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Archaeology and Economy in the Ancient World

25

Ancient Mining Landscapes

Panel 4.2

Frank Hulek
Sophia Nomicos (Eds.)

Propylaeum
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Volume 25: Ancient Mining Landscapes

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Edited by

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Cover illustration: Metallurgical workshops of classical times at the archaeological site of Drymos/Souriza (Laurium, Greece). Photo P9051977 by S. Nomicos. © Hellenic Ministry of Culture and Sports/Ephorate of Antiquities of East Attica

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PREFACE

On behalf of the 'Associazione Internazionale di Archeologia Classica (AIAC)' the 19th International Congress of Classical Archaeology took place in Cologne and Bonn from 22 to 26 May 2018. It was jointly organized by the two Archaeological Institutes of the Universities of Cologne and Bonn, and the primary theme of the congress was 'Archaeology and Economy in the Ancient World'. In fact, economic aspects permeate all areas of public and private life in ancient societies, whether in urban development, religion, art, housing, or in death.

Research on ancient economies has long played a significant role in ancient history. Increasingly in the last decades, awareness has grown in archaeology that the material culture of ancient societies offers excellent opportunities for studying the structure, performance, and dynamics of ancient economic systems and economic processes. Therefore, the main objective of this congress was to understand economy as a central element of classical societies and to analyze its interaction with ecological, political, social, religious, and cultural factors. The theme of the congress was addressed to all disciplines that deal with the Greco-Roman civilization and their neighbouring cultures from the Aegean Bronze Age to the end of Late Antiquity.

The participation of more than 1.200 scholars from more than 40 countries demonstrates the great response to the topic of the congress. Altogether, more than 900 papers in 128 panels were presented, as were more than 110 posters. The publication of the congress is in two stages: larger panels are initially presented as independent volumes, such as this publication. Finally, at the end of the editing process, all contributions will be published in a joint conference volume.

We would like to take this opportunity to thank all participants and helpers of the congress who made it such a great success. Its realization would not have been possible without the generous support of many institutions, whom we would like to thank once again: the Universities of Bonn and Cologne, the Archaeological Society of Cologne, the Archaeology Foundation of Cologne, the Gerda Henkel Foundation, the Fritz Thyssen Foundation, the Sal. Oppenheim Foundation, the German Research Foundation (DFG), the German Academic Exchange Service (DAAD), the Romano-Germanic Museum Cologne and the LVR-LandesMuseum Bonn. Finally, our thanks go to all colleagues and panel organizers who were involved in the editing and printing process.

Bonn/Cologne, in August 2019

Martin Bentz & Michael Heinzelmann

Ancient Mining Landscapes: The Example of Laurion

Frank Hulek – Sophia Nomicos

Introduction

The economic importance of raw material exploitation, especially metal mining, for communities in antiquity has long been addressed. However, only during recent decades have scholars increasingly shifted the focus from technological questions[1] to the study of the wider landscape.[2] The material remains in mining regions include not only the primary mining remnants such as underground workings, process residues and installations for beneficiation, but also habitation sites and infrastructural remains that emerged in the course of exploitation.

If we assume that raw material exploitation can contribute to or even stimulate changes in a given economic system of a society, it is necessary to take a perspective beyond technological aspects in order to better understand possible interrelations. Consequently, taking into account the secondary structures such as agricultural installations, burial sites, sanctuaries or infrastructural remains may display networks that contributed to the success of ancient mining operations. Also, the working of raw material deposits by foreign communities has left traces in both the literary and archaeological record.[3] Such operations necessitated the introduction of new technologies as well as administrative measures. It therefore seems a promising approach to identify and describe indications of this process in the archaeological record by, for example, discussing aspects of technological transfer.

Such questions were addressed by the participants of the panel "Mining Landscapes", which was held at the 19th International Conference of Classical Archaeology "Archaeology and Economy in the Ancient World" at Cologne and Bonn in 2018. The proceedings of this panel are published in this volume.

The intention is, firstly, to provide an insight into existing and emerging research on ancient mining landscapes. Secondly, it aims to discuss how mining could affect not only the natural but also the cultural landscape. By focusing on select case studies, the third objective is to identify the material characteristics of mining areas, to highlight and explain differences, and to discuss possible recurring infrastructural and organizational patterns.

Theoretical and Methodological Background

As G. Weisgerber[4] argued, mining archaeological studies – like mining engineering[5] – should follow the different steps of the *chaîne opératoire,*[6] methodologically being highly process-orientated. This approach was expanded by Th. Stöllner, who developed a theoretical framework which takes not only the landscape of a given mining region into

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account but also other components of mining economies.[7] Th. Stöllner defines a mining region (or *Montanlandschaft*) as a "specialized region, whose primary economic structure is focused on the exploitation of (mineral) resources".[8] According to this concept, a *mining region* can be subdivided into a *mining district* that is a centre of production within the larger region, as well as an even smaller *mining ensemble* which, for example, consists of a mine, a smithy, and a smelting place.[9]

The success of mining, however, depends not only on spatial structures. Several components were identified by Thomas Stöllner that may contribute to long-lasting and productive mining operations in a given mining region:[10]

- The natural landscape
- The cultural landscape
- The mode of production
- The social and cultural tradition
- Trading modes
- And historical processes

Another constituent of past mining economies that the model considers is the *Duration of time.* Th. Stöllner distinguished between Phases of *extensive exploitation* (characterised by sporadic, seasonal grasp of the resources) and phases of *intensive exploitation.* This second category can be subdivided into an *anterior phase,* an *initial phase,* a *consolidation phase* and an *industrial phase.*[11] By applying the notion of an adaptive cycle[12] and adding a final *phase of collapse and reorganization,* a cyclical system of the usage of a deposit was established.[13]

Keeping these theoretical considerations in mind when analysing past mining economies may serve as a useful analytical tool when reconstructing the complex dynamics that led to sustained mining operations. Likewise, it can explain the rise and decline phenomena in mining landscapes.

Laurion

The Laurion mining landscape in Greece can serve as a particularly good case study regarding the interrelation of mining and landscape.[14] Here, the ancient written sources and the archaeological monuments – despite their destruction by modern mining activities – are incomparably numerous and well preserved.[15]

Mining in Laurion started at least in the Early Bronze Age.[16] The mining region, however, is primarily known as being the backbone of Athenian economy during the classical period. According to Herodotus (Hdt. 7, 144), the Athenian fleet that famously defeated the Persian army at Salamis in 480 BC was financed by the revenues of the Laurion mines. These are, furthermore, known for being the source of the silver from which the Athenian γλαῦκες Λαυριωτικαί[17] (i.e. the silver coins of Athens) were struck since the Archaic period[18] (fig. 1[19]).


Fig. 1: a: Archaic Athenian Tetradrachm av. b: Archaic Athenian Tetradrachm rv.

The development of mining landscapes and more specifically those in the Laurion can be described according to Th. Stöllner's terminology[20] as phases of *extensive* and phases of *intensive* mining. After a period of extensive mining in the geometric and for most of the archaic period, mining was apparently intensified during the late archaic period[21]. It peaked during the 5th and again during the 4th century BC[22]; during the Hellenistic era, earlier residues were reprocessed.[23] There is no evidence for systematic mining operations during Roman imperial times,[24] mining, however, was taken up again in the early byzantine period and ceased around 700 AD.[25]

It can be shown, moreover, that there is a close correspondence between mining and settlement development in the Laurion.[26] More specifically, it is noticeable that during phases of completely lacking mining activity or during extensive mining, only parts of the Laurion showed settlement activity, especially the coastal areas with no metal deposits.[27] In contrast to this, during phases of intensive mining, most notably during the classical period, the entire Laurion region was densely settled. This can be explained by the fact that the inland area lacked sufficient natural water sources as well as good soils for agricultural use. More arable land and infrastructure, such as harbours, existed only in the periphery of the metalliferous zone.

Research at Ari in the Laurion

Recent research in the Laurion carried out by the Ruhr University Bochum, concentrated on a region called "Ari", some kilometres to the north of the village Anavyssos (fig. 2). The project on "the prehistoric and Classical exploitation of lead and silver in Ari (Attica)" directed by H. Lohmann, lasted from 2012 until 2017. It was conducted in collaboration (synergasia) with the Ephorate of Antiquities of East Attica and the German Archaeological Institute at Athens. Its aim was to tackle open questions regarding ancient mining and metallurgy, both of which can be studied particularly well at Ari. Important characteristics of the project are the collaboration between mining and beneficiation engineers, mining archaeologists, natural scientists experienced in archaeometry, and Classical archaeologists.[28]

Ari forms the northwesternmost mineralization of the Laurion,[29] and the area covers approximately 5 km². The toponym Ari probably derives from the ancient Greek name Phrearrhioi, one of the demes (i.e. municipal subdivisions) of classical Athens.[30] Numerous ancient sites at Ari had already been documented in the “Karten von Attika” (sheets 16 and 17) in the 19th century,[31] such as ancient shafts, slag heaps and buildings. Also, more recent literature confirmed the density of sites in this small region, and recent excavations by the National Metsovian Technical University of Athens uncov-

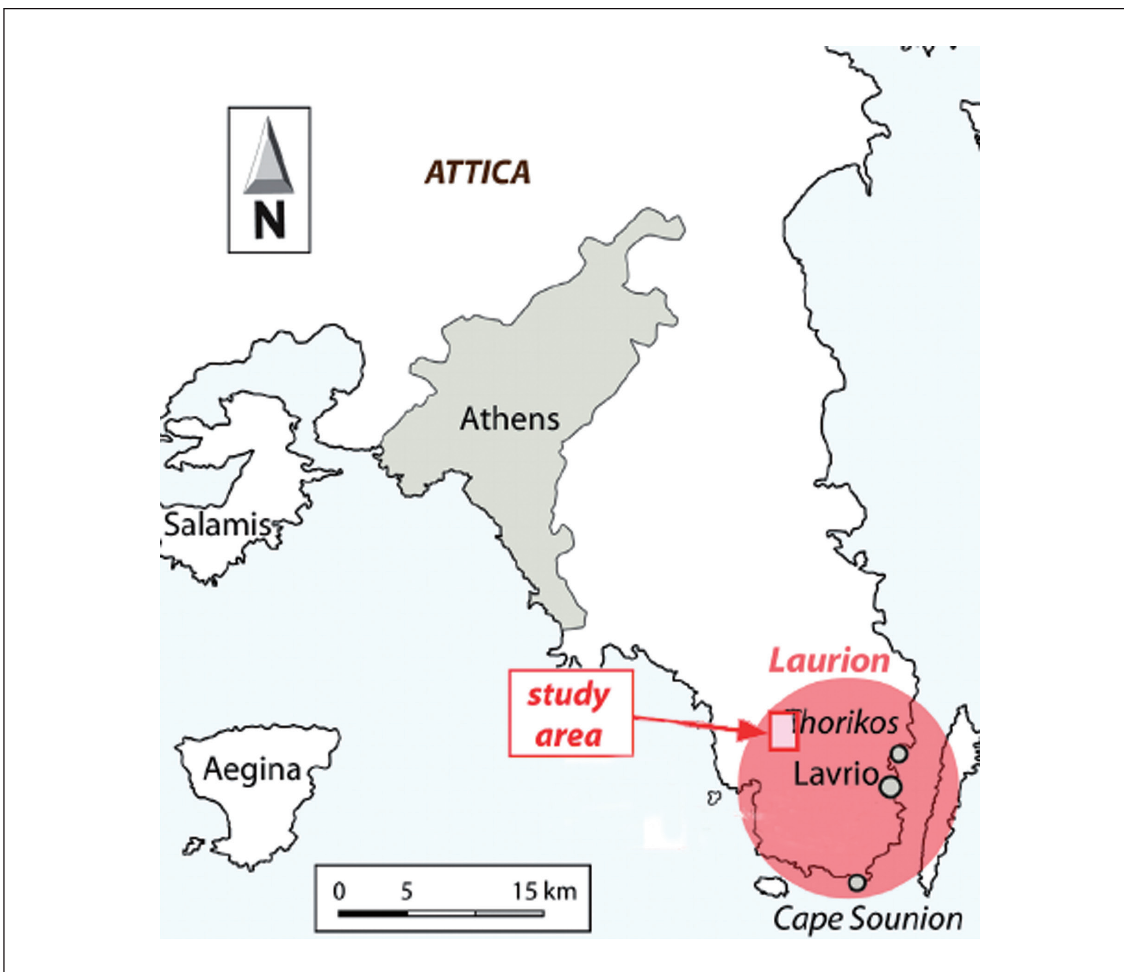

Fig. 2: Map of the Laurion.

ered several ancient metallurgical installations (ore washeries and smelting furnaces).[32] Therefore, further research and especially a survey aiming at documenting all extant elements of this small mining region promised new results for our understanding of the various economic, social, and cultural aspects related to mining. The projects' results are currently being evaluated and will be published soon.[33]

During the survey, a site on the slope of the hill Charvalo was discovered and catalogued as Ari 63. It raised our interest because its layout and vestiges of waterproof plaster in one of the rooms made us suspect it to be an ancient *ergasterion,* (i.e. a workshop where lead-silver ore was concentrated by the use of water). In the summer of 2016, the author (F. H.) explored this complex with four trial trenches (fig. 3). The first target was the room in which we suspected an ore washery of the well-known rectangular type.[34] It indeed turned out to be an ancient ore washery, virtually undisturbed by later activities. Protected by the collapse of the clay walls of the complex, fine sintered material was obtained from the bottom of the washing channels. Anno Hein from the Demokritos-Institute (Athens) analyzed this fine sintered material that turned out to be residue of the washing process. This will hopefully provide more accurate information on the composition of the ore used and on the yield of the process steps.[35] The washing floor of the washery, an inclined plane, shows clear traces of wear caused most prob-

Fig. 3: Orthophotography trial trenches at Ari 63A.

ably by scrubbing ore on it. This evidence contradicts the prevalent assumption about the operating mode of the washeries with the use of sluices.[36] However, it corroborates the older theory which was first put forward by the beneficiation engineer (and later politician) Phokion Negris, that they functioned as plane tables.[37]

In an adjoining room, lying on the floor, turned upside down, a bowl was found, one of the youngest pieces of the pottery inventory; it provides information about the end of use of the workshop in the later 4th century BC. The ore washing workshop thus fits into the second *industrial phase,* ending in early Hellenistic times.

In 2017, the author (F. H.) worked on the material from an old excavation in the Archaeological Museum of Lavrion. The rescue excavation was conducted by the late Evangelos Kakavogiannis and Olga Apostolopoulou in 1969/70, on the site of the Public Power Corporation (ΔΕΗ) oil power plant, right by the Frankolimani bay.[38] There was an ensemble of various buildings and complexes, namely a battery furnace for melting the ore, a presumptive cupellation furnace, an ore washery, other buildings and two cemeteries, and a possible mine shaft. The metallurgical residues from the furnaces are being analyzed at the Demokritos Institute and will probably provide further insight into the ancient smelting process. The ceramic findings and coins provide a dating of the individual complexes. The battery furnaces were in use during the first half of the 2nd century BC and are thus another example of the relocation of the smelting furnaces to the coast as well as the reprocessing of older process residues.[39] At the same time, the finds show how densely populated the surrounding area of the Thorikos[40] mining center was and how profoundly the mining and processing of ore affected the landscape.

Overview of the contributions in this volume

The panel "mining landscapes" has brought together many different perspectives, such as social, administrative, and technical views on landscapes shaped by mining in Antiquity.

Effie Photos-Jones presents results from her long-term project on the mineral wealth of the volcanic island of Melos (Cyclades, Greece), where "miltos" was mined in antiquity and shipped to places around the Mediterranean. This material was used as pigment, cosmetic, washing powder, and medicine.

Raphael Eser and Fabian Becker present the results of their research on Elba (Tuscany, Italy), an island that was important for the iron production of Etruria. They show that the landscape of the island and its natural resources, not only the ore but also wood for fuel, were exploited in order to facilitate the production and export of iron. Furthermore, evidence points to the continuation of iron exploitation until the time of the Late Roman Republic, when the written sources state that the central administration decided to abolish mining in Italy.

Norbert Hanel, who during the conference gave us a glimpse into the results of a survey in the Iglesiente mining region on Sardinia (Italy), presents the results of chemical analyses of brass ingots which he conducted in collaboration with Michael Bode. They show that the Roman empire exploited the mineral resources of outlying mining regions in order to satisfy the needs for brass.

Nerantzis Nerantzis presents the research of his team in the Northern Aegean, namely the Pangaeum and Lekani mountain ranges. There, control over the mining landscapes was contested between the indigenous Thracian tribes and the Greek city states (*poleis*) of the region. Eva Steigberger and René Ployer investigate the mineral resources of the Norican Alps (Austria) as well as their exploitation and trade. Especially during Roman times, the exploitation was intensified and comprised a broad range of raw materials.

David Quixal Santos presents research on the pre-Roman metal exploitation on the Eastern Iberian Peninsula and the results of the excavation of a furnace at Los Chotiles (Spain). The survey research by Victor Martinez Hahnmüller and Roald Docter covers a similar time span in the Punic sphere of influence around modern Cartagena. They describe the exploitation and organization of the hinterland of the Carthaginian colony.

Focusing on Roman times, Linda Gosner also examines mining on the Iberian Peninsula. She focuses on the subsidiary industries (e.g. esparto grass basket-making), which, as she corroborates, were stimulated during phases of intensified mining production in the region.

Regula Wahl-Clerici uses quantifying methods in order to reconstruct the Roman Empire's expenditures and revenues from the gold mines of Trêsminas and Jales (Portugal).

For organizational reasons, two papers which match this volume's topic are published in this volume, although they were presented in other panels during the conference. Alfred Hirt critically assesses the archaeological and literary sources for the organization of the mines and the processing of argentiferous lead ore from around Carthago Nova (Cartagena, Spain) during Roman times. He corroborates that the mines were leased to large scale public contractors. Luc Long and Christian Rico present an updated synthesis of how they reconstruct the maritime trade of iron in the Roman period, mainly from archaeometric analyses of iron ingots in shipwrecks at Les Saintes-Maries-de-la-Mer (Camargue, France).

Finally, four papers which were presented at the AIAC-conference, are not included in this publication. Thomas Faucher had already published elsewhere his results on Samut in the Eastern Desert (Egypt),[41] as did Hannah Friedman with her research on the copper mining landscape in the Faynan valley (Jordan).[42] Béatrice Cauuet spoke about the impact of gold and tin mining on certain territories in Gallia (France). Brais Currás presented a paper on the mining region along the rivers Tagus (today Tejo or Tajo in Portugal and Spain, respectively).

Desiderata

Having assembled these different perspectives, it became clear that there is a lot of regional variation in how mining transformed the natural and social landscape. Furthermore, there was support for the view that there are common denominators of mining regions that may enable us to predict theoretically how mining landscapes may have developed in a given region. This is especially relevant when distinct historical and archaeological information is lacking. In view of the differences, it is crucial to analyse the complexity of each mining landscape independently and to subsequently compare it with other regions in order to further refine the existing methodological framework of examining past mining landscapes.

Notes

[1] See e.g. Healy 1978; Craddock 1995; Craddock 2008.

[2] Stöllner 2003; Stöllner 2006; Stöllner 2008; Stöllner 2014; Bartels – Küpper-Eichas 2008; Lohmann 2005; Alonso Campoy 2009; Bebermeier et al. 2016; Nomicos 2021; Eisenach et al. 2017; García-Pulido et al. 2017, Baron et al. 2017.

[3] Cf. Domergue 2008; Hirt 2010; Papers by Nerantzis and Steigberger – Ployer in this volume.

[4] Weisgerber 1989; Weisgerber 1990.

[5] Cf. Handbooks of mining engineering such as Grumbrecht 1949.

[6] Leroi-Gourhan 1964.

[7] Stöllner 2004; Stöllner 2008; Stöllner 2014; Stöllner 2017.

[8] Stöllner 2008, 76 f. fig. 4.

[9] Stöllner 2004, 429 f.; Stöllner 2008, 76 f. fig. 4.

[10] Stöllner 2008, 72–75 tab. 2.

[11] Stöllner 2004, 430–439; Stöllner 2008, 77–80.

[12] See: Holling et al. 2002.

[13] Stöllner 2014, 138–140 fig. 7.3.

[14] This was the subject of the PhD thesis submitted to the Faculty of History of Ruhr University Bochum by the author, see: Nomicos 2017a. It was published in 2021 (Nomicos 2021) as a supplement volume of *Der Anschnitt*. For preliminary results, see Nomicos 2014 and Nomicos 2017b.

[15] From the abundant literature on the Laurion mines only a few titles are cited here: E. Dodwell in Boeckh 1828, 677 f.; Ardaillon 1897; Conophagos 1980; Lohmann 2005; Kakavogiannis 2005.

[16] Spitaels 1984; Nazou 2013. For recent finds indicating an even earlier use of Laurion ores, see: Kakavogianni et al. 2003; Kakavogianni et al. 2008, 45–57; Kakavogianni et al. 2009, 237–248.

[17] Aristoph. Av. 1106.

[18] cf. Ath. Pol. 10,1–2. – e.g. Head 1888, VIII–XX pl. 1; cf. Seltman 1924;Kraay 1956; Kraay 1975; Cahn 1975; but cf. Kroll – Waggoner 1984; Holloway 1999, 7–11; Kroll 2012; Konuk 2012; Flament 2007; van Alfen 2012, 88–104.

[19] Archaic Athenian silver coin ca. 500 BC: coin collection of Ruhr University Bochum, inv. M 1310. Diam.: 2,1 cm, weight 17,17 g, see: Nomicos 2015.
[20] Stöllner 2008.
[21] cf. Kakavogiannis 1989, 71–88; Kakavogiannis 2001, 365–380; Gill – Vickers 2001, 233 f. fig. 2 Tab. 2.764; Boardman 1963, 1–7; Cavanagh – Laxton 1984, 32–36; Nomicos 2020; Nomicos 2021, chapter 3.2.
[22] Compare: Conophagos 1980; Lauffer 1979; Kalcyk 1982; Lohmann 2005; Nomicos 2021, chapter 3.3 and 3.4.
[23] Strab. 9,399; Kalcyk 1982, 144 f.; Lohmann 1993, 244–246; Goette 2000, 106; Howgego 2000, 56 f.; van Alfen 2012, 97; Nomicos 2021, chapter 3.5.
[24] Pomp. Mela, 2,46; Paus. I,1,1; Kahrstedt 1954, 63; Lauffer 1979, 125. 134; Kakavogiannis 2013, 321–327; Nomicos 2021, chapter 3.6.
[25] Paul. Sil. Ecphr. S. Sophiae 679 f. – Lohmann 1993, 260; Salliora-Oikonomakou 2007, 46; Mattern 2010, 220; Kakavogiannis 2013, 326–341; Nomicos 2021 chapter 3.7.
[26] see Nomicos 2021.
[27] Nomicos 2021.
[28] Lohmann 2005; Lohmann 2020.
[29] Marinos – Petraschek 1956, 104 f.
[30] Traill 1975, 45. 62. 67; Vanderpool 1970; Lohmann 1993, 74. 78; Bultringhini 2005, 36–38, but cf. Salliora-Oikonomakou 1996–1997, 137.
[31] Milchhöfer 1889, 25; Kaupert – Curtius 1904, maps 16. 17; Ardaillon 1897, 31; cf. Marinos – Petraschek 1956, 104 f.
[32] Tsaimou 2005; Tsaimou 2006; Tsaimou 2007; Tsaimou 2008; Tsaimou 2010; Tsaimou – Tsaimou 2010; Tsaimou et al. 2015; cf. also Parras 2010, 145.
[33] Lohmann 2016; Lohmann 2020; Hulek 2019/2020.
[34] Cordella 1869, 96; Negris 1881; Conophagos 1980; 224–245; Domergue 1998; Kakavogiannis 2005, 229–252; Lohmann 2005, 114.
[35] Cf. similar analyses on material from Agrileza (Laurium): Photos-Jones – Ellis Jones 1994, 327–355; Rehren et al. 2002.
[36] Konophagos 1970; Conophagos 1980, 224–245; Meier 1998, 6–8; Papadimitriou 2017, 400–403; but cf. Kakavogiannis 2005, 240–242; Kepper 2005, 7 f.
[37] Negris 1881; Ardaillon 1897, 68 f.; Nomicos 2021, 63–68.
[38] Liagouras – Kakavogiannis 1972, 150 f.; Konophagos 1974, 243–247; Conophagos 1980, 280; Kalcyk 1982, 144. 149. 208 fig. 24; p. 211; Kakavogiannis 2005, 261 f. 270–273. 283. 294; cf. Trikkalinos 1977, 319; Kakavogiannis 2005, 270 f. n. 668.
[39] Lohmann 1993, 244; Kakavogiannis 2005, 283; Börker 2018, 69–72; cf. above n. 25. – Doubts expressed by Mussche 1998a, 66.
[40] On Thorikos and the respective bibliography, cf. Mussche 1998b; Docter – Webster 2018; Laffineur – Docter forthcoming
[41] Brun et al. 2013; Redon – Faucher 2017; Faucher 2018.
[42] Friedman 2013.

Image Credits

Fig. 1a: coin collection of Ruhr University Bochum inv. M 1310, Nomicos 2015, fig. 1. – Fig. 1b: coin collection of Ruhr University Bochum inv. M 1310, Nomicos 2015, fig. 2. – Fig. 2: after Rosenthal et al. 2013, 90 fig. 1. – Fig. 3: Ari-Project, Ruhr University Bochum, F. Hulek.

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Solfataric Alum Exploitation during the Greco-Roman Period: Some Considerations on its Nature, Enrichment, and Preparation for Market

Effie Photos-Jones – George E. Christidis

Abstract

In the Greco-Roman (G-R) period, alum, the traded commodity, was used extensively by many industries (e.g. textiles, tanning, metals, or as mineral medicinals). It is thought to have travelled from source (the volcanic landscapes of Greece and Italy) to markets, in dedicated amphorae. Alum, the raw material, was made up of a combination of alum group and other minerals, both soluble and insoluble. The two components would have been separated via a cycle of dissolution-evaporation prior to packaging and shipment. But in what shape did alum, the commercial product, travel to market? We present here simple laboratory-based experiments, combined with X-Ray diffraction (XRD) analysis, to demonstrate that alum, the shipped product from these sources, would have been a gel-like material of varying colouration, from clear/off-white to darker shades, depending on level of iron impurities. Aluminium sulfates are highly hygroscopic; travelling as a gel rather than powder, over long-distance sea routes, would have ensured that the product arrived at its destination in a market-approved condition. Travelling as powder would have resulted in water absorption and stickiness.

Introduction

In the Greco-Roman (G-R) period alum, the traded commodity, was used by many and diverse industries (e.g. textiles, tanning, metals, or as mineral medicinals)[1]. It was already known in the Mycenaean period as evidenced in Linear B texts.[2] Alum 'rock' was mentioned in Hittite texts[3] and by Herodotus.[4] In the Roman period, Dioscorides[5] and Pliny[6] discuss extensively its nature, sources and properties to include its use as a hemostatic. Recently our group demonstrated that it can be active as an antibacterial, as well.[7]

G-R alum is conventionally equated with potassium alum ($KAl(SO_4)_2 \cdot 12\,H_2O$). This is a convenient generalisation since a. it refers primarily to the main ingredient in the traded commodity and b. does not take into account either the variety of source materials or the processing they may have undergone prior to shipment to markets. Therefore, when researching the alum industry of the Greco-Roman period it is perhaps best to keep in mind that, in this context, potassium alum is used as a generic name, rather than as a signifier of mineralogical identity.

Alum, the raw material, originated from two volcanic landscapes i.e. Melos, SW Aegean, Greece and the Aeolian Islands, in the Tyrrhenian Sea, Italy (figs.1a/b/c). Today

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we know that this is solfataric alum consisting primarily but not exclusively of natural alunogen and/or natural potassium alum as well as a host of other soluble and insoluble alum group minerals (Table 1). This type of raw material would have been extracted and processed quite differently from alunite (rock alum), also known in antiquity and originating from other sources (for example, Egypt) requiring roasting prior to lixiviation (i.e. immersion in water in order to separate the soluble from insoluble components.

In reference to the alum (*alumen*) of Melos, Pliny[8] discusses three types: *stypteria phorime* (meaning, abundant), *stypteria paraphore*, and *melinum*. The former is described as 'liquid'. Our work so far, on Melos, has matched *melinum* with alunite ($KAl_3(SO_4)_2(OH)_6$), (in association with quartz and kaolinite), and 'liquid' alum (*stypteria phorime*) with solfataric alum, primarily alunogen ($Al_2(SO_4)_3{\cdot}17H_2O$) with or without potassium alum ($KAl(SO_4)_2{\cdot}12(H_2O)$). It is not clear whether *stypteria paraphore* was 'liquid' or solid. Pliny describes alum as 'earth exudations' (*salsugo terrae*), clearly pointing to solfataric alum (see below). Whether the 'liquid' alum was liquid (or gel-like) because of processing or because it was liquid in its natural state remains unclear. Nevertheless, travellers to Melos in the 18th century reported seeing alum 'liquor' in a cavern in the southeast of the island (*a cavern which distils this aluminous liquor*).[9]

Fig. 1: 1a: Map of the Mediterranean with some well-known localities with solfataric alum (Italy: Ischia, Naples, Lipari, Vulcano; Greece: Melos, Sousaki, Thera, Kos/Nissyros) – 1b: the island of Melos with place names mentioned in the text – 1c: the island of Vulcano with place names mentioned in the text

Mineral	Chemical formula	Colour
Alum-(K)	$KAl(SO_4)2.12H_2O$	White
Alunite	$KAl_3(SO_4)_2(OH)_6$	White
Alunogen	$Al_2(SO_4)_3.17H_2O$	White
Anhydrite	$CaSO_4$	Colourless to pale blue
Ettringite	$Ca_6Al_2(SO_4)_3(OH)_{12}.26H_2O$	Colourless to yellow
Halotricite	$FeAl_2(SO_4)_4.22H_2O$	Colourless – white
Gypsum	$CaSO_4.2H_2O$	Colourless – white
Hydrobasaluminite	$Al_4(SO_4)(OH)_{10}.12\text{-}36H_2O$	White
Millosevichite	$Al_2(SO_4)_3.17H_2O$	Red
Natroalunite	$NaAl_3(SO_4)_2(OH)_6$	Grey-white
Pickeringite	$MgAl_2(SO_4)_4.22H_2O$	Colourless – white
Steklite	$KAl(SO_4)_2$	Colourless – white
Sulphur	S	Yellow
Tschermigite	$(NH_4)Al(SO_4)_2.12H_2O$	Colourless
Tamarurgite	$NaAl(SO_4)_2.6H_2O$	Colourless
Voltatite	$K_2Fe^{2+}{}_5Fe^{3+}{}_3Al(SO_4)_{12}.18H_20$	Green to greenish-black

Table 1: Sulphate and aluminium sulfate minerals from Campi Flegrei, Naples and Melos and Vulcano, Aeolian Islands.

The purpose of this short paper is to draw attention to the extraction of solfataric alum in the G-R period to experimentally simulate the dissolution-evaporation cycle underpinning solfataric alum enrichment by using samples of solfataric alum (from the Aeolian island of Vulcano). The laboratory-based experiments aim to provide some insight into how alum might have looked after processing (in colour, hue) and how it would have travelled (as ‘liquid’ or solid). We suggest that alum, the product shipped out from these sources, would most likely have travelled as a gel, rather than a powder. Brief mention is made of the two amphorae, one from Melos and the other from Lipari, thought to have been used for the transport of alum.

Solfataric Alum

Solfataric alum is associated with fumaroles, i.e. vents where ‘steam’, containing gases like carbon monoxide and hydrogen sulphide, is emitted from the earth. A field of fumaroles is called a solfatara. Solfataric alum forms efflorescences, or mineral growths, which are transported to the surface as dissolved sulfate compounds and precipitate near the vent (fig. 2a). They form thick ‘sheets’ of white material that can be removed relatively easily from the walls and ceilings of caverns, contrary to open air vents which can loose these precipitates in the first rain, through dissolution. Today there are several localities across the Mediterranean with variable evidence for solfataric activity (fig.1a). Solfataras, together with hot springs, on land or under water, and warm soils (c. 60°C) are manifestations of an active geothermal field and by extension, of dormant volcanic activity. Melos has a geothermal field which was strong in the G-R period and most likely until the 18th century.[10] Presently, this field remains strong, although its surface manifestations are wanning. In Melos, the fumaroles that can be visible today occur largely in the southeast part of the island (Kalamos, Aghia Kyriaki, Palaeochori) (fig.1b); it is there that most of the archaeological evidence for likely Roman alum exploitation is concentrated.[11]

From the Roman period onwards soluble potassium alum was ‘synthesized’, by roasting insoluble alunite (probably mixed with other minerals as well), and subsequently immersing the roasted ore into vats full of water. Soluble potassium alum would readily dissolve in water, and subsequently collected following evaporation. Archaeological

Fig. 2: 2a: Photo of aluminium salts precipitating out of salt-rich steam and deposited around vents, within the Fyriplaka cavern, SE Melos. These incrustations can be removed easily by hand – 2b: Entrance to the Cave of Alum, Faraglione, Vulcano. Both at the entrance and interior of the cave, there is large variety of white/off-white crystals of various aluminium sulfates forming encrustations of various thickness. Main ‘door’ entrance: 1.6 m high.

evidence for the extraction and processing of alunite-rich rock comes from 7th century CE Lesvos, in the northeastern Aegean.[12] In later periods, rich alunite deposits were worked in Italy, near Rome and in Aegean Turkey.[13]

Regarding the processing of solfataric alum, natural alunogen or or potassium alum, Singer quotes the mining expert,[14] Fougeroux de Bondaroy who visited the area of the Campi Flegrei near Naples and its associated solfataras, in 1755. The hot soils of the Campi Flegrei were used as an energy source. Fougeroux de Bondaroy's illustration (fig. 3a) shows a large tank (c) full of water placed into the hot soils; the alum earth (d) was thrown in and mixed thoroughly to dissolve the soluble salts. The supernatant liquid from the large tank was then removed and deposited into cauldrons (e), which were also embedded in the hot soils. Most of the water would eventually evaporate and the thick layer of pure crystallised alum salt would be removed and packaged.

We have suggested that similar cycles of dissolution-evaporation of natural solfataric alum probably took place in the G-R period in Melos, using the hot soils of the southeastern part of the island (Aghia Kyriaki, fig. 1b), as a heat source. Direct evidence is hard to come by. There is hardly any mineralogical difference in composition, shape, and form between raw materials, intermediate waste and products; furthermore, the installations which could have been in place in the G-R period can only be considered very basic. In the absence of clear archaeological evidence for the processing of the soluble alum group minerals, we have proposed a model for its processing (fig. 3b).

Apart from Melos, another key producer of alum in the G-R period was the Aeolian island of 'Lipari'.[15] We take 'Lipari' to refer either to the island itself or the entire cluster of Aeolian islands, or specifically to the islands of Lipari and neighbouring Vulcano. Today there is relatively limited evidence for fumaroles on Lipari,[16] although in antiquity it might have been quite different. On the other hand, solfataric alum and sulphur were exploited in Vulcano as recently as the late 19th century, probably using methods no different than those practiced in the G-R period.[17]

Regarding the geological appearance of alum on Vulcano, alum, sulphur and alunite are present in the Faraglione area and in the crater, La Fossa (fig.1c); kaolin is present in the Faraglione but not in the crater. Vulcanello, in the northern part of the island, is a small island which formed as a result of a volcanic eruption in 180 AD.[18] Faraglione and Vulcanello are characterized almost exclusively by soluble alum salts, slightly soluble sulfates, like gypsum, and insoluble sulfates like alunite and natroalunite (Table 1); there is also native sulphur. Vulcanello is poor in mineralogical variability. The difference in mineralogy between La Fossa and the Faraglione is due to the temperature and composition of the gases as well as chemical modification (not mixing) procedures between different sources.[19] The La Fossa crater is dominated by high temperatures (up to 400°C or higher is common, even close to the surface), Cl-SO_4-rich water, with Boron, Fluorine and metals, deriving from single-step condensation of high enthalpy fluids.[20] By contrast, the flat lands to the north, Faraglione, and Vulcanello are characterized by modification of the shallow aquifers by the input of chemical elements and enthalpy

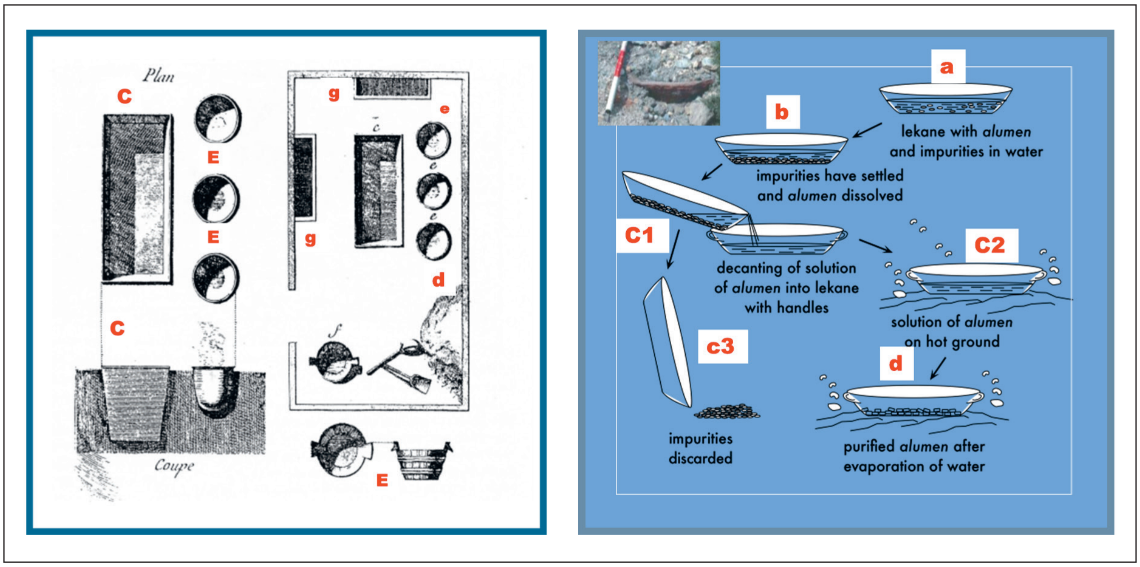

Fig. 3: 3a: Plan of hut at Campi Flegrei, near Naples, after de Fougeroux de Bondaroy (18th century)(presented in Singer 1948): a large tank (c), full of water was placed into the hot soils; the alum earth (d) was thrown in it and mixed thoroughly to dissolve the soluble salts. The supernatant liquid from (c) was then removed and deposited into cauldrons (e), which were also embedded in the hot soils. Vats (g) dedicated to other types of minerals, like ammonium chloride, which was also extracted from the same area, at the time – 3b: top left: lekane (shallow wide-open ceramic vessel) likely to have been used in the evaporation of alum salts, embedded within sediments, Aghia Kyriaki, Melos. Main illustration: schematic diagram of the dissolution-evaporation stages within lekanae: (a) shows one of these vessels filled with water and salts and embedded in hot soils; (b) non-soluble minerals settle in the bottom while soluble ones are decanted into a new vessel and placed elsewhere on the solfatara; (c) pure alunogen and/or other soluble minerals as well, are collected and packaged.

from the ascending fumarolic vapours, which are separated from the high temperature hydrothermal aquifer.[21] These steam-heated modified hydrothermal fluids have a considerably lower temperature close to the surface (c. 100℃), which increases to 200℃ at a depth of 200 m.[22]

The main source of alum on Vulcano's Faraglione area is the Cave of Alum (*Cave di Alume*) (fig. 2b), presently the site of a cavern extensively exploited in the 19th c and overlooking the island's main port. The cavern is not open to the public, but, having acquired permission from the landowner to map its interior we have created a 3D sketchfab model[23] thereof allowing one to 'navigate' its interior. The samples collected from the cavern have a distinct mineralogy consisting entirely of aluminium salts such as alunogen, pickeringite, magnesio-aubertite (a rare mineral which has Vulcano as its type locality) and tamarugite (Table 1). There are currently no active fumaroles within the cavern, only thick layers of aluminium salts, which make it a unique place to study the environment and mineralogy of this important resource. 19th century documentary records suggest that the products of that mine were processed in 'workshops' in its immediate vicinity.[24]

Experimental Work

For the laboratory-based experiments described in this paper we used one sample, CAVAL 1, deriving from the Cave of Alum, Faraglione, Vulcano (fig. 4a-left). 30 g of CAVAL 1 were placed in a beaker with 100 ml of distilled water. CAVAL 2 (fig. 4b-middle) represents the milky white solute which formed and was allowed to settle and was subsequently filtered, resulting in CAVAL 3a (fig. 4c-right). CAVAL 3b was the coarse-grained residue which was retained by the filter paper. CAVAL 3a was then placed on a hot plate and heated to c. 100°C for 30 minutes. The result was a gelatinous mass (CAVAL 3c, fig. 4d) which was poured out on a plastic boat and allowed to cool.

Further to the above, an additional batch of 30 gr of CAVAL 1 was dissolved in 100 ml of distilled water, resulting in CAVAL 7a, the milky-white solute, and CAVAL 7b, the residue in the beaker. CAVAL 7a3 was the residue retained by the filter paper. CAVAL 7a (milky solute) was then divided in two parts: CAVAL 7a1 was the (re)filtered solute, while CAVAL 7a2 was the unfiltered solute, the same as CAVAL 7a. Both were heated to c. 100°C for 30 minutes. CAVAL 7a2 was removed from the hot plate just before dryness. A gel was formed which upon cooling was poured into another plastic boat. Unlike CAVAL 7a2, CAVAL 7a1 was allowed to evaporate to full dryness, resulting in a gelati-

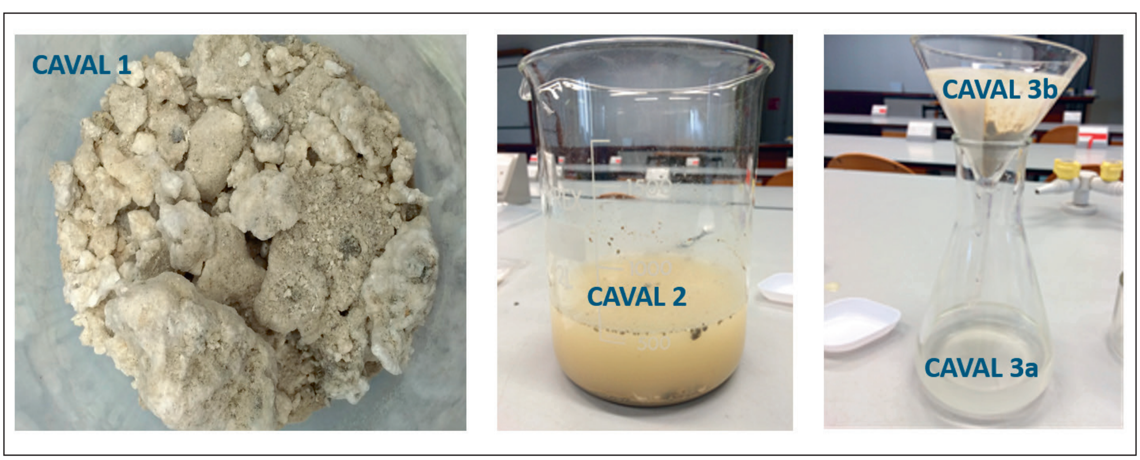

Fig. 4: from left to right: 4a: CAVAL 1, sample of 'alum' from Cave of Alum, Faraglione, Vulcano – 4b: CAVAL 2, milky white solute, arising from the dissolution of CAVAL 1 in water – 4c: CAVAL 3a: near-clear solute following filtering: CAVAL 3b: residue retained in the filter paper.

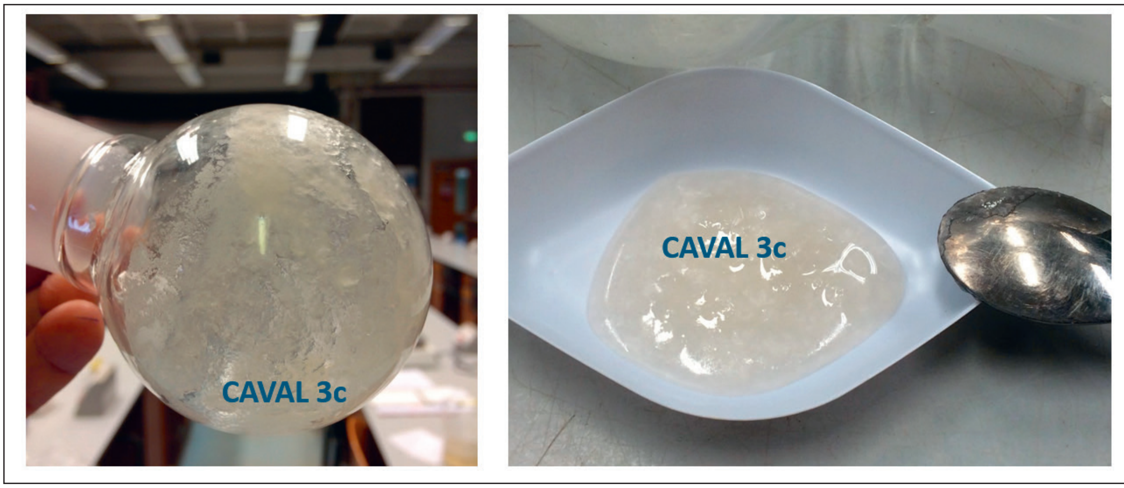

Fig. 4d: CAVAL 3c, a gel-like material, is the product obtained after heating CAVAL 3a at near 100℃, for approximately half an hour; the sample was not allowed to go to complete dryness complete dryness.

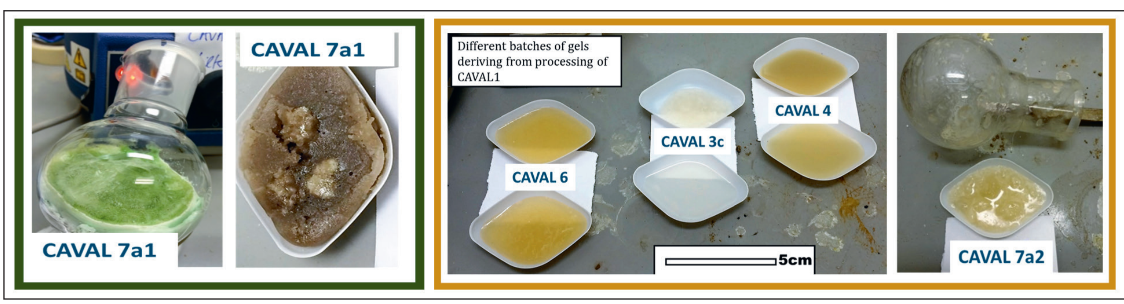

Fig. 5: 5a: green solid mass of CAVAL 7A1 resulting from over heating/heating to dryness. When water was poured in the glass vessel the mixture turned a grey brown, a colour it retained upon cooling – 5b Different batches of processed CAVAL 1 heated but not to dryness resulting in gel-like materials of the compositions shown in Table 2.

nous mass of green colour that adhered to the glass walls (fig. 5a). When 10 ml of water was added to this mass the gel dissolved and the colour of the solution changed from green to dark grey. The colour and gel-like nature of CAVAL 7a2 is shown in fig. 5b together with gels produced from the dissolution-evaporation of other subsamples of CAVAL 1.

X-ray Diffraction Analysis

The mineralogical composition of the Vulcano samples was determined with X-ray diffraction (XRD) at the School of Mineral Resources Engineering, Technical University of Crete, using a Bruker D8 Advance Diffractometer equipped with a Lynx Eye strip silicon detector, and using Ni-filtered CuKα radiation (35 kV, 35 mA). Data were collected in the 2θ range 3–70° 2θ with a step size of 0.02° and counting time of 1 s per strip step (total time 63.6 s per step). The XRD traces were analysed and interpreted with the Diffrac Plus software package from Bruker and the Powder Diffraction File (PDF). The quantitative analysis was performed on random powder samples (side loading mounting) by the Rietveld method using the Autoquan©software package version 2.8.

Results

The results of the XRD analyses are presented in Table 2. A small sub-sample was removed from CAVAL 1 and was analysed by X-ray diffraction (XRD) (fig. 4). The sub-sample contained both hydrous and anhydrous minerals as well as amorphous matter which could exceed 40% (by mass) and some unknown phases constituting 10% (by mass) of the total. The minerals presented here make up the remainder 50% and refer to the crystalline phases. The alum minerals are aluminium sulfates, potassium, sodium or magnesium sulfates or iron aluminium sulfates. There is also the less common magnesium-bearing copper aluminium sulfate (Mg-aubertite).

CAVAL3c and CAVAL7a2, which are enriched subsamples of the original CAVAL 1, are mineralogically different. The latter is rich in alunogen (major) and pickeringite (minor) plus tamarurgite (minor), while the reverse is true for CAVAL3c: pickeringite (major) and alunogen and potassium alum (minor). CAVAL3c was filtered before heating but CAVAL7a2 was not; CAVAL3c is characterised by a clear/off-white colour, while CAVAL7a2 has a distinct yellowish tint, suggesting iron-rich phases. However this has not been verified by XRD analysis suggesting levels below the limit of detection.

CAVAL7b and CAVAL7a3 represent residues: the first settled at the bottom of the beaker, the second was retained by the filter paper. In both cases all partly soluble/insoluble minerals (gypsum, anhydrite, natroalunite and jarosite) settled or were retained but some alunogen was 'lost' to the residue.

Unlike CAVAL7a2, CAVAL7a1 was heated to complete dryness, resulting in a bright green-coloured gel attached to the flask wall and which may be associated with the presence of rozenite. To remove it from the flask, water had to be added, in which instance, the gel turned from green to dark grey. It is not clear why there was that colour change.

From the above results we conclude that when different sub-samples of CAVAL 1 underwent enrichment, the resulting product was a gel-like material in all cases. What

<	sample description	Alunogen $Al_2(SO_4)_3 \cdot 17H_2O$	Potassium-alum $KAl(SO_4)_2 \cdot 12H_2O$	Gypsum $CaSO_4 \cdot 2H_2O$	Anhydrite $CaSO_4$	Natroalunite $NaAl_3(SO_4)_2(OH)_6$	Tamarugite $NaAl(SO_4)_2 \cdot 6H_2O$	Hexahydrite $MgSO_4 \cdot 6(H_2O)$	Pickeringite $MgAl_2(SO_4)_4 \cdot 22H_2O$
CAVAL 1	original ‚alum‘ sample	12,5		5,8			14,6		47,3
CAVAL 3C1	filtered solute (3a) after heating at 100C	7,5	4,3						88,2
CAVAL 7A2	unfiltered milky solute = 7a	92,7					1,7		5,6
CAVAL 7A1	filtered milky solute of 7a	14,5	0,7				15,7	17,9	47,4
CAVAL 7A3	insoluble part of CAVAL 1 and similar in composition to 7b	14,5		13,4	2,4	37,4			
CAVAL 7B	insoluble part of CAVAL 1 and similar in composition to 7a3	15,9		56,2		16,4			
		Aubertite $CuAl(SO_4)2Cl \cdot 14H_2O$	Sulphur-a	Jarosite $KFe^{3+}3(OH)_6(SO_4)_2$	Halotrichite $FeAl_2(SO_4)_4 \cdot 22H_2O$	Rozenite $Fe^{2+}SO_4 \cdot 4(H_2O)$	Amorphous	Unknown phases	
CAVAL 1	original ‚alum‘ sample			5,6	9,4	4,8	×	×	
CAVAL 3C1	filtered solute (3a) after heating at 100C								
CAVAL 7A2	unfiltered milky solute = 7a								
CAVAL 7A1	filtered milky solute of 7a			0,8		3			
CAVAL 7A3	insoluble part of CAVAL 1 and similar in composition to 7b		5,5	26,8					
CAVAL 7B	insoluble part of CAVAL 1 and similar in composition to 7a3			11,5					

Table 2: The minerals identified by XRD in the experimental samples. Values in weight percent.

was different was the final colour of the gel, reflecting variation in relative amounts of iron bearing minerals. When traces or indeed larger quantities of iron were present, the resulting gel went from a light yellow (CAVAL 7a2) to deeper yellow-brown as in CAVAL 4 and CAVAL 6 (we have no XRD data for these two samples). We suggest that the colour of gel might have dictated different uses in mordanting i.e. the clear/off white for white cloth, the darker shades for darker cloth.

Pliny alludes to stringent tests (with pomegranate juice) for quality control of commercial alum, implying than even small amounts of iron would be unacceptable to traders and users of alum as a mordant.[25] A non-clear/white alum sample, when used as a mordant, would have had an adverse effect on the final colour of the dye particularly for light colours. Separating soluble iron sulfates such as halotrichite from soluble alunogen/potassium alum could not have been straightforward. Nevertheless, Pliny refers to some practice whereby "the part that is collected (from the cavities where it is placed in the winter …) first is the whiter" pointing to some method of separation involving fractional crystallization.[26] Fractional crystallisation, if indeed practiced in antiquity, would have been a very efficient way of dealing with the complex nature of the raw material where even trace amounts of impurities would have had a drastic effect on the quality of the final product, as shown in figs 4 and 5. It is therefore possible that both clear/white alums and 'tinted'/dark alums were manufactured intentionally. The latter may have been used apart from mordants for darker colours for other industries, like tanning.

Alum Amphorae

It has been claimed that alum travelled in dedicated amphorae: Melos type 1a amphora is thought to have been produced in Melos[27]; while Richborough 527 was manufactured in Lipari. Neither of them was deemed suitable for foodstuffs.[28] The Melian amphora circulated between the end of the first century BC/first century CE until at least the third century CE.

It would be difficult to confirm the above hypotheses. Be that as it may, our experimental simulations have shown that processed alum would have largely travelled as a gelatinous mass in *an* amphora-type container, either exclusively dedicated to it or not. Aluminium sulfates are highly hygroscopic, meaning that they readily attract and hold on to moisture or water molecules from the environment either via absorption or via adsorption. This suggests that if powdered aluminium sulfates, rather than gels of the same, travelled in sealed amphorae over long distance and by sea, on arrival the powdered contents may have agglomerated into a 'sticky mass' which would have been difficult to empty. This may have necessitated the breaking of the amphora to recover the contents and perhaps even further treatment of the latter (drying/grinding or other process). By travelling as gels, aluminium sulfates would have travelled safely to their destinations. Regarding its shelf life, it is expected that the gel would eventually begin to crystallise, with the rate of crystallisation being dependent on levels of moisture and temperature associated with storage. The simple reconstruction experiments described above, combined with XRD analysis of the minerals found within each sub-sample, lead us to the following conclusions:

Conclusions

- In the Greco-Roman period, solfataric alum consisting of a number of soluble and insoluble alum group minerals was perhaps the likely raw material for industries requiring large quantities thereof such as, for example, mordants for textiles or the tanneries. Solfataric alum was relatively easy to extract from fumaroles within caverns, once access into the latter was made possible. Open-air solfataras (outwith caverns), once may have had a temporary cover placed over them so that the deposited salts were not washed away in the first rain.
- The solfataric alum was most likely processed through a dissolution-evaporation cycle for the express purpose of removing insoluble components. This was achieved in an 'eco-friendly' way, namely with the use of the solfatara's hot soils as an energy source. It required no more sophisticated equipment than large ceramic containers embedded into these soils.
- Our simple experimental reconstruction showed that enriched solfataric alum would range from clear/white to tinted yellow to dark brown. A clear or off-white alum batch consisting of minerals like alunogen, potassium alum, or magnesium alum would be appropriate as a mordant of white cloth. Others with a distinct greenish and/or brownish hue consisting of the above but with iron sulfates as well, may have been used for darker colours and/or other industries. Pliny's advice that one should check quality (absence of iron) with some natural reagent, is a reminder of the industry's need for mordants that would not taint the fabric.
- Overheating the enriched alum beyond the evaporation stage appears to have generated new anhydrous phases like hexahydrite, resulting in a significant reduction in the grade of the alum (as per colour) in a mechanism that is not yet clearly understood.
- Finally, it appears that alum transported as a gel in amphorae may have been the best option since it combined a substantially enriched raw material with the reassurance that it would arrive at its destination, unaltered and ready for use. In the archaeological record, how commodities travelled, is normally examined from the perspective of the container and rarely from the perspective of the contents. This brief experimental work shines the light on the latter.

Notes

[1] Singer 1948; Borgard et al. 2005.
[2] Firth 2007.
[3] Levey 1958.
[4] Hdt. 2, 180.
[5] De Materia Medica V.123.
[6] Plin. Nat. HIst. 35, 52.
[7] Photos-Jones et al. 2016.
[8] Plin. Nat. HIst. 35, 52.
[9] Photos-Jones – Hall 2014.
[10] Hall et al. 2003a; 2003b; Photos-Jones – Hall 2010.
[11] Photos-Jones – Hall 2014.
[12] Archontidou 2005.
[13] Singer 1948.
[14] Singer 1948, 173.
[15] Plin. nat. 35, 52.
[16] see Cave di Kaolino.
[17] Photos-Jones et al. 2018.
[18] Harry 2002.
[19] Federico et al. 2010; Inguaggiato et al. 2018.
[20] Garavelli et al. 1997.
[21] Inguaggiato et al. 2018.
[22] Federico et al. 2010.
[23] <https://sketchfab.com/models/7d9c5bcf95b948ae95091cd36a502d4d> (last accessed 18th September 2021). We are indebted to Dr Brian Barrett, Geographical and Earth Sciences, Glasgow University, for the preparation of this model, originally presented in Photos-Jones et al. 2017.
[24] Salvator 1893.
[25] Plin. nat. 35, 52.
[26] Hall – Photos-Jones 2009.
[27] Raptopoulos 2005. <https://archaeologydataservice.ac.uk/archives/view/amphora_ahrb_2005/details.cfm?id=375> (last accessed 18th September 2021).
[28] Borgard – Cavalier 2003; Borgard 2005.

Image Credits

Fig. 1: after Photos-Jones and Jones 2018, fig. 1 and annotated Google Earth maps, by the authors – Fig. 2: by the authors – Fig. 3a: after Singer 1948, fig. 103.– Fig. 3b: Photos-Jones – Hall 2014, fig. 8.14.– Fig. 4–6: by the authors. – Table 1: adapted and expanded from Photos-Jones et al. 2018. – Table 2: by the authors.

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New Insights into an Old Iron Mining Landscape: Elba Island

Raphael A. Eser – Fabian Becker

Abstract

While the ancient mining of iron ore and its further processing on Elba Island is an undeniable fact, the duration of iron production and its impact on the island's landscape is still not clear. Modern research assumes different beginnings for the exploitation and smelting of iron. In contrast, the end of iron production is dated exactly to the mid-1st century BC and linked to different reasons, including lack of fuel wood, preservation of resources, and cheaper iron from the provinces.

Our paper presents the recent archaeological results of an interdisciplinary research project on ancient iron mining and smelting on Elba. On the basis of archival material, new 14C-dates, and the current state of the art, the following aspects are discussed: 1) the chronology and (re-)location of ancient iron mines; 2) the prolonged chronology of iron smelting on Elba; 3) the development of iron processing through Elba's *longue durée.*

New radiocarbon dates and currently underestimated archaeological finds indicate a new chronology of iron production from the 6th century BC to the 2nd century AD. The topo-chronological evaluation shows a concurrent acceleration of smelting even in remote areas of Elba in order to make use of the secondary resources as well as already existing maritime trade routes. The continuation of Elban iron production after its presumed end in mid-1st century BC is contrary to the development on the Tuscan mainland.

Elba Island: a Mining Landscape for Millennia

Nothing has shaped the landscape of Elba Island more than its iron. Although there was copper production by the indigenous population during the Early Iron Age,[1] the iron mines were key to the island's history on a superregional scale. Indeed, an early beginning of iron exploitation is often cited,[2] with the first exploiters likely coming from just 11 kms across the sea. The Etruscan city-state of Populonia, already a metallurgical centre of copper smelting, transformed into a hotspot of iron processing around 600 BC (fig. 1b).[3] Fostered by the iron from Elba and other metals from the *Colline Metallifere* – the heartlands of *Etruria Mineraria*[4] – Populonia's economic importance increased. Therefore, the Syracusans raided Elba in 453/52 BC, certainly attracted by the iron deposits. Given different dangers from the south, protection of Elba became an emerging factor.[5] As a response to that, multifunctional, fortified hilltop settlements

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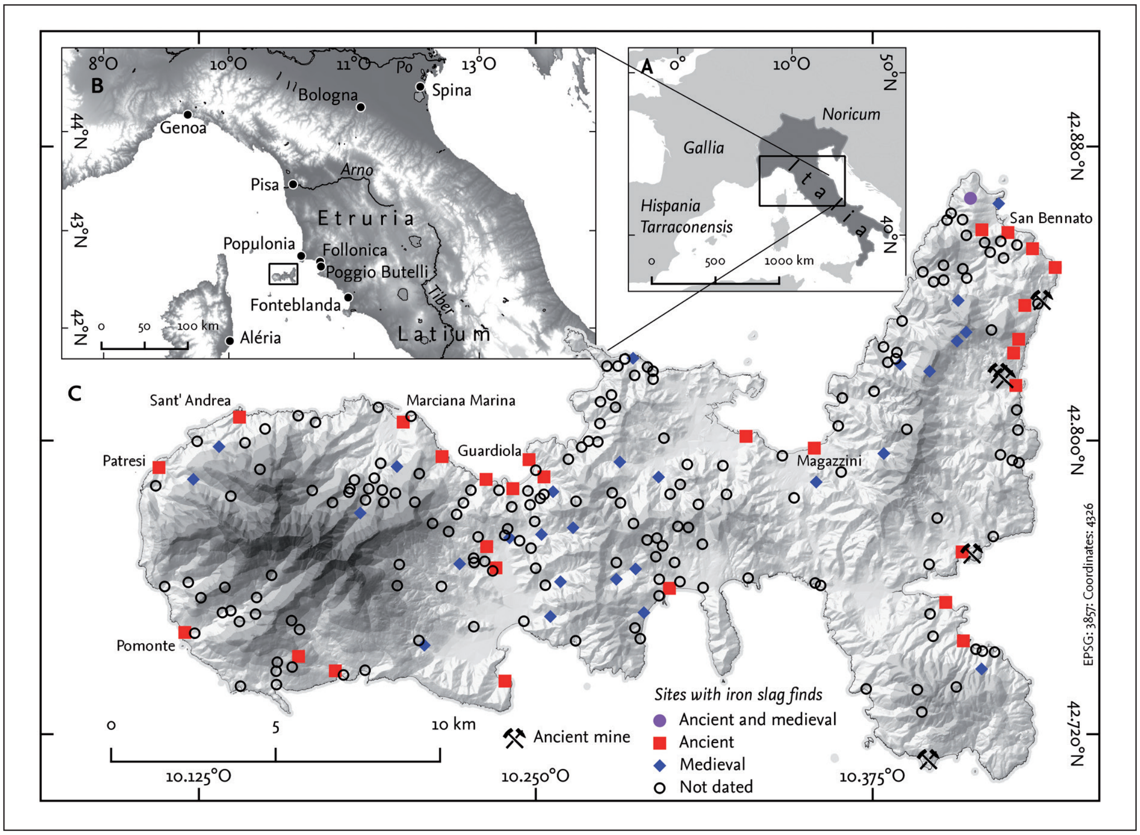

Fig. 1: A: *Italia* and adjacent provinces of the early Roman Empire – B: Location of Elba in front of Etruria – C: Map of Elban sites with iron slag finds of different smelting periods.

were built intensifying agriculture, pastoralism, and crafts. In addition to mining, these had further impact on the landscape.

With the Roman occupation of the island (1st half of the 3rd century BC), the entire island was actively used for iron production. Smelting sites were installed not only close to the mines, but also in the far west of the island to exploit all (forest) resources.[6] For more than two centuries, huge amounts of waste were dumped in the mines and tons of slag were left on the plains and beaches of Elba. Since the mid-1st century BC, Elban iron production decreased due to a lack of fuel,[7] or political decisions, such as the conservation of resources or cheaper iron from the provinces – to name a few possible reasons.[8] Subsequently, the island turned into a resort with luxurious villas during the Roman Imperial era.[9] Populonia's iron production struggled and ceased in the 1st century AD. Poets of the late antiquity can only write about Elba's former legendary wealth of iron.[10]

A hiatus in iron production lasted until the 11th century AD, when the Masters of Pisa reactivated iron exploitation on Elba.[11] Seasonal smelting took place in inland locations until the end of the 14th century AD.[12] After an internal government conspiracy, Pisa lost the only active mine of Rio to the new Masters of Piombino, who could hardly defend their iron against pirates and opponents. Although the rulers over Elba changed continuously between the 16th and 19th century – Medici, Neapolitan/Spanish, English, Napoleon, and the Grand Duchy of Tuscany – Rio's raw ore was still traded.[13] From 1853, travellers' and mineralogists' reports about old waste dumps and large, ancient slag heaps[14] promoted the exploitation of Elba's iron mines with up-to-date methods. Unfortunately, centuries-old findings from Rialbano to Capo Calamita (fig. 2) were overprinted without any archaeological documentation.[15] As Italy proclaimed autarky in iron supply in the interwar years, ancient iron-rich slags from Elba, Populonia, and Poggio Butelli were mined and re-smelted. Most archaeological evidence was destroyed without any record.[16] After World War II, Elba's iron industry declined, and tourism became the most important sector. With the closing of the last mine in 1981,[17] Elba lost its long-lasting importance as the ironworks of Italy. However, the imprint of mining and smelting activities has remained in the landscape.

In this paper, we discuss the chronology and topography of iron mining and smelting on Elba using archival material and new 14C-dates to establish several spatio-temporally distinct phases of iron production in antiquity.

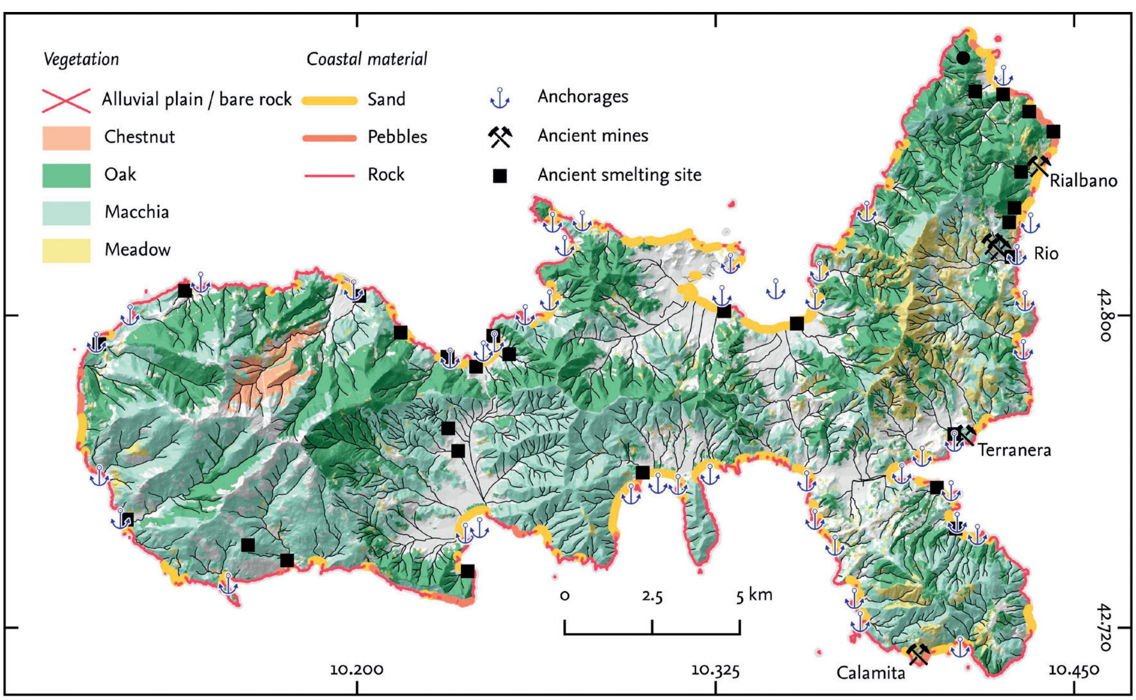

Fig. 2: Map of Elba with ancient smelting sites, beach characteristics, historical anchorages, present forest cover, and creeks.

Iron Mining on Elba: its Beginnings and Locations

If a society (e.g. Etruscan or Roman) wishes to achieve economic progress over the *longue durée* by mining, ore deposits must fulfill certain requirements.[18] Elba's iron ore deposits favour this development:

- Quality ore: Analyses showed predominately high-quality hematite mineralization with an iron content of c. 73% in the northern part (Rialbano, Rio, and Terranera; fig. 2).[19] The magnetite ores of the Calamita Mine in the southeast have also relatively high iron contents (approximately 52%).[20]
- Accessibility: All mines are located directly on the coast, which promotes sea-based transportation of large quantities of ore with lower costs than inland transport. Due to the geological setting of eastern Elba, all ancient deposits could be exploited by open-pit mining.[21]
- Sustainability: Long-term and permanent use of Elban ore deposits was secured. This is not only proved by the ancient topos of the 'inexhaustibility' of the mines,[22] but also by their exploitation in the Middle Ages and modern times.

The onset of mining on Elba is mainly dated by indirect evidence. Even today, it is claimed without any evidence that iron mining began in the 10th century BC.[23] The scarce occurrence of early iron in northern Etruria from the same time[24] makes it clear that this date is too early. Indirect evidence of early iron mining on Elba in the 8th century BC[25] has been taken from a hematite fragment found in the *Scarico Gosetti* on Pithecusae/Ischia.[26] However, its validity can be doubted for several reasons: (I) The fragment was found in a secondary, non-stratified context with finds ranging from the Late Bronze Age to the 2nd century BC.[27] (II) The Elban origin of the ore was declared by macroscopical analysis and thus the result should be handled carefully without supplementary analysis.[28] (III) Even if the small ore fragment is of Elban provenance and dates to the 8th century BC, it can be assumed that such sized material was used just for jewelry production,[29] which did not require large-scale mining on Elba.

Another issue besides dating is the exact location of ancient pits. However, old reports and occasional maps[30] from the beginning of the modern mining era (1853) have assisted in some re-localisations. For instance, in 1862, W. Jervis reported on the Rialbano mining district (fig. 3a):

> "An ancient excavation is seen above the present one, on the sea cliff, and a line of similar ones is reached on ascending the hill. […] the abundance of *gettate* [i.e. overburden] all around prove the agency of man."[31]

This corresponds well to a sketch of the Grattarino mine, in which ancient overburden is documented left and right of a deeply engraved mining hollow.[32] As no medieval phase is known, this mine may be considered of ancient date.[33] Ancient open pit mining was also documented for the Terranera mine (fig. 3c).[34] Here, the overburden overlaid the

Fig. 3: Ancient mines of Elba with modern overprint; a: Rialbano – b: Vallone stope at Capo Calamita – c: Terranera – d: Bacino stope at Rio.

ore body and reached into the sea; during its removal (since 1880), fragments of ancient glass, copper sheets, terracotta, and copper nails were discovered.[35] An earlier planned exploitation in the Spanish period (18th century) apparently never took place due to the bribe of the Neapolitan prime minister.[36] A further sign of (small-scale) mining in antiquity is the reported overburden in the Vallone pit at Capo Calamita (fig. 3b); a wedge of bronze with traces of attrition suggests ancient mining on site.[37]

It is even possible to locate ancient mines in the long-living mining district of Rio[38] (fig. 3d). The mineralogist A. Krantz visited the mine three times – in 1835, 1839, and 1840 – before industrial exploitation started in 1853. Krantz published a geological map with areas of overburden that he distinguished between *gettate antiche* (ancient waste dumps; fig. 4, nos. I, II, XI) and *gettate vecchie* (old waste dumps; fig. 4, nos. XXI, XXIII).[39] Rusty mining tools of probable ancient origin were sometimes found in the *gettate antiche* and the possible sole ancient gallery called *'grotta romana'*.[40] Although this does not allow exact dating, it is clear that the Rio pits were active during antiquity. Further, a silver coin hoard – the final coin is dated to 74 BC – was discovered in 1902

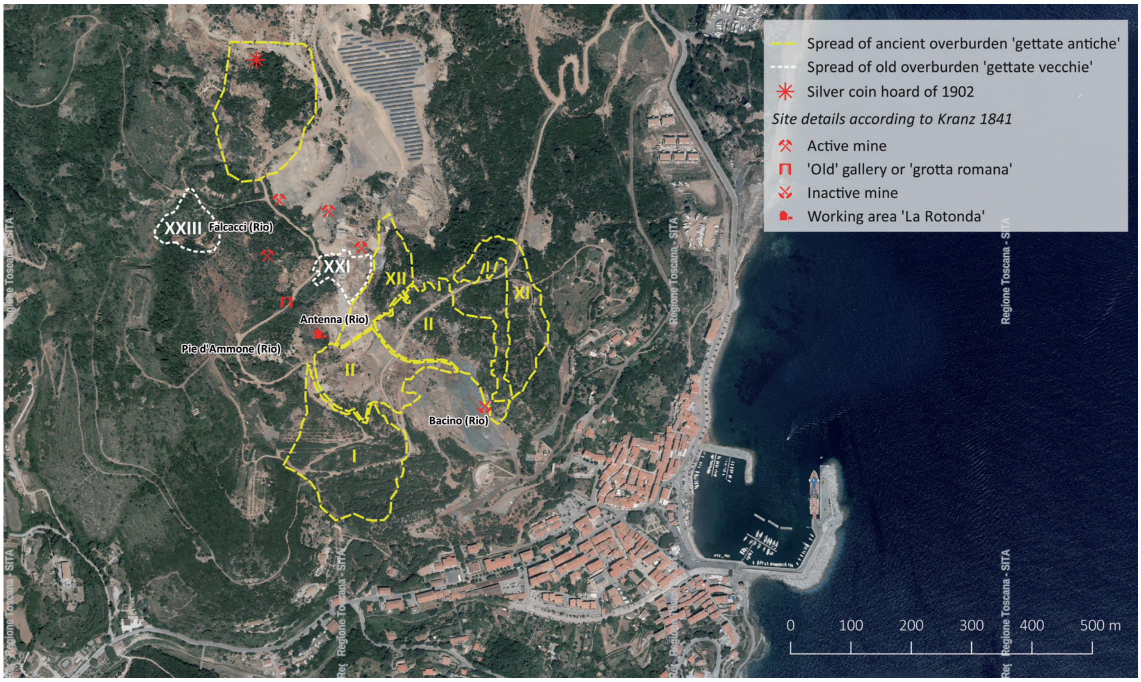

Fig. 4: Location of ancient and old overburden according to Krantz 1841 on modern satellite image.

in the northernmost overburden at Pozzo Fondi (Fig 4., without no.)[41] which points to mining around this date. From the location of the ancient overburden, we conclude that mining took place in the Bacino and Antenna stopes.

The best evidence for early iron mining on Elba was gained indirectly from dated contexts with finds of Elban iron ore. Ore fragments from 6th–5th century BC contexts in Genoa, Aléria, and Fonteblanda are often attributed to Elba without geochemical provenance analyses.[42] Iron ores from smelting sites in Pisa, San Piero a Grado (next to Pisa), and especially in Populonia and Follonica have proven Elban provenance and date to the 6th century BC (fig. 1b).[43] Iron objects of this time were only sparingly found in two grave contexts in the western area on Elba.[44] Simultaneously, the main settlement areas moved from west to east, closer to the mines,[45] which were probably controlled by Populonia. Hence, the 6th century BC can be considered as the beginning *initial phase*[46] of iron mining on Elba and of iron metallurgy on the Tuscan mainland.

Iron Smelting: Extended Chronology and State of the Art

In contrast to the occurrence of smelting sites along the Tuscan coast in the 6th and 5th century BC, the chronological evidence of iron smelting on Elba Island – collected by surveys and a few excavations by V. Mellini, R. Sabbadini, J. Nihlén[47], and A. Corretti[48] –

points to a delayed onset of smelting with the beginning of the Roman Republican period (3rd century BC).[49] An exception is the suggested chronology of the San Bennato site opposite Populonia. According to archaeomagnetic dating, the excavated smelting furnaces were already in use in the middle of the 5th century BC.[50] However, recent recalibrations point to a huge dating uncertainty (5th–1st century BC), indicating the archaeological dating of this context to the 3rd century BC might be more reliable.[51]

New radiocarbon dates from Elban sites may point to the onset of iron smelting in the 4th century BC. In Patresi in western Elba, a beach section containing a charcoal and iron slag layer (fig. 5, no. 4) was sampled and a charcoal fragment was dated to 360–150 or 140–110 BC at 95% confidence (fig. 6).[52] The earlier dating in the late 4th (or late 3rd) century BC may be possible as the upper slag layer (no. 2) – separated by a sterile stratum (no. 3) – contains fragments of Dressel 1 amphorae. Another late 4th century BC date was obtained from an in-slag charcoal sample from the Magazzini site in central Elba (figs. 1c. 6).[53] Iron slag of the 4th century BC was found at the hilltop settlement of Monte Fabbrello, which controlled the Magazzini area.[54] Smithing slags from the hilltop

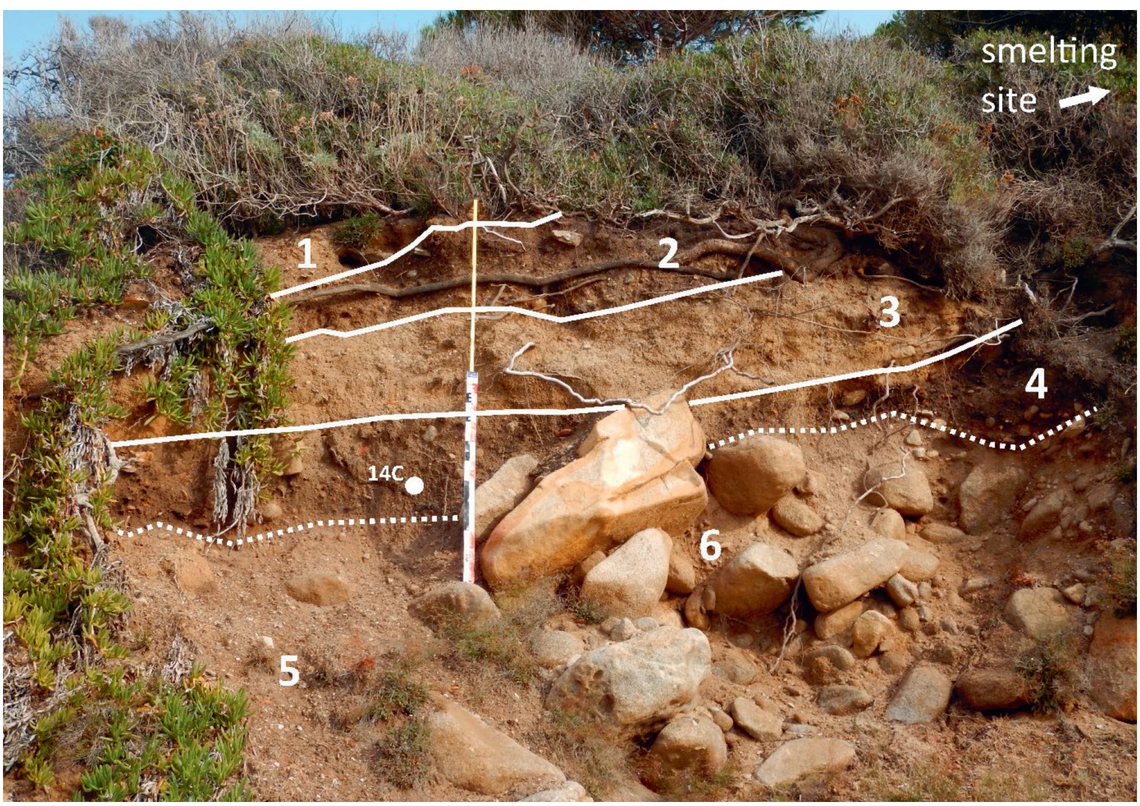

Fig. 5: Sampled beach section next to the Patresi site; 1: sterile layer – 2: slag-rich layer with Dressel 1 amphora fragments – 3: sterile layer – 4: slag-layer containing charcoal particles with spot marking the 14C-sample – 5: eroded beach section – 6: rocky layer. The profile is c. 2 m high.

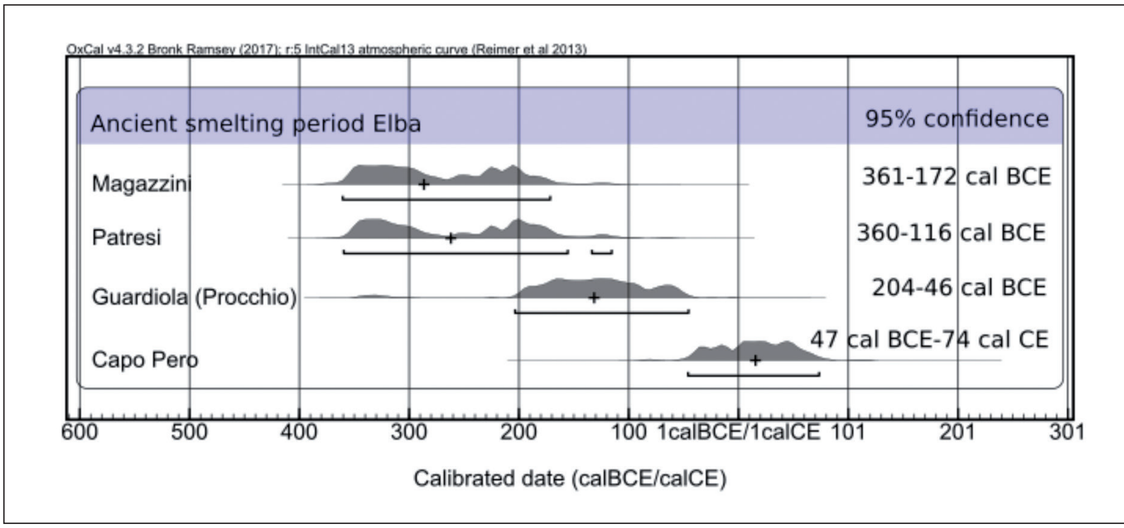

Fig. 6: Probability density functions of radiocarbon dates obtained from smelting deposits (Patresi, Guardiola, and Capo Pero), and in-slag charcoal (Magazzini).

settlement of Castiglione di San Martino – so far, the singular evidence for smithing on Elba – predate the Roman occupation.[55] Considering these dates[56], it seems possible that smelting was conducted along Elba's northern coast in the late Etruscan period.[57] An onset of smelting on Elba is reasonable in the light of the historic and economic context of Etruria. Facing threats from Celts, Syracusans, and Romans, the Etruscan city-states were in severe distress in the 4th century BC.[58] Hence, it seems only logical that there was a need to produce more of the strategically important iron using all of Elba's resources.[59]

This development towards the total exploitation of the island's resources for iron production was intensified after the Roman conquest, thus entering an *industrial phase.* Smelting sites were installed in most large bays with good landing facilities (sandy beaches) and anchorages (figs. 2. 7a). Fresh water supply came from nearby creeks (fig. 7b) and well accessible hinterlands provided further forest resources (fig. 7c).[60] For instance, smelting sites were clustered around the large Procchio bay, an area that benefited from dense vegetation on the north-exposed slopes of the Monte Capanne massif and the central Elba hills with good conditions for anchoring and landing ships (fig. 2; 7a. d). A radiocarbon date obtained at Guardiola confirmed the contemporary existance of one of these sites in the Roman heyday of smelting on Elba (2nd century BC; fig. 6).[61]

The end of iron smelting on Elba is commonly dated to the middle of the 1st century BC. However, a 14C-date obtained from Capo Pero in eastern Elba – close to the Rialbano mine – may suggest an extension of this chronology.[62] We sampled a charcoal-rich layer below a large solid slag conglomeration from the middle of the beach section. The date (50 BC–80 AD) merely points to activity at this site in the Early Roman Imperial

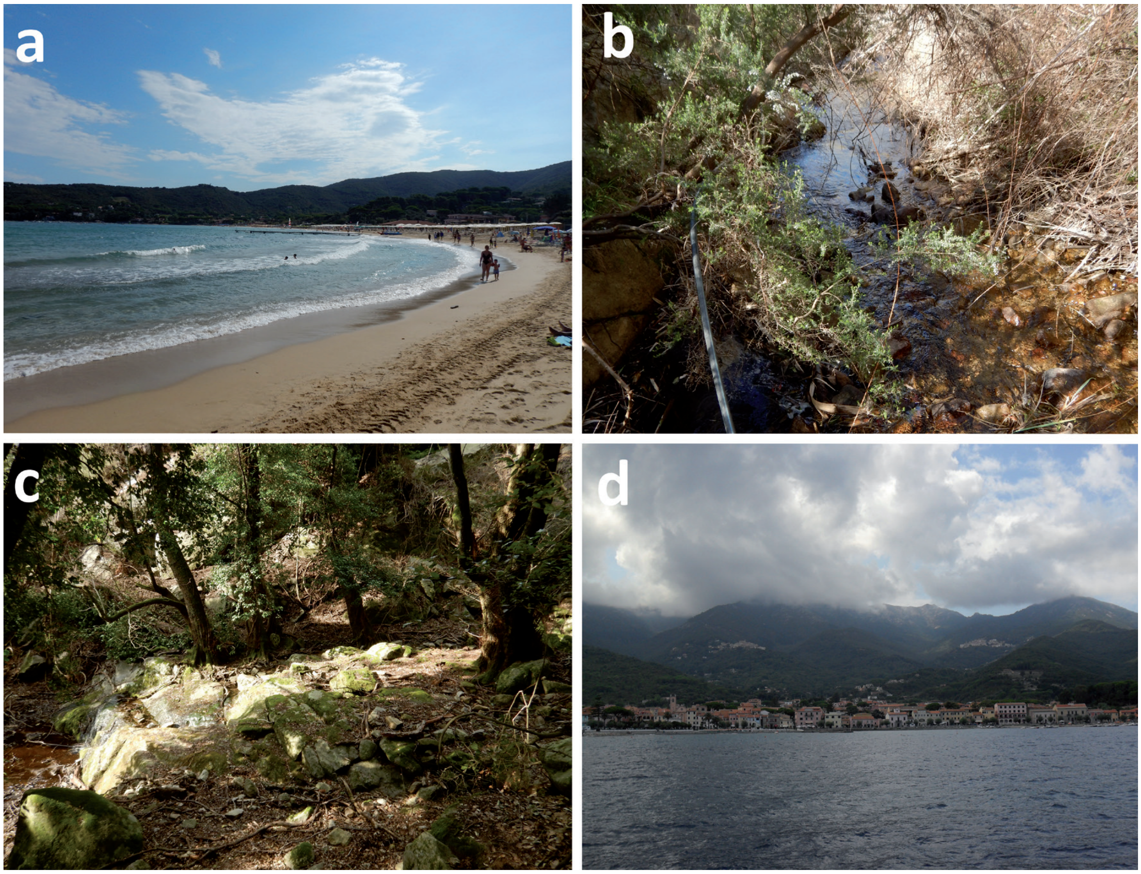

Fig. 7: Natural characteristics of Elba favouring the installation of smelting sites in antiquity; a: long beach of Procchio bay, suitable for landing – b: water-rich creek of the Pomonte valley – c: oaks in the upper Pomonte valley – d: thickly wooded slopes of the Monte Capanne massif above Marciana Marina.

period and therefore beyond the presumptive end of Elban iron smelting. Smelting at Capo Pero was concurrent to the occupation of villas on Elba and was perhaps part of their economy.[63] Furthermore, several smelting sites in the east and west of the island revealed evidence – including fragments of lamps, *terra sigillata,* amphorae, and coins – that attest to ongoing smelting on Elba in the 1st century AD.[64] Although iron smelting and mining continued, its intensity subsided gradually in the Roman Imperial period. New iron deposits in *Gallia, Noricum,* and *Hispania Tarraconensis* (fig. 1a) may have weakened the iron economy of Elba and Populonia, leading to a regional *phase of collapse.* The whole ferrous metallurgy seems to have declined in *Etruria mineraria* in the 1st century AD.[65] For Populonia, only one single forge of the 2nd century AD is known[66] and evidence for iron processing on Elba is completely lacking. Sporadical iron mining at least lasted into the late 2nd century AD, when a ship, sunken in the waters before the Guardiola smelting site, still carried hematite from Rio (fig. 1c).[67] After the 2nd century

AD, mining of Elban iron paused until exploitation began again in the Middle Ages (12^{th}–14^{th} centuries AD).

Conclusions

The history of the mining landscape on Elba during antiquity can be divided into different phases. An *anterior phase* can be seen in the possible exploitation of copper outcrops on the island, parallel to the copper smelting phase at Populonia (9^{th}–8^{th} century BC).[68] As the iron deposits on Elba were recognized, the metallurgical industry in Populonia turned from copper to iron in the 7^{th} century BC.[69] The *initial phase* of ferrous metallurgy then began in the 6^{th} century BC under Etruscan rule; iron mining occured on Elba, whereas smelting was conducted only on the Italian mainland. Both raw ore and raw iron were traded along the Tyrrhenian coast and even via Spina to the Adriatic region.[70] During the 4^{th} century BC, pressure on Etruria grew and the demand for iron increased, which favored the onset of iron smelting sites on Elba. This development led to the beginning of the *industrial phase* (3^{rd}–1^{st} century BC) under Roman rule, when smelting sites spread all over the island to exploit Elba's secondary resources. Large-scale transports of Elban ore to the smelting sites at Follonica bay continued.[71] The *phase of collapse* (late 1^{st} century BC–2^{nd} century AD) is characterised by the decrease and finally the end of iron smelting on Elba in the 1^{st} century AD, although sporadical iron mining on the island continued into the 2^{nd} century AD. Current knowledge suggests a long hiatus for several centuries until iron working on Elba resumed its activity under Pisan rule.[72]

Notes

[1] Corretti 2017, 449–451; Chiarantini et al. 2018, 13 f.

[2] Shepherd 1993, 143; Sperl 1993, 73; Berveglieri – Valentini 2001, 50.

[3] Chiarantini – Benvenuti 2009, 207–209.

[4] Zifferero 2017, 425–427.

[5] Diod. Sic. 11.88.4–5; Zecchini 2001, 139–145; Corretti 2017, 453 f.

[6] Corretti 2017, 454 f.

[7] On the presumed lack of fuel due to smelting, see Becker et al. 2020; Becker et al. 2021.

[8] Cambi 2009, 226 f.; Camporeale 2013.

[9] Corretti – Firmati 2011, 240.

[10] Corretti – Taddei 2001, 260; Corretti 2017, 457.

[11] Vanagolli 2012, 18.

[12] Corretti 1991.

[13] Mori 1960–1961, 176–178.

[14] Some slag heaps had more than 10,000 tons; Nihlén – Ejlers 1958, 25.
[15] Corretti 2017, 446 f.
[16] Pistolesi 2013.
[17] Vanagolli 2012, 67–70.
[18] On the requirements see Stöllner 2003, 420–422; Stöllner 2014, 135 f.
[19] Sperl 1993, 74. Tanelli et al. 2001, 243 tab. 2 nos. 1–2 & 4.
[20] Mori 1960–1961, 184.
[21] Benvenuti 1997, 40 tab. 2. On the geological and metallogenic framework, Tanelli et al. 2001, 240–245.
[22] Serv. Aen. 10.174; Corretti 2004, 281–283.
[23] Shepherd 1993, 143 for northern Etruria; Berveglieri – Valentini 2001, 50. 52 stating that even smelting started around 1000 BC (!).
[24] Delpino 1989–1990, 9 nos. 7–9 (one small corroded disc and iron patinas on two bronze objects); Giardino 2005, 498 f.
[25] Snodgrass 1971, 46; Ridgway 1992, 91; Turfa 2018, 648.
[26] The small piece of iron ore (2.5 × 2.5 × 1.4 cm) was found in the acropolis dump at the East side in 1965 and analysed by G. Marinelli, who claims his provenance from the Elban mine of Rio; see Buchner 1969, 97 f.; Buchner 1985, 46. The ore fragment from Scarico Gosetti and the analysis of iron slags from the necropolis of S. Montano (Ischia) were mixed up early on; cf. Snodgrass 1971, 43 n. 36.
[27] Buchner 1969, 98; Buchner 1975, 64; Corretti – Benvenuti 2001, 134 f.
[28] Bakhuizen – Kreulen 1976, 66 f. n. 83; Treister 1996, 36 f.
[29] Sperl 1993, 73.
[30] Thus, one discovers also lentil- and kidney-like shaped ore bodies, surrounded by ‘old’ and new overburden on the *Carta geologica dell’Isola d’Elba* of Lotti et al. (Roma 1885).
[31] Jervis 1862, 45.
[32] Scott 1895, 150 section IV.
[33] Written sources from the 12th century AD to the modern mining era onwards mention only Rio as an active iron mine; see Vanagolli 2012, 19–52. Occasionally a Roman date is mentioned without giving any reasons for it; see Capacci 1911, 414; Mori 1960–1961, 181.
[34] Scott 1895, 155 section XII.
[35] Orlandi – Pezzotta 1996, 53.
[36] Tanelli et al. 2001, 243 tab. 2 no. 4 vs. Ninci 1815, 160 n. (A).
[37] Scott 1895, 157 with 156 section XIV showing mining hollows; Capacci 1911, 414. Monaco – Mellini 1965, 90 n. 114. 92 fig. 9; the wedge weighs about 0.65 kg and was found by V. Mellini in 1879. Today it is in the Museo Archeologico in Portoferraio.
[38] Tanelli et al. 2001, 243 tab. 2 no. 2.
[39] Krantz 1841, 409–417. 424 with pl. 12.
[40] Buzzegoli 1762, 17 f.; Pini 1777, 61–63; Corretti 2017, 447.
[41] Capacci 1911, 414; Backendorf 1998, 105.
[42] Milanese 1987, 307 f. Jehasse – Jehasse 1985, 99–101. Ciampoltrini – Firmati 2002, 31–33.
[43] Suitable geochemical markers for hematite from Elba are high contents in tin and tungsten; see Benvenuti et al. 2013, 488–501; Corretti 2017, 451.

[44] One fibula at Masso d'Aquila, dating to the 1st half of the 6th century BC (Maggiani 2006, 441 note 6), and fibulae, a lance, and a corroded iron block at Monte Catino, dating to the early 6th century BC (Zecchini 2001, 85–88).

[45] Corretti 2017, 453 with 450 fig. 26.1.

[46] Phases according to Stöllner 2003; Stöllner 2014.

[47] J. Nihlén prolonged his research on Elba for two more years until 1961. Among his unpublished materials is a map of Elba with an additional 21 smelting furnaces found in 1960, incorporated here in Fig. 1c.

[48] Monaco – Mellini 1965, 47–90; Sabbadini 1919, 853–856; Nihlén 1958–1959, 1. 3. 18; Corretti 1988, 9–27.

[49] Becker et al. 2020.

[50] Firmati et al. 2006, 304.

[51] An earlier date than the 3rd century BC would be quite possible; for the problematic San Bennato site, see Becker et al. 2020.

[52] Poz-77808 (Patresi): 2170 ± 30 BP, 360–290 and 230–170 cal BC at 68.2% and 360–150 and 140–110 cal BC at 95.4% confidence. OxCal v. 4.3.2: Bronk Ramsey 2009; Bronk Ramsey 2017; IntCal13: Reimer et al. 2013.

[53] Poz-88893 (Magazzini): 2185 ± 30 BP, 360–280 and 240–190 cal BC at 68.2% or 370–170 cal BC at 95.4% confidence.

[54] Pagliantini 2014, cat. S.157.

[55] Corretti 2016, 215 f.; for the phases see Fabiani 2016.

[56] An Etruscan Py 4 amphora handle at San Giovanni is probably connected with iron smelting on site in the 4th century BC; Corretti et al. 2014, 191.

[57] The connecting element between these sites and the mining zone in the east is the sea route from Populonia to Corsica (fig. 1b); see Toscanelli 1933, 100; Arnaud 2006, 75 f.

[58] Maggiani 2017, 553 f.

[59] It is noticeable that Populonia booms in the 4th century BC, while other Etruscan cities suffer; see Fedeli 1983, 180; Camporeale 1985, 31.

[60] Corretti 1988, 25 f.

[61] Poz-77809 (Guardiola): 2110 ± 30 BP, 180–90 cal BC at 68.2% and 203–45 cal BC at 95.4% confidence; cf. Corretti 1988, 12 n. 40.

[62] Poz-77810 (Capo Pero): 1985 ± 30 BP, 40–30 cal BC and 20 cal BC–60 cal AD at 68.3% and 50 cal BC–80 cal AD at 95.4% confidence.

[63] Marzano 2007, 72.

[64] Becker et al. 2020.

[65] Fedeli 1983, 181; Corretti – Taddei 2001, 260.

[66] Acconcia – Cambi 2009, 178.

[67] Brambilla 2003, CD-ROM, image gallery XI; Personal communication by V. Serneels, Sept. 2018; for the dating of the wreck see Zecchini 2001, 209–219.

[68] Corretti 2017, 450–452; Chiarantini et al. 2018, 12.

[69] Corretti 2017, 452.

[70] Zuffa 1974, 160–164.

[71] Cucini Tizzoni – Tizzoni 1992, 51 f.
[72] Vanagolli 2012, 18.

Image Credits

Fig. 1: F. Becker, 2018; data according to Nihlén 1958–1959; map Nihlén 1960; Corretti 1991; Pagliantini 2014; own observations; hillshade: Regione Toscana 2014. – Fig. 2: F. Becker, 2017; data according to Regione Toscana 2014. – Fig. 3: R. A. Eser, 2015–2017. – Fig. 4: R. A. Eser, 2018; satellite image: Regione Toscana 2014. – Fig. 5: R. A. Eser, 2017. – Fig. 6: F. Becker, 2018. – Fig. 7: R. A. Eser, 2015–2017.

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Roman Brass Ingots from a Shipwreck near Aléria/Corsica – New Evidence on Brass Production in Gallia Lugdunensis

Michael Bode – Norbert Hanel

Since the 1st century BC the use of brass boomed within the Roman Empire. Numerous objects of daily life were made of this alloy, including vessels (especially the so-called Hemmoorer Eimer), furniture and box fittings, brooches and needles, statuettes and votive offerings, as well as weapons and military equipment parts.[1] With the coin reform of Augustus, brass was needed in larger quantities for the production of both *sestertii* and *dupondii*.[2]

The Shipwreck of Aléria and its Load

The discovery of a ship's cargo off the eastern coast of Corsica near the Roman provincial capital Aléria around 1980 provided important insights into the transport of metals within the Roman Empire. The load comprised at least 21 brass and 6 lead ingots, the latter were produced most likely in the Mendip Hills of Somerset, England.[3] The provenance of the brass ingots remained unclear. The brass ingots are of a bread-loaf shape (fig. 1). Their total weight is 92.55 kg. Despite their similar shape, their length varies from 17.5 to 24.5 cm. The width is between 8.5 and 13.5 cm and the height ranges between 3 and 5 cm (fig. 2).

Thanks to the *cognomina ex virtute* of L. Septimius Severus on the inscribed lead ingots, their production can be limited to approximately the period between February 197 and February 198 AD.[4] In contrast, there are no epigraphic elements on the brass ingots. The find context suggests a corresponding chronological classification, in the years shortly before 200 AD.

This cargo has considerably increased the number of brass ingots in the Imperium Romanum. Their number was previously at two; both were found in Britain.[5] Recently, the art trade added a more than 1.50 m long ingot (fig. 3) stamped C • PETRON • HERME.[6]

The Roman Copper and Calamine Industry

Brass is a mixture of copper and zinc, produced in Roman times in sealed vessels/crucibles by the cementation process.[7] The copper sources of this binary alloy are located in the western Mediterranean area, according to the current state of research. Lead isotope analyses on Roman copper ingots mainly point to the Iberian Pyrite Belt (e.g. the mines

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Fig. 1: Brass ingots from the Roman shipwreck of Aléria.

Fig. 2: Brass ingot from the Roman shipwreck of Aléria.

Fig. 3: Brass ingot from the Mediterranean with triple stamp inscriptions.

of Rio Tinto). But Los Pedroches in the Sierra Morena, the Montsant and the Molar-Bellmunt-Falset district near Tarragona, and the French Massif Central with Cévennes and Montagne Noir (e.g. Cabrière) are indeed other – more or less important – possible Roman copper mine districts.[8]

Within the boundaries of the Roman Empire, deposits of calamine and zinc ore have so far been insufficiently explored. In the western part of the Imperium Romanum there are deposits in Campania, Bergamo (Lombardy), in the French Massif Central (Mont-Lozère, Cévennes, Montagne Noir), in the Northern Pennines (North Yorkshire), and in both Germanic provinces in the area of Wiesloch (near Heidelberg) and in the Northern Eifel. Roman traces of exploitation are more or less assured.[9] Moreover, modern zinc deposits in the immediate vicinity of ancient lead-silver deposits such as the Lüderich in Rösrath (Germany), the Iglesiente (Sardinia), Laurion, Thasos (Greece), were certainly not disregarded in Roman times. On the other hand, there is hardly any calamine ore or indications of its exploitation on the ore-rich Iberian Peninsula.[10]

Geochemical Signatures of the Brass Ingots and the Deduced Provenance of Calamine and Copper

The brass ingots of the Aléria shipwreck have zinc contents of 22 to 29 wt%. Since zinc ore is typically associated with lead minerals and partially intergrown with them, brass has relatively high levels of lead, ranging from 1 to almost 4 wt% in the Aléria ingots. The lead isotope comparison is therefore restricted to investigate the origin of the zinc. After evaluation, possible candidates are two regions in the west of the Roman Empire: either Northern Yorkshire in Britannia or the Cévennes/Montagne Noir (Département Gard) in Gallia Narbonensis/Gallia Lugdunensis.[11]

Interestingly, numerous large cementation crucibles (with heights of about 50 cm) from Lugdunum are proven for the manufacture of brass in the late 1st century AD.[12] They suggest an origin of the brass ingots of Aléria from this region (as an additional cargo to the lead ingots) rather than from Britain, where an equivalent archaeological record so far is missing. It fits also that the area south of Lyon (Pilat, Monts d’Ardèche, Cévennes) is designated as a lead-zinc-rich district.[13]

A look at the brass ingots’ chemical patterns leads to the same result. Considering that the partially significant amounts of tin (up to 1.14 wt%) most likely entered into the ingots and not in workshops – as primary (commercial) products and bulk commodities – via the copper or zinc ore, and that there are tin-bearing copper mineralizations at Charrier northwest of Lyon (fig. 4)[14], we might also have a candidate for the copper metal. Whether this suspicion is substantiated must remain open here. According to current knowledge, the ancient exploitation of copper deposits in the Massif Central was of a rather minor importance.[15] In summary, with these local sources nearby, an-

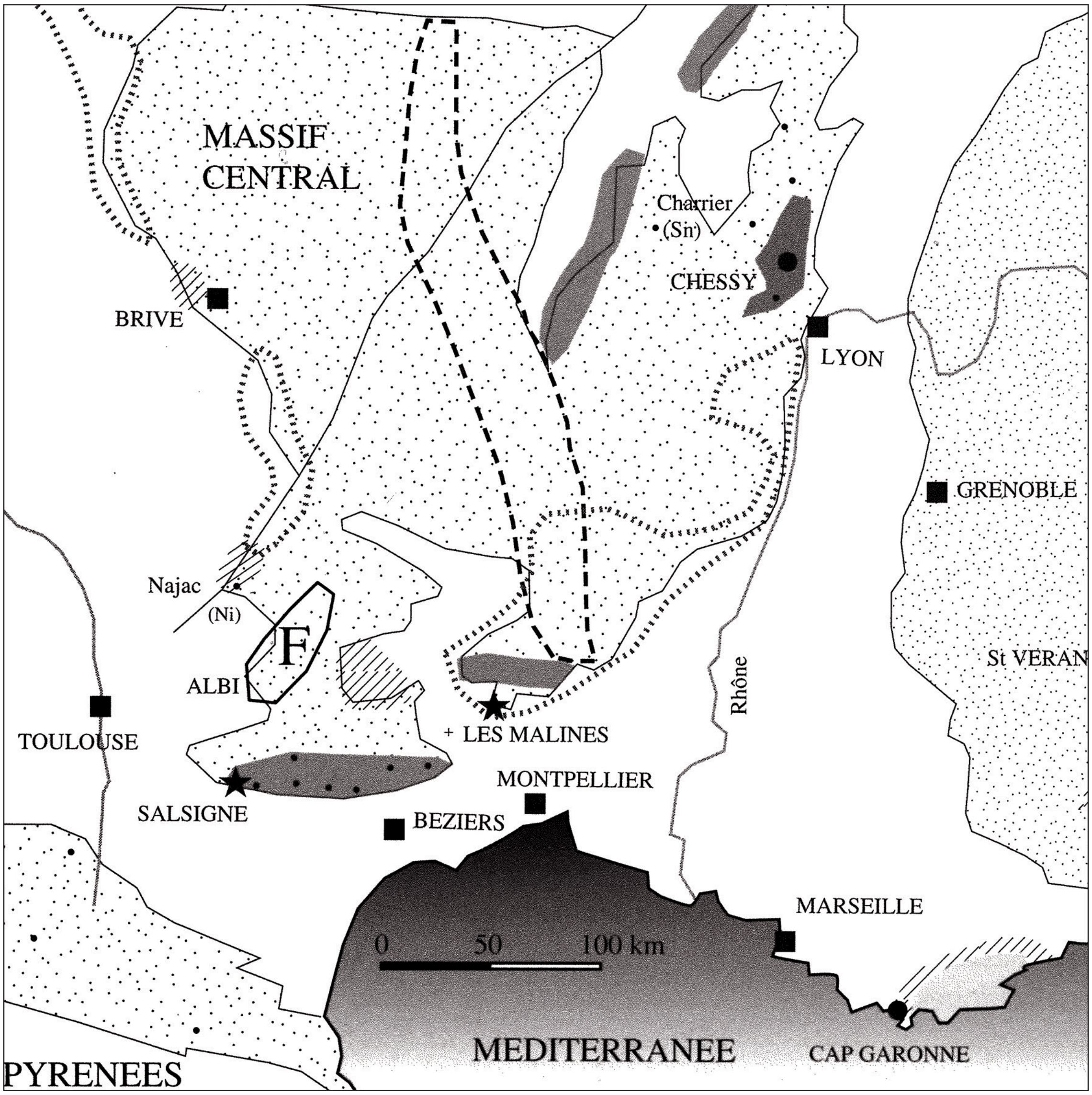

Fig. 4: Map of the copper and zinc deposits in Southern France.

cient Lyon may have been one or possibly the main brass production centre of the Roman Empire towards the end of the 2nd century AD.

Based on the find spots of further lead ingots with inscriptions from the early Severan period on the Gallic mainland, it is possible to reconstruct a transport route (fig. 5) of the shipload from Britain to Rome.[16] Under the premise of an origin of the zinc and copper from the Cévennes and the evidence of brass production by cementation crucibles on the spot (although this is earlier), a load of the brass at Lugdunum would be conceivable.

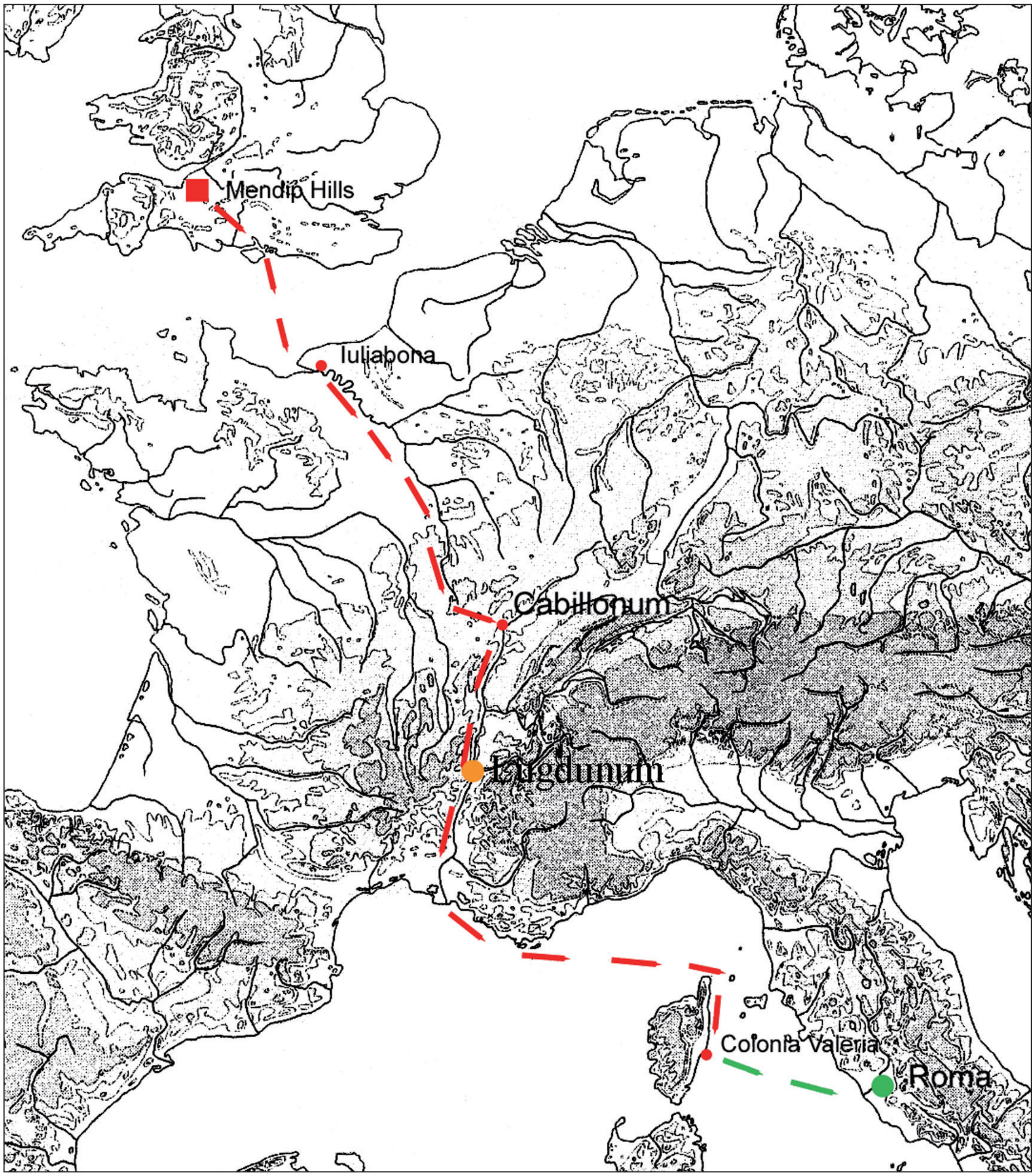

Fig. 5: Possible transport route of the Severan lead ingots made of British lead via Corsica to Rome. Presumed further load of the brass ingots in Lugdunum.

Notes

[1] Hammer 2001, 614; Hauptmann 2006, 565; Istenič 2009.
[2] R.-Alföldi 1978, 157–160.
[3] Weisgerber 2007; concerning the lead ingots: Hanel et al. 2013.
[4] Hanel et al. 2013.
[5] RIB II 1 no. 2407.1 with stamps V•H•ÊT•B (FO Colchester); Bayley1998, 11, Weisgerber 2007, 149 (FO Claydon Pike, Gloucestershire).
[6] Rothenhöfer 2016 assumes a Mediterranean origin.
[7] Hanel – Bode 2016, 169 with bibliography.
[8] Rico et al. 2006; Klein et al. 2007; 2009; Jézégou et al. 2011; Bode et al. 2018.
[9] See in detail Hanel – Bode 2016, 170–174.
[10] Domergue 1990, 80.
[11] Hanel – Bode 2016, 172–174.
[12] Picon et al. 1995.
[13] Leblanc 1997.
[14] Leblanc 1997, 21 f. figs. 1.2.
[15] Domergue et al. 2006, 138.
[16] Hanel et al. 2013, 316–319. 322 fig. 1.

Image Credits

Fig. 1–2: Photos N. Hanel. – Fig. 3: Photo P. Rothenhöfer. – Fig. 4: After Leblanc 1997, 22 fig. 2. – Fig. 5: Map N. Hanel.

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The Organization of Mining and Metal Production in Aegean Thrace from the Archaic to the Roman Period

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Abstract

The significant metal deposits of the North Aegean were renowned in the ancient world through mentions in myths and historical accounts. Long before the arrival of the Greeks in the Thracian littoral, the processing of minerals to produce copper, lead-silver, and the collection of alluvial gold was common among the native populations. With the gradual establishment of Greek colonies and *emporia* in the Archaic period, an increase in mineral exploration and metal production is manifested by relevant archaeological findings. Interdisciplinary research in this region was initiated in the early 1980's when several mining shafts and metallurgical sites were located across Mount Pangaeon and the Lekani mountain range. In recent years renewed interest on the study of mining landscapes in Aegean Thrace combined with new excavation projects brought about important new information. This paper discusses the issue of mining and metallurgical activity across this region from the Classical to the Roman period in light of recent archaeological data. The ongoing excavation project at Pistyros (Pontolivado), a Thasian *emporion* west of the Nestos estuary, has yielded large volumes of metallurgical slag. Initial examination has confirmed that these residues derive from the reduction of iron ores in furnaces and forging of the blooms, as well as copper and lead/silver extraction dating to the Classical and Hellenistic periods. While the evidence for mining exists at various localities in the Lekani, presumably in Thracian territory, secondary processing and the manufacture of objects was achieved within this Greek fortified site. In this context, accessing, controlling, and negotiating mineral resources among the indigenous Thracian populations and the inhabitants of the Greek settlements are fundamental in understanding the organization of metals production in the North Aegean.

Introduction

The north Aegean is a region well-known for its mineral wealth, with abundant evidence for mining and metal production over long periods of time. Ancient literary sources such as Herodotus,[1] Thucydides[2] and Strabo[3] refer to extensive gold and silver extraction undertaken by local Thracian tribes and Greek colonists alike. Until recently, limited studies have focused on establishing a detailed chronology for the emergence and gradual development of this strategic technology, crucial for economic expansion in the ancient world. Archaeological research of the last twenty years provided proof for the earliest stages of this metallurgical tradition, which emerged in the Late Neolithic

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with the extraction of copper and silver; this was further consolidated and expanded during the Early Bronze Age. Most of the studied evidence consists of small assemblages of copper production residues deriving from the prehistoric settlements of Promachon-Topolnica,[4] Sitagroi,[5] Dikili Tash[6] on the mainland, Limenaria[7] and Aghios Antonios[8] on Thasos, and Mikro Vouni on Samothrace. For the periods after the Greek colonization, the evidence becomes more substantial, with large mining regions featuring underground tunnels, installations for ore enrichment, voluminous heaps of metallurgical slag, and the increasing deposition of metal artefacts in settlements and cemeteries.

Some early attempts to investigate the organization of metal extraction in antiquity were initiated in the 1980's, when several mining and metallurgical sites were located across Mount Pangaeon, the Lekani mountain range, and Thasos. The then IH′ Ephorate of Antiquities and the Institute for Geological and Mineral Explorations (IGME) were responsible for these pioneering efforts to locate and document the evidence in the field.[9] At the same time, ancient literary references to mining and metal production were studied in detail, given their potential to complete our knowledge. In recent years it became clear that trying to understand the technical developments in transforming minerals into metals involves examining the social organization and cultural context within which the communities of the region interacted with their natural environment.[10] Thus, further issues have started being addressed such as settlement patterns, the organization of space as a reflection of social relationships, degrees of social stratification directly linked to labor division, and the scales of specialization in crafting.[11] An approach that introduces the concept of productive landscapes is more precise at explaining the long term interaction of human communities within certain environmental settings.

Colonization and Metals Production in the North Aegean

Colonial expeditions of the Archaic period brought Greeks of the Aegean islands and Asia Minor to the Thracian shores, which were renowned for their riches from earlier contacts in the Mycenaean period.[12] In general, an increased interest in this region is manifested especially around the end of the 6th century and throughout the Classical period until the Macedonian conquest. This interest was related to precious metals, fertile agricultural land, and the thickly wooded territories exploited for their timber.[13] The major settlements that were established were colonies and *emporia* that formed a broad network across the littoral. They often had conflicting interests, and occasional alliances and hostilities with the local Thracian populations inhabiting the hinterland (fig. 1). This colonial system was characterized by certain means of production that were necessary to fuel their economic expansion in new territories by appropriating natural resources.[14] Its success was based on a capacity to adapt to the given settings by incorporating the indigenous labor force in the exploitation of resources and the

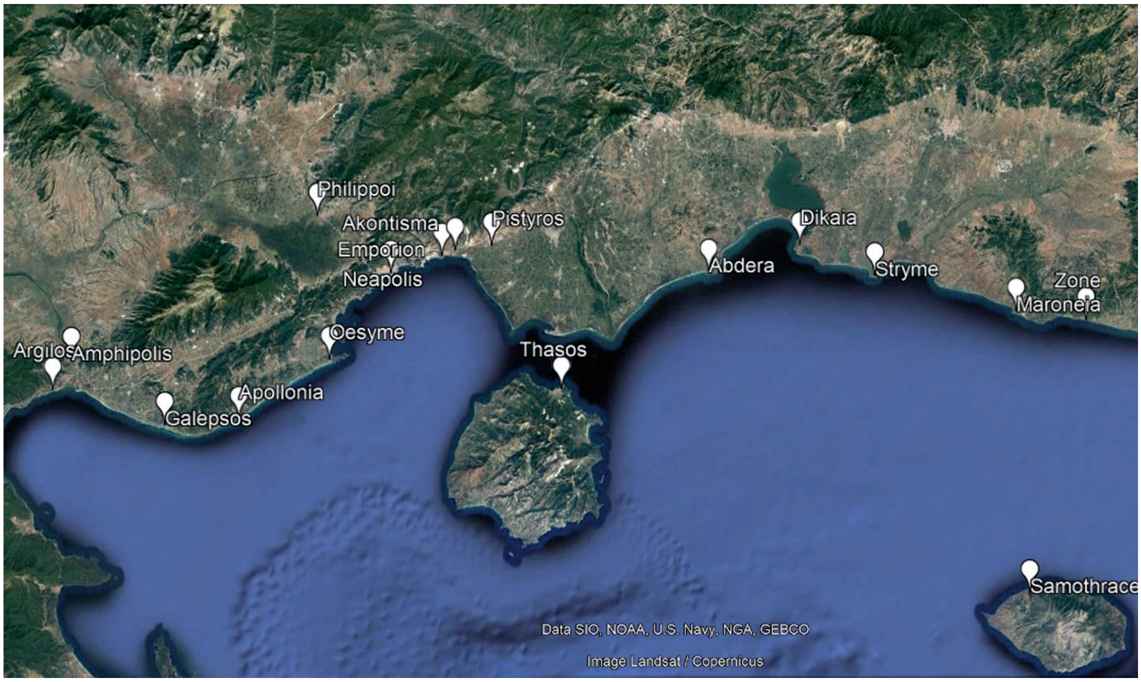

Fig. 1: Map of the region showing the major colonies and *emporia.*

local elites into this system of controlling production and consumption. The striking of silver coins in a number of mints across this region is a clear indicator of either direct or indeed negotiated access to precious metals.[15] Therefore, this region represents a characteristic case study for approaching the organization of mining and metallurgy, particularly through the co-existence of producer and consumer populations representing diverse cultural backgrounds.

Around the first third of the 7th century BC an expedition of Parian colonists was established on Thasos, where they founded a permanent settlement, while seeking to expand on the opposite shores.[16] Archilochos clearly mentions that the local inhabitants held control of the rich metal resources on the island, and Herodotus later mentioned their gold mines between Ainyra and Koinyra.[17] Gold was also mined near the acropolis at the outskirts of the Thasian metropolis but except for the mining galleries, limited data for gold working have been studied so far.[18] Yet, it is the large-scale extraction of argentiferous lead ores that left behind substantial material evidence (fig. 2) on the western part of the island, which was studied by an interdisciplinary project directed by the Max-Plank Institute for Nuclear Physics of Heidelberg and Bergbau Museum in the 1980's.[19] Moreover, based mainly on numismatic evidence, researchers have suggested that silver mining on Thasos witnessed two peaks, the first between 500 and 410 and the second around 370–310 BC.[20] A third peak in Thasian silver extraction has been suggested for the Roman period. In all these phases it is not clear if the labor force was drawn from a local population of the island working under colonial administration or

Fig. 2: Slag heap at Skoridia, western Thasos from the smelting of argentiferous lead ores.

if indeed slaves were brought from elsewhere. Whatever the case, a large number of laborers would have been necessary in the mines and processing workshops for the purification of silver and gold. On the Thracian littoral, the expansion of the Thasians was focused on the mineral-rich region of Lekani, described by Appianus as the mount of the *Sapaioi.*[21]

The evidence from further inland, around Mount Dysoron and the Rhodope mines in modern-day Bulgaria, suggests that Thracian silver and gold was exported but not minted as coin until later in the 4th century BC. Therefore, during the early phase of Greek colonial expansion, it is certain that some of the mines on the mainland were under the control of local tribes,[22] but it is unclear to what extent the Thracian tribes mined, extracted, and minted the silver. Some scholars tend to see the Thracian side as rather passive[23] or alternatively as striking their silver coinage in Greek mints as part of a deal for access to the mineral resources. But Thracian communities or powerful individuals who had both precious resources and access to international trade might have been interested in adopting the technologies of refining silver and striking coins.[24] As suggested by the numismatic evidence, the shared coin types between Thracian groups have given rise to a number of theories ranging from monetary and military alliances to a less formal co-operation in the use of mines or mints. Cooperative mining based upon arrangement between parties could account for the simultaneous minting of tribal, civic, and royal coinages in the region of the Strymon at a time when only the mines of Dysoron, Prasias and Pangaeon were operative.[25]

This reciprocal relation is reflected in the cases of Maroneia, founded by Chian colonists, and Abdera founded by Klazomenians and Teians in the 7th century BC. The circulation of silver coins struck in Maroneia by the end of the 6th century BC and the payment of increased tribute to the Delian League from 454 BC suggest that the city had access to a mining zone, possibly within its *chora.* Alluvial gold was most probably exploited along the course of rivers Lissos and Makropotamos and the region of Xylagani, where gold grains are found isolated or hosted in quartz bodies and iron-pyrites.[26] Remains of underground exploitations have been located at various sites mainly in the region of Konos-Kassitera in the form of mining galleries for the extraction of auriferous and argentiferous ores.[27] At a locality known as Ktismata, south of the Aghios Georgios hilltop, mining activity on a ferromanganese deposit has been identified and studied to a preliminary degree. Small-scale mining was conducted through a vertical shaft with three helicoidal galleries; analysis of the mineralization revealed high sulfide contents.[28] Pottery finds date these traces of exploitation to the 2nd century BC, suggesting that mining in the wider region of Maroneia was an important activity for at least 400 years. An expertise of the Maronitans in mining technology is echoed in a passage by Harpocration, who mentions a rich silver-bearing lode at Laurion that the Athenians named Maroneia possibly due to its exploitation by miners from Thrace.

In Abdera the striking of silver and gold coinage starts from 520/515 BC and the city's tribute to the Delian League demonstrates that the Abderitans also had access to precious metals. Within the *chora* of Abdera, its limestone and granite geology does not contain any significant mineral deposits and the closest source of precious metals lies near the modern village of Kimmeria to the north. This mining zone contains magnetite, iron-pyrite and chalcopyrite containing precious metals in significant contents.[29] It lies well within Thracian territory, highlighting again a reciprocal situation or a shared exploitation of metal resources between locals and colonists.

Moving on to the west of river Nestos and toward the Strymon estuary, we will focus our attention on the mineral-rich region where Thasian expansion was consolidated in the Classical period.[30] This extended coastal zone became known as the Thasian 'continent' and included the major colonies of Neapolis, Oesyme and Galepsos and smaller *emporia* such as Antisara, Akontisma, Pistyros and Skapte Hyle.[31] Ancient historians inform us that the Thasians extracted a large output in precious metals from the island and their mainland colonies until the Athenians took control of their mines (465 BC). Although the zone occupied by the Thasians is bound between the Aegean and the Lekani and Symvolo mountains, their sphere of influence appears to have extended beyond the southern foothills and into the mineral-rich uplands. According to Herodotus, during the Persian Wars the mines of Mount Pangaeon were exploited by the indigenous Thracian tribes, the Pieres, Odomantoi and Satres.[32] Since the Thasians had not penetrated the hinterland near Mount Pangaeon, their claims on mineral deposits should have stretched directly north of their coastal colonies on the hills that offered visibility to Thasos across the Lekani and Symvolo mountains.[33]

Geological prospection across this region has confirmed the existence of a rich mineralization bearing precious and base metals often associated with signs of ancient and more recent exploitation.[34] In particular, a large number of underground galleries with associated shafts and adits have been recorded at Lekani, with the most prominent ones located near the modern villages of Makrychori, Perni, Petropigi, Lefki, Anestias, Chalkero, Palaia Kavala, Kryoneri and Zygos.[35] The extracted metal-bearing ores were mainly contained in iron deposits of hydrothermal origin, which occurred in association with manganese and other metals such as lead, zinc, arsenic and copper with significant contents of silver and gold. Since mining is an activity that was continuous, often spanning many centuries, the exact dating of various extraction phases is often problematic, mainly due to the obliteration of earlier evidence by more recent interventions. In a few cases, the shape of the galleries and extraction techniques hint to their dating in antiquity but in many localities the re-opening of ancient mines in the Ottoman period has obscured issues of chronology.[36] In similar terms, the metallurgical waste that forms large heaps of accumulated material over centuries is notoriously difficult to date as the latest phases covered or significantly disturbed older material.

Thasian Settlements and Metal Production in Southeastern Lekani: a Case Study

The region of the southern and southeastern Lekani in the prefecture of Kavala offers a unique opportunity to study metallurgy in a relatively clear chronological framework. This is mainly due to the existence of three colonial settlements of the Thasians and numerous locations with ancient mining and mineral processing evidence. A Thasian *emporion* that was established in the late 7th century BC is located near the modern village of Pontolivado and has been identified as Pistyros based on literary sources and relevant finds.[37] The site was discovered in 1971, but the recent systematic excavation initiated in 2014 has yielded large volumes of metallurgical slag representing direct proof for large-scale metallurgical practices.[38] It is important to note that this fortified *emporion* lies within short distance of a mining zone towards the northeast and northwest spreading across a radius of 8 km. About 5 km due west of Pistyros there are two more Thasian settlements both established in the 6th century BC that flank the modern village of Nea Karvali. They were investigated by Koukouli-Chrysanthaki, who suggested that the eastern one should be identified as Akontisma, while the second to the west remains unidentified.[39] The former is situated at the southern extremity of the mountain range controlling the entrance to the valleys of Anestias and Lefki towards the north, which are particularly rich in metallurgical evidence; the latter directly controlled the shipping of goods through a port.[40] The narrow zone where the three settlements were established, interlocked between the foothills and the sea, was certainly controlled by the Thasians at least until the Classical period as suggested by the finding

Fig. 3: Mine entrance west of Perni in the Lekani mountain range.

of numerous amphorae, coinage, and other finds. The mountain range to the north was inhabited by the Thracian tribe of the Sappaioi and the mining zone was within their territory.[41]

The southern foothills about 4.2 km northeast of Pistyros, between the modern villages of Perni and Petropigi, yielded evidence for surface and underground mining, as well as the primary processing of the ores.[42] During our recent field survey we confirmed the presence of iron mineralization, consisting mainly of goethite-limonite and secondary copper ores; according to previous geological research these contain significant amounts of precious metals.[43] An underground mine with a single entrance and narrow galleries of square profile measuring 1 × 1 m and running for a length of 150–200 m is located about 2 km west of the modern village of Perni (fig. 3). The tool-marks on the gallery walls made by miner's picks and hammers, as well as the characteristic profiles suggest a relative dating between the Classical and Hellenistic periods. Near the mine entrance there is abundant evidence for crushed hematite/goethite as well as stone slabs bearing tool marks caused by crushing, punchers, and pounders.

More substantial mining evidence comes from the valley that stretches north of Pistyros towards the modern village of Makrychori, located about 7 km to the northwest. Geological prospection has identified three mining locations that were opened to exploit the mixed sulphide deposits of Fe, Mn, Pb and Zn that contain significant levels of gold and silver.[44] The hills to the west and northwest of Makrychori are covered by numerous slag heaps across an extended area, suggesting an important locality for smelting the ores extracted in the above-mentioned mining locations (fig. 4). Based on pottery dating from the 4th to the 2nd century BC and the Roman period, at least part of these slag deposits should belong to antiquity. However, the largest volumes possibly

Fig. 4: Makrychori, mining location and metallurgy site, Lekani mountain range.

belong to the Ottoman period, when re-melting of ancient slag was practiced.[45] The presence of pottery, including Thasian amphorae and other domestic finds such as spindle-whorls, millstones, and mortars between the slag heaps and the village suggest the existence of some sort of a settlement that had developed to sustain the workforce or possibly a tower for controlling the operations as similar examples from Thasos suggest.

Our recent prospection in the valley of Anestias, 3.4 km northwest of Akontisma, resulted in finding a plateau by the banks of a stream where the processing and beneficiation of ores by crushing and grinding took place. The spot is reported by earlier researchers of the region, who located for the first time three large marble slabs bearing deep grooves or sluices (fig. 5) and interpreted these finds as structures for washing mineral ores.[46] This interpretation was based on similar finds that are known from Laurion, which were seen in conjunction with the rectangular washeries when they were discovered in the 1970's; together they were interpreted as helicoidal washeries used in the enrichment of argentiferous lead ores.[47] Initially, three such structures were found at Megala Pefka, Demoliaki and Bertseko, while more recently three more were discovered in better preservation at Ary II, III and IV.[48] In light of these new discoveries an alternative interpretation has been put forward whereby these structures are seen

Fig. 5: Marble slab with ridges, part of an edge runner mill at Anestias, Lekani mountain range.

as large, circular mills for crushing and grinding rather than washing the ores.[49] They are referred to as edge runner mills, which are circular structures with indentations forming the tracks for large wheel-shaped mills that were turned around a stable axis at the center. Similar structures recently discovered at Samut in the mining region of the Eastern desert of Egypt were also interpreted as edge runner mills.[50] It is worth mentioning that all such structures date to the Hellenistic period with no parallels pre-dating or postdating this chronological horizon. Judging on the similarity of the finds from Anestias to the published examples, we suggest that they were used in the same manner for the grinding of the silver and gold bearing ores of the region, or the by-products such as litharge or slag to retrieve entrapped metals.

Once enrichment was complete, the next stage involved smelting the ores in furnaces. This stage is well attested by the residues or by-products of such a process, namely the metallurgical slag. A large volume of such material is being recovered from the ongoing excavation at Pistyros and our study aims at reconstructing the various metallurgical processes that took place. It is important to note in this context that several pieces of millstones were found during excavation within the layers that yielded metallurgical slag. Thus, it could be suggested that the last stages of ore beneficiation were probably practiced on site. A preliminary examination of these finds helped to identify a fragment of a rotative hand-mill, a type that was used in industrial applications (particularly the grinding of ores) in the late Hellenistic and Roman periods. A detailed study of crushing and grinding tools from the museum of Thasos[51] has not yielded a millstone of this type used for this particular use and makes this the first known example so far in this region.

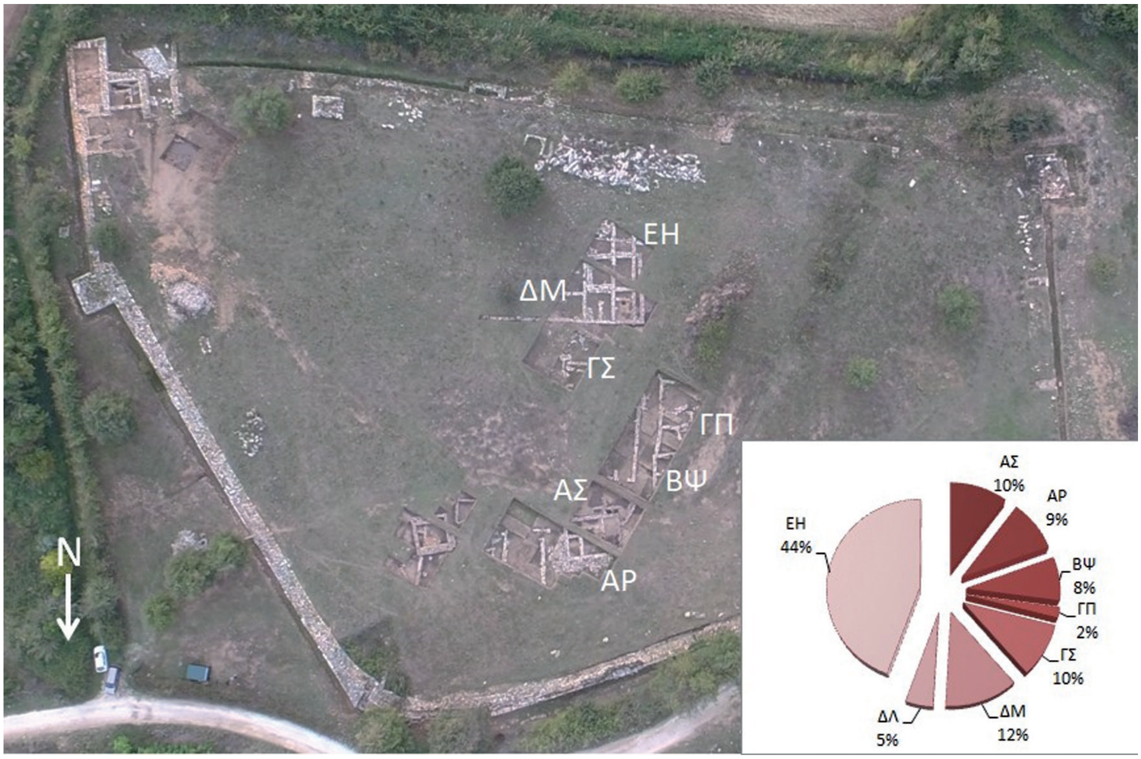

Fig. 6: Aerial photograph of Pistyros showing excavated trenches. The graph shows the relative abundance of metallurgical slag per excavated trench (Study seasons 2016–2017, total number of counted pieces: 2841).

The Thasian material consists of two types common for this particular period: Olynthian and giratory millstones. Therefore, based on our preliminary observations, the pre-treated ores that were transported to Pistyros were further processed and enriched; then they were introduced to the furnaces for extracting precious metals in addition to copper and iron that were also produced.

The metallurgical residues recorded so far (study seasons 2016 and 2017) derive from the surface and upper layers of the urban core (fig. 6). Substantial amounts derive from the destruction layer covering a building in the northern sector (trenches ΑΣ, ΑΡ) and a road with a north-south orientation (trenches ΓΠ, ΒΨ). They show a greater concentration in trench ΕΗ, which lies at a central area towards the south: its four squares (ΕΗ1–ΕΗ4) yielded 44% of the recorded material. This large volume of slag and a few furnace fragments were found associated with a complex building with multiple rooms of at least two architectural phases that dated to the 2nd century BC (fig. 7). Three areas with severely heated surfaces of reddish clay were revealed in proximity to wall corners of the southern rooms. Excavation of a circular, stone-built structure, filled with copper slag, is ongoing in order to elucidate its function and examine the possibility of any metallurgical associations.

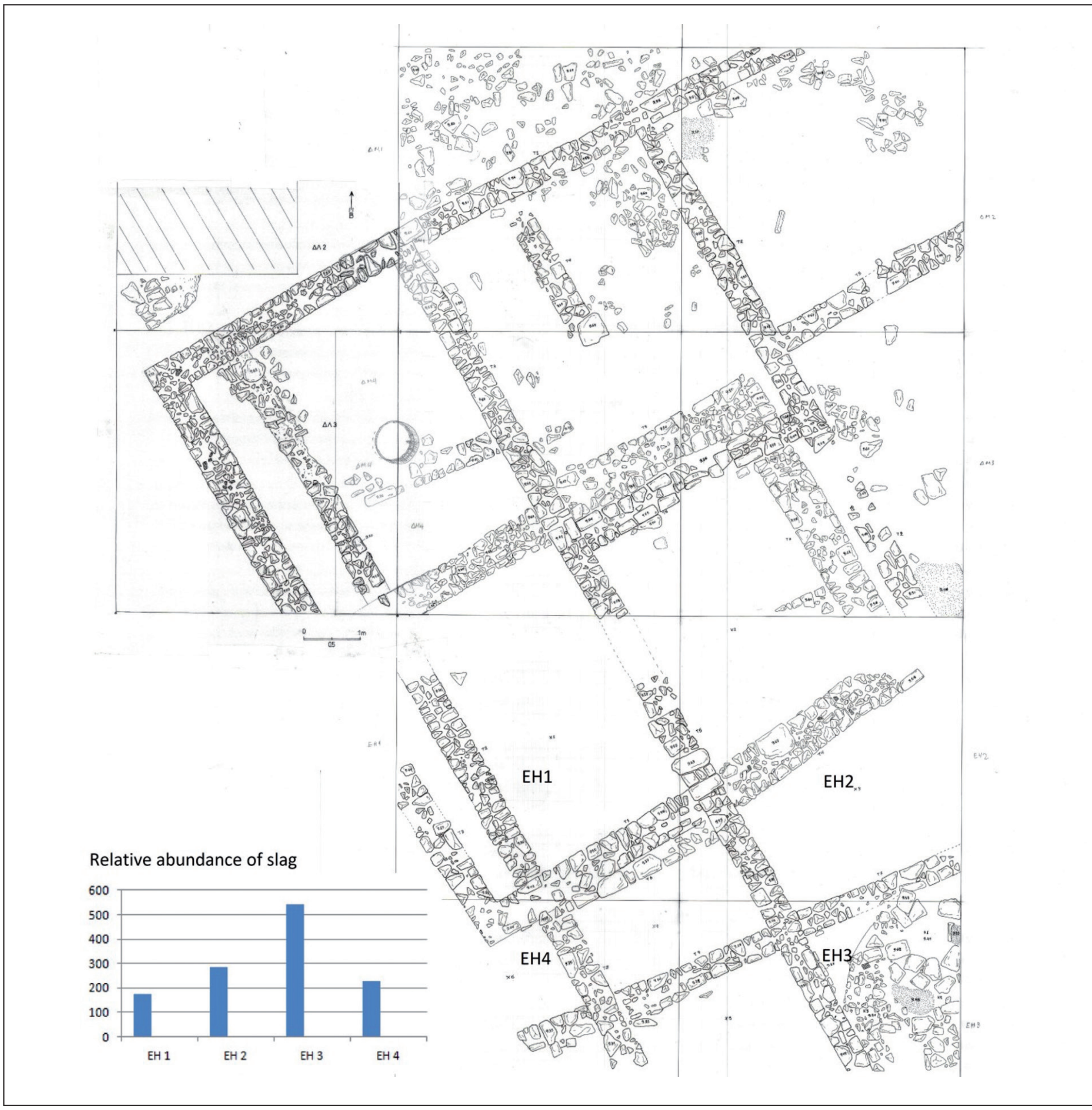

Fig. 7: Pistyros, plan of the Hellenistic building with metallurgical residues. Insert graph shows the relative abundance of slag pieces per square in trench EH (square EH3 yielded over 500 pieces).

A preliminary examination of the residues from the central trenches provided some clues regarding the main metallurgical processes represented here. Thus, the great majority of finds consists of smelting slag deriving from the reduction of iron, copper, and to a lesser extent, lead-bearing ores possibly associated with the Eastern Lekani deposits that contain such mineral assemblages.[52] Certain indicative characteristics such as oxidation crusts and surface inclusions were used to confirm the extraction of iron and copper, but prior to the analytical study more details are not available. The first category of iron smelting slag can be divided in two main subgroups: a) tap slag with ropey, flow patterns, and b) porous furnace slag. Another category of finds consists of forging or smithing slags deriving from the compaction of blooms and the fabrication of iron objects. Based on the preliminary assessment it could be suggested that forging was a common activity for producing blades, tools and various smaller objects. A third category consists of copper smelting slag, which were identified by the characteristic green-colored nodules of copper oxide minerals on their surface. A fourth category of finds is related to the processing of lead-containing minerals. These latter residues appear to derive from an initial smelting stage targeting to purify the ores from the gangue minerals. It is highly possible that if the lead contained appreciable silver contents, a second stage of separation would have been attempted on site. For the moment, no litharge fragments deriving from such a secondary process have been noted but only a small percentage of the finds has been recorded so far. It could be suggested that lead/silver separation through a cupellation stage took place on site or in the vicinity but for the moment the evidence is inconclusive. With the continuation of the macroscopic study and the subsequent instrumental analysis more substantial data will become available in order to better understand the processes by which metals were produced at Pistyros.

Conclusions and Prospects

Examining the geographical distribution of resources, mining evidence, and the sites where metallurgy was practiced helps to better understand the various stages of producing metals as steps in a dynamic process enacted within the landscape.[53] A hypothetical model for the organization of metal production across the Lekani is presented in fig. 8. The first stage of extracting the ore by underground mining was achieved at several localities, depicted as stars in the figure. The stage of enrichment by sorting, crushing, grinding, or washing is not always evident but should have taken place either near the mines or near the slag heaps, where smelting of the ores was conducted in furnaces. Access to water and fuel were equally important determining parameters as was access to minerals. West of Perni there is evidence for underground mining and exploitation of the surface mineralization, with evidence for crushing; no evidence for beneficiation or smelting is known in the vicinity. The valley of Anestias and the

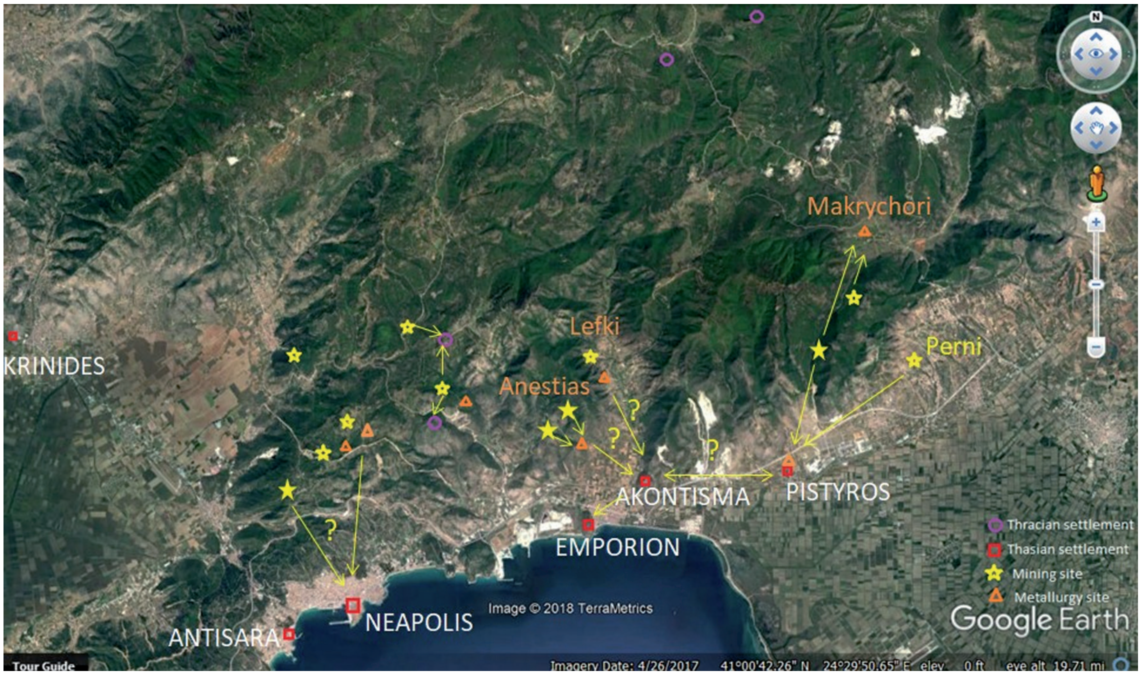

Fig. 8: Hypothetical model for the organization of metals production at Lekani.

nearby valley of Lefki have also yielded mining evidence, while the processing of the ores by grinding was conducted with edge runner mills as suggested by the relevant finds presented above. Small-scale smelting was also practiced near the processing sites (as suggested by the few pieces of slag), but it seems that the processed ores were transported somewhere else for the crucial stage of precious metal extraction, possibly in a centrally administered site under state control.[54] Thasian amphorae were found among the slag heaps at Makrychori and there were certain technological similarities of the metallurgical processes to those found in Pistyros. Thus, it could be argued that at least for a certain period in the Late Hellenistic and Roman times, both sites were producing metals simultaneously. Taking all the evidence together it appears that a chain of operations linking the described sites was enacted on a large-scale, with the valleys that had a north-south orientation playing a crucial role in the organization of production. Addressing consumption patterns is also important to better understand the demand that influenced production rates. Therefore, it is necessary to examine how metals were consumed in the Thracian littoral and in what cultural contexts.

Recent research in the broader region, particularly the numerous mining and smelting sites on Mount Pangaeon is already producing important results that add new information to our understanding of ancient metal production in northern Greece. The most important and extended mining area was located at Asimotrypes, where eight ancient mining adits have been recorded along a steep valley.[55] Further mining evidence comes from Mavrokorfi, while an important metallurgical center was established at Valtouda, on the southern flanks. At the latter, copper, gold, and silver were extracted during the Roman period.[56] With power centralized in Roman times at the *colonia* of Philippoi and the major urban center of Amphipolis, mining intensified to meet increasing demands across the territories of Lekani and Pangaeon respectively. It is still premature to arrive at certain conclusions as to how Roman administration and local elites impacted the leasing of mining contracts to safeguard the uninterrupted extraction of silver and gold. Surely, conscious political control over resources and state legislation played an important role for the expansion and ultimate decline in mining activity by late Roman times. More interdisciplinary research in the future could help towards investigating the identity of miners, metal producers and craftsmen, as well as their living spaces and relations with the consumers from the vibrant urban centers of the Thracian littoral and beyond.

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Notes

[1] Hdt. 6, 46–47.

[2] Thuk. 1, 100; 4, 105.

[3] Strab. 14, 5, 28; 7, 331–334.

[4] Koukouli-Chrysanthaki – Bassiakos 2002.

[5] Renfrew – Slater 2003.

[6] Seferiadis 1992.

[7] Bassiakos 2012.

[8] Nerantzis et al. 2016.

[9] Koukouli-Chrysanthaki 1990; Photos et al. 1986; 1989.

[10] Knapp et al. 1998.

[11] Stöllner 2015; Nerantzis 2015.

[12] Bolohan 2005, 167; Baralis 2009, 102.

[13] Tiverios 2008; Papadopoulos 2014, 188.

[14] Archibald 2000.

[15] Picard 2006; Kosmidou 2011.

[16] Graham 1978; Blondé et al. 2002.

[17] Hdt. 6, 46–47.

[18] Kozelj – Muller 1988; Grandjean 1999.
[19] Wagner – Weisgerber 1988.
[20] Pernicka et al. 1981.
[21] App. civ. 4, 13, 103.
[22] Hdt. 7.112; Xen. hell. 11, 5, 2. 11–43.
[23] Loukopoulou 2007.
[24] Tzochev 2015, 421.
[25] Kosmidou 2011, 442.
[26] Triantafyllos 2009, 192.
[27] Triantafyllos 2009, 192.
[28] Papastamataki et al. 2001.
[29] Melfos et al. 2003, 1203.
[30] Koukouli-Chrysanthaki 1980; Zannis 2014.
[31] Koukouli-Chrysanthaki 1990.
[32] Hdt. 7, 112, 1.
[33] Koukouli-Chrysanthaki 1990.
[34] Fornadel et al. 2011; Melfos – Voudouris 2016, 158.
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[44] Photos et al. 1989; Fornadel et al. 2011.
[45] Koukouli-Chrysanthaki 1990, 507.
[46] Photos et al. 1989; Koukouli-Chrysathaki 1990.
[47] Conophagos 1980.
[48] Tsaimou 2005.
[49] Papadimitriou 2016; see also: Nomicos 2013 and Nomicos 2021, 50–57.
[50] Brun et al. 2013.
[51] Nodin 2016.
[52] Melfos – Voudouris 2016.
[53] Nerantzis 2015, 74.
[54] Nerantzis 2015, 75 f.; Nodin 2016, 150.
[55] Vaxevanopoulos et al. 2017.
[56] Vaxevanopoulos et al. 2018.

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Noricum – Economic Factors in the Alps

Eva Steigberger – René Ployer

This paper deals with the cultural landscape of central *Noricum* before and during the Roman Empire. It gives an overview of mining materials, prominent sites, distribution and infrastructural features in this landscape dominated by mountains and river valleys.

The Danube Limes and the main road which followed the river's south bank is one of the regions to which products were delivered. From the 3rd century AD onwards, *Lauriacum*/Enns was the main city and legionary fortress of *Noricum.* Some settlements and *mansiones* are known from the *Tabula Peutingeriana* or the *Itinerarium Antonini.* Important roads lead toward *Iuvavum*/Salzburg to the west and from there via mountain passes towards the south and ending at Aquileia. There are two main north-south routes, and both require navigating mountain passes. They converge at the *municipium Virunum* in Carinthia (near Klagenfurt), before heading either southwest to Aquileia, or southeast to *Celeia*/Celje, where it branches off towards Aquileia, or to *Pannonia.* Three main east-west routes cross those north-south ones, always following river valleys of the rivers Enns, Mur, and Drau. Many discussions over the last century have offered variations of these routes.

The focus of this paper lies on the central region of *Noricum* between the so-called Salzkammergut to the north and the Carinthian valleys to the south (fig. 1). The region is defined by the eastern Alps and divided by the rivers Enns and Mur. A number of sites

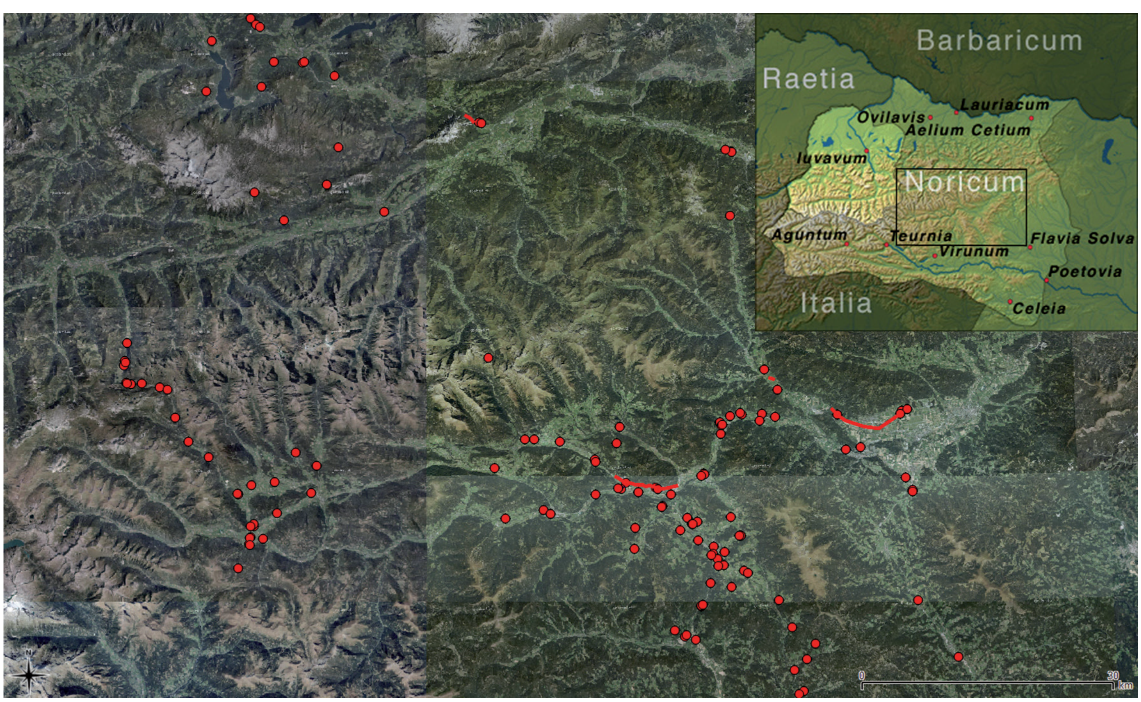

Fig. 1: Map of Roman sites in the Alpine region of *Noricum.*

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from cemeteries, parts of roads, settlements, *villae rusticae* as well as a great variety of finds confirm a strong Roman presence in the region – and also quite significant wealth. If we consider such factors as the lay of the land, then climate and agricultural potential, and large-scale agriculture cannot be the reason for the wealth that is evident in the large amounts of imported pottery, imported marble, coins and other luxury items.

Mining was a major regional economic factor which changed the landscape significantly. It is possible to detect a large-scale structural pattern of trade towards the south and Italy as well as towards the north and the Limes. So, the wealth displayed in this region with only some small-scale agriculture, must have come from other sources, such as mining. The resulting influx of money developed a desire, or even need, for luxury items. The visible remains in the landscape of the region combined with its finds lead to an identification of those economic roots. Projects organized by the Department of Archaeology of the Austrian Federal Monuments Authority have provided new insights towards the understanding of the economic factors in the Alps. They shall be presented and shall indicate how iron, salt, and marble extraction, and their trade, defined the inner alpine region of *Noricum* for centuries. Open-source ALS-models of the region, provided by the Styrian and Carinthian regional governments, show the rather bumpy features of mining landscapes in this region.[1]

Ferrum Noricum

Ferrum Noricum, Noric steel, is mentioned as high-quality steel in Latin and Greek literary sources since the end of the 1st century BC.[2] Diplomatic and commercial connections between the *Regnum Noricum* and Rome, however, date back to the first half of the 2nd century BC. These finally led to the foundation of a Roman trading post at the Magdalensberg Mountain in the first half of the 1st century BC.[3] Excavations and surveys conducted at the Magdalensberg show that this trading post was connected to a Late La Tène period *oppidum.*[4] The subsequent Romanisation of the Noric people facilitated the peaceful annexation of *Noricum* by Rome in 15 BC, and the Magdalensberg settlement became the first administrative and commercial centre of the new province. Numerous iron bars, and half-finished, as well as finished, iron objects found in this city on the Magdalensberg Mountain provide evidence of trade with *ferrum Noricum.*[5]

In the middle of the 1st century AD, under the Emperor Claudius, a new capital was established at *Virunum.* It was situated on the plain at the foot of the Magdalensberg Mountain, along the main north-south Roman road through *Noricum.* This route continued across the Alps to Aquileia, the Roman trading port in the northern Adriatic Sea. From here, Noric steel was shipped all over the Roman world.[6]

The most important region for the mining and production of *ferrum Noricum* was the area between Hüttenberg and Mösel, in southern *Noricum.* It has long been suspected that Hüttenberg, located north of the Magdalensberg – with its rich manganiferous iron ore deposits that were mined until 1978 – was the centre of production of this famous iron.[7] From 2003 until 2010 Brigitte Cech carried out archaeological research at the site of Semlach/Eisner.[8] She was able to uncover more than six furnaces, twelve smithies, an ore roasting pit, and the remains of a charcoal kiln. She also discovered beam slots and post holes of wooden buildings, as well as the stone foundations of houses. Iron smelting at the site started in the 1st century BC and lasted until the beginning of the second half of the 4th century AD. The evidence for buildings on the site, in addition to the material finds indicate that the workers and administrators lived there. The stratigraphy reveals that the spatial organisation of the site changed a couple of times during its occupation. Huge slag deposits show that large-scale iron smelting occurred here over a considerable period of time. Bloom smithing was carried out in small earthbound smithing hearths located near the furnaces. So far, the size and construction of the six furnaces excavated provide evidence of the expertise of the smelters working there.

In Möselhof, a few kilometres south of Hüttenberg, another smelting centre has been known for several decades.[9] In 2013, four smelting furnaces from two different phases were excavated, and a large building dating to the 2nd century AD was used as an outbuilding.[10] A vast slag dump and two water drainages, also of Roman origin, were found. A second building was a house with floor heating. The whole smelting area was used from the late La Tène period (Latène D2) to the 3rd century AD.

Gold Extraction

The extraction of gold was economically significant for the Roman province of *Noricum* in the early 1st century AD.[11] According to scientific analysis, the gold which was processed in the settlement on the Magdalensberg originated from the Tauern region of central *Noricum.*[12] Nothing is known regarding the mining of gold in *Noricum,* while the open-cast working of mined gold and the extraction of placer gold can be assumed based on the evidence from central and south-east *Noricum.*

Casting moulds for the gold ingots found at the settlement on the Magdalensberg Mountain provide sufficient evidence that processing the raw ore into gold ingots took place there.[13] Inscriptions on the casting moulds – and therefore on the finished ingots – are from the rule of Caligula and provide a firm date from 37–41 AD. Furthermore, a workshop to the south of the Magdalensberg settlement's forum can also be linked to the processing of gold. 15 furnaces erected on tile slats were documented. These were used for the smelting of gold during the first half of the 1st century AD.[14]

Gold extraction by panning is known from the Karth region in modern-day Lower Austria.[15] This region lies in the eastern foothills of the Alps and was situated in the Roman province *Pannonia,* very close to *Noricum.* Noticeable landscape formations have been identified as the remains of Roman mining activities using hydropower (hydraulic mining). These remains include basins, channels and water pipelines.

Prehistoric gold mining is also presumed at Rauris in the Salzburger Tauern (the so-called Tauerngold).[16]

Quarries

Iron ore and gold, however, were not the only commodities that transformed this region. Quarries were an important factor as well. Roman quarries, like the ones at Kraig and Gummern, both modern-day Carinthia, are of a more supra-regional importance and known for a long time. The site of Spitzelofen in eastern Carinthia is quite unknown and shall be presented here (fig. 2).

A Roman inscription found in 1817 was the first hint of something more, and first it was originally believed to be a temple of some sort.[17] In the early 1920s, masonry tools were found, namely 31 timber wedges; later some iron stonemason's hammers and chisels were also unearthed.[18] A small research project was started after new discoveries were reported. In 2015 and 2016 the Department of Archaeology of the Austrian Federal Monuments Authority produced the first complete topographic documentation, resulting in an overall plan. Two groups of quarries were identified and catalogued. Stone analysis proves the origin of the samples to be from Spitzelofen. So far all of them can

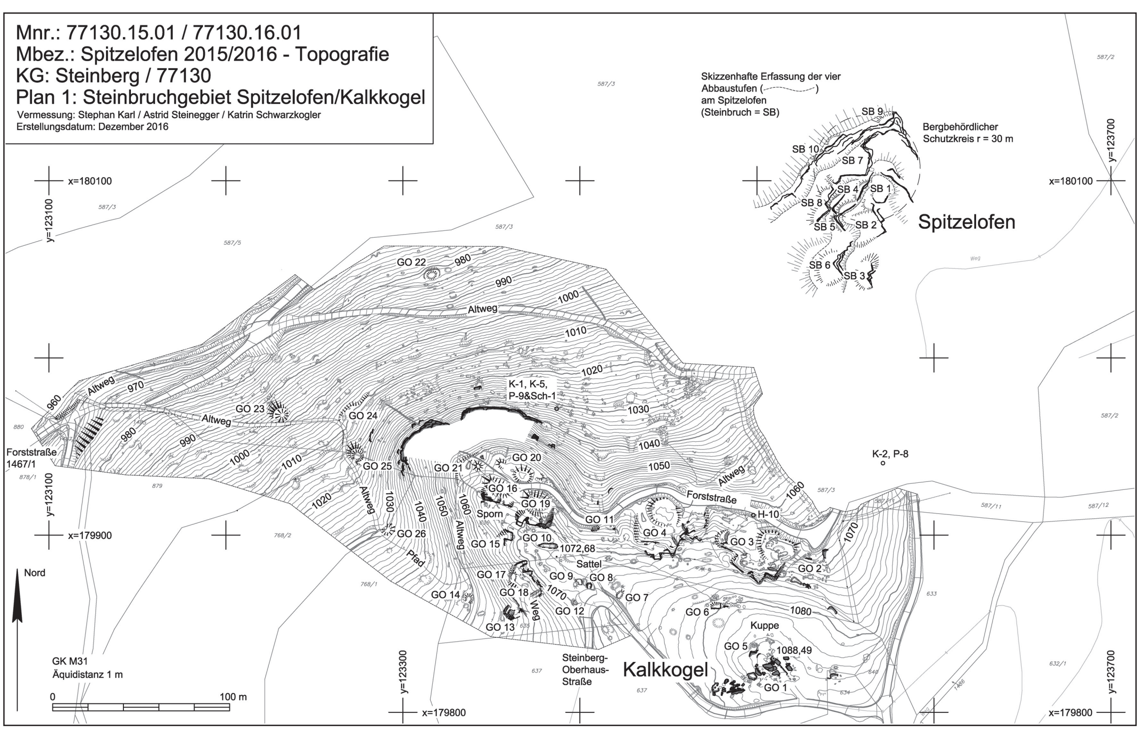

Fig. 2: Marble quarry in Spitzelofen, Carinthia.

be located in Carinthia. Further analysis is required before we can determine how far the marble was transported.

Salt Exploitation

Another important economic factor in the Alps was salt.[19] Although it is commonly assumed that salt production in Hallstatt started during the Neolithic period, the oldest concrete evidence for organized mining activities there dates from the Middle Bronze Age onward (1500 BC).[20] The heyday of prehistoric mining, to a depth of 200 meters, was during the Hallstatt period during the early Iron Age, between 800 BC and ca. 400 BC.[21] Around 350 BC, a gigantic landslide brought mining activities to a standstill.[22] The entire high valley, including all mine facilities, was covered beneath meters of rock and dirt. Therefore, salt mining started at a new location, higher up the mountain, during the La-Tène-period, at the so-called Dammwiese.[23]

Although the Romans established a large settlement near the lake and in the area of modern-day Hallstatt itself,[24] there is no evidence of Roman mining at this location. Scholars therefore assume that both the Late Iron Age settlement on the Dammwiese and the Late Iron Age Western group field still existed during the Roman period, and that the Romans contented themselves with asserting control over the salt trade.[25] Several researchers suggest a collapse of inland salt extraction and a shift of production sites to the coastlines in connection with the integration of central Europe into Rome's sphere of control.[26]

Only 10 km northeast of Hallstatt, however, substantial archaeological evidence for the continued extraction of Alpine rock salts in the Salzkammergut region was discovered at the Michlhallberg site, which lies at the southern foot of the Sandling Mountain.[27] The vicus found there was situated in the mountainous heart of *Noricum* at an elevation of about 1000 meters above sea level, but it was nevertheless well integrated in the provincial road network. Recent surveys have shown that the Roman road made a detour ascending the slopes of the Sandling right to Michlhallberg; the survey results have also connected this site with the alpine uplands of *Ovilava* in the north and *Virunum* in the south.[28] The area was damaged by several landslides and it was therefore difficult to ascertain traces of buildings. Nevertheless, during archaeological investigations carried out by the Federal Monuments Authority in the 1990s, hundreds of pottery sherds, coins, dress accessories, military equipment and objects of everyday use were found there.[29] Mining tools and the local salt deposits suggest an interpretation as a salt-mine, or a saltern. According to the dateable finds from the excavations, the site was occupied from the late 2nd century AD until the end of the 4th century AD. The spectrum of fibulas may also indicate the presence of the military or officials. There may be a correlation between the establishment of this salt production site and the appointment of the *legio II Italica* to *Lauriacum*/Enns after the Marcomannic Wars.[30]

The road, which led to the Roman site, was also part of the excavations. Over 120 horseshoes were found beside the unpaved trail without any consolidation.[31] A depot found in 2013 on the Michlhallberg consists of various tools for mining, a 40 kg anvil, and iron fixtures used for installing wooden brine-pipelines in mines.[32]

The site of Michlhallberg and the connected trade routes to *Ovilava* in the north and *Virunum* in the south illustrate that some rock salt deposits in the eastern Alpine area were still being extracted in Roman times. Furthermore, another recently discovered site connected to possible salt and certain iron ore mining was partially excavated in 2017–2018, warranted by a new interpretation of old finds. Moreover, in an area where known mines were in use until the 18th century, the site of a Roman villa lies near Mühldorf in the Drau River valley (modern-day Carinthia). It is situated in a location that is considered rather unfavorable for settlement, as it lies on the north side of the hill. Nonetheless, this villa had floor heating and finds which indicate a very wealthy owner.[33]

Distribution and Transportation Routes

All sorts of transportation methods must have been in use during Roman times in central *Noricum.* Main roads were paved and maintained certainly by some state officials. There were also small, winding tracks over the passes, and to the mining sites (fig. 3). As well, the first step of processing raw materials in the immediate vicinity of the extraction site should be considered. One recently discovered example of a marble workshop lies in Allersdorf, near the Spitzelofen quarry. Part of a marble base was found there, that could be identified as originating from the Spitzelofen quarry (fig. 2).[34]

Mountains had to be crossed and one such mountain pass, the so called Sölkpass was documented in the early 2000s by the Federal Monuments Authority, together with the University of Graz.[35] Prehistoric as well as Roman use is confirmed there. We should also keep in mind that transportation methods for different materials in the area likely did not change from the Roman times to the 18th century.

Settlement names, and more specifically those of *mansiones,* are known from literary sources, but most of them are not yet linked to sites. Last year we were able to connect the results of aerial photography and old excavation plans from the 1920s of a site at Katsch in the Mur River valley to produce a map for this site.[36] The discovery of a Mithras altar there[37] makes it probable that this settlement, once identified as a *villa,* is one of the *mansiones* that controlled the passes. Therefore, it controlled the distribution of iron, silver, gold and bronze from the central Alpine region towards the north and the Limes, or towards the south and Aquileia.

Fig. 3: Alpine road "Knappenweg" in Rohrmoos, Styria.

Summary

Metal-working can be counted among the most important economic undertakings in *Noricum.* Italian interest in these raw materials can be traced back historically to the 2nd century BC. Under Roman rule, the marketing and distribution methods were modified and greatly expanded. The extraction of gold was kept under Imperial control, while the iron tax allowed leases to be granted on the part of the state to private proprietors, the so-called *conductores ferrariarum Noricarum.* Salt mining has a very long tradition in the Alps, with the eponymic Hallstatt being one of the most famous prehistoric sites in Upper Austria. For a long time, it was assumed that the Romans also exploited the ancient salt mines of Hallstatt, but so far there is no proof to confirm this. A significant find complex of tools and settlements in an unfavourable environment near Hallstatt point to salt mining there, along with a very distinctive trade route system connecting those mountain settlements to the south and the north. A typically Roman phenomenon was the exploitation and working of marble in *Noricum;* for this, the outcrops in southern *Noricum* were favourably situated – in regard to transport – next to rivers, and were

significant beyond the borders of the province. Evidence of transportation and infrastructure clearly indicates a use of rivers, their valleys, and old, ungraded mountain routes that were adapted for Roman purposes. Mining above ground, as it was done in the region, has left its traces in the landscape. They remain visible for those who are able to detect them in the vast mountain forests which still preserve the remains of mining and processing metal in a region famous for its iron.

Notes

[1] <https://gis.stmk.gv.at/atlas/(S(svzcq4mbzuw2psjqvvf1jb21))/init.aspx?karte=kat&ks=das&cms=da&massstab=800000> (30th October 2018). <https://gis.ktn.gv.at/atlas/(S(mslwfyfe3iejwrsml2isv5xy))/init.aspx?karte=atlas_basiskarten> (30th October 2018).

[2] Hofeneder 2017.

[3] Piccottini 1996, 169.

[4] Cech 2014, 11.

[5] Dolenz 1996.

[6] Piccottini 1996, 187; Cech 2014, 11.

[7] Cech 2012; Glaser 2000.

[8] Cech 2008; Cech 2014; Cech 2015; Cech 2017.

[9] Glaser 2005.

[10] Eitler 2014; Mandl 2014. The rescue excavation conducted before construction on the site was funded by the Austrian Federal Monuments Authority (Bundesdenkmalamt).

[11] Recently e.g. Gleirscher 2013; Gleirscher 2014; Gostenčnik 2016.

[12] Strabo, Geografika, 4,6,12; e.g. Vetters – Pohl 2012.

[13] Piccottini 1996, 184 f.

[14] Gostenčnik 2016, 28–32 with older references.

[15] Cech – Kühtreiber 2013.

[16] e.g. Vetters – Pohl 2012.

[17] Karl 2017; Karl – Steinegger 2017; Karl 2021.

[18] Karl 2017; Karl – Steinegger 2017; Karl 2021.

[19] cf. Stockinger 2018, 183.

[20] Kern et al. 2008, 46 f. 50.

[21] Kern et al. 2008, 84.

[22] Kern et al. 2008, 158.

[23] Kern et al. 2008, 162–165.

[24] Grabherr et al. 2019, 333.

[25] Grabherr 2001, 92; Stockinger 2015, 191.

[26] Stockinger 2015, 183.

[27] Grabherr 2001.

[28] Windholz-Konrad 2018, D683–D686. The surveys were funded by the Austrian Federal Monuments Authority (Bundesdenkmalamt) until 2014 in cooperation with the Archäologische Arbeitsgemeinschaft Salzkammergut.
[29] Grabherr 2001.
[30] Stockinger 2015, 187.
[31] Grabherr 2001, 12. 71–74.
[32] Windholz-Konrad 2018, D683–D686.
[33] Piccottini 1989, 113 f.; Pircher 2020.
[34] Hebert 2011, 259.
[35] Mandl 2003.
[36] Steigberger 2020.
[37] Hebert 1997, 532.

Image Credits

Figs. 1–3: Bundesdenkmalamt

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Minería y metalurgia en el Este de la Península Ibérica durante los siglos IV–I a. C.: el caso concreto del territorio ibérico de Kelin

David Quixal Santos

Abstract

The Requena-Utiel Plateau, in the interior of the province of Valencia, was the territory of the Iberian city of Kelin/Los Villares (Caudete de las Fuentes, Valencia). In this territory, we have abundant information about the processes of metal exploitation and transformation from the 4th century BC until the Roman period. This is especially the case for iron, but also other metals, such as lead. Surface and gallery mining have been documented, as well as the presence of reduction and forge slag at numerous sites, and the existence of metallurgical furnaces and many processed tools. The northern border of the region, within the modern municipality of Sinarcas, is where this process reached its greatest development, especially during the Late Iberian period (2nd–1st centuries BC).

Introducción

La Meseta de Requena-Utiel, en el interior de la provincia de València, constituía el territorio de la ciudad ibérica de Kelin/Los Villares (Caudete de las Fuentes, València).[1] Las excavaciones en este yacimiento desde mediados del siglo pasado han sacado a la luz restos de un *oppidum* de unas 10 ha, con toda una serie de elementos que permiten abogar su estatus de lugar central (concentración de bienes de prestigio, urbanismo desarrollado, metalurgia, acuñación de moneda, muestras de escritura, etc).[2] Y, de forma paralela a las excavaciones, las campañas de prospección desarrolladas en la comarca desde los años 90 han permitido conocer un denso y jerarquizado poblamiento ibérico, con más de 200 yacimientos de entre los siglos VII y I a. C. En el presente trabajo recopilamos todos los datos existentes sobre procesos de minería y metalurgia en la zona (fig. 1), principalmente de hierro, aunque también de otros metales, en un arco cronológico que abarca los periodos ibérico pleno (IV–III a. C.) y final (II–I a. C.). De esta forma, pretendemos actualizar la información sobre esta temática, equiparándola a otros territorios ibéricos cercanos,[3] a la par que se da continuidad a lo realizado en otros estudios anteriores.[4]

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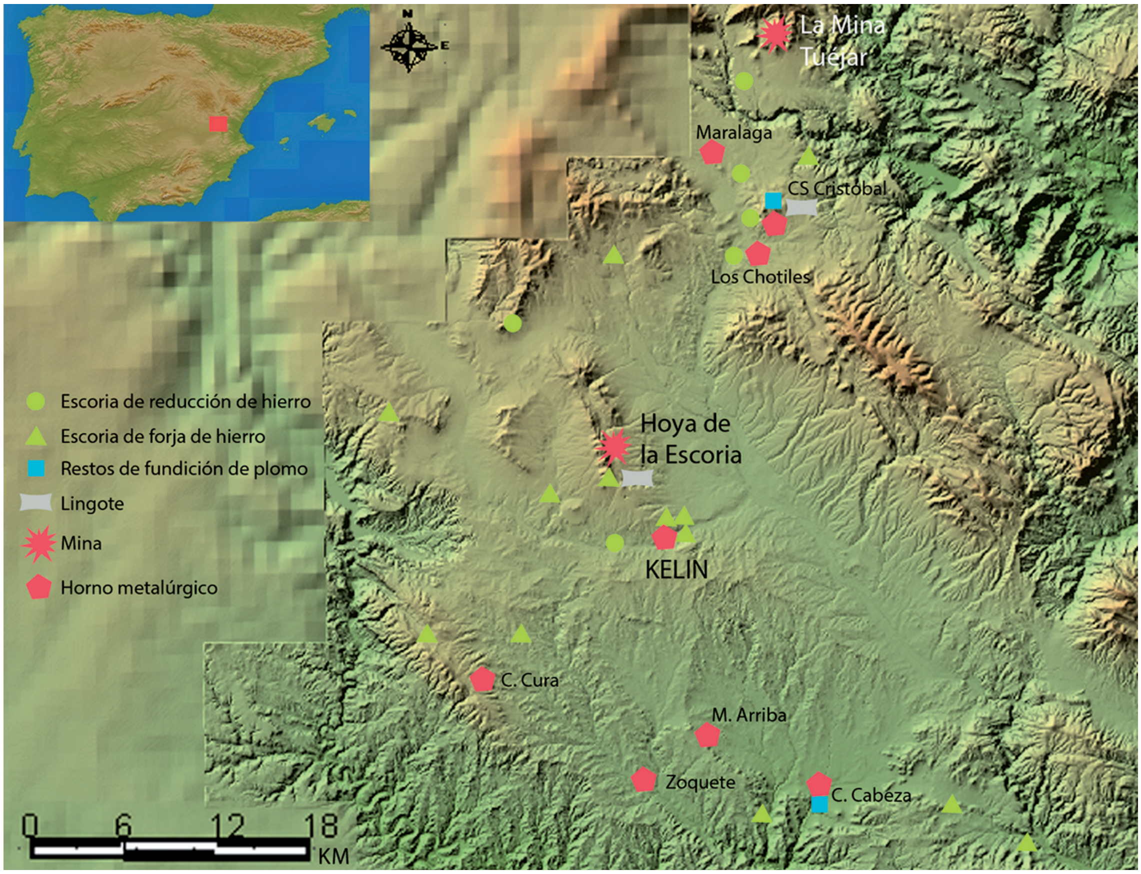

Fig. 1: Mapa del área de estudio con las diferentes evidencias metalúrgicas.

El lugar central, Kelin: la vivienda del comerciante.... y también herrero

En la ciudad de Kelin los trabajos arqueológicos se han centrado en dos sectores diferenciados. En el sector B, la parte más alta y predominante, se excavó una gran vivienda de 82 m^2 perteneciente a una familia de la aristocracia local durante el siglo III a. C.[5] De ella siempre se ha destacado la importancia de su bodega, una estancia con 70 ánforas destinadas a contener vino, así como la presencia de diferentes bienes de prestigio, por lo que el comercio sería la actividad principal de su propietario. No obstante, en una de las estancias de la casa también se halló un pequeño taller metalúrgico doméstico, compuesto por un hogar de forja excavado con forma alargada y revestido de arcilla, una losa pétrea que actuaría de yunque y una fosa delimitada con piedras para contener agua. En el mismo departamento había un legón de hierro, una pieza metálica indeterminada y unas pequeñas tenazas de herrero[6] (fig. 2). Tenemos bastantes ejemplos de otros talleres de herrero en el mundo ibérico, especialmente en la zona catalana,[7] que presentan estrechas similitudes con el aquí tratado (tamaño y forma de la cubeta, cocción rubefactada de las paredes de la fragua, etc.).

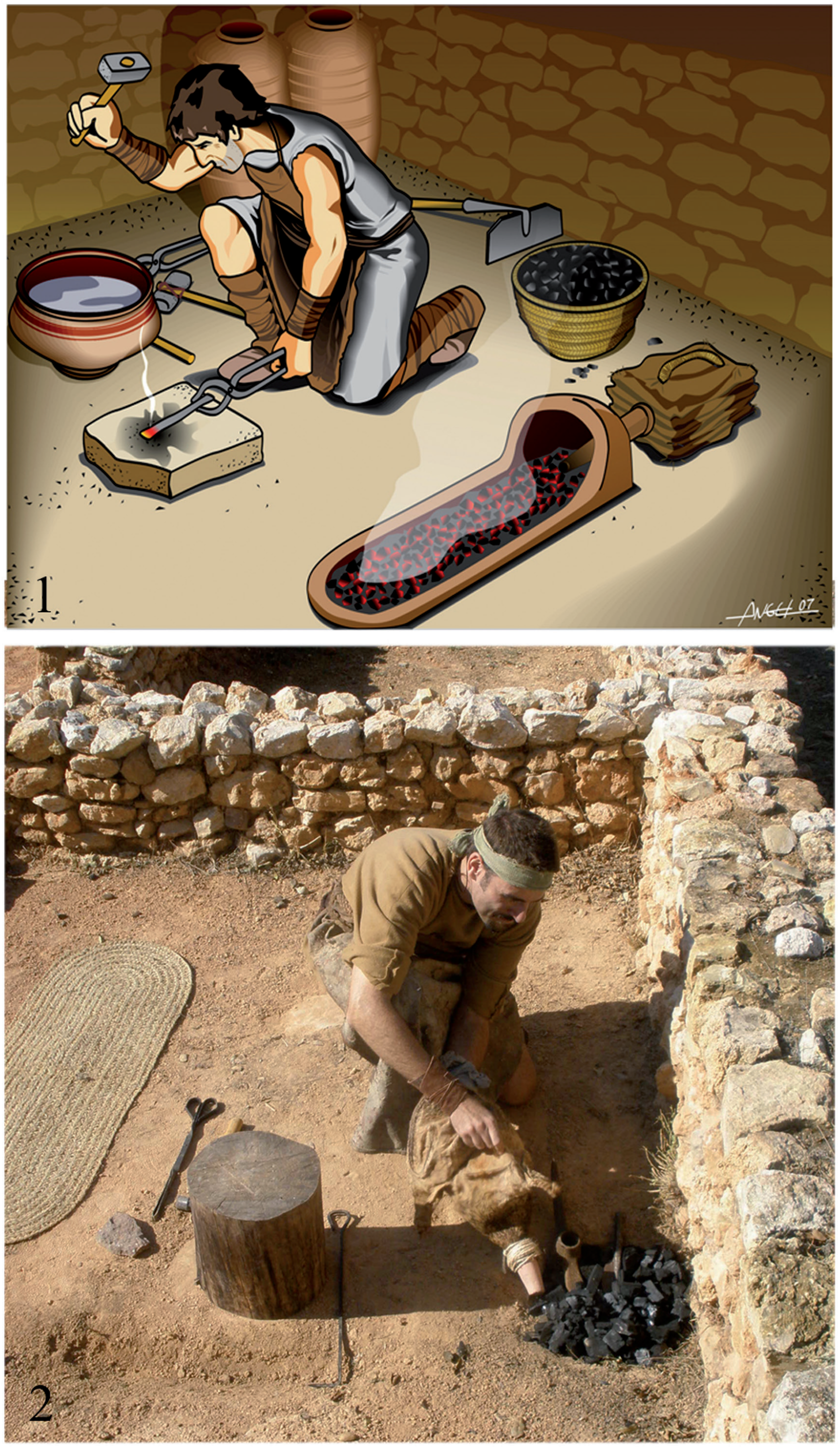

Fig. 2: Taller metalúrgico de Kelin (1) y recreación durante jornadas de puertas abiertas (2).

La presencia de abundantes escorias de forja y algunos restos de protolingotes dispersos por todo el yacimiento apunta, sin duda, a la existencia de otros talleres que debido al reducido porcentaje de superficie excavada todavía no han sido descubiertos.[8] Del mismo modo, de este *oppidum* procede una buena colección de herramientas y elementos de construcción de metal, la mayoría depositados en la Colección Museográfica Luis García de Fuentes (Caudete de las Fuentes), aunque no podemos determinar con seguridad si se trata de producciones locales.

La orla septentrional, Sinarcas: minas, escoriales y hornos

Dentro de este amplio territorio, una zona destaca por encima de todas en cuanto cantidad y variedad de evidencias de procesos siderúrgicos: el actual término municipal de Sinarcas (València) y alrededores, en el límite Norte de la comarca. Allí se han detectado diversos puntos potenciales de extracción del mineral. Aunque la explotación minera durante la Protohistoria generalmente consistía en la recolección superficial de minerales, también tenemos ejemplos de aprovechamiento de vetas polimetálicas superficiales o trabajo en galería. En ambos casos, el mejor ejemplo lo constituye la histórica Mina de Tuéjar (fig. 3), aunque siempre es complicado plantear una datación inicial para este tipo de explotaciones diacrónicas en las que no se suelen localizar materiales asociados.[9] La tradición siempre ha defendido un origen romano para la misma,[10] si bien el patrón de asentamiento de su entorno y las evidencias materiales del llano de Sinarcas apuntan

Fig. 3: Mina de Tuéjar. Explotación de vetas polimetálicas (1) y galerías (2 y 3).

a un comienzo anterior. Además de esta mina, en bastantes yacimientos de la zona también se han localizado trozos de mineral en bruto.

El hierro requiere de una primera reducción en el propio lugar de extracción, lo que genera las llamadas escorias de reducción o licuadas, de características formas curvas. Su localización en los yacimientos es importante porque está indicando una primera actividad siderúrgica en el entorno más inmediato, previa a la obtención de lingotes o a la transformación de los mismos en útiles.[11] La presencia de zonas forestales para abastecerse de madera como combustible era un requisito ineludible y Sinarcas seguramente reuniría esas condiciones silvícolas. En la zona existe una elevada concentración de escoriales de reducción, tanto cerca de la Mina de Tuéjar, como de los caminos que conducen a ella. Sin duda, el más importante es el Campo de Herrerías (Sinarcas), una gran dispersión de escorias en la que hemos documentado material ibérico en prospección y donde también se recuperaron cerámicas romanas en el pasado.[12]

Otro núcleo importante fue Los Chotiles, donde en 2017 se realizó una campaña de excavación, documentado restos asociados a un horno de reducción (fig. 4 y 5.1).[13] En-

Fig. 4: Excavación de Los Chotiles. Restos de un horno de reducción de hierro.

Fig. 5: Evidencias de transformación metalúrgica en el territorio de Kelin. Escorias de Los Chotiles (1), Cañada del Pozuelo (2) y El Molino (3). Toberas de Muela de Arriba (4) y Cerro de San Cristóbal (5). Diferentes escalas.

contramos abundantes escorias de este tipo en otros yacimientos del entorno como Cañada del Pozuelo, La Maralaga, El Molino o La Cabezuela/Pocillo de Berceruela, todos en Sinarcas (fig. 5.2 y 5.3). La mayoría tienen ocupación ininterrumpida entre los siglos IV y I a. C., incluso llegando a época imperial, por lo que no siempre se puede precisar la cronología de la actividad. Aquí se plantea la duda de si se trataría de procesos de transformación siderúrgica cerca de los propios puntos de extracción o aprovechamiento superficial, o bien serían puntos intermedios donde realizar un primer depurado antes de llegar a los principales poblados.

La segunda transformación sería un tratamiento de depuración de la lupia, previo paso a la obtención del lingote y su trabajo en la forja, y podría darse en hornos metalúrgicos más pequeños, ya en los propios asentamientos, de ahí la presencia de algunas escorias de reducción también intramuros. Por otro lado, también se han documentado un gran número de escorias post-reducción o de forja, caracterizadas por presentar ángulos y aristas vivas. Éstas ya se relacionan con una actividad de herrería, encaminada a la elaboración de objetos. En resumen, el número de yacimientos ibéricos de esta zona en los que se han localizado escorias, tanto de reducción como de forja, es muy elevado.

Además de las escorias, existen otros objetos que pueden indicar la existencia de hornos metalúrgicos pretéritos. En el Cerro de San Cristóbal (Sinarcas), importante poblado fortificado, se han hallado toberas ibéricas.[14] Una de ellas es doble (fig. 5.5), aunque dicha característica no tendría por qué comportar necesariamente el trabajo de dos herreros, sino que podría ser accionada por una misma persona usando ambas manos de forma alternativa. En otro poblado fortificado muy cercano al anterior, el Cerro Carpio (Sinarcas), se han encontrado restos de fundición de plomo y grandes planchas quemadas.[15] Por otro lado, en La Maralaga, yacimiento que albergaba un importante horno de producción cerámica y cronología final (siglos II a.C – I d. C.), también se documentó un horno metalúrgico,[16] evidenciando una interesante asociación entre hornos metalúrgicos y cerámicos, tal y como sucede también en las Casillas del Cura (Venta del Moro).[17]

La Casa de la Cabeza: metalurgia doméstica en el Ibérico Final

Las excavaciones en el asentamiento rural de los siglos II-I a. C. de la Casa de la Cabeza (Requena, València), en el sector meridional de la comarca, también han mostrado la existencia de una metalurgia de carácter doméstico durante los momentos finales.[18] La mayor parte de las evidencias se recuperaron en el sector 1, una pequeña área de trabajo auxiliar, separada del resto del núcleo, donde se documentaron dos departamentos aislados con función de almacén, alternando con sendos espacios abiertos. Entre otros materiales, se han recuperado diversos goterones o restos de fundación de plomo (fig. 6.5), vinculables a un posible horno de herradura de pequeño tamaño ubicado en la entrada de uno de los almacenes[19] (fig. 6.3).

Fig. 6: Evidencias de transformación metalúrgica en Casa de la Cabeza. Hogar (1), posible yunque (2), horno (3), tenazas (4), goterones de plomo (5) y tobera (6). Diferentes escalas.

Por otro lado, en los espacios abiertos se han documentado los restos de dos hogares alargados (fig. 6.1). Su tamaño, su ubicación extramuros y su grosor nos llevan a pensar que también pudieron servir en algún paso del proceso de transformación del metal. Podrían tratarse de restos de hornos mal conservados, ya que el grado de cocción del fondo es bastante elevado y sus formas son rectangulares/ovaladas. Estas placas de arcilla recuerdan a las documentadas en otros poblados ibéricos como El Oral, donde existía una asociación con restos de combustión y una piedra alisada utilizada como yunque.[20] En la Casa de la Cabeza, en ambos casos los hogares están próximos en el espacio a sendas losas pétreas, que quizás pudieron actuar como yunque en el proceso de fragua y martilleado. Una de ellas, la más pequeña, presenta muestras de piqueteado, mientras que en el otro se halló una gran losa pétrea, visible incluso antes de comenzar las excavaciones (fig. 6.2). Inicialmente consideramos que se trataba de un umbral de uno de los departamentos, no obstante, quizás habría que otorgarle una función más acorde con la actividad desarrollada en el espacio.

En el sector 2, plataforma principal donde se extendería el hábitat y el resto de los equipamientos productivos, se recuperaron unas espectaculares tenazas de herrero de 40 cm de longitud (fig. 6.4). Esta pieza es el único indicio de metalurgia en todo el sector, por lo que posiblemente responda a simples cuestiones de almacenamiento o deposición, siendo más fácil de relacionar con el resto de los elementos descritos anteriormente. Tenemos otros ejemplos de tenazas similares, aunque no se trata de un objeto especialmente frecuente en el registro arqueológico protohistórico. Existían de dos tipos: a modo de pinza, como las halladas en la Bastida de les Alcusses,[21] y compuestas por dos piezas cruzadas y un tamaño mayor, propias de momentos tardíos (siglos III–II a. C.). De estas últimas tenemos interesantes paralelos en Anseresa y Ampurias,[22] así como en los yacimientos celtibéricos de Numancia y Ventosa de la Sierra.[23]

El agua necesaria durante todo el proceso metalúrgico estaría asegurada mediante la existencia de una posible cubeta, así como una tinaja con pitorro vertedor protegida en una especia de alacena. Completan el conjunto otros objetos relacionados con la metalurgia como un trozo de tobera procedente de una prospección de los años 70 del siglo pasado (fig. 6.6), un posible fragmento de pico o martillo, así como diversas escorias de forja recogidas en superficie. Hallazgos aislados, algunos de los cuales mal conservados, pero que permiten reconstruir todas las fases finales de los procesos metalúrgicos del hierro y el plomo.

Otros indicios a lo largo del territorio

Fuera de las zonas hasta ahora tratadas, el número de evidencias desciende considerablemente, reduciéndose a los hallazgos dentro de los principales poblados fortificados del territorio. Destacamos la documentación de una posible zona de explotación del mineral en superficie en las faldas orientales de la sierra de La Bicuerca, concretamente en el paraje de la Hoya de la Escoria (Utiel) (fig. 1). Una vez más, la toponimia hace referencia a las características del lugar. Muy cerca de allí, a los pies del poblado del Cerro de la Peladilla (Fuenterrobles) apareció un interesante conjunto formado por una falcata damasquinada junto con algunos útiles y lingotes, lo que fue interpretado como un posible depósito de herrero.[24]

En La Albosa, extremo meridional de la comarca, se encuentra el poblado de la Muela de Arriba (Requena), donde se existían al menos dos hornos y se recuperó una gran tobera cerámica[25] (fig. 5.4). No muy lejos de allí, en la granja ibérica de El Zoquete (Requena), con una ocupación entre los siglos V–III a. C., también se hallaron fragmentos de otra tobera cerámica y escorias de forja, aunque en la excavación del lugar no se pudo precisar la ubicación del horno.[26]

En los diferentes asentamientos se han recuperado múltiples objetos de hierro: armas, herramientas agrícolas, elementos de carpintería, fíbulas y piezas indeterminadas. No obstante, la producción de todos ellos no tiene por qué ser siempre local, de ahí que su dispersión esté también en relación con las redes de comercio e intercambio regionales.

Lectura económica y social de una actividad importante en el proceso de cambio cultural

La siderurgia constituyó una actividad importante entre los siglos IV y I a. C. en Kelin y su territorio, especialmente a partir del siglo III a. C., si bien la mayoría de los talleres y hornos detectados tendrían un carácter local o familiar. Solamente se puede hablar de especialización en una zona concreta: la orla septentrional. Allí, una interesante dinámica poblacional iría ligada al desarrollo de la actividad minero-metalúrgica, con la explotación de la Mina de Tuéjar y otros puntos superficiales, presencia de escorias en la mayoría de los núcleos, documentación de hornos, toberas y el hallazgo de numerosos objetos de hierro.

Piezas como la falcata de La Peladilla, fruto de un alto grado de especialización artesanal, permiten reabrir el debate sobre la existencia o no de artesanos metalúrgicos itinerantes, quienes se desplazarían por los diferentes poblados y territorios haciendo objetos por encargo.[27] Otra opción es interpretarlos como objetos producidos en pocos talleres donde se concentrarían los artesanos especializados para luego exportarse, de ahí las grandes similitudes formales.[28]

Desconocemos el estatus o posición social que podrían tener los artesanos en la sociedad ibérica. En el caso de la vivienda nº 2 de Kelin, aunque albergaba un simple taller destinado a tareas domésticas y autoconsumo, permite reflexionar sobre cómo la familia propietaria también tendría la capacidad de fabricar piezas o reparar sus propias herramientas, sin ello estar reñido con su actividad principal comercial, que es la que le otorga riqueza y le permite ser considerada como parte de la aristocracia local.

Un aspecto en ocasiones pasado por alto es el contenido simbólico que tendrían este tipo de actividades. El artesano metalúrgico era un oficio que conllevaría conocimientos arcanos: la capacidad de modificar la materia obtenida de la naturaleza.[29] Este hecho les otorgaba, si no estatus, al menos un importante prestigio y reconocimiento social. Tenemos un gran vacío de información sobre si las actividades metalúrgicas conllevaban implícito algún tipo de ritual en sí o la propia concepción que tenía las sociedades, de la misma forma que podían tener carácter sacro aspectos aparentemente tan cotidianos como el ciclo agrícola. No obstante, es llamativo como en la zona de Sinarcas, parece darse una asociación en el espacio entre algunas áreas de reducción y hornos siderúrgicos, con ubicaciones de necrópolis o tumbas aisladas. Esto sucede en Los Chotiles, El Molino o La Maralaga: todos presentan indicios de actividad metalúrgica en un lugar donde también existiría un carácter funerario. Del mismo modo, llamativa es la presencia de escorias de hierro en algunas inhumaciones infantiles de El Molón,[30] a sabiendas del alto contenido simbólico y propiciatorio que tenían este tipo de prácticas funerarias en la sociedad ibérica. Poco podemos aportar más, a la espera de futuros hallazgos.

Para concluir, recalcamos que las actividades metalúrgicas toman auge en los siglos finales, ya a partir del siglo III a. C., pero sobre todo después de la conquista romana (siglos II–I a. C.). La metalurgia jugó un interesante papel en el complejo proceso de cambio cultural acaecido en zonas como Sinarcas, donde el patrón de asentamiento muestra una llamativa estabilidad. Los recursos metálicos hacían de esta zona una de las más interesantes para la nueva organización territorial en época romana, equiparable a los suelos más fértiles de los llanos centrales de la comarca. Precisamente en ambos espacios es dónde encontramos una mayor continuidad en las estructuras poblacionales entre época ibérica y romana. En este sector septentrional, tres esferas poblacionales (íberos, celtíberos y romanos) estuvieron en constante interacción, dando lugar a muestras de hibridación cultural como la conocida Estela de Sinarcas[31] (fig. 7); dinámicas que, posiblemente, fuesen realidad gracias al impulso dado por la siderurgia durante esos siglos finales.

Fig. 7: Estela de Sinarcas.

Notas

[1] Mata et al. 2001; Moreno 2011; Quixal 2015.
[2] Mata 1991.
[3] Bonet – Mata 2002; Guérin 2003; Pérez Jordà et al. 2011.
[4] Mata et al. 2009.
[5] Iborra et al. 2010, 109.
[6] Mata et al. 2009, 112 s.; Mata 2019, 131 s.
[7] Rovira 1998; 2000.
[8] Mata et al. 2009, 115.
[9] Lorrio et al. 1999, 163 s.
[10] Palomares 1966, 243.
[11] Ferrer 2000.
[12] Montesinos 1988, 18.
[13] La excavación se integró dentro del programa anual de campañas del Servicio de Investigación Prehistórica de la Diputación de Valencia. Sus estructuras y materiales se encuentran en proceso de estudio.
[14] Iranzo 2004, 232.
[15] Iranzo 2004, 180.
[16] Lozano 2006, 135.
[17] Mata et al. 2001, 316.
[18] Quixal et al. 2010; 2011; 2012.
[19] Quixal 2015, 48.
[20] Abad y Sala 1993.
[21] Nicolini 1990.
[22] Sanahuja 1971, 13; Rovira 1997, 64.
[23] Lorrio et al. 1999, 169.
[24] Lorrio et al. 1998–1999.
[25] Valor 2004.
[26] Quixal et al. 2008.
[27] Quesada et al. 2000, 294.
[28] Rovira 2000.
[29] Quesada et al. 2000, 294.
[30] Lorrio et al. 2010.
[31] Quixal 2015, 209 s.

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Subsidiary Industries and Cross-Craft Production in the Roman Mining Landscapes of Southwest Iberia

Linda R. Gosner

Introduction

Studies of the economic role of mining and other large-scale extractive industries, such as quarrying, often focus on the big-picture questions: how much was extracted and where did it go? Recently, however, closer attention to the archaeology of mining landscapes themselves has allowed scholars to consider the impacts of Roman imperial mining on local economic organization. In this paper, I examine one facet of local mining economies by looking at the role of subsidiary industries and cross-craft production in Roman mining landscapes in southwest Iberia. Artifacts recovered from Roman mines of the early imperial period – including Riotinto and Aljustrel – show that potters, smiths, carpenters, and basket-weavers supplied the tools necessary for underground mining across this region. Through an exploration of esparto-grass weaving and the production of water-lifting devices, I suggest that the increased scale of mining stimulated pre-existing local industries, but also brought about the importation of technological traditions for use in novel ways. Ultimately, I argue that better understanding these and other local industries in mining landscapes can help us move beyond a top-down understanding of Roman imperial mining. This approach sheds light on the integration of the Roman economy at multiple scales, from the local to the global, as well as the lived experience of laborers and craftspeople in mining landscapes.

Subsidiary Industries and Cross-Craft Production in Roman Economies

Subsidiary industries comprise the varied types of craft production that are carried out alongside and in support of dominant industries. Cross-craft production is the sharing of tools, equipment, ideas, labor, technologies, and other resources across industries.[1] In Mediterranean archaeology, these two related topics have rarely been explored in non-urban landscapes and industries centered outside the city. The one exception to this is research on the production of amphorae alongside viticulture and oleiculture in Roman agricultural landscapes, such as the production of Dressel 20/23 amphorae as containers for Baetican olive oil.[2] In studies of near-industrial production and extraction (including Roman mining and quarrying), economic questions typically focus on the dominant industry. Accordingly, scholarship on the organization of labor, production, and the economy in mining landscapes has often overlooked the essential role that smaller-scale and less-visible industries played in the quotidian operation of mines. The various stages of mining – from prospection, to opening shafts and galleries, to smelting, to transporting

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ores – required contributions from specialists in multiple professions beyond mining. Although these supporting industries were subsidiary to mining itself, they were indispensable to its operation.

The study of interactions among craftspeople in urban landscapes has recently received a great deal of attention. This is especially true in cities like Rome and Pompeii, for which there is abundant evidence of production. Among the results of this work is our increased understanding of how cross-craft production and economic interconnections benefitted craftsmen and workshops in urban landscapes and promoted social ties among laborers. In her analysis of Roman tanning, for instance, Sarah Bond asserts that leather production served as an "economic hub" in the wider animal processing industry, with activities ranging from butchery, to glue production, to fur processing, to cobbling.[3] Workers needed to communicate and share resources across these industries to acquire animals and their by-products. This type of cooperation has also been noted in Pompeii, where workshops for dyeing and fulling textiles often clustered nearby one another to facilitate interaction.[4] Significantly, interactions across varied industries included not just the sharing of material resources, but also the exchange of organizational strategies, technologies, and economic practices.[5] The dynamics of craftspeople and interactions among industries can and should also be studied in rural and industrial landscapes, as well as in contexts where dominant, imperial industries were integrated with small-scale, private industries.[6] An analysis of mining tools and equipment in the mining landscapes of southwest Iberia provides one productive way forward.

Roman Imperial Mining in Southwest Iberia

The landscapes of the Iberian Peninsula were famous in antiquity for their abundant metals, and scholars have long recognized the contribution of this region to the Roman imperial economy.[7] Environmental studies have further confirmed the large scale of mining in Iberia and the pollution it produced in classical antiquity.[8] Because of the scale of mining and its contribution to the Roman imperial economy, Iberia is a particularly apt location in which to explore the role of subsidiary industries in Roman mining. Here, I focus on evidence from mines in the geological region of the Iberian Pyrite Belt in southwest Iberia. A metal-rich swath of land roughly 200 km long and 30 kilometers wide, the Iberian Pyrite Belt stretched from Seville in the east to the Atlantic coast of the Alentejo region in southern Portugal in the west.[9] Across this region, mining took place from early in prehistory and was further catalyzed by Phoenician, Punic, and later Roman demand.[10] Under Roman administration, extraction was accomplished through underground mining, where copper as well as lesser quantities of silver and other ores were extracted through the excavation of vertical shafts and horizontal galleries, sometimes many stories deep. In the 1st and 2nd centuries AD, these mines provided ores that went into copper-based coinage minted in Rome and other objects.[11] Red pigments – a

Fig. 1: View of the contemporary mining landscape of Riotinto, Spain in 2013.

byproduct of smelting – were used across the empire, including Egypt and Italy.[12] Two of the best-studied mines in the region include Riotinto (Huelva, Spain) and Aljustrel or Roman *Vipasca* (Baixo Alentejo, Portugal), locales where contemporary mining allowed for the collection of many pieces of Roman equipment from Roman mines (fig. 1).[13]

Equipment and Industry in Southwest Iberia

Material evidence recovered from the mines in southwest Iberia demonstrates that many industries contributed to the production of mining equipment used in the various stages of underground mining.[14] Deep shafts and galleries required loggers and carpenters to provide wooden scaffolding and ladders, which have been recovered from Aljustrel and other sites. Iron chisels, picks, and other excavation equipment were cast by smiths and fitted with wooden handles. As they were used in the mines, such tools were frequently sharpened or repaired. Evidence of these tools remains in the form of metal picks, wooden mallets, and tongs, while the discovery of whetstones in the vicinity of mines provides evidence for the maintenance of metal equipment (fig. 2). Fiber or metal buckets and baskets as well as hemp or esparto ropes were used to create pulley systems for bringing ore to the surface. Flooded mines had to be drained, which was often accomplished using mechanical water-lifting devices such as the Archimedean screw or water wheel. Miners required specialized footwear and clothing woven from textiles or cut from leather. Finally, ceramic oil lamps or wooden torches were made to

Fig. 2: Sandstone used as a whetstone for sharpening iron mining tools (Museo de Huelva).

illuminate the dark, dusty underground passageways as miners worked. While multiple subsidiary industries were involved in the production of equipment, I will focus on two types of equipment and the contexts in which they were crafted: esparto grass objects and mechanical water-lifting devices. A closer look at the production of this equipment demonstrates the varied technological traditions and laborers across subsidiary industries who contributed to and benefitted from local mining economies.

Esparto Grass Production: A Local Industry Intensified

Esparto grass is a perennial plant used for basketry and textiles that grows in semiarid Mediterranean environments. The esparto species native to Iberia is known for its quality and durability.[15] Products woven from this plant were produced in parts of Iberia as early as the Neolithic period, most famously for the intricate, polychrome baskets and sandals from the Cueva de los Murciélagos near Granada.[16] Similar products are still made for artisanal purposes today.[17] Ancient examples of esparto objects demonstrate that the sophisticated technical skills required to craft esparto long-predated Roman presence in the region. Though esparto grows naturally in Iberia, it was likely being grown and harvested at increasing levels – and potentially even cultivated – by the Iron Age, as the industry grew in response to Phoenician and Punic economic demand.[18]

Under Roman rule, esparto grass became an essential component of subterranean mining equipment. It was used to produce safety coverings and clothing, including helmets, tunics, and sandals, ropes and baskets for lifting ore out of shafts, and canteens for water. Many examples survive from the Republican-period lead and silver mines in southeast Iberia around Cartagena (Roman *Carthago Nova*), a location where esparto production was especially prolific and of a particularly high quality (fig. 3).[19] Similar

Fig. 3: Esparto grass and wood basket from *Carthago Nova* (Museo Arqueológico Municipal de Cartagena).

types of equipment were also used in the mines of southwest Iberia during the early empire, as demonstrated by examples recovered intact from the underground mines of Aljustrel (fig. 4, fig. 5). Fragmentary pieces of equipment have also survived from the mines at Riotinto, such as bronze frames onto which baskets were once woven (fig. 6).[20] These pieces, while incomplete, attest to collaboration between esparto grass weavers and smiths to produce finished items. Similarly, many of the earlier baskets from *Carthago Nova* are made with wooden framing, making it necessary to have carpentry skills and a suitable supply of wood for this industry as well.

The production of esparto objects is a laborious, multistage process that involves cultivating, harvesting, alternately drying and soaking the raw materials, and pounding the leaves so they are supple and suitable for working. In his *Historia Naturalis,* Pliny the Elder (*HN* 19.7–8) suggests that this was a seasonal activity. Ethnographic research on contemporary communities shows that esparto is often a craft done alongside pastoralism and subsistence agriculture.[21] Later, the weaving of the products themselves requires the kinds of tactile skills developed through gradual exposure to the craft, often from a young age in household contexts. The importance of hands-on experience and knowledge of the local landscape in the production of esparto objects indicate that local people – including, perhaps, women and children – were likely the ones producing the esparto equipment for mining. Therefore, the existing skills of local people in and

Fig. 4: Esparto grass helmet from Aljustrel (Museu Geológico de Lisboa).

Fig. 5: Esparto grass basket from Aljustrel (Museu Geológico de Lisboa).

Fig. 6: Bronze ring, once part of an esparto grass basket from Riotinto (Museo de Huelva).

around mining landscapes were redeployed within the Roman imperial economic system, making this local industry and the technical knowledge involved essential to the economies of Roman mining. The production of specialized esparto products must have brought local crafters into interaction with miners, overseers, and other craftspeople through the making and distribution of this equipment. Esparto crafters, who perhaps engaged in agriculture and pastoralism on a seasonal basis or also produced esparto goods for use outside of mining, then, became an essential part of the social and economic networks in mining landscapes.

Water-Lifting Devices: Innovative Implementation of Hellenistic Technologies

As with esparto grass equipment, the water-lifting devices recovered from mines in southwest Iberia also show the ways that cooperation across industries and among different sectors of the mining community was key to the success of mining. By contrast, however, the creation and use of water-lifting devices in mines shows the interaction of both foreign and local knowledge. The large-scale of Roman mining in the Iberian Pyrite Belt, combined with the region's distinctive geology, meant that shafts and galleries often had to be extended below the water table. Efficient methods for removing underground water were devised for extraction to continue. This could be accomplished through the construction of inclined galleries and evacuation channels or simply by bailing water out by hand. However, water-lifting equipment made the process more efficient. The various types of water lifting devices that have been discovered in Roman-era mines of southwest Iberia include bucket-chains, Archimedean screws, and water wheels or *norias,* among others.[22] The origins of many of these water-lifting devices can be traced to the Hellenistic East. Many were invented – or at least first described – by Hellenistic scientists and inventors in Alexandria in the 3rd century BC. These machines saw many of their first practical applications, improvements, and wide use in agriculture, urban water management, as well as mining in the Roman West.[23] While the exact mechanism of transfer of this knowledge is still up for debate, it may have circulated among the educated in technical texts or have been brought to Iberia by trained engineers who either traveled with the Roman army or migrated themselves as specialists for hire.[24]

The adaptation of these technologies for the practical needs of mining operations, however, involved not only the import of outside technologies, but also the use of local resources and multiple local industries for their production and implementation. Water wheels were commonly used in the Iberian Pyrite Belt in the 1st and 2nd centuries AD at locales including Riotinto, São Domingos, and Tharsis. At Riotinto, the remains of more than 50 water wheels have been uncovered, mostly in the process of 19th and 20th century opencast mining. Because so many were recovered intact and have been thoroughly published, this is an excellent corpus of objects with which to examine the practices involved in their production. Wheels typically reached diameters of between 3.6 and 4.6 meters and had between 22 and 27 buckets.[25] They were constructed with a combination of timber and bronze elements for the axis, spokes, and buckets (fig. 7). In one water wheel that has been extensively studied, now in the Museo de Huelva, multiple different species of wood were used, including walnut, pine, and fir. Local timber was sourced selectively: the hard walnut wood was employed to make the buckets, an element that needed to be more durable than other components.[26] Thus, even though the design of water wheels can be traced to technological traditions outside Iberia, their construction relied on loggers, carpenters, and smiths to fashion and repair their components. Even in state-owned woodlands of the Roman Empire, most logging was carried out by private hands.[27] Thus, there is reason to believe that this demand, while created by the imperial mining industry, still relied heavily on local economies and laborers to provide this essential service.

Once the components of wheels were finished, they were inscribed with numbers to aid in quick assembly after they were transported through the underground mines in pieces to their destination. Traces of these numbers have been preserved on surviving pieces from Riotinto.[28] The relatively uniform size of wheels would also have facilitated the repair of broken elements so that entire devices would not have to be replaced when single elements failed. The arrangement of multiple wheels together at Riotinto is also

Fig. 7: Wooden buckets for water wheels from Riotinto (Museo de Huelva).

significant because this type of complex system is not used with water wheels outside of mining. In the South Lode of Riotinto, for instance, eight Roman water wheel pairs were discovered, which together raised water over 29 meters to the surface (fig. 8).[29] Thus, although engineers were using a technology common to other industries such as urban water infrastructure, construction, and milling, they were innovative in their implementation of it according to the demands of the local landscape and the scale of the specific industry. Commonalities among the design of water wheels found across the Iberian Pyrite Belt further suggest that their design was adapted to the particular circumstances of mining.[30] Ultimately, the implementation of waterwheels and other water-lifting devices served to bring technical knowledge from outside of Iberia, make innovative use of that knowledge in mining, and utilize local resources, skills, and labor.

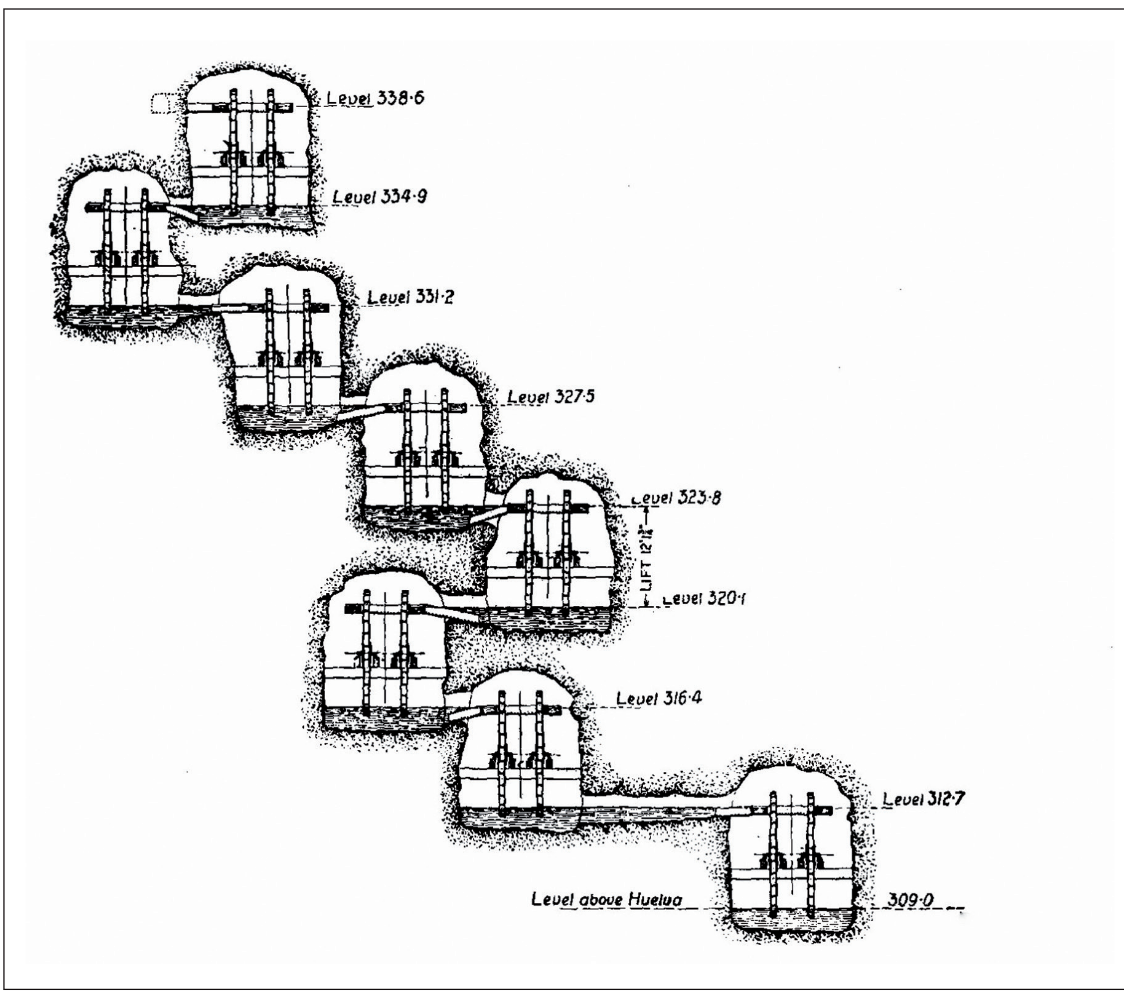

Fig. 8: Reconstruction drawing of a system of eight pairs of water wheels from Riotinto.

Conclusions and Further Considerations

Further study of the subsidiary industries that supported imperial mines in Roman Iberia will illuminate details about the significant role that local production had in imperial extraction. While this discussion has been limited to those industries most closely linked with mining economies, many other industries should be taken into account. For instance, the agricultural sector was especially key, as food produced locally and farther afield was needed to sustain populations of specialized laborers engaged in mining.[31] For now, this specific look at the crafting of tools and other equipment used in underground mining in the Iberian Pyrite Belt has shown the variety of ways that laborers and craftspeople living in and around mining landscapes sustained the operation of the copper and silver mines of the early empire. Subsidiary industries – ranging from esparto grass weaving, to potting, to carpentry – became essential to local economies and supported the work of large-scale mining. Many of these industries were inextricably linked to one another and engaged in cross-craft production, dependent on the sharing of equipment, materials, and technologies. Roman extraction, then, incited the formation of social and economic ties across varied subsidiary industries. These processes altered local economic organization and, ultimately, sustained and supported large-scale Roman imperial mining in southwest Iberia.

Notes

[1] Miller 2007, 237–246; Shimada 2007.

[2] E.g.: Blázquez Martínez 1992; Remesal Rodríguez 1998; Bourgeon 2017.

[3] Bond 2016, 97 f.

[4] Flohr 2013a, Flohr 2013b.

[5] Murphy 2015.

[6] For more on the organization of the mining industry in this period, see Hirt 2010.

[7] E.g., Davies 1935; Domergue 1990; Edmondson 1987; Orejas et al. 1999; Wilson 2007.

[8] Hong et al. 1996, Hong et al. 1994; Rosman et al. 1997; McConnell et al. 2018.

[9] García Palomero 2004; Gibbons – Morena 2002, 483–487.

[10] Rothenberg – Blanco-Freijeiro 1981; Hunt Ortiz 2004; Gosner 2016.

[11] Klein et al. 2004, 478 f.

[12] Mazzocchin 2008, 692; Walton – Trentleman 2009, 858.

[13] For information about the long-term history of the mines, including more recent periods, and the history of collecting, see: Delgado Domínguez 2012; Harvey 1981; Salkield 1987. The Vipasca tablets are among the other famous finds from Aljustrel, see: Domergue 1983; Edmondson 1987, 244–249; Orejas 2002.

[14] The artifacts discussed here are now preserved in museum collections in Spain and Portugal, including the Museo de Huelva, the Museo Minero de Riotinto, the Museu Geológico de Lisboa, the Museu Nacional de Arqueologia (Lisbon), and the Museu Municipal de Arqueologia de Aljustrel.

[15] Fajarado et al. 2015.
[16] Cacho Quesada et al. 1996.
[17] Alfaro Giner 1984.
[18] Buxó 2008, 152.
[19] Bañón Cifuentes 2010.
[20] Palmer 1927, 305.
[21] Fajardo et al. 2015, 372.
[22] Blair et al. 2006; Simms – Dalley 2009; Oleson 1984.
[23] Wilson 2002, 17–28; Oleson 2000; Oleson 1984.
[24] On technical knowledge transfer with reference to water-lifting devices, see: Schneider 2008, Oleson 1984.
[25] Manzano Beltrán et al. 2010, 350.
[26] Manzano Beltrán et al. 2010, 363–365.
[27] Harris 2017; Meiggs 1982.
[28] Ojeda Calvo 1999, 30–33.
[29] Delgado Domínguez – Regalado Ortega 2010; Palmer 1927, 303; Schneider 2008, 165.
[30] Manzano Beltrán et al. 2010, 375 f.; Domergue et al. 1999.
[31] On agriculture around the Roman copper mines at Wadi Faynan, see, Friedman 2013. For a specific look at southwest Iberia, see: Pérez Macías 2014.

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Fig. 1–7: by the author. – Fig. 8: Palmer 1927, 303.

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Considerations on the Profitability of Roman Gold Mining in the Northwest of the Iberian Peninsula during the 1st and 2nd Centuries AD

Regula Wahl-Clerici

Like today, the possession of mineral resources, especially gold and silver mines, meant wealth and power in Antiquity. Both also are important foundations for maintaining power and securing peace.[1]

According to Cassius Dio (52,28,1–6), Maecenas briefly summarizes the foundations for a prosperous and profitable Roman economy in a conversation with Augustus and his general Agrippa. He mentions various possibilities for substantial tax revenues in order to be prepared not only for the running costs but also for possible crises. Mines are expressly named as a source of income. The possibility of increasing state revenues through the sale of state property is also mentioned. This meant that potential economic problems could be passed on to the owner or the tenant.[2]

Taking these circumstances into consideration, questions on the organisation of the gold mines in the North-western part of the Iberian Peninsula arise. The ancient mines preserved in this region clearly demonstrate that the cost of extracting the precious metal in this region was often very high (fig. 1). The necessary preliminary work to enable the extraction alone required the skills of well-trained engineers as well as a large workforce. These include the complex water supply systems (fig. 2) and the underground mining that had to be carried out to exploit the deposits (fig. 3). Looking at the examples of the *territorium metallorum* Tresminas/Jales (Concelho Vila Pouca de Aguiar, Distr. Vila Real, P), of Las Médulas (Prov. León, E) and in the Telenos mountains (Prov. León, E), questions arise immediately on the costs of the extraction of the metal. At the same time, the enormous remains of ancient mines preserved at these places are proof of a management working to a plan and an organization that could afford very large investments, which did not yield immediate profits.[3]

These few indications must suffice to demonstrate the distinction between the two levels of economy dealt with here, the economy of the whole of the Roman Empire and the management of a particular mine or mining district. These two levels must be differentiated when researching the profitability of gold mines. It will become apparent that the needs of the Imperial economy took precedence over the economic considerations of the individual mine or mining district, at least for the first two centuries of the Principate, the period in which the deposits considered here were exploited. Although these two levels are inextricably linked, this will be examined separately below.

In principle, the profit of any business is calculated from the difference between yield and investment. Thanks to the rich tradition of written sources in Egypt, researchers interested in the ancient economy could demonstrate that the local estate administrators did indeed take the most basic principles of business management into account.[4] To

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Fig. 1: *Territorium metallorum* Tresminas/Jales, Corta de Covas: The southern and northern opencast pits are separated by a rock ridge (in the middle of the picture), seen from the west.

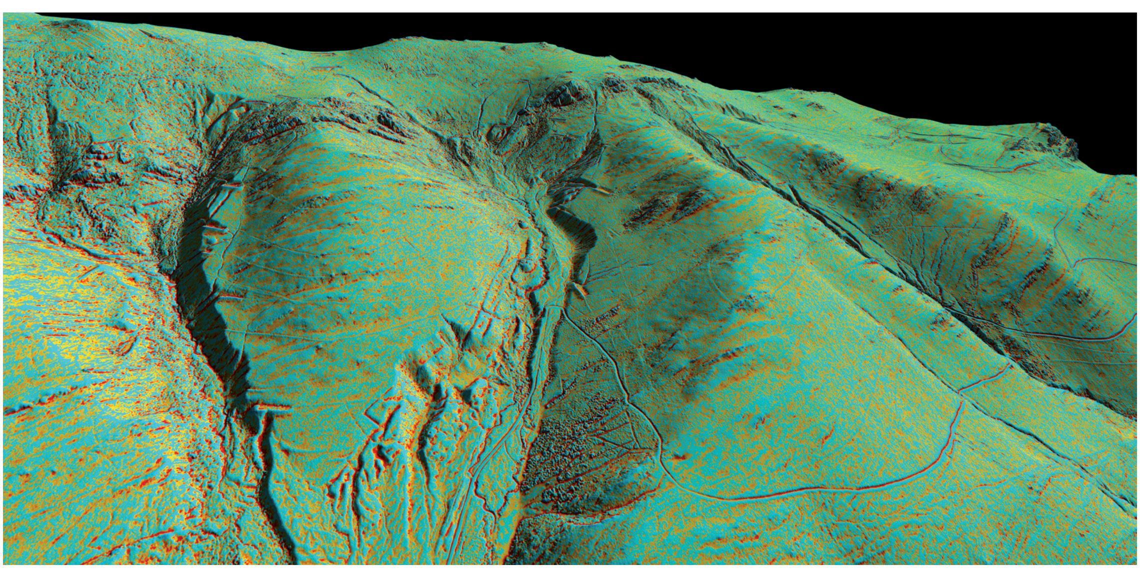

Fig. 2: Teleno massif (province of León, E): Mining zones, water reservoirs and aqueducts, seen from the south (tilted). Data: ALS of the Instituto Geográfico Nacional de España, processed by the Morphological Residual Model [MRM] method on the basis of 1 point per 50 cm².

Fig. 3: *Territorium metallorum* Tresminas/Jales: Galeria do Pilar with the channel (0.8–1 m wide and 23 m deep) and the pillar that gave it its name in the background.

what extent this also applied in the mines in the North-western part of the Iberian Peninsula during the 1st and 2nd centuries can only be guessed at on the basis of the preserved monuments, because of the very limited number of written sources.

This raises the question of the criteria that can best help solve this quandary. Dr. A. Wiechowski (RWTH Aachen University) drew our attention to a modern list of various criteria usually investigated and evaluated by experts after the discovery of a deposit of precious metals. These criteria are established before the start of exploitation in order to convince potential investors. Despite the enormous technical developments since Antiquity, it turns out that some of these criteria still apply and can be investigated on the basis of the surviving remains of Roman mining.

Some of the most important indicators are

- The gold content and the size of the deposit and
- its mining possibilities.

Both are directly related to

- the nature of the ore body and the surrounding rock.

This entails the following problems

- of processing and smelting the metal ore.

Which leads to

- personnel costs and

- the cost of setting up the infrastructure.

But it all ultimately hangs on

- the value of the product on the (world) market.

The Value of Gold in the Roman Empire

The principle that there must be a market for it applies to all products.[5] Pliny the Elder (23–79) was astonished to find:

> Indeed, I am surprised that the Roman people always demanded silver, not gold, from defeated peoples as a tribute; for example, from Carthage after defeating Hannibal [in the second Punic War 218–201 BC] 800,000 pounds; 16,000 pounds per year distributed over 50 years, but no gold. (N. H. 33, 51)

Since its introduction in 211 BC, the denarius was the most valuable Roman coin, which led to a great demand for silver from then on. The aureus only became the highest nominal coin after the coin reforms under Augustus, even if the sestertius (HS) always remained the standard unit of account. With gold and silver coins, the nominal value was more or less equivalent to the metal value.[6] This meant that sufficient gold had to be available to produce these coins and consequently guarantee that enough coins were in circulation.[7] Not all of this gold had to be mined of course, because considerable sums regularly came back into the treasury from taxes, customs revenues, etc.[8]

The army devoured most of the state's expenditure, estimated at 400 to 500 million sesterces annually.[9] Evidence that some of the soldier's pay was paid in gold can be found, for example, in the excavations at the site of the battle of Varus of 9 BC.[10] The *viaticum,* the fee for entering the army, could also be paid in aurei.[11] It was probably unavoidable for purely logistical reasons that a good part of the pay had to be paid out in gold and silver coins, as Speidel's calculations for the Vindonissa legionary camp in Switzerland showed.[12] The various *donativa, praemia* and release payments are not even included in this amount.

The key point of this very summary compilation is the high dependence on gold of both the Emperor and the Empire. This applied to both maintaining the loyalty of the army and guaranteeing tribute payments. The salaries of civil servants were also an important item in government expenditure.[13] Large sums also had to be made available to satisfy the population of Rome by supplying grain, setting up games, and constructing magnificent buildings and the irregular *congiaria* paid out to the inhabitants of Rome.[14] Gold consequently played a pivotal role in Roman economy, or as Maecenas put it, in the 'well-being of the state'.

Deposits – Mining – Processing

The richness of the gold deposits in the Northwest of the Iberian Peninsula is confirmed by Pliny the Elder, who in his position as financial procurator of the province of Hispania Tarraconensis, also inspected the gold mines of the province. He reports (N. H. 33, 78) that 20,000 pounds of gold (about 6.5 t) were extracted annually in Asturias, Callaecia and Lusitania from the alluvial deposits alone.[15]

Gold mining by leaching river gravel began long before the Roman conquest of the Northwest of the Iberian Peninsula. Strabo (3,3,4) calls all major west-facing rivers in Portugal 'rich in gold'. They are: the Tagus (Tejo/Tajo), called the 'gold-rich Tagus' by Catullus (29,20), the Mundas (Mondeo), the Vacus (Vouga), the Durius (Douro/Duero), the Lima (Lethe or Limaeas or Belion) as well as the Baenis or Minius (Minho/Miño).[16]

The enormous amounts of material washed out can be deduced from a statement by Pliny (N. H. 33, 76):

> Thus the earth is washed away and slides into the sea and the broken mountain is dissolved; Spain has already pushed its land far into the sea for these reasons.

The basic condition for the profitable extraction is of course the content of valuable metals in the deposit. At the same time, the nature of the deposit determines the mining, processing, and smelting procedures, all of which are necessary to obtain the pure valuable metals.

The problems in determining the ancient gold content of a Roman mine are manifold. First of all, we have to bear in mind that only those areas are preserved which – for whatever reason – were not mined. Another requirement would be that a deposit would have a more or less constant gold content, which of course is not the case. The estimated size of the mining zones is also important. A telling example is the Corta de Covas mine in Tresminas, where the large discrepancy between the size of the mining zone published by Harrison and the far smaller one published by Wahl is obvious, which of course also applies to the quantity of gold (fig. 4a, b).[17] At the same time, the preserved monuments of mining prove that the Romans were able to optimise the yield with their techniques.

The list compiled by Domergue makes it clear that the total quantity of gold extracted from the Northwest of the Iberian Peninsula during the 1st and 2nd centuries is estimated at around 190 tonnes.[18] While this sounds like a lot, when distributed over about 200 years it is just 1 t per year on average. And 122,100 aurei could be produced from it, which corresponds to a value of 12,210 million HS. The discrepancy to the 400 to 500 million HS required annually by the army alone is evident.

The production costs had to be deducted from the maximum possible value of extraction in a mine. These in turn depend on the nature of the ore body and the surrounding rock, and also determined the mining procedure and the necessary processing and

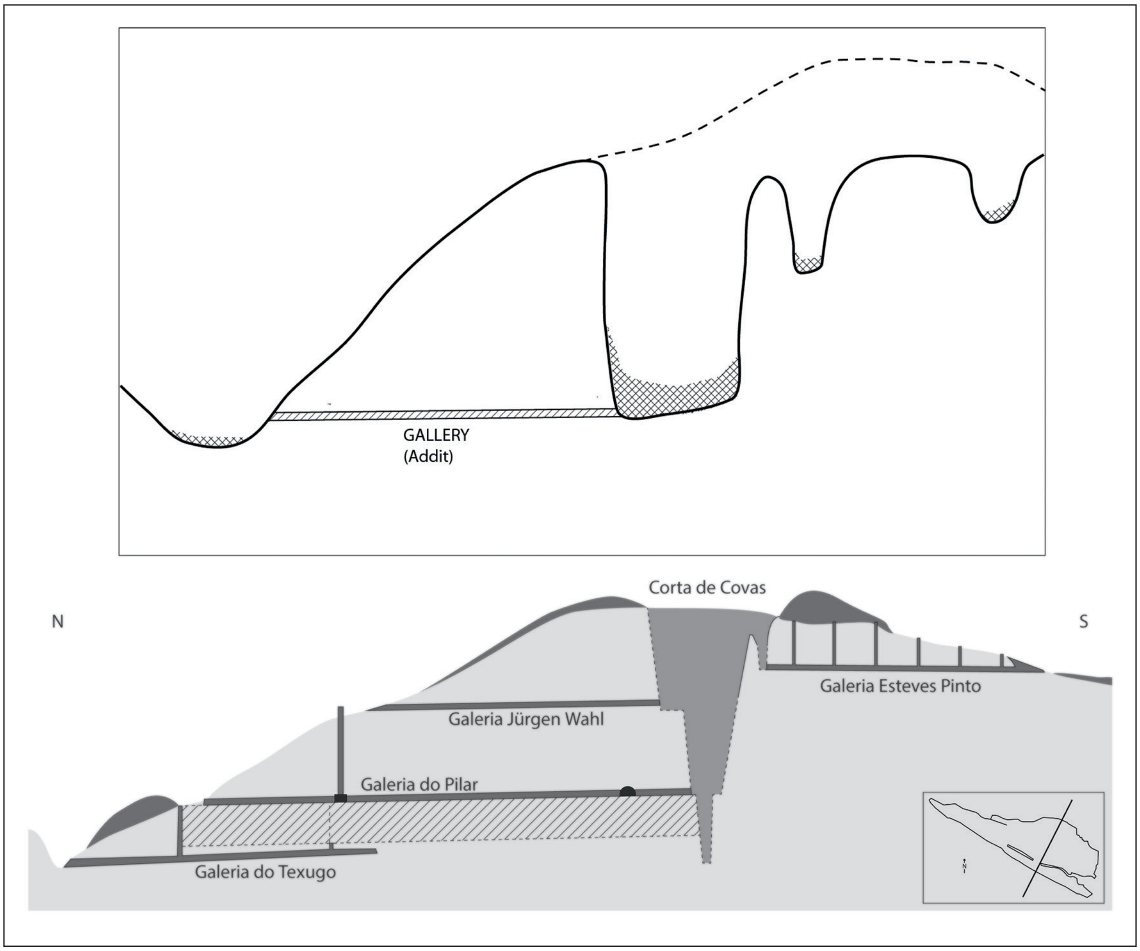

Fig. 4: a: *Territorium metallorum* Tresminas/Jales: Cut through the Corta de Covas. b: *Territorium metallorum* Tresminas/Jales: Cut through the Corta de Covas. c: *Territorium metallorum* Tresminas/Jales: Position of the cut through the Corta de Covas.

smelting procedures. The problem of the compilation of the production costs will now be dealt with on the basis of various examples.

The washing out of gold from the river gravel is not technically demanding, but it is labour-intensive. According to Strabo (3,2,9), the women of the Artabri, the Celtiberian inhabitants of the Northwest of the Iberian Peninsula, loosened the river gravel and washed out the gold in sieves that were woven like baskets.

Much more complex was the mining of alluvial deposits that were no longer located in the rivers themselves. The examples of Las Médulas (fig. 5) and Las Omañas (both in the province of León, E) give us an idea of the effort required to mine them and so extract the gold. The magnificent landscape of Las Médulas bears witness to the process described by Pliny as *arrugiae* (N. H. 33, 70), whose result he calls *ruina montium* (N. H. 33, 66). It was necessary to crush the former river gravel, which had almost baked into a

Fig. 5: Las Médulas (Province León/E), seen from the south.

conglomerate. A system of tunnels and shafts, some of which are still accessible today, prove that water was supplied in large quantities (fig. 6). This method of washing out the gold-bearing rock had the advantage that it was also softened for the subsequent washing process.[19]

The gold mined in the *territorium metallorum* Tresminas/Jales was *aurum canalicum* or *canaliense* (Pliny N. H. 33, 68), that is, gold embedded in veins in the rock. Tresminas also had tunnels, galleries, and shafts dug for prospecting and/or production and drainage.[20] Mining was carried out using hammer and pick and/or by setting fire to the rock face. The resulting rock then had to be stamped, ground, washed and smelted (N. H. 33, 68–69). The approximately 1000 preserved stamp mill bases, the innumerable ore mills, and the washing plant with two rows of 17 platforms each (of which the western one was supplemented with sedimentation basins to the side) are witnesses of these processes.[21]

Water had to be brought into all mines, either for the mining itself as in Las Médulas or the Teleno mountains, or for the subsequent processing, as in Tresminas, Las Médulas and the Teleno mountains.[22] The difficulty was that, as mining progressed, new pipelines had to be built again and again: in Las Médulas ten aqueducts in all were built, the longest being 143 km long.[23] In Tresminas, twelve parallel aqueducts with a maximum

Fig. 6: Las Médulas (Province León/E): Water supply tunnel.

length of 30 km were built.[24] Along with the aqueducts, reservoirs, river drains, tunnels, etc. had to be created. One example of the buildings associated with these aqueducts is the earth dam of Outeiro, which was part of the Tresminas mine and is 21 m high, with a base width about 70 m and an upper length of 130 m.[25]

The construction and maintenance costs for the aqueducts were certainly kept as low as possible in mining. Comparisons can be made between the 180 million HS construction costs of the 91.2 km long Aqua Marcia in Rome, built in 144 BC, and those of 350 million HS for the 69 km long Aqua Claudia, which had the Anio Novus built on top of it in 38–52 BC.[26] This means that the cost of the longest aqueduct in Las Médulas must be estimated at between 30 and 50 million HS.[27]

The consequences of these figures for the calculation of the profit margins in the gold mining areas in the Northwest of the Iberian Peninsula are noteworthy, as can be demonstrated with the example of Las Médulas. It is estimated that around 4.7 tonnes of gold[28] were mined here over a period of around 200 years, from which 574,000 aurei could be mined, corresponding to 57,400,000 HS. In other words, the total gold production of Las Médulas was at best sufficient to pay for the construction of not even all ten aqueducts. The purpose of this comparison is not to obtain any exact figures, but to draw attention to the proportionality between the profit and the investment costs.

Furthermore, disposing of the pit water, the natural flow of water collected in the mine also caused costs. The most primitive method, but one that required a lot of personnel, was scooping the water out. According to Pliny (N. H. 33, 98), this method was still in use in Roman times in the "Baebelo" mine in Andalusia. This mine had already produced 300 pounds of silver every day in Hannibal's time and was excavated 1500 steps deep in Pliny's time. There is evidence of installations such as Archimedes' screws, scoop wheels, bucket wheels, or combinations of these.[29]

These installations had to be applied when it was not possible to lead the water out through a channel in a tunnel due to the topography of the deposit. Both examples can be found in the *territorium metallorum* Tresminas/Jales. The Jales ore vein was mined using bucket wheels, as evidenced by the remains of wood and a bronze vessel.[30] Older miners of the modern mining works remember ancient tunnels that drained the northern mining zone.

The mine of Tresminas is famous for its large tunnels, which were cut into the mountain at the height of up to 1.80 m and a width of 4 metres. They were used for the transport of the material to the surface of the slope and at the same time led water out through channels (fig. 7). The construction of these tunnels was expensive and required superior skills from the mine surveyors.[31] This also applied to the tunnels and shaft

Fig. 7: *Territorium metallorum* Tresminas/Jales: The Galeria dos Morcegos with pilot drift and partial excavation.

systems in Las Médulas, mentioned above. Another example can be seen in the aerial photographs in Las Omañas.[32] The need for surveyors was great, as the construction of the aqueducts was not possible without them.[33]

Not to be underestimated are the costs for the wood needed in a mine. Large quantities were needed for fire-setting (in order to shatter the rock), a technique that was only used on the surface in Tresminas; it could also be detected as having been used underground in Valongo (Porto district, P). Wood was also needed in large amounts for the production of charcoal, which was indispensable for smelting and forging operations.[34]

In Antiquity, wood was the most important material for the construction of machines and devices of any kind. This also included the carpentry in the tunnels and shafts of the mine and the superstructure of the washing facilities. Therefore, the wood was carefully selected with regard to its use and processing.[35]

This very summative and incomplete overview of the material costs involved in the running of a mine can give us a schematic picture of the investments that were necessary to attain the coveted metal. In addition to the various jobs mentioned so far, we also need to factor in the prospection, which, as the example of Tresminas shows, could become very costly in a primary mine.[36]

Personnel Costs and Organizational Form

However, on a basic level, the mines were a source of income. Hirt writes, "The guiding principle of the Roman mining and quarrying administration was to keep imperial involvement to a minimum without renouncing control of these ventures."[37] Heil expresses himself in a similar way when he states, "the imperial mining administration was basically nothing more than a big machine to skim off profits."[38]

Written sources that would allow us to explore possible forms of organization at individual locations are rare. In addition, we must assume that the respective forms of administration were established according to needs and possibilities, depending on the time, the metal extracted and the province, and that they were hardly subject to a stringent system. The bronze plates of Vipasca, on which the laws enacted by Emperor Hadrian (117–138 AD) are recorded, offer a small insight into the circumstances of a mine. They demonstrate that a complex system of leases for a wide variety of works was created to exploit the silver mines.[39] Leases were also established in the *aurariae Dacicae,* an imperial domain in the Dacian mountains. These are known from contracts concluded there between 131 and 167 AD.[40]

The excavated mining zones of Vipasca (Lusitania) and Alburnus Maior (Dacia) reflect these leasehold concessions.[41] An obvious contrast to this is the "Corta de Covas" mining zone in the *territorium metallorum* Tresminas/Jales (fig. 4b, 8a, b). Based on lamp finds, the zone was exploited during a period from the 1st century to the first half of the 2nd century AD.[42] The striking element in this mining zone is the consequence

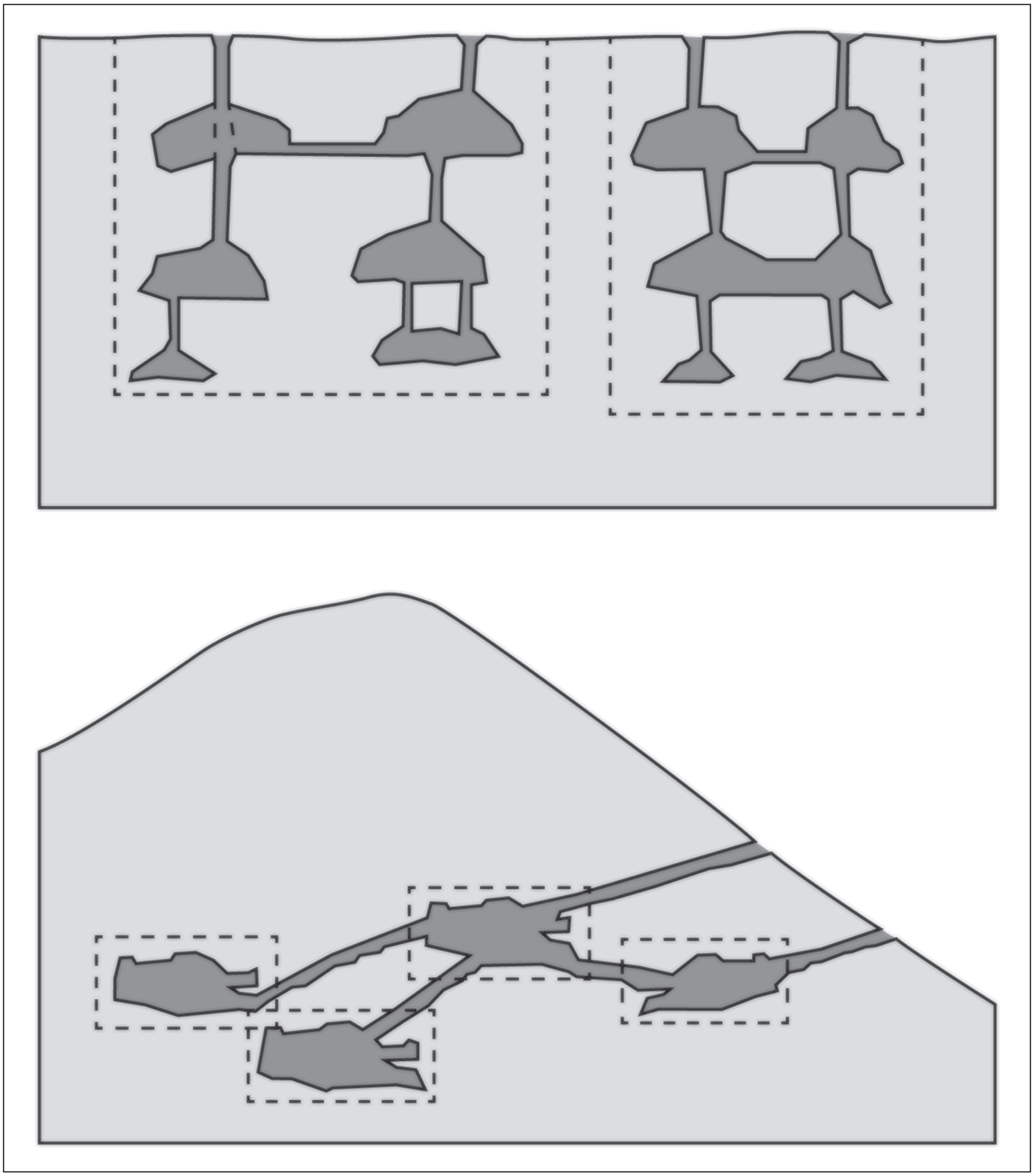

Fig. 8: a: *Vipasca* (Aljustrel, Distrikt Beja, P): Schematic cut through the mining zone with the concession boundaries. b: *Alburnus Maior* (Rosia Montana, Ro): Schematic cut through one of the mining zones with the concession boundaries.

in the construction of the tunnels, some of which are connected to each other underground, to facilitate extraction and drainage.

The construction of these tunnels in Tresminas was complex and expensive and was obviously planned and started long before the extraction had reached the appropriate level. Proof of this is the Galeria dos Morcegos, whose excavation was abandoned due to the lack of gold concentration at the destination of the tunnel.

The people from Clunia (province Burgos, E), which had migrated to Tresminas from the northern Meseta were *mercenarii,* that is, free labourers.[43] They were probably quite sought after, as Clunia had an underground canal system that supplied it with water. These people were therefore familiar with working underground.[44]

This systematic approach can only lead to the conclusion that at least for this phase, a hierarchically organized administration was in charge of the mine, probably a *procurator metallorum* with extensive competences.[45]

Another approach is taken by Sastre and Sánchez-Palencia/Orejas, which is essentially based on the interpretation of the *tabula Paemeiobrigensis* from Bembibre (Prov. León/E) and their archaeological research. The latter includes not only a single mining zone, but takes the entire region into account.[46] They conclude that here, the political structures of the Celtiberian population were not destroyed after the conquest, but cleverly exploited by the Romans to their advantage. Selected clans or tribes were left a certain amount of autonomy, but they had to pay their tribute in gold, which meant that the production costs could be passed on to the local population and their chiefs.[47]

The most important criticism of this form of organisation concerns the personnel required for the complex techniques. Although the Celtiberians were experienced miners, we cannot deny that there was a large difference between a Republican mine, as it was operated in the south and east of the Iberian Peninsula, and a mine from the imperial period, as we know it from the northwest.[48] As already mentioned, the investment costs for most mines in the Northwest of the Iberian Peninsula were rather high. The specially trained personnel must also have been expensive, whether they were members of the army or not.[49]

However, it may be possible that the local population was responsible for the extraction of the ore in a (as yet undefined) transitional period. This could be due to the fact that the provincial structures were only gradually established.

Slaves also were part of the population of a Roman mine. From the punishments mentioned on the bronze tablets of Vipasca, we can conclude that for the same offence, punishments were somewhat milder for free labourers than for slaves.[50] There is little to suggest that the labour of slaves or of *damnati ad metalla* was used to reduce costs in the Roman gold mines in the Northwest of the Iberian Peninsula or in Dacia.[51]

Rosumek emphasizes the possibilities of technical progress and rationalization in order to address the imbalance between costs and benefits in Roman mining. It is however questionable, whether these measures really led to an effective reduction in production costs.[52]

Closing Remarks

It was the objective of this brief presentation to highlight the gaping difference between the potential profit and the necessary investment into the gold mines in the Northwest of the Iberian Peninsula. Even if Roman mines can be classified as 'large machines for skimming off the proceeds', the preserved remains and the calculated production quantities cannot conceal the fact that the production costs swallowed up a large part of the profit. Other authors have shown various approaches to solving this problem, highlighting in particular the possibilities of cost reduction in production.

Among the costs, those for personnel can be estimated to have been the highest. By leasing out gold-mines or even by handing over the entire responsibility to the local tribes, the Roman state was able to achieve significant savings. However, structures such as the more complex water supply systems and the access tunnels to the mining zones, which were constructed on a high technical level, speak against such forms of organisation. In these places, a proper management was needed which organised not only the administration but also the execution of the work. On the other hand, it cannot be ruled out that the small-scale organisations were preferred in earlier or later phases of mining.

The fact that the nominal and the metal values of Roman coins was more or less identical meant that an enormous amount of gold had to be available to mint coins, and that these amounts even increased over time.[53] The return of coins through the collection of direct and indirect taxes hardly sufficed for a sufficient number of new minting.

It is obvious that the demand for gold was ultimately more important to the Roman state than the costs of its extraction. Consequently, the primacy of the economy of the whole Empire as expressed by Maecenas can be seen in the approach to gold mining in the Northwest of the Iberian Peninsula.

Translation: Dr. S. Hoss

Notes

[1] Heil 2012, 155; Speidel 2009; von Reden 2015, 75. 171: In Homer's epics, wealth, excellence, and leadership are virtually inextricably linked within a competitive warrior context.

[2] Based on the written sources, we know that the deposits of Vipasca (Aljustrel, Beja district, P) and Dacia (Romania) were leased out, see Flach 1979 and Noeske 1977.

[3] Domergue 2008, 190–240.

[4] Von Reden 2015, 97.

[5] Current examples are the cost of the minerals necessary for the batteries of electric cars, such as lithium (2001: 2US$/kg, 2017: 13 US$/kg) and cobalt (2003: 40 US$/kg, 2008: 120 US$/kg, 2017: 60 US$/kg). After

<http://www.elektroniknet.de/elektronik/power/das-ende-der-abhaengigkeit-146341-Seite-3.html.> Downloaded 09. 01. 2019.

[6] Wolters (1999, 371–373) discusses the relation between gold and silver and the fluctuations in the value of these metals. The price of gold in Italy fell by a third within two months after the Taurisci had discovered a new gold vein (Polyb. 34,10,10–14 = Strabo 4,6,12). Similar distortions resulted from the looting of the Gallic temple treasures by Caesar (Suetonius, Caesar 54,2). The Romans were well aware that there was sometimes a discrepancy between the coin value and the metal value, as proven by Cassius Dio (78,14, 3–4): "Antoninus gave [the peoples at the mouth of the Elbe] full coins, while for the Romans he had only falsified silver and gold: one type was made of lead with silver, the other of copper with gold plating".

[7] Silver is not considered here. See Drexhage et al. 2002, 149–156 for a summative discussion of the banking and credit system in Antiquity, including various individual examples. It should be added that the gold standard of many currencies was only abandoned in the 20th century.

[8] Strabo (2,5,8) pointed out that customs revenue for goods from the British Isles would bring in more money, while the expenditure of the conquest would be expensive, despite the expected tribute payments (4,5,3). Gold could always be re-melted and reused with virtually no losses. This was quite common, see App. Civ. 5,6,26: Brutus and Cassius seized all precious metal tableware and jewellery in order to mint coins.

[9] Drexhage et al. 2002, 52.

[10] Van Heesch 2014, 140; Wolters 1999, 375. We know from the Pompeii disaster that gold, silver and bronze coins were in parallel circulation and that amounts of over 100 HS were generally kept in aurei.

[11] Van Heesch 2014, 140: The soldier Apion writes to his father Epimachus that he has received three aurei, the equivalent of 75 denarii.

[12] The calculated pay of 8 million HS would have meant 8.1 t of silver coins or 656 kg gold coins per year, see Speidel 1996, 75 f.

[13] Calculations by Duncan-Jones (1994, 37–39) showed that the salaries of the senatorial legates and governors during the 2nd century AD amounted to 43,5 million HS.

[14] Overview in Drexhage et al. 2002, 54.

[15] A comparison with the amounts calculated below shows that Pliny seems to have exaggerated the yield.

[16] Fernández Nieto 1970, 71.

[17] Harrison 1931, fig. 4.A; Wahl 1988, 225; Wahl-Clerici 2010; Wahl-Clerici – Helfert 2017, fig. 13. For the contents of the Jales and Gralheira mines, see Bachmann 1993, 153 f.; Martins – Martins 2017.

[18] Domergue 2008, 209. It is still unclear today whether the 20 tonnes of gold calculated by Bachmann (1993, 154) would have meant all the gold produced from all three deposits of the *territorium metallorum* Tresminas/Jales.

[19] Domergue 2008, 129–139.

[20] The gold of the Tresminas-deposit was embedded in silicified schists, see Ribeiro et al. 2006, tab. 1; Wahl-Clerici – Wiechowski 2013.

[21] Wahl 1988; Wahl-Clerici – Helfert 2017; Wahl-Clerici 2018.

[22] Wahl-Clerici 2016 and 2017.

[23] Matías Rodríguez 2004, 181 f.

[24] To reduce costs, the Aqua Tepula and Aqua Iulia were installed on top of the Aqua Marcia in Rome, which also made significant savings possible; see Aicher 1995, fig. 22.
[25] Wahl-Clerici 2018, Abb. 37.
[26] Aicher 1995, map 7.
[27] The figures are based on the assumption that in a mine, the costs for one km of aqueducts, together with the structures required for the storage of the water amounted to a maximum of 1/10 of the aqueducts for the city of Rome.
[28] Domergue 2008, 209.
[29] Oleson 1984; Domergue 2008, 122–128.
[30] Oleson 1984, 228 f.: Minas dos Mouros refers to the *territorium metallorum* Tresminas/Jales, Portugal.
[31] Wahl 1988, 226–230; Wahl-Clerici – Helfert 2017; Wahl-Clerici 2018.
[32] Co-ordinates: 42.663° N, 5,882° W.
[33] Pliny the Younger, Epist. 10, 41, 42, 61, 62; Nonius Datus: CIL VIII 2728 = 18122.
[34] The estimates of Harris (2018, 216) for the production of 80,000 tons of iron per year in the whole of the Roman Empire results in a demand for wood that would use 26,000 km² of forest, which corresponds to almost 2/3 of the area of Switzerland (41,285 km²).
[35] Ulrich 2008, 448–450, tab. 17.1; Harris 2018; Wilson 2008.
[36] Wahl-Clerici/Wiechowski 2013. A large number of different prospection buildings have also been preserved in Valongo (district Porto, P), see Wahl-Clerici et al. 2019, fig. 15.
[37] Hirt 2010, 368.
[38] Heil 2012, 168.
[39] Flach 1979.
[40] Noeske 1977.
[41] Domergue 2008, 205 fig. 124.
[42] Wahl 1988, 240.
[43] For the wages of the *mercennarii* see Noeske 1977, 396–403; Mrozek 1989.
[44] Pers. Comm. Clara Valladolid Esteban, who is writing a PhD on the *Clunienses* and their migrations.
[45] Domergue 2008, 196–203. According to Domergue, the organizational form was largely dependent on the metal extracted. In a discussion, Hirt emphasized the possibility of a single (wealthy) tenant or a leasing company.
[46] Alföldy 2000.
[47] Orejas – Sánchez-Palencia 2002, 591; Sastre 2012.
[48] Strabo writes (3,2,9) that Poseidonios compares the works of the Turdetani, who lived in present-day Andalusia and according to him had the habit of digging difficult and deep tunnels to extract ore, draining them by means of Archimedean screws, with the Attic mines of Laurion. For the incorporation of Celtiberian terms into the Roman mining language, see Wahl-Clerici – Wiechowski 2013, 299.
[49] See Hirt 2010, 208. The largest water allocation went to the Centurio, the Decurio, and the architect.
[50] Flach 1979, §§ 10, 13, 17.
[51] Noeske 1977, 345.
[52] Rosumek 1982, 148–162.
[53] Drexhage et al. 2002, 48.

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Fig. 1: photo: C. Wahl. – Fig. 2: H. Pires. – Fig. 3: photo: R. Wahl-Clerici. – Fig. 4a: after Harrison 1931. – Fig. 4b: after Wahl-Clerici 2010. – Fig. 4c: after Wahl-Clerici 2010. – Figs. 5–7: photo: R. Wahl-Clerici. – Fig. 8a. b: Domergue 2008, fig. 124, after Cauuet.

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Mining and Territory at Carthago Nova

Alfred M. Hirt

Since the seminal publication by Claude Domergue on 'Les mines de la peninsule Ibérique dans l'Antiquité romaine', Spanish and French archaeologists have intensified archaeological excavations and epigraphic surveys of mining areas on the Iberian Peninsula. These have provided new data and offered inspired interpretations of new and known material.[1] This material, in combination with the literary and epigraphic evidence, has improved our understanding of exploitation of metal resources in southern Spain; at the same time it raises questions which, as we shall see, cannot be satisfyingly answered. Recently, Almudena Orejas and Christian Rico have offered their comprehensive and enticing reading of the evidence from the Sierra de Cartagena and the Sierra Morena; in particular, they addressed issues of access, possession, and ownership of mines in a province.[2] In light of the recent scholarly discourse on possession and ownership of public land in the Late Republic, a reconsideration of some of the more significant points seems appropriate.[3] The focus of this paper is on the mining areas of 'La Union' to the east of Cartagena, and, to a far lesser degree, on Mazarron to the west of the city.

During the upturn of mining activity in the 19th century in 'La Union' to the east of Cartagena, numerous slag heaps were observed and re-smelted in order to acquire the remaining lead; ancient mining shafts and tunnels were also encountered, but mostly destroyed by the modern mining operations. Much of the dateable evidence, therefore, hails from installations associated with the processing of argentiferous lead sulphide or galena stemming from the mines. El Gorguel, a battery of four smelting furnaces associated with mines some 5–6 km to the east of Cartagena, witnessed a first phase of activity from around 200 BC to 110 BC (according to pottery finds), and a second phase lasting from the late 2nd century BC to the first quarter of the 1st century AD.[4] Another site in Sierra de Cartagena, Cabezo del Pino, yielded what have been described as 'washeries' for silver and lead, alongside ovens. The establishment of this complex dates to around the late 3rd and the early 2nd century BC with major activity unfolding throughout the mid-2nd century BC. The washeries were seemingly in operation, more or less, down to the early 1st century BC, and the complex was abandoned in the second quarter of the 1st century BC.[5] A further foundry was discovered at La Huertecica on the Mar Menor to the east of Cartagena, which saw its heyday in the mid-2nd century BC, a steep decline in activity during early decades of the 1st century BC, and finally it was shut down in the early decades of the 1st century AD.[6] This observation of decline in the early 1st century BC seems to tally with the interpretation by Claude Domergue of the dateable material recorded in the mines of the Sierra de Cartagena.[7]

These findings have been linked with a further observation relating to the mould marks and cold stamp impressions on ingots found in Cartagena, its harbour, or on shipwrecks which have been linked with the Sierra de Cartagena through lead isotope

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analysis. Ingots dating to the late 2nd or early 1st century BC showed mould marks with the names of one or two individuals of Italian origin; these marks are applied when smelted lead is poured into a cast form.[8] The ingots from the shipwreck of Comacchio, thought by Domergue to originate from the Sierra de Cartagena as well and dated to the reign of Augustus, seemed to have been marked with stamp impressions of abbreviated names after the ingots had been cast, in other words, were stamped cold. Some of the early mould-marked ingots and the later stamped ingots carried the same family names, such as *Utii, Turii, Planii Russini,* and *Iuni* – if we believe Domergue's reading of the stamp impressions on the Comacchio ingots. These Italian names are well attested in the epigraphy of Carthago Nova in late 1st century BC/early 1st century AD. The change on the ingots in how these names are indicated, either in mould marks or in stamp marks, was interpreted to reflect a degradation of the *Planii Russini* or the *Turii* from former proprietors of silver mines to mere merchants of lead ingots.[9]

Both the decline of smelting/washing activities associated with argentiferous lead mining in the Sierra de Cartagena, and the supposed demotion of some Italian families from possessors of mines to merchants of ingots has stimulated attempts at explaining these phenomena. The chief narrative sees the latter as a result of changes to the status of land, which triggered the exclusion of small-scale Italian mining companies from the mines. This hypothesis rests on a section in Strabo's *Geographies,* completed during the reign of Tiberius, in which he claims that in his day and age the silver mines near Carthago Nova were not publicly owned anymore, that is, not owned by the state; instead these were now private possessions (τὰ ἀργυρεῖα οὐ μέντοι δημόσια … ἀλλ᾽ εἰς ἰδιώτας μετέστησαν αἱ κτήσεις 3.2.10). Cicero, in his speech held in 63 BC before the senate on the agrarian bill of Rullus, also makes mention of (public) lands near Carthago Nova (*de lege agraria* 1.2.5). The assumption has been that these public lands included the public mines which Strabo describes.

If so, it was felt that the privatisation of these lands, which Strabo makes reference to, must be associated with the establishment of Carthago Nova as a *colonia* sometime after 63 BC and before the mention of *duoviri quinquennales* on the bronze coins minted by the city perhaps as early as the mid-1st century BC.[10] What exactly happened is not clear: it is thought that occupiers of public argentiferous lead mines either lost possession of the mines to the new colonist owners, or gained ownership themselves by being properly registered as colonists and proprietors of the mines. Another possibility discussed is that the mines became public property of Carthago Nova itself: two lead ingots found at Riotinto were marked NOVA CARTHAGO, which may suggest some form of involvement of the colony in mining.[11] Though this narrative, crafted from the available literary, epigraphic, and archaeological sources, is overall convincing, there are some issues with it.

Ager occupatorius

Let us turn to the issue of *ager publicus* at Carthago Nova first: if we follow the idea that Strabo's public silver mines stand on the public lands (which Cicero says are near the city), then the question arises as to who could access these mines, who could gain possession of them, and under what arrangement these were exploited.

In answering these questions, we face some difficulties: for instance, employing the writings of the land surveyors in order to understand the use of public lands, and indirectly, of mines on public land, has its pitfalls. Unless we postulate that Roman law did not change over 400 years, the content of these texts from the 2nd century AD, often reworked in 3rd and 4th century AD, cannot necessarily be applied without caution to public land in the Middle and Late Republic.[12] Also, much of the data on land arrangements pertains to Italy and to the lands of *coloniae;* for the Republic, we have little detail on how provincial and public lands in the Roman West were dealt with in general.[13]

Antonio Mateo argued that the mines near Carthago Nova were not farmed out on the basis of a *lex censoria* to public contractors for five years; instead the mines stood on *ager occupatorius,* on which a *vectigal,* a tax, was imposed by the state; the collection of this tax was possibly undertaken by *publicani.*[14] This, it was argued, would provide miners with a long term perspective, allowing them to invest in the exploitation of argentiferous lead. Only the public contract for collection of the *vectigal* by *publicani* would be subjected to re-evaluation by the authorities every five years, by the censors in Rome, or, more likely, the governor in Nearer Spain.[15]

Given that *ager occupatorius* can be occupied quite easily, the mines near Carthago Nova would have attracted many people; Strabo tells us that Polybius (34.9.8–11) reports some 40,000 men working in the silver mines there (3.2.10). Who these people were is not clarified: Diodorus' narrative on the mass movement of Italians to Spain taking over the mines and deploying slaves to exploit rich lodes of silver and gold (5.36) have been thought to apply to the Sierra de Cartagena as well. The archaeological evidence from there is perceived to indicate the presence of Italians in the mining zones near Carthago Nova. The names appearing on lead ingots and in the epigraphic evidence associated with Carthago Nova are understood to be Italian, thus lending further support to the idea that they took over the operation of the mines in the Sierra de Cartagena as well.[16]

Some reservations pertain to the *ager publicus* of Carthago Nova being *ager occupatorius.* Firstly, the term *ager occupatorius* itself is anachronistic: it does not really emerge in our sources prior to the writings of the land surveyors in the 2nd century AD.[17] Even so, most of the public land throughout Italy, as Saskia Roselaar has argued, was *ager occupatorius* in all but name. This legal category of public land, however, seems not ideally suited for the purpose of continuing or commencing mining operations. *Ager occupatorius* was land that could be occupied by anyone, that is Romans, Latins, and Italians, in return for rent, a *vectigal.* The possession of this land, however, was precarious as it simply could be taken away by the state when the need arose.[18] More importantly, even if occupiers of such public land were willing to accept this risk, they would face further insecurities. These insecurities are still reflected in a passage on *ager occupatorius* by Siculus Flaccus in his *De condicionibus agrorum* (Th. 102).

> "There is no bronze record, no map of these lands which could provide any officially recognized proof for landholders, since each of them acquired a quantity of land not by virtue of any survey, but simply whatever he cultivated, or occupied in the hope of cultivating. Indeed, some made maps of their holdings in private, which are not binding on them in respect of their neighbours, or on their neighbours in respect of them, since the matter is voluntary."

In light of the absence of any form of official registration by the Roman state, opening a mine on *ager occupatorius* seems a rather hazardous undertaking. Given the difficulties of establishing and securing possession of a clearly defined plot of land in order to commence or continue mining, one would presume that potential occupiers would be rather hesitant to invest in a mining operation **and** pay rent on the land.

What is more, the indication that possessors of *ager occupatorius* made their own maps of the lands they claimed suggests that such possessions were regularly contested – and not by peaceful means. By the 2nd century BC, disputes over the possession of *ager occupatorius* seem to have prompted the development of two legal instruments which allowed an occupier of public land to secure its possession. One was the *interdictum uti possidetis,* which guaranteed that the person in possession of the land at the moment of a lawsuit was declared the rightful possessor unless he had acquired the land by force or stealth, or had received it from another party without security of tenure.[19] The other instrument was the *interdictum unde vi* (attested in the *lex agraria* of 111 BC), which allowed a person who had lost access to his land by force to be seen as still possessing the land.[20] The availability of both instruments does not exactly inspire confidence in the capacity to secure and protect one's possession against rapacious neighbours or new arrivals – especially in a silver mining district. In short, not only could the land be removed from one's possession by the state at any point in time, one also needed to be weary of violent neighbours or new arrivals who had no scruples in using violence to secure a mine.

On top of this, we may expect that rent, *vectigal,* was more likely to be collected from mining districts (unlike arable land in Italy turned into *ager occupatorius*). Livy claims that M. Porcius Cato, in 195 BC, after pacification of the province, drew *vectigalia magna* from iron and silver mines (34.21.7). Strabo quotes Polybius when saying that some 25,000 drachmae were collected daily from the public mines of Carthago Nova for the people of Rome – likely collected as *vectigal* (3.2.10). The fair calculation and efficient collection of rent, though, necessitates at least some knowledge of which possessor occupies or runs which public mines; a land cadastre or at least the registration of mines at a central archive would be expected.

Without the possibility to register the land one has occupied and secure the returns on the investment in mining equipment, labourers, slaves, perhaps even furnaces, washeries, fuel, etc., it seems unlikely that individuals or companies would have been attracted to invest anything in the exploitation of argentiferous lead in the Sierra de Cartagena. Unless we want to postulate a registration procedure similar to the one attested under Hadrian for occupied mining plots in the Vipasca tablets, *ager occupatorius* would have provided a rather ill-fitting framework for a sustainable mining industry at Carthago Nova.[21]

Mould Marks, Seal Impressions, and Miners

The advantage of the *ager occupatorius* hypothesis appears to be the fit it provides with the evidence for a multitude of small-scale mining companies run by individuals, as suggested by the mould marks on lead ingots. This interpretation of the evidence rests on Claude Domergue's seminal study of mould marks, stamp impressions, inscribed numerals, and nail holes on ingots.[22] His explanation for the sequence of marks and stamp impressions applied to an ingot has proven to be robust, but I remain unconvinced as to the claim that the personal names in mould marks must indicate the possessors of mines. On lead ingots dating to the late 2nd and early 1st century BC the names of one or more individuals (sometimes preceded by the term *soc(ietatis)*) appearing in mould marks are rendered in the possessive genitive, thus indicating ownership of the freshly cast lead ingot. Whether the owners of these lead ingots ran the smelting furnaces and/or were directly involved in mining the argentiferous galena remains conjecture. Of course, we cannot exclude the possibility that some of these small-scale companies controlled the whole lead trade, from mining to processing to marketing and sale. However, I am more comfortable in suggesting a segmentation of production where the tasks of mining, processing, or trade are taken on by different individuals and companies.[23]

In short, the picture emerging from the mould-marks suggests at best the multitude of different owners/traders of lead ingots, but they do not provide proof for a multitude of individuals or small-scale companies mining in the Sierra de Cartagena. But who then was mining the argentiferous galena mines near Carthago Nova? Strabo, based on Polybius, does claim some 40,000 people working in the silver mines there; whether this number is accurate, whether these workers were slaves or free men is secondary at this point; but who deployed or employed them is the question which needs to be answered.

Contracting gold and silver mines out to *publicani* appears as the default mechanism of the Roman state.[24] This seems to have applied to the mines near Carthago Nova as well. Based on mould marks on lead ingots and the actual moulds and stamps, Juan Antonio Antolinos Marín and Borja Díaz Ariño assume that the mining district of

Mazarrón to the west of Carthago Nova was partly in the hands of a *societas argentifodinarum Ilucronensium* by the mid/late 1st century BC.[25] The processing and trading of lead aside, the name of the company strongly suggests that it was involved in the mining of argentiferous galena. So far, there seems to be no evidence suggesting that the company operated at Mazarrón already in the late 2nd and early 1st century BC. Based on Domergue's interpretation of mould marks it was assumed that large scale *societates* replaced individuals or small-scale companies by the mid-1st century BC, but there is nothing to categorically exclude the possibility of large scale *societates* being present in the mining districts before the mid-1st century BC.[26]

Decline

The perceived decline of activity at and subsequent abandonment of foundries and washeries such as El Gorguel or Cabezo del Pino in the early 1st century BC was linked to the establishment of Carthago Nova as a colony. Yet, we cannot be certain that the argentiferous galena mines of the Sierra de Cartagena or at Mazarron were on the *ager publicus* Cicero mentions. Establishing the full picture of mining, smelting, and trading ventures connected to the argentiferous lead deposits is impossible, given that we know absolutely nothing about what happened to silver. We do not know whether the same companies and individuals noted on the lead ingots traded silver as well, or whether different companies, perhaps even *societates publicanorum,* dealt with this precious metal, or whether it was directly carted off by the state immediately after cupellation. Apart from the literary sources such as Strabo or inscriptions such as the mould marks on ingots naming a *societas argentifodinarum,* the silver mined has left little traces in the archaeological evidence. This becomes especially problematic when assumptions are made about the rise or decline of silver production based on the inscribed lead ingots and historical context alone. Perhaps a re-examination of lead ingots regarding silver content and de-silverization of lead in combination with a renewed study of Republican silver coinage (along the lines of Hollstein 2000) might help shed some light on this neglected chapter.[27]

Summary

The aim of this brief paper was to raise some issues with the predominant narrative, not to discount it. Firstly, the understanding of public land as *ager occupatorius* seems not to provide a good legal framework conducive to the economically sustainable exploitation of precious and rare metals. Secondly, mould marks on lead ingots only really indicate the owners of said ingots, but strictly taken, do not necessarily indicate who is running the mine. The default position of the Roman state was to lease out mines to large-scale public contractors who might well be in place already earlier, even though they are not explicitly noted on ingots. Thirdly, an examination of the silver content of lead ingots said to hail from the Sierra de Cartagena might contribute another facet to the storyline of decline observed in this important mining region.

Notes

[1] Most notable are the recent projects undertaken by Juan Antonio Antolinos Marín in the Sierra de Cartagena or by Luis Arboledas Martínez (2010) or Luis Maria Gutiérrez Soler (2010) in the Sierra Morena, just to mention a few.
[2] Orejas – Rico 2015.
[3] Roselaar 2010 with further bibliography.
[4] Antolinos Marín 2012, 64–74.
[5] Antolinos Marín – Rico 2012, 74–89, esp. 89.
[6] Alonso Campoy 2009, 33.
[7] Domergue 1987, 358–390; Domergue 1990, 233.
[8] Orejas – Rico 2015, 523.
[9] Domergue et al. 2012; Orejas – Rico 2015, 526. A recent lead isotope analysis now suggests that the ingots from Comacchio are more likely to hail from the Pangaion range in Macedon, see Rothenhöfer 2018.
[10] Abascal 2002.
[11] Orejas – Rico 2015, 527.
[12] Roselaar 2010, 12–14.
[13] e.g. *lex agraria* of 111 BC on Africa, or Cicero's Verrines and letters [Sicily, Gaul], see Carlsen 2003 with further bibliography.
[14] Mateo 2001, 65.
[15] Orejas – Rico 2015, 523 f.
[16] Domergue 1990, 251–266.
[17] Roselaar 2010, 89.
[18] Roselaar 2010, 94.
[19] Roselaar 2010, 114.
[20] Roselaar 2010, 115; Cic. Tull. describes such a case, as does Cic. *Mur.*12.26 and *Rep.* 1.13.20.
[21] At Vipasca, a plot of land or existing mine (*puteus*) could be occupied and was later officially assigned to the occupant with the payment for a *pittacium,* a 'registration fee', cf. Hirt 2010, 266–267.
[22] Domergue 1998.
[23] See also Antolinos Marín – Diaz Ariño 2012, 27.
[24] Livy tells us that in 167 BC the Macedonian mines were shut down by the senate as they could only be exploited through *publicani* (45.18.3–5); this injunction is further clarified as pertaining to gold and silver mines only, with copper and iron mines being exempted (45.29.11). Whether the *publicani* were to run the mines or only collect rent on them is not further illuminated by the passage (Mateo 2001, 59). Pliny the Elder points out that there was a *lex censoria* ensuring that the *publicani* did not employ more than

5,000 men in the gold mines of Victumulae on the land of Vercellae (*nat. hist.* 33.78). Furthermore, Strabo claims that the Salassi found themselves in regular disagreement with the *publicani* over the supply of water to the gold mines the latter had contracted (4.6.7).

[25] Antolinos Marín – Díaz Ariño 2012.

[26] Domergue 1990, 253–277.

[27] To my knowledge, the lead ingots said to hail from the Sierra de Cartagena or Mazarron have only been examined in order to determine their origin through the analysis of lead isotopes; the question of whether the ingots from the Comacchio shipwreck, for instance, were de-silvered seems not to have been directly addressed so far (e.g. Domergue et al. 2012; Trincherini et al. 2010). A recent paper published by Matthew Ponting argued that the chemical composition of Iron Age and Roman lead items from Somerset suggests that "they were not produced from lead that had been de-silvered, but from smelted galena with variable silver contents" (2018, 185). This means that no cupellation process had taken place even though the technology was available. It appears that a choice was made not to de-silver the smelted lead because the silver content may have been deemed uneconomical to exploit. A proper analysis of the ingots from Republican Spain could help us to understand the decline in mining activity observed and whether or not this might be connected with a decrease of silver in the galena.

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The Long-distance Trade of Iron in the Early Roman Empire: the Case Study of Gallia Narbonensis. An Updated Synthesis

Luc Long – Christian Rico

Since iron is the most common metal on Earth, it has been the most used all throughout history, and accompanied the development of ancient human societies from the moment they controlled its metallurgy.[1] Among non-precious metals, iron was traded over long distances by sea. However, it was poorly studied for a long time. As fig. 1 shows, there are very few spots where iron ingots have been documented or reported for the Roman period. Many of these are isolated finds, out of context, and for a long time we lacked complete iron in ship cargoes. Do single and isolated finds of iron bars only reveal a local trade, from port to port? As iron could be produced at least everywhere, it seems obvious that the market's supply depended firstly on local or regional resources. Actually, this idea is not completely satisfactory. We must also take into account the minimal interest that divers and archaeologists paid for a long time to such a rough material, which is poorly preserved over long periods underwater. It is also possible that iron loads have been neglected during many underwater explorations and

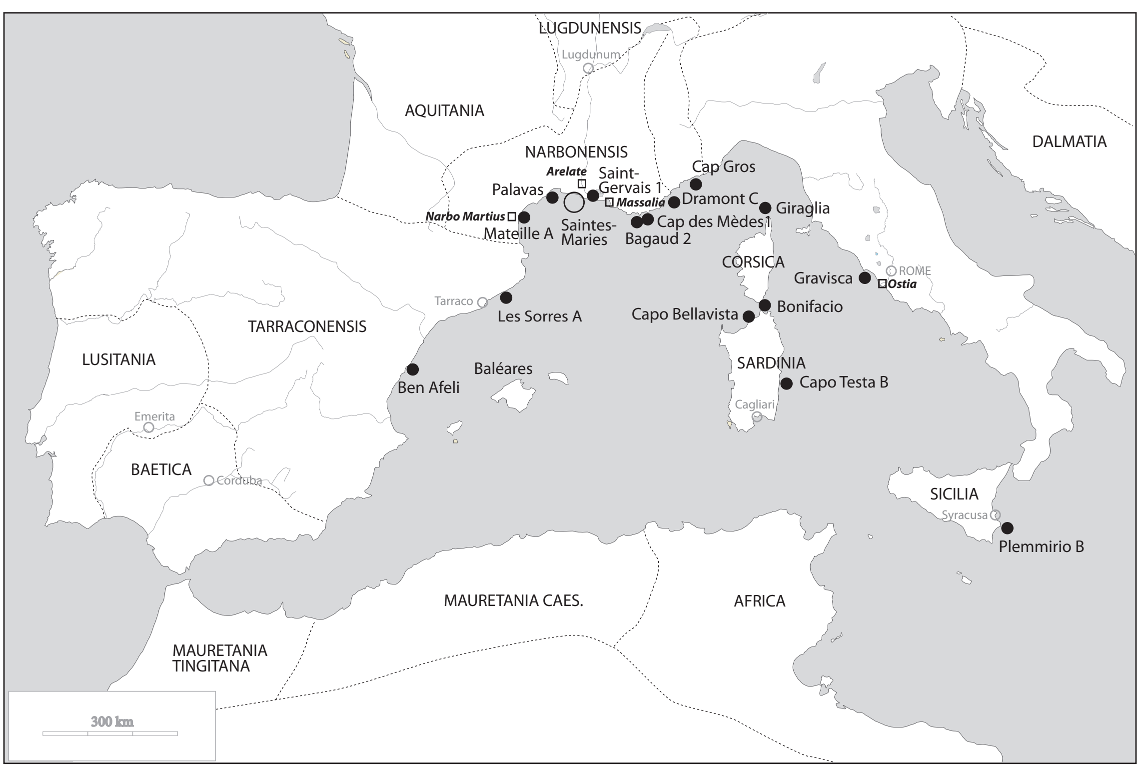

Fig. 1: Iron bar finds in the Western Mediterranean until the Saintes-Maries finds.

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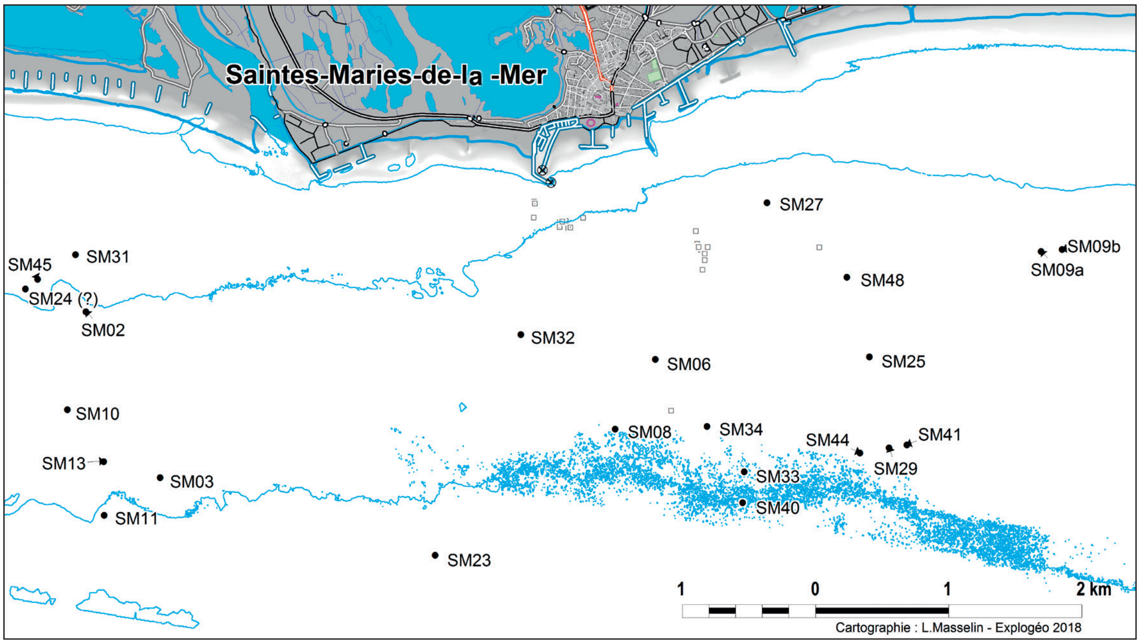

Fig. 2: Map of the iron-loaded shipwrecks off Les Saintes-Maries-de-la-Mer.

never been reported. We can also suppose that because of the physical characteristics of iron, part of the material may have partly or totally disappeared.

Since the end of the 1980s, archaeological surveys off Saintes-Maries-de-la-Mer in Southern France, off the mouth of the river Rhône (fig. 2), have totally changed our perception of the Roman maritime trade in iron. In what properly looks like a maritime cemetery, with more than a hundred wrecks identified from several historical periods, no less than twenty-three of these appear to be partly or completely loaded with iron bars (table 1). Conscious of the importance and interest, as well as the originality of the first discoveries, the French ministry of Culture gave support to Luc Long, from the Department of Underwater Archaeology of the same Ministry, to carry out systematic surveys of the zone. His aim was to locate and identify new shipwrecks to obtain chronological elements and, more generally, to produce original data that could help us to better know the importance of the sites, the composition of the cargoes, and their origin.

The aim of this paper is to present an updated synthesis of how we can currently reconstruct the Roman maritime trade of iron, mainly from the discoveries at Les Saintes-Maries-de-la-Mer.

Wreck	Year of discovering	Typology of iron bars	Chronology
SM 2	1991	Types 1L and 4C	1st quater of Ist c. CE (amphorae Haltern 70 and Dr. 2–4 from Tarraconensis)
SM 3	1992	Types 1L et 2M	0–60 d.C. (Terra sigillata Drag. 15a)
SM 6	1995	Types 1L, 2M, 3, 4C, 5 and 6	2nd half of Ist c. BCE (Campanian black-ware Morel 2270)
SM 8	1995	Type 2M	1st half of Ist c. CE (amphora Dr. 7–11)
SM 9	1989	Types 1L, 2M, 3 and 4C	1st quater of Ist c. CE (same stamps IVL // EROTIS reported in *SM 2*)
SM 10	1996	Types 1L and 4C	No data
SM 11	1996		No data
SM 23	2003	Type 2	No data
SM 24	1998	Types 1L, 2M and 4L	Mid Ist c. CE terra sigillata Drag. 29b (between 40 and 90 CE)
SM25	2003	Type 2M	No data
SM27	2005	Bars and iron nails in buckets	No data
SM29	2015	Types 2M and 3M	Italic terra sigillata Goudineau 32b (*Conspectus* SIG-IT 31.1), from last years of Ist BCE and 30
SM31	2015	Type 7L	Pascual 1 or Dressel 2/4 from Tarraconensis, Ist s. c CE
SM32	2015	Types 2M, 5LM	Fragments of Dressel 2/4 and Dressel 20, Ist s.c. CE
SM33	2016	Type 2M	No data
SM34	2018	Types 1M and 4C	No data
SM40	2016	Type 2M	No data
SM41	2015	Type 8C	Pascual 1 amphora handle, Italic terra sigillata, from 30 BCE to 50 CE
SM42	2016	Rough iron blooms and rare type 1M and 2M bars	No data
SM44	2018	Type 2M	No data
SM45	2018	No data	Not studied at the moment
SM48	2018	Type 4C	Not studied at the moment

Table 1: The different wrecks with iron freight from Les Saintes-Maries.

The Shipwrecks, the Iron Cargoes, and Their Chronology

Twenty-three shipwrecks loaded with iron bars are listed (table 1) at the little watering-place at a depth of 12/18 meters (fig. 2). Part of them have yet been published, as Saintes-Maries (or SM) 2, 3, 6, 8, 9 and 10.[2] Others, discovered in the last ten years, have only been presented briefly and their study is still in progress (SM11, 13, 23, 24, 25, 27, 29, 31, 32, 33, 34, 40, 41, 42, 44, 45, 48).[3] Accordingly, information is unequal. None of the shipwrecks have been completely excavated. They can be easily identified by sometimes large and massive blocks of iron bars brought together by corrosion and often dislocated in several pieces by the nets of the fishermen. Very little is known about the ships themselves, their capacities and the additional freight they could possibly have carried along with the iron bars. Among them, the better known are SM2, SM9 and SM10 that seem quite different. Finds from SM10 suggest a relatively small ship, not more than 9–10 meters long, with a load of 5–6 tons of iron. In front of it, SM9 and SM10 are bigger and heavier ships. SM2 is supposed to be 15–18 m long, for a load of about 20 to 50 tons of iron. The cargo consisted also of 40 Spanish amphorae, principally Dr. 2–4 type. SM9 is more impressive, measuring approximately 18 meters long, and with its freight estimated at no less than 100 tons of iron. In a few of them, like SM2, archaeological explorations have revealed other goods, like amphorae, which are of interest in order to date the wreck. In others, the existence of some materials or artefacts close to the corroded blocks of bars are helpful to define their chronology (see, for instance, in table 1, SM3 and SM6). For all the others, the similarity of the composition of the iron freights in each of them argues for the assumption that they are all Roman ships. Therefore, they probably belong to the same historical period, from the mid-1st century BC to middle or end of the 1st century AD. As we shall see, many bars bear stamps and some of these are found in multiple vessels, which indisputably reinforces the proposed chronology.

The Iron Bars: Typology and Epigraphy

In most of the wrecks, fragments of the cargoes were removed from water. With the support of a crane, one or several blocks, of more or less importance, were withdrawn from the sea, so that a large number of pieces could be studied in detail. Indeed, the dismantling of the blocks showed that the larger blocks were composed of hundreds of bars, and the smaller ones made up of tens of blocks. They were usually well-preserved, and belonged to different types.

The current typology was published for the first time in 1997,[4] then completed in 2006.[5] It is an open typology, as some subtypes of the six main groups identified are not yet archaeologically attested. The main forms were defined by measuring the section of the bars and the ratios between their width and thickness. For each of the six groups, we have defined three subtypes according to the length of the bars (table 2). "C" stands

Form	Designation	Dimensions width × thickn. (in cm)	Weight	Wreck
1	Flat and rectilinear bar	4 ± 1,3 × 2 ± 0,5		
1C	short			*Ben-Afelí ?* *Cap Gros ?*
1M	medium	Long. 54–61	2,5–4,2 kg	*SM3 SM9*
1L	long	Long. 74–138,5	3,9–11,7 kg	*SM2 SM9 SM10 SM24 Capo Testa B?*
2	Thin bar, square section	3,5 ± 0,5 × 2,5 ± 0,5		
2C	short			–
2M	medium	Long. 40–71	1,5–5 kg	*SM6 SM8 SM9 SM23 SM25 SM27 Bagaud 2? St-Gervais 1*
2L	long			*Ben-Afelí*
3	Thin and heavy bar	4 ± 0,5 × 3,5 ± 0,5		
3C	short	Long. 30–38		*SM6 SM8*
3M	medium			–
3L	long	Long. 85		*SM24*
4	Massive bar, square section	6 ± 1,8 × 5 ± 1,5		
4C	short	Long. 20,8–29,9	2–7 kg	*Capo Bellavista?* *Bagaud 2* *SM2 SM6 SM9 SM10 SM24*
4M	medium			–
4L	long	Long. 76–191	22–33 kg	*SM24*
5	Short bar	Close to form 3 5 ± 0,5 × 3,5		
5C	short	Long. 26–31	2,9–3 kg	*SM6 Bonifacio*
5M	medium			–
5L	long			–
6	Flat plate with rounded ends	10 ± 0,5 × 3,7 ± 0,7		
6C	short	Long. 27–33	4,4–8,2 kg	*SM6, Mateille A*
6M	medium			–
6L	long			–
7	Long and very fine bar	149 × 1,3–1,4 (section)		*SM31*
8	Short and round flat plate	11/12 (diameter) × 4,2/4,4 (thickness)	1,7–2,8 kg	*SM41*

Table 2: Iron bar typology.

for "courte" ("short" in French), which pertains to bars no longer than 40 cm. "M" stands for "medium" bars, between 40 and 75 cm. "L" stands for "long", with a length ranging from 75 cm and onwards. Since the publication of the typology, the new finds off the mouth of the Rhône river have afforded some new data to complete it; two new types were identified. Table 2 presents an updated synthesis of the typology (see also fig. 3).

Among all these forms, 1L, 2M, and 4C forms are the most commonly documented at present. Despite their differences, all are standardized and normalized artefacts and we can assume that such a normalization was imposed by the market. Surely the general form, long or short massive bars, was suitable either for transport or storage. Nevertheless, it seems obvious that the different forms responded to different uses by the blacksmiths, who had to transform the bars at the end stage into manufactured artefacts. It is of course difficult to assign one or several precise and specific destinations to each of the different forms and subtypes (e.g. 4L bars for heavy and massive objects, like anchors, or flat 1L bars for chariot wheel tires). Smaller bars were convenient for a large number of artefacts, weapons, tools, and all sorts of everyday objects. The market, and surely the traders, seemed to have had a certain influence over the work of the metallurgists. But we don't know much about the whole organization of it, as we completely lack original textual data. Indeed, although the iron bars from Saintes-Maries revealed a rich epigraphic corpus, none of the documented marks can be assigned to the specific commercial steps of iron's "chaîne opératoire".

Among the Saintes-Maries shipwrecks, SM2, 3, 6, 9, 10, 24, 33, 40 and 41 have afforded stamped bars; the number of stamps roughly depends on the size of the corroded blocks removed from the sea. Until then, we had very little information on the epigraphy of iron bars. Only three stamps were documented: FERRO in Ben Afelí (Northwestern Spain), HAEDVI in Palavas (France), and SATVRNINI in Bonifacio (Corsica). We now have no less than 21 stamps or groups of stamps, and, as we shall see, many bars bear combinations of two, three and even four stamps (see table 3). The corrosion and the smallness of the stamps do not always make it easy to read the inscriptions they contain. Some of them remain totally illegible. The marks are of two types: small rectangular stamps 20/30 mm long and 5/7 mm wide; circular stamps of no more than 9/10 mm diameter. The latter appear systematically associated with rectangular stamps. Both types are in negative and have inscriptions in relief. They were made by a matrix that was surely stamped at the end of the shaping process in the same workshops. Thus, we can relate these marks with the production stage of the metal. In the same series, stamps or groups of stamps are located in the same position, either on one or the other side of the bar, or in the central part of it. The regularity of these markings, and the care given to their making, reinforce the production-stage interpretation of the stamps. At the moment we do not have any archaeological evidence that iron blooms were transported directly from the metallurgical centres where they were produced to secondary workshops to be transformed into ingots. Thus, we can closely connect the stamps to the smelting sites.

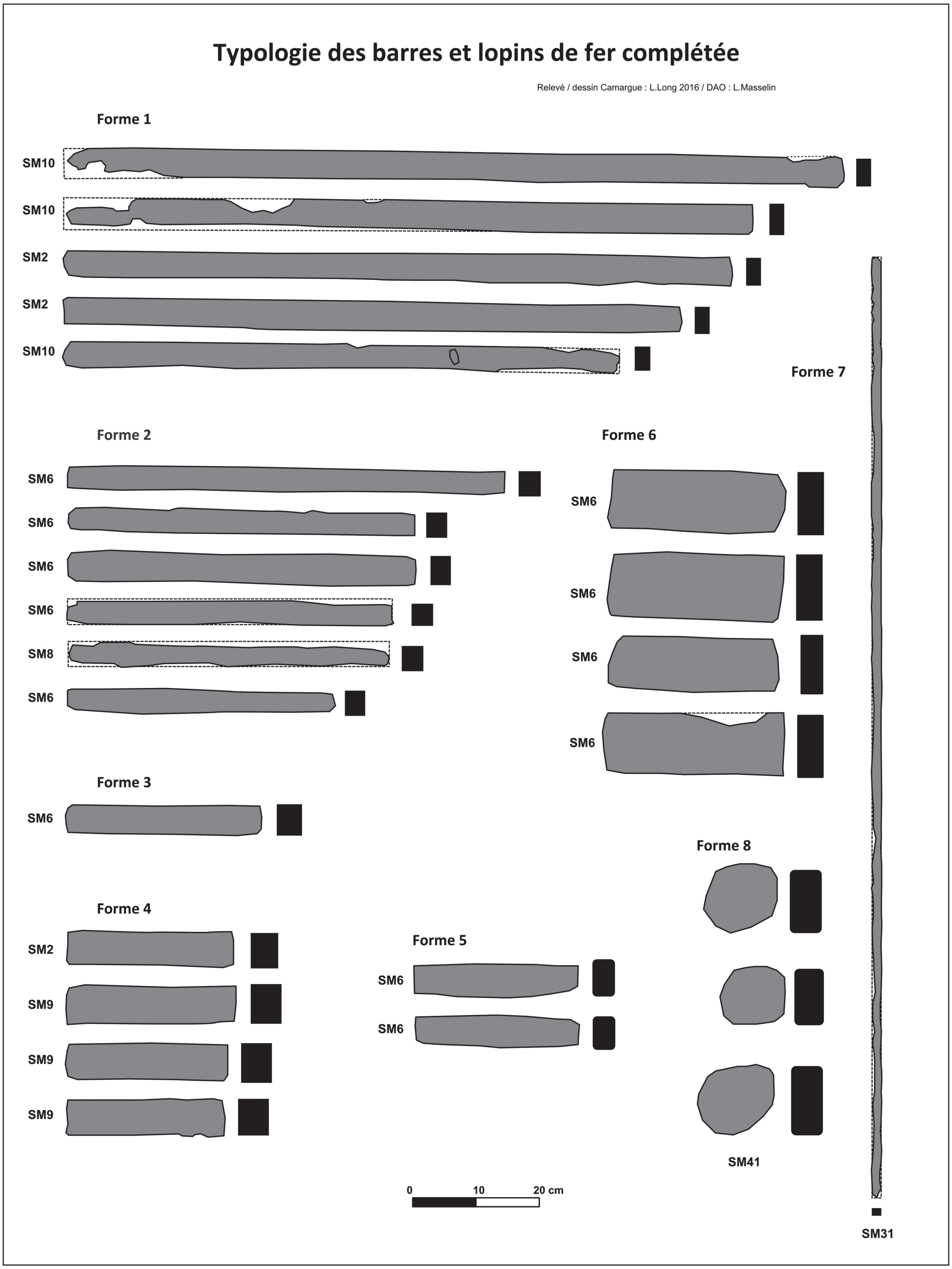

Fig. 3: Typology of the Saintes-Maries iron bars (completed 2016).

Combination	Stamp	Form	Location	Wreck
1	C. RVTILI CAVLI (?) I[---]CI ; CAECI ; T. COR ; T. AFRAN GALLICVM LICIN PORC{...} ?	2M 4C 4C	right side central	**SM 6** **SM 9** **SM 9** **SM 33 & 40** **SM 40**
2	[---] // [.]AT[	2M	central	**SM 6**
3	[----]MI // [----]MI	2M	central	**SM 9**
4	FAL (?) // CAECI	4C	central	**SM 9**
5	CAECI // H MARI // S	4C 1 or 2	central	**SM 9** **SM 3**
6	(*unidentified stamps*)	2M	central or one or another side	**SM 9**
7a	MAXIMI // MAXIMI // [---]	1L	central	**SM 10**
7b	Q CATO // Q CATO // TEREN	1L	central	**SM 10**
8	FVLVIOR // FVLVIOR MANI ? // [MANI ?] (*unidentified stamps*)	4C 4L 3L	central both sides central	**SM 10** **SM 24** **SM 24**
9	IVL // EROTIS (twice repeated) (*unidentified stamps*)	1L - 4C 4C 4L	left side one or another side	**SM 2** **SM 9** **SM 24**
10	S // LEPIDI // N (*ancora*)	4C	left side right side	**SM 2**

Table 3: Stamps and combinations of stamps documented on iron bars from the Saintes-Maries-de-la-Mer.

They give personal names, often abbreviated, usually in the genitive, as C. RVTILI, CAECI, FVLVIOR(um), MARI, LEPIDI, MAXIMI. Sometimes, combinations of stamps give the complete name of an individual, as Q. CATO // TEREN for *Q(uintus) Teren(tius) Cato,* or IVL // EROTIS *for Iul(ii) Erotis.* Circular stamps generally bear a single letter, as H (in the group CAECI // H), S (group MARI // S), and S and N in the association S // LEPIDI // N. The meaning of them is uncertain, but we can suppose they are the initials of names, *nomina gentilicia* or *cognomina.* For instance, concerning the group S // LEPIDI // N, one of the two single letters could be a *praenomen* (Sextus or Numerius), with the other as the initial of the *nomen.* In any case, all these stamps, either rectangular or circular, were made at the same moment, and refer to the same person. What has not been explained to a satisfactory degree is the meaning of the different combinations of stamps. At the moment, ten of these are documented (see table 3). The fact that some of these combinations are used by several producers, as occurs on SM 5 and 8, could be interpreted as evidence that they worked in the same mining area. But it cannot be decreed as a rule. For instance, as analytics showed, stamps of Lepidus and Iulius Eros were reported in the same wreck (SM9); their workshops were in the same area, in the Montagne Noire in Narbonne's hinterland. However, each of them adopted a different combination of stamps to individualize their own products.

Ferrum Gallicum. About the Provenance of the Saintes-Maries Iron Bars

GALLICVM. This is the very latest, and important, find in Les Saintes-Maries, which occurred during the archaeological campaign carried out in summer 2018. This campaign focused on two wrecks, SM33 and SM40, both known since 2016. Both wrecks gave then 2M type bars bearing stamps, and one mentioned a possible [LI]CIN(ius).PORC[---]. The new survey produced two fragments of iron bar marked with this original stamp, repeated twice on each of them, and containing an adjective neuter instead of a personal name (fig. 4a–b). GALLICVM could not be interpreted in any other way than to mean *(ferrum) Gallicum.* Such an appellation is completely original for iron. On the other hand, it is documented for Roman lead, and especially for German lead, on ingots with moulded marks mentioning GERMANICVM (Rena Maiore), PLVMB(um) GER(manicum)/GERM(anicum) (SM1, Fos-sur-Mer), or *(plumbum)* GER(manicum)/GERM(anicum) (Tongeren, Île-Rousse, Fos).[6] As the stamp is only documented in a fragment of bar at SM40, it is not possible to link it to the producer known by the fragmentary stamp [LI]CIN PORC[---]. If both stamps could be associated, we can imagine that it was the way for the workshop to certify the real origin of the metal. The stamp GALLICVM would appear to be a label of quality destined for the traders rather than for the consumers (i.e. black-smiths). Was this label necessary for the producer to distinguish its products from iron from others places (i.e. non-Gallic places), in the context of tough competition between iron from different mining areas? Surely it is too early to assert

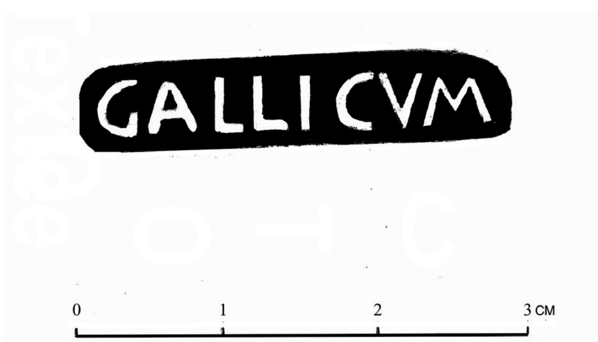

Fig. 4: a–b: Stamp GALLICVM (SM40).

this, as our knowledge on global iron trade in Roman times is limited at present. We especially lack information about which areas had enough resources to support a long-distance maritime trade in iron, and could have played a singular role in it, as we have for other metals. At the same time, data are scarce about the archaeological contexts of most of the shipwrecks from Les Saintes-Maries. We lack information about the possible freight that completed the iron cargoes and very few of them had additional artefacts. These could indicate a possible origin of the wrecked ships which could be, in some cases, the same as the iron's origin. A helpful alternative exists with the geochemical tools developed in the last three decades to trace ancient ferrous materials. They have been tested with success since the beginnings of the century on several iron bars from Les Saintes-Maries.

Among elemental analyses on slag inclusions, the most common geochemical method currently used is to establish the chemical signature of ancient iron;[7] as part of this, trace element analyses provided the best results for some of the iron cargoes of Les Saintes-Maries. Recently, another but less-destructive method, based on iron isotopes, was tested on some of the same bars analysed by the trace element method.[8] Indeed Fe isotopes provide a more constrained signature than trace elements because of the negligible contamination of the smelting device during iron ore reduction. This method not only confirmed the results obtained by trace element analyses but also gave new and more certain information about the provenance of some bars that the first method failed to establish concretely.[9]

Thirteen bars were analysed in 2001 and 2009 from 4 shipwrecks, (SM2, SM6, SM9 and SM10), the chronology of which falls between the mid-1st century BC and the mid-1st century AD. Trace element analyses revealed three main groups, each with homogeneous chemical signatures. The first is composed by form 2C bars, none of them marked; the second, long bars of 1L type and 4C bars all bearing the stamps IVL // EROTIS. The third group corresponds to 4C ingots stamped with S // LEPIDI // N. A fourth group seems to be distinguished, but the chemical signature is more heterogeneous. A single bar, of 1L type, does not fit with one or another of the previous groups. The respective chemical signatures of these groups were compared with those established for some ancient ferrous mining districts. The 2nd and 3rd group present a signature that perfectly matches with the composition range of the ore established for the Montagne Noire, close to Narbonne. This was one of the Gauls' main iron mining districts in Roman times, active from the second quarter of the 1st century BC to mid-3rd century AD, with an iron production estimated at no less than 100,000 tons.[10] Furthermore, iron isotope analyses confirm these results, and they suggest the same origin for the bars of the 4th group, for which trace element analyses did not indicate a definite provenance. On the other hand, both the trace element and iron isotopes analyses coincided in setting apart group 1 (2M type bars), which has chemical signatures different from those of the Montagne Noire. In short, geochemical analyses show that the iron submerged off Les Saintes-Maries comes from at least two different areas. One is the huge iron district of the Montagne Noire; analyses of this material have allowed us to link two producers (Iulius Eros and Lepidus), known by the stamps they use to mark their products. The other district is still to be archaeologically identified. And the way to do this will be by increasing the number of analyses on archaeological devices (ore, slag) from other mining areas not only in Southern Gaul but anywhere. These other analyses must come from places with enough resources to have played a role in a long-distance trade. In addition to these studies, there needs to be an increase in trace element and Fe isotope analyses on the iron bars from Les Saintes-Maries. The main objective is to complete the current database chemical signatures and to finally identify the main sources of the Roman maritime trade in iron.

In Conclusion

Surely, twenty years after the first finds off Les Saintes-Maries-de-la-Mer, we are still at the very beginnings of the research and far from proposing a precise view of the Roman maritime trade in iron. But much progress has been made from the archaeological and the archaeometrical point of view. The Saintes-Maries-de-la-Mer finds confirm the existence of an organized maritime trade of iron as exists for others metals. Part of this trade was surely based in one of the main commercial harbour of Southern Gaul, *Narbo Martius* (Narbonne), where the production, or at least part of the production of the workshops located in the Montagne Noire converged. Now we need to specify whether or not iron from other contemporary mining areas close to Narbonne (like those of the Corbières and the Eastern Pyrenees) used Narbo's facilities for their export. But we also need to do the same for more distant iron mining areas, like the ones documented in Central Gaul, which could have exported at least part of their production to the Mediterranean. The aim is to reconstruct the different networks that existed to supply the Roman Mediterranean market with iron.

What was the final destination of the iron submerged off Les Saintes-Maries? The location of the wrecked ships suggests that if not all, at least part of them sank when trying to engage themselves in the river Rhône, or when unloading their iron cargoes onto fluvial crafts. Surely, this iron would have normally reached important cities towards the Rhône valley, like Arles (*Arelate*) and Lyon (*Lugdunum*), from where part of the metal could have been redistributed to other places. Was one of these places the military market of the Northern provinces? We cannot exclude it, as the Roman *gladius* found on SM9 could indicate the presence of a Roman official in charge of iron bars destined for the army.[11]

More generally, this is one of the great stakes for future investigations, that of the markets for the iron produced in distant and specialized mining areas and, at the same time, the whole organization of its trade.

Notes

[1] Mangin dir. 2003.
[2] Long 1997; Long et al. 2002.
[3] Long – Duperron 2015; 2016.
[4] Long 1997, 84.
[5] Coustures et al. 2006.
[6] Raepsaet-Charlier 2011, 187–191.
[7] Coustures et al. 2006; Baron and Coustures 2011.
[8] Milot 2016.
[9] Coustures et al. 2006; Baron – Coustures 2011; Coustures et al. 2016; Milot et al. 2016.
[10] Fabre et al. 2016.
[11] Long et al. 2002, 175.

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The economic importance of raw material exploitation, especially metal mining, for communities in antiquity has long since been addressed. Only during recent decades, however, have scholars increasingly focused on the material remains. These include not only the primary mining remains, such as underground workings, process residues and installations for beneficiation, but also habitational sites and infrastructural remains that emerged in the course of exploitation.
The intention of this panel at the 19th International Congress for Classical Archaeology was to provide an insight on existing and emerging research on landscapes that were distinctly transformed by mining. It aimed furthermore at discussing how mining could affect not only the natural but also the cultural landscape. By focusing on select case studies, the intention was to identify the material characteristics of such areas, to highlight and explain differences, and to discuss possible recurring infrastructural and organisational patterns.

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