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Isotopic and elemental analyses of north-western French Bronze Age metal hoards

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Abstract: The north-west of France is one of the regions of Europe with the greatest number of Bronze Age metal hoards. This leads to the presence of several tens of thousands of whole or fragmented deposited objects. The region has no major copper deposits. The metal had to be imported from the various copper-producing regions of Europe. Over the last fifteen years, an analytical study has been carried out on these objects, leading to the production of more than 2,000 elemental chemical analyses obtained by ICP-OES and more than fifty lead isotope analyses realised by MC-ICP-MS. Analyses show that in the early Middle Bronze Age, copper was supplied from Wales. The spread of this metal seems to have been confined to the regions bordering the Atlantic and the English Channel/North Sea. From the second Middle Bronze Age onwards, the trades change radically, with copper possibly coming from the Iberian Peninsula and Austria. These networks seem to remain in place during the first phase of the Final Bronze Age. With the second period of the Final Bronze Age, the copper supply diversified. This can be seen from the elemental analyses. Unfortunately, it is not possible to identify the origin of the copper in objects from this period because of their high lead content, probably added deliberately to the alloy. Fragments of copper ingots are rare but do exist. Their isotopic analysis could indicate a Central European origin. At the end of the Final Bronze Age, the diversity of metal composition was even greater, reflecting the increasing complexity of the networks. The many fragments of copper ingots found in the deposits suggest a range of origins, from the western Alps to central Europe, as well as the Mediterranean regions.

Keywords: North-West France, Bronze Age, metal hoard, elemental analysis, lead isotope analysis, copper supply, ancient supply network.

Résumé : Le nord-ouest de la France est l'une des régions d'Europe où il y a le plus grand nombre de dépôts métalliques terrestres de l'âge du Bronze. Cela conduit à la présence de plusieurs dizaines de milliers d'objets entiers ou fragmentés ainsi déposés. Or, cette région ne possède pas de grands gisements de cuivre. Le métal ainsi immobilisé a dû être alors importé des différentes régions productrices de cuivre européennes. Depuis une quinzaine d'années, une étude est menée sur l'analyse des objets des dépôts de cette région conduisant à la production de plus de 2 000 analyses chimiques élémentaires obtenues par ICP-OES et plus de cinquante analyses isotopiques du plomb produites par MC-ICP-MS. Les analyses révèlent qu'au début du Bronze moyen, l'alimentation en cuivre se fait depuis le Pays de Galles, plus précisément depuis la mine de Great Orme. La diffusion de ce métal semble cantonnée aux régions attenantes au domaine atlantique et celles limitrophes à la Manche/Mer du Nord. Plus au sud, le long de la façade atlantique, dans la région aquitaine, le métal du dépôt de Martillac, tout en ayant la signature du métal de Great Orme, semble être mélangé avec du cuivre d'une autre région productrice, dont l'origine n'a pas encore été déterminée. À partir de la seconde période du Bronze moyen, les circuits changent radicalement avec du cuivre pouvant provenir d'une part de la péninsule ibérique (région de Huelva) ou d'Italie (Vlasugana) ainsi que de l'Autriche, notamment le domaine minier de Mitterberg. De plus, il est fort probablement que du métal provenant du secteur minier de Great Orme ait encore été utilisé à cette période, soit qu'il s'agisse de recyclage de métaux de la période précédente, soit que du métal ait été importé depuis le Pays de Galles, cette mine étant encore en activité à cette période. Ces réseaux semblent rester en place au cours de la première phase du Bronze final. Avec la deuxième période du Bronze final, l'alimentation en cuivre se diversifie. Cela transparaît à travers les analyses élémentaires. Ainsi, l'analyse d'objets de plusieurs dépôts du nord-ouest permet de mettre en évidence cinq signatures différentes, basées sur les compositions élémentaires qui peuvent traduire autant d'origines du cuivre différentes. À cette période, les objets produits contiennent du plomb dans l'alliage, parfois en forte teneur, ce que laisse penser que ce plomb est un ajout. Il est donc impossible de tracer l'origine du cuivre de ces objets en réalisant des analyses isotopiques. La particularité de certains de ces dépôts, c'est la présence de lingots barres très riches en plomb, dont des parallèles peuvent être trouvés avec des lingots présents dans les régions d'Europe centrale, bien que ceux-ci ne sont pas tout à fait similaires. Les fragments de lingots de cuivre sont rares dans ces dépôts mais ils existent cependant. Leur analyse isotopique pourrait traduire une origine d'Europe centrale. À la fin du Bronze final, la diversité de composition du métal est encore plus grande traduisant une complexification dans les réseaux. Les analyses élémentaires montrent sept signatures chimiques différentes. Ces objets contiennent tous du plomb dans l'alliage. Leur analyse isotopique montre bien qu'ils sont composés par des mélanges de métaux de différentes origines. Heureusement, de nombreux fragments de lingots de cuivre sont présents dans les dépôts et permettent de proposer des origines pour ce métal. Ces origines sont très diverses allant des Alpes occidentales à l'Europe centrale (Slovaquie) en passant par le sud des Alpes italiennes. Du cuivre des régions méditerranéennes depuis Chypre, l'Espagne (Huelva), le sud de la France, et peut-être la Sardaigne, pourrait également avoir alimenté le nord-ouest de la France. Ainsi, à l'instar des autres études menées en Europe à partir des analyses élémentaires et isotopiques sur les objets des dépôts métalliques, les réseaux d'échange se complexifient à travers l'Europe, au fur et à mesure que l'on avance dans l'âge du Bronze. La poursuite des recherches est essentielle pour saisir l'ampleur et la chronologie des activités minières de cuivre au cours des différentes périodes historiques dans les cordillères Bétiques.

Mots clés : France du Nord-Ouest, âge du Bronze, dépôts métalliques, analyses chimiques élémentaires, analyses isotopiques du plomb, réseau d'échanges.

The Bronze Age is characterised by the use of bronze alloys, although these appeared earlier in Eastern Europe, probably during the Chalcolithic period. While the use of this alloy developed slowly during the Early Bronze Age, offsetting that of arsenic or non-arsenic copper, from the Middle Bronze Age onwards its increasingly important use can be seen in the many artefacts that make up terrestrial metal hoards. Of course, the metal recovered in this way only represents a fraction of the metal in circulation, but its chemical composition can still be considered partially representative of the metal stocks built up during each period in a defined region. All regions across Europe seem to have participated in this phenomenon, to a greater or lesser extent, even those without copper or tin ores. With the spread of metallurgy, metal trading networks were set up throughout Europe, as copper and tin ore deposits were unevenly distributed across the continent. These metal masses may have been transported over considerable distances across the continent, as studies of several European regions have shown, combining typological studies of the objects and elemental chemical and isotopic analyses of the lead in them (Ling et al., 2013; 2014; 2023; Pernicka et al., 2016; Melheim et al., 2018; Kmosek et al., 2020; Berger et al. 2022; Nowak et al., 2023; Bruyère et al., 2024). Western Europe has remained on the sidelines of these regional studies, and this work should contribute to a better understanding of the movement of metal masses towards the western extremity of Europe.

In the north-west of France, a very large number of Bronze Age metal objects have been discovered, mainly in terrestrial hoards (Briard, 1965; Milcent, 2012; Nordez, 2019; Bordas, 2023), but also in riverbeds (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 flat axeheads that were found, most of which can probably be attributed to the Chalcolithic period, although a minority could 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 most occurrences encountered are not recognised as significant deposits by modern geologists, except perhaps one sector located in the northern department of Finistère (Marcoux, 2017). However, while some areas may have been rich enough to be considered as small deposits, allowing for 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 have been imported from other regions of France or Europe.

The long-distance transport of masses of metal is still relatively unclear, particularly as regards their nature: primary-type copper ingots, secondary-type alloy ingots or objects. The presence of fragments of copper ingots in the metal hoards indicates that the raw material may have circulated in this form. This is particularly true of the Late Bronze Age, where copper ingots were numerous in hoards (Bordas, 2023). Secondary-type ingots of lead bronze alloys have also been found in Late Bronze Age deposits in western France (Boulud-Gazo et al., 2022), suggesting that these may also have travelled. The discovery of Bronze Age shipwrecks containing objects such as weapons and ornaments, in addition to ingots, shows that finished objects produced in distant regions also circulated (Berger et al., 2022). The circulation of the ornaments between the Atlantic and continental domains has also been demonstrated through elemental chemical analyses (Couderc et al., 2021). The movement of metal in these various forms, and perhaps from several different sources, might suggest that it is difficult, if not impossible, to obtain chemical and isotopic signatures that would enable us to characterise regional artefact production. What's more, exchange networks vary in space and time, further complicating the situation. Nevertheless, as other studies have already demonstrated (Gavranović et al., 2022; Ling et al., 2023), analyses carried out on statistically significant corpus make it possible to detect chemical signatures specific to a region for a defined period.

This is the approach that was initiated in western France as part of a program that began more than 15 years ago. The study presented here concerns the stages of the Bronze Age for which most of the metal objects have been found in hoards. The Early Bronze Age period is not covered. For the Early Bronze Age in north-western France, metal objects have been found in tombs and do not seem to reflect a massive production. From MBA1 onwards, various types of objects were deposited in hoards. This phenomenon continued into the Early Iron Age, albeit in varying forms and to various extents. The starting hypothesis is that, from MBA1 onwards, the quantity of metal buried is so great that new metal is needed to produce new objects in quantity. It should be remembered that north-western France is the region of France, if not Europe, with the greatest richness of metal contained in hoards. As the Armorican Massif does not seem to be rich enough in copper to produce all these objects, it must have been necessary to bring in new copper from one or more copper-mining regions in Europe. Through an elementary analysis of the bronze objects and copper ingots found in the hoards, we will attempt to trace the origin of the copper.

CONTEXT OF THE BRONZE AGE IN NORTH-WESTERN FRANCE

The area covered by this study is a part of medio-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 debated, but its limits and the internal dynamics that drive it still are (Bordas, 2023). For 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.

The typology of the cultural artefacts reveals connections with the surrounding regions, providing an initial overview of the networks that developed during the Bronze Age (Milcent, 2012; Nordez, 2019; Bordas, 2023). Most of the known Bronze Age metal objects from north-western France come from non-funerary hoards. The nature and interpretation of these contexts remain open to debate, between economic needs (founders' reserves) and ritual practices. The typology of hoards based on the frequency of functional categories of objects, as well as their state of fragmentation, shows that the composition of hoards is not random and becomes increasingly complex over time (Bordas, 2023). There could therefore be an analytical bias towards this phenomenon. However, as we shall see below, this diversity is of little importance in the study of compositions when a sufficient number of chemical analyses are taken into account.

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 recherches géologiques et minières, 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; 1975). Fahlore could be also observed. Meteoric alteration zones are 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.

SAMPLING METHODOLOGY TO IDENTIFY THE CHEMICAL AND ISOTOPIC SIGNATURES OF METAL STOCKS

The objects analysed in this project, which focuses on western France, come exclusively from land-based metal hoards (table 1). In fact, analyses of metal from a casting workshop would make it possible to certify the working of a particular type of metal in a given region. However, workshops such as Aubervilliers (Melin et al., 2020) and Fort-Harrouard in the Paris region, or Montélimar in the Rhône valley (Néré et al., 2023) do not exist in the west. The two workshops recognised so far are at Mez Notariou on the island of Ouessant (Finistère), where the contexts are complex and no analysis has yet been carried out, and at Saint-Avé in Morbihan (unpublished), where no fragmentary metal waste has been found. At the latter site, only a few objects were collected in a pit in the workshop, in

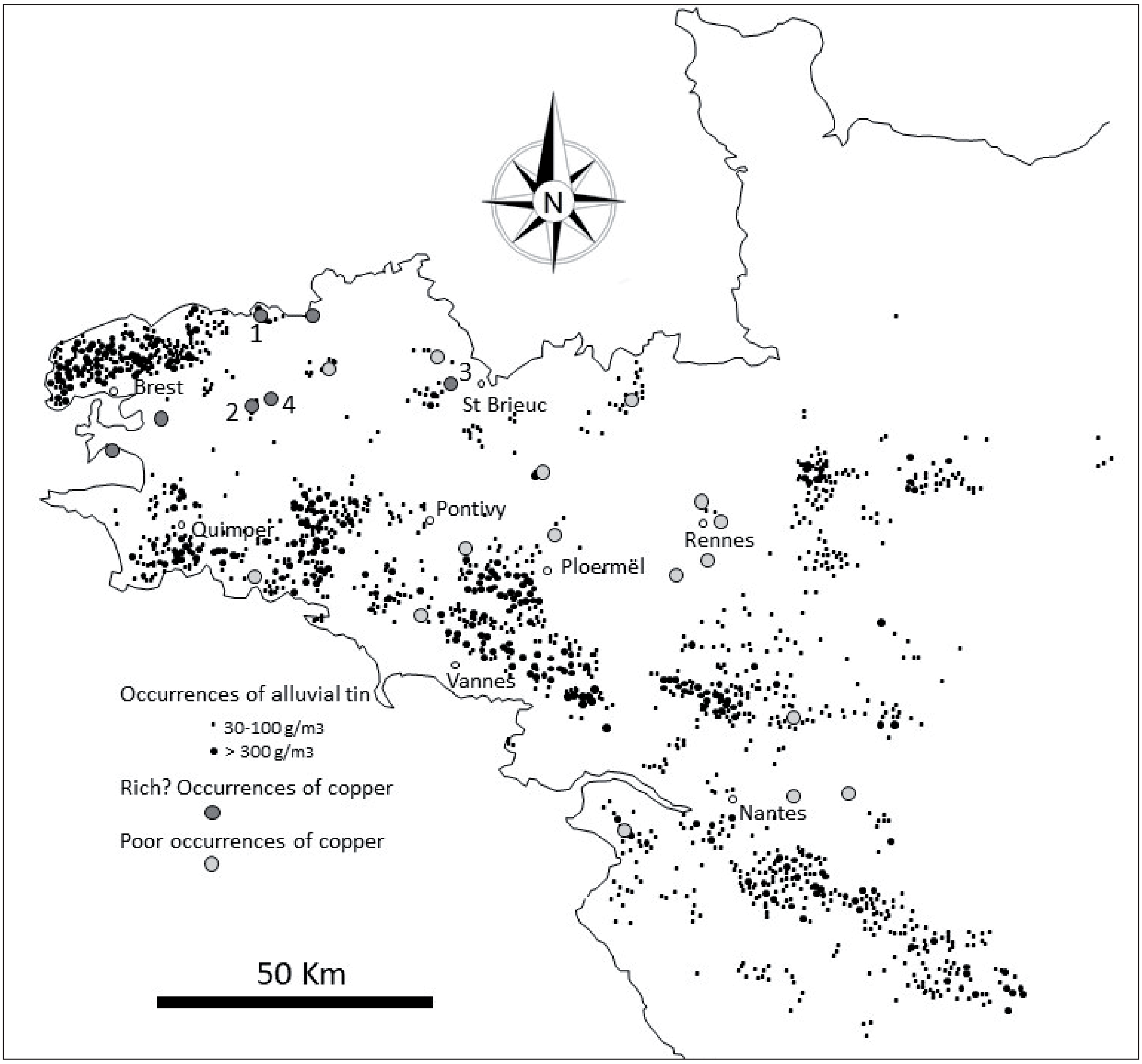

Fig. 1 – Distribution map of alluvial cassiterite (Guigues et Devismes, 1969) and copper occurrences in the Armorican Massif (data from Marcoux 2017). 1: Lanmeur; 2: Huelgoat; 3: Trémuson; 4: Carnoët.

what might have been a terrestrial metal hoard identified at the time as a foundry reserve. Analyses have not yet been carried out, however.

To establish a regional signature (or more than one), the study has therefore focused on objects found in terrestrial metal hoards. The hoards taken into account in the study largely correspond to those recently discovered, for which the context is known and the integrity is respected (table 1). Hoards found in the past, in the nineteenth century, were part of private collections where mixing may have occurred, particularly when they were passed on to heirs. Thus, for a long time, Armorican-type socketed axes were placed at the very end of the Bronze Age, whereas it is now known that they were produced during the Early Iron Age. Lengthy historiographical investigations have brought this to light (Gomez de Soto, 2014), and elementary chemical analyses have finally demonstrated it (Le Carlier de Veslud et al., 2018). However, some older hoards have been analysed. These are the eponymous hoards, such as those at Tréboul, Rosnoën and Saint-Brieuc-des-Iffs. Knowledge of the accurate context of these deposits is essential if the analyses are to be correctly interpreted in terms of chronology. Once the signatures for each period are known, it is then possible to follow any continuities in the use of the objects in subsequent periods.

The sampling, which is statistically representative, focuses on several types of objects where possible. For some periods, for example, no copper ingots are known to exist in the deposits. Sampling is concentrated on finished objects with an a priori ‘regional’ typological affinity. For hoards with a wide variety of objects, all functional categories are taken into account in the sampling.

Hoard	Department	Period	Nb. elementary analyses	Nb. analyses in annexes	Nb. isotopic analyses	Nb. analyses in annexes	Comments
Tréboul	29	MBAa1	77	77	5	5	
Martillac	33	MBAa1	14	14	5	5	
Boisgervilly	35	MBAa2	13	13	5	5	
Boulay-Morin	27	MBAa2	10	10	5	5	
Saint-Thois	29	MBAa2	30	30	0	0	
Heucqueville	27	MBAa2	41	41	0	0	
Saint-Germain d'Esteuil	33	MBAa2	6	6	3	3	
Malassis-copper ingots	36	MBAa2	19	19	10	10	
Malassis objects	36	MBAa2	27	27	5	5	
Rosnoën	29	LBAa1	12	12	5	5	
Saint-Brieuc-des-Ifs	35	LBAa2	26	26	6	6	
Plérin	*22*	*LBAa2*	*27*	*0*	*0*	*0*	*in a forthcoming publication*
Soullans	*85*	*LBAa2*	*73*	*0*	*11*	*0*	*in a forthcoming publication*
Saint-Sauveur	*50*	*LBAa3b*	*20*	*0*	*2*	*2*	*Gandois and al., 2019*
Mérézel	*56*	*LBAa3b*	*139*	*0*	*14*	*0*	*in a forthcoming publication*
Lanhuron	*29*	*LBAa3b*	*25*	*0*	*13*	*0*	*in a forthcoming publication*

Table 1 – List of hoards analysed in this study, including the number of elemental analyses carried out on deposit objects and the number of those shown in table 2, as well as the number of isotopic analyses and the number of those shown in table 3. Hoards written in italics correspond to those whose analyses were used to produce the diagrams. These analyses are either already published, or will be in another submitted publication.

On the other hand, many sampled objects are foundry waste, such as feeders or crucible bottoms, which are probably less likely to have been transported over long distances than other objects, such as ornaments. Primary copper ingots also help to identify these signatures, because if they are present in the region concerned, it means that some of them were potentially used to produce objects. Isotopic analysis of the lead contained in these ingots allows us to put forward hypotheses as to their origin, and to see whether they come from one or more producing regions. Numerous analyses of objects from north-western France have revealed consistent levels of the main trace elements (silver Ag, arsenic As, nickel Ni, and antimony Sb) over a given period, defining regional chemical signatures (Le Carlier de Veslud et al., 2017; 2018; Le Carlier de Veslud and Le Bannier, 2018). In addition, other elements such as iron (Fe), cobalt (Co), and bismuth (Bi) can also be identified. These vary from period to period, indicating changes in metal supply. These materials constitute stocks of metals for the production of objects of regional typology.

Putting these results into perspective with those obtained for other regions helps to sketch out the geographical contours of these regional signatures, for each major period of the Bronze Age. These regions supplied by the same sources could be very vast, or even correspond more or less to the boundaries of cultural domains (Véber et al., 2003). Assuming that the copper supply in these distant regions came from different sources, the objects produced in these regions would have different chemical compositions. It is therefore important to know the chemical and isotopic signature of objects from the same period in several given regions, on the assumption that they were produced there, and to compare them.

ANALYSIS METHODS

Numerous elementary chemical analyses were carried out between the 1960s and 1990s in Rennes (Giot et al., 1975; Bourhis and Briard, 1979, Briard and Bourhis, 1984). These analyses made it possible to identify the nature of the alloys making up the objects and to observe possible differences between the different periods. However, the number of analyses is too small and the sampling is often too disparate, making it difficult to identify the signatures. In addition, since these analyses were carried out using an arc spectrometer, they lack the precision required to identify different signatures. As a result, these older analyses were not used at all in this programme, which only uses analyses carried out in Rennes over the last fifteen years.

Samples were taken with a micro-drill from the sound metal after stripping of the weathered surface layer, enabling more than 40 mg of metal to be taken, leaving a surface impact of around 1 mm. The quantity of metal sampled is important for the representativeness of the analysis. In fact, metals can have a small chemical variability. This may be due to segregation caused by the slow cooling of a thick object. It may also be due to the presence of lead 'balls'. These metallic atoms tend not to associate with the copper atoms in the alloy and tend to gather in masses of varying size depending on the lead content of the alloy and the cooling rate of the moulded object. Thus, with 40 mg of material sampled, sampling is less sensitive to these analytical biases than with smaller samples. Analyses carried out on several zones of the same object have shown that this type of sampling enables us to see that trace element levels are more or less the same throughout the object (Le Carlier de Veslud and Le Bannier, 2018).

Elemental compositions of major (Cu, Sn, Pb) and trace (Ag, As, Bi, Co, Fe, Ni, Sb, Zn) elements of the samples taken were obtained at the Archéosciences laboratory in Rennes by ICP-OES (Inductively Coupled Plasma - Optical Emission Spectrometry; Ultima Expert). The analysis protocol is based on that of Mille and Bourgarit (2000) and is fully described in Aranda et al. (2013). Alloying elements are given in percentages (calculated from concentration in mg/l), and trace elements in ppm (10,000 ppm = 1 %). The machine was calibrated using 22 standards with a wide concentration range for each element, giving a negligible measurement error. The uncertainties are mainly a result of laboratory manipulations. The uncertainties are 1.6 % for tin and lead, and 2.2 % for copper and all trace elements. An international standard (Br 207) of known composition was analysed at the same time as the samples to verify that there was no machine deviation during the analysis sessions, and from one session to the next.

In accordance with the results from the whole elemental analysis of alloy and typology, some objects were chosen to measure the Pb isotopic ratios. Priority is given to copper ingots, when they exist, because they have the isotopic ratios of the ores from which they are extracted. According to the period, bronze objects have one or more basic elemental chemical compositions. Where several groups can be defined on the basis of their elemental composition, isotopic analyses are carried out, as far as possible, on bronze objects in each group, and even better on copper ingots. This program has not yet been fully achieved due to a lack of funds to carry out these expensive analyses. In each group, when they exist, objects with a 'regional' typology have been chosen as a priority in order to identify a signature that could be representative of a local production of objects.

'Classic' bronze objects, which do not contain lead in the alloy, are also analysed as a priority. Contents of several percent can be interpreted as lead additions, changing the isotopic signature of objects and making it impossible to trace the copper ore. But we also have to be careful with these wrongly substantiated interpretations. Thus, at the Great Orme mine, it was found that lead, in the form of PbS galena, accompanied copper mineralisation (especially malachite) in the deposit (Williams, 2023). As it was impossible to completely separate the galena from the copper-bearing minerals because the minerals were so intertwined, it was this combination that was introduced into the smelting furnace. The copper produced, which may contain a few percent lead, has the isotopic signature of galena rather than malachite. Lead isotope analyses are also carried out on lead-rich objects. The aim is to trace lead additions to objects if these appear to be evidence, or to recognise signatures representative of lead-rich copper deposits. In the case of the MBA1 objects from the Great Orme mine, the origin of the leaded copper was not too difficult to identify. This is not the case with the Late Bronze Age artefacts, which have much higher lead contents and diverse elemental chemical signatures. In the latter case, there are probably mixtures of copper sources and perhaps additions of lead.

Lead isotope analyses have been initiated and realised in SEDISOR/GEO-OCEAN in Brest, Finistère. Approximately 10 mg of sample powder was dissolved in Teflon beakers in a mixture of HNO_3 (^{14}N) and HCl (^{10}N) *(aqua regia)* at an elevated temperature (100 °C) for 36 hours. After evaporation, the solid residues were recovered in ^{1}N HNO_3 and the Pb was separated on a column using the protocol described by Gale (1996). Measurements of Pb isotopic compositions were carried out by MC-ICP-MS Neptune (Thermo Scientific) at the Pôle de Spectrométrie Océan in Brest. The Pb isotope ratios were corrected for instrumental bias and isotopic fractionation using White's Tl method (White et al., 2000) and the NIST SRM 981 measurement for all three samples. The reproducibility of the measurements is of the order of 0.002 (2 σ) for $^{206}Pb/^{204}Pb$ and $^{207}Pb/^{204}Pb$ and 0.005 (2 σ) for $^{208}Pb/^{204}Pb$. These three isotope ratios are taken into account in the search for copper sources by comparing the values of the objects analysed in this study with those of mineralised domains in Europe, known to have been exploited in ancient times, or showing strong suspicion of exploitation. As all the domains have been tested, if they are not mentioned in the following paragraphs, it is because they do not correspond to the isotopic values of the objects analysed. To simplify reading, the diagrams only show the domains that may correspond to the objects. The domains taken into account correspond to major domains actually known (table 2). The validity of the isotopic signatures of these areas varies from one to another. While some mining sectors are well known in terms of mining archaeology, such as the Great Orme, Ross Island and Mitterberg mines, other sectors are less well understood. For example, Sardinia and Romania are known through the analysis of mineralisation sampled by geologists. We don't really know whether they were mined in ancient times. Another interpretation problem concerns the high isotopic variability of certain areas. For example, Slovakia has a very high isotopic variability, which often leads to this region being proposed as a potential source. Similarly, the overlap in the isotopic diagrams of several mining areas raises the question of the validity of this method alone. It is then necessary to compare these isotopic data with the elemental chemical compositions, which can help to discriminate between sources. Finally, there are mineralised areas that are not yet known, or have not been sufficiently analysed. These include veins in the Pyrenees and Vosges mountains for example.

Finally, propositions made in this work are no more than hypotheses. Only the comparison with archaeological data (typological affinities of metal objects, but also of other materials such as ceramics and lithics) can help to confirm these hypotheses. The essential contribution of this analytical approach is to be able to say where copper does not come from.

Ross Island	Rohl and Needham, 1998
Copa Hill	Rohl and Needham, 1998
Great Orme	Williams, 2023
centre and south west Sardinia	Begemann et al., 2001; Boni and Köppel, 1985
North and north-west Sardinia	Stos-Gale et al., 1997; Begemann et al., 2001
France Cabrières	Pranges and Amber, 2005
France Queyras (included. Saint Véran)	Artioli et al., 2014
Slovakia	Schreiner, 2007; Andras et al., 2010
Spain Jaén	Marcoux, 1998; Klein et al., 2009
Spain Huelva	Marcoux, 1998; Klein et al., 2009
Spain Asturies	Huelga-Suarez et al., 2012
Italia Vlasugana	Artioli et al., 2014
Italia south Toscane	Artioli et al., 2014
Italia South Alps AATV	Artioli et al., 2014
Cyprus	Stos-Gale and Gale, 1994
Austria Tyrol	Höppner et al., 2005
Austria Mitterberg	Pernicka et al., 2016
Romania Baia Mare	Marcoux et al., 2002
Romania Apuseni	Marcoux et al., 2002

Table 2 – Copper-mining domains known by isotopic analyses, used to compare with isotopic analyses obtained on Bronze Age objects and ingots studied in this work.

RESULTS FOR EACH BRONZE AGE PERIOD

First stage of Middle Bronze Age (MBA1/ Bz B): Tréboul horizon (1550–1450 BC)

The discovery of the Tréboul hoard (fig. 2) has enabled us to group some bronze objects, found in the deposit or on their own. Briard (1965) listed a number of these objects, mainly located in Brittany. He then noted a greater density of objects to the west of Brittany. In 1990 the Tréboul horizon was updated with the addition of discoveries and the revision of older ones (Briard, 1990). The group then grew to around thirty ensembles and over forty individual objects. This shows that its influence is more extensive than previously thought, extending right up to the limits of Upper Brittany. To the south, along the Atlantic coast, it is difficult to pinpoint the limits of dispersion of this type of object. It should be noted that long-flanged axeheads are found in the Médoc (Lagarde-Cardona, 2012) and Vendée (Pautreau, 1979), though also in Brittany, but palstaves come from Brittany, Normandy and the mid-western region (Nordez, 2019). Two hoards were analysed for this period. These include a part of the Tréboul hoard (Finistère), and some axes from the Martillac hoard (Gironde).

For the Tréboul hoard, which contains 142 objects, seventy-seven objects were analysed for elemental chemistry (table 3). These include twenty-four fragments of undetermined axes, ten flanged axes, three palstaves, eight fragments of spearheads, two sword heads, seventeen fragments of sword blades, two fragments of daggers, two rivets, seven masselottes and two floor castings. Five lead isotope analyses were also carried out (table 3): a flanged axe, a fragment of an axe, two fragments of sword edge and a masselotte. For the Martillac hoard (fig. 2), 14 flanged axes were analysed for elemental chemistry (table 2), and 5 of them were analysed for isotopy (table 4).

The elemental chemical composition of all objects is identical with objects made of ‘classic’ bronze (lead content up to 0,1 %) and others of lead-rich bronze of up to 15.3 % Pb (average at 0,58 %; table 3). The tin content (2.37 to 18.09 %, average at 10.66 %) 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. 3). Similarly, isotopic compositions were identical between the two groups (table 3). The presence of lead did not influence the isotope ratio values. The axes from the Martillac hoard contain less lead (up to 0.54 %, average 0.15 %) and tin (4.05 to 12.14 %, average at 7.59 %) than the objects from Tréboul. While the Ag, As, and Ni contents are approximately identical between the two hoards, the Sb content shows a very clear difference, with a much higher content in the axes from Martillac than in the objects from Tréboul. This would seem to indicate a probable different origin for the copper.

With regard to isotopic analyses (table 4), the $^{206}Pb/^{204}Pb$, $^{207}Pb/^{204}Pb$ and $^{208}Pb/^{204}Pb$ ratios of the objects from Tréboul are all compatible with only two areas of production: the Great Orme mine and the Slovakia deposits (fig. 4). These objects show a very strong typological affinity with objects from the Acton Park horizon in the British Isles. The comparison of elemental and isotopic chemical compositions shows also a real correspondence (Williams and Le Carlier de Veslud, 2019). According to recent results, the copper in the ‘Acton Park’ type objects comes from the Great Orme mine. Indeed, it appears, judging from the similarity of chemical and isotopic compositions, that this metal was also used to produce the MBAa1 artefacts from the north-west of France. The higher or lower amount of lead is linked to the presence of galena veinlets within the deposit intersecting the cop-

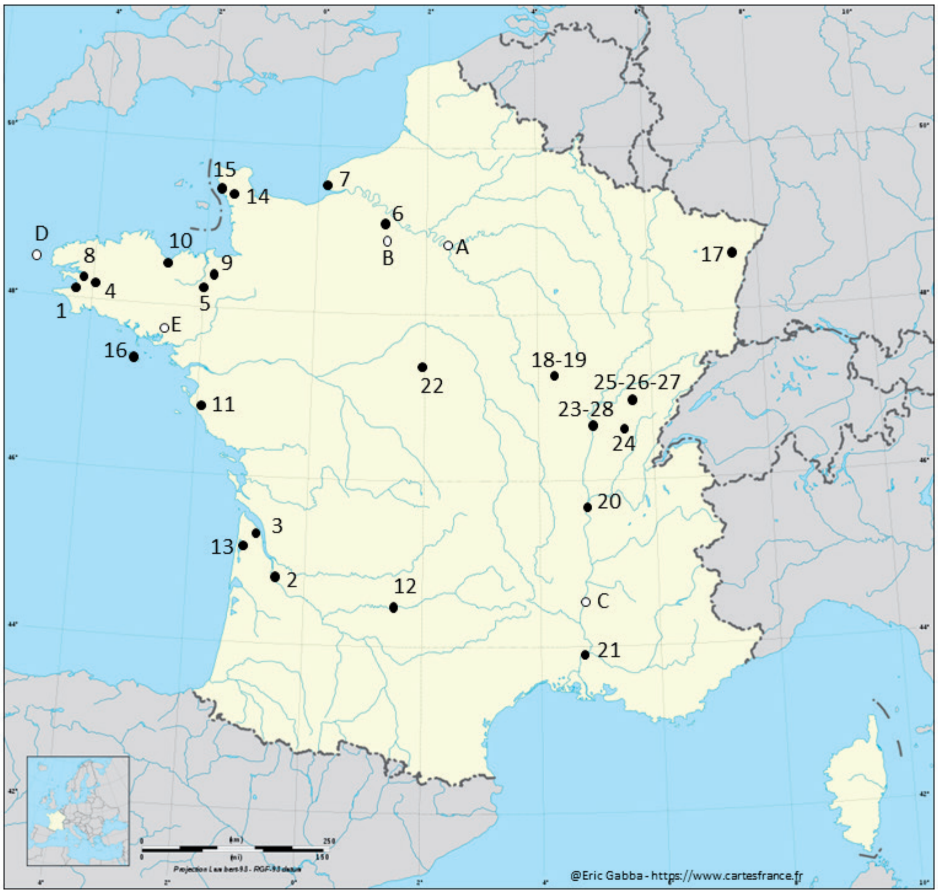

Fig. 2 – Location map of sites mentioned in text. *Atlantic hoards*: 1: Tréboul (MBA1); 2: Martillac (MBA1); 3:Saint-Germain-d'Esteuil (MBA2); 4: Saint-Thois (MBA2); 5: Boisgervilly (MBA2); 6: Boulay-Morin (MBA2); 7: Heucqueville (MBA2); 8: Rosnoën (LBA1); 9: Saint-Brieuc-des-Iffs (LBA2); 10: Plérin (LBA2); 11: Soullans (LBA2); 12: Saint-Sulpice (LBA2); 13: Hourtin (LBA3a); 14: Saint-Sauveur-Le-Vicomte (LBA3b); 15: Surtainville (LBA3b); 16: Mérézel (LBA3b). *Other location hoards*: 17: North-East (Hochfelden); 18: Centre-East (Granges-Sous-Grignon); 19: Centre-East (Vic-de-Chassenay); 20: Rhone valley (Ternay); 21: South (Monfrin-Romanès); 22: Malassis; 23: Centre-East (Ouroux-sur-Saône); 24: Centre-East (Lons-Le-Saunier); 25: Centre-East (Saizenay); 26: Centre East (Thézy); 27: Centre East (Prétin); 28: Centre East (Chalon-sur-Saône). *Workshops* : A: Aubervilliers; B: Fort-Harrouard; C: Montélimar; D: Mez Notariou; E: Saint-Avé. .

per deposit 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).

Concerning the axes from Martillac, for the three isotopic ratios, one object corresponds to the Tyrol domain or Slovakia, while the other four objects correspond to the Great Orme domain (fig. 4). These four compositions are slightly offset from those of the Tréboul objects while being aligned in the direction of the object located in the Tyrol or Slovakia domains. One possible hypothesis is that the Martillac axes may have been produced using a mixture of copper from two different sources, the main contribution being copper from the Great Orme, the other possibly being represented by Tyrol or Slovakia. This hypothesis needs to be confirmed by further analysis of objects from the Médoc.

Elemental analysis of artefacts of the same chronology from other French regions (the Rhône Valley, southern France, Burgundy and Alsace; fig. 2) shows that artefacts from Alsace (Ag content average at 1,037 ppm, As at 5,464 ppm, Ni at 17,482 ppm and Sb at 3,333 ppm) have a very different chemical composition (fig. 3). Similarly, artefacts from the south of France (Ag content average at 170 ppm, As at 1,097 ppm, Ni at 268 ppm and Sb at 204 ppm), from the Rhône Valley (Ag content average at 87 ppm, As at 1,012 ppm, Ni at 446 ppm and Sb at 53 ppm; Delrieu et al., 2015) and from Burgundy (Ag content average at 129 ppm, As at 1,652 ppm, Ni at 843 ppm and Sb at 172 ppm; Forel 2009) have a chemical composition similar to each other but different from that of the north-west and Alsace. Finally, the analysis of the artefacts of Tréboul shows that the spread of this metal seems to have involved only the regions close to the Atlantic/North Sea coast, as also reflected in A. Williams's research (2023).

Table 3 (right page) – Elemental compositions of Tréboul (MBA1), Martillac (MBA1), Boisgervilly (MBA2), Boulay-Morin (MBA2), Saint-Thois (MBA2), Heucqueville (MBA2), Saint-Germain-d'Esteuil (MBA2), Malassis (MBA2), Rosnoën (LBA1) and Saint-Brieuc-des-Iffs (LBA2) hoard artefacts.

Dépôt	Dpt	Period	Lab analysis #	Ech #	Type	Cu	Pb	Sn	Ag	As	Bi	Co	Fe	Ni	Sb	Zn
						(%)	(%)	(%)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)
Tréboul	29	MBAa1	Ren-000822	49 5 16/22	axe (frgt)	83,04	0,11	14,11	395	16992	555	295	289	8243	154	476
Tréboul	29	MBAa1	Ren-000823	49 5 16/23	axe (frgt)	86,52	0,93	11,44	311	6450	571	171	111	2679	298	508
Tréboul	29	MBAa1	Ren-000824	49 5 16/21	axe (frgt)	87,04	0,80	11,04	338	6442	538	207	433	2399	279	458
Tréboul	29	MBAa1	Ren-000825	49 5 16/1	axe (frgt)	84,66	1,30	12,55	397	7774	552	270	2213	3033	144	488
Tréboul	29	MBAa1	Ren-000826	49 5 89	sword blade	93,07	0,06	5,73	326	7395	591	81	241	2089	187	528
Tréboul	29	MBAa1	Ren-000827	49 5 17/4	spear head	87,37	0,08	10,59	368	8378	556	265	6510	2769	236	513
Tréboul	29	MBAa1	Ren-000828	49 5 16/11	axe (frgt)	80,73	1,40	16,49	368	7927	503	240	608	3569	159	454
Tréboul	29	MBAa1	Ren-000829	49 5 16/9	axe (frgt)	88,86	0,16	9,86	208	2652	555	727	5195	1150	112	497
Tréboul	29	MBAa1	Ren-000830	49 5 16/15	axe (frgt)	88,40	0,37	10,21	313	5808	539	177	397	2188	322	486
Tréboul	29	MBAa1	Ren-000831	49 5 16/4	axe (frgt)	80,08	6,49	12,23	383	7067	510	193	378	2930	145	435
Tréboul	29	MBAa1	Ren-000832	49 5 16/8	axe (frgt)	83,18	3,83	11,53	374	7540	535	335	1305	3813	172	573
Tréboul	29	MBAa1	Ren-000833	49 5 16/19	axe (frgt)	81,82	6,45	10,52	385	7243	528	118	260	2948	154	476
Tréboul	29	MBAa1	Ren-000834	49 5 16/14	axe (frgt)	86,14	0,07	11,98	482	12455	546	142	363	3430	111	499
Tréboul	29	MBAa1	Ren-000835	49 5 16/3	axe (frgt)	88,36	0,41	10,07	345	6438	537	216	809	2592	161	485
Tréboul	29	MBAa1	Ren-000836	49 5 16/20	axe (frgt)	82,78	0,42	14,60	343	13935	534	211	347	5977	130	489
Tréboul	29	MBAa1	Ren-000837	49 5 16/16	axe (frgt)	79,91	1,19	18,09	253	5161	495	14	94	1497	113	429
Tréboul	29	MBAa1	Ren-000838	49 5 16/6	axe (frgt)	86,83	1,05	10,95	330	6693	539	216	533	2770	206	475
Tréboul	29	MBAa1	Ren-000839	49 5 101/5	masselotte	87,42	0,12	11,51	307	6022	539	122	600	1420	105	455
Tréboul	29	MBAa1	Ren-000840	49 5 101/3	masselotte	89,15	0,46	8,86	349	7440	537	316	3058	2929	178	509
Tréboul	29	MBAa1	Ren-000841	49 5 88	sword blade	90,12	0,28	8,76	298	4310	581	164	465	1762	305	499
Tréboul	29	MBAa1	Ren-000842	49 5 18	spear head	82,23	0,19	16,57	304	5137	517	176	702	1827	981	432
Tréboul	29	MBAa1	Ren-000843	49 5 93	sword blade	90,42	0,28	8,36	318	4522	546	179	1044	1825	444	504
Tréboul	29	MBAa1	Ren-000844	49 5 44	dagger base	88,85	0,07	10,53	175	2455	539	110	776	863	85	471
Tréboul	29	MBAa1	Ren-000845	49 5 95	sword blade	89,93	0,58	8,47	314	5765	547	135	604	2160	134	483
Tréboul	29	MBAa1	Ren-000846	49 5 17/2	spear head	92,18	0,05	5,46	379	8139	562	584	8696	4065	164	534
Tréboul	29	MBAa1	Ren-000847	49 5 73	dagger base	88,02	0,45	10,42	292	5889	559	230	570	2736	236	534
Tréboul	29	MBAa1	Ren-000848	49 5 57	sword blade	90,37	0,00	9,27	40	1198	630	118	208	448	416	517
Tréboul	29	MBAa1	Ren-000849	49 5 70/8	Rivet	90,07	0,33	8,61	192	5056	576	184	1209	1940	114	550
Tréboul	29	MBAa1	Ren-000850	49 5 101/1	masselotte	85,65	3,26	9,80	611	5535	542	166	1204	3690	585	522
Tréboul	29	MBAa1	Ren-000851	49 5 86/1	sword head	83,57	1,45	13,83	706	5503	544	184	1420	2600	151	486
Tréboul	29	MBAa1	Ren-000852	49 5 62	sword blade	87,28	0,00	11,61	718	5247	551	227	1566	2129	164	547
Tréboul	29	MBAa1	Ren-000853	49 5 28	spear head	88,69	0,21	9,99	949	5536	565	227	459	2106	709	538
Tréboul	29	MBAa1	Ren-000854	49 5 101/2	masselotte	87,89	1,09	9,98	494	5394	547	202	752	2221	322	512
Tréboul	29	MBAa1	Ren-000855	49 5 61	sword blade	84,68	3,13	11,01	832	5812	524	234	986	2742	176	494
Tréboul	29	MBAa1	Ren-000856	49 5 6	long flanged axe	86,36	1,08	11,41	360	5649	536	246	1268	2625	279	527
Tréboul	29	MBAa1	Ren-000857	49 5 101/4	masselotte	87,29	1,03	10,60	632	5488	545	193	723	2412	298	543
Tréboul	29	MBAa1	Ren-000858	49 5 70/9	Rivet	83,61	0,88	14,48	589	5152	515	125	34	3043	320	503
Tréboul	29	MBAa1	Ren-000859	49 5 101/8	masselotte	92,99	0,24	2,37	100	1953	558	983	38783	942	0	659
Tréboul	29	MBAa1	Ren-000860	49 5 24	spear head	87,92	0,00	10,97	904	6342	536	114	850	1659	79	545
Tréboul	29	MBAa1	Ren-000861	49 5 101/7	masselotte	87,14	1,34	10,46	509	5531	534	205	270	2597	336	543
Tréboul	29	MBAa1	Ren-000862	49 5 22	spear head	88,85	0,47	9,84	517	3958	558	203	545	1709	382	514
Tréboul	29	MBAa1	Ren-000863	49 5 83	sword head	88,91	0,16	9,72	475	5738	533	261	2121	2111	304	538
Tréboul	29	MBAa1	Ren-000864	49 5 25	spear head	82,74	2,72	13,09	1030	7347	505	365	1993	2614	218	463
Tréboul	29	MBAa1	Ren-000865	49 5 63	sword blade	91,31	0,00	7,80	902	3607	570	115	644	1227	1342	512
Tréboul	29	MBAa1	Ren-000866	49 5 21	spear head	84,22	4,91	9,80	697	5792	538	170	567	2297	231	495
Tréboul	29	MBAa1	Ren-000867	49 5 48	sword blade	89,51	0,15	9,54	67	3591	527	353	1140	1652	258	525
Tréboul	29	MBAa1	Ren-000868	49 5 8	long flanged axe	84,62	3,40	11,21	105	3812	566	179	455	1602	474	506
Tréboul	29	MBAa1	Ren-000869	49 5 101/6	masselotte	91,22	0,02	7,91	426	4418	568	139	306	1889	189	533
Tréboul	29	MBAa1	Ren-000870	49 5 101/9	masselotte	84,99	0,63	13,25	344	5719	524	188	1611	2106	327	514
Tréboul	29	MBAa1	Ren-000871	49 5 67	sword blade	88,66	0,00	10,45	351	4467	540	153	730	1442	663	499
Tréboul	29	MBAa1	Ren-000872	49 5 58	sword blade	91,30	0,10	7,50	315	6171	547	185	1467	1653	276	421
Tréboul	29	MBAa1	Ren-000873	49 5 16/34	axe (frgt)	75,78	15,31	7,85	377	6888	477	16	35	2278	204	328
Tréboul	29	MBAa1	Ren-000874	49 5 10	long flanged axe	85,48	1,01	11,89	382	8045	548	274	3525	2697	321	436
Tréboul	29	MBAa1	Ren-000875	49 5 56	sword blade	91,50	0,37	7,35	271	4294	551	181	344	1450	300	416
Tréboul	29	MBAa1	Ren-000876	49 5 53	sword blade	88,44	0,72	9,05	324	6853	569	373	6285	2851	256	449
Tréboul	29	MBAa1	Ren-000877	49 5 16/28	axe (frgt)	80,29	3,02	15,37	300	7194	520	218	989	3367	211	411
Tréboul	29	MBAa1	Ren-000878	49 5 14b	palstave	89,61	0,17	8,83	376	8193	539	131	896	3093	232	431
Tréboul	29	MBAa1	Ren-000879	49 5 9	long flanged axe	87,68	0,94	9,83	398	8117	546	366	2045	3182	322	448
Tréboul	29	MBAa1	Ren-000880	49 5 14a	palstave	89,73	0,13	8,77	387	8595	571	127	384	3029	221	446
Tréboul	29	MBAa1	Ren-000881	49 5 3	long flanged axe	87,88	0,48	10,43	348	6959	545	186	940	2317	407	405
Tréboul	29	MBAa1	Ren-000882	49 5 16/2	axe (frgt)	87,48	1,40	9,99	311	6102	536	223	1092	2399	201	402
Tréboul	29	MBAa1	Ren-000883	49 5 15	palstave	92,10	0,75	4,91	434	10436	586	688	3458	6067	234	461
Tréboul	29	MBAa1	Ren-000884	49 5 54	sword blade	89,60	0,34	8,94	420	6136	545	190	1009	2044	374	441
Tréboul	29	MBAa1	Ren-000885	49 5 16/7	axe (frgt)	85,54	2,08	11,14	360	7391	547	200	666	2709	232	408
Tréboul	29	MBAa1	Ren-000886	49 5 52	sword blade	89,18	0,59	9,15	303	6161	561	156	933	2053	216	416
Tréboul	29	MBAa1	Ren-000887	49 5 16/17	axe (frgt)	80,52	4,64	13,49	294	6965	498	367	1674	3054	216	379
Tréboul	29	MBAa1	Ren-000888	49 5 16/18	axe (frgt)	89,53	0,31	9,12	295	6095	569	149	204	2125	541	427
Tréboul	29	MBAa1	Ren-000889	49 5 5	long flanged axe	85,90	1,13	11,86	382	6469	528	152	451	2206	524	408
Tréboul	29	MBAa1	Ren-000890	49 5 49	sword blade	86,80	0,61	11,37	312	6804	556	193	1285	2432	225	408
Tréboul	29	MBAa1	Ren-000891	49 5 4	long flanged axe	87,88	0,31	10,68	354	6376	564	187	772	2079	466	428
Tréboul	29	MBAa1	Ren-000892	49 5 90	sword blade	85,58	1,47	11,79	342	7002	542	194	106	2762	230	416
Tréboul	29	MBAa1	Ren-000893	49 5 7	long flanged axe	82,98	3,34	12,08	391	7880	551	557	3362	2623	265	420
Tréboul	29	MBAa1	Ren-000894	49 5 16/5	axe (frgt)	84,32	1,98	12,51	322	6906	516	189	640	2664	202	386
Tréboul	29	MBAa1	Ren-000895	49 5 16/10	axe (frgt)	86,95	2,05	9,82	333	6388	533	226	764	2844	303	397
Tréboul	29	MBAa1	Ren-000896	49 5 13	long flanged axe	88,98	0,42	9,58	324	5129	559	277	1188	1874	403	442
Tréboul	29	MBAa1	Ren-000897	49 5 2	long flanged axe	86,75	0,64	11,36	369	6951	559	206	1192	2411	371	511
Tréboul	29	MBAa1	Ren-000898	49 5 16/12	axe (frgt)	82,21	0,31	16,12	293	6834	517	206	2068	2890	217	501
minimum						75,78	0,00	2,37	40	1198	477	14	34	448	0	328
maximum						93,07	15,31	18,09	1030	16992	630	983	38783	8243	1342	659
médiane						87,37	0,58	10,46	351	6171	545	193	772	2411	232	486

Dépôt	Dpt	Period	Lab analysis #	Ech #	Type	Cu	Pb	Sn	Ag	As	Bi	Co	Fe	Ni	Sb	Zn
						(%)	(%)	(%)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)
Martillac	33	MBAa1	Ren-001524	mart 10	long flanged axe	90,25	0,09	8,40	166	5867	719	224	148	3707	1009	749
Martillac	33	MBAa1	Ren-001525	mart 24	long flanged axe	91,78	0,06	5,68	129	9287	794	765	165	9919	2863	942
Martillac	33	MBAa1	Ren-001526	mart 9	long flanged axe	91,04	0,03	7,85	85	4871	687	33	79	3952	411	742
Martillac	33	MBAa1	Ren-001527	mart 6	long flanged axe	90,48	0,16	7,88	161	7301	795	300	209	4401	859	744
Martillac	33	MBAa1	Ren-001528	mart 13	long flanged axe	89,85	0,54	8,47	239	5352	723	219	149	3267	700	744
Martillac	33	MBAa1	Ren-001529	mart 3	long flanged axe	91,55	0,24	6,97	191	6036	760	216	253	3095	1033	763
Martillac	33	MBAa1	Ren-001530	mart 5	long flanged axe	90,06	0,15	8,09	3740	6459	737	206	241	3679	1171	779
Martillac	33	MBAa1	Ren-001531	mart 18	long flanged axe	91,12	0,14	7,19	240	7583	774	259	372	4052	1439	792
Martillac	33	MBAa1	Ren-001532	mart 19	long flanged axe	90,14	0,24	8,76	275	2733	590	295	423	2613	836	747
Martillac	33	MBAa1	Ren-001533	mart 7	long flanged axe	92,18	0,07	5,22	203	12733	869	357	271	7208	2862	758
Martillac	33	MBAa1	Ren-001534	mart 15	long flanged axe	86,30	0,16	12,14	224	6946	683	306	338	3843	1020	618
Martillac	33	MBAa1	Ren-001535	mart 21	long flanged axe	93,21	0,10	4,05	161	14464	959	432	395	7476	1669	869
Martillac	33	MBAa1	Ren-001536	mart 1	long flanged axe	90,74	0,25	7,81	287	5552	670	118	291	2895	1479	703
Martillac	33	MBAa1	Ren-001537	mart 2	long flanged axe	90,07	0,07	7,70	163	10334	893	409	95	7111	1885	748
minimum						86,30	0,03	4,05	85	2733	590	33	79	2613	411	618
maximum						93,21	0,54	12,14	3740	14464	959	765	423	9919	2863	942
médiane						90,61	0,15	7,83	197	6702	748	277	247	3898	1102	748
Boisgervilly	35	MBAa2	ren-000774	1	palstave	81,95	0,08	16,65	190	4555	524	295	884	5728	746	338
Boisgervilly	35	MBAa2	ren-000775	2	palstave	82,95	0,19	15,79	289	3758	552	305	586	3823	1075	354
Boisgervilly	35	MBAa2	ren-000776	3	palstave	83,99	0,22	14,72	690	2523	528	217	2182	3663	483	377
Boisgervilly	35	MBAa2	ren-000777	4	palstave	86,24	0,01	12,85	125	1948	510	367	1812	3552	404	271
Boisgervilly	35	MBAa2	ren-000778	5	palstave	82,96	0,15	15,78	220	3852	548	357	362	4622	808	336
Boisgervilly	35	MBAa2	ren-000779	6	palstave	81,52	0,09	16,66	186	6000	526	412	1503	7479	918	325
Boisgervilly	35	MBAa2	ren-000780	7	palstave	83,68	0,13	15,25	203	2924	523	287	552	3902	691	327
Boisgervilly	35	MBAa2	ren-000781	8	palstave	79,79	0,06	18,86	155	3249	501	379	2491	5265	485	305
Boisgervilly	35	MBAa2	ren-000782	9	palstave	82,31	0,14	16,27	231	4560	557	360	621	5058	1077	324
Boisgervilly	35	MBAa2	ren-000783	10	palstave	81,17	0,12	17,22	201	5861	545	386	995	5634	949	344
Boisgervilly	35	MBAa2	ren-000784	11	palstave	81,63	0,13	17,13	226	4196	546	309	109	4239	1123	297
Boisgervilly	35	MBAa2	ren-000785	12	palstave	83,29	0,12	14,77	214	6174	541	572	1301	8274	845	326
Boisgervilly	35	MBAa2	ren-000786	13	palstave	82,47	0,32	16,05	248	4233	563	329	518	4424	913	310
minimum						79,79	0,01	12,85	125	1948	501	217	109	3552	3552	404
maximum						86,24	0,32	18,86	690	6174	563	572	2491	8274	8274	1123
médiane						82,47	0,13	16,05	214	4196	541	357	884	4622	4622	845
Boulay-Morin	27	MBAa2	ren-000678	3471	palstave	85,69	0,02	13,99	113	1071	587	55	0	520	351	506
Boulay-Morin	27	MBAa2	ren-000679	3472	palstave	88,47	0,14	9,72	222	4050	613	541	2968	6147	1543	624
Boulay-Morin	27	MBAa2	ren-000680	3473	palstave	80,80	0,13	17,71	235	3158	621	274	630	6730	1461	575
Boulay-Morin	27	MBAa2	ren-000681	3474	palstave	80,12	0,15	18,51	243	3009	548	396	983	5495	1095	431
Boulay-Morin	27	MBAa2	ren-000682	3475	palstave	85,35	0,07	13,48	212	2536	599	175	301	4626	2078	518
Boulay-Morin	27	MBAa2	ren-000683	3476	palstave	85,44	0,15	13,30	233	3464	579	174	0	5226	1266	521
Boulay-Morin	27	MBAa2	ren-000684	3477	palstave	79,83	0,35	18,86	341	2689	589	275	622	3470	914	677
Boulay-Morin	27	MBAa2	ren-000685	3478	palstave	82,64	0,16	16,04	319	2851	543	211	381	5345	1378	542
Boulay-Morin	27	MBAa2	ren-000686	3479	palstave	81,30	0,25	16,46	273	4478	568	331	3955	8307	1282	689
Boulay-Morin	27	MBAa2	ren-000687	3482	palstave	80,44	1,42	17,07	256	2977	548	262	9	4662	1003	953
minimum						79,83	0,02	9,72	113	1071	543	55	0	520	351	431
maximum						88,47	1,42	18,86	341	4478	621	541	3955	8307	2078	953
médiane						81,97	0,15	16,25	239	2993	583	268	502	5286	1274	559
Saint-Thois	29	MBAa2	ren-000505	ST8	palstave	81,72	0,17	16,96	92	2285	551	294	326	5900	1336	672
Saint-Thois	29	MBAa2	ren-000506	ST12	palstave	87,79	0,03	11,24	29	1930	558	748	183	4765	506	686
Saint-Thois	29	MBAa2	ren-000507	ST30	palstave	82,55	0,05	15,30	43	6098	518	560	4329	8063	747	678
Saint-Thois	29	MBAa2	ren-000508	ST40	palstave	88,41	0,07	10,81	25	2123	557	188	540	2505	466	632
Saint-Thois	29	MBAa2	ren-000509	ST43a	palstave	84,17	0,16	14,92	83	1365	574	246	383	3110	1059	696
Saint-Thois	29	MBAa2	ren-000510	ST43b	palstave	84,32	0,15	14,75	65	1330	568	255	674	3115	1015	802
Saint-Thois	29	MBAa2	ren-000511	ST44	palstave	88,23	0,08	9,78	40	11473	611	169	97	4954	986	743
Saint-Thois	29	MBAa2	ren-000512	ST48	palstave	81,68	3,70	13,72	747	1937	712	179	601	3160	903	767
Saint-Thois	29	MBAa2	ren-000513	ST53	palstave	84,10	0,07	14,69	38	2446	553	245	86	6258	1062	677
Saint-Thois	29	MBAa2	ren-000514	ST54a	palstave	85,43	0,80	12,73	135	2027	681	318	315	4599	1485	855
Saint-Thois	29	MBAa2	ren-000515	ST54b	palstave	86,03	0,80	12,15	254	1951	670	311	324	4489	1411	803
Saint-Thois	29	MBAa2	ren-000516	ST74	palstave	83,87	0,14	14,91	65	2366	544	321	341	5340	1047	792
Saint-Thois	29	MBAa2	ren-000517	ST77	palstave	83,13	0,17	15,42	226	2560	588	361	364	6562	1391	732
Saint-Thois	29	MBAa2	ren-000518	ST83	palstave	85,05	0,06	13,76	39	2148	556	240	1391	5500	709	671
Saint-Thois	29	MBAa2	ren-000519	ST93a	palstave	81,02	0,15	17,59	134	2818	546	318	367	6083	1403	679
Saint-Thois	29	MBAa2	ren-000520	ST93b	palstave	82,23	0,15	16,33	159	2827	545	341	979	5879	1449	683
Saint-Thois	29	MBAa2	ren-000521	ST99	palstave	86,64	0,13	11,50	133	2745	569	301	1200	10799	756	739
Saint-Thois	29	MBAa2	ren-000522	ST107	palstave	85,09	0,43	13,52	195	1919	553	246	401	4135	1375	735
Saint-Thois	29	MBAa2	ren-000523	ST114a	palstave	83,57	0,19	15,09	187	2770	566	256	81	5560	1365	666
Saint-Thois	29	MBAa2	ren-000524	ST114b	palstave	84,20	0,18	14,51	123	2619	553	258	132	5520	1294	679
Saint-Thois	29	MBAa2	ren-000525	ST118	palstave	85,21	0,10	13,37	113	2646	565	251	558	6588	1618	787
Saint-Thois	29	MBAa2	ren-000526	ST127	palstave	84,58	0,10	14,18	74	2401	575	303	244	5788	1333	699
Saint-Thois	29	MBAa2	ren-000527	ST137	palstave	83,15	0,09	15,51	94	2679	542	354	433	6474	1218	671
Saint-Thois	29	MBAa2	ren-000528	ST138	palstave	81,96	0,17	16,75	55	2362	560	283	282	5242	1646	724
Saint-Thois	29	MBAa2	ren-000529	ST143a	palstave	85,41	0,08	13,03	39	3505	537	286	343	7638	1779	685
Saint-Thois	29	MBAa2	ren-000530	ST143b	palstave	85,52	0,08	12,95	39	3310	555	286	289	7669	1726	690
Saint-Thois	29	MBAa2	ren-000531	ST149	palstave	86,96	0,11	11,32	23	4283	562	619	1625	7314	865	829
Saint-Thois	29	MBAa2	ren-000532	ST150	palstave	83,26	0,14	15,25	59	2438	551	426	1174	6541	1495	765
Saint-Thois	29	MBAa2	ren-000533	ST151	palstave	85,58	0,10	13,37	20	3044	545	239	564	3045	1356	684
Saint-Thois	29	MBAa2	ren-000534	ST152	palstave	87,13	0,41	11,53	77	2631	569	290	327	3322	1324	743
minimum						81,02	0,03	9,78	20	1330	518	169	81	2505	466	632
maximum						88,41	3,70	17,59	747	11473	712	748	4329	10799	1779	855
médiane						84,45	0,14	13,97	75	2503	557	288	365	5540	1328	698

Dépôt	Dpt	Period	Lab analysis #	Ech #	Type	Cu	Pb	Sn	Ag	As	Bi	Co	Fe	Ni	Sb	Zn
						(%)	(%)	(%)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)
Heucqueville	27	MBAa2	Ren-001061	R Hqvil 2524-25	palstave	77,78	0,03	21,67	55	227	487	640	1 923	828	522	498
Heucqueville	27	MBAa2	Ren-001062	R Hqvil 2524-26	palstave	86,30	0,06	12,50	173	3 024	517	648	806	4 908	782	547
Heucqueville	27	MBAa2	Ren-001063	R Hqvil 2524-27	palstave	87,76	0,13	10,78	337	3 226	541	775	1 052	6 112	788	576
Heucqueville	27	MBAa2	Ren-001064	R Hqvil 2524-28	palstave	80,19	0,34	17,92	424	3 917	550	816	2 677	5 175	997	915
Heucqueville	27	MBAa2	Ren-001065	R Hqvil 2524-29	palstave	85,04	0,03	13,59	162	2 792	519	924	1 832	5 899	746	570
Heucqueville	27	MBAa2	Ren-001066	R Hqvil 2524-30	palstave	78,89	0,47	19,62	316	2 446	524	573	1 192	3 923	745	572
Heucqueville	27	MBAa2	Ren-001067	R Hqvil 2524-31	palstave	83,07	0,04	15,61	88	2 780	515	679	1 259	5 965	956	533
Heucqueville	27	MBAa2	Ren-001068	R Hqvil 2524-32	palstave	85,61	0,22	13,02	323	3 519	527	632	431	4 609	933	565
Heucqueville	27	MBAa2	Ren-001069	R Hqvil 2524-33	palstave	84,79	0,31	13,61	171	4 012	531	670	618	5 285	1 096	558
Heucqueville	27	MBAa2	Ren-001070	R Hqvil 2524-34	palstave	82,60	0,13	15,98	183	3 536	505	828	1 152	4 801	1 295	531
Heucqueville	27	MBAa2	Ren-001071	R Hqvil 2524-35	palstave	89,42	0,06	9,41	109	2 759	537	728	1 061	4 608	750	594
Heucqueville	27	MBAa2	Ren-001072	R Hqvil 2524-36	palstave	84,04	0,14	14,50	140	3 831	534	618	619	5 906	1 021	576
Heucqueville	27	MBAa2	Ren-001073	R Hqvil 2524-37	palstave	84,05	0,08	14,62	186	3 564	538	672	390	5 688	968	559
Heucqueville	27	MBAa2	Ren-001074	R Hqvil 2524-38	palstave	82,75	0,10	15,64	112	4 520	510	773	1 357	6 344	981	534
Heucqueville	27	MBAa2	Ren-001075	R Hqvil 2524-39	palstave	84,14	0,02	14,19	84	4 757	499	924	2 260	6 734	597	578
Heucqueville	27	MBAa2	Ren-001076	R Hqvil 2524-40	palstave	86,03	0,02	12,99	39	2 944	528	536	423	3 389	1 185	527
Heucqueville	27	MBAa2	Ren-001077	R Hqvil 2524-41	palstave	84,82	0,05	14,33	78	2 264	495	583	131	3 378	550	553
Heucqueville	27	MBAa2	Ren-001078	R Hqvil 2524-42	palstave	83,04	0,01	15,66	61	2 760	472	219	1 415	6 953	362	672
Heucqueville	27	MBAa2	Ren-001079	R Hqvil 2524-24	palstave	89,08	0,08	9,73	206	3 057	558	395	778	5 190	556	407
Heucqueville	27	MBAa2	Ren-001080	R Hqvil 2524-23	palstave	88,00	0,04	10,52	111	3 290	538	588	724	8 138	595	388
Heucqueville	27	MBAa2	Ren-001081	R Hqvil 2524-21	palstave	84,30	0,12	14,40	205	4 076	540	376	1 064	4 029	1 016	402
Heucqueville	27	MBAa2	Ren-001082	R Hqvil 2524-21	palstave	86,95	0,26	10,93	446	3 428	560	351	8 459	3 770	1 133	459
Heucqueville	27	MBAa2	Ren-001083	R Hqvil 2524-20	palstave	85,81	0,19	12,65	258	5 405	531	394	174	5 368	979	370
Heucqueville	27	MBAa2	Ren-001084	R Hqvil 2524-19	palstave	81,72	0,11	16,91	197	4 179	520	356	1 104	4 999	771	375
Heucqueville	27	MBAa2	Ren-001085	R Hqvil 2524-18	palstave	83,92	0,19	14,67	201	4 456	548	303	567	4 766	1 044	399
Heucqueville	27	MBAa2	Ren-001086	R Hqvil 2524-17	palstave	85,16	0,08	9,96	121	2 349	541	263	39 434	4 166	700	412
Heucqueville	27	MBAa2	Ren-001087	R Hqvil 2524-16	palstave	90,64	0,31	8,11	130	2 458	539	217	821	4 274	608	424
Heucqueville	27	MBAa2	Ren-001088	R Hqvil 2524-15	palstave	85,97	0,12	12,49	272	3 948	543	421	1 776	5 639	1 247	416
Heucqueville	27	MBAa2	Ren-001089	R Hqvil 2524-14	palstave	82,81	0,08	15,74	199	4 057	534	344	1 043	6 168	1 010	421
Heucqueville	27	MBAa2	Ren-001090	R Hqvil 2524-13	palstave	83,41	0,13	15,22	237	3 780	483	294	1 311	4 781	1 134	382
Heucqueville	27	MBAa2	Ren-001091	R Hqvil 2524-11	palstave	82,48	0,19	16,29	282	3 542	478	233	319	4 463	690	454
Heucqueville	27	MBAa2	Ren-001092	R Hqvil 2524-10	palstave	83,44	0,74	15,00	419	1 959	486	220	1 695	2 505	443	481
Heucqueville	27	MBAa2	Ren-001093	R Hqvil 2524-9	palstave	80,26	0,28	18,55	435	2 247	479	301	1 331	2 940	908	468
Heucqueville	27	MBAa2	Ren-001094	R Hqvil 2524-8	palstave	84,95	0,05	13,37	124	7 646	512	659	1 274	5 125	629	393
Heucqueville	27	MBAa2	Ren-001095	R Hqvil 2524-7	palstave	84,10	0,11	14,49	236	4 413	504	432	891	5 086	919	395
Heucqueville	27	MBAa2	Ren-001096	R Hqvil 2524-6	palstave	84,12	0,07	14,45	122	4 226	486	365	1 320	5 975	631	386
Heucqueville	27	MBAa2	Ren-001097	R Hqvil 2524-5	palstave	79,47	0,24	18,88	227	4 565	491	336	1 008	6 148	955	374
Heucqueville	27	MBAa2	Ren-001098	R Hqvil 2524-4	palstave	80,50	0,11	18,38	125	3 160	483	258	823	4 195	590	380
Heucqueville	27	MBAa2	Ren-001099	R Hqvil 2524-3	palstave	87,03	0,10	11,38	169	5 023	526	390	1 494	6 103	754	420
Heucqueville	27	MBAa2	Ren-001100	R Hqvil 2524-2	palstave	88,03	0,09	10,58	130	3 373	542	303	2 410	5 126	621	435
Heucqueville	27	MBAa2	Ren-001101	R Hqvil 2524-1	palstave	82,98	0,07	14,59	110	7 695	508	615	6 583	6 946	751	437
minimum						77,78	0,01	8,11	39	227	472	217	131	828	362	370
maximum						90,64	0,74	21,67	446	7695	560	924	39434	8138	1295	915
médiane						84,12	0,11	14,45	173	3536	524	432	1104	5125	782	459
St Germain-d'Esteuil	33	MBAa2	Ren-001537	St G-ES 28	axe	81,21	2,74	15,17	366	1795	576	152	543	3430	1006	911
St Germain-d'Esteuil	33	MBAa2	Ren-001538	St G-ES 25	axe	83,16	0,10	15,89	225	1314	614	135	442	3594	1211	1023
St Germain-d'Esteuil	33	MBAa2	Ren-001539	St G-ES 23	axe	84,13	0,23	14,79	282	1657	642	125	405	3522	1202	621
St Germain-d'Esteuil	33	MBAa2	Ren-001540	St G-ES 27	axe	80,95	2,90	15,29	365	1730	565	151	514	3404	981	915
St Germain-d'Esteuil	33	MBAa2	Ren-001541	St G-ES 26	axe	86,32	0,13	12,61	187	2255	560	99	361	4613	658	696
St Germain-d'Esteuil	33	MBAa2	Ren-001542	St G-Es 22	axe	83,62	0,39	15,21	576	1098	649	113	451	3195	794	937
minimum						80,95	0,10	12,61	187	1098	560	99	361	3195	658	621
maximum						86,32	2,90	15,89	576	2255	649	152	543	4613	1211	1023
médiane						83,39	0,31	15,19	324	1693	595	130	446	3476	993	913
Malassis	36	MBAa2	Ren-000978	36R 208	ingot	96,58	0,04	0,83	422	505	865	578	15 441	344	3 213	4 000
Malassis	36	MBAa2	Ren-000979	36R 232	ingot	97,99	0,04	0,09	369	179	790	356	15 064	338	413	1 280
Malassis	36	MBAa2	Ren-000980	36R 236	ingot	96,24	0,12	1,52	902	799	895	696	12 488	299	1 524	3 590
Malassis	36	MBAa2	Ren-000981	36R 214	ingot	97,93	0,03	0,46	538	211	783	479	7 247	175	732	5 709
Malassis	36	MBAa2	Ren-000982	36R 215	ingot	98,80	0,03	0,02	137	200	597	141	9 430	271	47	675
Malassis	36	MBAa2	Ren-000983	36R 228	ingot	97,92	0,03	0,62	671	555	894	614	6 155	200	1 481	3 675
Malassis	36	MBAa2	Ren-000984	36R 206	ingot	94,64	0,04	0,02	104	12 312	586	524	13 855	24 584	392	677
Malassis	36	MBAa2	Ren-000985	36R 210	ingot	98,28	0,11	0,20	325	1 126	1 754	487	8 100	354	284	1 610
Malassis	36	MBAa2	Ren-000986	36R 217	ingot	97,46	0,03	0,05	261	123	723	378	21 503	278	133	1 184
Malassis	36	MBAa2	Ren-000987	36R 233	ingot	99,27	0,03	0,34	498	115	746	96	1 031	157	110	839
Malassis	36	MBAa2	Ren-000988	36R 209	ingot	98,45	0,10	0,49	793	527	791	540	3 459	178	74	3 220
Malassis	36	MBAa2	Ren-000989	36R 229	ingot	98,81	0,02	0,02	118	98	594	79	9 223	738	40	668
Malassis	36	MBAa2	Ren-000990	36R 213	ingot	98,18	0,02	0,12	397	201	606	473	13 408	221	221	1 306
Malassis	36	MBAa2	Ren-000991	36R 240	ingot	96,73	0,28	0,02	109	1 928	582	293	20 278	5 248	588	644
Malassis	36	MBAa2	Ren-000992	36R 211	ingot	98,54	0,02	0,02	95	2 807	582	169	6 401	3 344	121	633
Malassis	36	MBAa2	Ren-000993	36R 221	ingot	98,59	0,03	0,55	469	765	798	97	2 048	282	1 463	2 429
Malassis	36	MBAa2	Ren-000994	36R 212	ingot	98,77	0,04	0,25	434	687	833	560	4 709	198	906	1 088
Malassis	36	MBAa2	Ren-000995	36R 207	ingot	97,37	0,17	0,19	490	15 254	834	792	3 162	212	162	1 780
Malassis	36	MBAa2	Ren-000996	36R 219	ingot	97,07	0,08	2,14	827	486	713	471	2 958	164	57	1 407
Malassis	36	MBAa2	Ren-000997	36R 13	palstave	87,11	0,11	11,59	230	3 095	569	378	1 481	4 518	1 158	547
Malassis	36	MBAa2	Ren-000998	36R 41	palstave	91,43	0,24	7,07	302	1 456	620	492	3 829	4 302	754	907
Malassis	36	MBAa2	Ren-000999	36R 160	bracelet	89,03	0,12	9,07	230	3 829	573	268	2 571	4 835	5 006	534
Malassis	36	MBAa2	Ren-001000	36R 129	bracelet	85,74	0,10	13,16	208	2 319	535	279	497	4 675	906	507

Table 3 (continued, left and right) – Elemental compositions of Tréboul (MBA1), Martillac (MBA1), Boisgervilly (MBA2), Boulay-Morin (MBA2), Saint-Thois (MBA2), Heucqueville (MBA2), Saint-Germain-d'Esteuil (MBA2), Malassis (MBA2), Rosnoën (LBA1) and Saint-Brieuc-des-Iffs (LBA2) hoard artefacts.

Dépôt	Dpt	Period	Lab analysis #	Ech #	Type	Cu	Pb	Sn	Ag	As	Bi	Co	Fe	Ni	Sb	Zn
						(%)	(%)	(%)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)
Malassis	36	MBAa2	Ren-001001	36R 151	bracelet	83,58	0,09	15,79	167	757	517	153	561	2 426	396	486
Malassis	36	MBAa2	Ren-001002	36R 253	masselotte	88,93	0,09	10,10	217	2 004	545	307	538	4 017	717	547
Malassis	36	MBAa2	Ren-001003	36R 198	bar ingot	83,27	0,09	15,48	378	1 522	547	312	5 058	2 549	428	732
Malassis	36	MBAa2	Ren-001004	36R 12	palstave	89,69	0,11	9,63	181	419	547	69	437	3 175	359	532
Malassis	36	MBAa2	Ren-001005	36R 57	sword blade	85,66	0,03	13,04	204	2 976	536	458	618	6 388	980	498
Malassis	36	MBAa2	Ren-001006	36R 34	long flanged axe	81,25	0,04	14,50	143	3 404	506	520	25 986	10 531	498	501
Malassis	36	MBAa2	Ren-001007	36R 42	palstave	91,28	0,23	7,60	318	1 490	616	274	1 432	3 228	648	837
Malassis	36	MBAa2	Ren-001008	36R 255	masselotte	87,85	0,14	11,01	241	2 223	550	269	408	4 741	1 082	537
Malassis	36	MBAa2	Ren-001009	36R 197	bar ingot	86,28	0,23	12,64	296	1 554	557	199	383	3 991	963	511
Malassis	36	MBAa2	Ren-001010	36R 54	sword blade	85,33	0,09	13,45	216	2 519	533	314	411	5 797	963	503
Malassis	36	MBAa2	Ren-001011	36R 247	ingot	89,75	0,14	0,01	193	21 681	570	1 216	40 837	32 122	3 631	715
Malassis	36	MBAa2	Ren-001012	36R 238	ingot	98,66	0,09	0,01	308	144	610	199	9 411	374	41	1 376
Malassis	36	MBAa2	Ren-001013	36R 234	ingot	98,51	0,09	0,03	390	195	827	181	10 092	251	370	1 391
Malassis	36	MBAa2	Ren-001014	36R 239	ingot	98,91	0,01	0,01	95	1 292	556	94	4 663	3 423	63	545
Malassis	36	MBAa2	Ren-001015	36R 231	ingot	97,81	0,30	0,19	365	4 035	742	1 867	7 080	239	491	2 173
Malassis	36	MBAa2	Ren-001016	36R 205	bar ingot	95,22	0,69	0,15	417	1 003	1 028	443	29 047	364	1 364	5 687
Malassis	36	MBAa2	Ren-001017	36R 241	ingot	94,24	0,01	0,09	113	6 143	549	2 067	25 422	20 933	829	547
Malassis	36	MBAa2	Ren-001018	36R 4	palstave	86,74	0,25	11,49	260	6 376	586	1 311	640	4 491	851	663
Malassis	36	MBAa2	Ren-001019	36R 196	bar ingot	80,73	0,19	18,18	251	1 679	526	417	333	4 287	865	596
Malassis	36	MBAa2	Ren-001020	36R 167	bracelet	85,97	0,10	12,86	193	2 153	547	382	892	5 068	844	621
Malassis	36	MBAa2	Ren-001021	36R 127	bracelet	85,99	0,17	12,85	289	1 857	544	463	883	4 172	1 052	678
Malassis	36	MBAa2	Ren-001022	36R 223	foundry waste	81,37	0,13	17,26	211	2 732	519	454	653	5 819	1 412	583
Malassis	36	MBAa2	Ren-001023	36R 1	palstave	81,10	0,13	17,34	230	2 708	532	455	2 637	5 757	1 370	606
minimum						80,73	0,01	0,01	95	98	506	69	333	157	40	486
maximum						99,27	2,90	18,18	902	21681	1754	2067	40837	32122	5006	5709
médiane						89,75	0,10	7,60	282	1554	586	314	2637	3404	794	715
Rosnoën	29	LBAa1	ren-000688	49.1.14	rapier	88,04	0,13	11,21	419	1309	691	231	0	2333	609	644
Rosnoën	29	LBAa1	ren-000689	49.1.19	rapier	85,14	0,11	13,91	440	1583	661	215	1555	2207	748	924
Rosnoën	29	LBAa1	ren-000690	49.1.20	sword	88,20	0,23	10,69	569	1632	913	359	219	2201	768	2100
Rosnoën	29	LBAa1	ren-000691	49.1.22	sword	87,17	0,24	11,88	653	1621	811	275	265	2114	753	606
Rosnoën	29	LBAa1	ren-000692	49.1.16	rapier	86,35	0,14	12,67	445	2151	695	203	0	3330	994	546
Rosnoën	29	LBAa1	ren-000693	49.1.1	socketed hammer	73,34	0,21	25,82	504	1644	595	202	0	2004	1036	390
Rosnoën	29	LBAa1	ren-000694	49.1.24	sword	87,61	0,18	11,50	718	1322	751	352	579	1705	916	750
Rosnoën	29	LBAa1	ren-000695	????	rapier	86,03	0,04	13,59	172	793	598	81	0	928	432	409
Rosnoën	29	LBAa1	ren-000696	49.1.29	sword	86,55	0,08	12,74	383	1808	631	231	355	1663	599	635
Rosnoën	29	LBAa1	ren-000697	49.1.21	sword	86,99	0,22	12,10	633	1463	822	241	636	1587	859	685
Rosnoën	29	LBAa1	ren-000698	49.1.9	palstave	85,27	0,22	13,69	705	1546	828	397	1322	1799	864	706
Rosnoën	29	LBAa1	ren-000699	49.1.8	palstave	84,87	0,19	13,03	459	2103	686	241	11038	2953	1019	527
minimum						73,34	0,04	10,69	172	793	595	81	0	928	432	390
maximum						88,20	0,24	25,82	718	2151	913	397	11038	3330	1036	2100
médiane						86,45	0,19	12,71	482	1602	693	236	310	2059	813	640
Saint-brieuc-des-Iffs	35	LBAa2	Ren-002071	St-Brieuc 73918-A2	ingot	97,41	0,41	0,20	1324	2720	378	976	11054	288	641	4009
Saint-brieuc-des-Iffs	35	LBAa2	Ren-002072	St-Brc 10	palstave	75,16	12,35	8,41	4240	4763	300	302	111	2242	7368	526
Saint-brieuc-des-Iffs	35	LBAa2	Ren-002073	St-Brc 3	palstave	67,94	18,90	7,97	4551	5151	294	178	107	1273	7576	476
Saint-brieuc-des-Iffs	35	LBAa2	Ren-002074	St-Brc 8	palstave	89,55	1,73	3,27	12462	17960	467	124	194	1308	18272	638
Saint-brieuc-des-Iffs	35	LBAa2	Ren-002075	St-Brc 16	palstave	75,93	7,61	13,25	3928	4403	318	341	264	2048	6075	587
Saint-brieuc-des-Iffs	35	LBAa2	Ren-002076	St-Brc 5	palstave	71,39	17,74	5,91	4762	4627	320	333	275	1786	7204	683
Saint-brieuc-des-Iffs	35	LBAa2	Ren-002077	St-Brc 31	winged axe	85,73	0,19	12,28	405	1730	332	3156	6484	2585	448	1603
Saint-brieuc-des-Iffs	35	LBAa2	Ren-002078	St-Brc 7	palstave	86,11	3,41	7,10	5986	6761	356	368	2140	2255	9393	676
Saint-brieuc-des-Iffs	35	LBAa2	Ren-002079	St-Brc 23	palstave	88,44	1,51	7,67	5408	5569	358	210	83	1662	7845	694
Saint-brieuc-des-Iffs	35	LBAa2	Ren-002080	St-Brc 73918-B6	masselotte	87,87	2,34	7,40	4701	4917	329	376	470	1997	7228	680
Saint-brieuc-des-Iffs	35	LBAa2	Ren-002081	St Brc 49	sword blade	89,20	0,54	7,82	6605	7291	393	202	199	1805	10603	723
Saint-brieuc-des-Iffs	35	LBAa2	Ren-002082	St Brc 73918-B2	masselotte	81,93	8,12	7,28	6615	7089	360	275	168	1807	10737	482
Saint-brieuc-des-Iffs	35	LBAa2	Ren-002083	St Brc 22	palstave	88,85	2,16	6,54	6449	7173	381	196	224	2086	9753	596
Saint-brieuc-des-Iffs	35	LBAa2	Ren-002084	St Brc 20	palstave	85,13	6,17	6,55	5657	6690	374	202	381	797	7899	720
Saint-brieuc-des-Iffs	35	LBAa2	Ren-002085	St-Brc 73918-B5	masselotte	66,03	25,07	6,75	3596	3127	310	351	1662	966	5824	1979
Saint-brieuc-des-Iffs	35	LBAa2	Ren-002086	St-Brc 4	palstave	87,30	2,66	8,00	5684	5741	380	267	158	1952	8933	562
Saint-brieuc-des-Iffs	35	LBAa2	Ren-002087	St-Brc 33	winged axe	91,45	0,46	5,72	4942	6076	356	1265	2291	2682	7834	729
Saint-brieuc-des-Iffs	35	LBAa2	Ren-002088	St-Brc 52	sword blade	90,18	0,31	3,07	15178	20138	561	43	114	1719	23880	536
Saint-brieuc-des-Iffs	35	LBAa2	Ren-002089	St-Brc A	palstave	91,33	0,43	2,42	12039	16990	461	75	83	671	24674	573
Saint-brieuc-des-Iffs	35	LBAa2	Ren-002090	St-Brc 73918-A5	masselotte	87,16	4,47	5,22	7598	8127	399	271	113	2173	12544	578
Saint-brieuc-des-Iffs	35	LBAa2	Ren-002091	St Brc 24	palstave	67,20	24,43	6,14	3782	4572	278	271	161	1889	7046	560
Saint-brieuc-des-Iffs	35	LBAa2	Ren-002092	St-Brc 54	sword blade	85,96	4,38	7,93	4480	4749	375	595	397	1897	7085	689
Saint-brieuc-des-Iffs	35	LBAa2	Ren-002093	St-Brc 50	sword blade	89,14	1,16	6,48	7767	9978	417	311	444	1816	12740	615
Saint-brieuc-des-Iffs	35	LBAa2	Ren-002094	St-Brc 73918-B3	masselotte	87,58	3,64	4,59	9819	11346	441	219	256	1225	17061	633
Saint-brieuc-des-Iffs	35	LBAa2	Ren-002095	St-Brc 46	sword handle	81,86	10,04	3,67	9346	12873	421	271	69	1325	16288	583
Saint-brieuc-des-Iffs	35	LBAa2	Ren-002096	St-Brc 30	winged axe	83,19	4,17	8,70	9678	12569	415	352	202	1811	15518	670
minimum						66,03	0,19	0,20	405	1730	278	43	69	288	448	476
maximum						97,41	25,07	13,25	15178	20138	561	3156	11054	2682	24674	4009
médiane						86,63	3,53	6,65	5670	6383	374	273	213	1809	8416	636

Table 3 (end) – Elemental compositions of Tréboul (MBA1), Martillac (MBA1), Boisgervilly (MBA2), Boulay-Morin (MBA2), Saint-Thois (MBA2), Heucqueville (MBA2), Saint-Germain-d'Esteuil (MBA2), Malassis (MBA2), Rosnoën (LBA1) and Saint-Brieuc-des-Iffs (LBA2) hoard artefacts.

	ID sample	206Pb/204Pb	207Pb/204Pb	208Pb/204Pb
MBAa1	2 σ	0,001	0,001	0,002
Tréboul	49 5 8	18,317	15,627	38,352
Tréboul	49 5 16/3	18,327	15,628	38,356
Tréboul	49 5 89	18,741	15,653	38,466
Tréboul	49 5 93	18,337	15,634	38,377
Tréboul	49 5 101/1	18,316	15,625	38,347
MBAa1	2 σ	0,0005	0,0005	0,0015
Martillac	mart 10	18,4420	15,6553	38,4581
Martillac	mart 6	18,4189	15,6485	38,4342
Martillac	mart 13	18,3487	15,6374	38,3884
Martillac	mart 5	18,4070	15,6458	38,4199
Martillac	mart 21	18,7753	15,7054	38,6887
MBAa2	2 σ	0,0005	0,0005	0,0015
Boisgervilly	BG1	18,1745	15,6648	38,4119
Boisgervilly	BG3	18,1699	15,6575	38,4110
Boisgervilly	BG5	18,1516	15,6548	38,3714
Boisgervilly	BG7	18,1799	15,6618	38,4037
Boisgervilly	BG8	18,2594	15,5455	38,4321
MBAa2	2 σ	0,0005	0,0005	0,0015
Boulay-Morin	3479	18,2283	15,6651	38,4435
Boulay-Morin	3477	18,0752	15,6544	38,3061
Boulay-Morin	3473	18,0066	15,6489	38,2361
Boulay-Morin	3474	18,1542	15,6568	38,3955
Boulay-Morin	3471	18,3566	15,6706	38,5329
MBAa2	2 σ	0,0005	0,0005	0,0015
St Germain-d'Esteuil	SG 25	18,0751	15,6529	38,2954
St Germain-d'Esteuil	SG 23	18,1302	15,6539	38,3644
St Germain-d'Esteuil	SG 27	18,6262	15,6691	38,7785
MBAa2	2 σ	0,0005	0,0005	0,0015
Malassis-ingot	36 R 214	17,9070	15,6396	38,1371
Malassis-ingot	36 R 234	18,0103	15,6434	38,2493
Malassis-ingot	36 R 206	20,8292	15,7911	40,4465
Malassis-ingot	36 R 207	18,1838	15,6568	38,4318
Malassis-ingot	36 R 208	17,9185	15,6338	38,1318
Malassis-ingot	36 R 221	17,8460	15,3326	37,2708
Malassis-ingot	36 R 232	18,0050	15,6493	38,2563
Malassis-ingot	36 R 210	18,1182	15,6509	38,3653
Malassis-ingot	36 R 217	18,0052	15,6445	38,2534
Malassis-ingot	36 R 240	19,7551	15,7432	39,6809
Malassis	36 R 41	18,0549	15,6517	38,2908
Malassis	36 R 54	18,0931	15,6609	38,3405
Malassis	36 R 197	18,1844	15,6586	38,4301
Malassis	36 R 205	17,9014	15,6445	38,1407
Malassis	36 R 12	18,1349	15,6572	38,3779
LBAa1	2 σ	0,0005	0,0005	0,0015
Rosnoën	49.1.1	18,2177	15,6612	38,4437
Rosnoën	49.1.8	18,1779	15,6642	38,4260
Rosnoën	49.1.16	18,1850	15,6706	38,4484
Rosnoën	49.1.20	18,1927	15,6657	38,4442
Rosnoën	49.1.21	18,1754	15,6629	38,4236
LBAa2	2 σ	0,0005	0,0005	0,0015
Saint-brieuc-des-Iffs	St Brieuc 49	18,285	15,650	38,423
Saint-brieuc-des-Iffs	St Brieuc 23	18,364	15,640	38,426
Saint-brieuc-des-Iffs	St Brieuc 10	18,484	15,634	38,460
Saint-brieuc-des-Iffs	St Brieuc A	18,389	15,642	38,444
Saint-brieuc-des-Iffs	St Brieuc 3	18,436	15,638	38,447
Saint-brieuc-des-Iffs	St Brieuc 8	18,367	15,651	38,472
recent LBAa3	2 σ	0,0005	0,0005	0,0015
St Sauveur	lingot 1	18,1602	15,6356	38,2793
St Sauveur	lingot 2	18,2152	15,6311	38,2424

Table 4 – Lead isotope compositions of Tréboul (MBA1), Martillac (MBA1), Boisgervilly (MBA2), Boulay-Morin (MBA2), Saint-Germain-d'Esteuil (MBA2), Rosnoën (LBA1), Saint-Brieuc-des-Iffs (LBA2) and Saint-Sauveur (LBA3b) hoard artefacts.

Second stage of Middle Bronze Age (MBA2/Bz C): Moutiers horizon (1450–1300 BC)

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, which are scattered in the regions of the same name. A total of 450 hoards have been identified in these regions, with a total of 3,148 objects inventoried (Nordez, 2019) with tin contents ranging from 9 % to 15 % (average 12 %). This number is largely underestimated because 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 and Quentinet, 2023). However, local copies are always possible.

6 deposits were analysed as part of this study (fig. 2). These are the hoards at Boisgervilly (35), composed entirely of palstaves, for which 13 elemental chemical analyses were carried out and 5 isotopic analyses; Boulay-Morin (27), also composed of palstaves (10 elemental chemical analyses and 5 isotopic analyses); Saint-Thois (29), for which 30 palstaves were analysed for elemental chemistry; Heucqueville (27), where all 31 palstaves were analysed for elemental chemistry; Saint-Germain-d'Esteuil (33), where only 6 axes were analysed for elemental chemistry and 3 for isotopes; and finally the Malassis hoard (18). The latter hoard, considered to be slightly later, is located in central France and contains objects with typological attributions from the Atlantic and continental domains. Unlike the typical MBAa2 hoards mentioned above, this type of complex hoard includes a wide variety of objects, and also, very interestingly for research into copper sources, fragments of copper ingots. Elemental analysis of the axes shows a very high compositional homogeneity for most of the Atlantic seaboard, from Normandy to the Médoc, with a classical bronze composition (table 3). Compositional homoge-

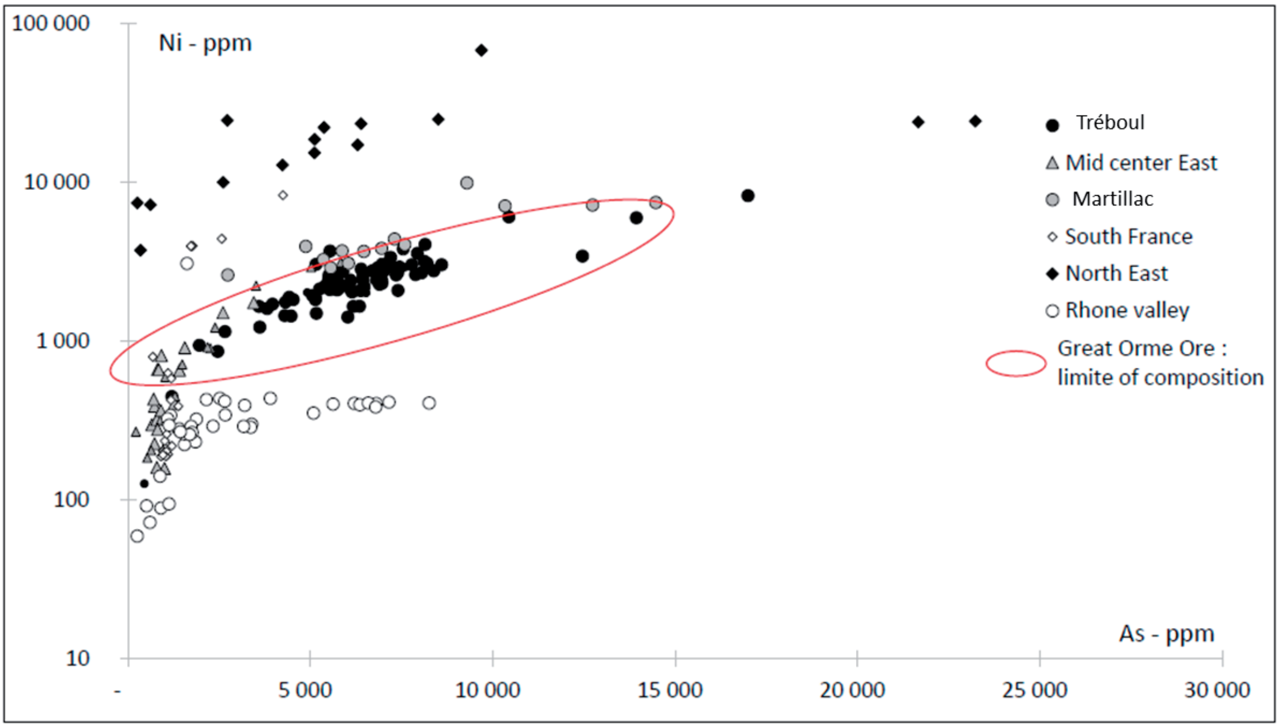

Fig. 3 – Comparison of Ni and As contents of Tréboul and Martillac hoard artefacts with that of Rhône valley (unpublished data), Mid-Centre-East (Gabillot, 2021), North-East (unpublished data), South (unpublished data) artefacts from hoards, and with Great Orme ore compositions.

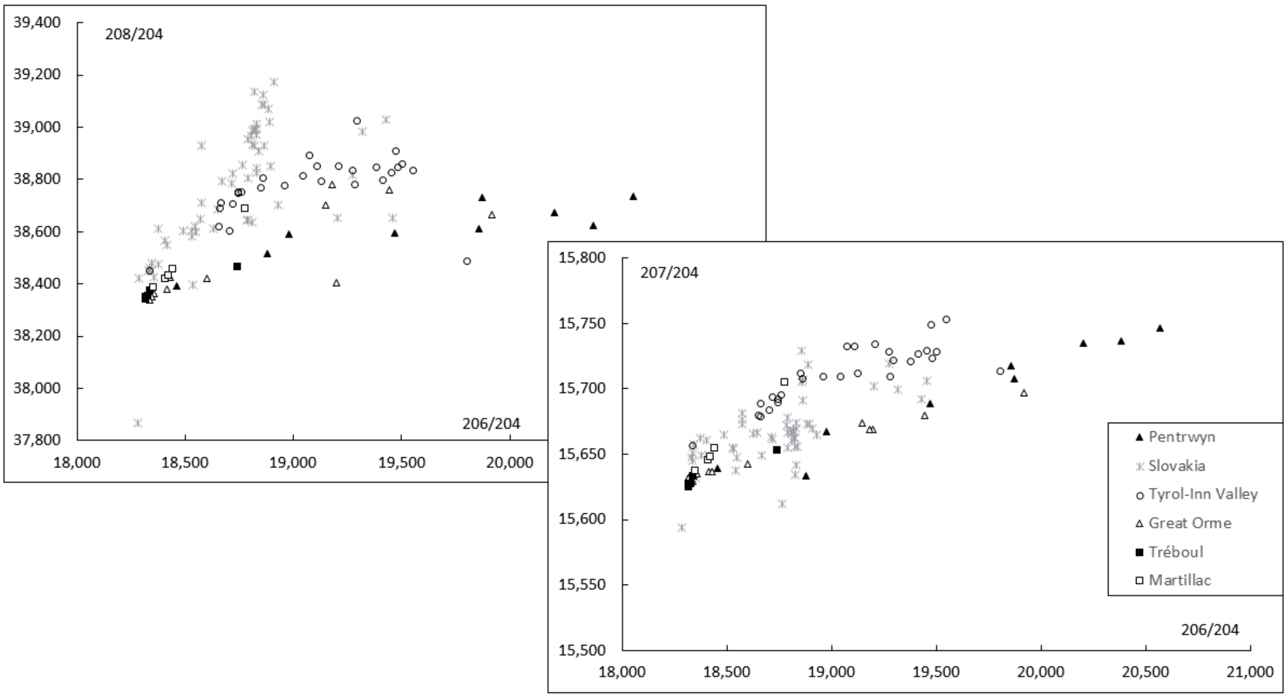

Fig. 4 – Lead isotopes diagrams for Tréboul and Martillac hoards artefacts, compared to Great Orme, Slovakia and Tyrol (Inn Valley) copper ore domain values.

neity is also high relative to that of the axes from the Burgundy and Franche-Comté hoards, particularly in terms of trace element contents. Overall, the Malassis hoard shows the same variation in elemental composition as the hoards mentioned above (fig. 5). Only a few objects and ingots have much lower levels of As, Ni and Sb (Briard et al., 1969).

This composition seems quite different from that of the previous period for north-western France (fig. 6). The average Ni content is higher in MBA2 (5,111 ppm) than in MBA1 (2,399 ppm). The same applies to Sb (1,056 ppm in MBA2 compared with 232 ppm in MBA1). By contrast, the average As content is higher in MBA1 (6,161 ppm) than in MBA2 (2,868 ppm). This observation suggests a radical change in the origin of the imported metal. However, some MBA2 axes from the northwest show sometimes a chemical composition identical to objects from the previous MBA1 period, and show a difference from axes from eastern and central France. The compositions of the axes from Burgundy and the centre of France are similar and do not come close at all to the composition of MBA1. 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 MBAa2, or that objects from MBA1 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 (fig. 6). In particular, these objects have a high average Ag content (1,599 ppm) and low Ni (815 ppm) and As (1,153 ppm). Isotopic analyses were carried out on axes from north-western France, south-west France (Saint-Germain d'Esteuil) and central France (Malassis) (table 4). 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

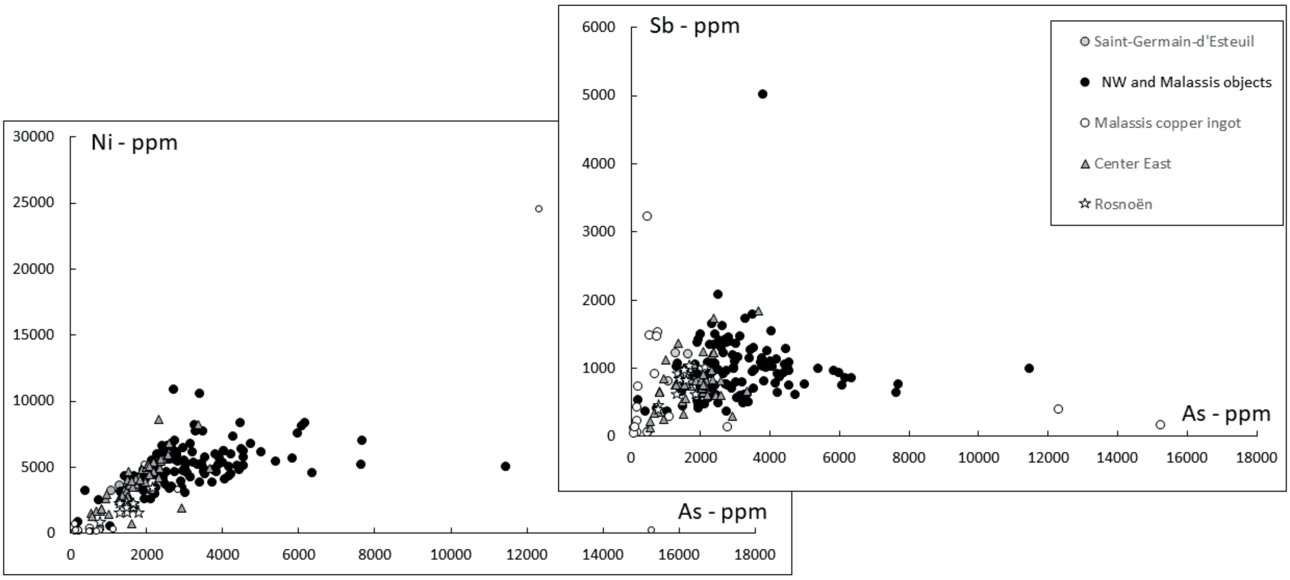

Fig. 5 – As/Ni and As/Sb diagrams for MBA2 and LBA1 north-West and MBA2 Médoc hoard artefacts compared to MBA2 Malassis artefacts and copper ingots, and MBA2 Centre-East hoard artefacts..

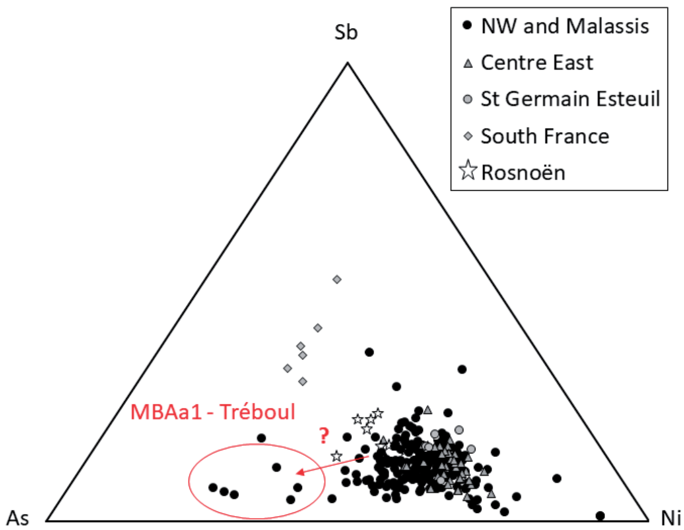

Fig. 6 – Ternary As/Ni/Sb diagram for MBA2 and LBA1 north-West and MBA2 Médoc hoard artefacts compared to MBA2 Malassis, South and Centre-East hoard artefacts, and MBA1 Tréboul artefacts.

the copper could be Spain (Huelva), in the first approach. However, the signatures of the Malassis copper ingots seem to point to Spain (Huelva) and/or Italy (Valsugana), on the one hand, and to Austria, with the district of Mitterberg, on the other (fig. 7a and b). 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 three mentioned districts. The hypothesis of the use of copper from the Great Orme mine could perhaps be confirmed because some analyses seem to point toward the Great Orme isotopic domain from the alignment of points.

First stage of Late Bronze (LBA1/Bz D–Ha A1): Rosnoën horizon (1275–1140/1125 BC)

With the beginning of the Final Bronze Age, the typology and number of hoards changed radically. The Rosnoën group comprises barely fifteen or so assemblages and a few isolated objects in Brittany. Most of them are located in central-western Brittany. A few groups are located in Ille-et-Vilaine and swords are thrown at the mouth of the Loire (Nallier and Le Goffic, 2008). The type of palstave changed, as did the type of hoard, in which the artefacts are varied and partially fragmented.

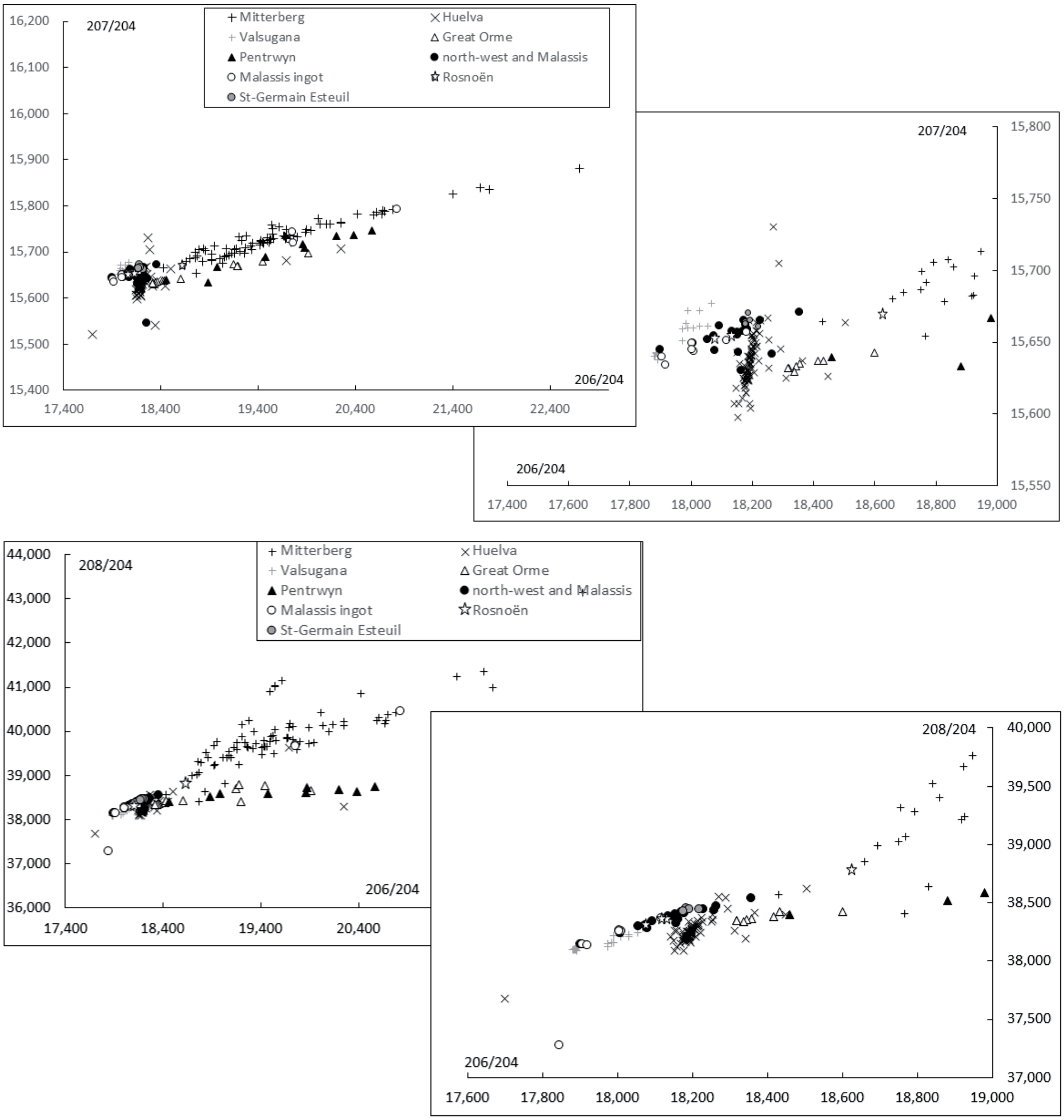

Fig. 7 – Lead isotopes diagrams for MBA2 and LBA1 North-West and Médoc hoards artefacts, compared to Mitterberg, Valsugana and Huelva copper ore domain values..

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.

The eponymous deposit of Penavern in Rosnoën (fig. 2) was discovered in 1944 and partially acquired by P.-R. Giot for the Penmarc'h museum. J. Briard described this lot in his thesis in 1965. Since then, the deposit has been better documented (Nallier and Le Goffic, 2008). Some of the objects dispersed among the family of the discoverer have been examined. The hoard contains 88 items, including whole swords, rapiers, daggers, spear points, axes, triangular scrapers, and at least one socketed hammer. 12 elemental analyses were carried out for this hoard (table 3). 5 isotopic analyses were also produced (table 4).

The chemical and isotopic compositions of the axes are identical to those of the other objects in the hoard (average content of Ag at 508 ppm, As at 1,581 ppm, Ni at 2,069 ppm and Sb at 800 ppm) and are almost identical to those of the previous period (figs. 5, 6, and 7). 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 for this period, these results should not be considered definitive.

Second stage of the Late Bronze Age (LBA2/ Ha A2–Ha B1): Saint-Brieuc-des-Iffs horizon (1140/1125–950 BC)

In Late Bronze Age 2, there are more hoards than LBAa1, but far fewer than in MBAa2. The artefacts in hoards are numerous, often several dozen specimens, up to 200 artefacts. The artefacts are most often fragmented. Axes are represented by massive palstaves, also known as 'Rosnoën' type axes because they are fairly identical to the previous period (Briard and Verron, 1976).

Four hoards were analysed in this study (fig. 2). Firstly, there are the two hoards at Soullans (Vendée; Boulud-Gazo et al., 2022), objects from the unpublished Plérin hoard (Côtes-d'Armor) and part of the Saint-Brieuc-des-Iffs hoard (Ille-et-Viliane). A wide variety of objects are collected in these hoards, and it would be tedious to make an inventory of them here. However, there are a number of special features. The Soullans hoards contain bar-shaped alloy ingots. This type of ingot was also found in the Bouygues hoard at Saint-Sulpice (Lot; Milcent et al., 2022). The largest objects from these hoards were analysed for elemental chemistry (82 analyses, mainly of bar-shaped alloy ingots, copper ingots, fragments of swords, axes, and bouterolles). The Plérin hoard contains reniform type bracelets that point to the continental domain, particularly in eastern France (Eluère, 1975). 27 objects were analysed for elemental chemistry for the Plérin hoard. These were mainly massive palstaves with a right-angled stop-ridge, but also fragments of swords and javelins, bracelets, and casting wastes. The Saint-Brieuc-des-Iffs hoard contains continental-type ornaments (Briard and Onnée, 1972). Unfortunately, the latter was not sampled due to its fragility. Only the most massive objects were selected, i.e. massive palstaves with a right-angled stop-ridge, winged axes, casting wastes, and sword fragments, for a total of 27 elemental chemical analyses (table 3) and 6 isotopic analyses (table 4).

What is special about this period is the nature of the alloy, which contains lead (from 0.08 % to 48,47 %, with an average of 5,32 %) 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. The LBAa2 axes contain lead, while the LBAa1 axes do not (fig. 8). Similarly, the levels of the four main trace elements (Ag, As, Ni and Sb) do not correspond at all (fig. 8; see contents in previous paragraph for LBA1 and

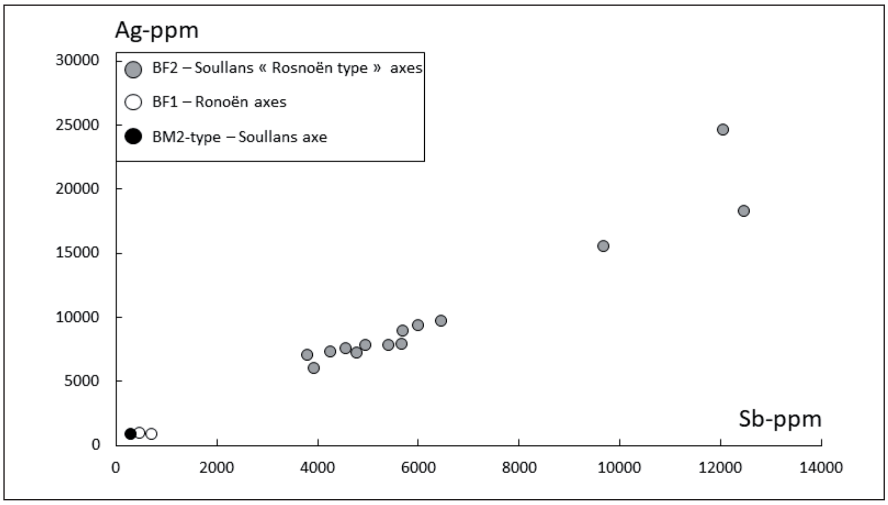

Fig. 8 – Comparison of Ag and Sb contents of MBA2 type palstave and of Rosnoën type axes of LBA2 Soullans hoards, with LBA1 Rosnoën type axes.

below for LBAa2). The isotope ratios are also different. This leads us to believe that the origin of the metal changes completely between the LBAa1 and LBAa2, 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 MBAa2 period, found in an LBAa2 hoard in Vendée (Boulud-Gazo et al., 2022), has the chemical and isotopic composition of objects from this earlier period.

Nevertheless, objects from the Atlantic seaboard seem to be made from copper of several different origins (fig. 9). The copper may come from:

1) copper ingots; poor in Ag (about 300 ppm) Ni (120–230 ppm) and Sb (140–210 ppm) and with a little richness in As (2,500–5,800 ppm);

2) a type of alloy, somewhat poor in As (300–2000 ppm), Sb (200–1,200 ppm), Ni (100–1,000 ppm), and Ag (less than 1,000 ppm), mainly represented by a part of Pb-rich bar ingots (2.5–48.5 %) and some artefacts from Soullans hoards;

3) another type of alloy rich in As (1,000–8,000 ppm), with a low content in Ni (100–1,500 ppm) with moderate to high content in Sb (2,500–12,500 ppm) and Ag (1,000–7,000 ppm), represented by the other part of Pb-rich bar ingots and some artefacts from Soullans hoards, and some artefacts from Saint-Brieuc-des-Iffs and Plérin;

4) another one very rich in As (8,000–20,000 ppm), Sb (12,500–25,000 ppm) and Ag (7,000–15,000 ppm), and somewhat rich in Ni (700–2,500 ppm), represented by some artefacts of Soullans and Saint-Brieuc-des-Iffs hoards, with chemical characteristics which can be observed in artefacts from Wilburton Step in England (Williams, 2023);

5) finally, an alloy very rich in As (3,000–10,000 ppm) and Ni (2,000–6,000 ppm) and rich in Sb (6,000–12,000 ppm) and Ag (4,000–7,000 ppm). This chemical composition is particularly represented in the Plérin hoard. This type of metal is recognised in Switzerland (Rychner and Kläntschi, 1993) and could have an Alpine origin. The origin could also be Slovakia because of the presence of an Ni-rich ore district (Nøorgard et al., 2021).

The mixture of sources can also be seen in the isotopic analyses, with the points representing the analyses of alloy artefacts 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 LBAa2 objects with copper deposits is not meaningful. Comparing these isotopic compositions with European lead deposits does not provide any information either (fig. 10). 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 the Great Orme (fig. 11). However, a comparison of the elemental compositions of the LBAa2 objects with those of the MBAa1 objects, the copper of which almost certainly came from the Great Orme, shows that these two groups of objects do not have the same elemental composition at all: the MBAa1 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; fig. 2), dated to the following period (Couderc et al., 2021). An isolated point could also refer to a closer ore, located in the western French Alps (fig. 11).

End of the Late Bronze Age (LBA3/Ha B2-B3): Vénat horizon (900-800 BC)

In the recent Late Bronze Age 3, there are an extremely large number of metal hoards, with a wide variety of numerous objects (weapons, ornaments, tools, ornaments

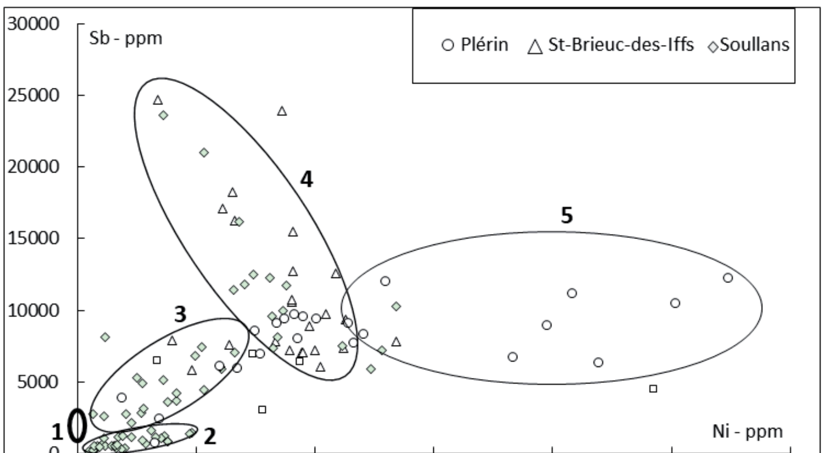

Fig. 9 – Binary diagram Ni/Sb showing the fifth type of elemental compositions observed in North-West LBA2 hoard artefacts.

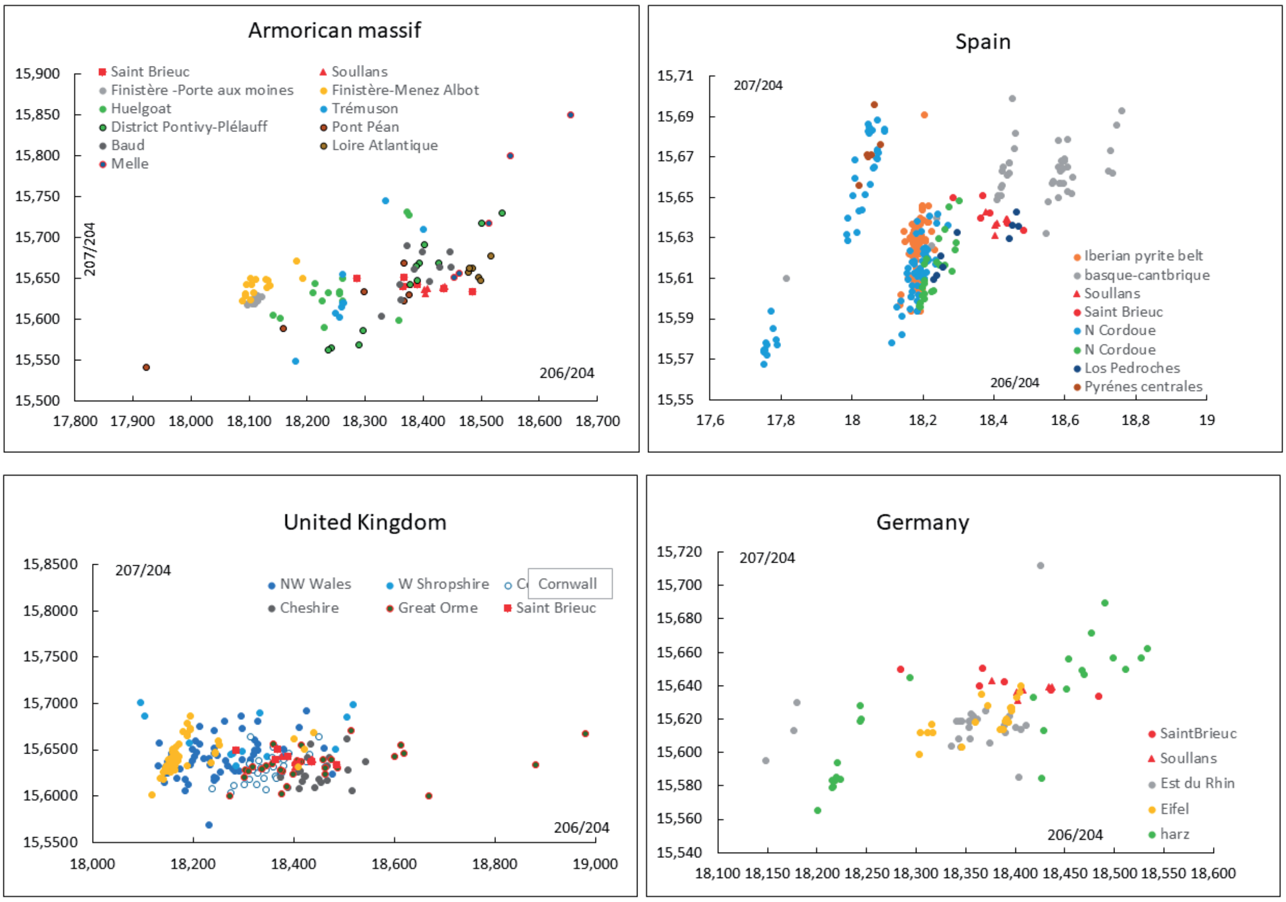

Fig. 10 – Lead isotopes diagrams for LBA2 North-West hoards artefacts, compared to lead deposits form Armorican massif, Spain, Germany and United Kingdom.

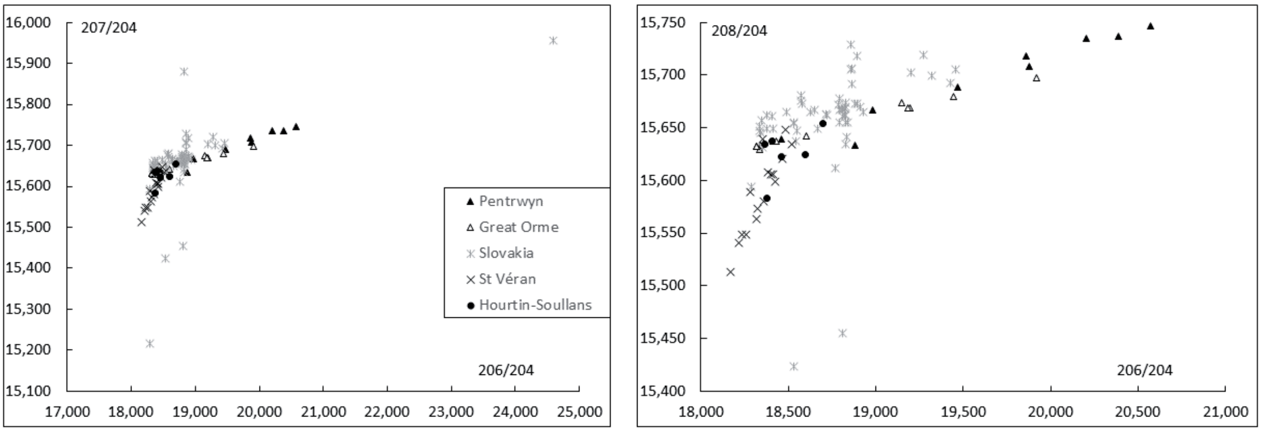

Fig. 11 – Lead isotopes diagrams for LBA2 and LBA3a North-West hoards copper ingots, compared to copper deposits form Great Orme, Saint-Véran and Slovakia.

of carts, care tools, casting wastes, etc…), most often fragmented, including fragments of copper ingots (Milcent, 2012; Bordas, 2023). There are more located close to the sea in particular, but some are placed in the centre of Brittany (Fily and Boulud-Gazo, 2009).

Three hoards were analysed for this study (fig. 2). The first, Le-Bois-de-l'Enfer hoard at Saint-Sauveur-Le-Vicomte (Manche), is made entirely of copper ingots. The 20 elemental analyses have already been published (Gandois et al., 2019). Two isotopic analyses have been carried out since then (table 3). Elemental analyses of the Surtainville hoard have also been published (Le Carlier de Veslud et al., 2018). The Mérézel hoard (Bordas, 2019; 2023) in the commune of Le Palais at Belle-Île (Morbihan) was recently analysed. A total of 91 elemental chemical analyses and 15 isotopic analyses were obtained.

Elemental chemical analyses of artefacts from Mérézel show a wide range of compositions suggesting various sources of copper. It should be noted that the majority of objects have lead in the alloy up to 23 % (table 5). Various composition groups have been identified, but perhaps some groups could be brought together in the future with new analyses.

1) The first group, which includes the largest number of objects in the hoard (87), as well as the largest number of copper ingot fragments (29), has low contents of Ag (130–2,300 ppm), As (100–1,500 ppm), Ni (100–1,300 ppm), and somewhat high contents of Sb (300–6,700 ppm). It is also in this group that objects of Atlantic typology are present in greater numbers.

2) The second group consists of just 8 objects, including one copper ingot. It is characterised by very high contents of Ag (1,700–22,600 ppm) and As (2,000–25,600 ppm), low contents of Ni (200–2,500 ppm), and extremely high contents of Sb (10,000 to 107,000 ppm).

3) The third group comprises 7 objects. It is characterised by low contents of Ag (900–1,700 ppm) and As (1,000–3,300 ppm), low contents of Ni (400–2,800 ppm), and high to very high contents of Sb (6,700–35,200 ppm).

4) The fourth group is made up of 3 objects and is mainly characterised by a very high Ag content (2,000–16,000 ppm), a low As content (1,100–1,500 ppm), and a high to very high Sb content (6,000–34,700 ppm). Ni content varies from low to high (100–6,200 ppm).

5) The fifth consists of 5 objects including 2 ingots. It is characterised by low to high contents of Ag (80–1,200 ppm), high contents of As (4,000–8,000 ppm), low contents of Ni (400–1,200 ppm), and fairly high contents of Sb (1,600–3,800 ppm).

6) The sixth group consists of only two objects, including a fragment of ingot. It is very low in Ni (200–300 ppm), low to high in Ag (300–1,200 ppm), high in As (4,200–7,300 ppm), and very high in Sb (7,000–44,000 ppm).

7) The seventh group is composed only of a fragment of a copper ingot. It is characterised by a high content of Ag (2,652 ppm) and Sb (3,246 ppm) and a low content of As (124 ppm) and Ni (529 ppm).

It's worth noting that at this period, metal did not only travel in the form of ingots, but manufactured objects were probably also part of the trade. However, the presence of copper ingots in almost all chemical categories, combined with the fact that most of the objects have a regional typology, suggests that the metal travelled mainly in the form of copper ingots. The large number of hoards made up entirely of ingots provides further support for this hypothesis.

A comparison of the elemental compositions of objects of the recent Late Bronze Age 3 with those of Late Bronze Age 2 shows similarities for some objects, suggesting continuity in the supply of copper from the same sources (fig. 12). Comparison with objects from the east of France (fig. 13) shows that the copper supplying the Atlantic domain is significantly different from that supplying the continental domain (Véber, 2009).

As we have seen from the elemental analyses of bronze objects, copper ingots show a very wide variation in composition, which is confirmed by isotopic analyses (fig. 14a and b), implying multiple supplies throughout Europe. Three ingots show a compatibility with Spain (Huelva). A majority of ingots show correspondence with Slovakia. However, some of these also have a positive link with the Great Orme, Saint-Véran, the Italian Alps (Alto-Adige Trentino Veneto AATV), and Cabrières. One ingot is also compatible with an Austrian origin (Mitterberg). Finally, two or even three ingots could come from Cyprus (Kalavassos). Sardinia in the north-west has a small isotopic proximity, but this origin is less evident. Given this diversity, it is difficult to propose reliable sources of copper at this stage. A comparison of elemental chemistry with copper produced in these different sectors will certainly enable us to refine our knowledge of these sources.

DISCUSSION

This study provides an initial overview of the supply of copper during the Bronze Age in north-western France. The origins of copper ore have been determined or pro-

			Cu (%)	Pb (%)	Sn (%)	Ag (ppm)	As (ppm)	Bi (ppm)	Co (ppm)	Fe (ppm)	Ni (ppm)	Sb (ppm)	Zn (ppm)
Group 1	87 objects	min	58,97	0,07	2,72	135	95	212	0	52	102	314	0
Group 1	87 objects	*max*	*94,44*	*37,79*	*19,42*	*2256*	*1499*	*362*	*96*	*3789*	*1296*	*6674*	*853*
Group 1	87 objects	**median**	**86,33**	**3,26**	**9,88**	**772**	**1014**	**295**	**24**	**268**	**685**	**2963**	**613**
Group 2	8 objects	min	68,02	1,91	0,02	1737	2085	279	0	98	225	9820	121
Group 2	8 objects	*max*	*92,07*	*23,47*	*11,13*	*22590*	*25091*	*1352*	*483*	*1040*	*2464*	*107023*	*1150*
Group 2	8 objects	**median**	**75,31**	**12,78**	**8,47**	**2866**	**5132**	**304**	**81**	**135**	**811**	**13057**	**636**
Group 3	7 objects	min	65,04	0,48	8,20	866	937	252	13	81	402	6705	206
Group 3	7 objects	*max*	*87,56*	*22,83*	*13,04*	*1731*	*3309*	*422*	*54*	*3212*	*2772*	*35230*	*721*
Group 3	7 objects	**median**	**86,83**	**3,36**	**10,00**	**1174**	**2184**	**298**	**31**	**500**	**1122**	**9210**	**609**
Group 4	3 objects	min	67,71	3,11	7,53	2019	1159	241	10	79	98	5997	524
Group 4	3 objects	*max*	*86,28*	*22,82*	*7,94*	*16214*	*1492*	*376*	*61*	*2949*	*6188*	*34753*	*785*
Group 4	3 objects	**median**	**85,10**	**4,53**	**7,63**	**14403**	**1301**	**324**	**35**	**1314**	**1810**	**6031**	**746**
Group 5	5 objects	min	76,50	0,09	0,01	76	4135	285	0	37	375	1595	176
Group 5	5 objects	*max*	*97,49*	*9,18*	*14,01*	*1209*	*8002*	*509*	*138*	*257*	*1206*	*3748*	*671*
Group 5	5 objects	**median**	**95,50**	**1,14**	**3,11**	**464**	**5034**	**348**	**0**	**45**	**413**	**1977**	**579**
Group 6	2 objects	analysis	98,06	0,87	0,07	264	4221	317	0	532	284	7111	260
Group 6	2 objects	analysis	90,31	2,14	3,52	1176	7349	348	11	120	174	44086	665
Group 7	1 object	analysis	98,40	0,18	0,08	2652	124	305	0	308	529	3246	726

Table 5 – Minimum and maximum values, and median values for each group of elemental composition for LBA3b Mérézel hoard.

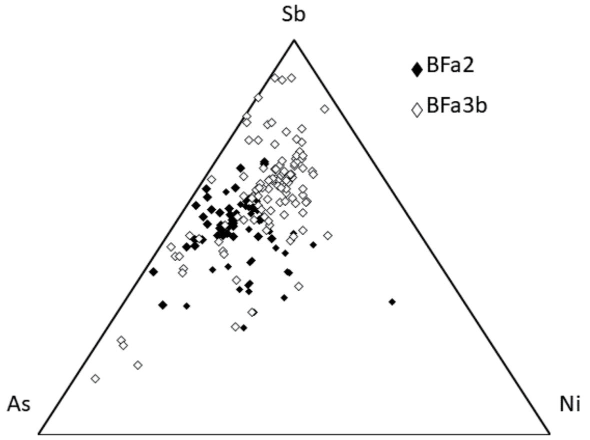

Fig. 12 – Ternary As/Ni/Sb diagram for North-West LBA3b hoard artefacts compared to that LBA2 North-West hoard artefacts.

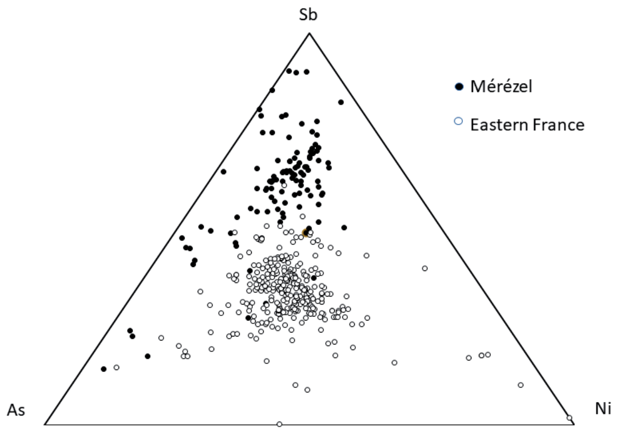

Fig. 13 – Ternary As/Ni/Sb diagram for North-West LBA3b hoard artefacts compared to that LBA2b North-East hoard artefacts.

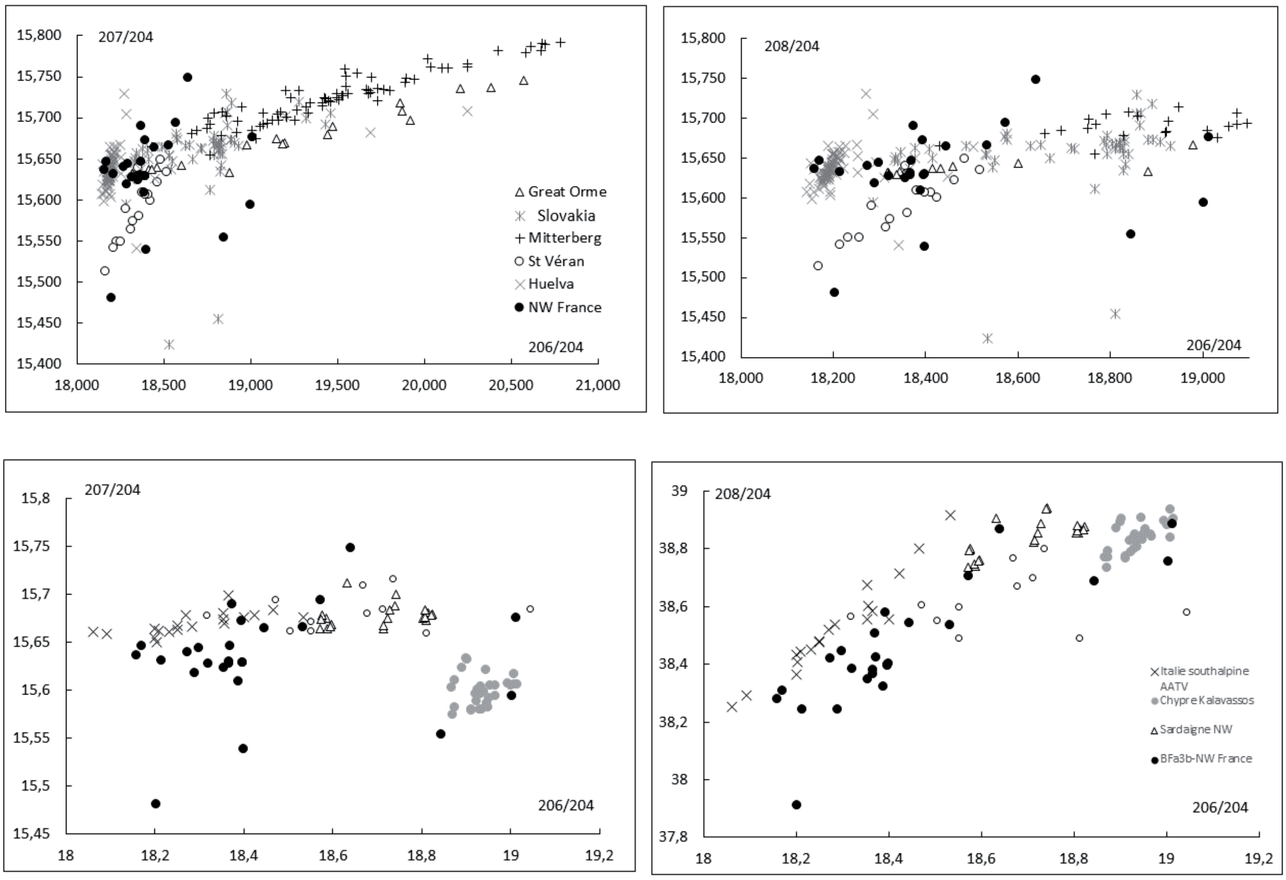

Fig. 14 – Lead isotopes diagrams for LBA3a North-West hoards copper ingots, compared to copper deposits form Great Orme, Slovakia, Mitterberg, Saint-Véran, Huelva, Italia southalpine AATV, Cyprus Kalavassos, Parys Moutain, Sardinia NW..

posed for the production of objects from several periods. This has been made possible by a large series of elemental and isotopic analyses that have already identified regional signatures, corresponding to metal stocks that vary in time and space. Although the metal analysed comes from metal hoards in which the objects may have a distant provenance, the focus of the analyses on regionally typical objects, foundry waste, and copper ingots makes it possible to identify the signatures of these stocks of metals used in the region concerned. Nevertheless, the exhaustive sampling enables us to approach the supply networks and their evolution for the first time.

These analyses suggest that the metal stocks in circulation were not the same in the Atlantic, Continental, and Mediterranean areas, although the nature of these differences has yet to be clarified. This statement needs to be qualified because when analyses reveal a high degree of homogeneity in chemical signatures over a large geographical area, this can be interpreted as indicating the intense circulation of raw materials and artefacts within a very extensive geographical zone, without making it possible to trace the exchange networks more precisely. These results also show that stocks of metals of different origins appear to be present in the same hoards, highlighting the diversity of copper sources. They show too that the nature and origin of copper change over time.

For the Middle Bronze Age 1, copper seems to have come from Atlantic areas, and the copper most probably comes from the Great Orme mine in Wales. The analytical data concur with the typological observations, i.e. the objects from the Tréboul horizon show typological similarities to those from Acton Park. Williams (2023) has shown that copper supplies from the Great Orme are not confined to north-west France. Copper supply networks extend along the coasts of the English Channel and the North Sea, even as far as Sweden. This copper also seems to be distributed on the Aquitaine coast, which, however, also seems to be supplied by a second source. Comparison with other French regions seems to show that these networks were not able to penetrate significantly into the territory, although objects linked to the Tréboul horizon have been recognised as far as the Alps (Gabillot et al., 2023). The study of this period is not yet complete, and we now need to identify the limits to the circulation of this metal within France.

From the Middle Bronze Age 2 onwards, the supply of metal became much more important, with various sources, some of them probably very distant.

In the Middle Bronze Age 2, despite the very high chemical homogeneity of the bronze axes in the hoards, analyses show that they are made up of a mixture of copper of at least two origins: one probably from the south, with a potential Spanish origin (Huelva) or Italian (AATV); the other from the east, with metal from the large Mitterberg production area. A third source could be considered, taking into account the metal from the Great Orme. This metal could correspond either to the re-use of objects from the previous period made in the region or to newly imported metal, as the Great Orme mine was still in operation at this time. Despite a possible partial continuity of copper supply with the previous period, the analyses show a fairly drastic change in metal supply trades. The provenance of copper from Austria is consistent with the expansion of the tumuli culture. Although the north-west of France shows few artefacts linked to this culture, it would seem that the raw metal, probably in the form of ingots, spread further west into the Atlantic region. The similarity of the elemental chemical and isotopic compositions of the objects from the hoards from central and central-eastern France to those in the west also supports this hypothesis. The Spanish influence, in terms of copper supply, can also be seen as an expansion, northwards along the Atlantic coast, of a possible supply from the south in Aquitaine in the previous period.

For the Late Bronze Age 1, only one deposit, from Finistère, has been analysed. Consequently, very little information is available to support discussion of the origin and expansion of the metal supply. However, elemental chemical and isotopic analyses show a close similarity between objects from this period and those from the previous period, suggesting continuity in terms of metal supply, whereas the method of deposition of objects is changing in the hoards, and the number of these is decreasing drastically. Are we confronted with a lack of metal in the Atlantic domain, or are we simply facing cultural changes?

For the Late Bronze Age 2, the situation seems to have changed considerably in terms of copper supply networks. Chemical and isotopic analyses show several metal compositions that may correspond to as many sources. Because of the presence of lead in alloys, it is currently difficult to know the origin of most copper sources. However, the very high content of lead suggests that it may have come from a separate source. Nevertheless, elemental analyses have revealed groups of compositions that differ from those of copper ingots. Two sources of metal are used in the composition of heavily leaded bar ingots. The search for a typological match for these objects leads us to Eastern Europe, and in particular Slovakia, where this type of material has also been recognised, although the objects' shape is not quite identical (Boulud-Gazo et al., 2022). Elemental chemical analyses may also lead us eastwards due to the very high nickel content of some alloys. Austria, with the Mitterberg sector, could be a potential source, as well as ores located in Slovakia. Finally, the presence of a Klentice-type sword handle in the Late Bronze Age 3a Hourtin hoard (Couderc et al., 2021), which may have originated in this sector, is a further factor supporting the hypothesis that this region of Eastern Europe was the source of some of the copper. The chemical proximity of objects from north-west France to those from the Wilburton horizon in England raises questions. The large island has numerous lead deposits that could have supplied the continent with lead-rich alloys. Unfortunately, isotopic analyses cannot distinguish between several regions containing lead deposits in Western Europe. Finally, from the Late Bronze Age 2 onwards, we can see that the network supplying copper to north-western France became more complex and spread over greater distances.

For the Late Bronze Age 3b, the mixture of metals from different sources seems to be even greater. This can be seen in the elemental analyses of bronze objects and copper ingots. Isotopic analyses of the copper ingots seem to indicate sources of copper of different origins, ranging from the western and eastern Alps to central Europe. Origins in Mediterranean regions such as Cyprus, Sardinia, southern Spain, and southern France are also assumed. This southern origin can be compared with the fact that most of the copper ingots found in metallic hoards in north-western France are located on the south coast of the peninsula, from Finistère to Pays de la Loire (Bordas, 2023). The link between Mediterranean countries is also evident in the typology of the objects. Objects with typological affinities to Nuragic pieces have been observed in north-western hoards. By contrast, occurrences have been found in Sardinia (Bordas, 2023). Similarly, a Huelva-type sword was brought up from the bottom of the English Channel off Normandy (oral communication H. Gandois), also showing a link with Spain. A link between the Iberian Peninsula and the Nordic countries has also been demonstrated by isotope analyses (Ling et al., 2013). Finally, the link with the regions of north-east France, and beyond with western Germany, is known through the presence in north-western hoards of objects of oriental typology such as sickles, tintinnabuli, or bracelets, of the Vandrevanges type in particular. The movement of metal objects also contributed to long-distance exchanges. The use of these metals of different origins leads to the production of regional objects whose chemical and elemental signatures correspond mainly to mixtures. As in the previous period, metal stocks are being built up.

To sum up, 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 toward Europe. Perhaps the numerous tin deposits in Brittany encouraged these exchanges. The region also faces Cornwall, which has the largest tin reserves in Europe, and which probably supplied the whole of Europe with this metal (Williams et al., 2025). The north-west of France probably played a major role in the transport of goods, including metals, which probably led to the development of a significant regional metallurgy.

CONCLUDING PERSPECTIVES

The programme 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 to identify the many sources of copper used during the Middle and 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 potential continuities in the supply of metal or real ruptures. For the north-west, it would therefore be interesting to analyse MBAa1 objects further to the east of the Armorican peninsula, but also further towards the centre of France, in order to determine the distances over which Welsh copper may have spread. In the same way, it would be necessary to develop the database for the LBA1 period, covering the whole of the Armorican peninsula and even further east. While objects from this period seem to have a composition very close to that of the previous period, at least for the few objects analysed so far, it is also possible that it corresponds to a transition period to the next period, LBAa2, which presents a very clear difference in chemical and isotopic composition from MBAa2. It would also be desirable to be able to analyse all of the rare fragments of copper ingots found in hoards from this period in order to better identify the potential sources of the copper. Finally, for the last period, which corresponds to LBA3b, because of the extensive mixing of metals in the production of bronze objects, the focus should also be on copper ingots, of which there are fortunately many, but which alone have the signature of the ores.

However, these results encourage us to continue this analytical approach with quantitatively significant series that are strategically sampled from a functional, geographical and typochronological point of view. Combined with isotopic analyses of lead, copper, and iron, these data are contributing to discussions on the movement of metal masses across France and, more broadly, across Europe during the Bronze Age.

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