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Traded raw steel: the roman masses from the Saintes-Maries-de-la-Mer wrecks

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Abstract

The metallographic analyses of four steel masses from the SM42 and SM43 wrecks in Saintes-Maries-de-la-Mer, France, confirm that they are raw products that were traded in the Mediterranean area in the same way as semi-finished products or amphorae. The masses were roughly hammered and cut to facilitate cleaning and compacting and are made of highly carburised steel. These masses from wrecks SM42 and SM43 are the only fully carburised materials found in all 45 iron-carrying wrecks from antiquity discovered at this location. This suggests that steel was traded in the Roman Empire in the form of roughly hammered raw materials obtained by cutting large blooms into smaller parts.

1. Introduction

The study of all upstream products in the iron production chain of operations, and not only finished objects, is fundamental to understanding the technical practices involved and the nature of the raw materials traded. A major difficulty lies in the fact that because these intermediate-stage products are destined to be transformed, they are rarely found. This is true regardless of the period or technical area of interest (from Protohistory to the Middle Ages). Despite this difficulty, studies have been conducted relatively recently on intermediate (semi-finished) products, such as protohistoric currency bars (Berranger, 2009) and bipyramids (Bauvais, 2007) and ancient Western Roman bars (Pagès, 2008). It is also in the context of the Western Roman world that we are conducting our study of a product that has not yet been extensively examined: crude masses, or blooms.

In the iron bloomery process chain of operations, the bloom (or crude mass) is the metallic product that is obtained directly in the shaft furnace after the reduction of the ore. It is a raw material that could potentially be exported and traded. But, so far, no evidence of this kind of trade has been provided. The bloom is the first semi-finished product obtained in the chain of operations. It is generally described as shapeless, oval or oblong, with an irregular and jagged surface, covered

with outgrowths and cavities that can be very large and very deep (several centimetres). It is therefore an unsuitable mass for directly forging a finished object. It needs to be compacted and rid of impurities (especially entrapped slag) to provide a mass of forgeable metal, often shaped into bars. As it is never destined to remain in this raw mass form, its discovery is rare and always exceptional.

In 2003, Radomir Pleiner inventoried 370 crude or partially compacted blooms from 90 sites, mainly in Eastern and Central Europe, especially the Carpathian Basin (Pleiner, 2003, 2000). They relate to different periods between the early Iron Age and the 16th century. Of this batch, fifteen artefacts were identified for our period of interest, the Western Roman world. This is because, in addition to crude masses and fragments, the inventory included semi-finished products at an advanced stage of shaping and compacting.

For our current purposes and period of interest, the Roman period, only the ten “split blooms” from Pannonia were considered as crude masses. These split blooms were obtained by being deeply notched, in their centre, with an axe while still hot, dividing them into two equal parts. Two of the split blooms were found in Sopron, one in Lake Hévíz, one in Szalacska, and six in Keszthely Fenékpuszta, all in Pannonia (Hungary) (Gömöri, 1981; Hegedüs, 1961; Pleiner, 2003, 2000; Rozsnoki, 1979; Sagi, 1979). However, their dating remains controversial. The masses from Lake Hévíz and Keszthely Fenékpuszta appear to date from the 5th century. Additional, more recent discoveries, also at forge sites, include two crude masses found in Piani d'Erna in Italy, dating from between 210 BC and 60 AD (Fluzin, 2006), two found at the Entremont oppidum (Aix-en-Provence, France), dating from the second half of the 2nd century BC, and another found at the "La tête de l'Ost" oppidum (Mimet, France), dating from the same period (Fournier and Milcent, 2007). Although the latter three crude masses were unearthed in a Gallic context, they are relevant because they were located in environments that were highly Romanised, directly prior to the Roman conquest and colonisation of Gaul. Whether in the Roman world, or in the Gallic and medieval periods, in the vast majority of cases the crude masses are found at sites dedicated to forging activities, in the workshops where they were worked, but never in areas where ore was smelted. Therefore, these products circulated from the reduction sites to the forging sites. Nevertheless, as yet, no crude masses have been discovered in a circulation context.

All the discovered masses (in Roman and other contexts) show traces of hammering which may have taken place upon removal from the shaft furnace to take advantage of the metal’s thermal inertia. Signs of outgrowths having been flattened onto the surface can often be observed. Flattened surfaces would also facilitate the storage and transport of the masses (Berranger and Fluzin, 2007). The morphology of the Roman masses of Pannonia are distinctive in that they are “split blooms”, masses that have been notched to divide them into two equal parts. In specimens from the medieval period, these notches were also observed and can sometimes be multiple and parallel to each other. One hypothesis is that this practice facilitated the future cutting of the bloom. Another hypothesis is that the notch enabled the internal quality of the metal to be shown during trade (Gömöri, 1981). This practice is also attested in Roman Italy, where one of the Piani d'Erna masses shows a shallow notch of 15mm, which appears to be the first step of a longitudinal cutting (Fluzin, 2006). Cutting the crude masses into smaller pieces does seem to be a prerequisite to the compacting and cleansing of the metal. Since the Roman blooms weighed between 33 and 70 kg upon their removal from the furnace, such volumes would have to be broken up into masses weighing no more than 20 to 25 kg in order to be compacted and shaped (Pagès and L’Héritier, 2020).

Due to their size and weight, blooms are difficult to handle and even more difficult to analyse by metallography. Several sampling strategies have been adopted so far. For the Lake Hévíz bloom, the Szalacska bloom, one Sopron bloom, and five of the blooms from Keszthely-Fenékpuszta, only one

centimetric sample was taken from each, at the edge, in an area where cutting was easy (Hegedüs, 1961; Rozsnoki, 1979). The authors point out that these samples are not sufficient to determine the nature of the blooms, due to their potential heterogeneity. For this reason, this method of sampling was repeated up to six times at different locations for the Sopron and the Keszthely-Fenékpuszta blooms, in order to explore the heterogeneity of the material (Rozsnoki, 1979). More recently, the Piani d'Erna blooms were cut in half lengthwise to obtain an overall macrographic view in one plane and to study representative 10 x 10 cm^2 subsections by metallography (Fluzin, 2006). Similarly, one of the Keszthely-Fenékpuszta blooms was cut crosswise using a water jet and then ten 4 x 4 cm^2 sections were studied by metallography (Török and Barkoczy, 2022).

The metallographic analyses carried out on these Roman masses reveal metal of two different natures: either mainly made of steel or mainly ferritic. All but one of the Pannonia masses are clearly made of steel, although they are heterogeneous in terms of carburisation. The Sopron mass, which was investigated by taking multiple centimetric metallographic samples, consists of two parts. Its lower part is a highly carburised, often hypereutectoid, steel whose carbon content can reach that of pig iron (ledeburite is present). Its upper part is eutectoid steel, decarburised around the edges into ferrite. The lower part of the Keszthely-Fenékpuszta mass, which was preferred for investigation because the upper part did not contain enough metal, is formed of ledeburite with some islands of pearlite (Hegedüs, 1961; Rozsnoki, 1979). In the slice from the same mass, the eutectoid steel observed has decarburised into ferrite at the periphery. Single samples from the eight other Pannonia masses show varied situations, always with a steel tendency. The sections of the Lake Hévíz mass and three of the Keszthely-Fenékpuszta masses are steel with a carbon content close to or higher than hypereutectoid steel. The sections of two of the Keszthely-Fenékpuszta masses and one of the Sopron masses are composed of a mixture of ferrite and steel. The samples taken from the Keszthely-Fenékpuszta mass cut into two parts are all highly carburised (hypereutectoid and pig iron) with the exception of one, which is hypoeutectoid (Török and Barkoczy, 2022). No quenching was observed on these latter artefacts. Only the Szalacska section in Pannonia is ferrite (Hegedüs, 1961; Rozsnoki, 1979), as are the two masses from Piani d'Erna. In the latter two, steel is present only in very small areas, mostly around the larger porosities that created a channel for the transport of gas. In one of these masses, a small part of the microstructural composition was transformed by quenching.

All these masses have the common feature of being very porous. In all the studies it is mentioned that there are very few slag inclusions compared to the number of porosities. The inclusion percentage has not been measured for the Pannonia crude masses. It is estimated to be between 10% and 15% for the Piani d'Erna masses (Fluzin, 2006). This percentage, which was deduced from the macroscopic observation of the whole section, has probably been underestimated. The porosities are centimetric in size and are more or less deformed, depending on the extent of the hammering and their location in the mass. Numerous porosities inside the metal were observed. Near the most hammered areas, they are closed or in the process of closing. Information about the morphology of inclusions is less detailed for the Pannonia masses, which also show signs of hammering, particularly at the periphery (deformed grains, twins, and decarburisation). Close to the periphery, inclusions should be deformed and aligned perpendicular to the hammering direction.

This article presents the complete metallographic study of four raw masses discovered in Roman wrecks off the coast of Saintes-Maries-de-la-Mer (Bouches-du-Rhône, France), on one of the major communication routes between the Mediterranean and Gaul (Pagès, 2014; Pagès et al., 2022, 2011a). This study was placed within the framework of ancient economic history and aims to better understand the mechanisms at work in the trade of raw or semi-finished materials over medium and long distances, particularly with regard to the nature of the products being traded – in this case,

metal. Another objective of this publication is to show all the benefits that an "exhaustive" metallographic analysis of raw materials can bring to the history of techniques, while also opening up new perspectives.

2. Materials and methods

2.1) Context

Between the 1990s and 2020 (Long, 2021; Long and Spada, 2022), a research program on the Rhone delta was conducted by Luc Long to inventory the underwater and subaquatic discoveries off the coast of the Camargue (Bouches-du-Rhône, France). In this context, 43 ancient wrecks were discovered, at the mouth of an old arm of the river, the Saint-Ferréol Rhône (Figure 1). The majority of the ships (31 out of 43) carried metal cargoes, and 23 carried only iron in the form of bars. To date, this is the largest collection of remains of the Roman iron trade. It attests to the importance of this north-south and south-north trade route between the Mediterranean on the one hand and Gaul, Gaul-Belgium and Germania on the other (Pagès, 2014; Pagès et al., 2022, 2011a).

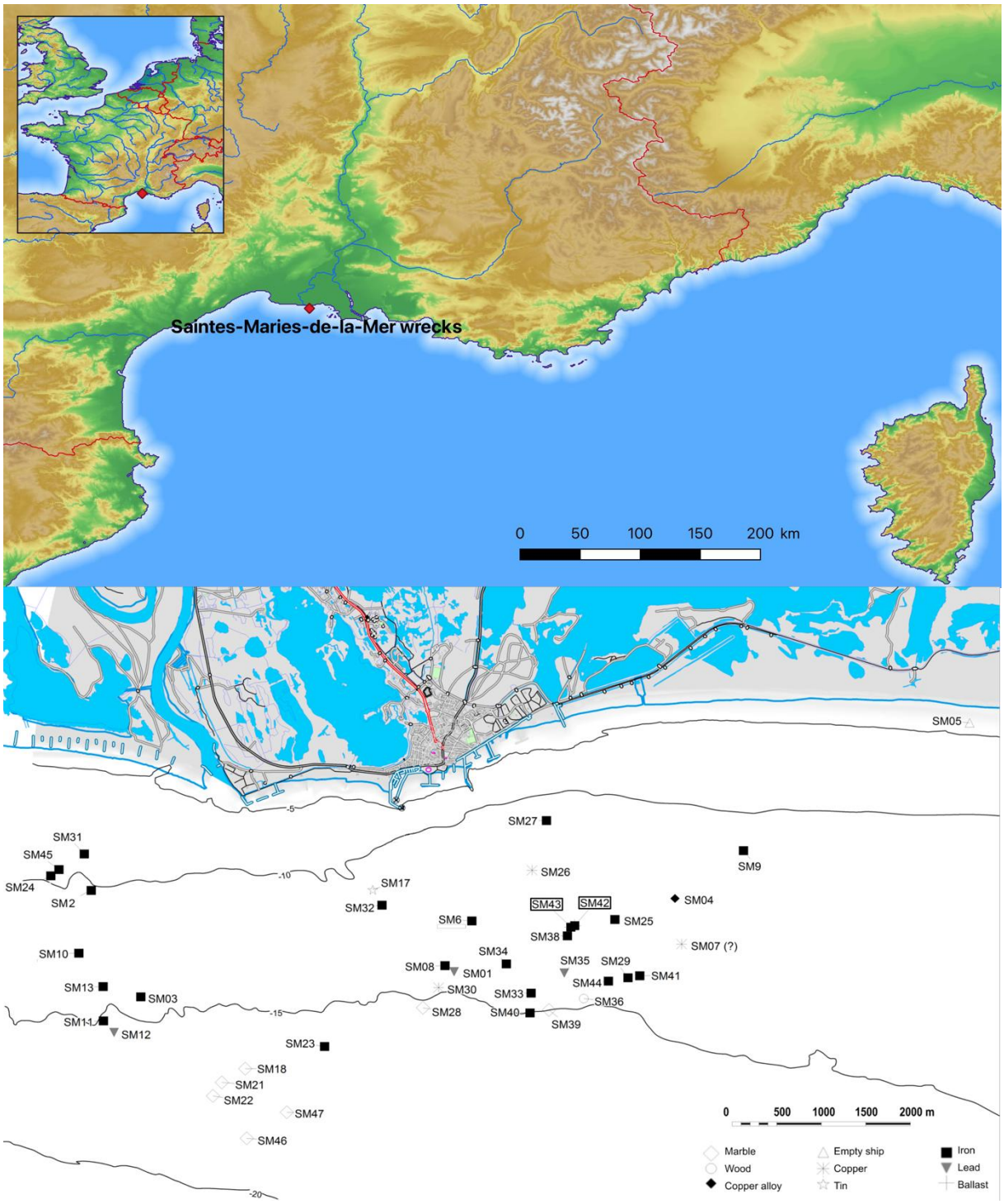


Figure 1 : The ancient wrecks of Saintes-Maries-de-la-Mer (Bouches-du-Rhône, France). The numbers of the wrecks studied are outlined in a box.

As part of this research program, in 2015, a fisherman, Pascal Chabaud discovered two alignments, at a depth of 9 to 10 m, of what he believed to be rectilinear and parallel piles of stones and pebbles separated by about 70 m (Figure 2). In 2016 and 2017, the remains were again examined by Luc Long and his team (Long, 2021; Long and Spada, 2022). Renamed SM42 and SM43, these remains are in fact two similar ship loads, located very close to each other, which may have been part of a convoy before being submerged simultaneously. The remains of a Roman fishing net became attached to SM43 after the sinking, unless the net was part of the ship's original equipment. The net was fitted with a discoidal limestone sinker and a Dressel 20 amphora neck, presumably

reused as a sinker, which dates the wreck to the 1st century AD. Each of the two similar loads consists of a rectilinear pile of extremely heavy and fairly regular round or oblong concretionary iron masses of 30-40 cm in diameter.

Figure 2 : the concretionary masses of the wreck SM43 in the turbid water of the Rhone delta

2.2) Raw materials

From these piles, four masses were collected and studied (Figure 3). Three were from wreck SM42 and one from wreck SM43. The masses were measured in dissimilar states. The measurements of SM42.18.4(29) and SM42.18.2(27) were taken before clearing the concretions and again after the metallographic section had been cut (see below), whereas those of SM43.18.6(25) and SM42.18.5(30) were taken only after clearing. The sides of the masses before clearing range from 27 to 41 cm, whereas they range from 9 to 36 cm after clearing (Table 1). The difference is even greater for their weights, which range from 35 to 54 kg before clearing and from 11 to 25 kg after clearing. The uncleared masses are large, more or less oblong spheres covered with marine concretions (Figure 3). The two cleared masses – SM42.18.5(30) and SM43.18.6(25) – have numerous protuberances and cavities visible on the surface, indicating that the material is still in a very rough state. The SM42.18.5(30) mass is elongated and two of its sides seem to have been flattened by hammering, while the SM43.18.6(25) mass is spherical in shape, but some hammering marks are visible in different places on its surface.

Table 1: Dimensions of the studied masses

	Before clearing of concretions				**After clearing** (max. dimensions)			
Sample Number	**L(cm)**	**l(cm)**	**e(cm)**	**m(kg)**	**L(cm)**	**l(cm)**	**e(cm)**	**m(kg)**
SM43.18.6(25)	/	/	/	/	21	21	12	11
SM42.18.5(30)	/	/	/	/	36	14	12	16
SM42.18.4(29)	37	30	27	35	13	11	9	13
SM42.18.2(27)	41	30	32	54	23	22	14	23

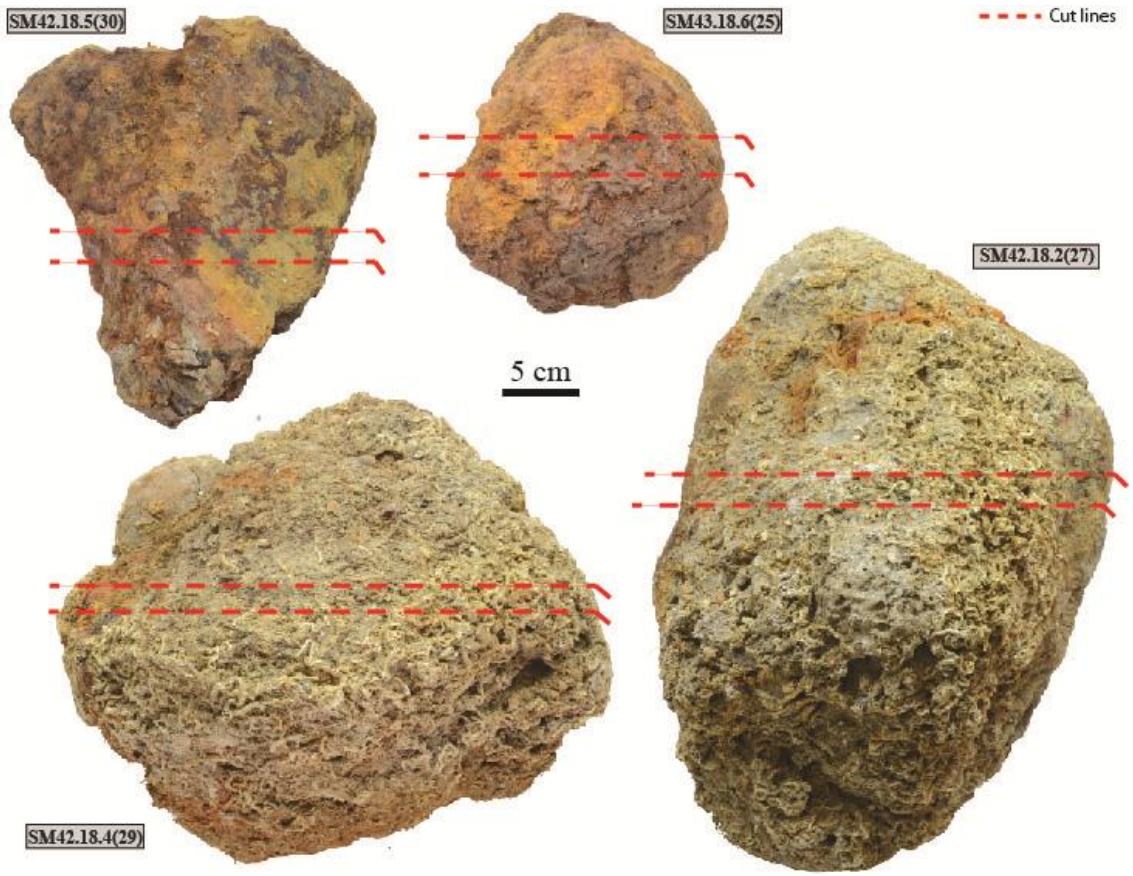


Figure 3: Masses retained for study, from the SM42 and SM43 wrecks at Saintes-Maries-de-la-Mer : SM42.18.5(30) and SM43.18.6(25) after clearing marine concretions and SM42.18.4(29) and SM42.18.2(27) before clearing. Photo credits: J-C Méaudre.

2.3) Methodology

To take into account the potential heterogeneity of the material, a 15 mm-thick slice was cut crosswise through the middle of each mass to obtain representative cross-sections that could be quite wide. A band saw was used, with lubricant and slow velocity, to reduce heating. It is important to notice that the band saw was the only way to cut these masses, due to their thickness. The obtained sections were 14 x 12 cm^2 and 21 x 12 cm^2 for SM42.18.5(30) and SM43.18.6(25), respectively. It was therefore necessary to reduce their size in order to meet the constraint imposed by the polishing equipment: a maximum of 12 x 12 cm^2. After a macrographic study, following an approach already published (Pagès et al., 2011a, 2011b, 2008), representative sections were taken, which were 9.6 x 10 cm^2 and 10 x 13 cm^2, respectively. The sections of the two other, smaller, masses were studied in their entirety. For SM42.18.2(27), however, it was necessary to divide the initial section into two parts: 13 x 7 cm^2 and 9 x 7 cm^2. There was no need to divide the SM42.18.4(29) section, which was 11 x 9 cm^2.

The micrographic sections were moulded in resin, grinded under water using silicon carbide abrasive papers (grade 80 to 1200), and then polished using 9, 3, and 1µm diamond suspension under ethanol. Metallographic observations were made before and after chemical etching (Nital reagent) under optical microscope (bright field reflection), using a ZEISS Imager A2 Vario Axio microscope coupled with an Axiocam 305 colour camera controlled by ZENcore software. Photographic coverage of the entire surface of the polished section was produced at x50

magnification using a motorized stage. These images were then assembled to provide a metallographic view of the entire section. For characteristic areas, micrographs at different magnifications (x100 to x1000) were also taken. Oberhoffer etchings were not carried out because their interpretation is impossible in carburized areas, as it is the case here (see below).

Traditional metallographic analysis along with image processing and analysis made it possible to obtain quantitative data. One type was the inclusion percentage (%Inc), which is the ratio of the number of pixels corresponding to inclusions and porosities to the number of pixels corresponding to the total surface of the sample (L'Héritier, 2007; Pagès et al., 2011b). The percentage of surface area occupied by each type of iron-carbon alloy grade was also determined.

As far as possible, local Vickers microhardness measurements completed the study to confirm some microstructures and potential thermal treatments. Qness A10+ microdurometer was used with 200g load.

3. Results

At a macroscopic scale, the sections all show numerous porosities, visible to the naked eye, up to centimetre size, and some slag inclusions (Figure 4). In the SM42.18.5(30) and SM42.18.4(29) masses, about 2 cm of charcoal, trapped in the metal matrix, is even visible. Microscopic observation also reveals a large number of porosities, ranging in size from 50 µm to 500 µm. There is no preferential orientation of the inclusions or porosities. All are very slightly deformed and evenly distributed over the entire section. The amount of slag inclusions compared to porosities is very low. The inclusion percentages vary significantly but are consistently high, between 20 and 47% (Table 2). It should be noted that the walls of the pores are often lined with corrosion products.

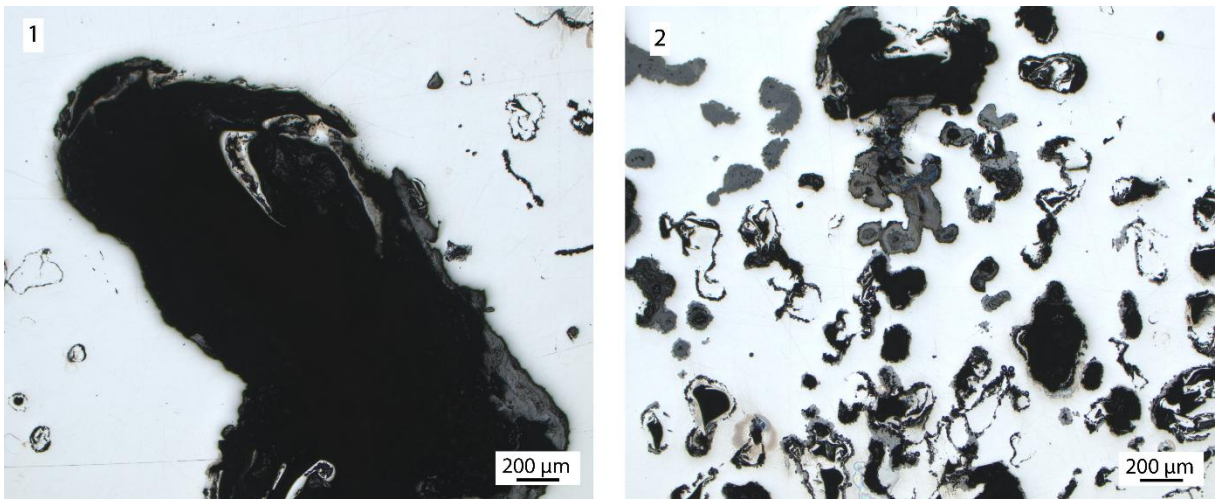
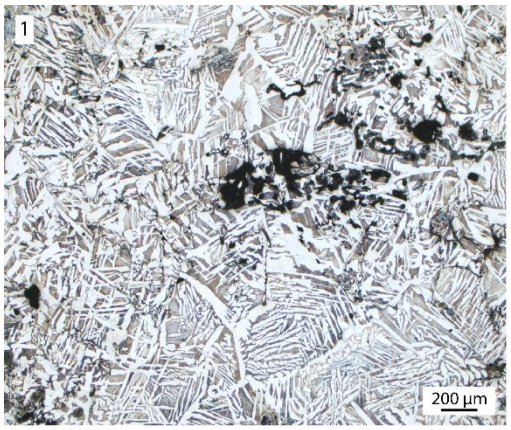


Figure 4: Mass SM42.18.4(29). 1) Open and slightly deformed porosity with metal folds. 2) Multiple open or closed porosities with metal folds, surrounded by corrosion.

As far as their microstructure and composition are concerned, the masses of the wrecks at Saintes-Maries-de-la-Mer are all predominantly made of steel. Several cases can be distinguished (Figure 5). The SM42.18.5(30) mass reveals a section that is entirely composed of hypereutectoid steel, characterised by the presence of cementite needles in a pearlitic matrix (Figure 5.6). It is the most carburised of the four masses studied. The SM42.18.4(29) mass is also highly carburised. Throughout the section, the steel is in the form of fine pearlite colonies, indicating rapid cooling of the material, and even sometimes in troostite form (Figures 5.4). Local microhardness measurements in these same fine pearlite colonies area, for the SM42.18.2(27) and SM43.18.6(25) masses, confirm

the rapid cooling. In these areas, the hardness values are between 250 and 300 HV (Figure 5). That is slightly superior to the expected values for pure perlite, around 220 HV, obtained in equilibrium state conditions. Around the porosities, the metal is slightly decarburised, reaching levels of around 0.3% carbon. In these areas, the presence of acicular ferrite (Widmanstätten structure) shows non-equilibrium cooling. Hypereutectoid steel structures are found in different places, and ledeburite is visible in the core of the mass. The SM42.18.2(27) mass is highly carburised, except in the periphery, where carbon contents are lower and can be as low as about 0.2%. In these areas, the pearlite is lamellar, but Widmanstätten structures have been identified. In the rest of the section, the pearlite is in fine colonies. The SM43.18.6(25) mass stands out from the others, as it is somewhat less carburised. Its core has a low-carbon ferrito-pearlitic zone (0.2-0.3% carbon) with lamellar pearlite and, again, Widmanstätten structures (Figure 5.1), but the carbon contents are higher and homogeneous in most of the section as well as in the periphery, with zones of fines pearlite colonies and hypereutectoid steel.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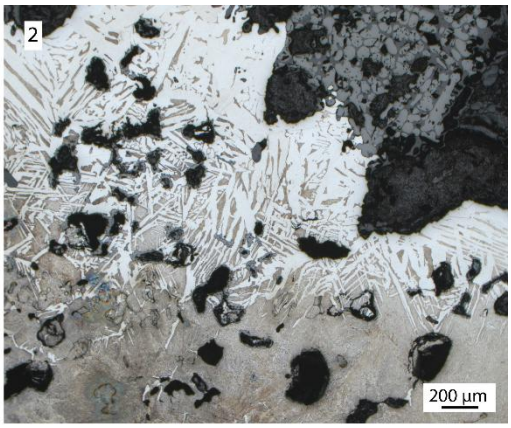
200 µm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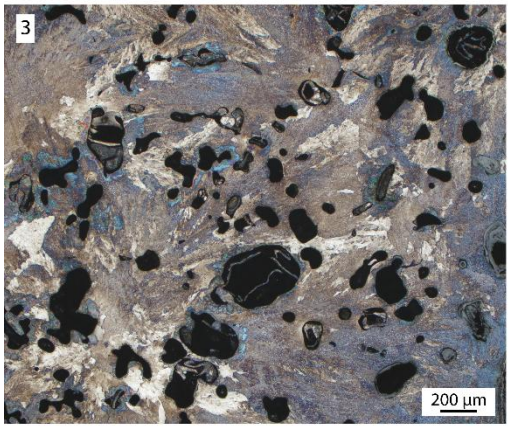
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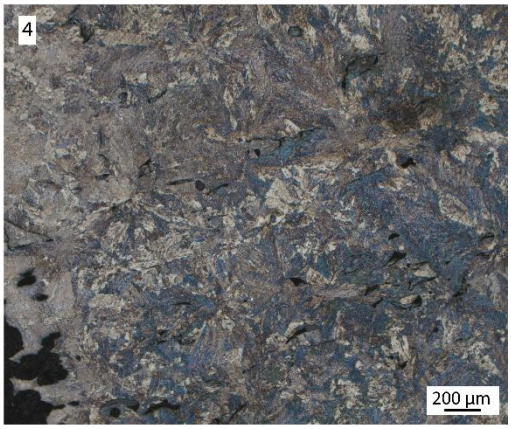
200 µm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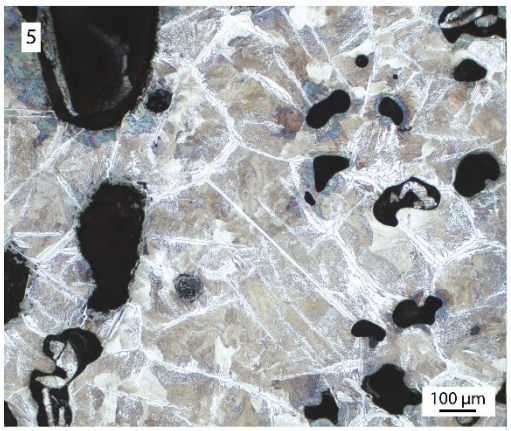
200 µm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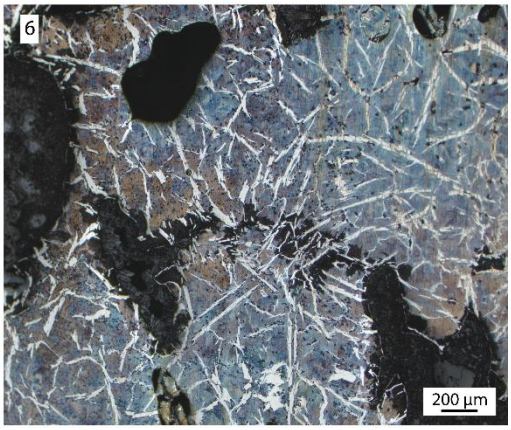
100 µm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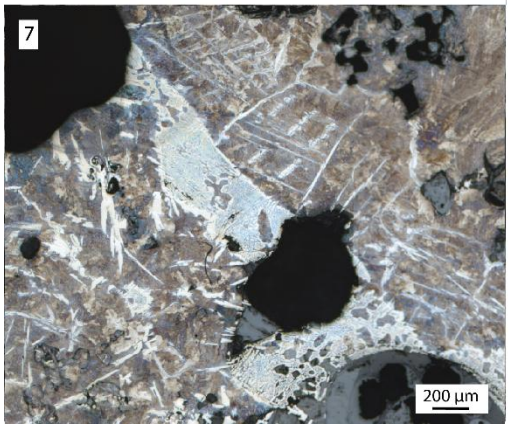
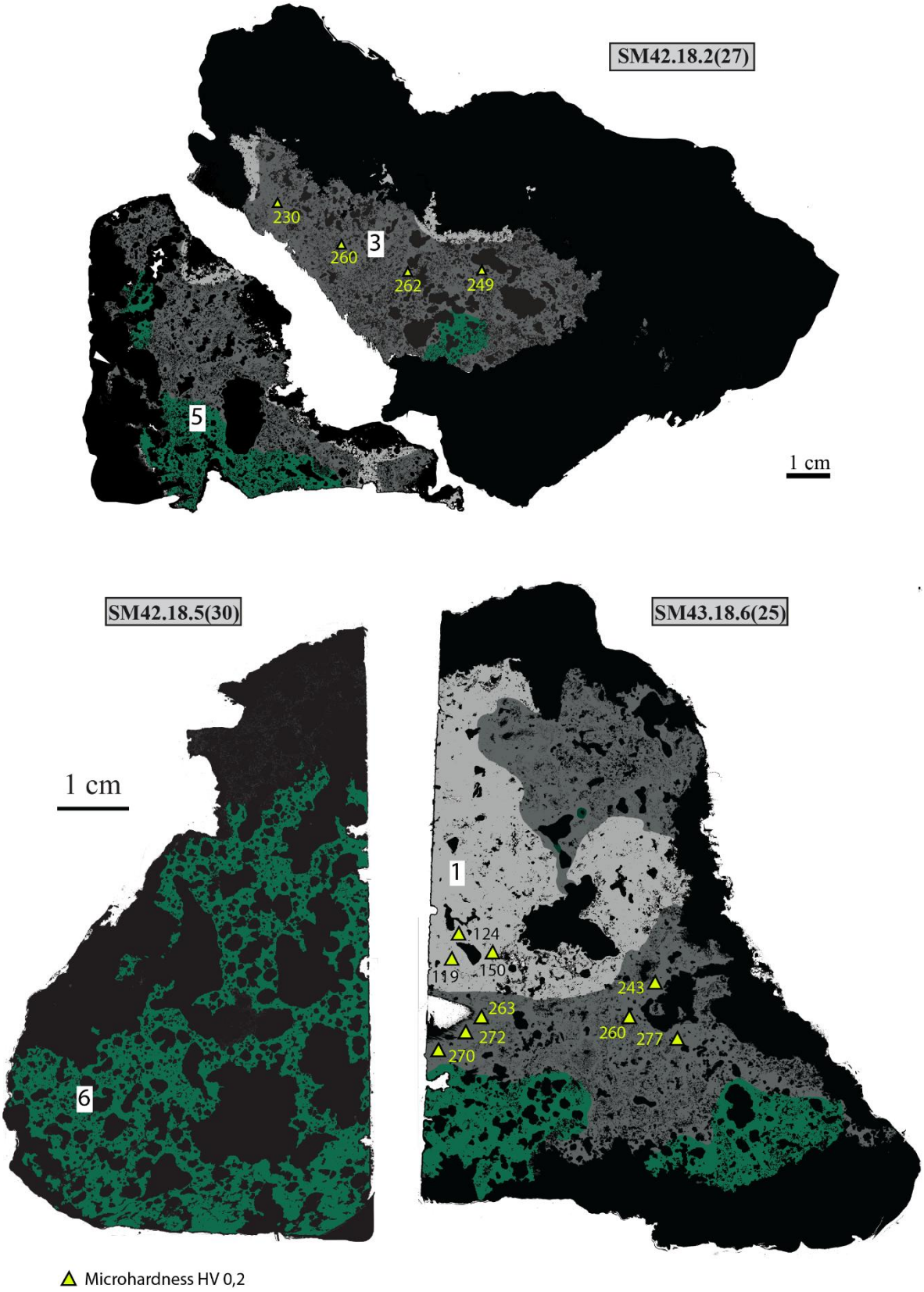
200 µm


7
200 µm


SM42.18.2(27)
230
260
262
249
3
5
1 cm
SM42.18.5(30)
1 cm
6
SM43.18.6(25)
1
124
119
150
243
263
272
260
277
270
Microhardness HV 0,2

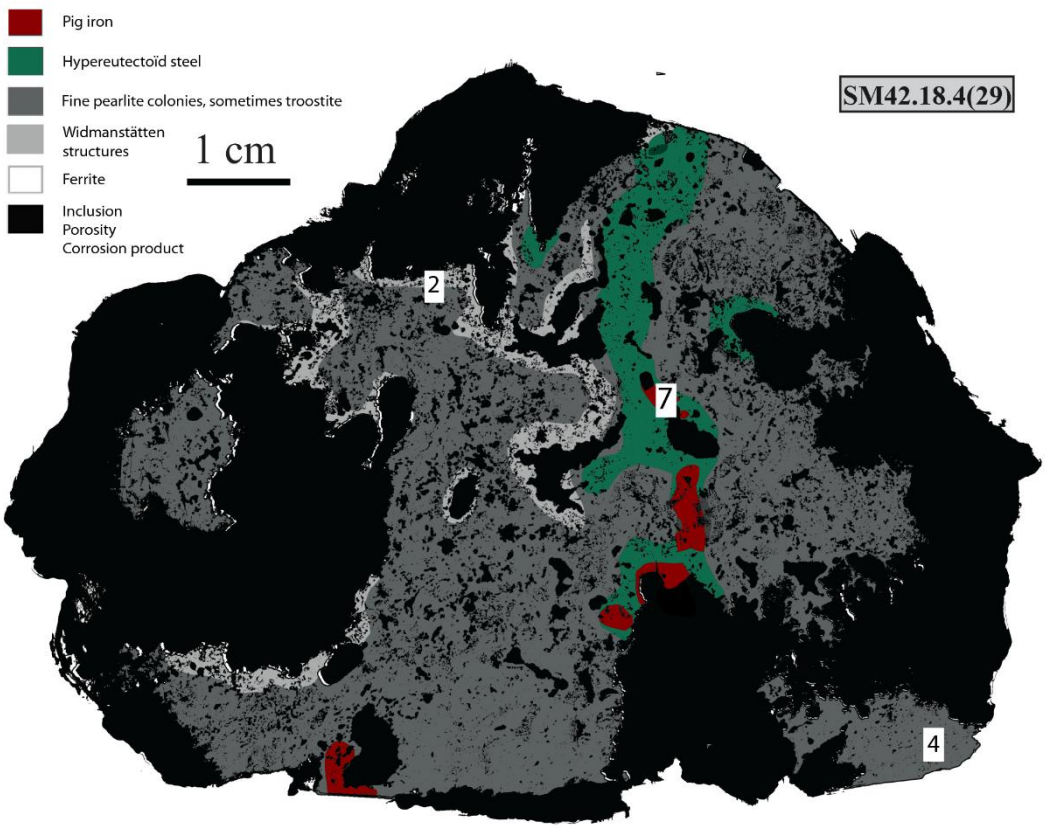


Figure 5: Distribution of the different microstructures for the studied masses. Micrographs: 1) Ferrito-pearlitic area in SM43.18.6(25). 2) Graduation of carbon content in SM42.18.4(29), from a ferrito-pearlitic structure at about 0.2% to a much more carburised zone with acicular ferrite showing non-equilibrium cooling, peripheral decarburisation.3) Fine pearlite in SM42.18.2(27). 4) Troostite in SM42.18.4(29). 5) Hypereutectoid steel, cementite needles, pearlitic matrix in SM42.18.2(27). 6) Hypereutectoid steel in SM42.18.5(30). 7) Ledeburite in a hypereutectoid steel matrix in SM42.18.4(29).)

Based on the different microstructures observed on the four raw masses, six classes were defined: fully ferritic (C% ≤ 0.02), low carburised ferrito-pearlitic steel (0.02≤ %C ≤0.3), relatively carburised Widmanstätten structures, fine pearlite (eutectoid steel), hypereutectoid steel (0.8≤ %C ≤2.1) and pig iron (2.1≤ %C). For each of the masses, the percentage of the surface occupied by these different classes is given in Table 2.

All four masses show a significant percentage of carburised surfaces and never pure ferrite. Moreover, fine pearlite colonies and sometimes troostite was observed in all four masses. This structure is evidence of rapid cooling of the material after a maintain in the austenitic domain. This type of structure was observed both in the core of the masses and at its periphery. This is also the case for the hypereutectoid steel structures observed in the four masses. The proportion of these hypereutectoid structures differs between the masses. While they constitute about 15% of the surface for the SM42.18.4(29) and SM43.18.6(25) masses and 30% of the SM42.18.2(27) mass, they make up 100% of the SM42.18.5(30) mass. Cementite needles are also visible in the most corroded areas of these masses, at the periphery.

Table 2: Microstructures observed on the masses

Microstructures \ Sample N°	SM43.18.6(25)	SM42.18.5(30)	SM42.18.4(29)	SM42.18.2(27)
%Inc	22	47	27	34
Surface% of ferrite	0	0	0	0
Surface% of low carbon ferrito-pearlitic steel (0.02≤ %C ≤0.3)	0	0	0	0
Surface% of Widmanstätten structures	34	0	8	5
Surface% fine pearlite colonies, sometimes troostite	50	0	79	63
Surface% hypereutectoid steel	16	100	12	32
Surface% of pig iron	0	0	1	0

4. Discussion

The evidence found on the surface (flattening) or inside (folds) of each of the masses suggests that they have all been hammered in order to compact them. However, the porosities are only slightly deformed, if at all, and are still very numerous. The hammering was therefore of a preliminary nature, superficial and not very intense. For the SM42.18.2(27) mass, the peripheral decarburisation could indicate that this hammering phase was carried out after a heating phase in an oxidising atmosphere.

If we do not take peripheral concretions into account, all the Saintes-Maries-de-la-Mer masses have a weight between 11 kg and 23 kg, lower than the whole masses from Piani d'Erna (Fluzin, 2006), from Pannonia (Gömöri, 1981; Hegedüs, 1961; Rozsnoki, 1979; Sagi, 1979) and the others known for the medieval period (Domergue, 2004; Fluzin, 2006; Leroy et al., 2000; Pagès and L'Héritier, 2020). Therefore, it cannot be excluded that the masses of the SM42 and SM43 wrecks were derived from the cutting of larger masses, in accordance with the practice identified for one of the whole raw masses from Piani d'Erna (Fluzin, 2006) and those from Pannonia (Gömöri, 1981; Hegedüs, 1961; Rozsnoki, 1979; Sagi, 1979). It has been shown that during antiquity, as in the Middle Ages, the raw masses worked in forges to be compacted and purified generally do not exceed 20/25 kg, due to technical, energy and practical constraints (Pagès and L'Héritier, 2020). Thus, the masses from the wrecks of Les-Saintes-Maries-de-la-Mer were, as it is, able to be directly compacted and cleansed in the forge.

The four crude masses from the SM42 and SM43 wrecks are all composed of steel. This is a remarkable point. They are among the few examples of masses made entirely of very carburised microstructures. A similar composition could be found in four of the Keszthely-Fenékpuszta masses (Gömöri, 1981; Hegedüs, 1961; Rozsnoki, 1979; Török and Barkoczy, 2022), but more exhaustive analyses of the material are needed for three of them, from which only one sample was observed. A mass half made of carburised microstructures (the other half being ferritic) is known from the Gallic period at Entremont (Berranger and Fluzin, 2007). Also in Gaul, this type of structure has been observed in small pieces of metal, whose mass does not exceed 200 g: notably at the Madeleine II site (Clermont-l'Hérault, Hérault, 4th-5th century) and at the Roc de Pamplona site (Argelliers, 5th century) (Pagès, 2008; Pagès et al., 2005). Small steel fragments have also been found in Pannonia, for example, in the Roman camps of Strebersdorf (Pagès et al., 2020), at the Semlach/Eisner site

(Austria, 1st century BC - 4th century AD) (Birch, 2017), and at the Magdalensberg site (Austria) (Straube, 1996). The latter fragments are very highly carburised steels, sometimes with a hypereutectoid or pig iron structure.

It is worth noting that examples of raw masses made predominantly of significantly carburised microstructures are rare. Furthermore, archaeological bars made entirely of steel are very rare for the Roman world, if not non-existent. When all the studies are combined, the analyses of the sixty bars from the wrecks of Saintes-Maries-de-la-Mer show that none are entirely made of carburised microstructures (Gosselin, 2021; Pagès, 2008; Pagès et al., 2011a). Significantly carburised structures (> 0.3 % of carbon) never occupy more than 50% of the observed surface of the material. As a result, the Saintes-Maries-de-la-Mer raw masses studied here constitute the largest batch of all-steel material traded, even more so if one assumes that all the cargo masses of the SM42 and SM43 wrecks are predominantly made of steel.

How can we explain the trade of steel in the form of raw and probably cut masses and not in the form of bars as was common in the Roman world for iron? The decision to not shape the steel prior to its trade could be explained by a desire to avoid decarburisation, which often occurs during the oxidising heating phases that are carried out to compact and purify the metal, and to reduce the loss of material during its compacting and purification. It is estimated that between 30 and 50% of the purified mass ends up as scrap after this phase (Serneels et al., 2004). The percentage of loss could be higher for masses made of steel, which is more brittle, harder and less ductile, and therefore more difficult to forge. According to this reasoning, during antiquity, steel materials could have been exported in the form of roughly hammered and cut masses to be transformed later by skilled craftsmen. This, at least, is what the SM42 and SM43 wrecks from Saintes-Maries-de-la-Mer suggest.

The small, loosely compacted steel fragments found at forge sites are often interpretated as fragments of crude masses that were deliberately abandoned because they could not be worked: unusable rejects (Birch, 2017; Török and Barkoczy, 2022). With the discovery of the steel masses from the SM42 and SM43 wrecks, the interpretation of these small steel fragments could be revisited. They would simply be leftover pieces of raw material that had been traded to be compacted and cleansed at the site, for use in the manufacture of objects (or parts of objects) requiring steel. These “rejects” may therefore be scraps just like any other type of scrap material from the forging process – the remains of raw or almost raw masses of imported steel.

The steel masses of SM42 and SM43 have all undergone post-smelting treatments: mechanical treatments related to their cutting and slight compacting. Moreover, all the masses analysed have undergone rapid cooling, outside the conditions of thermodynamic equilibrium, as shown by the systematic presence of a large proportion of fine pearlite colonies and troostite at the periphery and in the bulk of the materials. Nevertheless, no martensite was observed. This such fine pearlite structures might form when the hot steel mass was taken out of the furnace and left to cool outside.

5. Conclusion

The metallographic analyses carried out on the four steel masses from the SM42 and SM43 wrecks of Saintes-Maries-de-la-Mer (Bouches-du-Rhône, France) confirm that they are raw products that circulated within the framework of the great Mediterranean trade in the same way as semi-finished products or amphorae. These masses were roughly hammered in order to compact them slightly. They were also very probably cut to facilitate their future cleaning and compacting. They are mainly made entirely of highly carburised steel. This type of structure had already been found in centimetric and peripheral samples of the Roman crude masses from Hungary. In view of these observations, it is possible to affirm that crude masses made of steel were traded. Moreover, these masses from wrecks SM42 and SM43 are the only ones fully constituted of carburised material from

among the 45 iron-carrying wrecks from antiquity discovered at this location. All the other bars that were analysed are ferritic, only partially made of steel, or made of phosphorous iron, but never entirely constituted of carburised microstructures. It can therefore be seriously assumed that steel was at least partly traded in the Roman Empire in the form of roughly hammered raw materials probably obtained from larger blooms that were cut into smaller parts.

The identification of traded raw masses of steel raises the question of their origin. Do they all come from the same production area? Were they collected before being marketed in order to provide a supply of materials with similar qualities? Future studies of the provenance of the SM42 and SM43 masses from Saintes-Maries-de-la-Mer should provide some answers to these questions.

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Declaration of competing interest

The authors declare that they have no competing financial interests or personal relationship that could have appeared to influence the work reported in this paper.

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