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Northwestern Iberian Tin Mining from Bronze Age to Modern Times: an overview

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Abstract

The northwestern Iberian Peninsula has been well known for its mineral wealth since classical times, including for gold and for tin. In fact, the Iberian tin belt is the largest in western Europe (covering an area of c. 200,000 km²), containing tin deposits that were accessible from ancient times. Nevertheless, few archaeological studies have been dedicated to ancient tin mining in the region, unlike gold mining, for which major mining complexes are known from Roman times (e.g. Las Médulas, N Spain, and Três Minas, N Portugal). In this paper, evidence for tin mining in different periods, from the Bronze Age to modern times, is discussed, based on selected case-studies, using various approaches developed for the study of ancient and modern tin mining, by members of the present Iberian Tin Research Group. An introduction to the geographical and geological contexts of Iberian tin, and the history of investigation on Iberian tin mining, is included.

1 Introduction

In his chapter dedicated to Iberia, Roger Penhallurick (1986, 95-103) stated that the Iberian tin belt is large and three times the length of the Cornish-Devonian field. In fact, the Iberian tin belt is not just much larger than the Cornish-Devonian field, it is the largest extension with tin ores available in Western Europe. Nevertheless, its importance has not been widely debated in archaeological historiography, resulting in some periods of strong affirmation, and others of almost total invisibility, depending on historical context at particular times, or on specific interests of individual researchers. Unlike the intensive and detailed studies on Roman gold mining and Pre-Roman copper mining that have taken place, tin mining has not received a similar level of research commitment, particularly in Iberia. This runs counter to the role that tin is known to have played in ancient times: knowing that tin ores are not evenly distributed in the European territory, tin must have had far-reaching exchange routes needed for bronze fabrication, particularly to Eastern Mediterranean areas where tin sources lack.

Reasons often given for the lack of research in ancient tin mining are that early tinworks supposedly exploited mainly alluvial deposits. This was a system of mining that is believed to have left very few remains, if any, whereby more recent mining works (as for wolfram and tin in the 20th century) destroyed earlier evidence, particularly in the case of mining in primary deposits. An additional reason for the low profile of tin mining in archaeological literature might be that field evidence of many secondary placer mining works have, traditionally, been attributed to gold, but could have also been for tin. In fact, since tin and gold are present in the very same districts, and gold mining has been far

more appealing to researchers, few proposals as to the possibility of tin mining are presented in archaeological discussions.

Thus, the supposedly small impact of ancient tin mining on the landscape might be due to a lack of detailed/focused investigations, or a poor understanding as to the nature of the Iberian tin resources itself. In truth, tin ores are distributed throughout a large area of Iberia; they are easily available at surface and lower depths, and can be mined by very simple techniques. Based on numerous descriptions by previous visitors to the tin works in Iberia, Penhallurick (1986, 97, 100) stated that 'enough has been said to indicate that alluvial tin and outcropping lodes are abundant ... it is clear that the tin is common at or very close to the surface ... differing from the alluvials of Cornwall'. This particular morphology of Iberian tin deposits could have generated rather superficial exploitation, easily erased in the landscape. Clearly, a combination of factors can contribute to the present scarce knowledge of the extent, intensity, and chronology of tin mining in Iberia.

Despite the lack of focused studies, there are some positive factors showing the potential for ancient Iberian tin mining. The Iberian tin belt, along its large extent, has a high density of mineralization available, following criteria suited for exploitation in the prehistoric and Roman periods, which are, according to O'Brien (2015, 13-15) outcropping deposits (which can include placers, as they are visible from the surface) with a grade high enough to enable ore recovery with manual or simple mechanical processes. Also, the existence of numerous settlements with significant evidence of metallurgical activity during the Bronze Age and Iron Age, in areas rich in tin, suggests that deposits in those areas were exploited since these early periods. Examples are the *Baiões/ Santa Luzia* cultural group (Late Bronze Age, Central Portugal), where bronze metallurgical remains have been recorded (Senna Martínez 2011, 2013) some of which are presented in more detail below. Also, the Iron Age hillforts (called *castros*) in Northern Portugal and Galicia (NW Spain), from which the case-study of Carvalhelhos will also be detailed below. In addition, some classical sources (amongst others: Pliny the Elder *Naturalis Historia* XXXIV) mention the *Lusitania* and *Gallaecia* regions as the origin of tin for the Mediterranean areas, and both regions correspond to the Iberian tin belt area.

However, the richness of Iberia in tin seems to have been totally forgotten, at least among the rest of Europe, during the medieval period. In fact, Iberian tin-rich mining provinces only become 'known' again in international circles by the end of the 17th and 18th century, mostly with the tin mines in the mining province of Monterrei (Ourense, Spain) (Meijide Pardo 1963). Later, from the beginning until the mid-20th century, numerous mines were opened for wolfram and/or tin along the extension of the Iberian tin belt, resulting today in numerous abandoned mining complexes. From these latest mining works, the rush for tungsten during the two world wars has been the most attractive and investigated aspect, leaving the tin mining almost invisible in the more recent historiography.

Aware of the great lack of archaeographic records on ancient tin mining, The Early Tin Iberian Group was formed in 2010 as a synergy between researchers from several institutions in Spain, Portugal and France, sharing an interest for tin in antiquity. Being an interdisciplinary group it aims to broaden the study of ancient tin in North West Iberia in a variety of directions (Fig. 1), such as documentary research, archaeometallurgical analysis and field survey to recognise ancient mining works and sample cassiterite, relying on the expertise of each researcher and institution. The group also integrates ethnological data to generate interpretative models and perform experiments with the aim of producing tin and bronze from Iberian ores. Besides the present authors, other researchers also contribute to focused studies; some of them have already been published, while others are in different stages of development.

In this paper, will be presented an introduction to the geographic and geological contexts of tin in the Iberian Peninsula, as well as a review of past archaeological investigation on tin mining since the 18th

century. Some selected case-studies related to Iberian tin mining will be presented and a discussion of some investigation approaches. Some of the case-studies are extracted from past published works by other authors, while others are part of on-going works by the present authors.



Fig. 1: Multidisciplinary approaches to ancient tin research

2. Geographical and geological contexts

The Iberian Peninsula is a large territory with almost 600,000 km², administratively divided between two countries, Spain and Portugal. The peninsula has a long coastline, bordered on the southeast and east by the Mediterranean Sea, and on the north, west and southwest by the Atlantic Ocean. The peninsula is separated from the rest of continental Europe by the Pyrenees Mountains, to the northeast.

The Iberian territory is predominantly formed by plateaus at the centre and in southwestern areas, with major mountain systems in the northwestern, northern and southeastern areas. The southern extremity is separated from the African coast by less than 20 km at the Strait of Gibraltar, known in antiquity as 'Pillars of Hercules'. This strait also separates the Mediterranean Sea from the Atlantic Ocean.

Environmentally, the Peninsula can be divided into two regions, one at the north and northwest with Atlantic climate influences and an Arctic flora, and another at the south and southeast with Mediterranean climate influence and a Mediterranean flora (Sánchez Goñi et al. 2002).

The Iberian coast has been inundated over time, since the Last Glacial Maximum (LGM) to c. 3,500 years BP when the present sea level was reached. Prehistoric and historical sea level variations are little known, but it appears that coastline shaping was controlled mostly by a climatically biased balance between erosion and supply of terrigenous sediments to the shore, as well as by deforestation and increasing agricultural land use in more recent times, resulting in a series of minor

transgressions and regressions (Dias et al. 2000).

The Iberian tin belt is located in the northwest region, covering an area of c.200,000 km², in an extension of c. 600 km northwest to southeast (Fig. 2). It is the largest area with tin available in Western Europe. All major rivers that flow through the Iberian tin rich areas follow a path westwards (e.g. Tejo, Mondego, Douro, Minho) with their lower course in the Portuguese territory, reaching the Atlantic coast and not the Mediterranean.

Studies of fluvial navigation have shown that until as recently as the mid-19th century, most of the major rivers were navigable several kilometres inland, in some cases up to 200 km, as the case of the Douro and Tejo rivers (Blot 2003). The strategic importance of the fluvial routs in past times was significant, and it would make interior tin sources very accessible to long distance maritime trading (Fig. 2). Several Phoenician settlements are known along the Iberian Atlantic coast, most situated at the head of past marine embayments or on estuary margins with easy access to the sea. This type of settlement exhibit a topographical criterion familiar from Phoenician trading-stations and merchant outposts in the Mediterranean (Wachsmann et al. 2009).

The relationship between the tin-tungsten ore deposits and magmatism, is widely recognized in the general context of the European Variscan Belt metallogenic provinces. In western Iberia, the primary Sn-(W) ore deposits, possibly exploited in ancient times, are located almost only in the Central Iberian Zone (CIZ) and Galicia-Trás-os-Montes Zone (GTMZ). Embedded in the Hercynian cratonic block these two paleographic units are differentiated by Precambrian, predominantly mafic-ultramafic rocks, and Silurian-Devonian metasediments (GTMZ), or neoproterozoic to carbonic metasedimentary and metavolcanic rocks (CIZ) (Fig. 3)¹.

In the two zones, the primary Sn-W ore deposits are spatially associated to granitoids emplaced mainly during and following the ductile deformation phase D3 of Namurian–Westphalian age after the collision between Gondwana and Laurentia. These granites can be split in two: mica syntectonic granites associated with migmatites, and the biotite post- tectonic granites type. The Sn deposits are related to the first type of granitic rocks that are slightly enriched in Sn. The hydrothermal characteristic of the ores is clear and the role of magmatic fractional crystallization is demonstrated by the granite–aplite/ pegmatite sequence. Besides some contributions of meteoric or metamorphic fluids, the ore results mainly from the interaction of residual Sn-rich fluids, separated from the crystallizing magma, with some parts of the cooling granite or metasedimentary wall rocks.

The mineralogy of the aplite–pegmatite veins and sills are compatible with a granitic rock. The accessory minerals comprise beryl, tourmaline, wolframite, uranium and rare earth elements phosphates, Nb- Ta oxides and Li minerals. The only important Sn mineral is cassiterite.

¹ Besides the Iberian tin belt which is associated with Hercynian magmatism, in Sierra de Cartagena district (SE Spain) are the only Tertiary tin deposits in Europe. These deposits were discovered in the turn of the 19th to the 20th century. Up to present no vestiges of old mining works have been identified or were documented during the 20th century exploitations. The ore appears in veins related to volcanic and subvolcanic rocks and also in stratiform deposits in carbonate levels which it impregnates. The mineral paragenesis of the former is cassiterite-pyrite-galena-sphalerite-iron oxides, and the latter cassiterite-stibnite, and possible carbonates of Pb, Zn and Fe. Gravimetric concentration of these ores is difficult due to their fine grain size (Marina, 1987: 84)

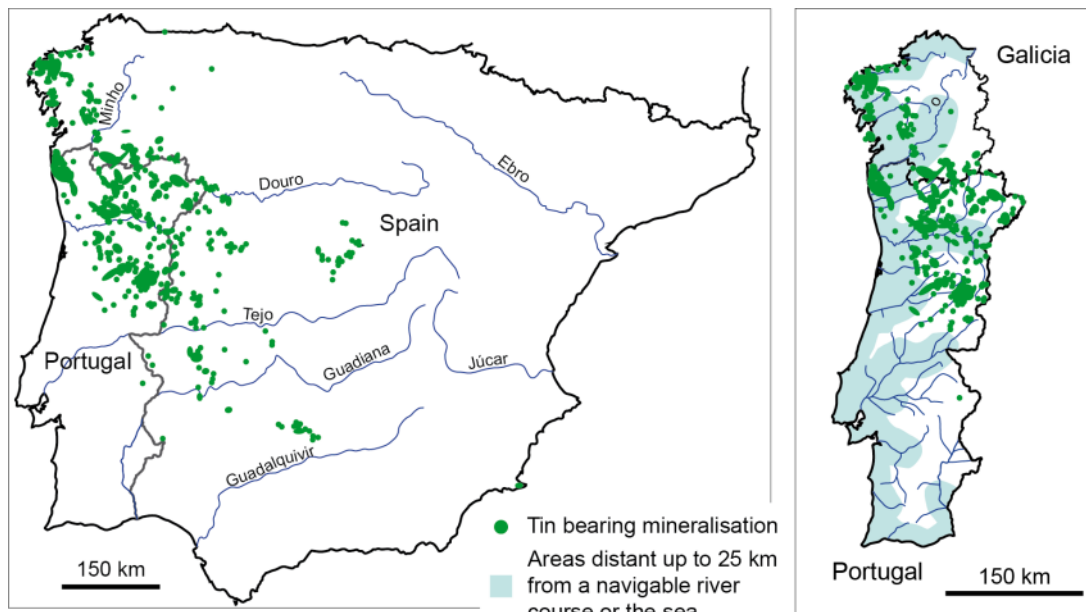


Fig. 2: Left: Tin bearing mineralisation in Iberian Peninsula (Sources: SIORMINP, IGME). Right: Limits of navigability until the mid-19th century in Portugal (adapted from Blot 2003).

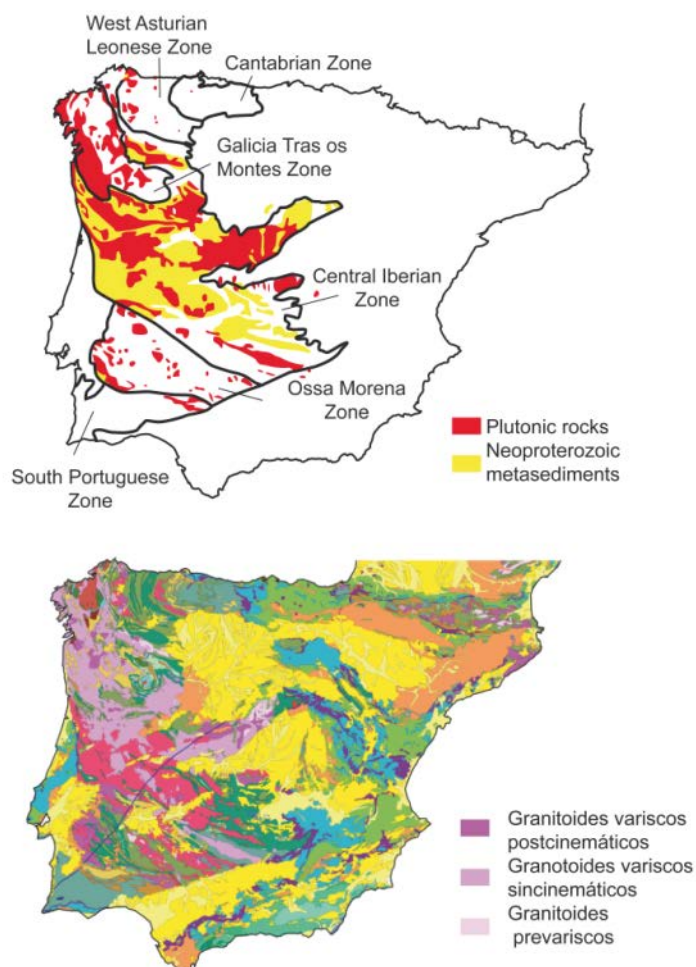


Fig. 3: Geological map of the Iberian Peninsula (adapted from Ribeiro and Sanderson 1996; Vera 2004).

3. The history of investigation

3.1. From the 18th to mid-20th century: between classical texts and geological prospection

The northwestern Iberian Peninsula has been well known since classical times for its mineral wealth, which includes gold and tin. Authors such as Diodorus Siculus (*Bibliotheca historica*), Strabo (*Geographica*, III) or Pliny the Elder (*Naturalis Historia*, IV & XXXIV) all described and wrote about it. They all agreed that the origin of tin for Mediterranean countries was in the extreme Occident, but they kept their descriptions at a regional level, referring to western Iberia (Lusitania and Gallaecia), southern Great Britain and the Cassiterides Islands² (Fig. 4) but do not refer to any specific mine. The Cassiteride Islands, somewhere in the Atlantic Ocean, have so far proved impossible to locate, but this mystery was also the triggering factor for the beginning of investigation on early tin mining. Since the 18th century, both Iberian and British writers wanted to prove that the Cassiterides were near their coast. The islands off the Galician coast were first identified as being the Cassiterides by Sarmiento in the second half of the 18th century (Sarmiento, 1758-1769). A few years later, Cornide Saavedra proposed a similar interpretation, contrary to the claims of the British writer, William Camden who identified the Cassiterides with the Isles of Scilly. Given the absence of tin mines in the Isles of Scilly, Cornide Saavedra provides the name of three places with tin mines in Galicia and northern Portugal, including one island: Ons Island, Monterrei and Lafoes (Cornide Saavedra 1790). During the 19th century, this question had new developments with the growth of the mining industry. The search for minerals was an opportunity to re-discover some ancient mines, and the mining engineers published notes and some extended papers about early tin mining based on what they could observe in the landscape (Pérez Domingo 1831; Borlase 1897). In Portugal, the encyclopaedic description of the district of Bragança by Alves (also known as Abade de Baçal) made use of this information in his book about mineral resources (Alves 1913). Later in the 20th century, the technical side of the mining research became stronger but some evidences of ancient works were still being recorded in the mining engineers' reports. As a result, the combined historical, technical and geological reports open a first window to the part played by Iberian tin in a large scale trade from the Bronze Age to Roman period, which the following phases of investigation will hopefully confirm with archaeological data.

² For a more detailed revision of classical texts about tin in NW Iberia, see Meunier 2011.

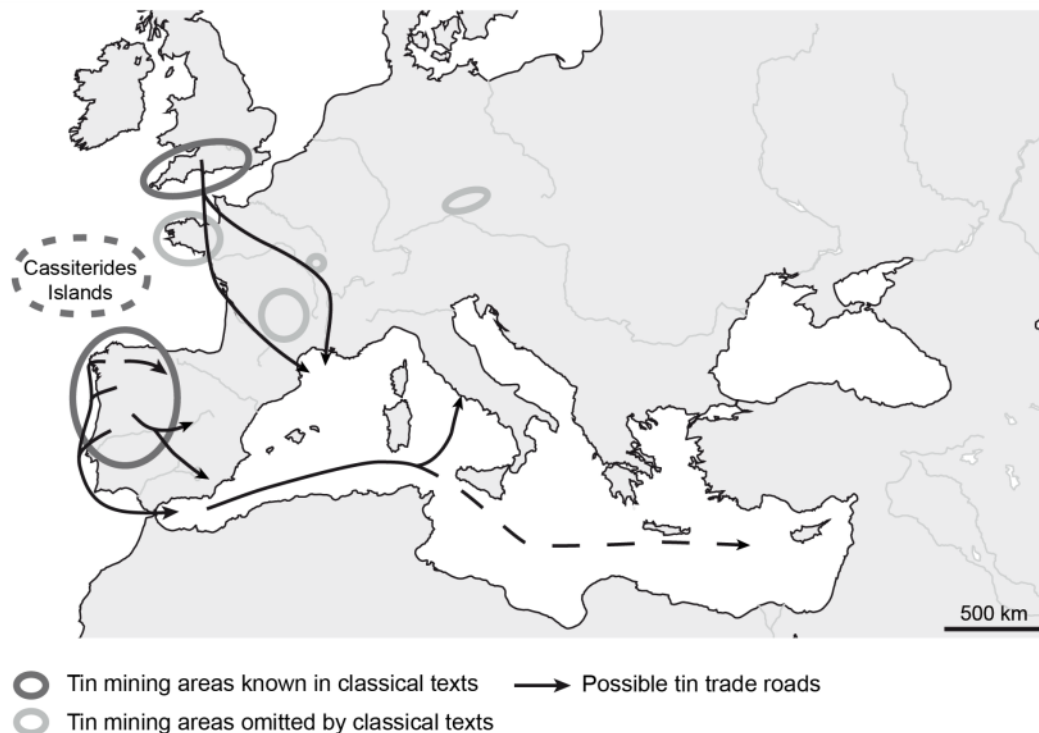


Fig. 4: Tin producing areas in Europe according to classical sources and the possible routes for the tin trade (after Meunier 2011).

3.2. Since the 20th century: a slow encounter between archaeology and mining

After the mining engineers, archaeologists started to focus their interest on the question of tin supply. They started with the classical texts, but soon considered bronze objects in their discussion. One of the most emblematic type of artefact considered were the single or double-looped palstaves from the Bronze Age which had a strong local character and were found in large quantities as isolated item or in hoards in northwest Iberia. The finding of moulds that served to produce them were recurrent, and these facts were considered to be strong arguments for local tin mining. Additionally, the distribution of this type of artefact, with a distinguished local shape, across the Iberian Peninsula (including areas with absence of tin sources) and along the Atlantic and Mediterranean coasts (with many examples found in modern Italy) was considered as a result of the tin trade (Joleaud 1929, Serpa Pinto 1933, Monteagudo 1954). Iberian geological data and mining developments were also being taken into account in these syntheses. All of this continued feeding the discussion about the location of the Cassiterides, moreover knowing that in some of the small islands in the Galician coasts, as in the Ons Island, ancient and modern tinworking existed (Obermaier 1944-1945, Monteagudo 1953, Madroñero 1994). The discussion and texts devoted to the location of the Cassiterides eventually subsided, while more recently it has been proposed that the Cassiterides were only the generic name for the occidental tin producing areas, and not a specific location within the Iberian Peninsula or the British Isles (Balboa 1997).

The emergence and subsequent development of mining archaeology since the 1970s has placed an increasing importance on fieldwork and multidisciplinary approaches. However, very few investigations were carried out to examine tin from the point of view of mining archaeology, so that knowledge on this theme has not evolved until recently. From Muhly's book in 1973 to Domergue's synthesis about mines in Antiquity in 2008, we find nearly the same scenario: after reviewing the classical texts, the geological data is used to identify where tin deposits are situated, and the same

few sites quoted are attributed to Roman works.

This situation can be explained partly by the reasons given above: part of the cassiterite must have come from tin bearing alluvium from the numerous rivers crossing the Galician or Portuguese territory and the exploitation of secondary placers left very few traces. Also, archaeologists often overlook tin mining traces, in part due to inadequate training and in part to considering it, a priori, as an impossible task. As a consequence, the lack of objective data about ancient mines prevents any reliable estimation of the amount of metal produced in ancient times. These intrinsic difficulties are known in literature as 'the problem of tin' (Mohen 1992, 101; Giunlia-Mair and Schiavo 2003; Rovira 2007: 22-24; Chakrabarti 1979). But even in this peculiar investigation context, tin resources are frequently used to explain some phenomena observed in northwestern Iberian societies since the Bronze Age. The possible tin trade routes are reconstructed from indirect sources of evidence such as the distribution of bronze objects, the distribution of menhir statues and warrior stelae (attributed to Bronze Age and showing frequently metallic objects), but also the spread of materials from areas in need of tin, such as Phoenician or Mediterranean affiliated objects, as found along the Atlantic Iberian coast and in inland central and northern Portugal (Ruiz-Gálvez Priego 1986; Martins 1996; Senna Martínez 2011, 2013).

In the last 20 years, only two academic works have examined the ancient exploitation of Iberian tin in detail. The first was by C. Merideth (1998a), who focused on the central area of Portugal and Spain and relied on data from a field survey of 42 sites. From these sites, he was only able to provide connections to ancient exploitation of tin at two archaeological locations: Cerro de San Cristóbal (Logrosán, Cáceres) and Torre Romana de Centum Cellas (Belmonte, Portugal); details for these two sites are presented below. More recently, focusing in northern Portugal and Galicia (NW Spain), E. Meunier (2011) undertook a documentary and bibliographical review of nearly 300 references and was able to highlight the potential for ancient tin mines in this region (see details below).

Relating to more recent tin exploitation, some academic works have been produced, including ethnoarchaeological studies. These include: the works of Fernández in the south of the Ourense province (Fernández 2011; Fernández et al. 2014); Ayán Vila et al. (2007) in the coastal area of southern Galicia; Alves (1999) on the mines of Panasqueira (Portugal); Fernandes (2008) on the Ervedosa mines (North Portugal).

4. Case studies

The cases presented here illustrate different aspects of recent tin mining research or investigations on archaeological remains carried out in Iberia by different researchers, including the present team. Case-studies are presented following their geographic location, from south to the north of the Iberian territory (Fig. 5).

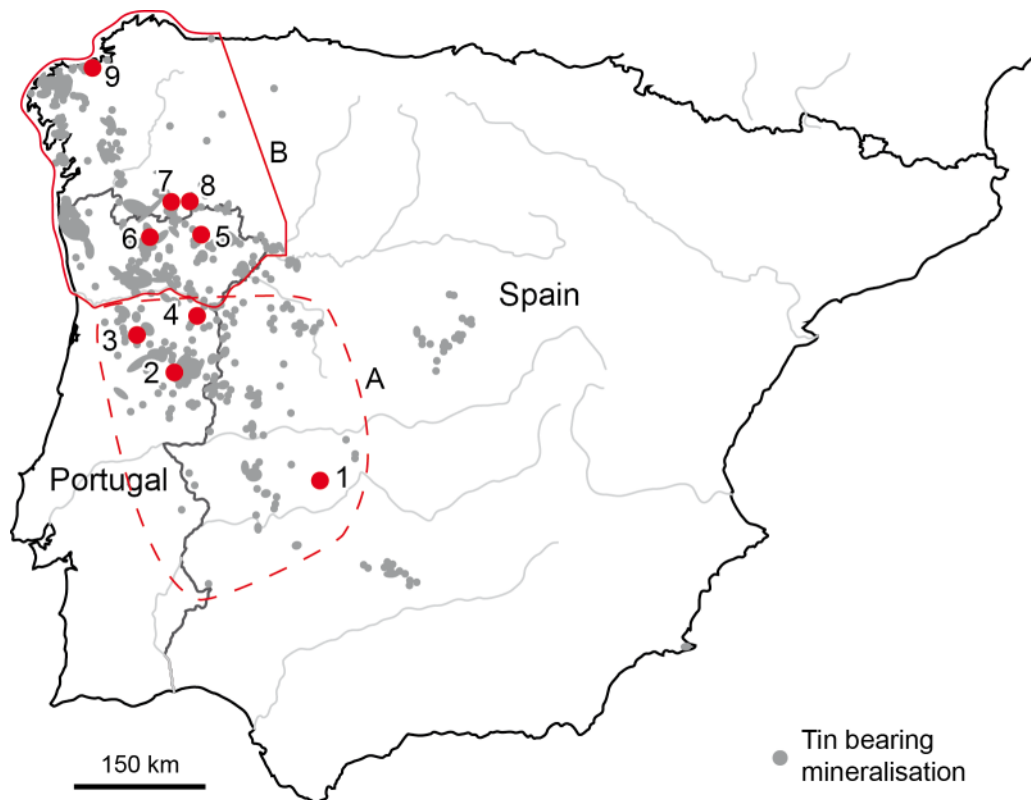


Fig. 5: Location of the case studies presented in this paper. 1: Cerro de San Cristobal, Logrosán. 2: Centum Cellas, Belmonte. 3: Castro de Nossa Senhora, Baiões. 4: Vale do Mouro, Coriscada. 5: Tuela Tin Mine, Ervedosa. 6: Castro de Carvalhelhos, Boticas. 7: Laza. 8: A Gudiña. 9: Punta Muros. A: Field survey Merideth 1998a. B: Bibliographic inventory Meunier 2011.

4.1 Cerro de San Cristóbal (Logrosán, Cáceres, central Spain)

The Cerro de San Cristóbal has been subjected to archaeological work from 1998 to 2002 (coordinated by C. Merideth until 2005) during which, tin mining and metallurgical remains were identified (Merideth 1998b, 1988c; Rodríguez Díaz et al. 2001, 2013). Despite disturbance by modern mining works, prehistoric layers have been recorded and attributed to the Late Bronze Age/Orientalizing period, between the 9th-8th/7th-6th centuries BC. More recently, a new programme of archaeological work and mining prospection in the Cáceres region has begun, by the initiative of the Logrosán City Council, which included new archaeological excavations on the site during the summer of 2013 (Rodríguez Díaz et al. 2014). The following is an overview of the site, based on this previous archaeological work.

One of the interesting facts is that this site is located at the very same place where cassiterite was mined, and metallurgical activity is documented too. The cassiterite is present in quartz veins, with associated arsenopirite and stannite, accompanied by smaller amounts of chalcopyrite, pyrite and sphalerite (Merideth, 1988c). During excavations at the mines, stone mining tools were found in undisturbed layers, and attributed to the Bronze Age. The site has circular or elongated huts, and materials related to metallurgy include crucible and mould fragments. Others related to ore dressing comprise heaps of gangue (mainly quartz), some crushing or grinding stones and mills.

A particularity of the site is that many of the protohistoric habitat structures have been constructed over the mining vestiges, which stratigraphically relates the beginning of tinworking to the Bronze Age. Also in the area, local miners in the 1950s documented quartz veins with malachite, as well as the occasional appearance of gold nuggets, during the mining and concentration of cassiterite.

Analysis of a slaggy surface on one crucible fragment has suggested that very fine ground cassiterite was added directly to copper (or copper ores) to produce bronze. The most recent excavations have uncovered tuyeres and metallic prills. Analyses have shown that prills are of bronze or copper with some arsenic. The role of the cassiterite mined in Cerro de San Cristobal among ancient trade networks is not known; nevertheless, in the case of cassiterite or metal exportation, the most natural way out would have been the southern valley of Guadiana river, which in turn would have provided an easy connection with Phoenician coastal contexts (Rodriguez Diaz et al. 2014).

4.2 Torre Romana de Centum Cellas (Belmonte, central Portugal)

Centum Cellas is a monument of central Portugal classified of national interest (Monumento Nacional), which comprises ruins of a Roman tower and other buildings. It is located near the confluence of two streams, whose placers are known to have been mined since ancient times. Archaeological excavations that took place from 1993 to 1998 (coordinated by IPPAR and directed by H. Frade), suggested that Centum Cellas would have been a villa or vicus, constructed at the mid-1st century AD. The villa belonged to a roman citizen named Lucius Caecilius, who was probably a tin trader (Frade, 2002; Alarcão, 2012).

During the archaeological work, iron slags and tin slags of dark-blackish colour and of relatively large size were found. Merideth (1998a) analysed some of these tin slags and some others that were at the surface of the site. SEM-EDS analysis showed that all tin slag fragments had tin contents that varied considerably (from 2.2% to 20% Sn), and that most areas measured also contained varying but high percentages of the elements niobium, titanium and tantalum.

The presence of these tin slags at the site shows that the villa or vicus probably developed around tin mining in the region, with tin smelting occurring on the site. The production of metallic tin would most likely have had commercial purposes.

4.3 Castro de Nossa Senhora da Guia, Baiões (Viseu, central Portugal)

The Castro de Baiões is one of the most emblematic Late Bronze Age archaeological sites in central Portugal. It received the attention of archaeologists when two torques and a bracelet made of massive gold were found in 1947 (Kalb 1990-92). Later, in 1971, another chance find provided several bronze palstaves, with a local northwestern Iberian typical shape from Bronze Age. Later, in the 1970s and 80s, some archaeological excavations took place, from which many more artefacts were retrieved, including various metallic objects attributed to the Late Bronze Age (e.g. socketed spearheads, bifacial double looped palstaves, unifacial single looped palstaves, daggers, rings, tranchet, chisels, etc.), as well as numerous metallurgical remains (Fig. 6). The metallurgical remains include fragments of moulds (as for palstaves), artefacts newly produced (still with the casting seams), and numerous fragments of diverse artefacts, among other metallurgical debris of difficult classification. Since then, other Late Bronze Age sites in the immediate vicinity (lying in a cluster within about 1-2 km of each other) have also been investigated and evidence of local metallurgical production has also been recorded. This group of sites has since been labelled the Baiões/Santa Luzia cultural group, and is located in most of the inland basins of the Mondego, Vouga and southern Douro rivers (Senna-Martinez 2000). Most artefacts found in this group are related to the 'Atlantic Bronze Age' traditions, but many artefacts are also clearly related to Mediterranean models (e.g. bowls with omphalos bottom; articulated roasting spit fragments; old types of fibulae fragments and early iron daggers from 12-10th century BC contexts). Radiocarbon dates show that these sites were occupied between 1250 and 550 BC (Senna-Martinez and Pedro, 2000; Vilaça, 2007).

In the last decade, elemental and microstructural analyses of metallurgical debris from Baiões have identified bronze metallurgy. In one particular study (Figueiredo et al. 2010), a slag fragment had copper and tin species present in different microconstituents, and a bronze prill with one side covered with metallic tin, which showed an interdiffusion process between the metallic tin and bronze, were also described. These two findings show that the site did not simply perform bronze recycling, but that metallic tin, or cassiterite, was known and circulated among the local metallurgists. Given the location of Baiões in a rich tin area, it is likely that during the Late Bronze Age, the local communities were exploiting their tin resources. In fact, at São Martinho de Orgens, just 15 km SE of the Baiões site and within the Baiões/Santa Luzia cultural group area, during the re-opening of a tin mine in 1941, the miners found a bronze dagger of the 'Porto de Mós' type (from the Bronze Age) which indicates that previous tin mining works could have been performed in that place (Vilaça et al. 2014)³.

The piece of metallic tin found in Baiões is, until now, the only Bronze Age tin fragment found or recognized in Iberia⁴. Other tin objects, such as bars or ingots, have been described in archaeological literature; however no scientific analysis has been made to confirm if they are of tin or other material. However, taking into account the numerous metallurgical remains from hundreds of Bronze Age sites in Iberia that have never been analytically studied, it would be no surprise if more tin samples are found during future investigations.

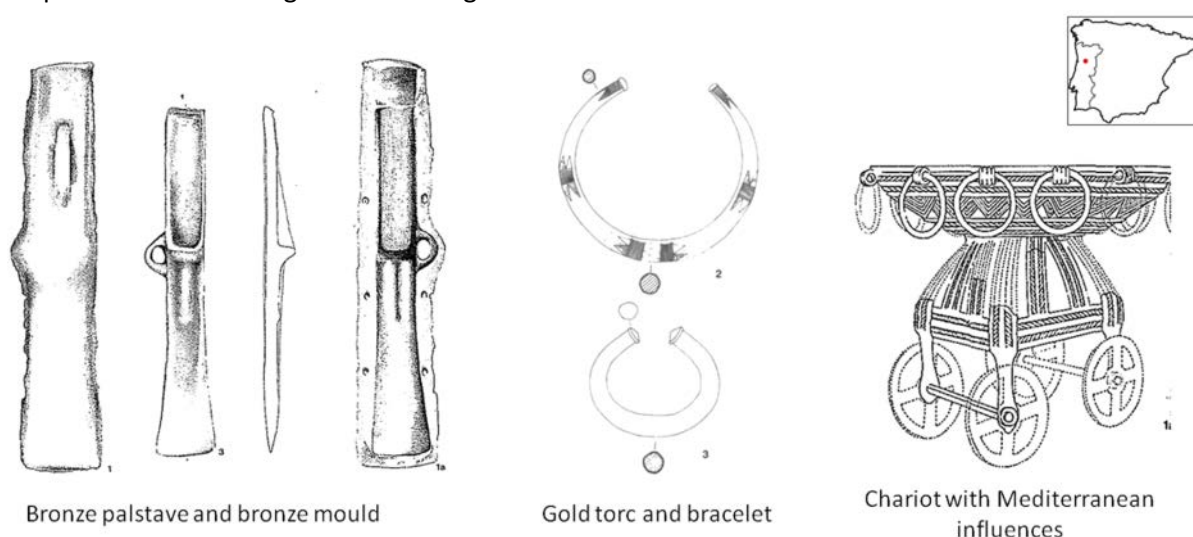


Fig. 6: Diversity of materials from the Late Bronze Age site of Baiões: bronze artefacts, artefacts with Mediterranean affiliations and gold artefacts (adapted from Silva 1986 and Kalb 1986). Other materials such as an iron knife and numerous metallurgical remains, including smelting slags and a small fragment with metallic tin were also found.

³ Some 80 km East of Baiões site, in Cabeço da Quinta das Flores (Guarda) a bronze axe from Late Bronze Age was also found during extractive tin works at a depth of 2 meters (Vilaça et al., 2014).

⁴ A few objects of tin have been found in Orientalizing or Iron Age contexts. These are a tin sheet with perforations found in an assemblage of materials of Phoenician and autochthonous affiliation dating to 900-770 BC in the city of Huelva (S Spain); six tin ingots (of various shapes) found in a Phoenician wreck at Bajo de la Campana (Murcia, SE Spain) dated to the 7th-6th century BC; a tin ingot and fragments found in a Greek wreck at the Cala Sant Vicenç, in the Mallorca isle, dated to the 6th century BC. Additionally, a few Iron Age tinned artefacts (from the second half of the first millennium BC) are also known from the Iberian Peninsula (Rovira et al. 1996).

4.4 Vale do Mouro – Coriscada (Mêda, central Portugal)

The archaeological site of Vale do Mouro (Coriscada, Mêda, N Portugal) is a Roman villa excavated by T. Silvino and A. Sá Coixão, between 2003 and 2009. This villa, one of the largest ever studied in Portugal, had its main period of activity by the end of the 3rd century AD. The production of olive oil and wine is well documented and was an important source of wealth for the owners of this establishment (Sá Coixão and Silvino 2010; Silvino and Sá Coixão 2010). Very close to this villa, a few metres eastward, more than ten opencast mines are still visible (Fig. 7). These opencast mines were known among the local town inhabitants who, during the 20th century, were mining for tungsten and tin in the region.

However, during 2014 a new excavation campaign uncovered a Roman building with important remains of waste material, made of blocks of quartz. This kind of remains is of a type known for sorting the ore before starting the metallurgical process, and provided evidence of mining activity linked to the villa.

A first survey of one of the mines was carried out in 2015 by E. Meunier and E. Figueiredo. The mine chosen was the closest to the Roman buildings (less than 50m). It proved to be an opencast trench, oriented east to west, of 27m length and between 0.5 and 1.6m width, and with a depth from a few cm to several metres, following some quartz veins in a granitic context. During this first survey it was possible to clean it along 9m and to a depth of 4.25m, though this was not the bottom of the mine (Fig. 8). The characteristics of the working are consistent with ancient mining.

The width of the trench is delimited by two veins, still visible in some points of the southern and northern walls where the miners left them, because they were too thin or barren in that level (we did not find any mineralization in the samples from the remaining quartz veins). The two veins are crossing themselves in the western end of the trench. In the lower part, the miners followed this larger vein with an underground excavation.

In the southern wall, tool marks made by picks are visible and well preserved. The use of picks is not specific to any particular period but neither discordant with an exploitation in Roman times, as known from many other sites (Domergue 2008). This type of mark is also visible in three notches in the eastern wall. These notches could be used to support a wooden structure to help to climb out of the mine. Their size and shape is similar to the lamp niches known in some Roman mines, but at this depth within an opencast trench, there would have been no need to illuminate the works.

A survey was also made of a large amount of rock found in the Roman building, and some samples of quartz vein were found with cassiterite. Preliminary SEM-EDS analysis to the cassiterite showed it to be composed by zones of very pure cassiterite as well as zones with impurities (e.g. Fe).

Despite not reaching the archaeological levels in the mine, which could have confirmed the Roman exploitation, during this first survey, the relation between some buildings of the villa and the ore sorting wastes leaves no doubt about a Roman phase of mining. These works could have been contemporary with the main phase of the villa (3rd century AD) but could also have begun as early as the 1st century AD, to which some archaeological materials recovered in the site belong to. Other phases of exploitation are of course also possible, and future works will try to reveal further data on the mining periods.

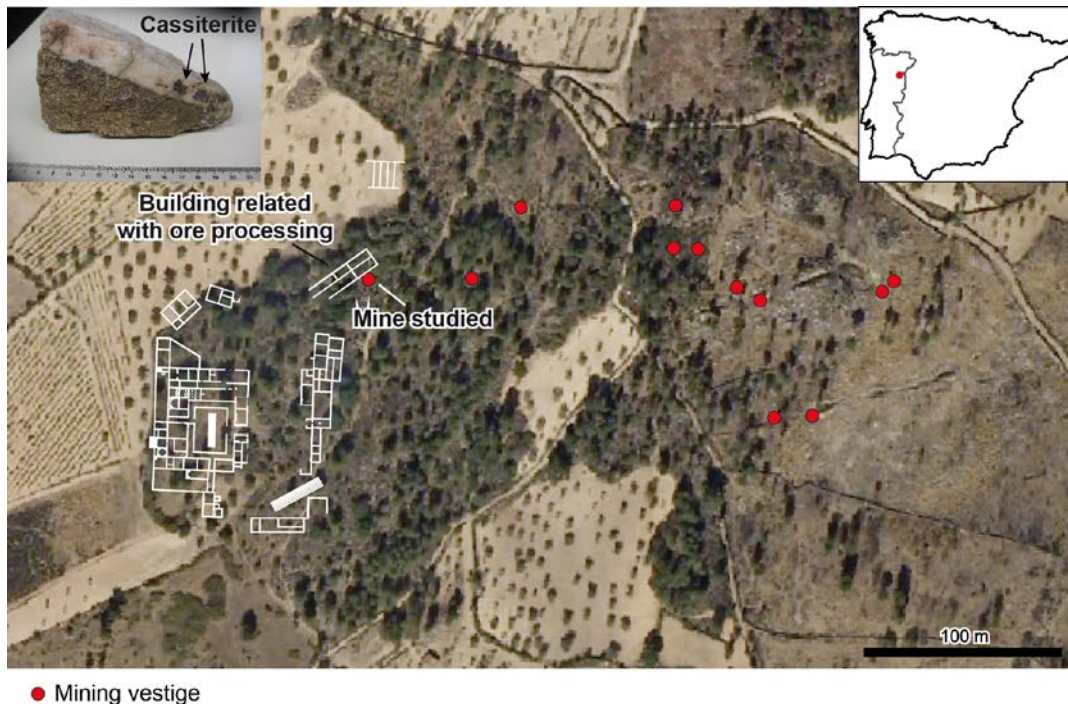


Fig. 7: The Roman villa of Vale do Mouro and the mining vestiges, with an example of a tin bearing quartz vein. Orthophoto: WMS service of igeo.pt.

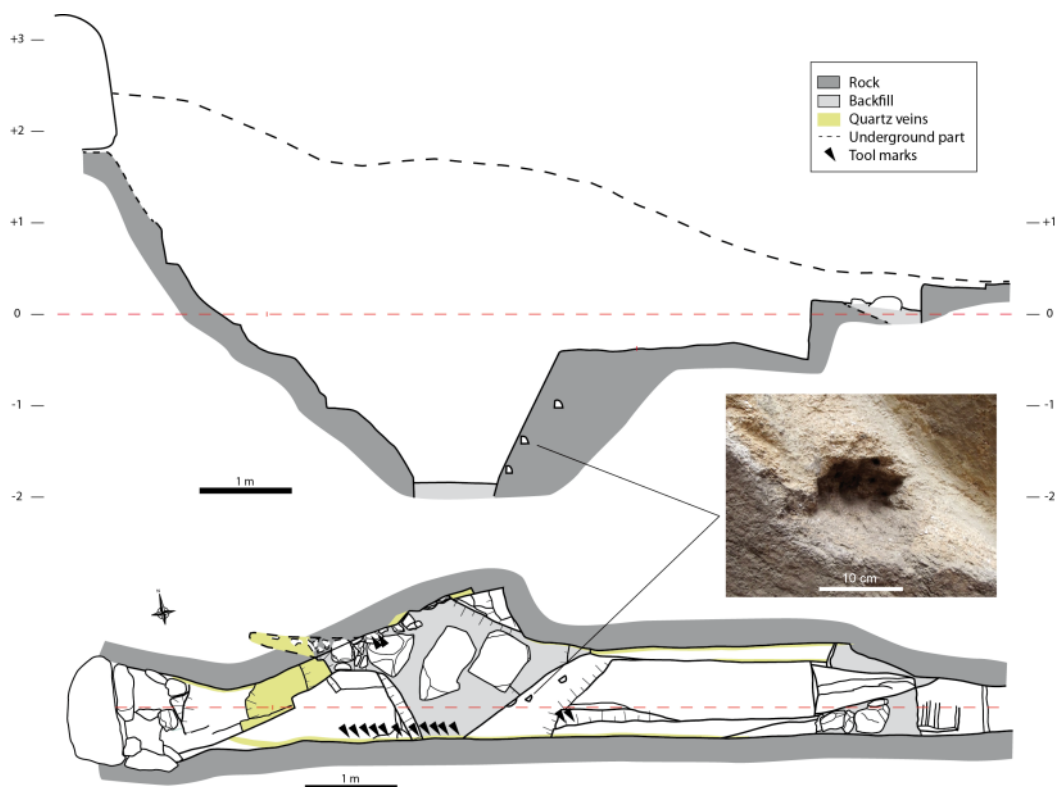


Fig. 8: Section and plan of the opencast trench closest to the villa buildings.

4.5 Tuela Tin Mines (Ervedosa, North Portugal)

The Ervedosa mines (Vinhais, North Portugal) began to be explored from the beginning of the 20th century, and until 1927 were worked by three concessions; the Borralheira, Pereiro, and Alto do Vale da Veiga. The mines were all in the southern margin of the Tuela river, having the washing and

enrichment processing on both sides of the river. In 1938, they were merged as the 'Couto Mineiro de Ervedosa', and were explored by a company, Tuella Tin Mines Limited, which worked until 1969 (Fernandes 2008). The mine reached production of 150 up to 300 tons of cassiterite concentrate (at 65-67% Sn) per year, which was almost exclusively exported to England.

The extraction took place along a principal vein, of large thickness, with a direction N 40°W and inclination 70-80°NE. This vein was little mineralized, but secondary veins with irregular shapes and with only a few centimetres in thickness were rich (stockwerk type). Thus, the mining works resulted in an important network of galleries and shafts. The mineralized areas were formed by 0.6-1.3% cassiterite, 2-4% arsenical pyrites, chalcopyrite, some iron and vestiges of zinc and gold (Gomes 1996).

During the hydraulic working at one of the mines, crushing and grinding stone tools were found that were believed to have served in the processing of cassiterite, attributed to the protohistoric/Bronze Age period (Veiga Ferreira and Castro 1949; Fernandes 2008) (Fig. 9).

Roman and pre-Roman occupation sites are known in the region. Specifically, in a hill over the Tuella river, near the mining works, there is a Bronze Age(?)/Iron Age hillfort called Muradal, which however, has never been archaeologically excavated.

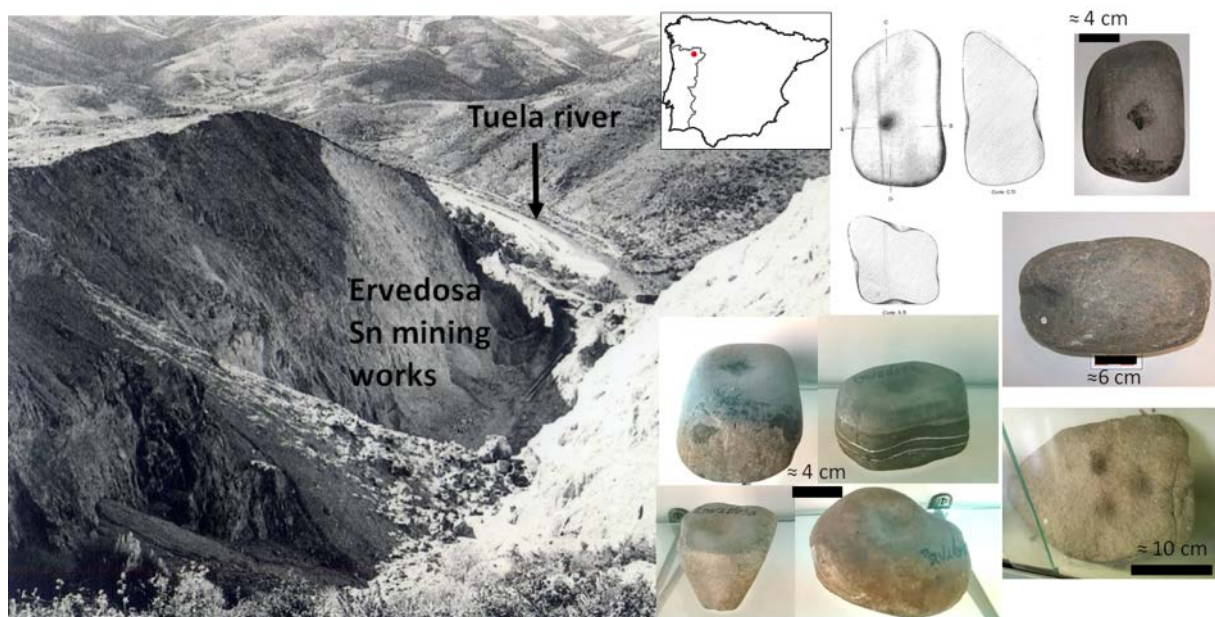


Fig. 9: At left a photograph from the Ervedosa Sn mining works, from the personal archive of Carlos Lindley (1930s), adapted from Fernandes (2008). At right images of crushing and grinding stone tools found during the modern mining works, believed to have served in the processing of cassiterite at protohistoric/Bronze Age period (adapted from Veiga Ferreira and Castro 1949; Fernandes 2008; and photographs from the authors).

4.6 Carvalhelhos hillfort (Boticas, North Portugal)

The Carvalhelhos hillfort (Boticas, North Portugal) was excavated through several campaigns directed by J. R. dos Santos Júnior from the 1950s to the 1980s. It is a fortified castro, and its occupation is attributed to the Iron Age/Roman transition, between the 2nd century BC and the 1st century AD (Fonte 2015).

The site is located in a region very rich in tin resources. The area of Barroso is known for aplite bodies associated with tin mineralisation (Ferreira & Noronha 1987). Most of these aplites with tin

mineralisation were described as countless, thin (metre-size, on average), mainly aplitic dykes and veins, commonly converted to kaolinite which contain low-grade (<3 kg/t) cassiterite mineralisation (Charoy et al. 1992). Frequent occurrence of cassiterite in the greisens surrounding the pegmatites have been reported in this area, and were exploited for tin on a small scale after the Second World War (Martins & Lima 2011).

During the archaeological excavations, several kilograms of slags, pottery, and some metal artefacts such as fibulae, rings and pins, as well as a few Roman coins dated to the 26-25 BC and 41-54 AD, were recovered (Fonte 2015). Also near the site, a 200 kg cassiterite deposit was found, which was interpreted as a 'hiding place made by the inhabitants in the imminence of an attack, possibly by the Romans' (Santos Júnior 1984).

An early study of a slag sample, by Maia e Costa (1966), suggested that this particular slag was a result of tin smelting activity. However, the very high iron (Fe) content and rather low tin (Sn) content within the sample, created some uncertainties about this interpretation (Tylecote et al. 1989). More recently, in an attempt to better understand the metallurgical activities at this site, more slag samples have been analysed, and the results show effectively that tin, as well as iron, extractive metallurgy was performed there. This study is still being developed; nevertheless, the presence of tin slags has now been confirmed. The results even show some similarities with the Centum Cellas examples (see above; Merideth 1996): the tin content varies considerably although is frequently upwards of ~30%, and the significant percentages of the elements niobium, titanium and tantalum are also present (Fig. 10), which are common occurrences in cassiterite from the Iberian tin belt.

After years of excavations, Santos Júnior (1984) concluded that 'the inhabitants of Carvalhelhos were skilled miners who exploited the cassiterite tin ore ... which was exploited in some pits dug on the periphery of the village'. These pits and other remains are difficult to identify today, in part due to mid-20th century mining works that destroyed evidence of previous episodes, and due to the intensive afforestation that the region underwent in the second half of the 20th century.

Currently, the Carvalhelhos is the only Iron Age hillfort from which tin slags have been identified and analysed. Nevertheless, as previously mentioned for the Bronze Age sites, future analytical studies examining metallurgical remains of the thousands of castros in northwestern Iberia could provide more evidence for tin extractive metallurgy in pre-Roman times.

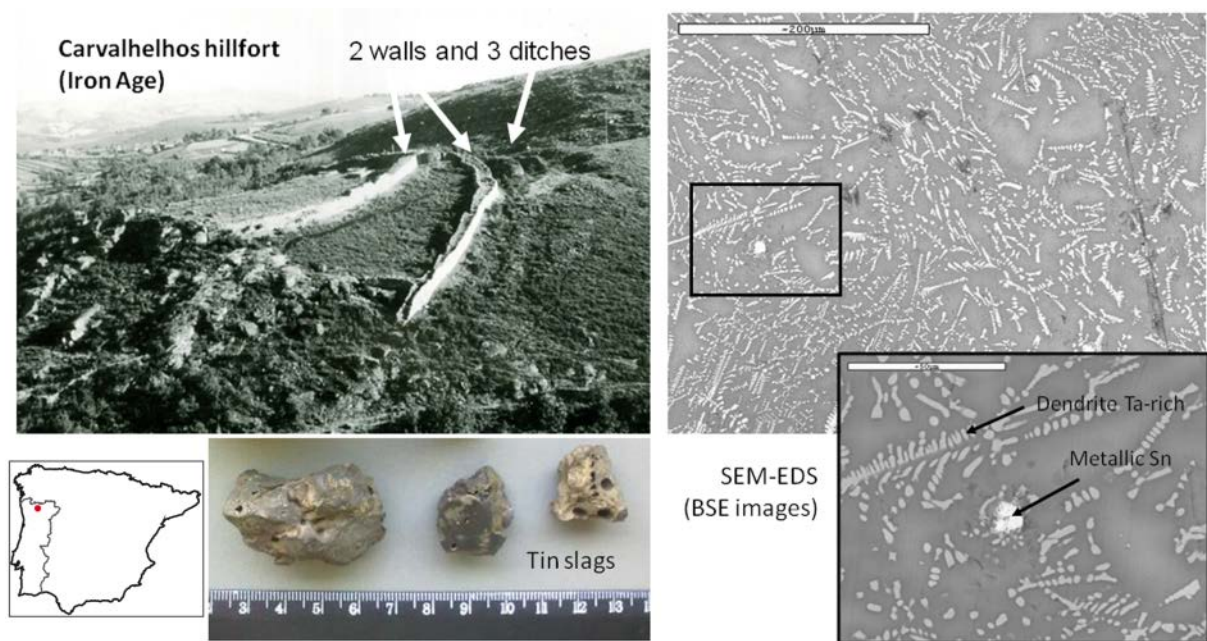


Fig. 10: Iron Age Carvalhoelhos hillfort at top left and samples of tin slags found in the hillfort at bottom left. At right, SEM-EDS (BSE) images of a typical microstructure of the tin slags.

4.7 Punta Muros (Arteixo, Northwest Spain)

Due to the recent construction of a harbour in Punta Langosteira (A Coruña), a small fortified settlement located in the top of a cliff which was going to be destroyed was subjected to archaeological excavations. This site, called Punta Muros (Arteixo, A Coruña, Spain), is of the Late Bronze Age, with some features that make it unique and exceptional in the far northwest of the Iberian Peninsula. Large, elongated and aligned houses have been uncovered, all with outside fireplaces and basins carved into the rock for metallurgical uses. It has been interpreted as a fortified factory dedicated to the production of bronze in its two forms: binary (copper-tin alloy) and ternary (copper-tin-lead alloy) (Cano 2011; Cano & Gómez, 2010). Of particular importance was the find of a lead ingot. The researchers of the site propose that crushed cassiterite was introduced directly during the metallurgical processes. They also claim that the origin of galena or cassiterite was close to the site. Galena could have been found between the pegmatitic rocks.

5. Investigation approaches

Beyond more traditional archaeological investigations, other approaches have been applied to specific questions relating to tin exploitation. Three examples, carried out by members of the present team are here presented.

5.1 Documentary survey: mapping modern and ancient tin mining in NW Iberia

Documentary synthesis, carried out by E. Meunier for the area to the north of the Douro River, resulted in the mapping of tinworks, whose chronology runs from the Bronze Age to the 20th century (Meunier 2011, 2014). The documentary sources used to produce this database are very diverse. Archaeological publications were used, but the main source was geological databases and mining engineers' reports. The objective was to compile a list of places where mining activity took place, during different chronological periods.

This investigation served to provide the first detailed database of past tin mining evidence in northern Portugal and Galicia (northwest Spain). Nevertheless, documentary sources are limited. For

example, the locations of tin mines are known only where previous archaeological or geological surveys have been completed, resulting in written documents; archaeological surveys are very few in number, but there are many geological surveys available, produced at the behest of the mining industry. Thus, the map resulting from this process shows information concentrated into locations/areas where modern mining interests prevail, so many tin resources and ancient mining activities are overlooked. Inevitably, therefore, the list is incomplete, and future field surveys still have to be undertaken.

The second constraint that hampers the work is the different forms of available documentation depending on its country of origin. For Spain, most of the reports from the IGME⁵ are available in an online database, providing many details on each mining site. For Portugal, only a database with mineral occurrences is online⁶. In this case, the information is mainly geological and mineralogical; the mining works are never described. Another problematic issue is the chronology of the mines. If, in some cases, mining engineers recorded the presence of 'old' works, there is seldom any indication of how old they were. In a few cases, they recorded the presence of archaeological remains (Roman coins, ceramics) or highlighted the ancient morphology of the works (nearly always considered of the Roman period), but mostly, there are no detailed descriptions. Archaeological documentation allows completion of the information in only a few cases.

The resulting list was used to prepare a map (Fig. 11), which presents the recorded mining sites, distinguishing the ancient ones from the modern or undated ones⁷. The wide, spatial spread of tin mining works is notable, despite the empty zones that result from the limitations of geological surveys. Another point of interest is the known location of ancient works in many areas, despite the very few archaeological investigations carried out in order to characterise them⁸. Primary and secondary deposits are also indicated. It can be shown that old works were recorded in both primary and secondary geological contexts.

Despite its limitations, this documentary work has presented an encouraging body of new data revealing great potential for future fieldwork directed towards early tin mining.

⁵ Spanish Institute of Geology and Mining (<http://info.igme.es/catalogo/?tab=2>).

⁶ Database SIORMINP (<http://geoportal.ineg.pt/geoportal/egeo/bds/siorminp/>), from the National Laboratory of Energy and Geology of Portugal.

⁷ The chronological data for ancient works are presented in Meunier 2014, fig. 3. It is to be noted that further ancient works are very probable to be discovered when archaeological field survey is to be carried out.

⁸ C. Domergue's survey of Roman mines in Iberian Peninsula is one of the few examples of this kind of investigation (Domergue 1990).

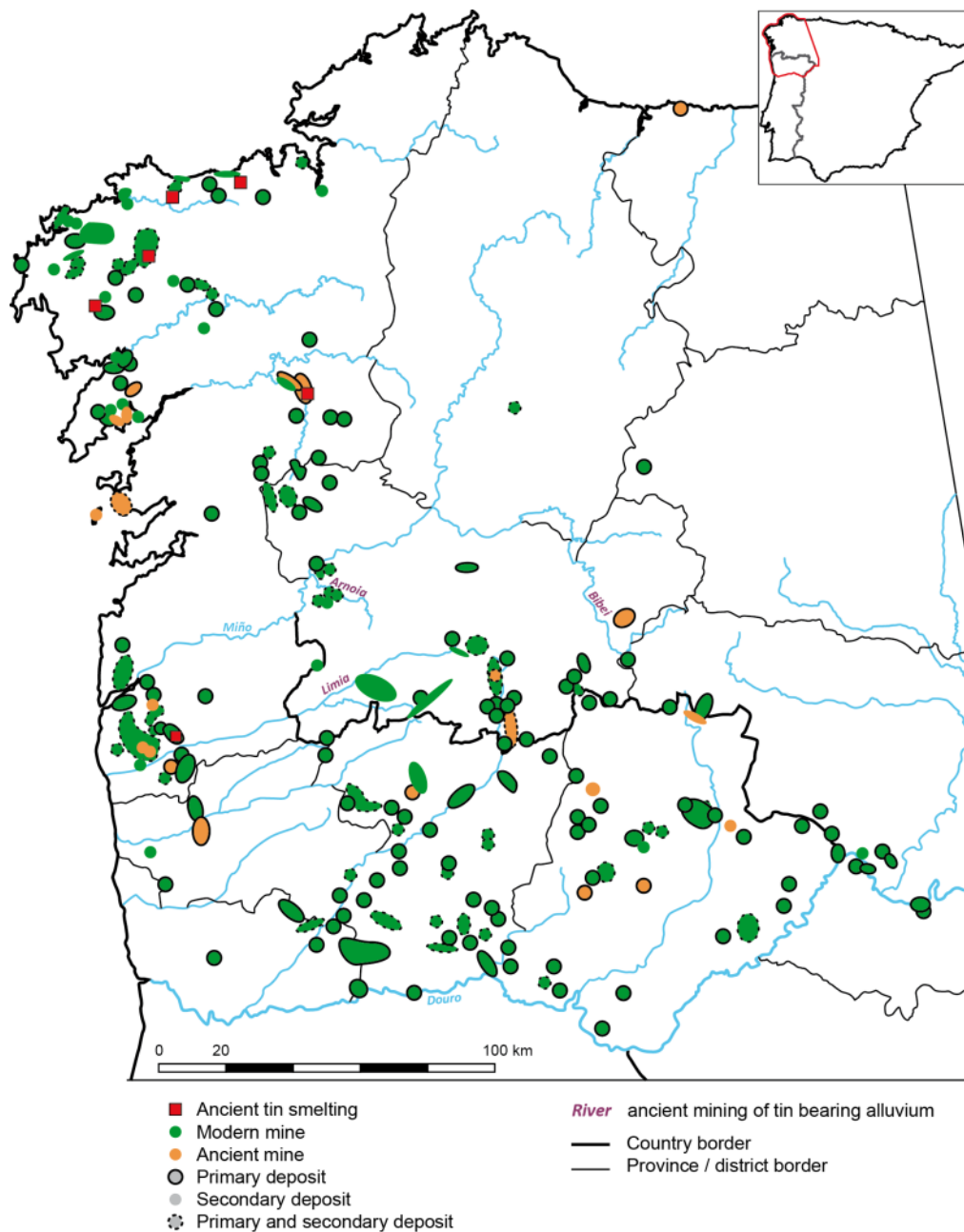


Fig. 11: Tin exploitation sites in the north-western Peninsula (Meunier 2011).

5.2 Ethnoarchaeology: the example of modern mining in Laza and A Gudiña (Ourense, Northwest Spain)

The southeastern area of Galicia (Ourense province), which includes the municipalities of Laza and A Gudiña, is characterised by an undeniable landscape value, but also by its industrial and mining heritage. During two research projects, the 'Archaeological Intervention project in the Monte Urdiñeira environment (A Gudiña and Riós municipalities)' and the 'Upper Támega Project', both directed by the University of Vigo⁹, research was carried on the exploitation of tin resources in recent times.

⁹ Proyecto de intervención arqueolóxica no Monte Urdiñeira e o seu contorno (Concellos de Riós- A Gudiña, Ourense). 2009 REF 2009-INOUE-04, 102A 209/417; Proyecto Alto Támega: Acciones en el Paisaje Patrimonial 2013 CITI 131H647.

The main aim was to obtain information about the usage and benefits of tin mining in a wide, cross-border region. The methodology followed an interdisciplinary approach, integrating the mining documentary collection from the Archivo Histórico Provincial in Ourense (AHPOu), field surveys, and the involvement of the local community, as well as interviews with older miners.

Tin mining works in the region have been recorded from the second half of the 19th century onwards, based on accounting ledgers, files and payment of taxes, namely in sites such as Trabisquedo and Valgrande (A Gudiña) (Fernández 2011), or Arcucelos (Laza) (Fernández et al. 2014). Field surveys confirmed a substantial level of tin exploitation, locating many examples of drift mining with multiple passageways, and evidence of industrial infrastructure. In addition, two open-pit mines (located in Vilameá, Laza and O Tameirón, A Gudiña) were detected, which could be related to the exploitation of gold.

The local community offered a social perspective as a first-hand resource, since many inhabitants had close associations with the recent mining works. The information they provided, clarified different aspects of the exploitation of tin ore, including the extraction technique, ore quality, and the gender-based segregation in the work environment. Moreover, many details regarding tin smuggling were documented, since this was a frequent activity, due to the cross-border nature of the area.

Two main conclusions can be highlighted from this investigation. First of all, the chronology of the contemporary tin exploitation is well documented between 1856 and 1964 in the AHPOu files. These documents also reveal the existence of remains of 'ancient works', which would need to be further investigated by archaeological prospection, to provide further details about possible mining activities during prehistory or antiquity. On the other hand, the two open-pit mines discovered would require further detailed investigation. The possibility to combine research into gold and tin mining in that area would be of great interest in the study of ancient patterns of metal exploitation.

5.3 Experimental archaeology: extractive metallurgy and tin or bronze production

In the context of the 'problem of tin', particularly the difficulty caused by the lack of a comprehensive archaeological data on extractive metallurgy, ethnoarchaeology and experimental archaeology are two tools of great potential. They represent an empirical way of better understanding bronze and tin production specificities, bringing some answers to a topic that is short on information.

Recently, during the ethnoarchaeological interviews with the local population in the region of Laza and A Gudiña (see details above) an opportunity to document a traditional way of producing a tin ingot with local ores occurred. One inhabitant who had been a tin miner in the mid-20th century and a former blacksmith, told about the way he and others used to produce tin for local consumption (as for tinning spoons and other utilitarian objects). He was very keen to put his old blacksmith workshop to work, to demonstrate tin production, which was duly documented.

This was an exceptional ethnological opportunity, during which it was possible to observe different stages of the metallurgical process: cassiterite reduction in open fire with absence of fluxes or container; fabrication of a mould using a turnip (a potato could also have been used, depending on the season); separation of metallic tin prills from slags and charcoal, and melting together in an iron frying pan; casting of tin in the turnip mould. The process was done in a traditional forge, with charcoal as fuel and manual bellows to fan the fire, and took less than half an hour. The ores used were of local origin (Lackinger et al. in press).

The information obtained from this ethnological experience, together with some archaeological data about ancient smelting procedures, were used to design some smelting experiments that were performed by the team using Iberian ores. With these experiments, it was aimed to get a clearer

understanding of the degree of difficulty/facility in metal production; to have some estimates on the efficiency using different ores or smelting techniques; and it was aimed to obtain materials that could be analytically studied and compared to archaeological samples. Additionally, the experiments were an opportunity to bring prehistoric metallurgy to a wide-ranging audience, from university students to professional archaeologists, including the general public, by performing public events.

Such metallurgical experiments have been performed since 2011 until the present, and involved the cementation process, co-smelting processes (simultaneously reducing copper ores and cassiterite for direct bronze production), and cassiterite reduction, for the production of tin. All the experiments were conducted in small-scale open fire structures, as a small pit dug into the ground. Fluxes were never added, and in some cases clay crucibles were used, while in others the reduction was made directly at the bottom of the pit. Two bellows were always used, with the tuyeres directed to the centre of the pit (Fig. 12). Variations in the bellows design, size and depth of the pit were included in some of the experiments.

Some of the experiments were more successful than others in producing metal. In respect to tin production, it has been generally perceived that the larger the cassiterite grains the higher recovery rates are attained (and with larger prills), and that the use of small open fire smelting structures can result in large amounts of tin loss due to the volatilization of Sn species (namely SnO) (Figueiredo et al. 2016).

In Table 1, the characteristics of the experiments performed and a summary of the results obtained are presented.



Fig. 12: (left) Experimental tin smelting operation performed in an open pit recreating prehistoric technologies; (right) tin prills recovered from the smelting experiment.

6. Some final notes

Tin resources in the Iberian Peninsula were available over a wide territory. Despite the absence of well dated ancient mines, there is indirect evidence for mining activities from the Bronze Age, Iron Age and Roman times.

With respect to modern times, mining activities have been documented since the 17th century only in a few places, but in the 20th century tin mining was performed in all provinces where tin resources occur.

So far, there are no elements to estimate the amount of tin produced in ancient times, but the regular presence of metallurgical vestiges in archaeological sites makes one presume that the exploitation of the local tin sources could have been performed on a regular basis from Bronze Age

to Roman times, and in the various provinces of the Iberian tin belt.

Difficulties in recognising ancient mining evidence in the field, and the lack of metallic tin in archaeological excavations, constrain the research on ancient tin in Iberia. However, this is not unique to the Iberian territory.

Recently, there has been new interest in re-opening some mining complexes, namely for Critical Raw Materials (as Ta and Nb). This could represent a new threat for any ancient remains not studied or recorded yet. This, combined with a general lack of interest in mining heritage preservation and the scarcity of funded projects in Portugal and Spain to perform such studies, seriously threatens the development of tin mining and metallurgy archaeological investigation in the Iberian Peninsula.

The building up of a multidisciplinary team, from different institutions and countries, has been a first step to try to overcome some of these problems. The possibility to apply for international projects, and to tackle different case studies with the most appropriate methodology, is now an opportunity. Also, recent progresses in the archaeometric field, such as the possibility of using tin isotopes to determine the provenance of tin in antiquity, may contribute to the development of wider interest in tin studies in the Iberian territory among the research community.

Acknowledgments

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