that differed from metal tools, particularly in tasks requiring precision scraping or abrasion rather than blunt force. However, important regional differences in tool types and bone selection strategies have also been observed. For example, the absence of certain tool types, such as wedges at Kartamysh, may reflect differences in excavation coverage or site formation processes, underscoring the need for further investigation. No dedicated ore-processing site has yet been excavated at Great Orme, and the underground workings at Kartamysh remain largely unexplored archaeologically. It is therefore possible that future excavations at these sites may uncover comparable material.

Importantly, this study contributes a detailed reference framework for evaluating bone tool use in prehistoric mining, based on morphological typologies and traceological analysis. While similar tools have been found at other sites variations in tool forms and raw material use suggest local adaptations driven by geological context, faunal availability, and mining strategies.

Overall, the findings from Great Orme highlight the sophistication and adaptability of Bronze Age mining technologies. Far from being a secondary product of subsistence activity, bone tool production reflects a targeted, functional response to the specific demands of ore extraction. Continued research, particularly experimental replication and wider inter-site comparison, will be essential for refining our understanding of prehistoric technological choices, labour organisation, and innovation within early extractive industries.

Declarations

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Contributions

Olga Zagorodnia: Conceptualization, Methodology, Formal analysis, Investigation, Writing - Original draft. **Harriet White:** Resources, Writing - Original draft, Writing - Reviewing and Editing.

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Figures

Figure 1

(a) Location of the Great Orme mine;

(b) an aerial view of the Bronze Age workings. Image by N. Jowett

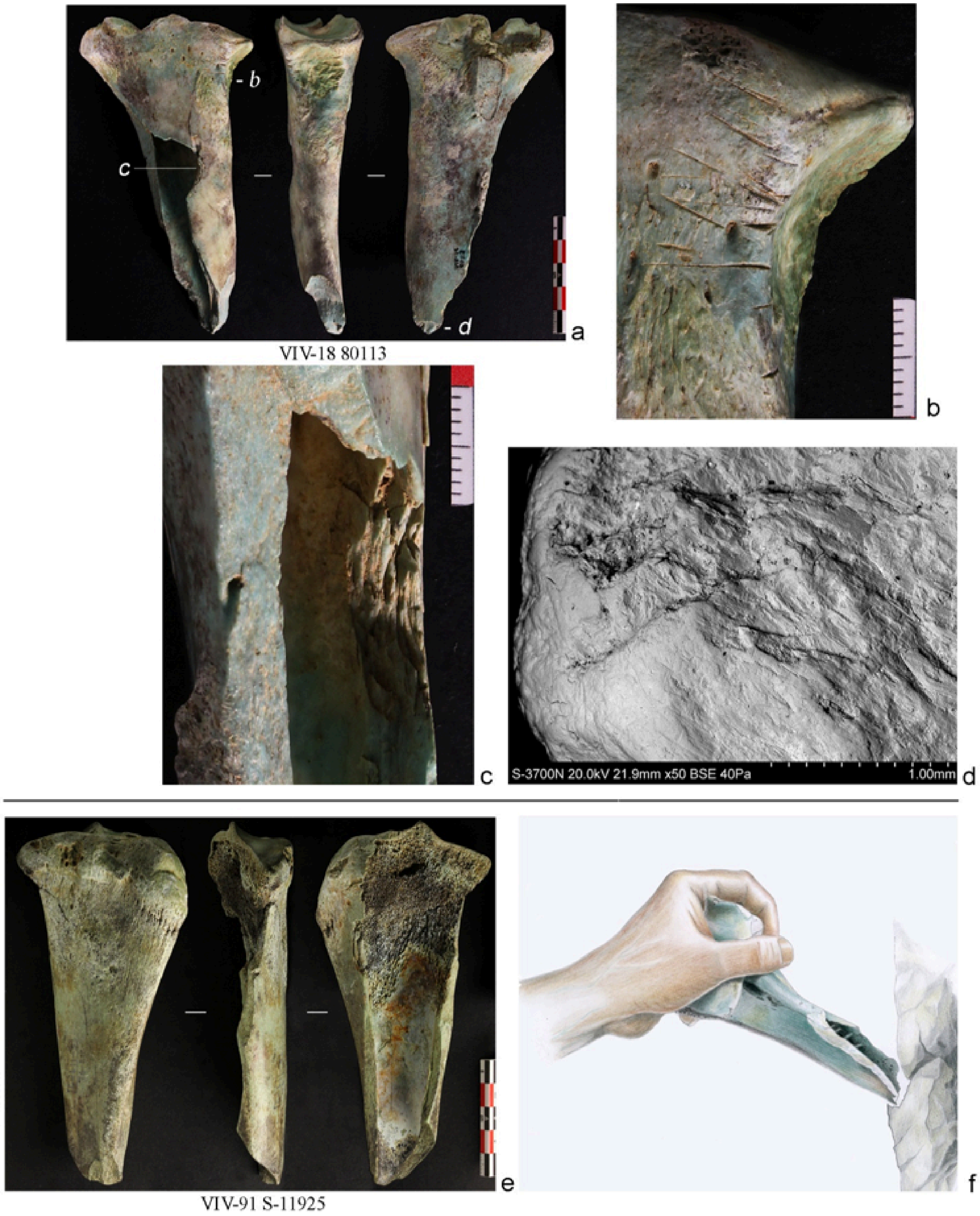

Figure 2

(a-e) Bone tools: wedges. Great Orme Mines; **(f)** reconstruction. Images by O. Zagorodnia, **(f)** drawing by A.Verbovsky. **(d)** copyright of the Trustees of The British Museum

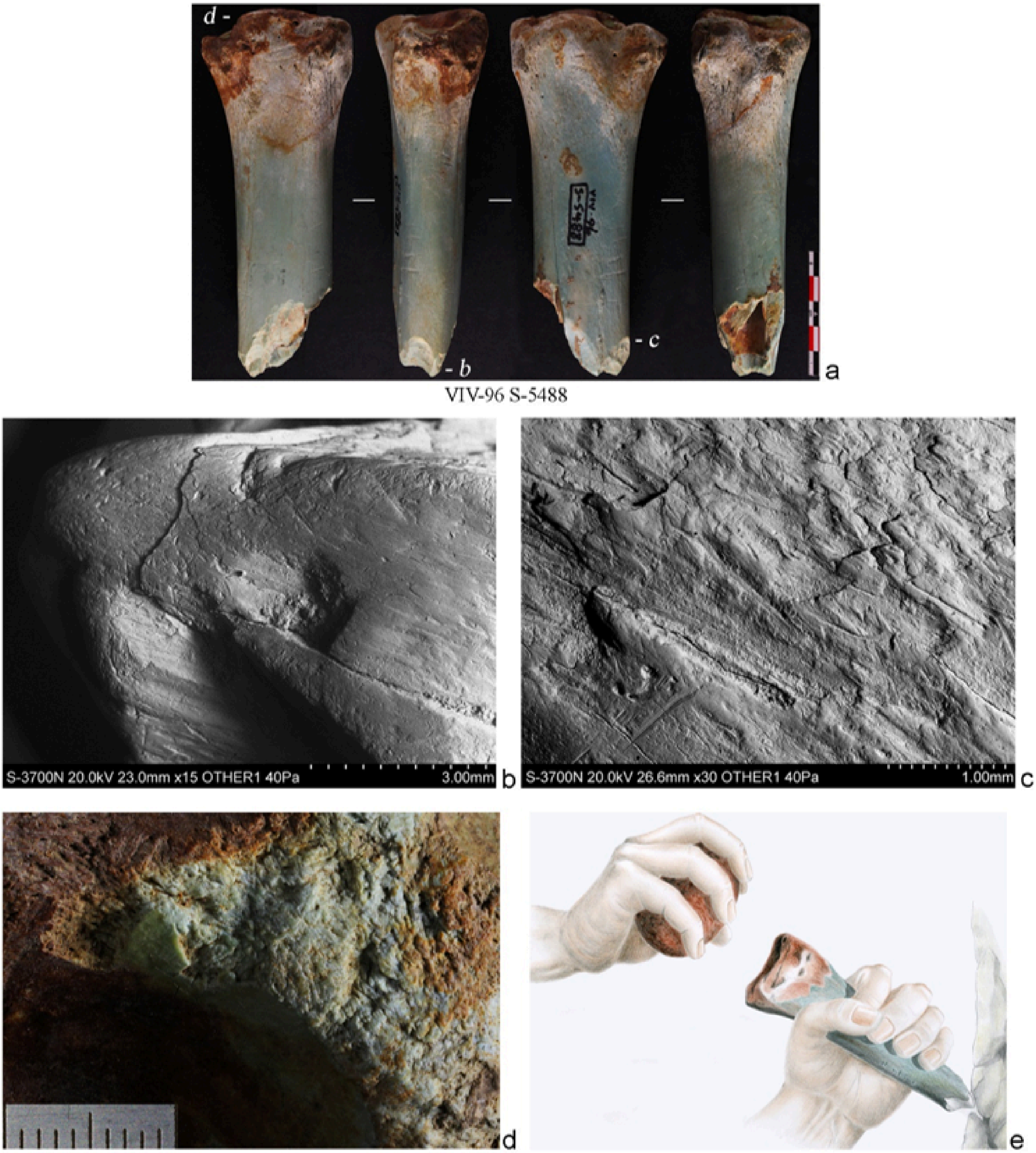

Figure 3

(a-d) Bone tools: wedges. Great Orme Mines; **(e)** reconstruction. Images by O. Zagorodnia, **(e)** drawing by A.Verbovsky. **(b, c)** copyright of the Trustees of The British Museum

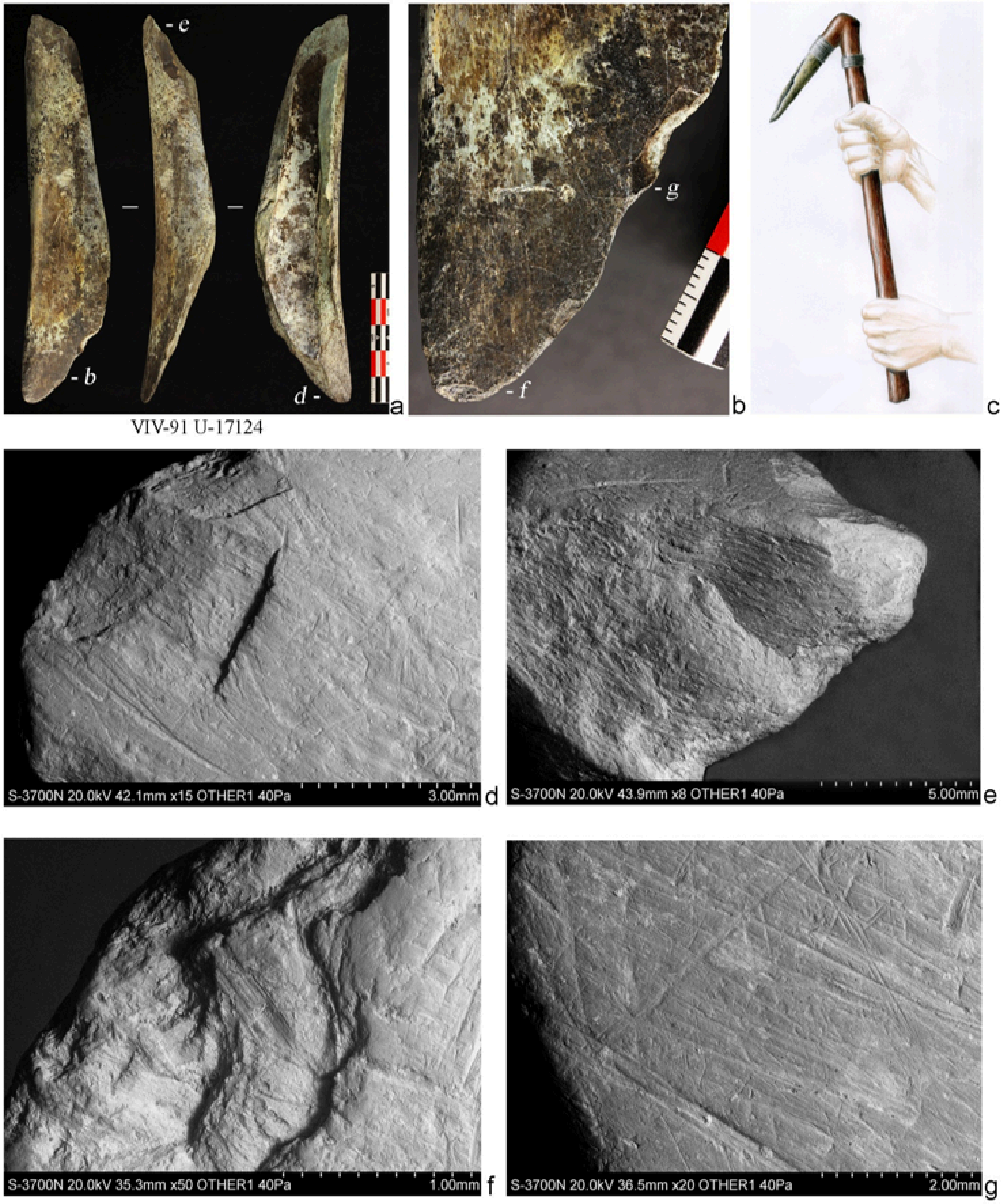

Figure 4

(a, b, d-g) Bone tools: wedges. Great Orme Mines; (c) reconstruction. Images by O. Zagorodnia, **(c)** drawing by A.Verbovsky. **(d-g)** copyright of the Trustees of The British Museum

Figure 5

(a-j) Rib bone tools: scrapers/ stirrers (?) Great Orme Mines. Images by O. Zagorodnia, **(c, h)** copyright of the Trustees of The British Museum

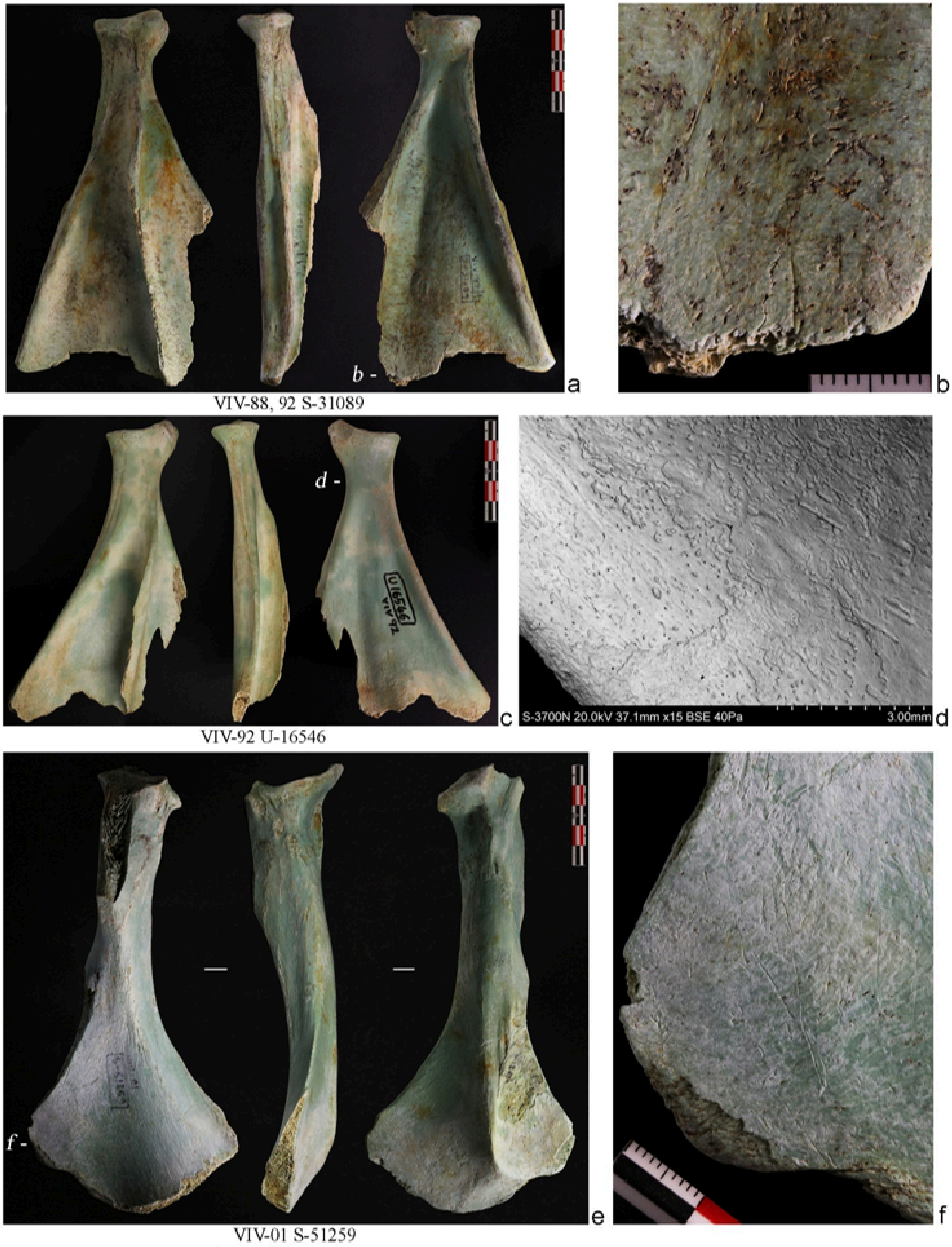

Figure 6

(a-f) Bone tools: scoops. Great Orme Mines.

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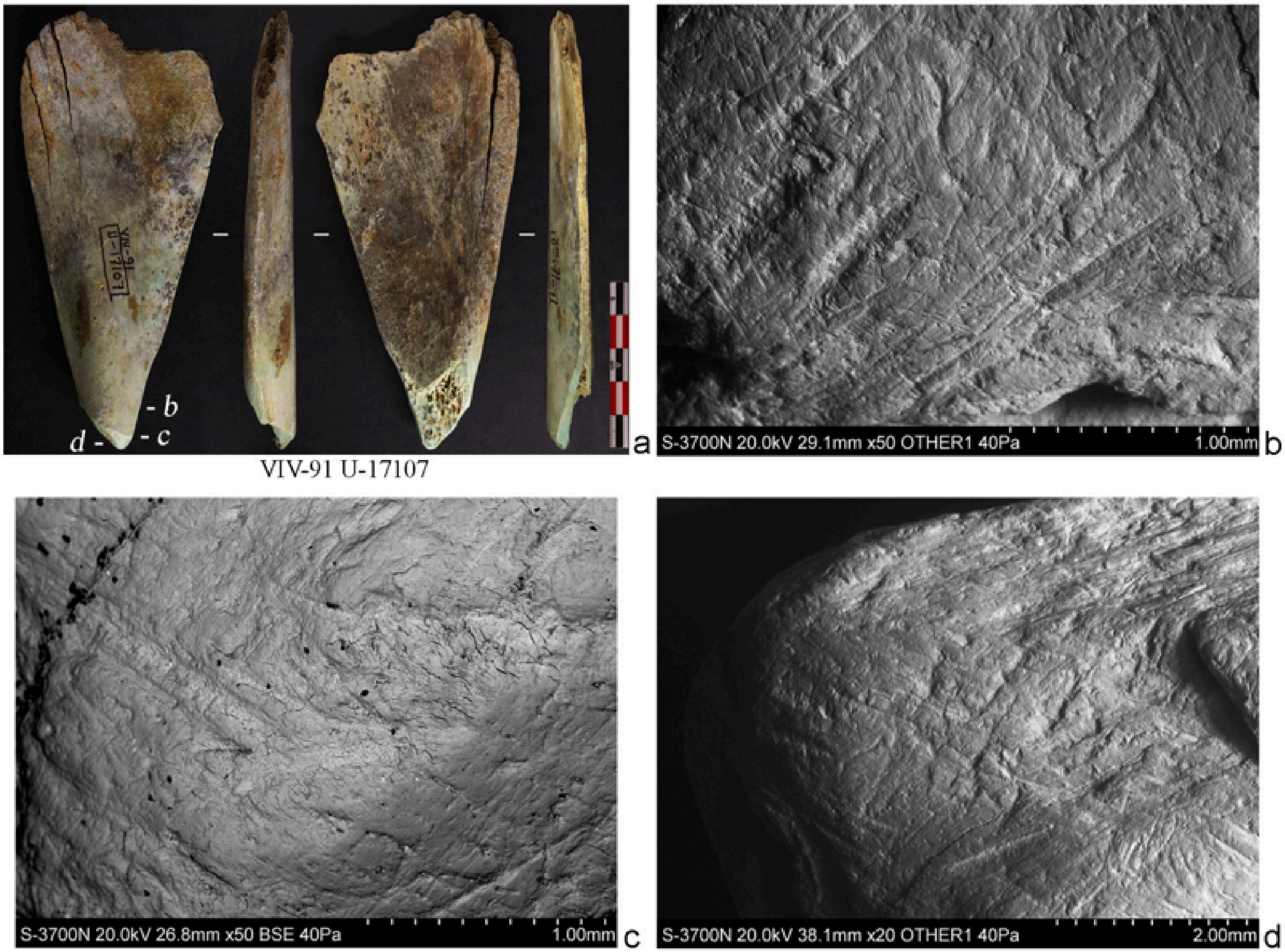

Figure 7

(a-d) Bone tools: awl. Great Orme Mines.

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