

Chemical and isotopic composition of Bronze Age Axes from the north-west of France

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Zusammenfassung

Chemische und isotopische Zusammensetzung von bronzzeitlichen Äxten aus Nordwestfrankreich

Der Nordwesten Frankreichs verfügt über wenige und womöglich schwache Kupfervorkommen. Überraschenderweise ist er jedoch auch eine derjenigen französischen Regionen, in denen chalkolithische bis endbronzezeitliche Metallobjekte, darunter viele Beile, in sehr großer Zahl in Gräbern der Frühen Bronzezeit und in Metallhorten ab der Mittleren Bronzezeit 1 vorkommen. In den frühesten Zeitabschnitten handelt es sich bei sehr vielen Beilen um Einzelfunde, sodass es fast unmöglich ist, sie in einen konkreten Kontext zu bringen.

Die vorliegende Untersuchung stellt eine chronologische Übersicht der Forschung zu Beilen und ihrer Typologie dar – mit einem Fokus auf die Ergebnisse der chemischen Element- und Isotopenanalysen. Obwohl in den frühesten Perioden möglicherweise einige armorikanische Vorkommen zur Herstellung von Artefakten genutzt wurden, wurde Kupfer eindeutig bereits in der Frühen Bronzezeit importiert. Bis zur Mittleren Bronzezeit 1 scheint das Metall zunächst aus den Vorkommen an der Atlantikküste zu stammen. Ab der Mittleren Bronzezeit 2 kam es dann offenbar aus anderen Regionen. Ab der Späten Bronzezeit 2 ist eine Vielzahl möglicherweise auch weiter entfernter Quellen aus den chemischen Signaturen der Artefakte, wie Beile und Kupferbarren, erwiesen.

Schlagerworte Armorikanisches Massiv, Kupferbeile, Bronzebeile, Bronzezeit, chemische Elementanalyse, Isotopenanalyse

Introduction

For several decades, the archaeometrical research has tried to determine the origin of raw materials used to produce copper-based metal artefacts, firstly by chemical analyses, then by isotopic ones. This research has been carried out in almost all countries in Europe¹. In France, for instance, examples of such studies are the works of Rennes University from 1960 to 1990 (such as Briard/Bourhis 1984; Bourhis/Briard 1985), as well as the works of the Centre de Recherche et de Restauration des Musées de France (C2RM-

Summary

The north-west of France is a region where copper deposits are rare and perhaps poor. Surprisingly, it is also one of the French regions where metal objects, including a large number of axes dating from the Chalcolithic period to the end of the Bronze Age, have been found in very large numbers in tombs of the Early Bronze Age period and in metal hoards from the Middle Bronze Age 1 onwards. For the earliest periods, very large numbers of axes have been found in isolation, which presents an almost insoluble problem of putting them back into context.

The aim of this study is to provide a chronological overview of research into axes, with a brief review of their typology. The study focuses on the knowledge of the nature of the metal through elemental chemical and isotopic analyses. While it is possible that some Armorican deposits may have been used to produce artefacts in the earliest periods, it seems clear that copper was imported as early as the Early Bronze Age. Initially, the metal seems to have come from deposits in »Atlantic« countries, until the Middle Bronze Age 1. From the Middle Bronze Age 2 onwards, the copper seems to have come from other regions. From the Late Bronze Age 2 onwards, a diversity of sources, some of which may be distant, seems evident, as can be seen from the chemical signatures of objects, including axes and copper ingots.

Keywords Armorican Massif, copper axes, bronze axes, Bronze Age, elementary chemical analyses, isotopic analyses

F)-team (Paris; such as Mille/Bourgarit 2000), which are still in progress. From 2007, a new research program of chemical analyses has been initiated at Rennes, and from 2017 some LIA analyses (Lead Isotopic Analyses) have been realised dealing with the north of France, including Brittany, Normandy, Loire, and regions of Central France have been carried out under the direction of the author. Studies of artefacts from other French regions have also been performed, enabling comparisons to be made over greater distances.

In the north-west of France, a large number of Bronze Age metal objects have been discovered, mainly in ter-

¹ For example, Höppner et al. 2005; Dolfini et al. 2020; Nørgaard et al. 2021; Berger et al. 2023; O'Brien 2023; Williams 2023. ² Briard 1965; Milcent 2012; Nordez 2019; Bordas 2023.

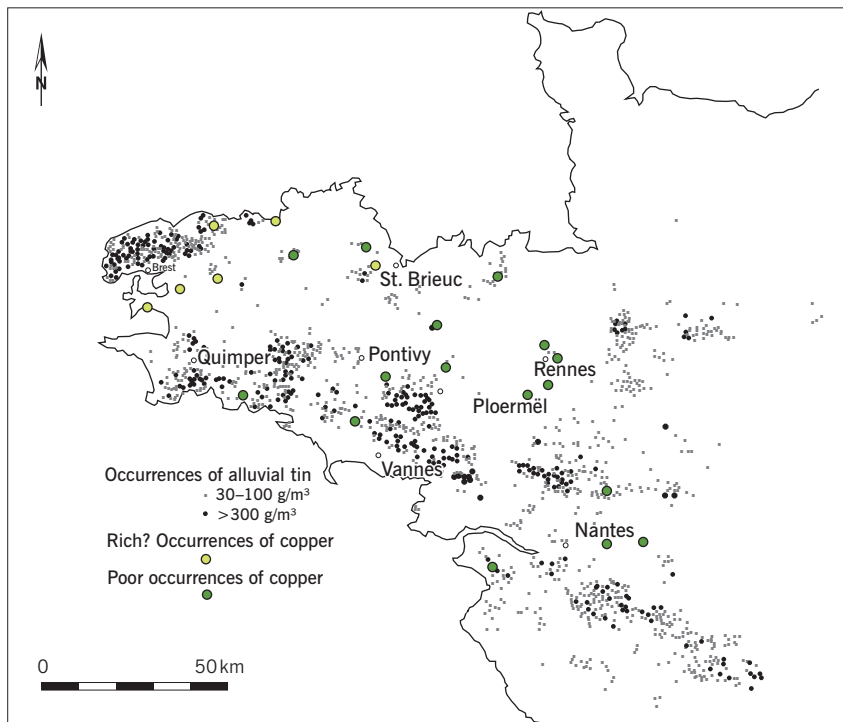


Fig. 1 Distribution map of alluvial cassiterite and copper occurrences in the Armorican Massif.

Abb. 1 Verbreitungskarte alluvialer Kassiterit- und Kupfervorkommen im Armorikanischen Massiv.

restrial hoards², but also in river beds (Mélin 2011) and in graves (Nicolas 2016), as well as isolated finds without any known context (Gandois 2018). In the latter case, it was mainly axes that were found, most of which can probably be attributed to the Chalcolithic period, although a minority can be linked to the more recent Bronze Age.

The main question that arises in this western region concerns the copper origin. Armorican deposits contain some evidence of copper, but the most occurrences encountered are not recognised as significant deposits by modern geologists, except perhaps one sector located in northern department of Finistère (Marcoux 2017). However, while some areas may have been rich enough to be considered as small deposits and allowing the production of artefacts in the earliest periods, it is clear that, at some point, given the size of the mass of metal needed for all the known artefacts, copper in metallic form has to be imported from other regions of France or Europe.

Copper resources in the Armorican Massif

The geological context of north-western France corresponds, for a very large part of the territory, to the Armorican Massif, whose latest major tectonic movements occurred during the Hercynian orogeny (400–300 Ma; Ballèvre et al. 2009). The terrain currently visible therefore corresponds to an ancient, now-eroded mountain belt, with numerous gold, tin, and lead deposits, but very little copper (Fig. 1; Marcoux 2017). Nevertheless, copper occurrences were observed by geologists at various points in Brittany in the early 19th century (Kerforne 1926) and then later during intensive geological surveys between the 1960s and 1990s by the BRGM (Bureau de Recherche Géologique et Minière, the French Geological Survey, Orléans). These are essentially polymetallic sulphide

mineralisations of the BGPC (Blende-Galena-Pyrite-Chalcopyrite) type. Chalcopyrite is usually speckled with other minerals, but may also be present as veinlets (Pierrot et al. 1973; Pierrot et al. 1975). Fahlore could be also observed. Meteoric alteration zone is generally non-existent due to the acidity of the soils and the high rainfall. However, a few sectors did show some covellite and, much more rarely, malachite (Robert 1970; Chauris et al. 1976). The quantities of these oxidised minerals are quite small. However, it is very difficult to determine the exact quantity of copper minerals in these deposits, as the descriptions made by geologists are often vague, using terms such as »rich,« »rare,« and »very rare.« In a region where copper is rare, one sector may be described as »rich« because it is exceptional in the regional context, although it is not a major deposit. Six sectors may nevertheless have contained copper in sufficient quantities to enable small-scale copper mining operations to be carried out. Unfortunately, three sectors were intensively mined in modern times, destroying any areas that might have shown signs of earlier mining: Lanmeur (Finistère) for associated tin (Robert 1970), and Huelgoat (Finistère), and, to a lesser extent, Trémuson (Côtes d'Armor) for galena (Chauris et al. 1976). A fourth sector (Carnoët, Finistère) is currently under archaeological investigation; here, a very small copper mine was exploited in the 18th century (Mulot 1984), and it is possible that some malachite may still be found. Unfortunately, for the moment no archaeological evidence of prehistoric mining has been found and no prehistoric mining tools have been discovered in connection with possible copper mining.

Analytical methods

In an attempt to characterise the origin of the copper, the analyses program of copper-based artefacts was relaunched

in Rennes fifteen years ago, initially using elementary chemical analyses by Horiba ICP-OES (Ultima Expert). Samples were taken with a micro-drill from the sound metal after stripping of the weathered surface layer, enabling 40 mg of metal to be taken, leaving a surface impact of around 1 mm.

These types of analyses provide accurate values for trace elements, making it possible to highlight chemical signatures for artefacts of the same chronology in certain geographical areas. The analysis protocol is based on that of B. Mille and D. Bourgarit (2000) and is fully described in Aranda et al. (2013). Alloying elements are given in % (calculated from concentration in mg/l), and trace elements in ppm (10 000 ppm = 1 %). Correlations between alloying elements and trace elements (Ag, As, Ni, and Sb), and between the trace elements themselves, are visualised using binary diagrams. Ternary diagrams can also be used for a better visualisation of the results. These elemental analyses reveal compositional groups that may reflect the type of metal used in a given region for a given period. This can also reveal possible recycling and mixtures of metals of various origins when a large number of objects are analysed. It is on the basis of these results that the objects that will benefit from isotopic analyses should be selected. Since 2017, lead isotope analyses have been initiated and realised in SEDISOR/GEO-OCEAN in Brest, Finistère, and they follow the method described in a previous article (Couderc et al. 2021). Unfortunately, isotopic results have not yet been fully processed. The reference database of known copper deposits is not complete, and there are many unknown or as yet unanalysed deposits that could modify interpretations. The diagrams presented here also lack precision and concern only the representation of $^{206}\text{Pb}/^{204}\text{Pb}$ vs $^{207}\text{Pb}/^{204}\text{Pb}$. For hypotheses, the $^{208}\text{Pb}/^{204}\text{Pb}$ value has been also taken into

account. As a result, the main outcome of the present study is to rule out some origins rather than determining precise ones. The few hypotheses put forward cannot therefore be taken as definitive results and further studies are needed.

Context and chronology of the Bronze Age in north-western France

The area covered by this study is Atlantic Europe, whose various definitions are based on the frequency of appearance and associations of types of metal production and specific cultural features (Milcent 2012). Today, the existence of a cultural Atlantic Europe domain is no longer really debated, but its limits and the internal dynamics that drive it are still debated (Bordas Moran Dupuch 2023). For P. Y. Milcent (2012), Atlantic Europe can be seen as »the image of a living, fairly fluid mechanism based mainly on the circulation of goods, people and ideas along the Atlantic coasts and within the lower basins of the main rivers that flow into them, on a scale that goes beyond community frameworks.«

As with the delimitation of territories, chronological limits are based essentially on the typology of bronze objects, most often found in metal hoards from the Middle Bronze Age onwards, as well as their frequency of appearance and association (Fig. 2). Axes, although not the best master artefacts, can contribute to this delimitation. However, the typological and/or chronological attributions of certain axes, particularly for the Middle and Late Bronze periods, need to be revisited in the light of the analytical studies, as we shall see below in the case of »Rosnoën« type axes.

Before the Middle Bronze Age, the chronological and cultural attribution is based on the material found in the many burial mounds in north-western France as well as on the

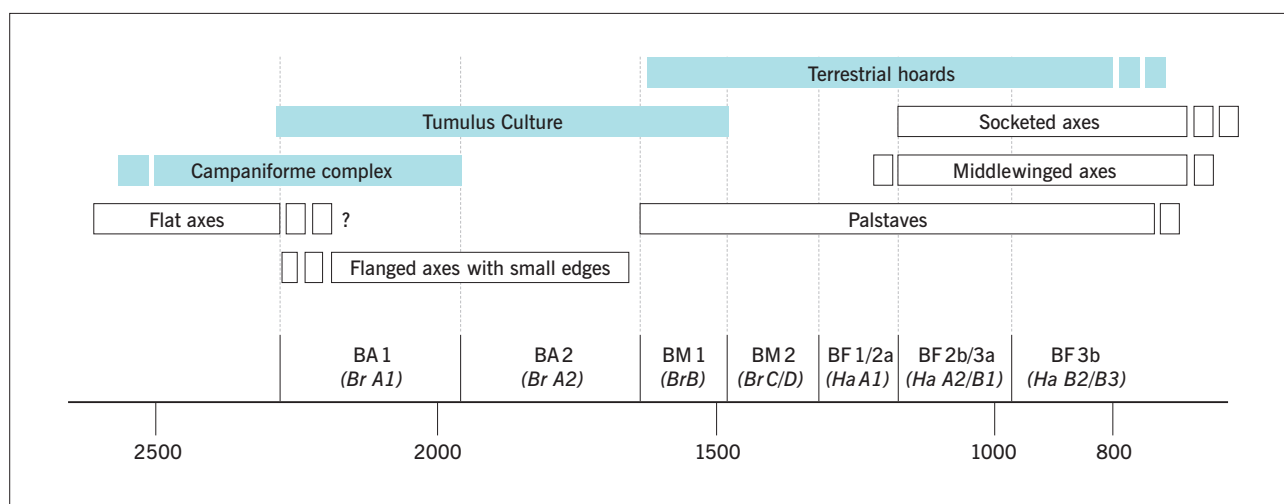


Fig. 2 Chronology of the Bronze Age in north-western France and probable dating of axe type production. For the Atlantic domain: A-EBA 1 = Atlantic Early Bronze Age 1; A-EBA 2 = Atlantic Early Bronze Age 2; A-MBA 1 = Atlantic Middle Bronze Age 1; A-MBA 2 = Atlantic Middle Bronze Age 2; A-LBA 1/2a = Atlantic Late Bronze Age 1/2a; A-LBA 2b/3a = Atlantic Late Bronze Age 2b/3a; recent A-LBA 3 = recent Atlantic Late Bronze Age 3. For the continental domain: Br A1 = Bronze Age A1; Br A2 = Bronze Age A2; Br B = Bronze Age B; Br C/D = Bronze Age C/D; Ha A1 = Hallstatt A1; Ha A2/B1 = Hallstatt A2/B1; Ha B2/B3 = Hallstatt B2/B3.

Abb. 2 Chronologie der Bronzezeit in Nordwestfrankreich und mögliche Datierung der Herstellung unterschiedlicher Beilformen. Für den atlantischen Bereich: A-EBA 1 = Atlantische Frühbronzezeit 1; A-EBA 2 = Atlantische Frühbronzezeit 2; A-MBA 1 = Atlantische Mittelbronzezeit 1; A-MBA 2 = Atlantische Mittelbronzezeit 2; A-LBA 1/2a = Atlantische Spätbronzezeit 1/2a; A-LBA 2b/3a = Atlantische Spätbronzezeit 2b/3a; rezente A-LBA 3 = rezente Atlantische Spätbronzezeit 3. Für den kontinentalen Bereich: Br A1 = Frühbronzezeit A1; Br A2 = Frühbronzezeit A2; Br B = Mittlere Bronzezeit B; Br C/D = Mittlere Bronzezeit C/D; Ha A1 = Hallstatt A1; Ha A2/B1 = Hallstatt A2/B1; Ha B2/B3 = Hallstatt B2/B3.

pottery found in settlements where metal remains are virtually non-existent. As a result, a number of artefact types, including axes, have been attributed to the Early Bronze Age. Unfortunately, many uncertainties remain, as most of the burial mounds known in the literature were excavated at an early date, so there is no way of absolutely dating them. However, the construction of these tombs, which began in the Early Bronze Age, seems to have continued for some time into the Middle Bronze Age. Some of the tombs also appear to have been reused or rebuilt well into the Bronze Age (Nicolas 2016), further disrupting the interpretation of these buildings. Finally, what really limits the chrono-typological study of axes produced before the Middle Bronze Age is their discovery in isolation in the ground, without any archaeological context.

The earliest known copper objects in north-western France have been dated to the 4th millennium. These are isolated axes with a completely different typology to those known from other periods, similar to axes known in Eastern Europe (Klassen et al. 2017). Metal, found in the form of beads and awls, really appeared at the end of the Neolithic period (Van der Linden 2006). The Artenacian Culture (central-western France) probably played a major role in the production and perhaps the spread of copper (Mille 2010). But it was very likely in the Bell Beaker context that more developed production appeared, with the manufacture of beads and awls as well as small daggers and Palmela heads (Van der Linden 2006). Most of the flat axeheads discovered without context can probably be attributed to this period. In fact, copper flat axeheads are widely found in the two main regions of France where other copper artefacts were also found in this period, namely, the south-eastern Mediterranean and the north-western regions (Gandois 2009).

The next period is divided into two stages essentially linked to the typology of the daggers: an early stage, Br A1 (2200–1900 BC), and a more recent stage, Br A2 (1900–1650 BC). These stages correspond to those attributed to eastern France and Germany. The Middle Bronze Age can also be divided into two stages (Nordez 2019). The early stage, A-MBA 1, corresponds to the Tréboul horizon (1550–1450 BC) (Briard 1965), equivalent to H. Müller-Karpe (1959) Bronze B for Central Europe and Germany, and A-MBA 2 corresponds to that of the Moustiers horizon (1450–1300 BC) (Nordez 2019), equivalent to Br C. The chronology of the Atlantic Late Bronze Age has been reviewed by Milcent (2012) and is based on six material sequences. The first stage of the Late Bronze Age corresponds to the Rosnoën horizon and may be divided into two sub-periods: the Early A-LBA 1 (Saint-Just-en-Chaussée horizon, 1275–1225 BC), equivalent to Br D1/D2, and the Late A-LBA 1 (Chailloué horizon, 1225–1140/1125 BC), equivalent to Ha A1. The second stage corresponds to the Saint-Brieuc-des-Iffs horizon, which may also be broken down into a first stage, the Early A-LBA 2 (Rédéné horizon) between 1140/1125–1050 BC (Ha A2), and a second, the Late A-LBA 2 (Boutigny horizon) between 1050 and 950 BC (Ha B1). Finally, the last stage of the Late Bronze Age corresponds to the Plainseau horizon, once again organised into two stages: the Early A-LBA 3 (Longueville horizon) from 950 to 900 BC (Ha B2) and the Late A-LBA 2 (Vénat horizon) from 900 to 800 BC (Ha B3).

Early metallurgy, (probably) Bell Beaker Culture

In recent years, rare Bell Beaker sites with traces of copper-working have been discovered in north-western France at Talmont-Saint-Hilaire in Vendée department (Gandois et al. 2020), Oléron in Charente Maritime department (Gandois/Soler 2022), and Concarneau in Finistère (Le Gall 2023). Metalworking has been evidenced through the analysis of ceramic sherds reused in metallurgy, proving that metalworking using furnace-vessel technology could have taken place in north-western France up to the western extremity of the Armorican peninsula. As a result, the question of local metal production has been revived. But to prove this, only a major forthcoming campaign of elemental and isotopic analyses of very ancient metal objects and rare Armorican ores will provide answers.

Nevertheless, it does seem that a part of objects could have been made in these western regions, as metalworking sites do exist. But some artefacts could also be imported, just as they were in other countries (Nørgaard et al. 2021a). What type of objects could have been produced? Axes? The lack of context prevents us from answering this question. A database has been compiled containing several thousand objects from the Chalcolithic and Early Bronze periods, over 2000 of which have been analysed in the past (Gandois 2018). Many of these analyses are old and inaccurate, so elementary chemical analyses will have to be done again, in conjunction with lead isotope analyses, which are currently non-existent in the search for copper sources. The general typology of flat axeheads in France is still based on the work of J. Briard and G. Verron (1976). The variability in the shape of the axes could indicate a variety of origins (Fig. 3a). This work needs to be taken up in more detail. However, a number of recent studies combining typological studies and chemical analyses point to widespread production in central-western France (Gandois et al. 2024) and, in some cases, as far afield as eastern France (Klassen et al. 2007). While an exhaustive analytical study is still lacking, a number of flat axes, found without context, from the north-west of France have been analysed by ICP-OES at the Rennes laboratory in recent years. Regardless of the type of axe, we can see that some of the axes are made of bronze, with tin contents ranging from 1–12% and with a low arsenic content of under 1%. Another part is arsenic-rich copper with an arsenic content between 1–9%. Finally, a few axes contain both tin and arsenic, but at low levels of between 1% and 3% for these two elements. The levels of some trace elements are highly variable, including Ni (from 0 to 40 000 ppm, median at 4000 ppm) and Sb (from 0 to 4500 ppm, median at 1000 ppm), suggesting different and perhaps distant origins. Indeed, nickel is very rarely found in Armorican peninsula deposits. The Armorican Bell Beaker Culture was probably heavily influenced by the Iberian Peninsula, and some axes may have travelled from these regions. Similarly, the south of France is very rich in flat axes (Guilaine 1972; Gandois 2009), which could also have travelled as far as the north-west of France. Finally, a local origin for the copper is always possible, but this has not yet been verified.

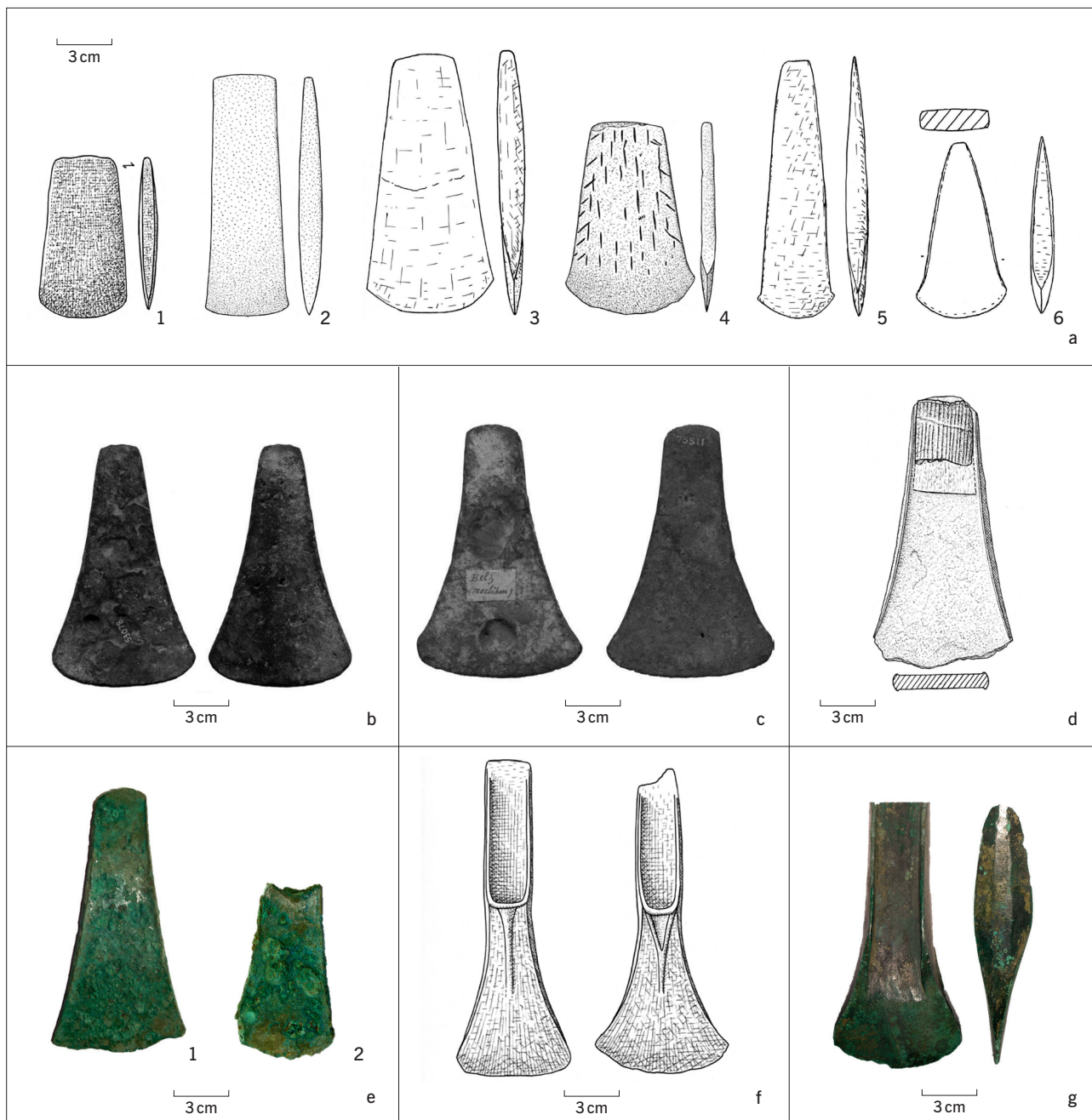


Fig. 3a–g a Flat axeheads from the Côtes-d’Armor department; b Flat axehead from the Ploudaniel hoard; c Flat axehead from the Belz hoard; d Low-flanged axeheads from the Trémel tumulus; e Low-flanged axeheads from the Crec’h Perros tumulus; f Palstaves from the Tréboul hoard; g Long-flanged axehead from the Tréboul hoard.

Abb. 3a–g a Flachbeile aus dem Dép. Côtes-d’Armor; b Flachbeil aus dem Hortfund von Ploudaniel; c Flachbeil aus dem Hortfund von Belz; d Beilklingen mit flachen Randleisten aus dem Tumulus von Trémel; e Beilklingen mit flachen Randleisten aus dem Tumulus von Crec’h Perros; f Absatzbeile aus dem Hortfund von Tréboul; g Beil mit langen Randleisten aus dem Hortfund von Tréboul.

Early Bronze Age (EBA A 1–EBA A 2)

During the Early Bronze Age, most metal objects were found in burial mounds. Their association with other types of artefacts, notably daggers whose typology is much better defined, makes it easier to position them in time, although there is still much debate on the subject (Nicolas 2016). However, the flared and low-flanged axeheads appear to be globally similar (cf. Fig. 3c). The composition of this type of axe shows that it is mostly made of bronze with an average

tin content of between 8% and 14% (average around 9%). Gandois (2018) shows that during Early Bronze Age A1, only some of the objects were made of bronze, and the tin content seems to increase slowly over time. In Early Bronze Age A 2, all the objects were made of bronze, including the axes. A few low-flanged axeheads have been analysed in recent years at Rennes. Some axes have fairly high levels of Sb (1750, 1950, and 2350 ppm for three of them) or Ni (3500 and 7400 ppm for two other axes), while the levels for the majority of axes vary between 20 and 700 ppm for

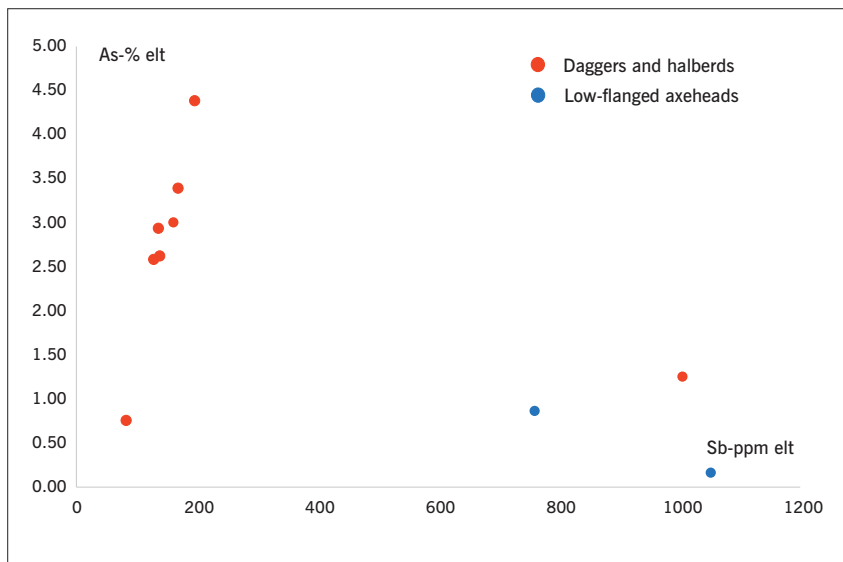


Fig. 4 Distribution of elemental chemical analyses in As-Sb diagram of Crec'h Perros artefacts.

Abb. 4 Verteilung der Artefakte von Crec'h Perros im As-Sb-Diagramm.

Ni and between 150 and 1100 ppm for Sb. These varying grades suggest that the copper may have come from more than one source. Only one axe is made of arsenic copper (1.2% As), while the other bronze axes have low levels of As (on average 0.2%).

The difference in alloy composition between axes and other objects (daggers, halberds) is significant. A number of the latter have higher As contents, ranging from 0% to 4.5%, with the majority having As contents of over 1.5%, and fairly low Ni and Sb contents. It is difficult to interpret these data accurately, as some of the axes were found without a context, and for the others the dating of the burial mound is not necessarily known. There may also have been a chronological change in the composition of the alloy. But it could mean that, for some time, these different alloys coexisted, as in the case of the Crec'h Perros burial mound (Côtes-d'Armor; Blanchet 2005), where ten metal objects were found and all alloy compositions were represented (no published data). For this burial mound, however, the two axeheads and one halberd show a real difference in chemical signature, based on trace element content, compared with the other seven objects, which consistently have their own chemical signature (Fig. 4).

Unfortunately, no isotopic analysis has been carried out on Early Bronze Age axes, so it is impossible to discuss the origin of these metals. We can, however, discuss the presence of artefacts of different origins in the large north-western quarter of France. For example, »Rippenbarren« type ingots have been found as far north as the Bay of the Somme in northern France (Blanchet/Mille 2009), so why wouldn't this metal have travelled further west too? Likewise, *lunulae* similar to those found in Ireland have been found on the peninsula (Briard 1987), showing a definite connection between these two regions. This connection has also been highlighted by the presence of copper and, more rarely, bronze axes, known as Ploukilla type (cf. Fig. 3b), from Plouhinec and Ploudaniel (Finistère), which are similar in terms of typology to Killaha type axes from Ireland (Gandois et al. 2019). The copper in the Irish axes is thought to have come from the Ross Island mine, Ireland (Northover

2004; O'Brien 2023). Chemical analyses carried out at the C2RMF (Paris) and in Rennes on these Briton axes show a composition similar to that of Irish axes, suggesting that the copper also came from this mine. However, a local origin for some artefacts cannot be completely ruled out without future isotopic analyses of the objects and potential ore deposits.

First stage of Middle Bronze Age (A[Atlantic]-MBA 1/Br B)

From this period onwards, metal objects were found mainly in rare metal hoards among objects of other types, mainly weapons. Objects from this period show a very strong typological affinity with objects from the Acton Park horizon in the British Isles. The A-MBA 1 long-flanged axeheads are found in the Médoc (Lagarde-Cardona 2012) and Vendée department (Pautreau 1979), but also in Brittany, and palstaves come from Brittany, Normandy and the mid-western region (cf. Fig. 3d-f) (Nordez 2019).

The elemental chemical composition of the axes is identical to the other types of artefacts found in the deposits, with objects made of »classic« bronze and others of lead-rich bronze of up to 15.3% Pb (Tab. 1). The tin content varied for all the objects with no influence from the lead content. As for trace elements, the composition is identical between classic bronze and lead bronze objects. There is a clear positive correlation between As and Ni (Fig. 5). Similarly, isotopic compositions were identical between the two groups. The presence of lead had no influence on the isotope ratio values.

In addition to the typological similarity with the artefacts from Great Britain, the comparison of elemental and isotopic chemical compositions shows also a real correspondence (cf. Fig. 5a-b). According to recent results, the copper in the »Acton Park« type objects comes from the Great Orme mine (Williams/Le Carlier de Veslud 2019). Indeed, it appears, judging from the similarity of chemical and isotopic compositions, that this metal was also used to produce the A-MBA 1 artefacts from the north-west of

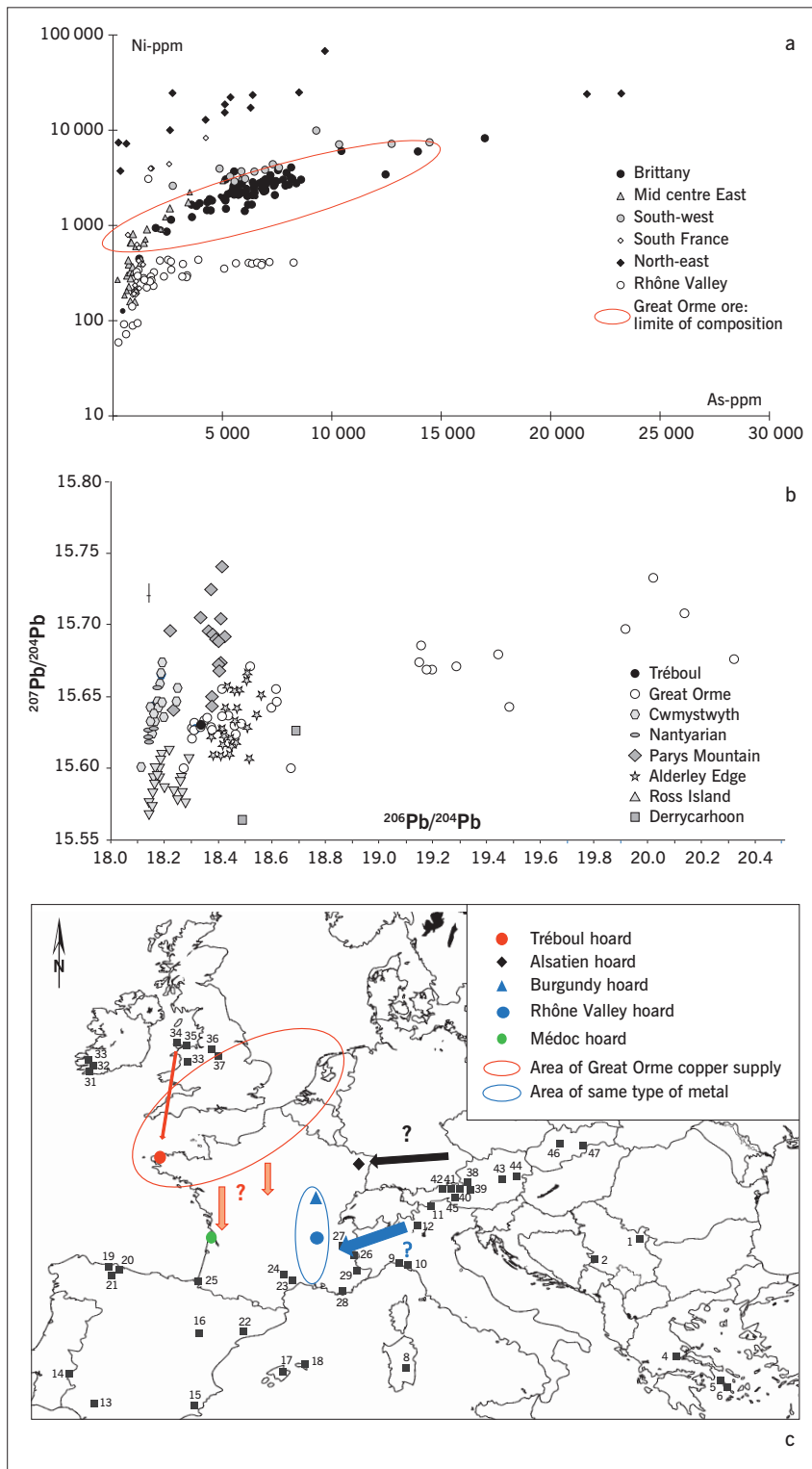


Fig. 5a–c a Comparison of Ni and As contents with contents from other hoards in France and with Great Orme ore contents; b Comparison of the isotopic composition of Tréboul artefacts with that of copper ores from the British Isles; c Location map of hoards: 1 Rudna Glava, Serbia; 2 Jarmovac, Serbia; 3 Ai Bunar, Bulgaria; 4 Othrys Mountains, Greece; 5 Kythnos, Greece; 6 Serifos, Greece; 7 Troodos Mountains, Cyprus; 8 Funtana Raminosa, Italy; 9 Libiola, Italy; 10 Monte Loreto, Italy; 11 Trentino, Italy; 12 Campolungo, Italy; 13 Chinflon, Spain; 14 Mocissos, Portugal; 15 Sierra de Orihuela, Spain; 16 Loma de la Tejeria, Spain; 17 Mallorca, Spain; 18 Mitja Lluna, Spain; 19 El Aramo, Spain; 20 El Milagro, Spain; 21 La Profunda, Spain; 22 Montsant, Spain; 23 Cabrières, France; 24 Bouco Payrol, France; 25 Causiat, France; 26 Saint Véran, France; 27 Les Rousses, France; 28 Maraval, France; 29 Clue de Roua, France; 30 Ross Island, Ireland; 31 Mount Gabriel, Ireland; 32 Derrycarhoon, Ireland; 33 Cwmystwyth, Wales; 34 Parys Mountain, Wales; 35 Great Orme, Wales; 36 Alderley Edge, England; 37 Ecton, England; 38 Mitterberg, Austria; 39 St. Veit, Austria; 40 Saalfeldener Becken, Austria; 41 Kitzbühel Kelchalm, Austria; 42 Schwaz Brixlegg, Austria; 43 Eisenerz, Austria; 44 Prein, Austria; 45 Virgental, Liechtenstein; 46 Spania Dolina Piesky, Slovakia; 47 Spanie Pole, Slovakia.

Abb. 5a–c a Ni- und As-Konzentrationen. Vergleich mit anderen Depotfunden aus Frankreich und mit dem Erzgehalt vom Great Orme, Wales; b Isotopenzusammensetzung. Vergleich der Artefakte aus Tréboul mit Kupfererzen von den Britischen Inseln; c Fundorte von Depots. 1 Rudna Glava, Serbien; 2 Jarmovac, Serbien; 3 Ai Bunar, Bulgarien; 4 Othrysgebirge, Griechenland; 5 Kythnos, Griechenland; 6 Serifos, Griechenland; 7 Troodos-Gebirge, Zypern; 8 Funtana Raminosa, Sardinien; 9 Libiola, Italien; 10 Monte Loreto, Italien; 11 Trentino, Italien; 12 Campolungo, Italien; 13 Chinflon, Spanien; 14 Mocissos, Portugal; 15 Sierra de Orihuela, Spanien; 16 Loma de la Tejeria, Spanien; 17 Mallorca, Spanien; 18 Mitja Lluna, Spanien; 19 Sierra del Aramo, Spanien; 20 El Milagro, Spanien; 21 La Profunda, Spanien; 22 Montsant, Spanien; 23 Cabrières, Frankreich; 24 Bouco-Payrol, Frankreich; 25 Causiat, Frankreich; 26 Saint-Véran, Frankreich; 27 Les Rousses, Frankreich; 28 Maraval, Frankreich; 29 Clue de Roua, Frankreich; 30 Ross Island, Irland; 31 Mount Gabriel, Irland; 32 Derrycarhoon, Irland; 33 Cwmystwyth, Wales; 34 Parys Mountain, Wales; 35 Great Orme, Wales; 36 Alderley Edge, England; 37 Ecton, England; 38 Mitterberg, Österreich; 39 St. Veit, Österreich; 40 Saalfeldener Becken, Österreich; 41 Kitzbühel-Kelchalm, Österreich; 42 Schwaz-Brixlegg, Österreich; 43 Eisenerz, Österreich; 44 Prein, Österreich; 45 Virgental, Liechtenstein; 46 Spania Dolina-Piesky, Slowakei; 47 Spanie Pole, Slowakei.

France. The higher or lower amount of lead is linked to the presence of galena veinlets within the deposit intersecting the copper deposit and which may have been used in the composition of the charge in the smelting furnaces, hence the similarity of the isotopic compositions. It is therefore not a deliberate addition (Williams 2023).

Analysis of artefacts of the same chronology from other French regions (the Rhône Valley, southern France, Burgundy and Alsace) shows that the spread of this metal seems to have involved only the regions close to the Atlantic/North

Sea coast (cf. Fig. 5c). Artefacts from Alsace to the north-east have a very different chemical composition. Similarly, artefacts from the south of France, from the Rhône Valley (cf. Fig. 3g; Delrieu et al. 2015) and from Burgundy (Forel 2009) have a chemical composition similar to each other but different from that of the north-west and Alsace. These deposits all contain axes that have hitherto been described as Neyruz type. However, these are copper axes containing very little tin (1% Sn on average). It would seem that the typological attribution of these axes needs to be reviewed,

	Nb analyses	Pb (min)	Pb (max)	Pb average	Sn (min)	Sn (max)	Sn average	Ag (min)	Ag (max)	Ag average
First stage of Middle Bronze Age (BMA1/Br B)										
Classical bronze artefacts	62	0	1.5	0.4	2.4	18.1	10.3	40	948	346
Leaded bronze artefacts	15	2	15.3	3.3	7.8	15.4	11.2	105	1030	377
Second stage of Middle Bronze Age (BMA2/Br C)										
Classical bronze axes	277	0.01	3.7	0.13	7.1	22.4	14.4	20	1210	173
First stage of Final Bronze (BF A1/Br D–Ha A1)										
Classical bronze artefacts	12	0.04	0.2	0.2	10.7	25.8	12.7	172	718	482
Second stage of the Late Bronze Age (BF A2/Ha A2–Ha B1)										
Copper ingots	3	0.2	0.4	0.3	0.05	0.2	0.06	257	1323	303
Poor trace element artefacts	12	0.09	22.5	2.1	7.4	14.7	11.8	279	1049	654
Leaded bronze ingots	26	2.5	48.5	18.1	3.4	18.4	11.5	157	5290	698
Ni rich artefacts	10	0.08	7.3	4.8	6.5	10.3	8.6	1574	5585	3238
As/Sb rich artefacts	25	0.4	28.2	8.2	5.4	15	9.8	290	4887	2913
Ag/As/Sb very rich artefacts	46	0.3	18.9	3.9	2.4	14.1	7.3	2220	15178	6013
End of the third stage of the Late Bronze Age (BF A3/Ha B2–B3)										
Atlantic type artefacts	86	0.07	37.8	3.26	2.7	19.4	9.9	135	2256	772
Copper ingots	28	0.01	0.9	0.14	0	0.7	0	33	8154	249
As only rich artefacts	5	0.09	9.2	1.1	0.01	14	3.1	76	1210	464
Sb only rich artefacts	7	0.5	22.8	3.4	8.2	13	10	866	1731	1174
Ag/Sb rich artefacts	4	3.1	22.82	4.5	7.5	7.9	7.6	2020	16215	14403
As/Sb rich artefacts	2	0.9	2.1		0.07	3.5		264	1176	
Ag/As/Sb rich artefacts	8	1.9	23.5	12.8	0.02	11.1	8.5	1737	22590	2866

since the axes attributed to the Neyruz type, particularly in Western Germany (Kienlin 2008), are made of bronze with a tin content either below 1% or higher, between 3% and 10%. These variations seem to indicate a typological attribution that needs to be clarified.

Second stage of Middle Bronze Age (A-MBA 2/Br C)

Metal from the Middle Bronze Age 2 in north-western France is known from the very large number of hoards made up either solely of ornaments or solely of axes, or, much more rarely, of assemblages of various objects, essentially associating axes with other elements of ornaments or weaponry (Boulud-Gazo et al. 2017). The axes are palstaves of various types – Breton, Norman, and Central-Western and long-flanged type without a stop-ridge in Vendée and Aquitaine areas (Fig. 6a), which are scattered in the region of the same name (Fig. 7a). A total of 450 hoards have been identified in these regions, with a total of 3148 objects inventoried, including 2710 axes (Nordez 2019) with tin contents ranging from 9–15% (average 12%). This number is largely underestimated due to the fact that many hoards have gone unreported for decades. These types of axes can be recognised in much more distant regions, in

central-eastern France for example, or even in the south, suggesting that objects were moved over long distances (Gabillot/Quentin 2023). However, local copies are always possible.

Elemental analysis of the axes shows a very high compositional homogeneity for most of the Atlantic seaboard, from Normandy to the Vendée, with a classical bronze composition (cf. Tab. 1; Fig. 7b). Compositional homogeneity is also high relative to that of the axes from the Burgundy and Franche-Comté deposits as well as to the slightly later Malassis hoard in central France, which is made up of a greater variety of objects, including copper ingots (Briard et al. 1969).

This composition seems quite different from that of the previous period for north-western France, suggesting a radical change in the origin of the imported metal. However, some A-MBA 2 axes from the north-west show a chemical composition identical to objects from the previous A-MBA 1 period, and show a difference from axes from eastern and central France (cf. Fig. 7b). The compositions of the axes from Burgundy and the centre of France are really similar and do not come close at all to the composition of A-MBA 1. It is therefore possible to imagine that copper from the Great Orme mining area was still being used in part of north-western France in A-MBA 2, or that objects

As (min)	As (max)	As average	Ni (min)	Ni (max)	Ni average	Sb (min)	Sb (max)	Sb average
1200	16992	6100	448	8243	2214	0	1342	246
3812	7880	6965	1600	3813	2742	145	584	216
227	11473	2680	425	44245	5070	110	5000	1060
793	2150	1600	930	3330	2060	430	1036	813
2470	5814	2720	127	287	227	142	641	209
746	3201	1257	185	2831	615	360	2385	684
336	3900	1111	95	1200	334	189	7420	947
1711	10271	5460	2939	6413	4280	4154	12454	7780
373	8030	3491	220	2667	1215	1086	7675	5823
4079	20138	6383	671	2685	1739	7081	24674	9539
95	1500	1014	102	1296	685	314	6674	2963
22	41879	975	101	600	248	94	40740	789
4135	8000	5034	375	1206	413	1595	3748	1977
937	3310	2184	402	2772	1122	6705	35230	9210
124	1492	1300	100	6190	1810	3246	34753	6030
4220	7350		285	175		7111	44086	
2085	25090	5132	225	2464	810	9820	107025	13060

Tab. 1 Range in variation of the contents of alloying elements (Pb, Sn; values in elemental ppm) and trace elements (Ag, As, Ni, Sb; values in elemental ppm) for the different types of composition of artefacts from north-western France for the A-MBA 1, A-MBA 2, A-LBA 1, A-LBA 2, and recent A-LBA 3 periods.

Tab. 1 Variationsbreite des Gehalts der Legierungselemente (Pb, Sn; Werte in ppm) und der Spurenelemente (Ag, As, Ni, Sb; Werte in ppm) für unterschiedliche Zusammensetzungen der Artefakte aus Nordwestfrankreich für die Zeiträume A-MBA 1, A-MBA 2, A-LBA 1 A-LBA 2 und A-LBA 3.

from A-MBA 1 were being recycled in large numbers in this region. On the other hand, all the axes from hoards found in the northern part of France, in the west and east, show a very clear difference in composition from the artefacts from the south of France. It will therefore be possible to see whether palstaves of north-western typological attribution found in the south of France are local copies or whether they are objects imported from the north.

Isotopic analyses were carried out on axes from north-western France and central France (Fig. 8). Unfortunately, the axes from eastern France have not yet been analysed. Comparison of the isotopic compositions of the north-western axes with the signatures of major copper-mining areas in Europe suggests that the origin of the copper could be Italy. However, the signatures on the Malassis copper ingots seem to point to a Sardinian origin (central and south-west), on the one hand, and an Austrian origin, in the district of Mitterberg, on the other. The objects do not have the signature of the ingots but lie on a straight line connecting the points representing the ingots located in the two mentioned districts. The hypothesis of the use of copper from the Great Orme mine is not confirmed by these analyses, as the orientation of the alignment of the points representing the objects does not point towards the Great Orme isotopic domain.

First stage of Late Bronze (A-LBA 1/Br D–Ha A1)

In the first period of the Late Bronze Age, the type of palstave changed, as did the type of hoard, in which the artefacts are varied and partially fragmented. The number of hoards as well as the number of artefacts per hoard is also much lower. Palstaves, known as »Rosnoën« axes, become more massive and have a right-angled stop-ridge (cf. Fig. 6b). The chemical (cf. Tab. 1; Fig. 7b) and isotopic (cf. Fig. 8) compositions of the axes are identical to those of the other objects in the hoard. These compositions are also identical to those of the previous period. While the typology of the axes has changed, as have the methods of deposition, the copper supply circuits seem to remain the same as before. However, given the limited number of analyses carried out during this period, these results should not be considered definitive.

Second stage of the Late Bronze Age (A-LBA 2/Ha A2–Ha B1)

In Late Bronze Age 2, there are more hoards, but far fewer than in MBA 2. The artefacts are highly fragmented. Axes are represented by massive palstaves, also known as »Rosnoën« type axes because they are fairly identical to the pre-



Fig. 6a–d a1 A-MBA 2 Brittany type palstave (to the left, Saint-Thois); a2 A-MBA 2 Norman type palstave (in the centre, Mouilleron-en-Pareds); a3 A-MBA 2 Vendean type strong edge axes (on the right, Mouilleron-en-Pareds); b A-LBA 1 Rosnoën type palstave, Rosnoën; c1 A-LBA 2 Rosnoën type palstave, Saint-Brieuc-des-Iffs; c2 A-LBA 2 winged axe, Soullans; c3 A-LBA 2 socketed axe, Soullans; d recent A-LBA 3 Plainseau type socketed axes, Gouesnac'h; d1 recent A-LBA 3 Wales type socketed axe, Gouesnac'h; d2 recent A-LBA 3 winged axe, Gouesnac'h; d3 recent A-LBA 3 winged axe, Gouesnac'h; d4 recent A-LBA 3 Nuragic type axe ingot, Mérézel; d5 recent A-LBA 3 palstave, La Rouillasse.

Abb. 6a–d a1 Atlantische Mittelbronzezeit 2 (A-MBA 2), Absatzbeil vom bretonischen Typ, Saint-Thois; a2 A-MBA 2, Absatzbeil vom normannischen Typ, Mouilleron-en-Pareds; a3 Randleistenbeil vom Typ Vendée, Mouilleron-en-Pareds (A-MBA 2); b Atlantische Spätbronzezeit 1 (A-LBA 1), Absatzbeil vom Typ Rosnoën, Rosnoën; c1 A-LBA 2, Absatzbeil vom Typ Rosnoën, Saint-Brieuc-des-Iffs; c2 A-LBA 2, Lappenbeil, Soullans; c3 A-LBA 2, Soullans; d A-LBA 3, Tüllenbeile vom Typ Plainseau, Gouesnac'h; d1 A-LBA 3, Tüllenbeil vom walisischen Typ, Gouesnac'h; d2 A-LBA 3, Lappenbeil, Gouesnac'h; d3 A-LBA 3, Lappenbeil, Gouesnac'h; d4 A-LBA 3, Beilbarren vom Typ Nuragic, Mérézel; d5 A-LBA 3, Absatzbeil, La Rouillasse.

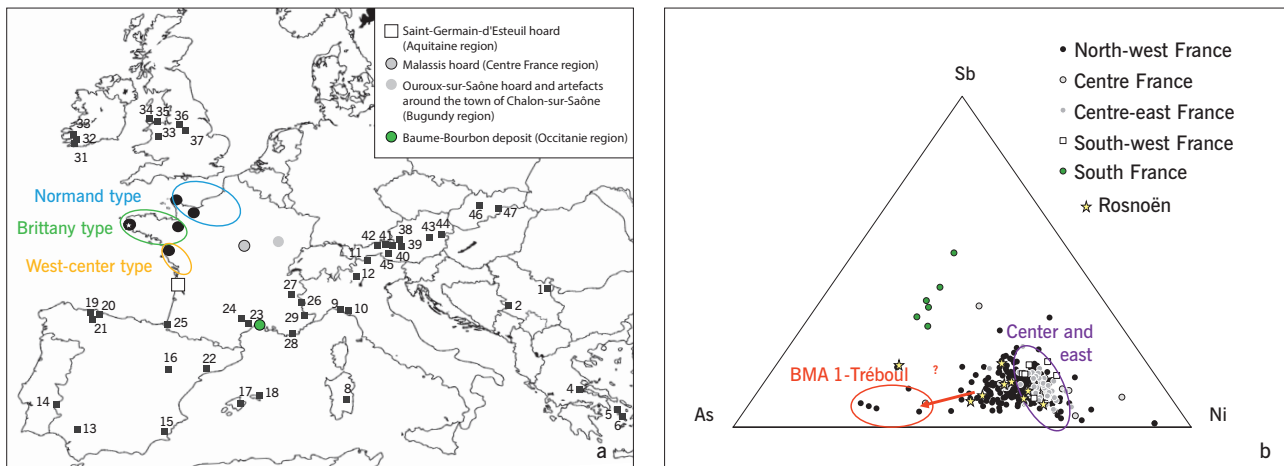
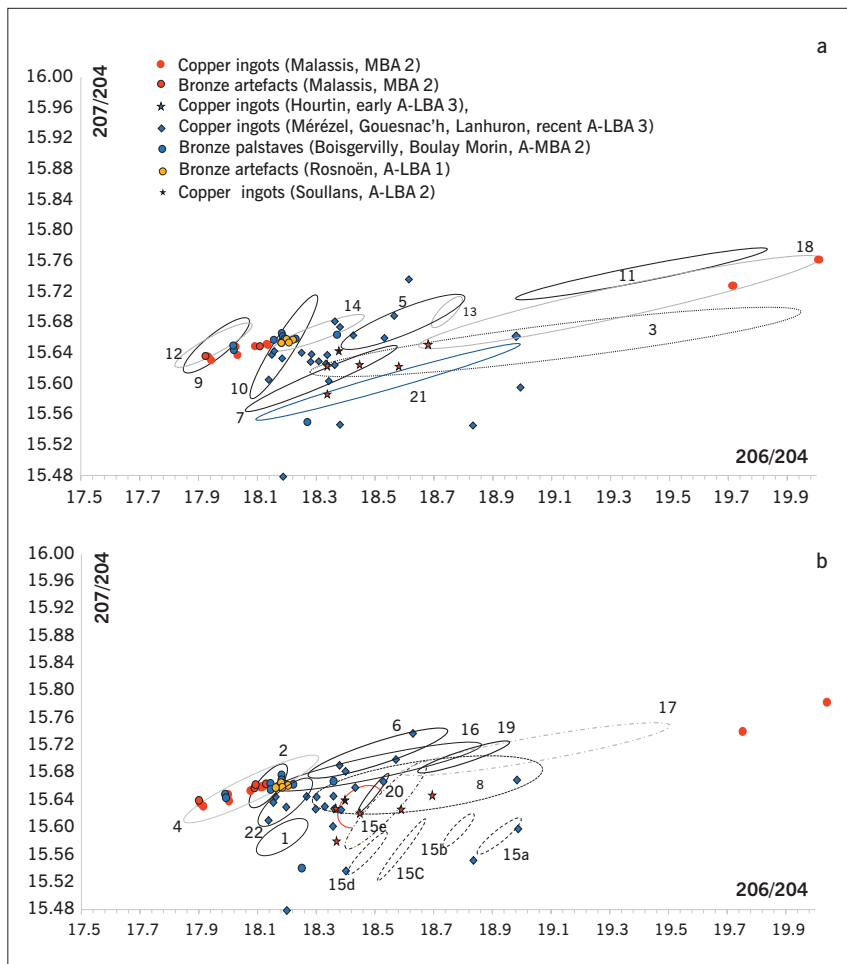


Fig. 7a–b a Distribution areas of A-MBA 2 palstaves (see name of copper mines in Fig. 5); b distribution of A-MBA 2 axe elemental analyses in As-Ni-Sb diagram, and comparison with MBA 2 axes from other French regions, and with A-MBA 1 artefacts.

Abb. 7a–b a Verbreitungsgebiete von A-MBA 2 Absatzbeilen (siehe Abb. 5 für die Namen der Kupferminen); b Verteilung von A-MBA 2-Beilen im As-Ni-Sb-Diagramm und Vergleich mit MBA 2-Beilen anderer französischer Regionen und mit A-MBA 1-Artefakten.

Fig. 8a–b Comparison of lead isotopic composition of artefacts with some copper ore deposits from Europe: 1 Ross Island, Ireland; 2 Copa Hill, Wales; 3 Great Orme, Wales; 4 Central and south-western Sardinia, Italy; 5 Northern and north-western Sardinia, Italy; 6 Cabrières, France; 7 Queyras, France (including Saint Véran); 8 Slovakia; 9 Jaén, Spain; 10 Huelva, Spain; 11 Asturias, Spain; 12 Vlasugana, Italy; 13 Southern Toscana, Italy; 14 Southern Alps, Italy; 15a Kalavassos, Cyprus; 15b Larnaca 1, Cyprus; 15c Larnaca 2, Cyprus; 15d Solea, Cyprus; 15e Limassol, Cyprus; 16 North Tyrol, Austria; 17 Tyrol, Austria; 18 Mitterberg, Austria; 19 Baia Mare, Romania; 20 Apuseni, Romania.

Abb. 8a–b Vergleich der Bleiisotopenzusammensetzung von Artefakten, deren Material aus europäischen Kupfererzvorkommen stammt. 1 Ross Island, Irland; 2 Copa Hill, Wales; 3 Great Orme, Wales; 4 Zentral- und Südwestsardinien; 5 Nord- und Nordwestsardinien; 6 Cabrières, Frankreich; 7 Queyras, Frankreich (einschl. Saint-Véran); 8 Slowakei; 9 Jaén, Spanien; 10 Huelva, Spanien; 11 Asturias, Spanien; 12 Vlasugana, Italien; 13 südliche Toscana, Italien; 14 südliche Alpen (Südtirol, Trentino und Venedien), Italien; 15a Kalavassos, Zypern; 15b Larnaca 1, Zypern; 15c Larnaca 2, Zypern; 15d Solea, Zypern; 15e Limassol, Zypern; 16 Nordtirol, Österreich; 17 Tirol, Österreich; 18 Mitterberg, Österreich; 19 Baia Mare, Rumänien; 20 Apuseni, Rumänien.



vious period (cf. Fig. 6c). It was from this period onwards that the first subterminal-winged axeheads and socketed axes were also found in western France; however, these are less common than palstaves.

Axes have the same chemical composition as other types of artefacts (cf. Tab. 1). What is special about this period

is the nature of the alloy, which contains lead (from 0.43–28.22 %, with an average of 3.23 %) in addition to copper and tin. A comparison of the composition of these palstaves with that of axes from the previous period, all defined as »Rosnoën« type axes, shows a clear difference in elemental and isotopic composition between these two populations.

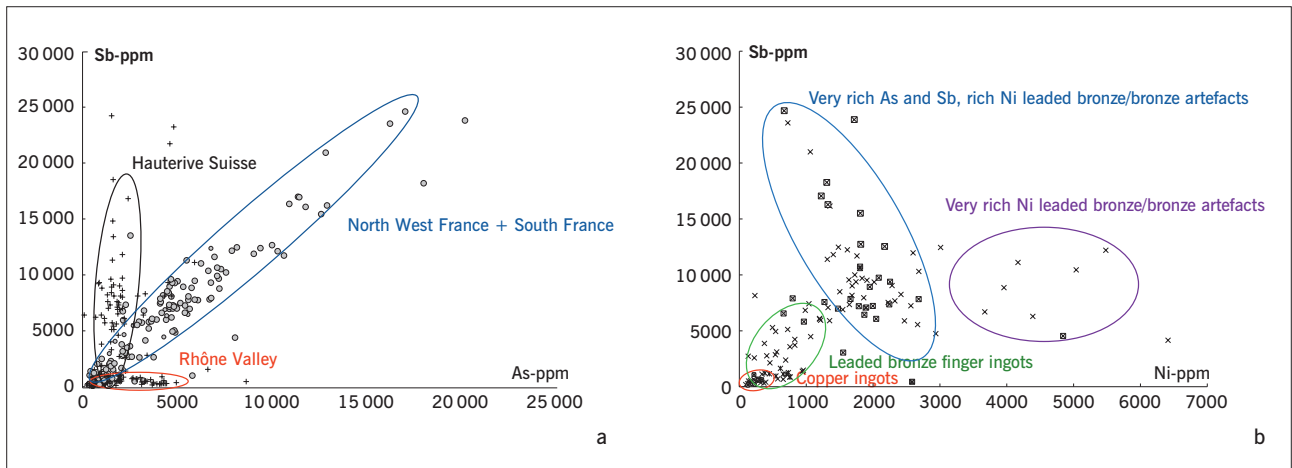


Fig. 9–b a Comparison of Sb and As contents of artefacts from north-western France with that of the Rhône Valley artefacts (unpublished data) and Hauterive from Switzerland; b distribution of elemental chemical analyses in Sb-Ni diagram of different types of composition for A-LBA 2 artefacts.

Abb. 9a–b a Vergleich Sb- und As-Konzentrationen in Artefakten aus Nordwestfrankreich mit denen in Artefakten aus dem Rhône-Tal (unpublizierte Daten) und aus Hauterive, Schweiz; b Verteilung von Artefakten der A-LBA 2 unterschiedlicher Zusammensetzung im Sb-Ni-Diagramm.

Date	Site	Type of axe	Reference	Cu	Pb	Sn	Ag	As	Bi	Co	Fe	Ni	Sb	Zn
Bell Beaker	Île Lemaire	Flat axehead	2801 coll. B	93.98	0	0	0	33816	1219	6	51	2921	1555	266
			2800 coll. B	93.11	0	0	0	46726	755	679	464	2198	2221	441
	2802		92.04	0,00	0	0	58177	547	166	0	3591	608	379	
	Riec-sur-Bélon			89.16	0	0	354	26747	4652	191	3385	41122	2904	471
	Maxent			94.24	0	0	0	40081	444	6	0	523	529	438
EBA	Crec'h Perros	Low-flanged axehead	185-2	92.01	0.02	7.30	1119	1600	595	9	608	1048	1052	570
			185-1	90.38	0.02	8.34	32	8600	595	11	1316	601	760	559
A-MBA 1	Tréboul	Low-flanged axehead	49 5 16/21	87.04	0.80	11.04	338	6442	538	207	433	2399	279	458
			49 5 16/34	75.78	15.31	7.85	377	6888	477	16	35	2278	204	328
			49 5 16/7	85.54	2.07	11.14	360	7391	547	200	666	2709	232	408
			49 5 16/12	82.21	0.31	16.12	293	6834	517	206	2068	2890	217	501
A-MBA 2	Boisgervilly	Palstave	n°1	79.67	0.07	16.18	185	4428	509	287	860	33408	725	329
			n°2	82.94	0.19	15.79	289	3758	552	305	586	3823	1075	354
			n°3	83.99	0.22	14.72	690	2523	528	217	2182	3663	483	377
			n°4	86.24	0.01	12.84	125	1948	510	367	1812	3552	404	271
			n°5	82.96	0.15	15.77	220	3852	548	357	362	4622	808	336
A-LBA 1	Rosnoën	Palstave	49.1.8	84.87	0.19	13.03	459	2103	686	241	11038	2953	1019	527
			49.1.9	85.27	0.22	13.69	705	1546	828	397	1322	1799	864	706
A-LBA 2	St. Brieuc des Ifs	Palstave	St-Brieuc 10	75.15	12.35	8.41	4240	4763	300	302	111	2242	7368	526
			St-Brieuc 3	67.93	18.90	7.97	4551	5151	294	178	107	1273	7576	476
			St-Brieuc 7	86.11	3.41	7.10	5986	6761	356	368	2140	2255	9393	676
			St-Brieuc 23	88.44	1.51	7.67	5408	5569	358	210	83	1662	7845	694
Recent A-LBA 3	Mérézel	Socketed axe	MZL 176	76.50	9.18	14.01	1209	8002	509	138	37	1206	1977	176
		Winged axehead	MZL 175	86.29	2.54	10.78	647	1114	277	6	170	520	3410	286
			MZL 425	86.39	3.35	9.59	1103	2741	288	44	99	1273	6705	206
		Sardinia axe	MZL 114	95.50	0.09	3.11	76	5034	285	0	45	375	1595	671
		Socketed axe	MZL 421	87.20	1.23	11.31	135	95	261	0	176	121	314	265

Tab. 2 Elemental composition of some axes from north-western France from EBA to recent LBA.

Tab. 2 Elementzusammensetzung einiger Beile aus Nordwestfrankreich von EBA bis zur jüngeren LBA.

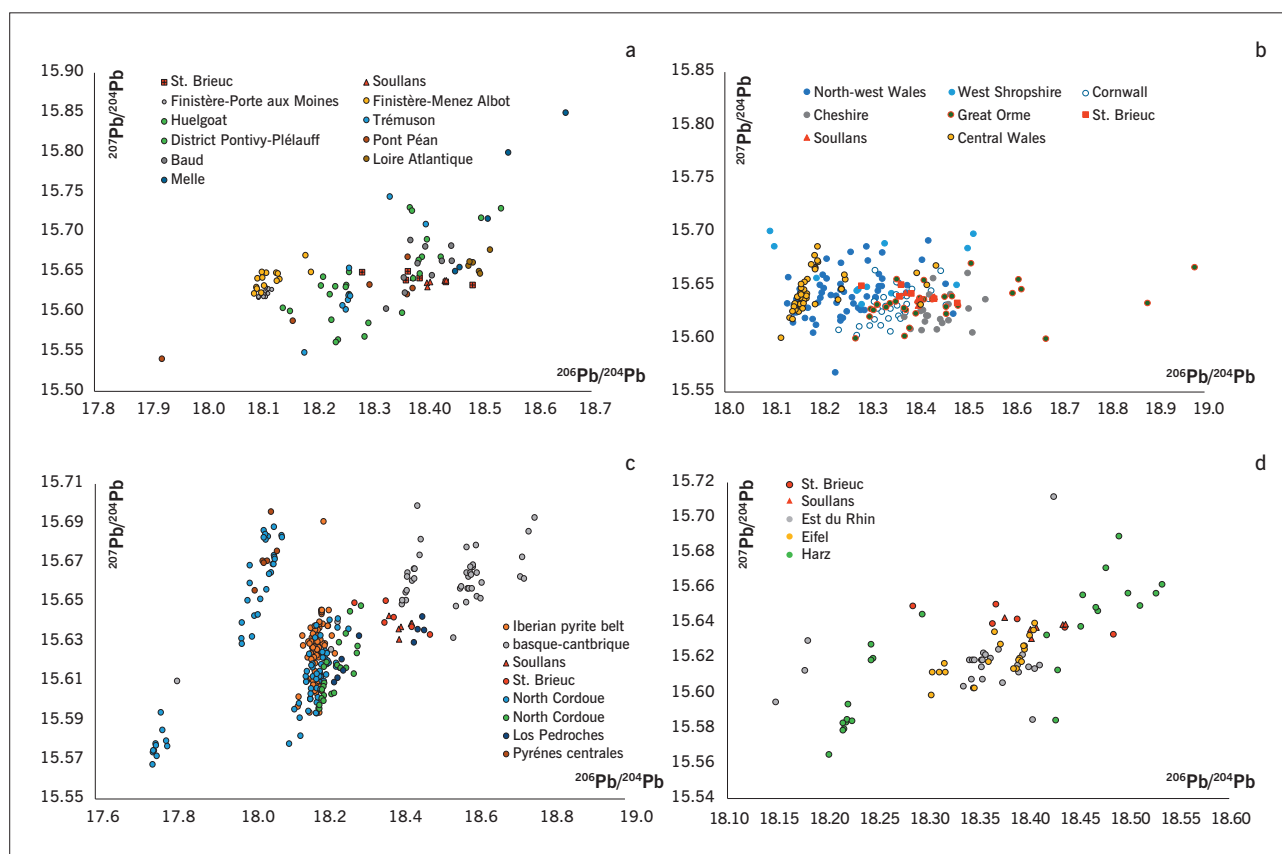


Fig. 10a–d Comparison of lead isotopic composition of A-LBA 2 artefacts with some lead ore deposits from Western Europe: Great Britain, Germany, Brittany, Spain.

Abb. 10a–d Vergleich der Bleiisotopenzusammensetzung von Artefakten der A-LBA 2 mit der einiger Bleierzvorkommen in Westeuropa: Großbritannien, Deutschland, die Bretagne, Spanien.

The A-LBA 2 axes contain lead, while the A-LBA 1 axes do not. Similarly, the levels of the four main trace elements do not correspond at all. The isotope ratios are also different. This leads us to believe that the origin of the metal changes completely between the A-LBA 1 and A-LBA 2, in north-western France, whereas the typology of certain objects remains more or less identical.

Another case study highlights the late use of axes produced in earlier periods. For example, a Breton palstave from the A-MBA 2 period, found in an A-LBA 2 hoard in Vendée (Boulud-Gazo et al. 2022), has the chemical and isotopic composition of objects from this earlier period.

More generally in France, A-LBA 2 axes and artefacts from the north-west show a similarity in elemental composition to artefacts from the south of France, but are completely different from those from the Rhône Valley (unpublished data) and Switzerland (Fig. 9a; Rychner/Kläntzchi 1993).

Nevertheless, objects from the Atlantic seaboard seem to be made from copper of several different origins (cf. Fig. 9b). The copper may come from: 1) copper ingots; 2) bronze ingots containing high levels of lead (cf. Tab. 1) – these two types of ingots have been observed in the deposits and have fairly low levels of As, Ni, and Sb; 3) some objects show a very high nickel content, implying another type of source; 4) other objects are also very rich in Sb and As, implying yet

another source. These last two compositions do not correspond to the compositions of the A-MBA 2 axes, which are much less rich in As, Ni, and Sb. The mixture of sources can also be seen in the isotopic analyses, with the points representing the analyses aligned on a mixing line (Fig. 10).

The very high lead content in the bar ingots suggests that lead was added to the alloy. Comparing the isotopic compositions of A-LBA 2 objects, including axes, with copper deposits is not really meaningful. Comparing these isotopic compositions with European lead deposits does not provide any information either. In fact, several artefacts correspond to these compositions: the Armorican Massif (Marcoux 1986), the British Isles (Rohl 1996), and Western Germany (Bode 2008).

The isotopic analysis of one of the two copper ingots from the Soullans hoards seems to indicate an origin from Slovakia or Great Orme (cf. Fig. 8). However, a comparison of the elemental compositions of the A-LBA 2 objects with those of the A-MBA 1 objects, the copper of which almost certainly came from Great Orme, shows that these two groups of objects do not have the same elemental composition at all: the A-MBA 1 objects are much less rich in Sb. So Great Orme copper couldn't be the source. The same situation was observed for copper ingots from the Hourtin deposit (Médoc), dated to the following period (Couderc et al. 2021).

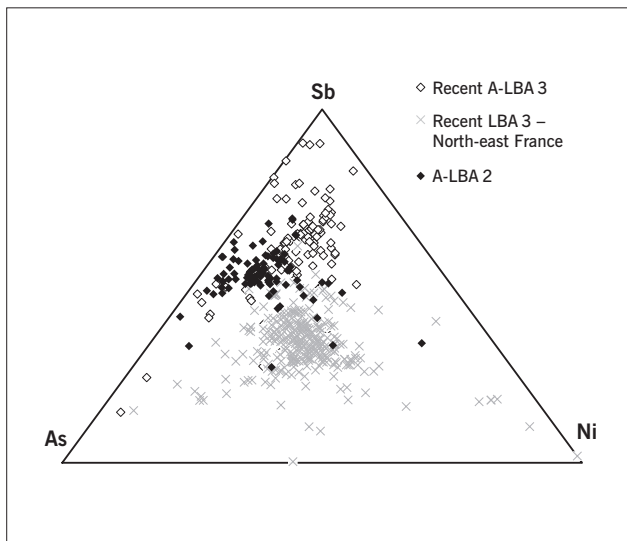


Fig. 11 Comparison of elemental composition of A-LBA 2 artefacts from north-western France, recent A-LBA 3 artefacts from north-western France, and LBA 3 artefacts from north-eastern France in the ternary diagram As-Ni-Sb.

Abb. 11 Vergleich der Elementzusammensetzung von Artefakten der A-LBA 2 aus Nordwestfrankreich, der A-LBA 3 aus Nordwestfrankreich und der LBA 3 aus Nordostfrankreich im As-Ni-Sb-Dreiecksdiagramm.

End of the third stage of the Late Bronze Age (recent A-LBA 3/Ha B2–B3)

In the recent Late Bronze Age 3, there are an extremely large number of metal hoards, with a wide variety of objects, including numerous fragments of copper ingots (Milcent 2012; Bordas 2023). Hoards contain many winged and socketed axes of local typology, some rare massive palstaves named once again the »Rosnoën« type, and some rare palstaves identified as A-MBA 2 relics. Some rare exotic axes such as the Wales type and Sardinian type axes can also be observed (cf. Fig. 6d). The Sardinian axe should be considered a bronze ingot because it is raw from the foundry. It is worth noting that at this period, metal did not only travel in the form of ingots, but manufactured objects were also part of the trade. As in the previous period, objects are largely fragmented, axes are no more numerous in hoards than other types of objects, and the majority of the axes seem to be used.

Elementary chemical analyses show a wide range of compositions suggesting various sources of copper. It should be noted that the majority of objects, including axes, have lead in the alloy (cf. Tab.1), as do the Sardinian axes. A compari-

son of the elemental compositions of objects including axes of the recent Late Bronze Age 3 with those of Late Bronze Age 2 shows similarities for a number of objects, suggesting continuity in the supply of copper from the same sources (Fig. 11). Comparison with objects from the east of France shows that the copper supplying the Atlantic domain is significantly different from that supplying the continental domain (cf. Fig. 11). Isotopic analysis values are highly variable, implying multiple supplies throughout Europe, perhaps Slovakia, Wales, Spain, the south of France, the Occidental Alps (except Austria), Cyprus and Sardinia (cf. Fig. 8). These hypotheses must be verified by elementary analyses.

Conclusion

In conclusion, it is not easy to define the origin of copper in bronze artefacts in a region where there is a lack of copper. It cannot be excluded that some copper objects may be related to regional copper ores for the Chalcolithic period, or even for the Early Bronze Age. But it seems fairly certain that copper was imported from various European mining districts from the Middle Bronze Age onwards. Until the Middle Bronze Age 1, copper seems to have come from Atlantic areas. But from the Middle Bronze Age 2 onwards, the supply of metal became much more important, with various sources, some of them probably very distant. Although this region is located at the end of the continent, it seems that it has always been part of a network for the exchange of goods. Perhaps the numerous tin deposits in Brittany encouraged these exchanges. In the earliest periods, from the Chalcolithic to the Early Bronze Age, the axes appear to have had an important social value. Like other metal objects, they seem to have been traded over long distances. From A-MBA 1 onwards, axes do not seem to be objects of greater value than others, and are treated in the same way in hoards, except for the Middle Bronze Age 2, where the specificity of axe hoards is remarkable and continues to raise questions.

The program developed in north-western France is far from complete. A great amount of work remains to be done on objects from the Chalcolithic period and the Early Bronze Age. Numerous chemical and isotopic analyses are still needed to try and identify the many sources of copper used during the Late Bronze Age. A greater number of analyses taken into account in this way can highlight chemical signatures that differ to a greater or lesser extent depending on the period under consideration. This makes it possible to see possible continuities in the supply of metal or real ruptures.

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