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Life and Death of Middle Bronze Age axes. The case of the Medocan hoards

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Abstract: The successive discoveries of two Middle Bronze Age flanged axe-heads hoards on the shores of Lake Léon (Landes, France) provided an opportunity to reassess the question of standardisation and homogeneity among so-called Médoc-type axes, characteristic of southwestern France between the 16th and 14th centuries BCE. This era is marked by a high density of metal hoards outside any known domestic or funerary context, especially large trapezoidal axe-heads averaging 740 g in weight and 20 cm in length. Between the rescue excavation of the first hoard in 2017 (30 axe-heads) and the excavation of the second in 2024 (10 axe-heads), an analytical protocol was developed to characterise the production and deposition of these artefacts. Based on an extended corpus of more than 300 Médoc-type axe-heads, the study examined morphology, mass, alloy composition, metal provenance, and traces of use and discard. Even if the whole protocol could not be applied on all the objects, the results are already significant.
3D morphometric analyses reveal the existence of replicas cast from shared moulds: within the Léon hoard, only eight axe-heads are unique, while the others fall into distinct groups of duplicates. Certain similarities between Médoc and Landes assemblages suggest regional technical networks. However, statistical analysis of weights and volumes shows no metrological regularity, ruling out any hypothesis of weight-based standardisation or monetary use. The relative homogeneity observed may instead reflect technical constraints or workshop-specific manufacturing habits.
Macroscopic observations confirm actual use and partial resharpening of cutting edges, implying the deposition of still-functional tools. Elemental and isotopic analyses indicate a homogeneous bronze derived from a single metal source and the axe-heads were probably cast from a single batch. Considering an extended corpus, the deposition practices (axe-heads set vertically with edges facing upward, often in wetland contexts) suggest a repeated, possibly ritualised behaviour at a regional scale within the atlantic area. Overall, the results point to coordinated production and deposition within a shared technical and symbolic tradition, locally differentiated through subtle variations. This protocol aims to be applied to other hoards to refine the conclusions.

Keywords: Aquitaine (France), Médoc (France), Middle Bronze Age, Atlantic Bronze Age, flanged axe-heads, hoard, standardisation, 3D morphometry, archaeometallurgy, lead isotope analysis.

Résumé : Les découvertes successives de deux dépôts de haches à rebords de type médocain de l'âge du Bronze moyen, sur les berges du lac de Léon (Landes), ont offert l'occasion de réactualiser les hypothèses relatives à la standardisation et à l'homogénéité de cette typologie de lames, caractéristique du Sud-Ouest de la France. Le phénomène médocain du Bronze moyen (xvi^e^-xiv^e^ siècle av. J.-C.) se caractérise par une forte densité de dépôts métalliques, sans qu'aucun lien n'ait pu être établi avec des structures domestiques ou funéraires. Ces dépôts sont essentiellement composés de lames de hache trapézoïdales massives, pesant en moyenne 740 g pour une vingtaine de centimètres de longueur. Ces objets se concentrent principalement en Aquitaine et sur ses marges.
Entre le sauvetage du premier dépôt de Léon en 2017 (trente haches) et la fouille en caisson du second en 2024 (dix haches), un protocole d'analyse a été élaboré afin de caractériser la production et les conditions de dépôt de ces objets. Ce protocole, appliqué d'abord au cas de Léon, puis étendu au corpus des lames de haches médocaines conservées au Musée d'Aquitaine et aux mesures de plus de trois cents exemplaires étudiés antérieurement, vise à déterminer le degré d'homogénéité du corpus à travers plusieurs critères : morphologie, masse, composition métallique, provenance de la matière première, traces d'usage et modalités d'abandon. Tous les volets n'ont pu être appliqués à l'ensemble du corpus, mais les résultats obtenus sur des échantillons représentatifs permettent déjà d'en évaluer la pertinence.
L'étude morphométrique, fondée sur la photogrammétrie et le scanner 3D, met en évidence une variété de formes limitée et l'existence de répliques issues de mêmes moules. La comparaison des modèles virtuels révèle des défauts de coulée similaires, confirmant la production sérielle à partir de moules communs, notamment au sein des dépôts. Dans le dépôt 1 de Léon, seules huit lames de hache sur trente sont uniques, les autres se répartissant en huit groupes correspondant à des moules ayant servi plusieurs fois. Certaines similarités interrégionales (entre objets landais et médocains, de part et d'autre de l'estuaire de la Gironde) suggèrent des traditions techniques

partagées, sans toutefois permettre d'affirmer l'usage de moules identiques.
L'analyse statistique des masses et volumes ne met en évidence aucune construction métrologique stable : aucune standardisation n'apparaît à l'échelle du corpus, écartant ainsi l'hypothèse d'un rôle monétaire de ces lames de hache par un critère pondéral. La relative homogénéité massique observée pourrait découler de contraintes techniques ou d'habitudes de fabrication propres à certains ateliers. Les variations de masse et de volume entre dépôts témoignent d'une production diversifiée, sans contrôle normatif strict.
Lorsque l'état de conservation le permet, l'examen macroscopique des tranchants montre des traces d'utilisation et d'affûtage fréquentes, notamment dans les dépôts monofonctionnels composés uniquement de lames de hache. Pour Léon, près de la moitié des exemplaires présentent un tranchant « asymétrique », indiquant un affûtage encore possible du côté opposé au tranchant émoussé. Ces observations suggèrent que les lames de hache ont eu un cycle de vie court, depuis leur fabrication jusqu'à leur dépôt pouvant sembler prématuré du point de vue fonctionnel, et peut-être dévolues à un usage très spécifique. L'analyse élémentaire des alliages révèle une composition homogène : le bronze ne comporte pas d'adjonction significative de plomb et présente un ratio cuivre/étain stable autour de 6:1, en accord avec la tendance régionale du corpus médocain. Les analyses isotopiques du plomb indiquent une origine commune du métal employé, suggérant l'usage d'un lot unique de matière première (probablement d'environ 20 kg), suffisant pour produire les trente lames de hache du premier dépôt de Léon. Ces données témoignent d'un approvisionnement structuré, peut-être fondé sur des échanges réguliers entre la côte orientale du golfe de Gascogne et une source métallifère spécifique.
L'étude des rares dépôts en place révèle enfin des similitudes notables dans les pratiques de dépôt. À Léon comme à Saint-Germain-d'Esteuil, les lames de hache sont déposées verticalement, tranchant vers le haut, parfois surmontées d'un ou plusieurs exemplaires disposés horizontalement. Des dispositions comparables sont observées pour les dépôts de Soulac-sur-Mer à l'extrême nord du Médoc, ainsi qu'ailleurs le long de l'Atlantique. Cette récurrence des gestes de dépôt, associée à la localisation fréquente des dépôts à l'interface entre milieux humides et secs, suggère une pratique ritualisée, inscrite dans des traditions régionales cohérentes dans le domaine atlantique, bien que présentant des variantes locales (présence de contenants, nombre et types d'objets).
En croisant l'ensemble des résultats (morphologiques, métallurgiques et contextuels) il apparaît que les lames de hache de Léon ont été fondues à partir d'un même lot de métal et déposées dans un intervalle de temps restreint. Plusieurs exemplaires ont été conçus pour un usage très spécifique, au vu de leur dépôt alors même que l'outil est encore utilisable : la finalité de ces objets était ainsi probablement anticipée dès leur fabrication. En observant un corpus plus large, l'homogénéité des formes, des compositions et des modes de dépôt traduit ainsi l'existence d'une tradition technique et symbolique commune à l'échelle régionale, tout en conservant des particularismes propres à certains groupes ou ateliers.
Ce protocole fondé sur la confrontation de données morphométriques, analytiques et contextuelles, constitue une base de travail innovante pour l'étude des dépôts du Bronze moyen dans le Sud-Ouest de la France. Son application à d'autres ensembles permettra d'affiner la compréhension des dynamiques de production, d'échange et de dépôt, et d'approfondir la question du rôle social et symbolique de ces objets dans les sociétés du Bronze moyen aquitain.

Mots clés : Aquitaine (France), Médoc (France), âge du Bronze moyen, Bronze atlantique, hache à rebords, dépôt, standardisation, morphométrie 3D, archéométallurgie, analyses isotopiques.

One of the most spectacular manifestations of the complex relationship between economy, technology and the symbolic sphere during the Middle Bronze Age (MBA) in south-western France (16th-14th centuries BCE), mainly in the most recent phases of this period (15th-14th centuries BCE), is the hoarding of large quantities of metal objects, mainly axe-heads, in a context where settlement and funerary patterns remain otherwise almost unknown. This regional phenomenon, well known in many other parts of Europe, has received attention in recent times. Céline Lagarde-Cardona has provided, in the framework of a larger synthesis about MBA metallurgy, a comprehensive approach of the hoards, of their composition, and the metallurgical techniques implemented in the making of the objects (Lagarde-Cardona, 2012). Some years later, Florian Couderc offered a synthesis focusing on the spatial distribution of these hoards in the specific area of the Medoc, west of the mouth of the Garonne River (Couderc, 2017). Both works offered a synthesis about the dynamics of the investigation from the late 19th century to the beginnings of the 21st. We will therefore limit ourselves, in this introduction, to summarize the main aspects of this process.

In the south-western Atlantic region, from the Charente River almost to the Pyrenees in the south, during the Middle Bronze Age, hoarding became quite a common practice while it was not frequent in the Early Bronze Age (fig. 1). 98 hoards have been found, among which 57 were located in the Medoc, the area where this process is the densest. Most of the hoards included exclusively axes-heads: in the Medoc, it was the case of 43 out of 57 of them. The most frequent type of axe-head (618 out of 822 in Aquitaine, 330 out of 403 in the sole Medoc: Couderc, 2017, p. 543) corresponds to a flanged axe having the general shape of a trapeze, weighing generally between 400 and 800 g, considered local and therefore named 'medocan axe' (*hache médocaine*). In most cases, the exact context of the discovery is unknown, but F. Couderc (2017, p. 544–554) demonstrated that in the Medoc most of the hoards were located at the interface between wet- and drylands. These axe-heads are sometimes associated with others from other origins (Central and northern Atlantic France, continental, mediterranean: Couderc, 2017, p. 543) but they can also provide the totality of the hoard, especially in the southern areas. It is for instance the case for two hoards studied for the first time in this paper, found at the southern edge of the lake of Léon (Landes).

There were few proposals of interpretations to explain this phenomenon in its regional context, beside the initial proposal of possible hiding places (Couderc, 2017, p. 531). Couderc emphasized the fact that the core region

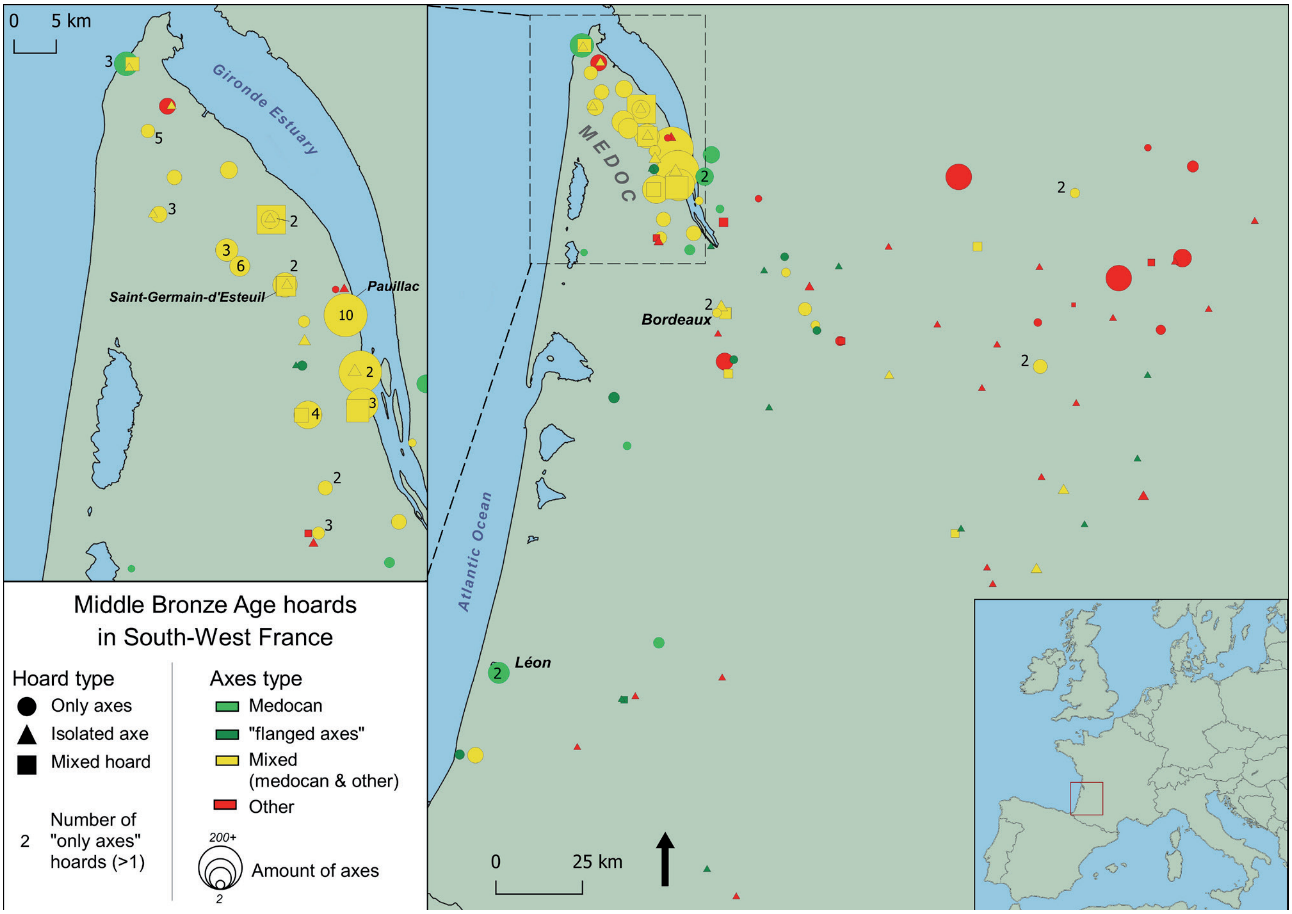


Fig. 1 – Map with location of the area of study. Left: the Medoc area.

where these hoards are observed is well connected to MBA long-distance trade networks, while it is deprived of the minerals allowing for copper-alloy metallurgy. In his opinion, the intensity of the hoarding practices would reflect the intensity of trade, and the location of most of the Medoc hoards near wetlands would be linked to the importance of sea- and river borne trade. Moreover, this phenomenon would have to be understood in a ritual framework (Couderc, 2017, p. 545–550).

In 2017, the recovery *in situ* of a MBA axe-heads hoard in Léon (Landes) gave the opportunity to extensively study the hoard itself and all the objects that were deposited in it (Gestreau, 2018). Later on, the mass removal of a second hoard, distant *c.* 30 m from the first one (Ihuel et al., 2021), and its subsequent excavation in laboratory offered a similar possibility. These discoveries have led to the elaboration of a study protocol allowing for a biographical study of the axe-heads, from their making to their burying. It involves analytical methods, 3D imagery, mathematic and statistical analyses, and very classical macroscopic observations. It was later extended to a larger corpus, with important context-dependant variants from one case to another. The results of this study are presented here.

Through the implementation of this protocol, we would like to address the specific question of the heterogeneity vs. the homogeneity of the hoarded axe-heads. This concerns chiefly their shape, volume and mass, all topics often linked with the issue of standardization. Standardization is itself linked with the idea that these hoards could have been a reserve of value and that the axe-heads could have been actually some form of currency. Even if the hypothesis has been rarely formulated concerning Medocan flanged axe-heads hoards, it appears frequently for explaining similar processes in different regions, especially since the 1980s and the researches of Jacques Briard on Armorican socketed axes (Briard, 1987a; 1987b; 2001; Briard and Rivallain, 1987).

We aim here at assessing if Medocan axe-heads were or were not standardized. Homogeneity and heterogeneity can also characterize the metal itself, its origins and the making of the alloy. Recent progress into research have shown that scales of integration regarding Bronze Age metal trade were underestimated (Ling et al., 2013; 2014; Melheim et al., 2018), while the intensity of recycling can in contrast have been overestimated. A long-distance, dense and permanent flow of metal seems to have characterized most of the Middle and Late Bronze Age, rather than scarcity and local recycling. In such cases, the relation between the metal supply chain, the making of the object, its use and hoarding must be reconsidered, as well as the temporality of this chain of events. The use(s) of each one of the axes could also be similar or on the contrary dissimilar, with an underlying question: did all the axe-heads deposited in the same hoard have had a similar use, or on the contrary were they similar objects having been used for different purposes? Last, but not least, the motives for their final burying may be quite the same from hoard to hoard, but may on the contrary vary, and depend on the history of each object or of the assemblage to which they belong. In other words, we intend to consider the biography of the hoarded Medocan axes, from their birth to their burying.

DATASET CONSTITUTION

Our dataset gathers 370 axe-heads, directly examined by us or known through the bibliography, belonging to 21 hoards. This material may have been recovered during archaeological excavations of some hoards but, more often (in the many cases of old discoveries) the recovery occurred without real archaeological supervision. Among this dataset, 117 axe-heads were recorded in 3D using photogrammetry and/or 3D scanning (see *infra*). Two hoards found on the shores of the Lake of Léon (Landes, France), gathering in total 40 axe-heads, have been directly observed by members of the team at each step of their recovery and study.

The hoards from Léon

In 2015, two hoards were identified by metal detectorist Marc Houzé at the southern edge of the Lake of Léon (Landes, France). Both were recovered by archaeologists of the French Ministry of Culture, the first one (hoard 1) in 2017, the second one (hoard 2) in 2021 (Gestreau, 2017; Ihuel et al., 2022). One axe-head belonging to hoard 2 was retrieved at the moment of its discovery in 2015. Distant of about 30 m, both were exclusively constituted of flanged bronze axes of the Medocan type (fig. 2). Both were underwater, but very close to the surface, at the time of their recovery (fig. 3). The area where they were found had been removed in the recent past (the 1960's), when the shores of the lake were landscaped (fig. 4); a survey was made, but did not allow for the discovery of any other archaeological feature than the pits where the objects were placed. The first hoard (Léon, hoard 1) was excavated on the spot, by scuba diver Grégory Bonnin, in 2017. Observations were complicated: as a result of the shallow depth of the hoard, a lot of suspended particles obscured the water. The hoard was constituted of 30 bronze axe-heads. 28 among these 30 axes were found in primary position, inside a 30 cm diameter pit, while 2 others were found lying at the bottom of the lake previously to the excavation (fig. 5). It is very possible that they were indeed in horizontal position on top of the hoard, as in Le Chalet hoard 2 (Saint-Germain-d'Esteuil, Gironde: Roussot-Laroque, 1999). The pit was 50 cm deep, and the axe-heads were laid standing on 3 levels, with the blade oriented upward or downward, sometimes alternatively. The top level gathered 7 axe-heads found in primary position. The medium level gathered 8 axe-heads,

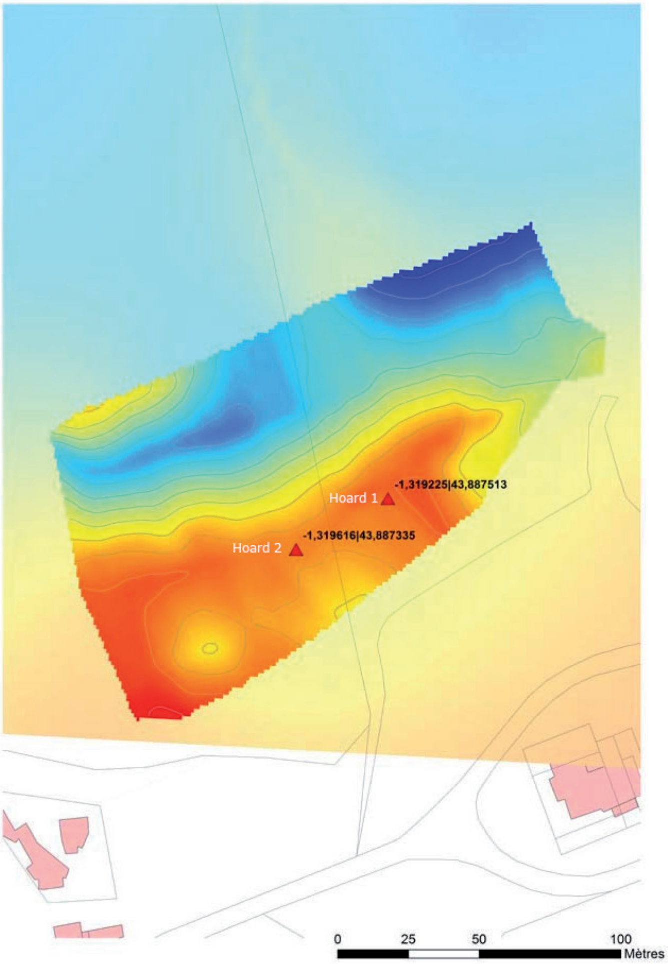


Fig. 2 – Location of the two hoards from Léon Lake (Landes, France). From Gestreau, 2018, fig. 7, p. 6.

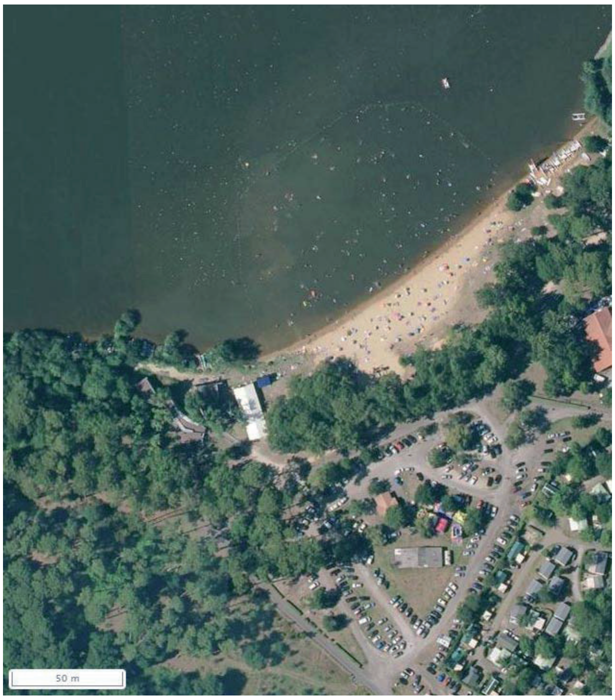


Fig. 3 – Léon Lake, southern shore, where the hoards were found. From Gestreau, 2018, fig. 2, p. 4.

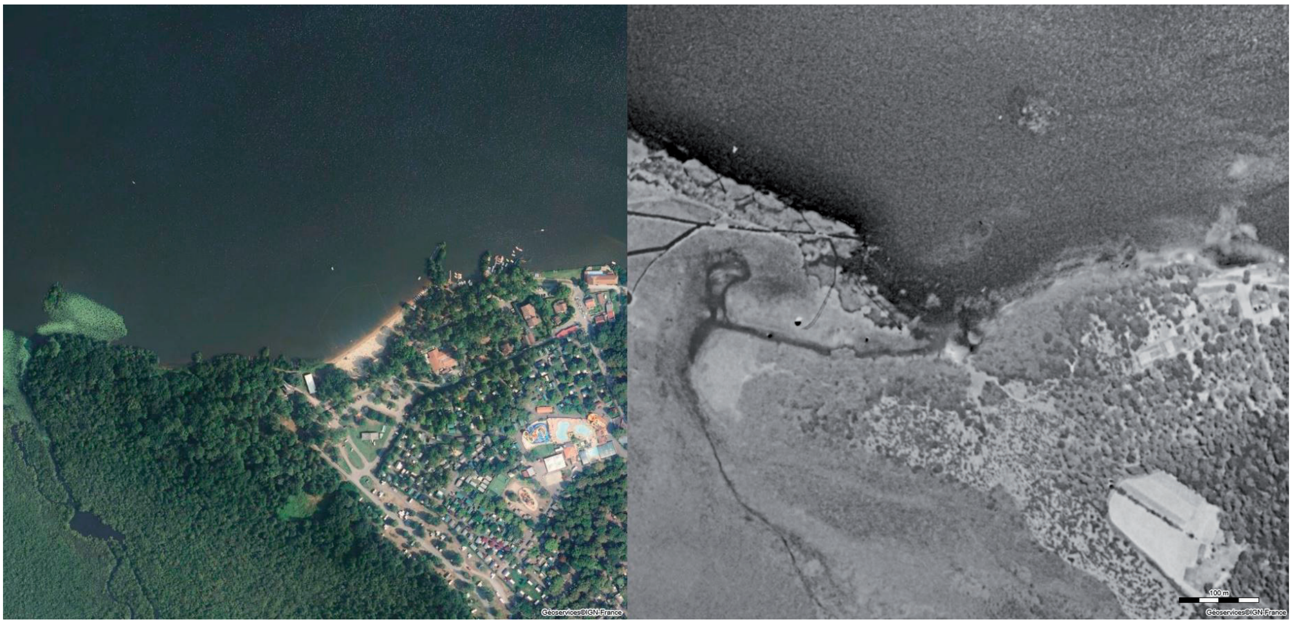


Fig. 4 – Léon Lake, southern shore, nowadays compared with 1964. From Gestreau, 2018, fig. 3, p. 4.

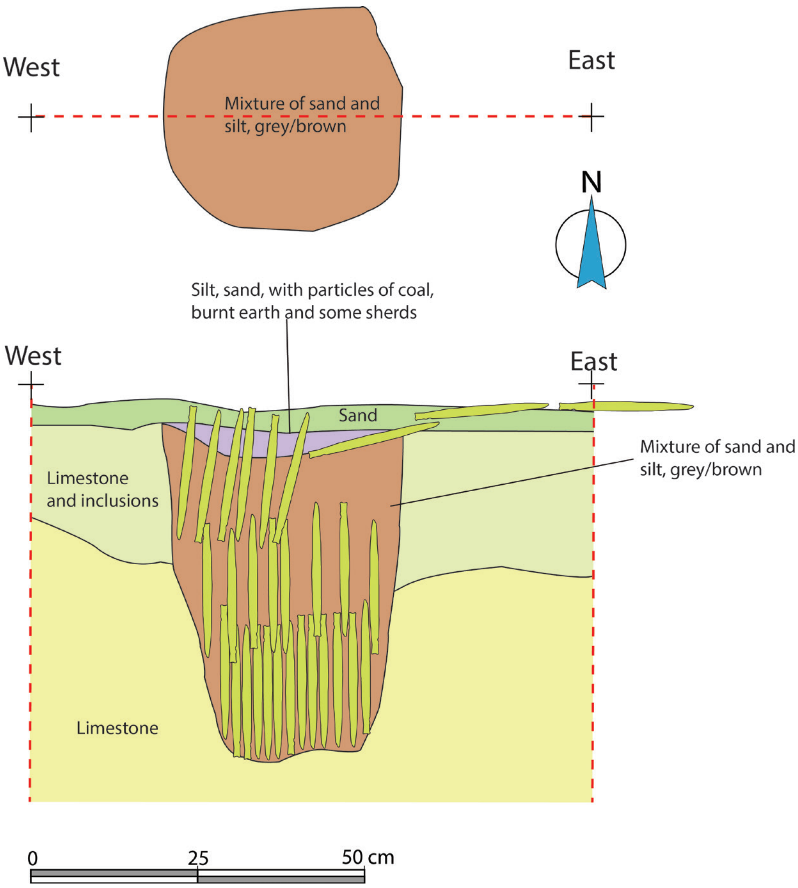


Fig. 5 – Schematic plan (up) and section (down) of Léon hoard 1, after Gestreau, 2018, fig. 8 p. 7, redrawn.

while the bottom one was made of 13 axe-heads. They were not systematically adjoined, which probably means that the pit was filled with earth (a greyish mixture of sand and silt) while the axe-heads were buried, or that they were maintained by some perishable material later substituted by colluvium (Gestreau, 2018).

The second hoard (Léon, hoard 2) was also detected in 2015, some 30 m east from hoard 1 (fig. 6). One axe-head, also lying on the bottom of the lake, was retrieved at the time of its discovery (fig. 7, no. 1). In order to optimize the

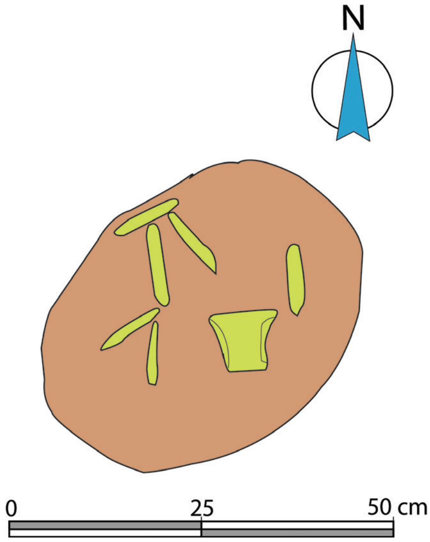


Fig. 6 – Schematic plan of Léon hoard 2, before its retrieval. From Gestreau, 2018, fig. 10, p. 9.

possibilities for direct observation, and given the absence of surrounding archaeological context, the hoard was extracted as a single mass in September 2022 for allowing an excavation in a laboratory. A barrel was driven into the ground around the hoard and extracted with an excavator. However, the bottom piece that was supposed to close the lower

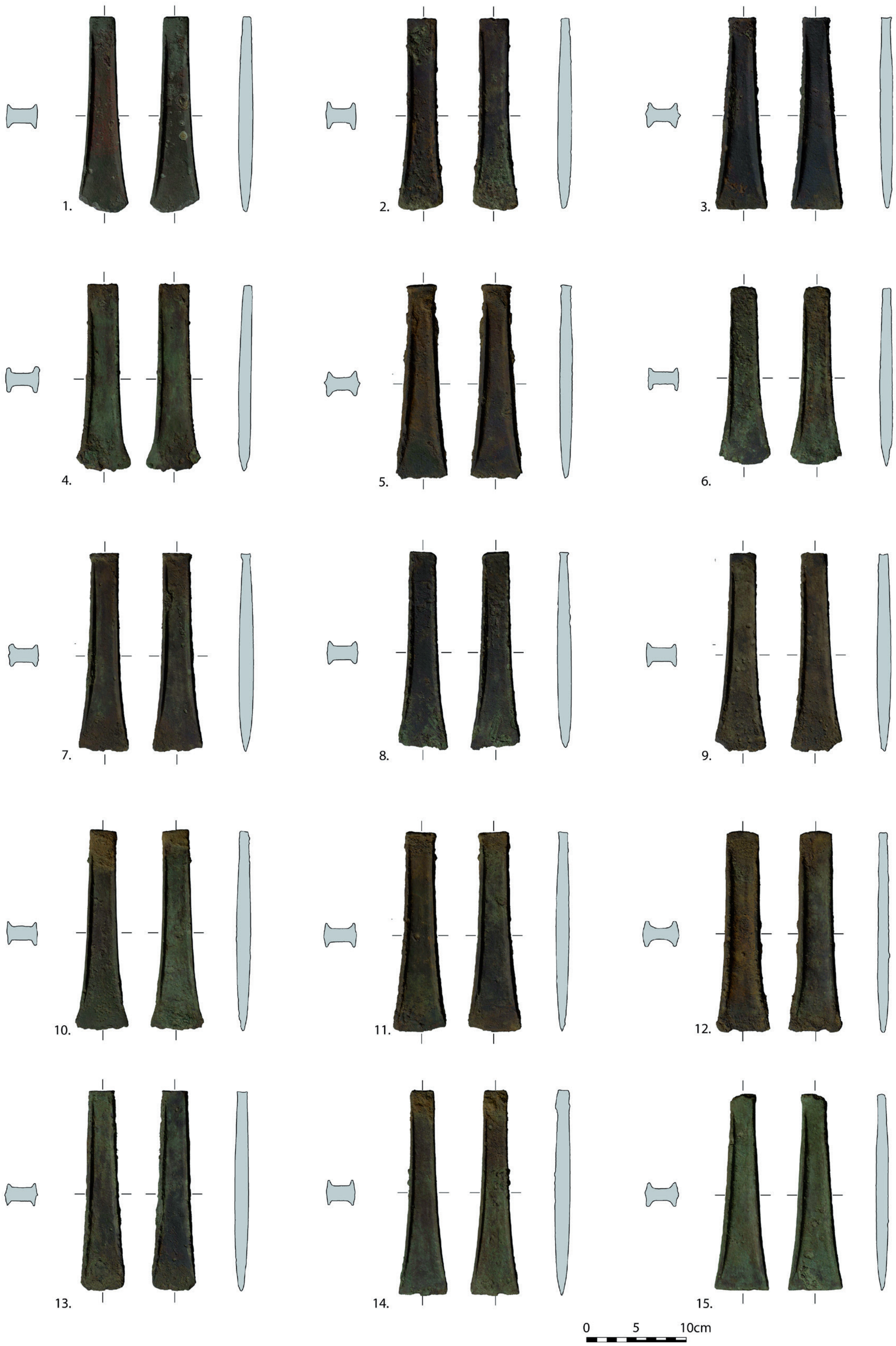


Fig. 7 – Axe-heads from the hoards of Léon 2 (no. 1) and Léon 1 (nos. 2-15). The numbers are those of the inventory given during their recovery (nos. 1-3) or during the 2017 excavation.

part of the barrel was bent in the process, and therefore was not hermetic any more: part of the sediment was washed down through the opening at the time of the removal of the sample (Ihuel et al., 2022).

The excavation in laboratory took place in March 2024, and revealed that the hoard included ten axe-heads: the one discovered at the bottom of the lake in 2015, and the nine others recuperated during the excavation process. None of them was found in primary position: they were literally sucked down when a depression of 40 × 15 cm was created by the washing of the sediment through the bottom of the barrel (fig. 8 and 9). Nonetheless, the excavation could establish that the axe-heads were originally deposited in an ovoid pit roughly oriented north/south, long c. 40 cm, wide c.18 cm, and deep 10 cm (fig. 10). At the centre of the pit, a small depression 20 cm long, 10 cm

Fig. 8 – Axe-heads from Léon hoard 2, seen from the "north". They were sucked into a depression due to the washing of the sediment through an opening on the bottom of the container.

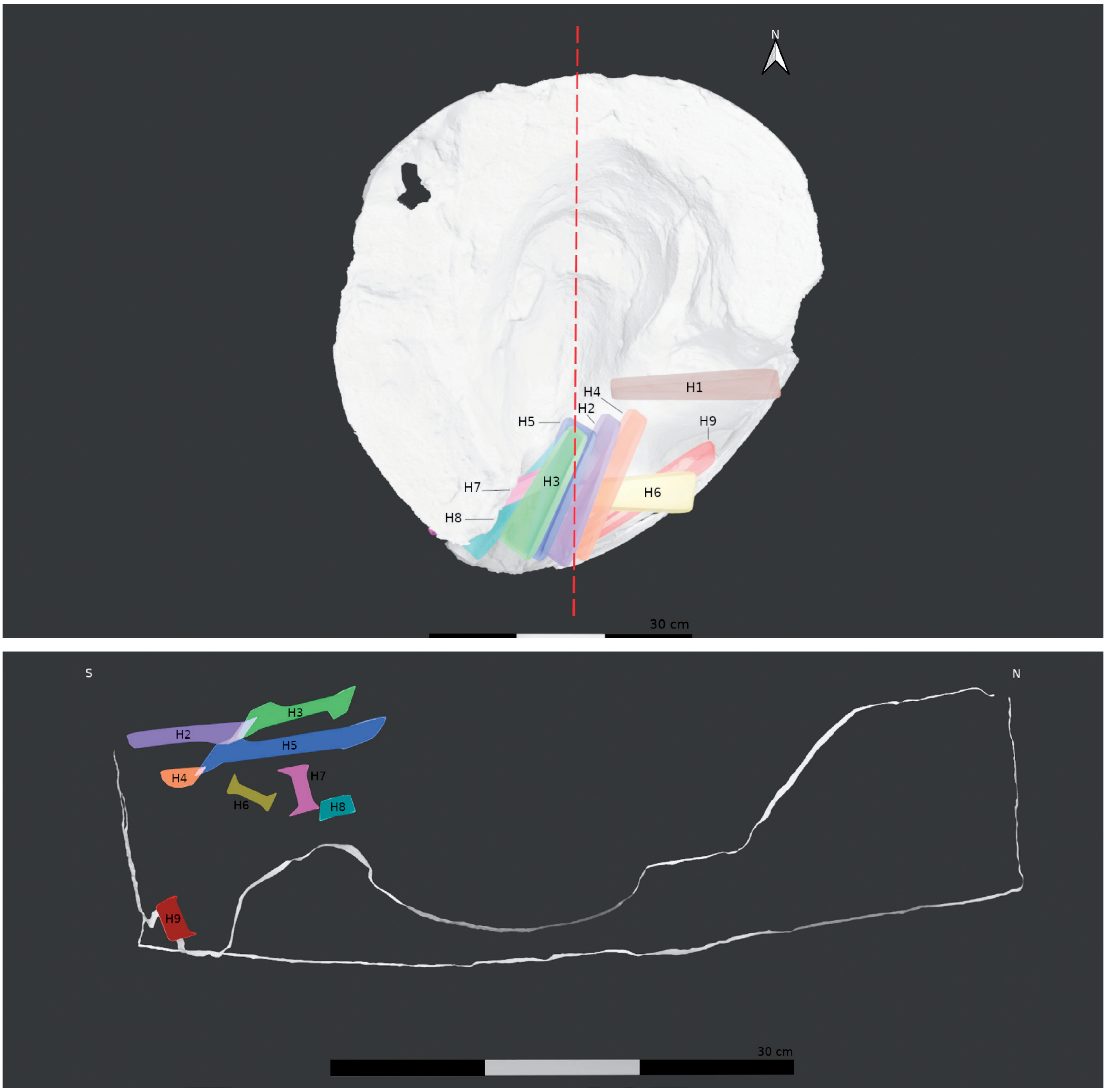


Fig. 9 – Plan and cross-section from Léon hoard 2, after the 3D reconstruction.

Fig. 10 – The pit of Léon hoard 2 where the axe-heads were deposited, probably vertically, seen from the "south".

Fig. 11 – Adjoining axe-heads from Léon hoard 2, seen from the "west".

large and 5 cm deep was observed. Most of the axe-heads were found with a slight tilt toward the opening in the bottom of the barrel. Their orientation was dissimilar: six of them had the edge of the blade downward, another upward. Two others were found in horizontal position. Five axe-heads were adjoining (fig. 11). It is too early yet to conclude with certainty, but it seems possible to infer that the axe-heads were deposited adjoining, mostly oriented in the same way and standing blade upward, as in the hoard 1.

These two hoards provide us with two set of axe-heads deposited simultaneously and distant a few meters away the one from the other (table 1). Even if the complete analytic protocol could only be applied to the 30 axe-heads of hoard 1 (fig.12-13) and one axe-head of hoard 2 (the one retrieved in 2015), the comparison between both allows for some comparison that enlighten the processes at stake during hoarding.

Other hoards

Our study also takes into account the axe-heads from four different hoards (table 2; all are on deposit at the Musée d'Aquitaine, Bordeaux): Le Chalet hoard 1 and Le Chalet hoard 2 (Saint-Germain-d'Esteuil), Le Pouyalet hoard 2 (Pauillac) and Minjacq (Martillac; this hoard contains axe-heads of *Martillac* type, which would pre-exist the Medoc axes). All these hoards except le Chalet 1 only contained axe-heads (they belong to Lagarde-Cardona's type A: Lagarde-Cardona, 2012, p. 198): 25 in Le Chalet 2, 16 in Le Pouyalet 2, at least 24 in Minjacq. Le Chalet 1 contained 33 axe-heads and 17 other objects (Lagarde-Cardona, 2012, p. 149–156). For different reasons, we could not study all of these axe-heads: 15 have been taken into account for le Chalet 1, 24 for le Chalet 2, 10 for Pouyalet 2, 14 for Minjacq.

Two of these hoards have been recovered in an archaeological context: Le Chalet 1 and 2. Both hoards were deposited into vases. In le Chalet 2, the axe-heads were disposed concentrically, their blade up, with one lying flat on top (Roussot-Laroque, 1999).

These hoards provide therefore 63 axes in total. Others objects, found isolated or from smaller hoards, will be referred to in other parts of this paper for addressing some specific topics.

ANALYTIC PROTOCOL

The protocol we introduce here was elaborated for studying the hoards from Léon, and aims at assessing the homogeneity or on the contrary the heterogeneity of the origins of the alloyed metals, the shape of the objects, their mass and volume, their use and their forms of discard/abandonment/deposition. This protocol remains in part theoretical because it has not been yet integrally implemented for the study of one specific hoard (even it is almost the case for Léon hoard 1). It should, though, be the case for Léon hoard 2. Yet, all of the steps of this protocol have been tested on a significant part of our dataset, and all have demonstrated their relevance and the accuracy of the data they returned. We present therefore this protocol in a methodological perspective, even if the results obtained during the elaboration of its different steps have – we believe- an undeniable interest.

As we will show, this protocol is particularly relevant for an application to case studies, as it focuses on

Inventory number	Length (cm)	Width, base of the blade (cm)	Width, heel (cm)	Edge of the blade	Weight (g)	Sample ID	Mould (certain)	Figure
1.2	19.2	4.6	3	curved, asymmetric	658.7	BDX25092		7.2
1.3	19.3	5.3	2.9	straight	634	BDX25093		7.3
1.4	18.8	5.6	3.2	curved, symmetric	679.3	BDX25094		7.4
1.5	19.6	5.2	3	straight	648.2	BDX25095		7.5
1.6	18.1	5.3	2.7	curved, symmetric	525.3	BDX25096		7.6
1.7	20.1	5	3	straight	666.9	BDX25097		7.7
1.8	19.7	5.1	2.7	curved, asymmetric	618.6	BDX25098	A-Le1	7.8
1.9	19.9	5.2	2.7	curved, asymmetric	612	BDX25099		7.9
1.10	20	5.3	2.7	straight	602.1	BDX25100		7.10
1.11	20.1	5.3	3	curved, asymmetric	642.8	BDX25101		7.11
1.12	20.2	5.4	3.2	straight	765.7	BDX25102		7.12
1.13	20.1	4.5	2.6	curved, symmetric	595.3	BDX25103		7.13
1.14	20.8	4.8	2.5	straight	668.2	BDX25104	C-Le1	7.14
1.15	19.8	5.4	2.5	straight	625.5	BDX25105		7.15
1.16	20	5.2	2.9	straight	647.7	BDX25106	A-Le1	8.16
1.17	20.2	4.4	2.5	curved, symmetric	719.3	BDX25107		8.17
1.18	20.1	4.9	2.5	straight	630.9	BDX25108		8.18
1.19	18.8	5.3	3.1	curved, symmetric	741.6	BDX25109		8.19
1.20	19.9	4.8	2.8	curved, asymmetric	661.6	BDX25110		8.20
1.21	19.1	4.8	2.9	curved, asymmetric	627.5	BDX25111		8.21
1.22	19.5	5.3	2.7	straight	626.2	BDX25112		8.22
1.23	18.9	5.2	2.9	curved, symmetric	619.1	BDX25113	B-Le1	8.23
1.24	20	5	2.8	curved, asymmetric	660.6	BDX25114	A-Le1	8.24
1.25	20.1	5	3	curved, asymmetric	661.8	BDX25115	A-Le1	9.25
1.26	19.3	5.2	3.1	curved, symmetric	683.7	BDX25116		9.26
1.27	20	4.9	2.8	curved, asymmetric	643.5	BDX25117		9.27
1.28	19.3	5.2	2.9	curved, asymmetric	662.7	BDX25118	B-Le1	9.28
1.29	20.1	5.4	2.8	curved, asymmetric	663.5	BDX25119		9.29
1.30	20.5	4.6	2.6	curved, asymmetric	660	BDX25120	C-Le1	9.30
1.31	20.1	5	2.7	curved, asymmetric	643.2	BDX25121		9.31
Total weight hoard 1					**1906**			
2.0 (axe no. 1, 2015)	19.8	4.9	2.6	curved, asymmetric	616.6	BDX25091		7.1
2.1	20	4.7	2.5	straight	592.2			
2.2	19.7	4.7	2.7	straight	592.7			
2.3	19.9	4.4	2.7	curved, asymmetric	603.4			
2.4	19.3	4.8	3	curved, asymmetric	565.5			
2.5	19.3	4.7	2.7	curved, symmetric	601			
2.6	19.2	4.7	2.6	straight	566.1			
2.7	19.7	4.8	3	straight	618.1			
2.8	19.2	5.1	2.8	straight	590			
2.9	19.9	4.8	2.8	straight	567.4			
Total weight hoard 2					**1191**			
Total weight hoards 1 and 2					**3097**			

Table 1– Axe-heads from Léon Hoards 1 and 2.

the axe-heads as individual objects and on specific hoards as groups of objects. Other approaches have dealt with variation among Middle Bronze Age metallic production, from the making of the alloy (recipe) to the morphometry of the objects (Forel et al., 2009; Wilczek et al. 2015; Gabillot et al. 2017a and b). These works privileged a 2D approach of axe-heads measurements and a thorough statistical analysis allowing for reassessing typological assignations and technical connectivity between different regions of Western Europe. We believe that our approaches are complementary, as they apply to different scales of analysis.

Step 1. Excavation and recovery of the axes; recording of field data

This part of the protocol could only be implemented for the hoard 2 from Léon, as it was the only unexcavated context we had the opportunity to study. As we said, the hoard was retrieved in one block, conditioned into a barrel. The axe-heads were still embedded in the sediment taken from the site. The hope was that the axe-heads would have stayed into their primary positions, which was not the case (fig. 14). Hoard 2 from Léon was excavated in laboratory, but we believe the methods we introduce here can also be implemented in the field, especially because most of them are not original and belong to the usual toolbox of field archaeology.

The aim is to obtain a comprehensive 3D recording of the stratigraphy and of all the taphonomic observations made during the excavation. For this, the first condition is, of course, to perform a stratigraphic excavation and to record all relevant observation. In order to obtain the 3D model of the stratigraphy, 3D recording has to be performed at each interface between stratigraphic units. Coded markers will allow for the alinement of the models of the successive interfaces, therefore allowing for a computerized volumetric reconstruction of the stratigra-

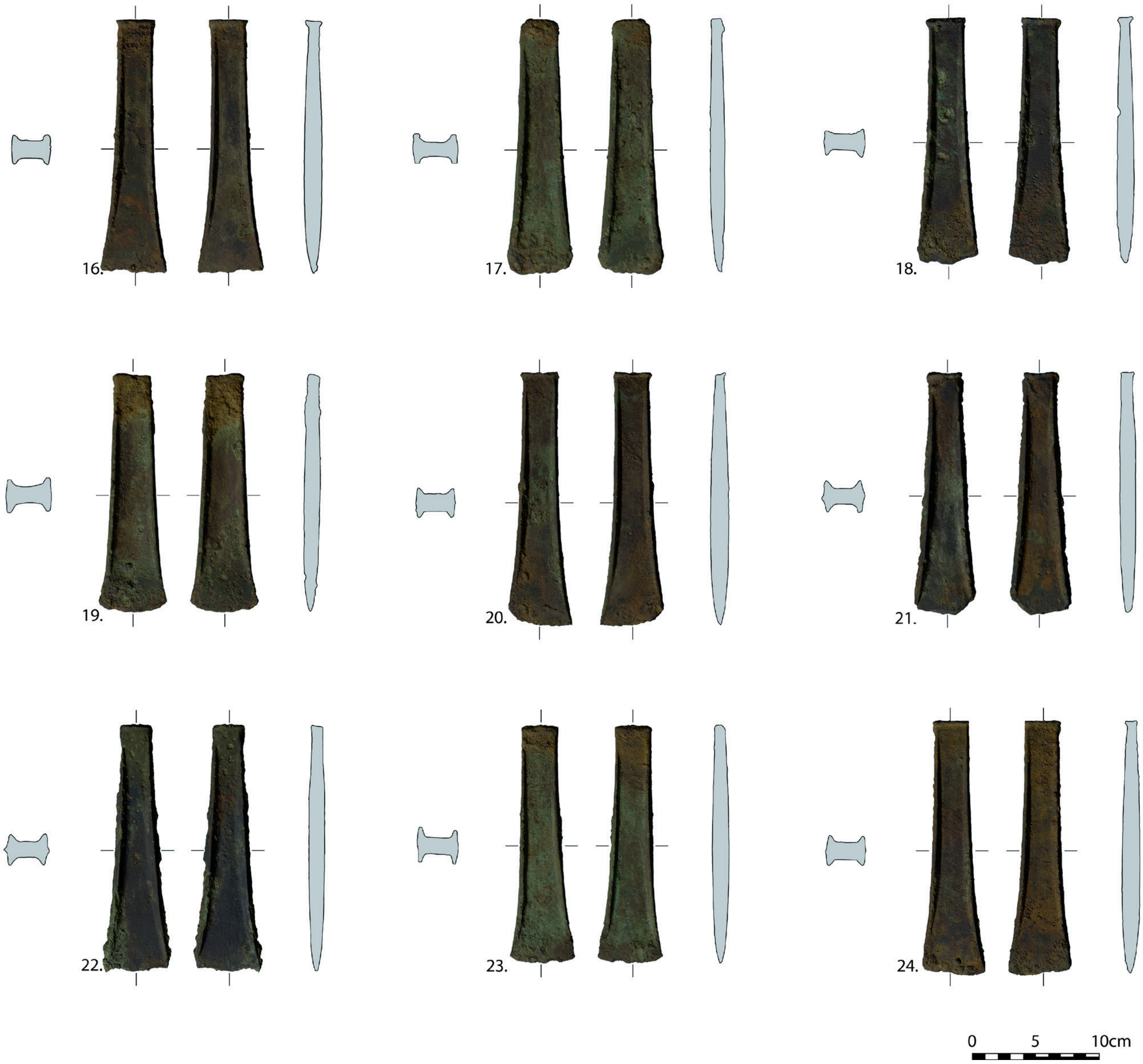


Fig. 12 – Axe-heads from the hoard of Léon 1. The numbers are those of the inventory given during the 2017 excavation.

phy of the hoard. If possible, these markers should be placed outside and around the excavation area in order to avoid obscuring part of the hoard and its stratigraphy. Given the importance of the position of each axe-head for determining depositional (i.e. gestures) and post-depositional processes (i.e. taphonomy), each phase of the excavation of the hoard itself was recorded: the upper part of each axe-head appears in the 3D model. This method allows for recording with maximal accuracy the location of each artefact. Once these artefacts are stabilised, they can be individually digitalized and virtually relocated to their original location. This last step could not be implemented in the framework of this study for lack of time, however.

In the specific case of Léon hoard 2, a photogrammetry of the entire stratigraphy was carried out and allows to situate each axe-head in its specific layer. As the hoard was contained in a metal drum, the photogrammetry was carried out using a ring flash to cancel out the problematic lighting conditions, and coded markers were positioned on the drum itself and around it, so that each photogrammetry could be referenced without obscuring part of the sediment.

Step 2: general study of the objects

All the objects we studied belong to the same type of axe-heads, the Medocan one: there was no need therefore for a typological study *stricto sensu*. Macroscopic analysis was aimed at studying use wear, observing stigmata related to technical processes performed during the making sequence (polishing, finishing of the axe-head, hammering of its bottom, initial sharpening of the blade when possible) or afterwards during maintenance/repair sequences (re-sharpening of the blade is the most obvious). All these observations contribute to the assessment

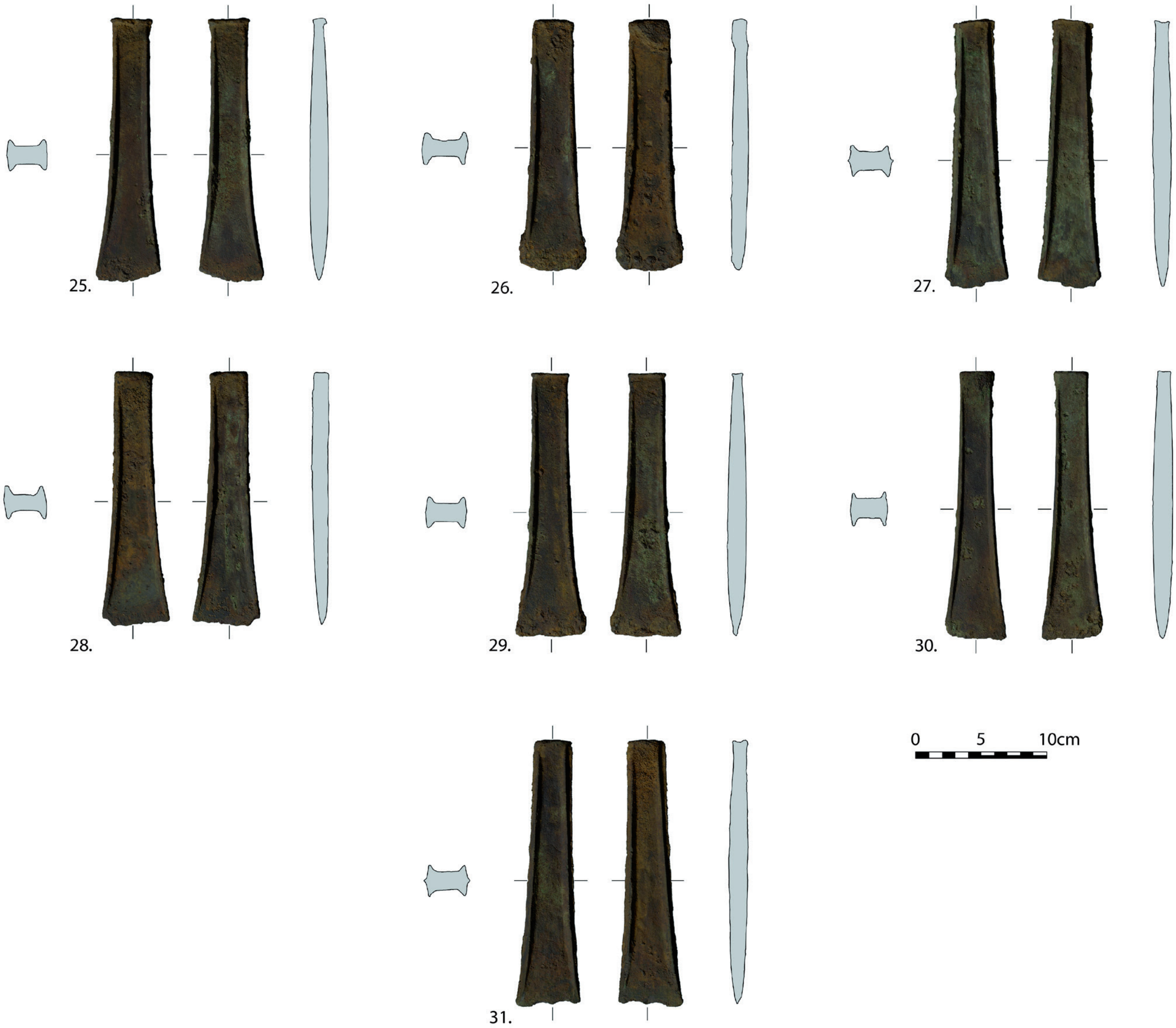


Fig. 13 – Axe-heads from the hoard of Léon 1. The numbers are those of the inventory given during their recovery (1-3) or during the 2017 excavation.

of homogeneity vs. heterogeneity into production processes, maintenance practices and uses.

Step 3. Assessing variability in shape, mass, and volume

The assessment of morphometric variability plays a central role in our project. Homogeneity in shape and mass may reflect homogeneity in use of the object: an identical tool for performing the same technical gesture. Homogeneity in volumetric morphology may reflect homogeneity in production. Medocan axe-heads were moulded in a two-parts mould. Evaluating their dimorphism allows for estimating which axe-heads could have been melted in the same moulds, as these would share most of their proportions. Homogeneity in mass, volume or included in some dimensions can be related to standardization, i.e. producing the objects according to notional norms originating from outside the technical sphere *stricto sensu*. For instance, if axe-heads were used as ingots for trade or even as currencies (as it is frequently admitted, see Introduction), their masses may be expected to have tended towards a certain homogeneity as the institutions of trade would represent an incentive towards standardization.

For addressing these questions, we developed a method involving different methods from manual measurement to 3D modelling of the objects, computerized processing of the 3D models, mathematics and statistical tests.

3D digitalisation of the axe-heads

In the framework of this research, 3D digitalization of the axe-heads has been performed through two different methods: scanning by Structured Light Scanner (SLS) and photogrammetry. The pros and cons of both methods

Hoard	Inventory number	Length (cm)	Width, base of the blade (cm)	Edge of the blade (cm)	Weight (g)	Mould (certain)
Le Chalet, hoard 1	D2009.I.10	19.6	5.5	curved, symetric	757.3	
	D2009.I.11	19	5.7	curved, symmetric	677.2	
	D2009.I.12	19	5.4	curved, asymmetric	692.9	C-Cha
	D2009.I.14	19.4	5.3	straight	720	
	D2009.I.15	19.5	5	straight	747.8	
	D2009.I.16	19.5	5.5	curved, asymmetric	663.4	C-Cha
	D2009.I.17	18.9	5.2	curved, asymmetric	703.8	
	D2009.I.18	15.7	4.9	curved, asymmetric	570	
	D2009.I.19	16.1	5	straight	408.1	
	D2009.I.20	16	5	curved, asymmetric	378.7	
	D2009.I.5	19.2	5.5	straight	715.3	
	D2009.I.6	19.5	5.2	curved, asymmetric	768.4	
	D2009.I.7	19.4	5.6	curved, asymmetric	737.4	
	D2009.I.8	20.2	5.7	curved, asymmetric	766.2	
	D2009.I.4	20	5.5	straight	767.7	
Le Chalet, hoard 2	D2009.I.2	20.3	5	*oxidized (straight ?)*	765.6	B-Cha
	D2009.I.50	20.7	5.3	*oxidized (straight ?)*	771.8	B-Cha
	D2009.I.51	20.5	5.2	straight	747	
	D2009.I.52	20.5	5.3	*oxidized (straight ?)*	749.3	
	D2009.I.53	20.9	5.7	straight	741.5	
	D2009.I.54	20	5.5	curved, asymmetric	721.7	
	D2009.I.55	20	5.6	curved, asymmetric	768.2	
	D2009.I.57	20.5	5.3	straight	766.7	
	D2009.I.58	16	4.7	curved, asymmetric	403.5	
	D2009.I.59	20.3	5.2	straight	754.4	D-Cha
	D2009.I.60	20.4	5.5	*damaged*	741.1	
	D2009.I.61	16.9	5	*oxidized (straight ?)*	414.6	A-Cha
	D2009.I.63	19.9	5.1	straight	759.8	B-Cha
	D2009.I.64	20.3	5.3	straight	758.6	
	D2009.I.65	18	5.3	curved, symmetric	650.5	
	D2009.I.66	15.6	4.7	curved, symmetric	389.9	
	D2009.I.67	15.2	4.9	curved, symmetric	409.4	
	D2009.I.68	16.7	5	straight	422	A-Cha
	D2009.I.69	19.8	5.1	straight	742.5	D-Cha
	D2009.I.70	15.8	4.5	curved, asymmetric	378.8	
	D2009.I.71	16.3	4.6	curved, asymmetric	432.8	
	D2009.I.72	16.7	5	straight	420.5	A-Cha
	D2009.I.73	15.7	4.4	straight	395	
	D2009.I.75	20.5	5	straight	779.4	
Le Pouyalet hoard 2	60.77.2	20.1	5.5	curved, symmetric	759.5	
	60.77.1	19.3	5.7	curved, asymmetric	784.1	
	60.74.3	21	5.6	straight	811.9	A-Pou2
	60.74.2	20.7	5.7	straight inclined	797.1	A-Pou2
	60.74.1	20.4	5.6	straight inclined	794.2	A-Pou2
	60.77.7	19.5	5.6	straight	771.1	C-Pou2
	60.77.5	19.7	5.5	straight	768.8	C-Pou2
	60.77.3	19.9	5.7	curved, symmetric	745.6	B-Pou2
	60.77.6	19.9	5.1	straight	769.4	B-Pou2
	60.77.4	19.7	5	curved, asymmetric	760.9	B-Pou2
Minjacq	2000.11.4	18.9	6.5	curved, symmetric	690.8	
	2000.11.3	14.7	6	straight	367.2	
	2000.11.7	17.7	6.6	curved, symmetric	638.3	
	2000.11.8	19.8	6.7	curved, symmetric	676.8	
	2000.11.6	18	6.8	curved, symmetric	658.9	
	2000.11.11	18	6.5	curved, asymmetric	633.7	
	2000.11.14	17	6.1	curved, symmetric	680.4	
	2000.11.2	13.8	3.7	curved, symmetric	262.5	
	2000.11.5	14.7	7.1	curved, symmetric	581.2	
	2000.11.13	15	6.5	curved, symmetric	539.6	
	2000.11.12	15	6	curved, asymmetric	504.1	
	2000.11.1	11.3	3.8	curved, symmetric	180.4	
	2000.11.9	11.6	7.5	curved, symmetric	372.4	
	2000.11.10	12.9	6.4	curved	335.2	

Table 2 (left page) – Axe-heads from the hoards taken into account in this study.

Fig. 14 – The indoor excavation of the hoard 2 from Léon. Phases of excavation (2) were preceded and followed by photogrammetric recording (1 and 3). Note the coded markers on the inside and outside wall of the container and on its support.

are well known: SLS is a high-cost method, but acquisition time is reduced and it provides almost directly a digital twin of the artefact at a 1:1 scale. Photogrammetry, on the other hand, is a low-cost method, but it is also much less time-effective than SLS, and the digital model has as a second step, to be scaled, a possible source for error.

All the 30 axe-heads from Léon hoard 1 were modelled through both methods, as one from Léon hoard 2, while all the others axe-heads of the corpus were recorded by photogrammetry.

The SLS used was an Artec Space Spider 2, with a certified minimum resolution of 0. mm. We were able to process the entire corpus in a single day. As the purpose of this SLS is the recording of small artefacts, it allowed for an optimal result (i.e. recording useful details, but not too precise, at the risk of generating heavier models for minimal useful gain). Like all SLSs, Artec Space Spider 2 is used for standardization, metrology and comparison of virtual models, but not for other purposes (in this respect, the production of textures is not up to the standard of current 3D visualization). The digitalisation by photogrammetry was implemented on the same objects, not only to compare to the SLS data, but also to fill the texture gap, and finally for experimental and teaching purposes.

The experiment showed differences in the volume calculated between the SLS-based models and the photogrammetry-based ones, but very slight (less than plus or minus 1 %). These differences may be due to inaccuracies in the photogrammetric digitalization (in the homothety of the model, for example, or in the uniformity/size of the meshes), but it may also be due to the calculation of the volume itself (which may be slightly distorted by the calculation itself, particularly in the case of aberrant faces on meshes topology).

The photogrammetry software used was Agisoft Metashape. Although the use of this solution does not meet the FAIR principles, Metashape is nevertheless the preferred solution in Humanities because it enables data to be processed from A to Z, while taking advantage of full integration of the hardware resources available (RAM, GPU, processor), unlike the alternative open source softwares, in particular Meshroom and Micmac.

This 3D recording allows for producing a high-quality graphic documentation. 3D models can be represented according to orthographic projections, and cross-sections can be inferred from the model. We obtain through this process a very accurate representation of the object, allowing moreover for comparison with objects drawn in 2D. But as we will see, the use of 3D recording has many more implications.

Assessing regularity in weight and standardization

In order to discuss the hypothesis according which Bronze Age axe-heads production would follow a notional metrology, data are analysed using two main methods: a Frequency Distribution Analysis (FDA) and a Cosine Quantogram Analysis (CQA).

The FDA aims at observing the distribution of the data, while taking into account the possible imprecision of weighing/measuring practices in ancient times (Poigt, 2022, p. 84–86). For this reason, the distribution curves are given with a margin of error of 5%. In other words, a value of 100 g will return all the sample data with a mass between 95 g and 105 g - i.e. between 100 g − 5% and + 5%.

CQA is a non-inductive mathematical-statistical method developed specifically to identify a *quantum* in a given sample, in other words a unit structuring that sample. It is essentially based on the identification of a smallest common integer divisor for the most represented values in the sample. This method was developed by David Kendall (1974), based in particular on the work of Thom (1955) and Broadbent (1955; 1956). Since the late 1990s, it has become the preferred method of investigation in archaeological metrology research (Pare, 1999; Pakkanen, 2011; Ialongo and Rahmstorf, 2018; 2019; Rahmstorf, 2019).

These two analyses are carried out using version 3.2 of the MetroTB tool (Poigt, 2022b). The combination of these two methods makes it possible to determine inductively and non-inductively whether the samples analysed are likely to be defined according to metrological modalities, and to characterise these distributions. Metrological distribution is expected to correspond to a series of clusters of values corresponding to at least one unit, its multiples and divisors. A similar metrological distribution between different datasets (different hoards, for instance) would imply that different geographical areas would share the same metrology.

On the other hand, a unimodal and symmetrical distribution would suggest technical habitus, Yet, a normal distribution around same value peaks in different geographical area would imply similarities in techniques going beyond a shared typology: common *habitus* suggesting complex relationship of knowledge transfer through apprenticeship beyond a local scale.

Assessing regularity in morphology

This part of the protocol had the double objective to identify similarity or on the contrary dimorphism between the different axe-heads. It also aims at detecting replication of blades, thus suggesting the use of a unique mould. There is a long tradition of research on this topic, based on the detection of common defects appearing in different axe-heads (see for instance Roussot, 1973, p. 131; and Lagarde-Cardona, 2012, p. 124, 243). We propose to go beyond this macroscopic observation and make an optimal use of the 3D models that allow for infinite manipulation of the axe-heads' digital twins. Firstly, the existence of the 3D model allows for a computerized, high-precision calculation of the volume of the object and therefore of its density, precious data for metrological and technical analyses. Secondly, the use of virtual models allows for experiences impossible in the real world, as for example the superposition of two objects, or better said of the point clouds obtained through their 3D digitalization. This task has been carried out using the software CloudCompare, a tool developed for electrical engineering which is used to compare 3D objects and identify differences between them, through the computation of the distances between the virtual models.

CloudCompare only allows for a comparison by pairs. The first step is to superimpose very accurately two different 3D models, using reference points (the ends of the flanges for example: fig. 15). One model is converted to a cloud of points, while the other (that will be used as reference), appears as an object with multiple faces (meshed model). The software computes the distances between the points of the cloud of and the closest face of the meshed model. If the distance between the points and the surface is close to 0, the objects are very similar or identical. A colour range graphically expresses the series of distances computed by the algorithm on the meshed object. A graph compiles the distances and gives a mean and a standard-deviation (fig. 16). A few initial tests aimed first at comparing the reference axe-head to itself (to determine the significance of the human-induced error, unavoidable in this process) and second very different axe-heads with each other. On this basis, we determined that a distance greater than 1 mm between two closest points is discriminant: in this case, the two axes compared are not considered as "identical". On the contrary, a field of values close to zero means identical axes.

The correct reading of the mean and the standard deviation is a key to understand the results. The mean of the series of distances between two axes is generally close to 0, as we compared similar axe-heads. If the standard deviation is high, it means that the values are too spread around the mean. It is in fact hiding "extreme" values that offset each other, and then the axes-heads are not so identical despite the 0-mean value. On the other hand, a mean and a standard-deviation close to 0 ±1 mm give good hints to consider two axe-heads as identical, maybe proceeding from the same mould.

From these CloudCompare comparisons, we sort the results according to three degrees of confidence. The fact that two axe-heads proceed from the same mould is considered 'unlikely' if the distances between the two models calculated are too great (fig. 17a). A common mould is considered 'probable' if the distances calculated show that two axe-heads were identical, in the absence of any other diagnostic element (like common casting defects or specific feature: fig. 17b). Finally, several axe-heads showing valid distances between their superimposed models and replicated casting defects lead to the conclusion of a 'certain' common mould (fig. 17c). Such approach allows for optimizing the use of information: casting defects are for instance very likely to be erased during the finishing of the axe-head by hammering, polishing, etc.

The sample analysed through this process gathers in total 119 axe-heads: over this total, some axe-heads that are too different need direct comparison. A preliminary sorting was made by comparing roughly their profiles. An orthophotograph of each axe-head has been extracted from their 3D model, from which it is easy to trace the

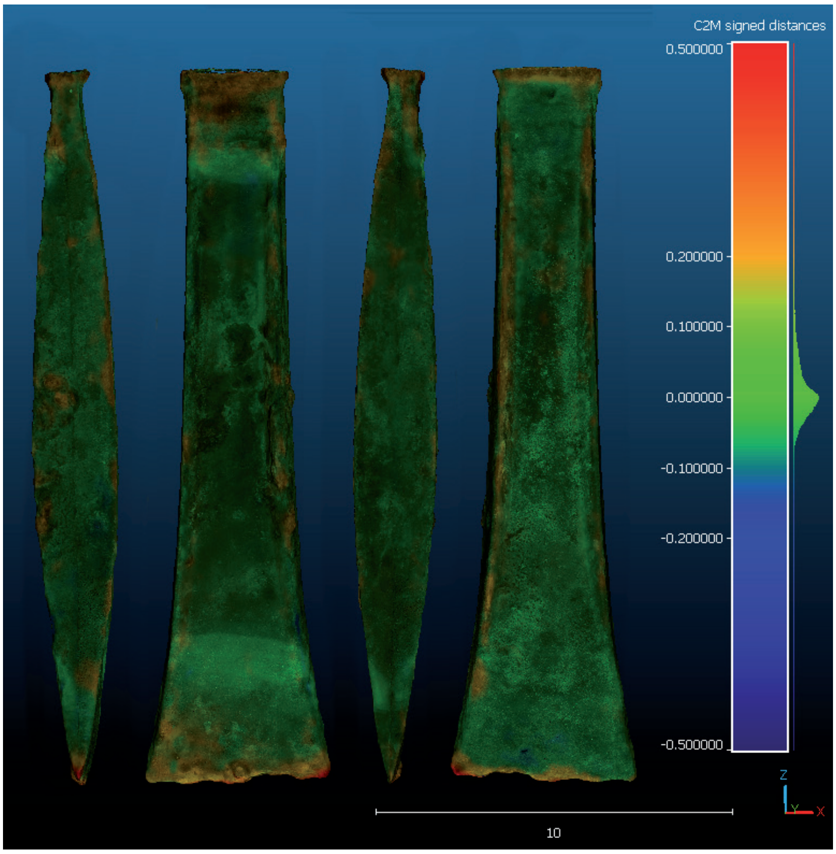


Fig. 15 – Compilation of the distances between the axes no. 8 and no. 16 from Léon, hoard 1, and visualisation on the model of the common (green) and different parts (blue/red).

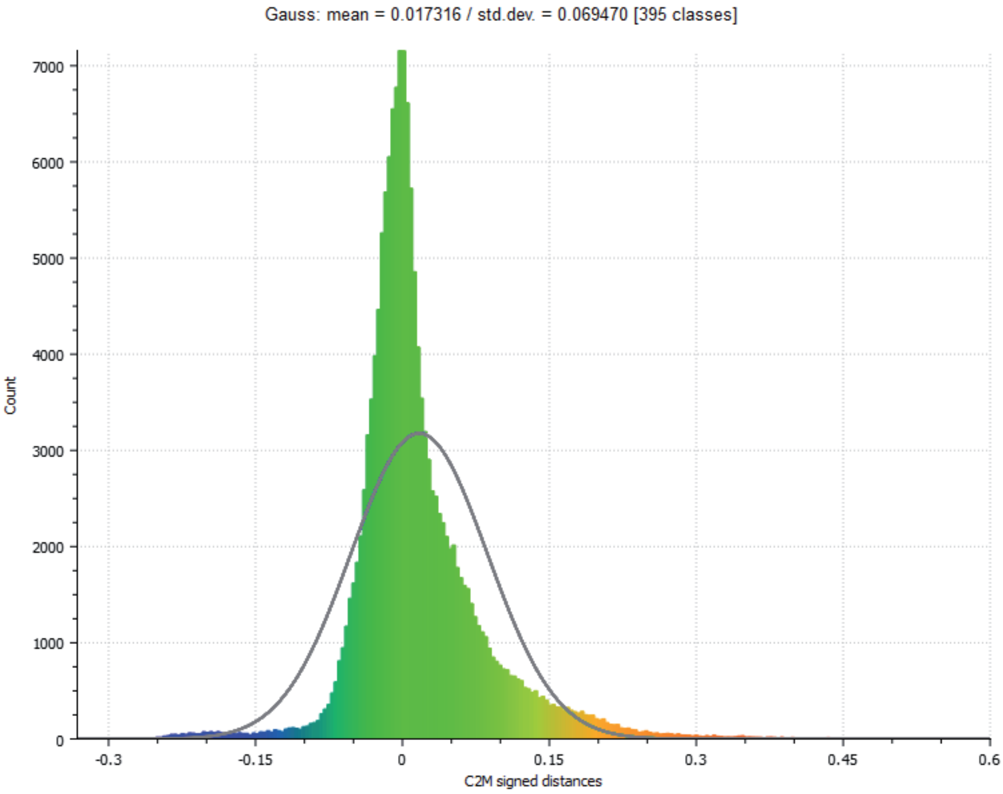


Fig. 16 – Graph compiling the distances and showing mean and standard-deviation between axe-head n°8 and n°16 from Léon. The mean and the standard-deviation are expressed in centimetres.

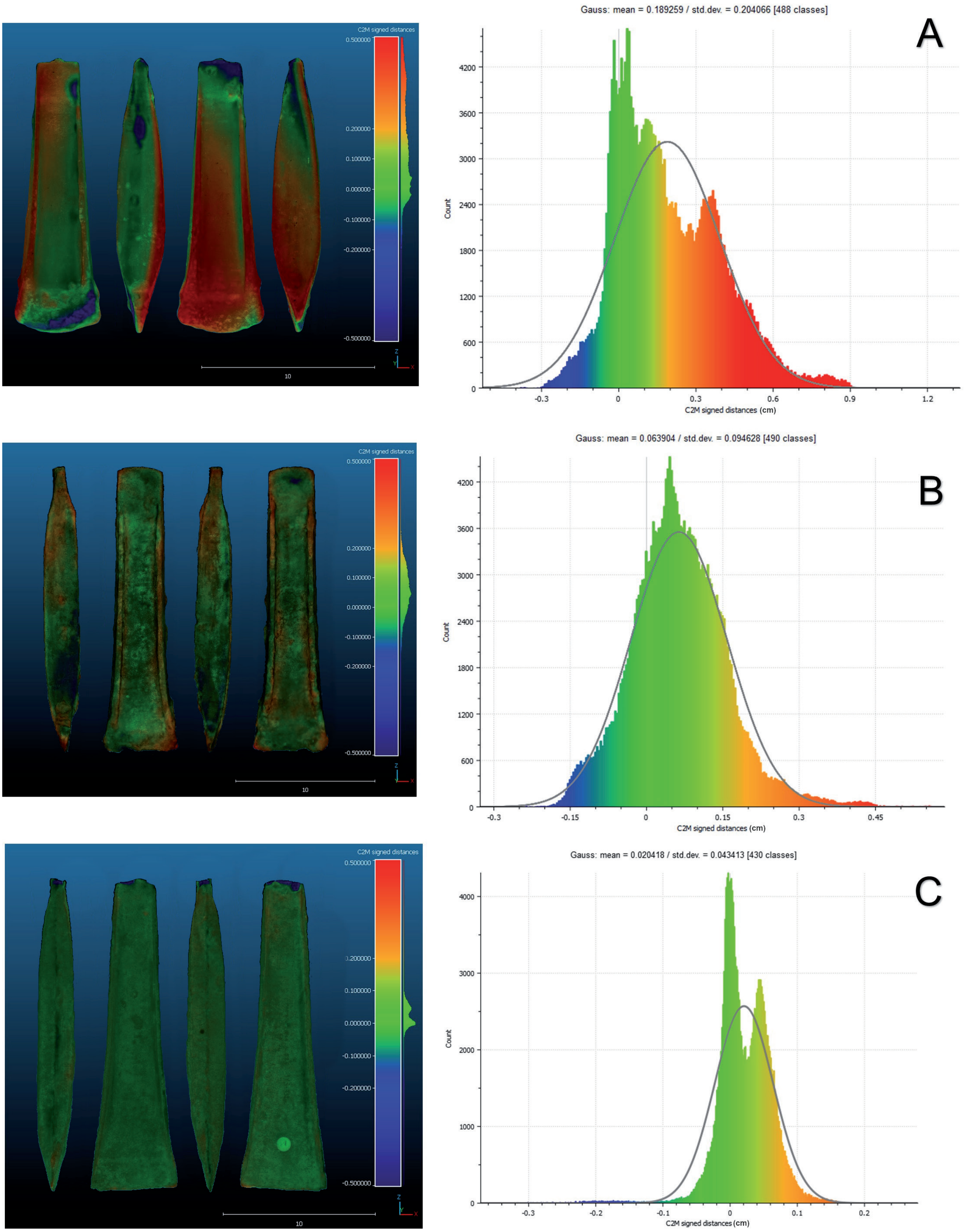


Fig. 17 – Outputs of CloudCompare comparison, showing the compilation of distances for axes that are too different to be considered similar (a&b) and axes that show distances acceptable to conceive a common mould or a replica (c).

profile of the object, and then compare which axe-heads share the same profile (fig. 18). Comparison is made step by step, increasing the window from the very local (within a specific hoard) to the regional. While performing this comparison, we deliberately ignored the cutting edge and the heel because the proportion of these parts depends on post-melting phases (finishing, maintenance and sharpening, etc.).

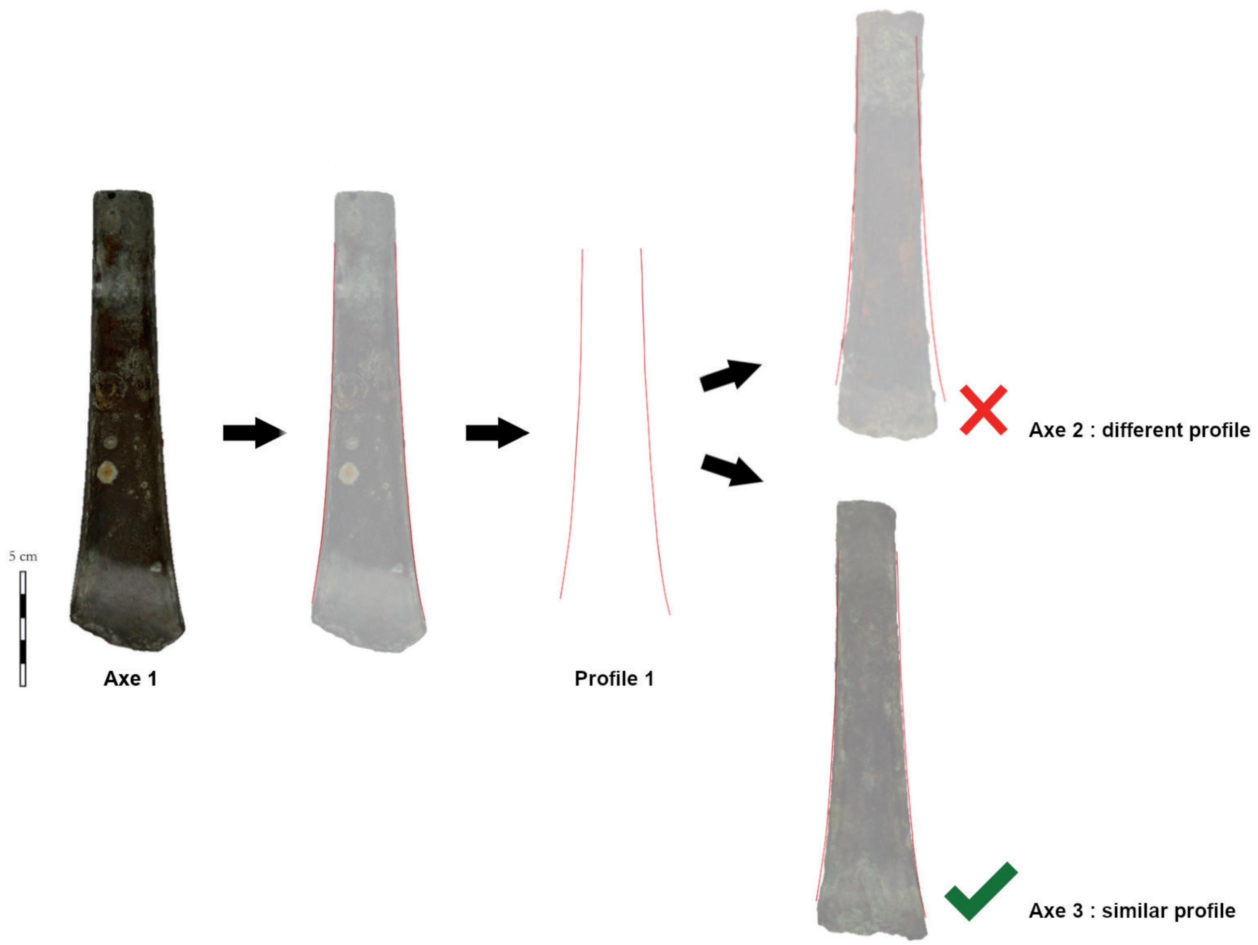


Fig. 18 – Methodology to gather profiles within hoards.

Assessing diversity in the origin of metal and in the making of alloys.

One of the main questions regarding the biography of our axes is obviously the nature of the metal used in their making. Firstly, there is the question of the origin of this metal: given that the south Atlantic Coast of France is devoid of sources of copper or tin ores, these metals must have come from other regions. Secondly, the alloying practices could have been more or less homogeneous. As for the origins of metals, only the copper sources can be assessed through the analysis of lead isotope ratios. Elemental compositions were also measured to determine the nature of the alloys.

The use of lead isotope ratios to study the provenance of metal artefacts has been a relatively common practice in archaeology since the early work of Brill and Wampler (1967; see Killik et al., 2020; Artioli et al., 2020 for a review). These ratios are specific to the geological context and are characteristic of the age of ore formation (Allègre, 2005). The lead isotopic signal, however, lies on a mixing line between the value of the copper source and that of the alloying elements. For bronze (Cu-Sn alloy), it is highly likely that two types of ore (containing copper and tin respectively) were used, but it is assumed that the lead comes mainly from copper ore (which is predominant by mass).

Isotopes 206, 207 and 208 are the products of the radioactive decay of uranium 238, uranium 235 and thorium 232, respectively. Isotope 204 is the only one that is not radiogenic. This aspect also presents a limiting factor: only geological formations of sufficiently different ages can be discriminated. This poses challenges for the Mediterranean area. There, ore deposits were formed during two geological episodes relatively close in time: the Variscan/Hercynian (Paleozoic) and Alpine (Mesozoic-Cenozoic) orogenies (Killick et al., 2020).

In addition to the use of isotope ratios, Albarède et al. (2012) have proposed the use of three independent geological parameters (T, μ, κ):

– T is an approximation of the geological age of the region from which the ores come (model age).

– μ corresponds to the $^{238}U/^{204}Pb$ ratio of the Earth's crust;

– κ corresponds to the ratio $^{232}Th/^{238}U$ and reflects the geological history of the continental province from which the ores originate.

These parameters reflect the geological history of the ore deposits. The objective here is not to attribute a precise source (this will be the subject of a later study), but to discuss the possible common origin of the metal ores.

Once again, our aim is to assess homogeneity vs diversity at all scales, i.e. from the very local (e.g. a specific hoard) to the regional (between different hoards found in different areas). However, in this study, only the 30 axe-heads of Léon hoard 1 and one proceeding from Léon hoard 2 have been fully analysed (i.e. lead isotope ratios and elemental composition). In a nearby future, all the axe-heads from Léon hoard 2 should also be analysed.

Each artefact was sampled twice using a single-use saw blade. The first sample was taken from the heel of the axe-heads, after which the surface was mechanically cleaned to remove surface corrosion. These samples were used to measure lead isotope ratios. The second sample, a few cubic millimetres in size, was taken from the edge of the blades. These micro-samples were mounted, then ground and polished to a 0.25 mm diamond finish to create a surface suitable for SEM-EDS analyses.

The elemental composition of the samples was obtained by energy-dispersive X-ray fluorescence spectrometry using two Oxford Ultim Max 100 spectrometers, coupled with scanning electron microscopy imaging (JEOL JSM IT500HR variable-pressure microscope). Measurements were carried out under a partial vacuum (20 Pa) with an acceleration voltage of 20 kV to avoid charging phenomena. The acquisition time was 60 seconds per spectrum over the 0–20 keV energy range. For all EDS spectra, the dead time during acquisition was around 30 %, with an average number of counts per spectrum greater than 10^6.

Due to the presence of arsenic (As) and lead (Pb) in the same samples, the As L ray series and the Pb M ray series were used for EDS analyses to avoid line overlap with the As K ray series and Pb L ray series. Six measurements were carried out on each sample, with the area analysed in each measurement being approximately 5.10^{-2} mm^2. For each sample, the compositional mean (Aitchison, 1986) of the six measurements was used. Results are expressed as mass percentages, normalized to 100 %. Values below 0.5 % should be interpreted with caution, but they are retained in the general composition as they provide qualitative information.

Lead isotope ratios were measured by multi-collection inductively coupled plasma mass spectrometry (MC-ICP-MS) at the Service d'analyse des roches et minéraux (SARM) of the Centre de recherches pétrographiques et géochimiques (UMR 7358 CRPG, Vandoeuvre-lès-Nancy).

Samples were weighed into 15 mL Savillex vial, and HNO_3 was added. The solution was heated at 115°C for at least 72 hours, evaporated, then mixed with HCl and heated again for 24 hours or until the sample was completely dissolved. After evaporation, 1 mL of 0.8 M HBr was added to place the sample in the same medium as that used in the ion exchange column.

Each sample was loaded onto approximately 50 microliters of AG1X8 resin in micro-columns (see Manhes et al., 1980), then 2 mL of 0.8 M HBr were used for elution. Lead was collected in 2 mL of 6M HCl (4 × 0.5 mL), dried, and redissolved in 1 mL of 0.5 M HNO_3.

Pb analyses were performed on an MC-ICP-MS (Neptune Plus, Thermo Electron) using Tl (NIST 997) as an external standard for mass bias (White et al., 2000). The Tl and Pb values used for NIST 981 are those of Thirlwall (2002).

T, μ, and κ were calculated from the $^{206}Pb/^{204}Pb$, $^{207}Pb/^{204}Pb$ and $^{208}Pb/^{204}Pb$ ratios according to Albarède and Juteau (1984) and Albarède et al. (2012; the parameters used for the calculation are those of these authors).

Data analysis was carried out using R version 4.4.0 (2024-04-24) (R Core Team, 2024) and the nexus 0.3.0 package (Frerebeau & Philippe, 2024).

RESULTS

The different steps of the protocol have been presented in their order of succession in the analytical process. However, our analytical *chaîne opératoire* does not parallel the ancient one. For instance, as the sampling needed for lead isotope and elemental composition analysis are destructive, they were performed last. For presenting the results, we will follow the ‘biographical’ order, from the making of the axes to their burying. We will consider them as individuals (the axe-heads) and as constituent of different groups, considered at different scales (hoard, grouping of hoards, technical group of the Medocan axe-heads).

Metal sources and alloys making.

The alloys used to make the 31 axe-heads from the Léon hoards we could analyse are binary copper-tin alloys (bronze). Arsenic (As), iron (Fe), sulphur (S), nickel (Ni), and zinc (Zn) are present as trace elements. Lead (Pb) content is generally a few tenths of a percent, always below 0.5 % (table 3; Frerebeau, 2024). It is therefore reasonable to assume that no lead was intentionally added to the alloys. With the exception of one individual sample with a higher Cu/Sn ratio (BDX25105), all the axes show similar, slightly scattered Cu and Sn contents, with an average Cu/Sn ratio of 6:1 (table 3; fig. 19).

Similarly, the lead isotope ratios show little dispersion (all ratios have coefficients of variation less than or equal to 0.2 %; table 4; Frerebeau, 2024). Only two samples show ratios that deviate noticeably from the rest of the values: BDX25110 and BDX25116 (fig. 20).

Lead model ages range from 344 to 503 Ma (table 5; fig. 21). The origin of the ores is therefore to be sought in formations of Paleozoic age. Interestingly, the distribution of model ages is quite old (mean age of 451 ± 27 Ma)

	Cu	Sn	As	Pb	Fe	S	Ni	Zn
mean	84.78	13.82	0.24	0.24	0.07	0.32	0.4	0.13
min.	82.72	7.84	0.12	0.17	0.05	0.2	0.19	0.12
Q25	83.81	13.32	0.22	0.2	0.06	0.27	0.37	0.13
Q50	84.4	14.16	0.24	0.24	0.07	0.3	0.41	0.13
Q75	85.19	14.83	0.27	0.28	0.07	0.38	0.45	0.14
max.	90.71	15.73	0.35	0.37	0.16	0.54	0.58	0.17

Table 3 – Summary statistics of elemental compositions (Q25, Q50, Q75: first, second and third quartile).

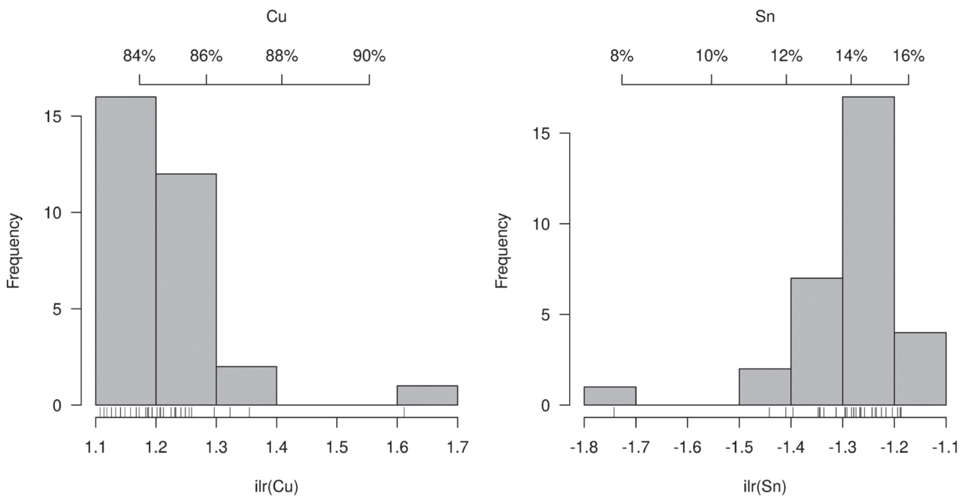


Fig. 19 – Histograms of copper (Cu) and tin (Sn) contents. See Filzmoser et al., 2009 for methodology.

	206Pb/204Pb	207Pb/204Pb	208Pb/204Pb	207Pb/206Pb	206Pb/207Pb	208Pb/206Pb
min.	18.078	15.654	38.296	0.855	1.155	2.102
Q25	18.136	15.657	38.358	0.861	1.158	2.112
Q50	18.155	15.658	38.378	0.863	1.159	2.114
Q75	18.178	15.659	38.391	0.863	1.161	2.115
max.	18.319	15.664	38.506	0.866	1.17	2.118
mean	18.16	15.658	38.378	0.862	1.16	2.113
sd	0.041	0.002	0.033	0.002	0.003	0.003
CV (%)	0.224	0.014	0.085	0.218	0.219	0.143

Table 4 – Summary statistics of lead isotope ratios (Q25, Q50, Q75: first, second and third quartile; sd: standard deviation; CV: coefficient of variation).

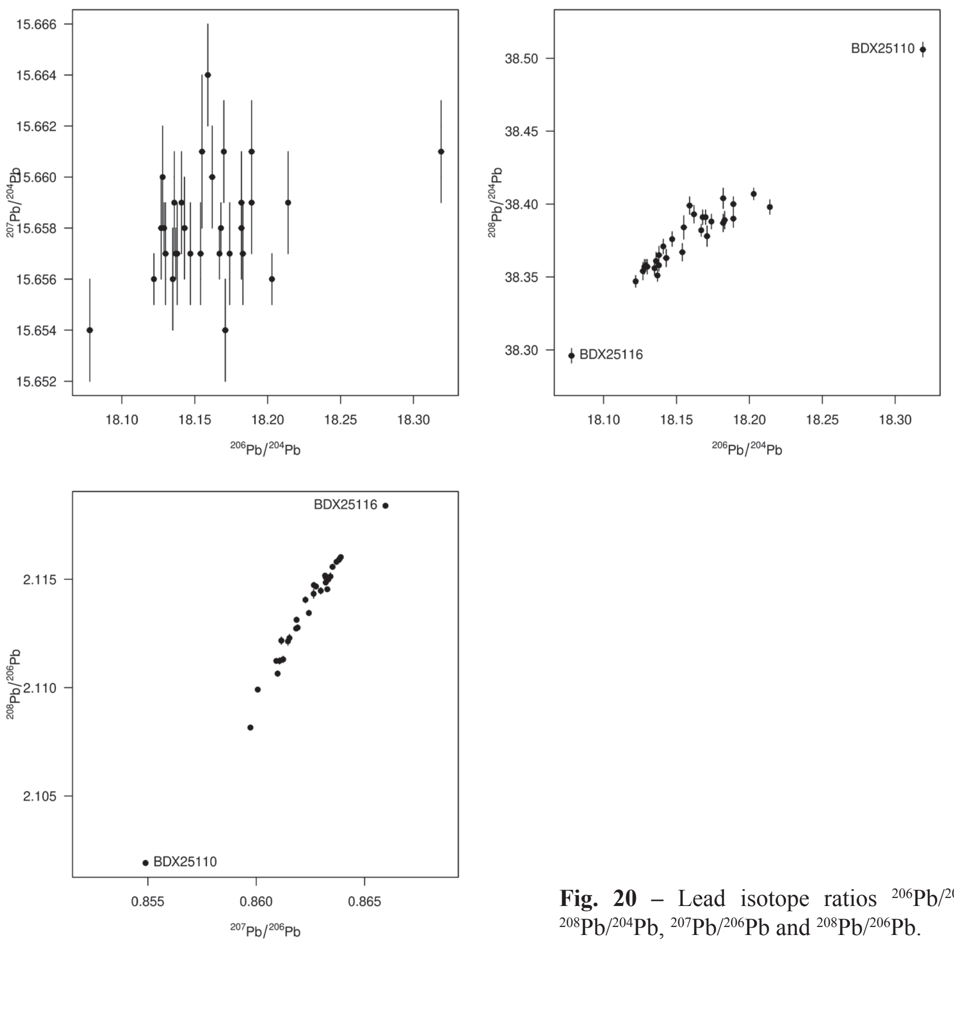


Fig. 20 – Lead isotope ratios $^{206}Pb/^{204}Pb$, $^{207}Pb/^{204}Pb$, $^{208}Pb/^{204}Pb$, $^{207}Pb/^{206}Pb$ and $^{208}Pb/^{206}Pb$.

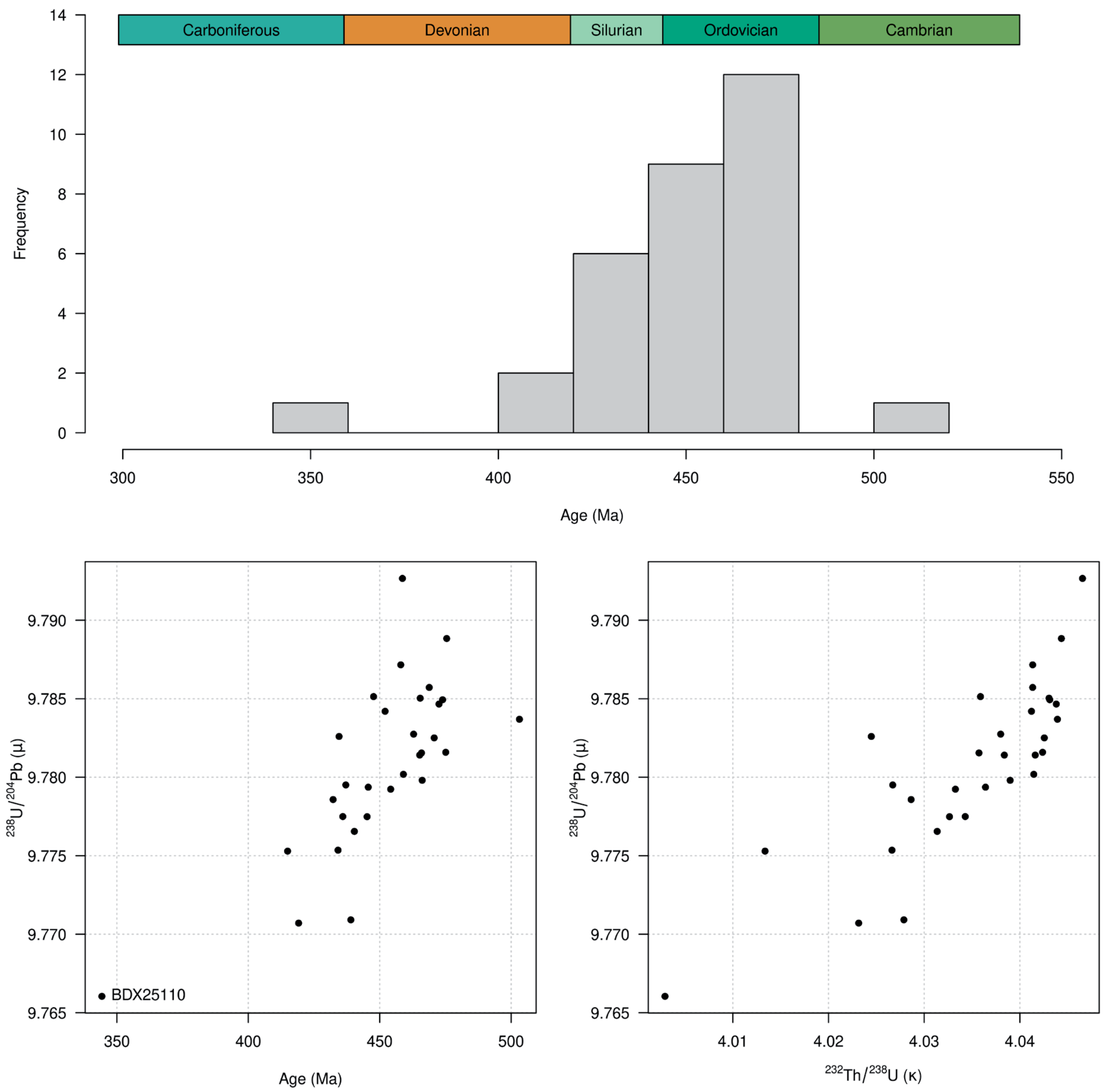
	age	mu	kappa
BDX25091	471	9.783	4.043
BDX25092	435	9.783	4.024
BDX25093	440	9.777	4.031
BDX25094	439	9.771	4.028
BDX25095	436	9.777	4.034
BDX25096	452	9.784	4.041
BDX25097	459	9.793	4.047
BDX25098	458	9.787	4.041
BDX25099	419	9.771	4.023
BDX25100	475	9.789	4.044
BDX25101	474	9.785	4.043
BDX25102	463	9.783	4.038
BDX25103	437	9.78	4.027
BDX25104	434	9.775	4.027
BDX25105	465	9.781	4.042
BDX25106	445	9.777	4.033
BDX25107	466	9.780	4.039
BDX25108	466	9.782	4.036
BDX25109	475	9.782	4.042
BDX25110	344	9.766	4.003
BDX25111	448	9.785	4.036
BDX25112	473	9.785	4.044
BDX25113	446	9.779	4.036
BDX25114	469	9.786	4.041
BDX25115	465	9.781	4.038
BDX25116	503	9.784	4.044
BDX25117	459	9.780	4.041
BDX25118	454	9.779	4.033
BDX25119	432	9.779	4.029
BDX25120	465	9.785	4.043
BDX25121	415	9.775	4.013

Table 5 – Geological parameters calculated from lead isotope ratios (ages in Ma).

and extends from the Lower Ordovician to the Upper Devonian, i.e., before the Variscan/Hercynian orogeny that began in the Devonian (c. 420 Ma) and corresponds to the formation of the majority of European and Mediterranean ore deposits (Killick et al., 2020). These ages allow for the exclusion of sources corresponding to very ancient formations (Scandinavian Shield and Pan-African orogeny), as well as the most recent formations (Alpine orogeny). In fact, the calculated ages correspond to the Caledonian orogeny (c. 530–400 Ma).

These results tend to suggest a common geological origin of the copper ores for all the 31 axe-heads, with the exception of BDX25110, which has a younger model age (Carboniferous). However, BDX25110 has a similar elemental composition to the rest of the axe-heads, despite a potentially different geological origin.

Fig. 21 – Geological model ages and $^{238}U/^{204}Pb$ (μ) and $^{232}Th/^{238}U$ (κ) ratios.



Inside one specific hoard, Léon hoard 1, metal origin seems therefore quite homogeneous. More surprisingly, the only axe-head from Léon hoard 2 that was analysed (BDX 25091) has an identical lead isotope ratio. Such result can be interpreted in two different ways. A first explanation would be that the French south-western coast had privileged relation with one specific ore-mining area. The second explanation would be that a copper load of at least 20 kg (the approximate weight of metal in the Léon 1 hoard) arrived in the region and the all the metal needed to cast 29 out of the 30 axe-heads of Léon 1 hoard (and at least one of Léon hoard 2) was taken out of this load. Both explanations do not contradict each other, but as we will see, the second one seems at this point more likely than the first. The alloying recipes seem consistent, and denotes a technical homogeneity that seems to expand beyond the Léon micro-region (Lagarde-Cardona, 2012, p. 190 has similar results). Processes that could induce significant variability, as the accumulation of axes over a long period, the intervention of many different makers, diversity in the geographical origin of the axes collected into the hoard, important recycling of metal, seem absent.

Making the axe-heads: moulding and finishing

Moulding

Moulding was always made in a 2-parts mould, probably made out of stone or clay (Lagarde-Cardona, 2012, p. 107). In Léon hoard 1, 8 distinct profiles could be identified; 13 different profiles for the two hoards of Saint-Germain-d'Esteuil, and 3 others for Pouyalet 2 (Pauillac). The Martillac hoard contains axe-heads that are too different from one another or too fragmentary. 8 profiles present in different hoards were identified, although with less certainty.

3D comparison (using CloudCompare, see before) returns the following results:

– *Léon hoard 1*: one mould (mould A-Le1) has been used for the casting of 4 axe-heads (nos. 8, 16, 24 and 25), as well as the only one analysed coming from Léon hoard 2. Two other moulds (B-Le1 and C-Le1) have been used for casting each at least two of the axe-heads (nos. 23 & 28: mould B; nos. 14 & 30: mould C). Five other probable moulds (D-Le1, E-Le1, F-Le1, G-Le1 and H-Le1) seem to have been used for the making of fourteen other axe-heads, but there are no casting defects to confirm this. Eight axe-heads are unique. The results for Léon 1 are illustrated in figure 22.

– *Chalet hoards 1 and 2*: four distinct moulds were identified with good probability, in spite of the significant corrosion gangues that could complicate the comparison of the digital 3D models. The first (A-Cha) has been used for casting 3 axe-heads (D2009.I68, D2009.I61, D2009.I72; the second one (B-Cha) formed the series D2209.I50, D2009.I02 and D2009.I63. The third one (C-Cha) has been used for axe-heads D2009.I12 and D2009.I16, and the fourth one (D-Cha) for axe-heads D2009.I59 and D2009.I69. Two very similar axe-heads with no common flaws suggest that they were probably cast in the same mould, without other evidence than the millimetric morphological resemblance (D2009.I17 and D2009.I7).

– *Pouyalet 2 hoard* revealed three different groups of profiles. One series of three axe-heads had already been identified as proceeding from the same mould in a previous study (Lagarde-Cardona, 2012, p. 124): it has also been detected with our protocol (mould A-Pou2: 60.74.1, 60.74.2, 60.74.3). Moreover, one other series of three axe-heads (60.77.03, 60.77.04, 60.77.06)

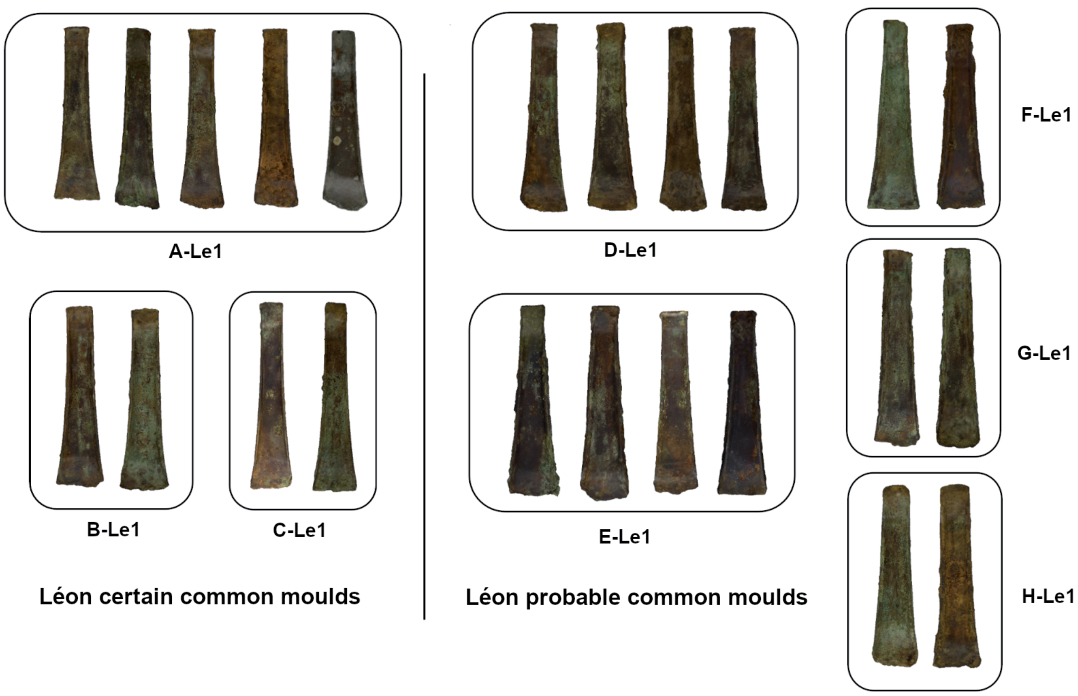


Fig. 22 – Results of common moulds analysis performed on Léon 1 hoard.

seem to have been cast in the same mould (B-Pou2), while another was used for making a pair of axe-heads (60.77.05, 60.77.07: C-Pou2). They show the best results of this study, despite the lack of casting defects (probably erased during the polishing) that could have brought an additional confirmation.

Axe-heads from Léon hoard 1 and Chalet hoard 1 and 2 seem to share similarities (the fact that they are the three largest hoards in the study undoubtedly biases this result). In Médoc, the axe-head 60.77.2 from Pouyalet 2 and the axe-head D2009.I6 from Le Chalet appear similar in terms of the distances calculated between their two 3D models. Outside the hoards that constitute the bulk of our sample, an axe-head from Ygos-Saint-Saturnin (60.99.1) show compatibilities with the axe-head no. 6 of Léon hoard 1, distant of about 50 km. Remarkably, axe-head no.6 is also the lighter of the hoard, even if it is not an outlier in any other aspect). Near the Gironde estuary, axe 60.47.1 from Cubnezais and the axe-head D91.16.1 from Lesparre-Médoc, seem to match together while the two sites are distant of more than 50 km, on different sides of the river.

Once again, there are no casting defects to fully validate these hypotheses and only the distances computing allows perceiving such comparisons.

Finishing of the axes

After the casting, the axe-heads could receive a series of modification: hammering of the heel to erase the traces of the pouring cup and to ease the fitting of the handle, polishing of the surface (including the erasure of the casting seam) and sharpening of the edge are the most obvious. Lagarde-Cardona (2012, p. 201–202) noticed that axes-heads, when they were the only type of artefacts in a specific hoard were well finished, meaning that no objects were deposited right after their casting. The observations made for the Léon hoards confirm this idea. In Léon hoard 1, most of the casting seams were erased, except for 7 axe-heads (nos. 3, 5, 13, 21, 22, 27, 31; fig. 6.3, 6.5, 6.13; 7.21, 7.22; 8.27, 8.31), a feature sometimes related with an imperfect fitting of the two halves of the mould. In Léon hoard 2, all of the casting seams were erased by polishing. Remarkably, in hoard 1, the axe-heads poorly polished do not belong to any of the three main groups (A-Le1, B-Le1, C-Le1). Axe-heads nos. 3, 21 and 22 belong to a same hypothetical group (together with no. 18) attributed to mould E-Le1, object no. 5 to possible mould F-Le1 (together with axe-head no. 15), and nos.13 and 27 to possible mould G-Le1. This feature seems linked with technical habits, and is not related systematically to an absence of use of the object: 4 of these 7 axe-heads were clearly worn out.

Using the axes

The use of the axes can be approached from two different perspectives. The first one is related to their morphology and their mass: besides determining its inertia and therefore its potential as a cutting tool, they can also relate to forms of abstract value depending on the weight and quality of the metal used. The other possible approach focuses on the use wear of the objects.

Volumes, masses and (possible) use

In the framework of this study, we could obtain directly (through direct measuring) or indirectly (thanks to previous studies) the weight of 370 axe-heads. Considered globally, they spread from c. 350 g to c. 850 g (fig. 23). The values are gathered mostly around 410 g, 657 g and 763 g. Nevertheless, these values present no arithmetical relationships that can suggest metrological features. Yet, the geographical and chronological extent can somehow blur the picture.

Reducing the spectrum to more cohesive samples may allow for figuring more local or short-lived standardization patterns. The two hoards from Léon provide a good case-study for very local and short-term behaviours, as they are distant only some 30 meters, and at least one mould is common to axe-heads belonging to both of them. As a reminder, hoard 1 contained thirty axe-heads, hoard 2 ten axe-heads.

The histogram of the masses of the two hoards shows that they follow a symmetrical, unimodal distribution (fig. 24). The masses of hoard 1 show a greater dispersion (with the presence of extreme values) and the interquartile ranges of the two repositories do not overlap, but this may be attributable to the small sample size of hoard 2.

The FDA highlights the general symmetrical distribution within the two hoards, taken separately or together, even if the masses of the axe-heads from hoard 2 are clearly lighter than within hoard 1. No multiple clusters of values – indicative of metrological distributions – can be distinguished and the difference between the two hoards cannot be understood as the subproduct of a metrological intention. The CQA show sinusoidal curves that are expected when dealing with samples normally distributed and they do not indicate construction around a metrological unit. The same applies if we consider globally the masses of the 370 Medocan axe-heads, allowing once more for discarding the idea of standardisation or metrology of the product, at least according to their mass.

Yet, what is obvious is that each hoard contains axe-heads of similar weight, while the difference of the mean mass of the axe-heads belonging to two different hoards could be significant even at a very short distance in space and time. Weights of Léon hoard 1 axe-heads spread from c. 525 g to c. 765 g, with a peak of values around c. 640 g and a mean of 649 g. In hoard 2 (contemporary to hoard 1 and distant 30 m), they spread from c. 566 g to c. 634 g, with a peak of values around c. 590 g, and a mean of 591,2 g (fig. 25). Axe-heads from hoard 2 are therefore significantly lighter than those from hoard 1, in spite of their proximity in time and space).

These observations demonstrates that the mass or the volume (forcefully related) were not linked with a metrology, not even at the scale of a very small territory, and

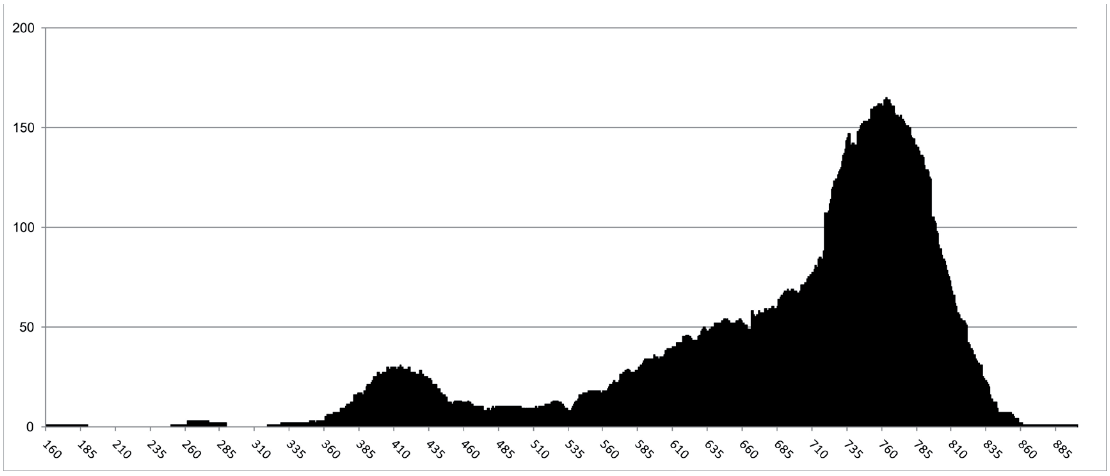


Fig. 23 – Frequency Distribution Analysis (FDA, with 5% tolerance) chart of the 370 axes masses measured in the framework of this study.

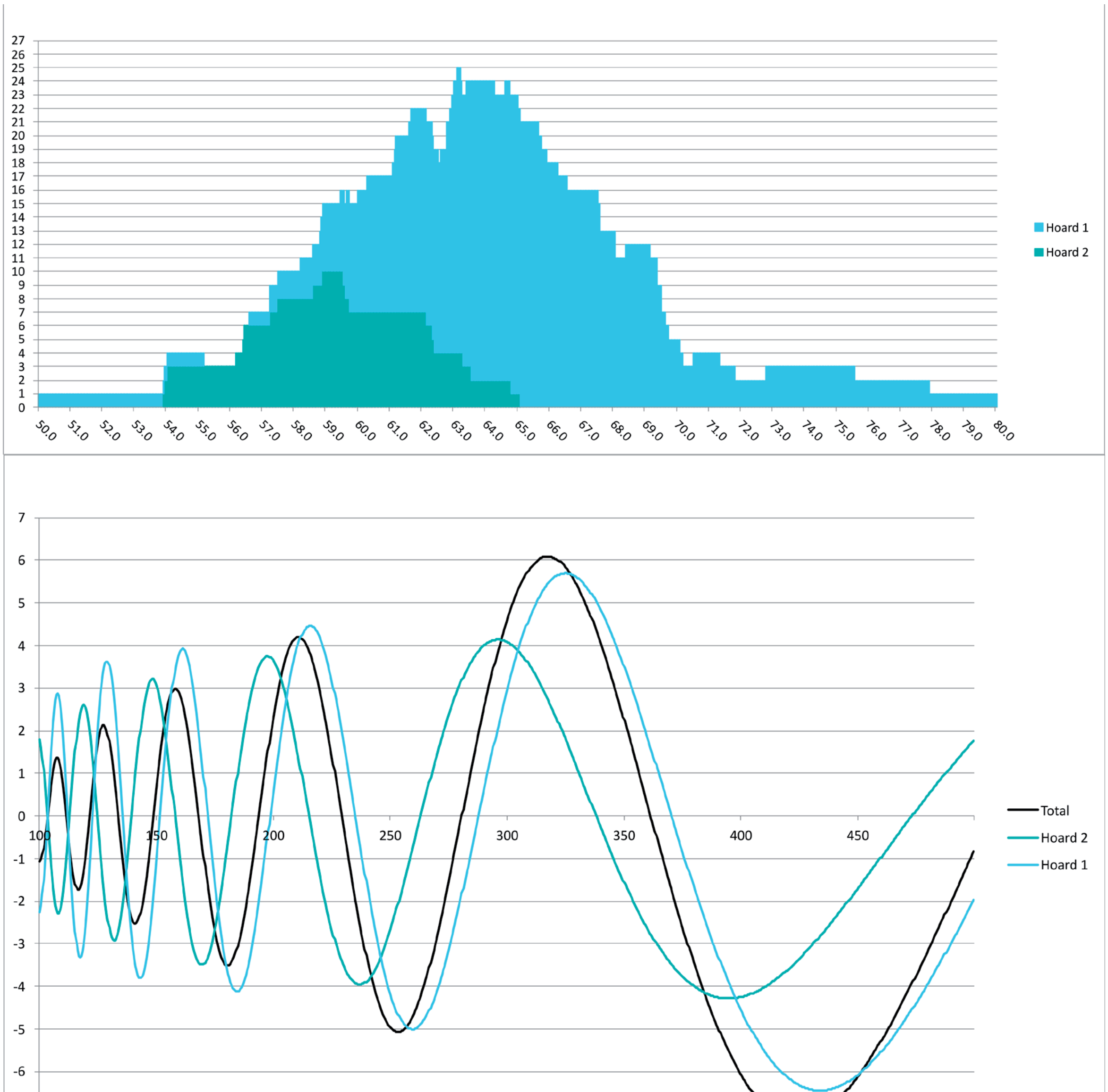


Fig. 24 – Stacked chart of the Frequency Distribution Analysis (FDA, with 5% tolerance) and Cosine Quantogram Analysis (CQA) curves of the axe masses from hoards 1 and 2 found at Léon.

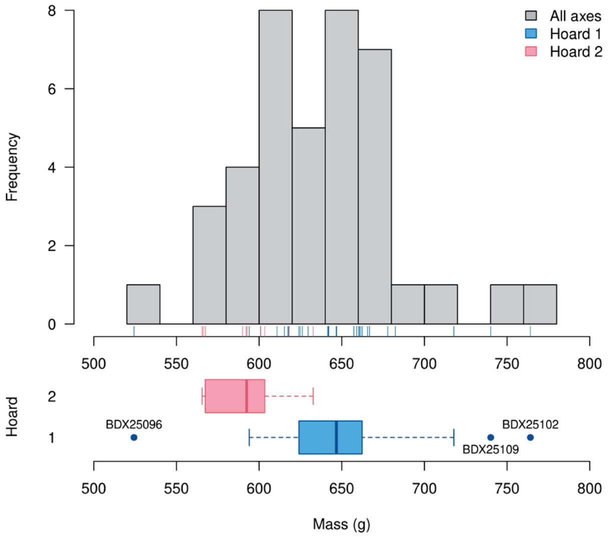


Fig. 25 – Distribution of the axe-heads from Léon hoards according to their mass.

we can therefore discard the hypothesis of their use as a currency based on a standard mass of metal. The relationship between the objects, their volume and mass must probably be understood as the result of a technical routine, the repetition of similar technical gestures aimed at the realisation of objects of similar shape and properties. Yet, these routines seem to vary from one productive context to another: in spite of being similar in shape, the axe-heads seem to be different in masses and volumes from one hoard to another, a situation clearly demonstrated by the Léon example.

The masses of the Medocan axe-heads spread over a range of c.450 g (fig. 23). If their general shape remains the same, the inertia of the objects must have significantly varied, as well as the strength needed for manipulating them repeatedly. This can suggest that the mass/volume of the objects were linked with their anticipated use, and that, therefore, axes were produced at least initially for a specific task.

Wear and use

Lagarde-Cardona (2012) already noticed that the axe-heads deposited into 'axes-only' hoards were often worn by use. The observations made on the Léon hoards confirm this fact. Wear is not easy to detect, as a short use can result in superficial wear whereas a good resharpening of the blade may erase traces. Moreover, post-depositional processes may have altered the edge. It seemed therefore wise to limit ourselves to general observations, allowing for a first characterization of the density/diversity of technical use(s) of the axes.

Three wear patterns have been discerned, taking into account the possible chipping of the edge as a consequence of post-depositional processes: one resulting in a straight edge of the blade, the other in an asymmetrical curve, the last in a symmetrical curve. The first one is characterized by a straight edge and symmetrical angles between the edge and the sides of the blade. It can result from a limited use (or from no use at all) after the sharpening of the blade consecutive to the casting, or from a drastic resharpening of the edge. In that configuration, the more the axe is used, the nearer the edge of the blade is from the wings of the axe-head (e.g.: Léon hoard 1, axes nos. 15 and 17). The second one is a symmetric wear, resulting in a curved edge and obtuse angles between the blade and the sides of the axes. The third one is an asymmetric wear, resulting in a sharp angle on one extremity of the edge and an obtuse one on the other side, and an asymmetrically curved edge. In Léon hoard 1, 9 blades had a straight edge, 14 an asymmetric one, 7 a symmetrically curved one. In Léon hoard 2, 6 had a straight edge, 3 an asymmetric one, 1 a symmetrically curved one. There is no obvious relationship between the use wear and any other characteristic of the axes. Most of the axe-heads produced into mould A-Le1 have an asymmetrical use wear, but one has a straight edge (no. 16). Only in two cases (nos. 5 and 22) a straight edge seems to be related with clear casting seams, even if both axe-heads seem to have been used.

The prevalence of asymmetric wear (17 out of 40 axes) is probably indicative of the fact that the axes had a short life-cycle. Discarding axe-heads that present such a wear seems premature in relation to their potential, as it would be sufficient to reverse the orientation of the blade in relation to the handle for exploiting the other side of the edge.

Discarding the axes: the constitution of the hoards

When a hoard is exclusively made of Medocan axe-heads, the objects are complete: fragmented axe-heads can only be found into mixed hoards. Only a few of these hoards have been excavated according to archaeological methodologies, but the observations made allow for making the hypothesis of possible patterns. In Léon, the hoards were deposited into pits with a circular opening, while in Le Chalet, a jar was used as container. In Le Chalet 2, the axe-heads were disposed concentrically, while in Léon 1, they seem to have been laid in several levels of lined-up objects. In Léon 2, the shape of the pit suggests a similar pattern, probably limited to one level only. But beyond these differences, patterns can be detected regarding the deposition processes. All axe-heads were deposited without their handle, and the geometry of the hoards shows that all objects were deposited simultaneously. At Léon 1 and Le Chalet 2, the axe-heads were disposed vertically, with the blade up. At Le Chalet 2, an axe-head was laid horizontally on top of the others. It is probable that the horizontal position of the two top axe-heads of Léon 1 corresponds to a same pattern. Even if in the Léon 2 hoard axe-heads were found in secondary position, it seems likely that the hoard had originally a similar morphology, with most of the axe-heads laid vertically while one or two others were laid horizontally on the top. These similarities between

Léon and Le Chalet are significant, as these hoards are respectively at the southern and the northern boundaries of the Medocan axes hoards area of distribution. These similarities suggest that gestures related with the constitution of an axe-heads hoard were repetitive, if not ritualized, at a regional scale. These observations converge with Couderc's (2017) conclusions, who emphasized the fact that these ritualized hoards took place at the interface between wetlands and drylands (a situation also observed at Léon).

Individual trajectories of different axes: the case of the outliers

Some of the objects are outliers in some aspects (mass, composition, origin of the metal). The observations made for Léon hoard 1, encompassing all steps from the making to the hoarding, allow for assessing the significance of these outliers and determine if these objects had a different trajectory before their simultaneous deposition with others or not.

Outliers: the metal properties

In Léon hoard 1, two axe-heads only (out of 30: nos. 20 and 26) are made with a metal which isotopic values differ significantly from the others. Yet, these axes do not differ in any other point of view from the others. Axe no. 20 belongs to the hypothetical 'mould D-Le1' group, together with 3 other axe-heads (nos. 7, 9, 11), none of them presenting any specificity differencing them from the other objects of the hoard.

One object differs from a compositional point of view (axe no. 15), but not from any other aspect. It belongs to the hypothetic 'mould F-Le1' group together with axe 5, which is not an outlier.

Outliers: the masses

One axe-head (no. 6) has a mass significantly inferior from the mean of the hoard, but it is its only specificity. Masses of axes nos. 12 and 19 are significantly higher than the mean. Axe-head no. 12 may have been cast in the same mould than axe-head no. 17 (not an outlier from any point of view), while axe-heads nos. 6 and 19 are isolated.

No object cumulates significant differences (i.e. a different metal *and* a different mass or shape) that would suggest that its trajectory differed significantly from the others. The specificities of these objects can therefore be interpreted as the discrete results of the very reduced diversity in technical practices and in uses. Axe-head no. 6 lighter weight (as well as its shorter dimensions) is probably the result of the use of a mould slightly smaller than the others, while nos. 19, 12 and probably 17 (very worn by use) were cast into one somehow bigger. The compositional differences observed for axe-head no. 15 can be related with contextual reasons (possibly a lack of tin at the moment of the making), as well as the different isotopic characteristics of axe-heads nos. 20 and 26 (a lack of new copper freshly arrived?).

DISCUSSION

Homogeneity vs diversity: a general assessment

Homogeneity and diversity regarding the constitution of axe-heads hoards can be assessed at two different scales: regional and local.

At a regional scale, from the northern part of the Gironde to the south of the Landes, deposition patterns seem relatively regular, at least as far as hoards containing exclusively axe-heads are concerned, even if too few of these hoards were excavated according to archaeological techniques. The axe-heads hoards are by far the most frequent kind of hoards in the Medoc and western Landes area, a first, obvious observation which characterizes regularity into hoarding practices. Medocan axe type dominates and is often exclusive (it is the case in Léon and Le Chalet 2), therefore showing that this specific hoarding practice corresponds to a technological horizon: this relationship between technique and hoarding practices is important, as will be emphasized later on.

Some regularity at a regional scale can also be inferred from the arrangement of the hoards: in both Léon hoards and in Le Chalet 2, most of the axe-heads were laid out vertically, blade up, while one or two of them were laid horizontally on top. In every hoard, wear seem highly variable from one axe-head to another: the constitution of the assemblages seems therefore to respond to the same dynamics, bringing together objects differently worn out.

However, beyond these common points, differences also appear: in our study area, the otherwise common practice of deposition in jars seems characteristic from the Medoc area (at least 6 cases), while the few southern hoards seem to be deposited into bare pits. Beyond that, as we will emphasize later on, the different hoards are characterized by interrelated specificities: the mean mass and therefore volume of the axe-heads is different form one hoard to another, even at a very local scale as demonstrated by the Léon example. Léon hoards 1 and 2 are distant only some 30m. They were probably deposited over a short period of time (we have no mean to determine which one is the oldest, at this point): one axe-head from Léon hoard 2 was made using the same metal and was cast into a mould also used for casting 4 of the axe-heads from hoard 1. Yet, the mean mass of the axe-heads from hoard 2 is significantly lower than the hoard 1 one. The axe-heads from hoard 2 were significantly lighter (around 50 g lighter) than those from hoard 1. The axe-heads from both hoards are themselves quite light in comparison with others. This difference in mean mass and volume is correlated with the fact that the moulds used in the making of the axe-heads of one specific hoard are normally not used elsewhere.

At a local scale, on the other hand, homogeneity appears first through the technical characteristics of the axes. Results from Léon 1 hoard suggest that the metal used for making almost all the axe-heads of the hoard could proceed from the same stock or at least from metal from a same origin. There is no local ore deposit in the Atlantic coast of southern France, so metal was forcefully imported. We do not have, for now, much information about the temporality of trade, i.e. the frequency with which metal arrived in a determined area. Indirect information suggests that the volumes traded in one specific expedition could not be very important (Gorgues and Milcent, 2018). The procurement of important volumes of metal would therefore have necessitated dense connections with metal-producing regions, whether through overland or maritime ways. At this point, it seems sensible to hypothesize that, on the long-term, metals from very diverse origin were used in any European Bronze Age region (Ling et al., 2013; 2014; Melheim et al., 2018). The homogeneity of the metal used in Léon 1 suggests that the time span between the procurement of the metal mass and the making of the object was short, therefore minimizing the probabilities for the mixture of coppers from different origins, or even the simultaneous deposition of axe-heads made from metal of different origins. This, in turn, suggests a rather streamlined process from the metal procurement to the making of the axes and their final burying.

Homogeneity also appears at a local scale through the metrics of the axe-heads and their mass: as seen before, the masses of the axe-heads of one specific hoard is normally distributed around a mean value. We interpret this fact as the result of a social/technical choice, a deliberate will of producing axe-heads having roughly the same mass and/or volume, made at a local scale. It cannot be the result of the homogeneity of the moulds used, as we have seen that different moulds were used for casting the axe-heads of a same hoard: this choice intervened before the making of the moulds, and the inner volume of the moulds has to be understood as a consequence of this choice. This fact appears more significant even if we consider that, in spite of the recurrence of axe-heads of a same type, the hoards seem to have a strong individuality from one main point of view: the mean mass/volume of the objects each of them contain, as already emphasized. The different hoards seem to have had a discrete, yet undisputable individuality from the point of view of the volume of metal used for making the axe-heads and the masses of the objects.

At this same local scale, the factors of heterogeneity are firstly the differences among the moulds used. Some were used for casting up to 5 axe-heads, while others only for one. This difference may be due to a certain extent to the difference of material used, stone for the moulds having been used for making several axe-heads, clay or even sand for the others. Yet, this difference into casting contrasts with the homogeneity of the metal source and alloying differences have also been observed in wear, probably reflecting specificity in the intensity of use rather than in its nature.

Agents in time: the dynamics of the constitution of a hoard

As we have seen, there is a commonality of technical practices, in the making of the axes but also probably in their use. Hoarding patterns, in turn, are similar, and this similarity alone allows for interpreting the constitution of a hoard as the consequence of a ritual (Couderc, 2017). This means that the persons involved into the making of the hoards shared a common technical and symbolic background. On the other hand, the strong individuality of the different hoards studied suggests that the action itself was the result of a cohesive small group, probably a local community as the main factor for differentiation seems to be linked with space.

Different actors can be identified within the group. First, the homogeneity observed into the making of bronze, from the origin of copper sources (at least) to the copper/tin proportions, suggests that a fairly reduced group of persons – perhaps one person only- was involved into this process. In contrast, the technical diversity observed in the making of the axe-heads (differences in the shape of the moulds and the material used for making them, in the finishing/polishing of the axe-heads) probably betrays the fact that, beside the alloying of the metals and its casting, all other steps were implemented by a diversity of actors (the making of the moulds and the finishing of the axe-heads, first of all). This diversity probably reflects the number of persons or corporate groups involved into this collective process. For Léon hoard 1, for instance, we can hypothesize that a maximum of 14 agents/corporate groups (corresponding to the maximum number of moulds we could identify) would have been involved into the sequence of actions that resulted into the making of the hoard.

All these agents cooperated over actions that seem to extend only over a short period of time: the homogeneity of the metal source (at least in Léon hoard 1) as well as the technical specificities individualizing each hoard probably show a streamlined, short-duration process from the making of the axes to their burying, as emphasized before. We propose here that the hoard was actually the conclusion of a coherent, planned process that begun with the procurement of the metal and continued with the making of the axes and their use, before their final, ritual, discarding. In other word, the procurement of the metal would have aimed at the making of a specific set of tools (hence their compositional homogeneity), made for a specific action performed by a limited group (hence their morphological homogeneity) and buried at the closure of the action (hence the different levels of wear). This proposition, at this point, must be understood as a hypothesis. Our results are still partial and do not allow for determining the degree of generalization of the patterns we observed. Yet, the Léon case study clearly points towards this direction, and no observation made in other parts of the area of distribution of the Medocan axe-heads seems to contradict our hypothesis.

The purpose of this chain of actions can be discussed: it began with a technical action, involved different actors at a community level, and was concluded by a ritual. It can therefore be interpreted as the result of a planned collective endeavour. The differences observed in the mass of the axe-heads could suggest that this endeavour varied in nature through places or time: the inertia of the axes would not be the same and would not allow for a totally similar technical action. Yet, recent works have demonstrated that the main factor conditioning the efficiency of an axe resides in its haft and in the haft/head assembly, no in its head alone (Dolfini et al., 2023), which means that differences in masses could be levelled by hafting techniques. This idea allows for hypothesizing that the hoarding ritual is the conclusion of a normalized chain of actions (maybe itself a ritual) identical in nature in all places where hoards exclusively composed of Medocan axe-heads were observed. In other words, the collective endeavour we identify had a normalized/ritualized dimension not only in the hoarding practices but over the whole sequence of actions, beginning with the making of the metal: axes were made for a specific purpose that supposed their ritualized burying once the process was complete. The different makers may also have been the users. Differences in wear and finishing/polishing may betray differences into proactiveness of the agents (some were more involved than the others in the collective effort) or into the technical skills or perfectionism of each one of them (some would accept axe-heads less polished or less regular in shapes than others).

This reconstruction provides a framework explaining the differences of mean masses observed from one hoard to another. Two variables can suffer micro-variations: the exact volume/mass of metal obtained through trade and the exact number of persons involved in the process. This makes the ratio of metal available per person variable to some extent that was probably very difficult to anticipate in the Bronze Age technical conditions: we propose that the variations of the mean mass of the axe-heads from one hoard to another result from this uncertainty. The very punctual recourse to other different metal sources (2 cases out of 30 in Léon hoard 1) can result from a punctual adaptation process to an unanticipated situation. This interpretation also supposes that all actors of the process was entitled to a roughly similar mass of metal, therefore suggesting redistribution processes among peers, probably outside of market processes.

It is difficult to determine what was *the exact* action that was performed through this complex chain of events, beside the fact that it was linked with woodworking and had a collaborative dimension at a local scale. Yet, the fact that they were not reused – even when they were almost new – nor recycled suggest that their use made them unfit for any other further purpose. The most straightforward explanation is that these objects, through their use, were loaded with *mana*, this supernatural energy studied by Marcel Mauss (1902-1903, p. 108–122) and which he defines as "what makes the value of things and people, religious value, magical value and even social value". This value may have become incommensurable in the profane word, for good or for bad, and the objects had to be ritually discarded from it. The use of the axes for clearance of symbolically significant wooden areas, procurement of timber and/or carpentry work for the making of specific building or boats are possible explanations, all compatible with the wetlands/drylands interface location of the hoards emphasized by Florian Couderc (2017), but other probably exist.

CONCLUSION

The protocol we introduced could not be systematically applied to all our dataset, but allows for connecting the results acquired in different case studies The systematic analysis of the isotope signature of all the axe-heads from Léon Hoard 1 allows for demonstrating, for the first time, the homogeneity of the metal stock used for making almost of all the objects of one specific hoard. Statistic approaches demonstrates that the mass or volume of the axe-heads was not standardized, not even at a very local scale, and on the contrary responded to micro-local social and technical choices linked, among other factors, to metal availability. Morphometric approaches based on 3D recording of the axes allowed for assessing the number of moulds used to produce the axes of one specific hoard. In the fast-moving fields of isotope studies and/or 3D approaches (see Théo Enudde's work in this volume), the possibility we had to put together such high-resolution data remains infrequent, even exceptional.

By connecting the data acquired during this investigation, we could hypothesize that all of the axe-heads of one Medocan hoard were cast from one specific lot of bronze probably prepared by a reduced number of specialists (maybe one), from a homogeneous metal stock. They were cast in a very short span of time, possibly by the different persons or corporate groups that would use them. They were used for a specific, probably common and unique, purpose. And finally, they were buried together. These axes, as their makers and users, had their individuality but belonged to a local group, itself part of a bigger regional entity. They were made for a specific task, so specific that they would have to be discarded once their purpose fulfilled. In other words, their end was anticipated at the very beginning of their existence.

This is a hypothetical scenario. We know it is valid at least at a local scale (it applies to Leon hoard 1), and we believe it applies to other Medocan hoards (the scope of our study) and beyond: further research, applied to other sets of closely-related hoards (from a geographical standpoint) could allow for verifying its relevance.[(1)]

1. Data availability statement: Elemental compositions and lead isotope ratios are available in https://doi.org/10.5281/zenodo.14036191.

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