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Ivory segmentation procedures with copper-based tools: Archaeological and experimental evidence

Procédés de sectionnement de l'ivoire à l'aide d'outils en cuivre : observations archéologiques et expérimentales

Miriam Luciañez Triviño, Corina Liesau von Lettow-Vorbeck

Abstract: Recent technological studies on Iberian ivory objects have revealed a wide range of techniques and tools used in ivory work. However, less attention has always been given to the use of copper-based saws and axes, as well as to their experimental validation. Through 13 experimental tests, we have studied the methods of sectioning elephant tusks. The main aim of sawing, with four different copper-based saws, was to determine whether they could effectively saw ivory, to assess their effectiveness, and identify the type of marks produced. The archaeological findings suggested that some Chalcolithic saws, as is the case of the saw of the so called "ivory workshop" from Valencina de la Concepción, were capable of segmenting ivory, but with limitations. The experimental tests demonstrated that this was possible under different conditions, although it is likely that they could not be used to saw large tusks. Probably, the Chalcolithic artisans adopted alternative methods, such as *sciage au fil sablé,* demonstrated by archaeological evidence, and possibly percussion, although the experimental results of the latter one are not entirely conclusive. The Bronze Age replicas used for the experimentation (pure copper, arsenical copper and bronze) appear to have been more effective in getting deeply into ivory, particularly the saws made of arsenical copper or bronze. We have not observed significant differences in the effectiveness of the two saws, nor in the extend of blade usage. As is the case with the Chalcolithic pure copper saw, the Bronze Age copper saw model could have been useful for sawing or dividing smaller pieces or segments of ivory. Since ivory has been regarded as a material of high social and economic value since prehistoric times, these tools enabled a controlled division of the raw material with the minimal loss of material during the working process. The development of different types and sizes of saws seems to demonstrate that Bronze Age craftspeople did not face the technical limitations seen during Chalcolithic times, and as a result, there are abundant traces of metal sawing documented, even for large portions of tusks.
Keywords: Ivory, technology, toolmark, copper tool, Iberian Peninsula.

Résumé : Les études technologiques récentes des objets en ivoire ibériques ont mis en évidence une grande variété de techniques et d'outils utilisés dans le travail de l'ivoire, mais peu d'attention a été accordée à l'utilisation de scies en cuivre, sous prétexte qu'elles seraient trop « tendres » pour être efficaces, une remarque qui, à ce jour, n'a pas été confirmée expérimentalement.

Au cours de 13 essais expérimentaux, nous avons testé des méthodes de segmentation des défenses d'éléphant, à la fois par des actions de pression dynamique (scie bidirectionnelle) et par percussion (percussion lancée tranchante). L'objectif principal du sciage était de vérifier, à travers l'expérimentation et en utilisant des répliques de scies archéologiques en métal fondu à base de cuivre, s'il était possible de subdiviser des matières premières aussi dures que l'ivoire d'éléphant. Le second travail expérimental visait à tester si la percussion avait également pu être utilisée à un moment donné comme technique de segmentation.

Les tests expérimentaux de sciage ont été réalisés à partir de répliques de scies archéologiques provenant du site chalcolithique de Valencina de la Concepción, ainsi que d'autres scies trouvées sur des sites de l'âge du Bronze, en particulier de la culture d'El Argar (El Argar et Ifre : fig. 1 et fig. 2). La découverte d'une série de scies dans les ensembles archéologiques, mais aussi dans des ateliers de travail de l'ivoire sur le site chalcolithique de Valencina de la Concepción et sur celui de Fuente Álamo, daté de l'âge du Bronze, nous ont, en outre, conduits à approfondir la question de l'usage de la scie métallique sur ces sites. Dans ces ateliers, au moins une partie de la chaîne opératoire du travail de l'ivoire a été documentée, bien qu'elle doive encore être précisée. Parallèlement, des indices de

travail d'autres matières premières (os, corne… sous forme d'éléments décoratifs fracturés et de déchets) présentent aussi des stigmates caractéristiques d'utilisation de scies métalliques (fig. 1). Pour l'expérimentation de la percussion, nous avons utilisé une réplique d'une hache en bronze (fig. 2).
En ce qui concerne les répliques des scies, nous avons voulu vérifier leur efficacité selon qu'elles aient été forgées (scie 0) ou non (scie 1), ainsi que leurs qualités et leur résistance en testant différents alliages : avec de l'arsenic à 2 % (scie 2) et avec de l'étain à 10 % (scie 3). Des mesures de dureté ont été faites sur différentes parties des lames de scies (tableau 1). L'expérimentation de sciage a été réalisée sur de l'ivoire tant sec que trempé, pendant des séquences d'action de 5 et 15 minutes.
Les résultats des tests expérimentaux montrent que toutes les scies, bien que rencontrant certaines difficultés, ont été capables de scier l'ivoire. La scie ayant donné les pires résultats de pénétration dans la matière a été la scie 1 (cuivre pur, scie réalisée sur une feuille préfabriquée), démontrant que le forgeage augmente la dureté et, par conséquent, les capacités de pénétration (scie 0). Il est surprenant de constater qu'entre la lame de scie en cuivre additionné d'arsenic (scie 2) et celle en bronze (scie 3), nous n'avons pas observé de différences significatives, ni dans les gestes ni dans la profondeur atteinte par ces outils. On notera cependant que la scie 3 a été la plus efficace (fig. 3). De plus, comme l'ont déjà souligné de nombreux auteurs (Pawlik, 1995 ; White, 1995 ; Christensen, 1999 ; Luciañez-Triviño, 2018), l'humidification de l'ivoire facilite quelque peu la pénétration dans la matière, mais ne semble pas fournir d'avantage notable par rapport à la coupe de l'ivoire à l'état sec.
Ces résultats semblent indiquer que les scies fabriquées dès le Chalcolithique étaient déjà capables de scier l'ivoire, malgré la dureté extrême de ce matériau. Le simple fait qu'elles aient été forgées, ou la teneur en impuretés associées aux minerais de cuivre (telles que l'arsenic dans la péninsule), a à l'évidence amélioré leur dureté et leur forgeabilité, entre autres. Cependant, bien que l'on connaisse des scies archéologiques à grande lame, la majorité d'entre elles présentent une taille moyenne, ce qui pourrait indiquer qu'elles n'étaient pas utilisées pour segmenter de grandes défenses mais plutôt des pièces de taille plus petite, ou encore pour créer des décorations sur les surfaces ivoirines. Les difficultés rencontrées pour pénétrer dans l'ivoire lors de l'utilisation de scies à base de cuivre auraient poussé les artisans à chercher d'autres solutions techniques pour segmenter de grandes défenses. Nous soutenons que le choix a été l'utilisation du sciage par abrasion avec une ficelle (sciage au fil sablé : fig. 4i et j), comme cela a été prouvé pour Valencina de la Concepción, et peut-être la segmentation par percussion. Toutefois, le test conduit par percussion tranchante (entaillage) à l'aide d'une hache en bronze a donné des résultats qui ne sont pas complètement compatibles avec les données archéologiques. Bien que cela reste incertain, nous suggérons que la défense de Valencina a peut-être été segmentée par un seul coup précis qui a séparé les segments de la défense.
Bien que les scies métalliques expérimentales imitant les modèles argariques de l'âge du Bronze ne changent pas substantiellement, en termes de types, par rapport au Chalcolithique, celles réalisées avec de l'arsenic et du bronze ont été plus efficaces pour pénétrer l'ivoire que celles en cuivre pur ou en cuivre forgé. Les scies de l'âge du Bronze semblent avoir été plus efficaces et capables de pénétrer en épaisseur, bien qu'avec certaines limitations. Leur emploi nécessite cependant un investissement considérable en temps. L'amélioration de l'efficacité des scies au cours de l'âge du Bronze pourrait également se refléter dans la présence de plus en plus fréquente de traces de sciage durant cette période, ainsi que dans l'absence d'indices de sciage au fil sablé pendant l'âge du Bronze en péninsule Ibérique.
Les artisans de l'âge du Bronze ont pu aussi se procurer des défenses déjà segmentées ou des disques d'ivoire. Ils pourraient enfin les avoir produits eux-mêmes à l'aide de grandes scies, telles que celles documentées sur certains sites de l'âge du Bronze.
Mots-clés : ivoire, technologie, trace technique, stigmate d'outil, outil en cuivre, péninsule Ibérique.

INTRODUCTION

Over the last decade, various archaeometric methods have enabled the identification and characterisation of diverse large teeth used in Prehistory. Among these, ivory (proboscidean tusks) remains the most common raw material in the Iberian Peninsula during both the Early and Late prehistoric periods. However, artifacts from other species such as sperm whale or hippopotamus have also been documented (e.g. Banerjee, 2002; López Padilla, 2011; Banerjee et al., 2012; Liesau von Lettow-Vorbeck and Moreno García, 2012; Schuhmacher, 2012 and 2016; García Sanjuán et al., 2013; Schuhmacher et al., 2013; Liesau von Lettow-Vorbeck and Cabrera Taravillo, 2024). These results suggest that not only larger items, such as containers, handles, or lids, held significant symbolic and economic value (Luciañez-Triviño et al., 2022), but also smaller objects like necklace beads or buttons conveyed prestige and meaning to their wearers, both in life and in death.

This study focuses on the segmentation of elephant tusks and the functionality of copper saws from Chalcolithic and Bronze Age sites in the Iberian Peninsula. The identification of saw marks on ivory artifacts from Chalcolithic (e.g. Nocete Calvo et al., 2013, p. 1582) and Iberian Bronze Age sites (e.g. López Padilla, 2011; Liesau von Lettow-Vorbeck and Schuhmacher, 2012; Barciela González, 2015; Liesau von Lettow-Vorbeck and Cabrera Taravillo, 2024) prompts our investigation into the efficiency of Iberian copper saws for ivory working.

From the beginning of the third millennium cal BC, copper-based saws in Iberia have been documented at several sites, alongside ivory, shell or bone materials bearing characteristic traces of metal sawing (e.g. Vargas Jiménez et al., 2012; Nocete Calvo et al., 2013). A great variety of saw types have been recorded since their earliest appearance: short, medium and long saws, with straight or curved edges (Ayala, 1991; Liesau von Lettow-Vorbeck, 2002). This variability may reflect different functions, as seen at the Chalcolithic site of Cabezo Juré (Huelva), a key metallurgical centre where diverse saw types were produced (Nocete Calvo, 2001, lám. 20, fig. 47) (fig. 1 a-e). Saws have also been found at various Bronze Age sites, particularly those associated with El Argar culture and related groups (Siret and Siret, 1890; Lull, 1983; Simón García, 1998; here fig. 1 h-m). During the Bronze Age (EBA and MBA), aside from the addition of rivets for handles and increased sizes, not major technological innovations in metal saws are documented until the Late Bronze Age, when band or double bow saws appear (Fernández Manzano, 1986; Liesau von Lettow-Vorbeck, 2002). Generally, saw finds from this period are rare, likely not due to reduced usage, but rather to the recurrent recycling of broken tools for casting new artifacts.

Most Chalcolithic and Bronze Age saws were made from copper with approximately 2% arsenic. It remains debated whether this was the result of intentional alloying or the natural presence of arsenic in the ore, given the great variability in the arsenic content observed in copper tools (Hook et al., 1987; Rodríguez Bayona, 2008, p. 162; Rovira Llorens, 2016), probably linked to the mineral source's heterogeneity. Regardless of origin, low levels of arsenic improve several mechanical properties of copper metallurgy (e.g. Charles, 1967; Northover, 1989; Budd and Ottaway, 1991; Montero Ruiz, 1994, p. 248; Lechtman, 1996; Rovira Llorens and Montero Ruiz, 2018).

To further explore the archaeological evidence, we present some experimental tests and discuss two sites with ivory artefacts and evidence of metal tool use: the Chalcolithic mega-site of Valencina de la Concepción (Seville; Vargas Jiménez et al.*,* 2012; Nocete Calvo et al., 2013, Luciañez-Triviño, 2018 and 2023) and the Bronze Age site of Fuente Álamo (Almería; Liesau von Lettow-Vorbeck and Schuhmacher, 2012; Schubart, 2012; Liesau von Lettow-Vorbeck and Cabrera Taravillo, 2024).

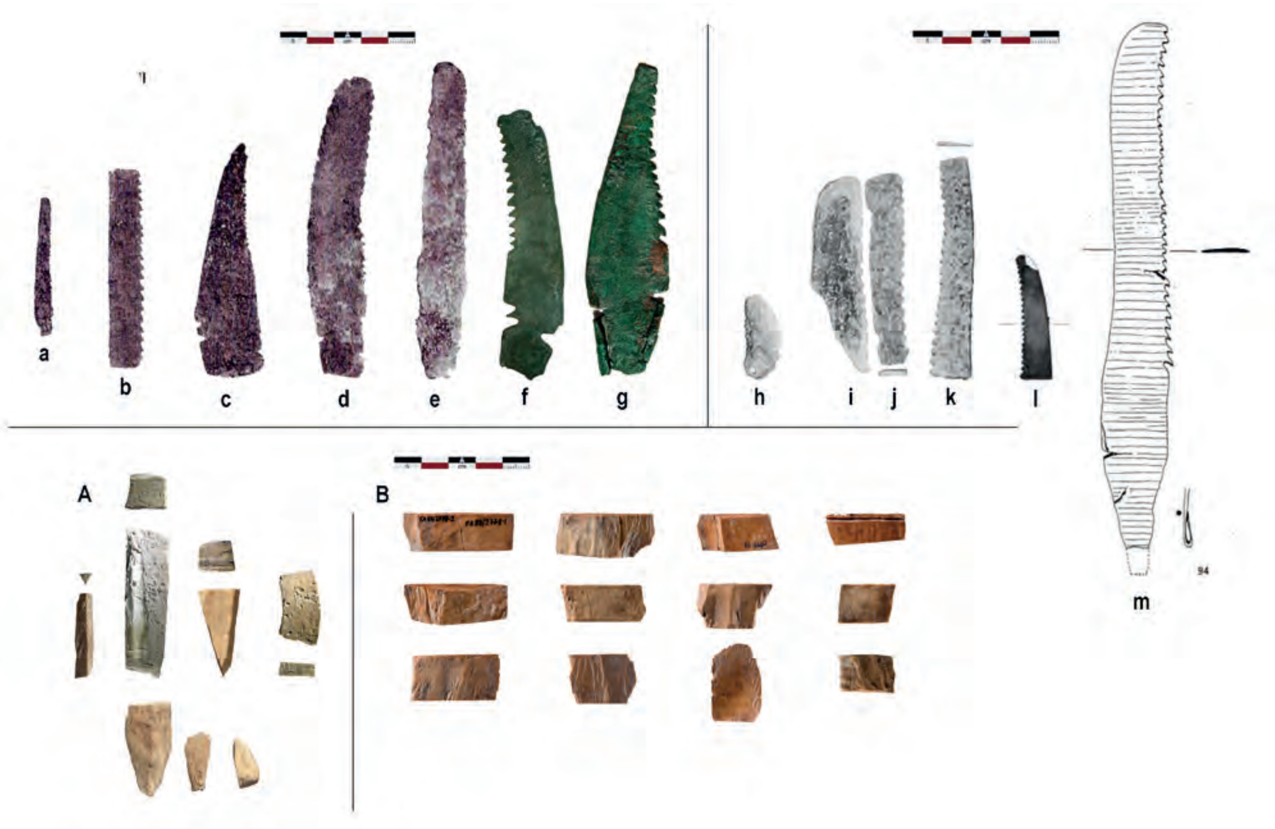

Fig. 1 – Selection of saws and production waste from the Iberian Copper Age (a-g and A) and Bronze Age (h-m and B): a-e) Cabezo Juré (Nocete Calvo, 2001; Nocete Calvo et al., 2013); f-g) Valencina de la Concepción (Luciañez-Triviño, 2018); h) Ifre (Siret and Siret,1890); i-j) El Argar (Siret and Siret,1890); k) El Oficio (Siret and Siret,1890); l) El Acequión (Benitez de Lugo Enrich, 2023); m) Niebla (Harrison and Craddock, 1981). A: productions wastes from Valencina de la Concepción (Structure 402);B: production wastes from Fuente Álamo (Liesau von Lettow-Vorbeck and Cabrera Taravillo, 2024, fig. 32). Photos: María Latova, DAI (from left to right) 15-2020-232; 15-2020-284; 15-2020-244; 15-2020-299; 15-2020-236; 15-2020-265; 15-2020-311; 15-2020-304; 15-2020-316; 15-2020-239; 15-2020-309; 15-2020-294).

***Fig. 1** – Sélection de scies et de déchets de production de l'Âge du cuivre ibérique (a-g et A) et de l'Âge du bronze (h-m et B) : a-e) Cabezo Juré (Nocete Calvo, 2001 ; Nocete Calvo et al., 2013) ; f-g) Valencina de la Concepción (Luciañez-Triviño, 2018) ; h) Ifre (Siret and Siret, 1890) ; i-j) El Argar (Siret and Siret, 1890) ; k) El Oficio (Siret and Siret, 1890) ; l) El Acequión (Benitez de Lugo Enrich, 2023) ; m) Niebla (Harrison and Craddock, 1981. A : déchets de production de Valencina de la Concepción (Structure 402), B : déchets de production de Fuente Álamo (Liesau von Lettow-Vorbeck et Cabrera Taravillo, 2024, fig. 3). Photos : María Latova, DAI (from left to right) 15-2020-3232 ; 15-2020-284; 15-2020-244; 15-2020-299; 15-2020-236; 15-2020-265; 15-2020-311; 15-2020-304; 15-2020-316; 15-2020-239; 15-2020-309; 15-2020-294).*

At Valencina de la Concepción, a partially excavated oval negative feature (Structure 402) contained bone, antler and small ivory fragments interpreted as manufacturing waste by the excavators. A copper saw was recovered from the same structure (fig. 1g), believed to have been used for working ivory and bone (Vargas Jiménez et al., 2010 and 2012, p. 78; Nocete Calvo et al., 2013). It was assumed that certain striations observed on some of these fragments were produced by sawing with a metal tool, possibly the copper saw found in the same structure (Nocete Calvo et al, 2013, p. 1587). The presence of only small fragments (production wastes, fig. 1A), without other technical categories such as blocks, blanks, or preforms, may indicate a specific space involved in a late stage of the *chaîne-opératoire* (Luciañez-Triviño, 2018, p. 205), or a waste disposal area.

At the Bronze Age site of Fuente Álamo, archaeological evidence points to at least three workshops: one from the Early Bronze Age and two from the Middle Bronze Age, which were identified through finds in two houses and a hilltop area. These included 11 fragments of sawed ivory discs from African steppe elephant tusks (fig. 1B), as well as fragments of objects such as a knob and broken bracelets. Small carving debris was also found, including a shell fragment (Charonia) with metal sawing marks (Liesau von Lettow-Vorbeck and Cabrera Taravillo, 2024).

1. EXPERIMENTATION

1.1. The raw material

Through a collaboration agreement, the ivory samples were provided exclusively for research purposes by the Ministry for Trade of the Government of Spain (Luciañez-Triviño, 2018). The raw material was considered unaltered, as it showed no fissures or cracks, or separation of growth rings. For these experimental tests, an African elephant tusk was used to segment it in two by direct hacking (*percussion lancée tranchante* in French, *levantamiento por percusión cortante directa* in Spanish, following the terminology of the Multilingual Lexicon of Bone Industries [Averbouh, 2016, p. 65]). For the sawing action two smaller half segments of ivory were used. The hacking action was performed on dry tusk, while for sawing, one dry piece and one that had been soaked the day before the experiment (15 hours submerged in river water at ambient temperature in a glass jar). In summary, the material was processed in two conditions: "unaltered dry ivory" and "unaltered soaked ivory."

1.2. Experimental tools

Two tests were carried out: 1) sawing with copper-based saws, and 2) cutting percussion using a bronze axe (handled like an adze).

For the first experimental test, four saws were employed (fig. 2). Saw 0 replicates the morphology of a saw from the Chalcolitic site of Valencina. It is made of 99.9% pure anodic copper and manufactured using a combination of thermal and mechanical treatments after casting and melting, a process identified in metal production in Valencina (Rodríguez Bayona, 2008, p. 172). The other three saws were designed based on models from El Agar culture of the Bronze Age: Saw 1 is made of pure copper, Saw 2 of arsenical copper (2% As), and Saw 3 is a bronze artifact (90% Cu-10% Sn). Except for Saw 1, both Saw 2 and Saw 3 sections feature a broader base than top, resembling an artefact from de El Oficio site (Siret and Siret, 1890, fig. 2 and fig. 48; here fig. 1k). These Bronze Age models had previously been employed in other experiments using various raw materials, including wood, antler, and both dry and fresh bone (Liesau von Lettow-Vorbeck, 1998 and 2002).

The hardness of all metal saws was measured using a diamond pyramidal tip durometer (FUTURE-TECH FM700) at the Institute of Materials Science of Seville (ICMS), providing hardness values in the Vickers scale (Hv; table 1).

Given the evidence of a possible cutting plane from hacking percussion on a tusk from Valencina (Luciañez-Triviño, 2018 and 2023; here fig. 3a-d), we also decided to test this technique. Axes from Valencina are typically massive, heavy and large (Cabrero García, 1985, Murillo Díaz et al., 1988; Arteaga Matute and Cruz Auñón-Briones, 2001; Nocete Calvo et al, 2008; Vargas Jiménez et al., 2010; López Aldana and Pajuelo Pando, 2013), making it unfeasible to replicate one for testing. Instead, we used a bronze axe replica (lent by Dr. N. Provenzano; here fig. 2) to study the marks produced on ivory.

1.3. The conducted experimentation

It is important to first clarify the terminology of this article, specifically what we mean by "sawing" and "transversal". We define sawing as the technique that, through pressure and a back-and-forth motion, is used to gradually penetrate the raw material with a tool featuring an active cutting edge. "Transversal" indicates the direction of the action relative to the longitudinal axis of the tusk (longitudinal axis = from the base to the tip).

Sawing was carried out on a half segment of ivory, specifically on its convex side, which corresponds to the outer surface of the tusk. The sawing tests were conducting using all four saws, with time intervals of 5 and 15 minutes for dry ivory, and 5 minutes for soaked ivory.

Direct hacking (*percussion lancée tranchante)* was carried out without a fixed time limit. The action took approximately half an hour to fully separate the dried tusk into two parts. First, the tusk was held at its proximal end, positioned vertically but slightly inclined, with the tip resting on a padded surface. The action was then performed peripherally, gradually increasing the tilt. The tusk was held with the left hand (fig. 2) so that the axe could be wielded with the right.

Fig. 2 – Experimental tools used.
***Fig. 2** – Outils expérimentaux utilisés.*

Measurements	SAW 0	SAW 1	SAW 2	SAW 3
1	108,9	66,5	133	222,1
2	132,3	66,9	147,5	196,3
3	137,6	64,9	105,1	160,1
4	140,8	75,1	118,3	238
5	147,4	74,1	126,4	200,1
6	134,6	72,2	137,3	159,8
7	132,5	80,3	137,9	161,8
8	157,8	77	127,8	212,9
9	113,8	69,6	147,6	184,9
10	118,8	80,7	134	194,3
11	136,9	60,9	127,3	203
12	122,5	63,3	117,2	228,9
13	147,1	59	130,3	191
14	128,8	62,3	116,1	211,7
15	110,3	63,7	107,6	236,1
16	130,3	62,4	116,6	329
17	140,3	62,9	117,3	177,4
18	148,7	63,3	126,9	180,2
19	154,7	62,4	117,9	203,7
20	138,4	62,5	120,4	212,9
Average	134,125	67,5	125,625	205,21
Standard dev.	13,951	6,708	11,707	37,407

Table 1 – Hardness measurements of the experimental saws (hardness values in the Vickers scale, Hv).
***Tabl. 1** – Mesures de dureté des scies expérimentales (valeurs de dureté sur l'échelle Vickers, Hv).*

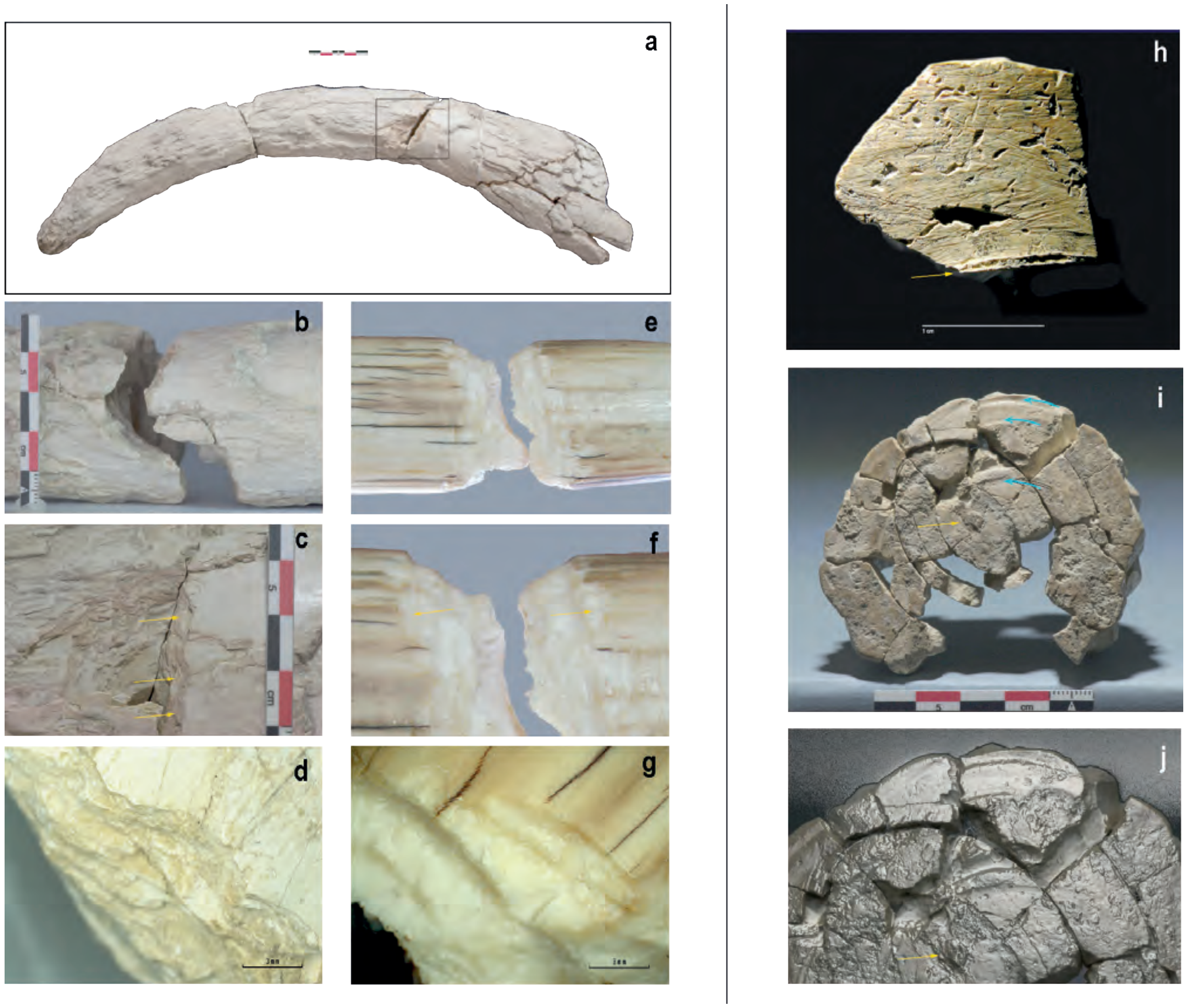

Fig. 3 – Archaeological and experimental examples of percussion and sawing. a: tusk from structure 10.042-10. 049 from Valencina (Ivory Lady tomb); b-d: traces on tusk (a) of possible cutting percussion; e-g: experimental traces of cutting percussion with bronze axe; h: evidence of sawing and bending in material from Valencina (Estructure 402); i-j: evidence of sawing by abrasion in ivory vessel from structure 10.042-10.049 from Valencina.

Fig. 3 *– Exemples archéologiques et expérimentaux de percussion et de sciage. a : défense de la structure 10.042-10. 049 de Valencina (tombe de la Dame d'Ivoire) ; b-d : traces techniques d'une possible percussion tranchante sur la défense (a) ; e-g : traces expérimentales de percussion tranchante avec une hache en bronze ; h : traces de sciage et de flexion sur du matériel de Valencina (Estructure 402) ; i-j : traces de sciage par abrasion sur un récipient en ivoire de la structure 10.042-10.049 de Valencina.*

2. RESULTS

Figure 4 illustrates the groove sections produced by sawing on both dry and soaked ivory. Each experimental saw created grooves with distinct shapes—reflecting the geometry of the cutting edge—but similar depths when used for the same duration. Notably, sawing grooves on soaked ivory were consistently deeper across all time intervals.

When sawing dry ivory, Saws 0 and 1 (both pure copper) encountered similar difficulties in penetrating the ivory, producing shallow grooves even after 15 minutes of sawing. Saw 1 was particularly ineffective, as its blade became completely stuck in the groove, preventing further progress. After 15 minutes, the blades of all saws were noticeably hot, and sawing could not continue in a single direction. The sawing action of Saw 2 (arsenic copper) performed better initially, but after 3 minutes, bidirectional action was no longer posssible, and the tool got stuck after 13 minutes. With Saw 3 (tin-copper), the initial 5 minutes of bidirectional sawing action was easy, although sawdust removal became necessary. Overall, Saws 2 and 3 showed little difference in performance.

When sawing soaked ivory, Saws 0 and 1 often slipped out of the sawing groove, but both remained functional for up to 15 minutes. Saws 2 and 3 performed similarly to Saw 1 up to 15 minutes but achieved greater depth into the material within the same time frame. Soaking proved most effective only at the beginning of the sawing pro-

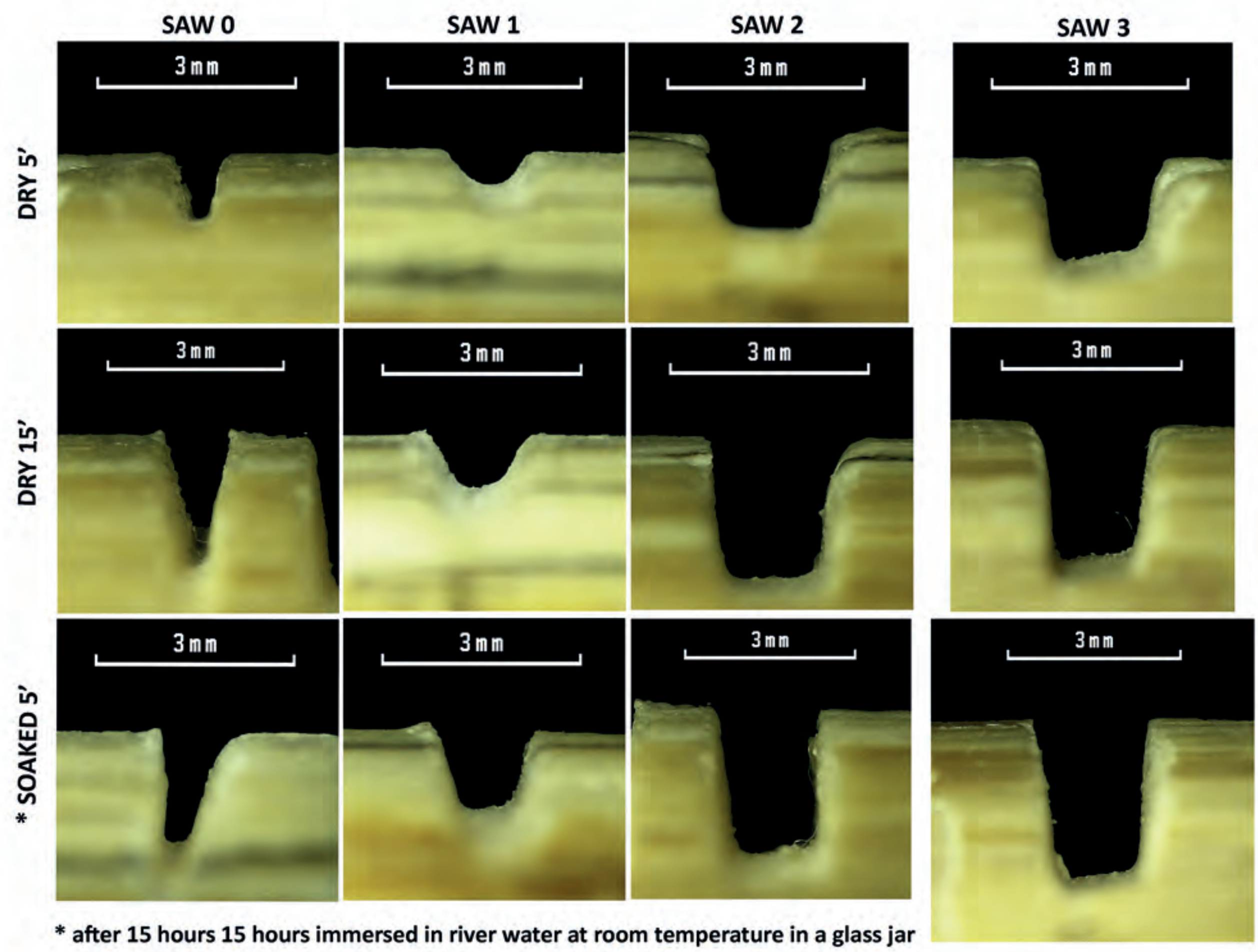

Fig. 4 – Profile of the grooves obtained through experimental sawing.
Fig. 4 – *Profil des rainures obtenues par sciage expérimental.*

cess compared to dry working, as water penetrates the ivory just a few millimeters before being expelled, leaving the ivory dry within minutes. During wet sawing, the removed material (ivory shavings and dust) adhered to the tool surface, forming a dense paste that increased the friction and hindered movement.

It should be noted that, under all working conditions, Saw 1 produced the poorest results in terms of penetration, possibly due to its low hardness (67.5 Hv). Saws 2 and 3 achieved similar depths and produced grooves with flat bottoms and straight, parallel walls. In contrast, Saw 0 (134 Hv) penetrated to nearly the same depth as Saw 2 (125 Hv) and Saw 3 (205 Hv), when used on dry ivory, but produced much narrower groove with a tight V-shape, clearly reflecting the shape of its cutting edge. Comparing the two pure copper saws, we observe that Saw 0 (manufactured using thermal and mechanical treatment) achieved a hardness of 134 Hv, while Saw 1, made from a standardized sheet of pure copper (Liesau von Lettow-Vorbeck, 2002, p. 276), reached a hardness of 67.5 Hv. As a transversal result of this experimentation, this suggests that the manufacturing method of Saw 0 significantly increased the hardness of the metal, regardless of its arsenic content, which in this case was zero.

In the cutting percussion test using the axe, considerable material loss was observed in the impacted area, resulting in a wide, very open V-shaped notch with a "chipped" appearance. Overlapping detachments were visible (see fig. 3 f, g), along with a large tongue of ivory produced by the final cut that completed the segmentation of the tusk (fig. 3e).

3. DISCUSSION

The experimental results demonstrate that all the saws are capable of penetrating and sawing ivory, and that soaking somehow improves the workability of the material. The effectiveness of soaking is a subject of debate, with differing critical perspectives (Hahn et al, 1995; White, 1995; Christensen, 1999; Steguweit, 2010; Hein, 2014). However, many authors, including ourselves, have observed that soaking improves the workability of ivory only at a superficial level and for a short period of time (a few minutes).

General observations concerning the sawing action with copper-based tools suggest the following: a) the shape of the cutting edge and the hardness of the tools are of considerable significance; b) friction within the groove and the inability to progress beyond a certain depth was observed for all the saws; c) the edges of the saws heat up during use; d) working with soaked ivory provides only limited advantage.

From an archaeological perspective, sawing marks are mostly found on small, thin items. There is little evidence of unidirectional sawing, likely because, after a certain depth, friction within the groove prevents further movement. Therefore, sawing likely progressed around the periphery of the block, always in a back and forth movement. Flexion tongues are frequently observed on the sawing planes of archaeological material. These projections indicate that sawing did not continue to completion, and the material was ultimately separated by bending (fig. 3h).

Overall, we propose that the Chalcolithic saw from Valencina was not suitable for all stages of obtaining large ivory supports, nor for operations requiring the cutting of thick sections. We suggest that the limited effectiveness of some Chalcolithic saws likely led artisans to explore alternative segmentation methods for large tusks. These may have included abrasion sawing with a cord (s*ciage au fil sablé;* here fig. 3i and fig. 3j), as demonstrated at Valencina de la Concepción (Luciañez-Triviño, 2023) or cutting percussion. Nevertheless, our experimental tests with percussion yielded only partial compatibility with the evidence from the tusk found in burial 10.042-10-049 at Valencina (fig. 3). This tusk, approximately 5 cm in diameter, appears to have been segmented using a sharp tool and percussion, with the action carried out from only one side. The final blow likely detached the tusk, leaving a large flexion tongue on the opposite face as evidence. The observed features and its preservation suggest that the tusk was already 'aged' at the time of segmentation. Nevertheless, cutting percussion requires further experimental validation.

The morphology of Bronze Age saws, despite some limitations, seems to have been more efficient, capable of penetrating greater thicknesses, albeit with a significant time investment. These improvements may be reflected in the increasing presence of sawing marks on other extremely hard materials such as hippopotamus teeth or large marine gastropod shells, in contrast to the earlier period. Notably, to date there is no evidence of *sciage au fil sablé* in peninsular Bronze Age materials. Metal sawing marks are well documented in numerous Bronze Age collections across the Iberian Peninsula (e.g., Barciela González, 2007, 2012 and 2015; López Padilla, 2011; Liesau von Lettow-Vorbeck and Schuhmacher, 2012; Liesau von Lettow-Vorbeck and Cabrera Taravillo, 2024) including for sawing a distal portion of elephant tusk at the Bronze Age site of Tabayá (López Padilla, 2011, p. 318, fig. V.1.20).

The use of segmentation techniques that do not involve metal tools challenges the assumption that metal sawing was the preferred or exclusive method for all stages of ivory working. However, all these saws were likely effective for cutting smaller pieces of ivory, producing smaller supports and objects, removing small sections or creating decorative elements.

Whatever prior manipulation may have occurred with elephant tusks, the evidence from Valencina de la Concepción demonstrates the use of "*sciage au fil sablé*", probably indicating no previous soaking. In contrast, Bronze Age craftspeople may have received segmented tusks or ivory discs or produced them using large saws, as documented at some Bronze Age sites. Although we have only focused on sawing and percussion as segmentation techniques, the archaeological record reveals abundant traces of other possible tools and procedures. These findings not only demonstrate a deep understanding of the treatment of the raw material, but also highlight the wide range of techniques and specialized tools used in the production of complex artifacts and personal adornments.

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Miriam Luciañez-Triviño
Universidad del País Vasco UPV/EHU,
Departamento de Pintura
(Área de Conservación y Restauración),
Facultad de Bellas Artes, Leioa, Spain
miriam.lucianez@ehu.eus

Corina Liesau von Lettow-Vorbeck
Universidad Autónoma de Madrid,
Departamento de Prehistoria y Arqueología,
Madrid, Spain
corina.liesau@uam.es

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