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27

The Exploitation of Raw Materials in the Roman World: A Closer Look at Producer-Resource Dynamics

Panel 4.4

Dimitri van Limbergen
Devi Taelman (Eds.)

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in the Roman World

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Edited by

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PREFACE

On behalf of the 'Associazione Internazionale di Archaeologica Classica (AIAC)' the 19th International Congress for 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

The Exploitation of Raw Materials in the Roman World: A Closer Look at Producer-Resource Dynamics

Dimitri van Limbergen – Devi Taelman

Pre-industrial societies were all dominated by agricultural production. What distinguishes them is the importance of the non-agrarian sector of the economy against that agricultural background. While not escaping the limits of an organic economy, the Romans stand out for having developed a wide range of manufacturing businesses and services (e.g. construction, fuel supply, metal- and pottery production), with an estimated involvement of between 10% and 20% of the total workforce.[1] This development stimulated the widespread and large-scale extraction of raw materials like stone, ores, clay and wood. Compared to other premodern economies, raw material consumption rates in the Roman world were thus high.

The way in which both renewable (e.g. wood) and non-renewable (e.g. stone, minerals, metal, clay) resources were exploited is an important determinant for the functioning and longevity of a pre-industrial economic system. Even in a territory as large as the Roman Empire, such activities put considerable pressure on the land. Strategies of resource-exploitation and conservation were essential in dealing successfully with this situation in the medium- or long-term. The question of how the Romans dealt with the uncertainty of natural reserves and the unpredictability of consumption is very much at the core of the debate on the non-agricultural ancient economy. The issue revolves around whether producer decisions and actions merely reflect a ‚substitution of resource sources' mentality – that is, exploiting a particular resource until depletion, after which new possibilities were simply explored further afield – or if optimal extraction strategies may be identified. In other words, how rational were the Romans in their exploitation of raw materials, and to which extent did they counteract over-exploitation for economic and ecological reasons?

On an Empire-wide scale, this research topic thus feeds into the long-standing debate on the nature and general performance of the Roman economy; that is, in essence, framed between formalist/modernist and primitivist/substantivist views, or fitted within market-driven vs. predation-driven models.[2] On a smaller scale, we are interested in a number of specific questions related to the nature of Roman economic practice, such as: 1) how did producers organise the exploitation of natural resources at hand (can we, for example, identify measures that show environmental concerns in their management strategies?); 2) how did (changes in) consumption behaviour affect exploitation and production strategies; 3) can we identify indicators of 'Smithian growth' in the production and distribution of non-renewable resources (e.g. standardisation, specialisation, prefabrication, stronger/weaker market integration etc.); and 4) did producing regions respond similarly or differently to changes in demand?

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Throughout a series of territorial cases studies, this section explores if, when, where and how the Romans pursued a harmonious balance between the limited availability of a particular resource and the law of supply and demand. The first paper by Fernando López Sánchez scrutinises the Roman fishing industry in the Mediterranean and explores the possible link between the seemingly efficient and sustainable exploitation of a sea with limited fishing capacities and the building of the empire under the *Pax Romana*. With the second paper by Fabien Becker et al., we shift our attention to Elba (Italy), and more specifically to the debate surrounding the possible end of iron smelting on the island due to deforestation around the mid-1st century BC. The third paper by Christophe Vaschalde et al. deals with the production of fuel for the great imperial amphora workshops of Loron in Croatia, and shows how these high-yield kilns were kept supplied through a rational management of the forest, and sustainable investments in the land. In the fourth paper, Sophie Insulander et al. focus on the logistics of stone supply in the Carnuntum-Vindobona area, based on a detailed provenance analysis of the stone monuments from these two important military centres on the Pannonian Limes. The stone resource economy is also the subject of the fifth paper by Florent Delencre et al., who analyse the use of stone in the buildings from the territories of the Aeduans and the Lingons civitates in Central-Eastern Gaul in the 1st century BC; this in order to shed light on the plurality of supply sources. The sixth and final paper by Maddalena Bassani discusses the exploitation of thermomineral resources in Roman Italy from the 2nd to the 4th century AD, and examines the use of some thermal by-products on the basis of archaeological and literary evidence.

Notes

[1] Bang 2008.

[2] Scheidel 2014; Temin 2013.

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Fishing Factories and the Limitations of Navigation in the Ancient Roman Mediterranean

Fernando López Sánchez

Salted Fish and the Development of the British Navy

Out of all the many accounts of mariners and their provisions, the largest number probably comes from the British Royal Navy, and these provide a suitable starting point for examining the food received by sailors at sea. In 1677, Samuel Pepys, the secretary to the Admiralty, copied into his Naval Precedents a contract he had set up with suppliers to the Navy,[1] specifying predetermined rations for each sailor. According to Navy regulations, either pork or beef were provided on four days each week up to the 1730s, with salted fish on the other three days.[2] As regards civilian vessels, rations for common sailors were not too dissimilar to those of the Navy, the main difference being the practicality of carrying livestock for the crew. The Navy did sometimes attempt to keep significant numbers of live animals on board for the consumption of the crew, but the primordial need was often for space for the large crews.[3]

The Navy did experience difficulties with the regular supply of provisions to ships stationed a long way from England, but, as time went on, sailors began to develop other means of obtaining additional food during their voyages.[4] The fishing industry, though, unquestionably played a key role in selling sailors sufficient foodstuffs to enable them to survive at sea. The quantity of salted fish issued was dependent on the type and size of fish. Pepys' contract, from 1677, mentions North Sea cod, haberdine (a different variety of large cod), "Poor John" (a type of hake) and stockfish (yet another kind of cod).[5] The rations provided were to change little in the century and a half following Pepys' signing of the contract.[6]

Given that dried fish constituted the principal ration in the Navy for three out of every seven days, the needs of British sailors had long exerted an important influence on the growth of domestic fisheries at some distance from England,[7] for example in Scandinavia as far back as the sixteenth century.[8] In the reign of Henry VIII (1509–1547 AD), demand from the English Navy may still have been modest in terms of quantity,[9] but the Navy had nevertheless become a priority for the King, and this became even more the case during the reign of Elizabeth I (1558–1603 AD), when England found itself in competition with increasingly global powers such as Spain.[10] Elizabeth's reign saw the creation of an explicit link between commercial fisheries and the Navy, with the introduction of weekly 'fish days' to encourage domestic consumption and thus the development of a commercial fleet.[11] The principal aim of this legislation was to ensure a supply of trained mariners, but it must at the same time have represented a secure source of supplies for the Navy, in the form of dried fish.[12]

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Navigation and the Limited Fishing Capacity of the Mediterranean

As has been pointed out by Fernand Braudel, the Mediterranean is not especially productive in terms of fish[13] and so throughout most of its history there have been relatively few fishermen, given that a significant fishing industry needs to provide sailors with staples, which often involves the maintenance of ports and recruiting available mariners. Furthemore, it has always been difficult to provision large fleets of galleys and sustaining trading routes: the population of a large fleet is equivalent to that of an ancient city of substantial size and supplying provisions for so many men has traditionally been beyond the power of most communities, since permanent naval bases have to be set up and careful organisation is required.

It has, therefore, been much more typical of Mediterranean history that large fleets have been built up from scratch, with specific expeditions in mind.[14] When war fleets have been needed, they have been generally constructed, collected and manned *ad hoc*,[15] and Braudel has indeed already identified the chronic shortage of maritime manpower in the Mediterranean in comparison with the North Sea and the Atlantic Ocean.[16]

While for much of the Classical Age the Athenians did possess comparatively organised naval forces, even they had to build ships and call up men for specific campaigns, as described by Thucydides in his account of preparations for the Sicilian expedition that began in 415 BC.[17] Octavian, too, was responsible for raising a series of war fleets in the early 30s BC to combat Sextus Pompeius, with preparations beginning in 38 BC after the loss of a fleet at Scyllaeum, which in itself illustrates the somewhat chaotic process of building a fleet.[18] Even in the twelfth and thirteenth centuries, when the Venetians did maintain relatively large fleets, their regular requirements were insignificant, and most of their naval forces were only called up in times of trouble.[19] In the sixteenth century, the Ottomans too tended to produce large fleets from scratch, aided no doubt by their good access to materials for construction,[20] and the other powers of the time also assembled large fleets from different sources, as was the case in the battle of Lepanto in 1571 AD.[21] Up until the seventeenth century, this shortage of manpower in the Mediterranean encouraged the use as rowers of slaves, part-time paid workers or condemned prisoners.[22]

From the time of Augustus onwards, though, the increasing political unification of the Mediterranean, the reduction in piracy and the consequent expansion of towns was a major stimulus for economic growth.[23] The greatest achievement of the Romans was perhaps their ability to facilitate over several centuries the mobilisation of manpower around the Mediterranean's key fishing grounds, and also to maintain fisheries in these important areas of the *Mare Nostrum*, whether for the use of the Imperial classes or to provide other services of political or commercial importance. The expanding presence of vats and fish-salting installations in the Mediterranean was not, then, primarily attributable to an increase in the consumption of fish in inland regions of the Mediterranean countries, and the spread of salted or dried fish during Imperial times should certainly not to be compared with the growing consumption of vegetables, cheeses and pulses in Italy, Spain and Greece.[24] It seems reasonable to infer instead that it was military, Imperial and logistical need which contributed to the expansion of fish-salting installations in key areas of the Mediterranean, as it is likely that at the time naval rations for the sailors, rowers and soldiers who lived and sailed in the great fleets were based on dried and salted fish.

Fish-Salting Installations in the Roman Western Mediterranean and the *classis Misenensis*

Fish-salting activity in the Roman Imperial world is highly visible from an archaeological perspective, because of the use of batteries of vats, made of *opus caementicium* and normally lined with the typical hydraulic mortar known as *opus signinum*, which was regularly used in Roman constructions that required waterproofing, such as cisterns and treading floors. It is not clear whether the use of salting as a preserving method for fish originated with the Greeks, with the Romans learning the process via their colonies in southern Italy, or whether it was a technique of Punic origin.

However, there is only clear evidence of salting vats in the Roman World in second-century BC Pompeii,[25] and it was during this period that Portus and Puteoli emerged as the main centres of the industry in Italy, supported by satellites, Centumcellae and Antium in particular, but also many smaller harbours, including those of the various *villae maritimae* of the region. It was only in the Roman Imperial period, though, and not before, that large installations with the typical batteries of concrete vats began to spread throughout the Mediterranean. The installation of most of the Roman fish-salting workshops of Southern Spain (and Portugal) may be dated then to the late first century, or the Julio-Claudian period, though it is also worthy of note that urban fish-salting workshops continued to be set up right into the days of the late empire, and in the fourth and fifth centuries AD most Hispanic *cetariae* were in fact located in urban or harbour areas.[26]

The spread of Roman fish-salting installations, whether large or small units of production, is an indicator of the complex organisation behind the activity, which was obviously dependent on supply of the items required for production (salt, fish and containers for distribution).[27] Everything points, though, to Italian fishermen having played a key role in providing the impetus for fish salting in the Iberian peninsula and elsewhere, with the dissemination of various more advanced techniques for the storage and treatment of the fish in the vats. Italian fishermen did in fact continue to exert an important influence on the fishing industry in different areas of the Mediterranean up to the nineteenth century, and it may be surmised that this was also the case in Roman times.[28] Indeed, the term 'transmerance' equates the changes in the sea and the movement of schools of fish to the seasonal paths followed by shepherds and their flocks, so it seems logical to suggest that fishermen played a similar role with regard to trade and the establishment of new settlements.[29]

As regards the spread of batteries of concrete vats througout the Western Mediterranean and the role played in this by Italian fishermen, it should, as Meloni pointed out, be stated that "the Misenensis fleet was not always and entirely based at Missenum".[30] For several centuries, in fact, Rome supplied important logistical and maritime support to the whole of the Western Mediterranean from Bay of Naples and the south of Hispania, presumably making use of the Misenum fleet, which left its mark on cities such as Gades, Carteia, Málaga, Almuñecar and Carthago Nova, all of which had highly significant fishing industries.[31] It is, then, very likely that, at certain times of the year during especific periods, these great ports housed significant detachments of the *classis Misenensis*, the imperial fleet of Misenum, as well as civilian cargoes involved in semi-official transport and other duties related to trading activity in the western Mediterranean. Indeed, had there been no Misenum fleet or regular transport of staple products by organised fleets using official or sponsored semi-official maritime channels, then the fishing industry in the Iberian Peninsula would never have been maintained after the first and up to the 5th century AD. The case of Spain was not an isolated one, either, as similar Roman fleets loaded with *annona* products circulated in the western Mediterranean between the Rhône valley, Rome and Africa continuously in the life of the empire.[32]

Fish-Salting Installations in the Roman Eastern Mediterranean and the Rise of the Bosphorus Region

The *Stadiasmus Maris Magni*, which was collated anonymously around the middle of the 2nd century AD, provides navigational information regarding the routes and harbours of the eastern Mediterranean.[33] The majority of the routes mentioned by this source, but also by Strabo (14.1–2), travel in an east–west direction, perhaps suggesting that the majority of maritime movements also moved in that direction,[34] at least as far as political and directed trade is concerned.[35] This apparent reality probably also indicates that Alexandria and other ports of the Levant controlled navigation from east to west in the Mediterranean via southern, or southern-central, maritime lanes.

Egypt was by the time of Augustus a major supplier of wheat and basic staples to Rome, with the Emperor claiming to have distributed grain to the *plebs* of Rome from his own granaries in Egypt.[36] At the end of his reign, Augustus left direct control of the *praefectura annonae* in the hands of two former praetors, who were to be reappointed to the office each year.[37] The official maritime trading lane between Egypt and Italy was also reinforced by Claudius through his promotion of winter navigation by merchants, attracting them to the *annona* service by offering privileges to shipbuilders and ship owners,[38] as well as other favourable terms financed by the state.[39] A passage by Seneca the Younger suggests that later, under Nero or shortly before, a truly "Alexandrian fleet" was created, bringing all or most of the grain from Egypt, first to Puteoli and then to Rome.[40] As Tacitus notes explicitly,[41] by the time of Vespasian, to capture Rome, one first had to control Alexandria, the "key" to Rome`s *annona (claustra annonae)*.[42]

Because of sailing conditions, it is of course somewhat unlikely that sailors travelling from Egypt to Italy would have used exactly the same southern Mediterranean maritime itinerary to sail back to their starting point. They would instead have made use of more favourable winds or currents, probably taking a more northernly route. The importance of the southern Mediterranean maritime lane from the east to the central Mediterranean, though, is probably proof of the virtual hegemony of Alexandria over the eastern Mediterranean during most of the lifetime of the Roman Empire. Alexandria might also have controlled, in Roman times, as it had done for several centuries before, another south-north route in the eastern Mediterranean, which used Rhodes as a central node[43] and took in many of the maritime regions of Asia Minor, even extending across the Aegean into Thrace.[44] In due course, this south-north axis developed even further, and in Justinian's time Egyptian trade channelled throughout Alexandria played an all-important role in supplying Constantinople with all of its needs, from luxury goods to raw materials and grain. Annual shipments of grain from Egypt to Constantinople in Justinian's reign amounted to 8,000,000 *artabes* or 27,000,000 *modii*, or enough to feed about 600,000 people, a truly enormous number.[45]

So important to the Mediterranean were Egyptian cargoes of grain that emperors sometimes distributed – or allowed to be distributed – Egyptian grain in the provinces, as they did in Rome.[46] Since Egyptian grain belonged formally to the emperor, both actions were in any case probably interpreted as acts of generosity on his part.[47] We know, for example, that Tralleis[48] and Ephesus[49] were given permission by Hadrian to import Egyptian grain, but Cyzicus too received Hadrian's authorisation to do so.[50] As some coin types from Tarsos demonstrate, both Caracalla and Severus Alexander also provided that city with Egyptian grain,[51] and when during the Antonine and Severian period many cities in Moesia and Thrace freely stamped their coins with images of Egyptian deities, even using production techniques typical of Egypt,[52] this was in all probability connected with the distribution of Egyptian grain in the region. Leaving aside Tomi, which was unique in displaying a notable and consistent Egyptian character to its coin issues, similar series are known to have been minted at Callatis, Nicopolis ad Istrum, Marcianopolis (Moesia Inferior), Pautalia, Augusta Traiana, Hadrianopolis and Anchialus (Thrace), as well as in other cities such as Serdica.[53] The enormous proliferation of granaries and *horrea* in Thrace and Moesia from the end of the second century onwards[54] coincides with cities in both regions minting coins with Egyptian motifs and hosting particularly large numbers of soldiers, who gathered there during the second, third and fourth centuries AD, either to act in the region or to be transferred to Asia Minor and the east.

As regards the concentration and movements of Roman troops around Thrace during Imperial times, it might also be mentioned that the Black Sea and Sea of Marmara regions were known for different kinds of fish including, but not limited to, tuna, mackerel, sardines and anchovies.[55] A. Marzano suggests that Black Sea products may in the third and fourth centuries have replaced Spanish ones in some markets.[56] I would suspect, though, that the activities of the Roman navies at the time were focused mostly on this region, and that this encouraged the proliferation and production of fisheries there. The numerous production centres in the region are similar to those found in the first and second centuries AD in the western Mediterranean at Carthago Nova, the mouth of the Rhône and the straits of Messina, and it seems likely that this shift in fishing activity illustrates how the Bosphorus region took advantage and become the heart of Imperial and official maritime activity from the second century onwards.

Conclusions

In this paper I have argued that the building of the Roman Empire and the subsequent *Pax Romana* had fundamental consequences for the fishing industry in the Mediterraean. The use of Roman technology in the fishing industry was not, however, primarily market-oriented, but geared to consumption by sailors and by the crews of Roman vessels, and above all by the Roman imperial navies.

There is no doubt that the Roman emperor did indeed act as a benefactor, but he was also responsible for maintaining and supporting large population groups, such as Rome and later other cities too, as well as a number of Roman armies spread throughout the empire. It was, therefore, under such a regime that the mechanics of imperial organisation had the space to evolve, and indeed were required to do so.

I have also suggested in my paper that the imperial *classes* played an essential role in monitoring communications in the Roman Mediterranean. The Mediterranean of the Romans was not rich in fish and other basic staples, and maintaining the maritime lanes necessary to the functioning of the empire was possible only with great effort, which was in turn dependent on the existence of a vast network of fishing installations. It was this fishing industry that made possible, but also came to limit, the intensive and safe navigation that characterised the Mediterranean in Roman times.

Notes

[1] Fictum 2016, 3; Bryant 1938.
[2] Fictum 2016, 8.
[3] Fictum 2016, 16 f.
[4] Fictum 2016, 21.
[5] Fictum 2016, 8.
[6] Fictum 2016, 4.
[7] Hutchinson et al. 2015, 9.
[8] Holm,1998.
[9] Knighton – Loades, 2000.
[10] Quinn – Ryan,1983.
[11] Jackson, 2000.
[12] Hutchinson et al. 2015, 9.
[13] Braudel 1972,138–140. 436. 448; Hopkins 2014, 136 f.
[14] Hopkins 2014, 16.
[15] Hopkins 2014, 15.
[16] Braudel 1972, 138–140; Hopkins 2014, 17.
[17] Thuc. 6.30–32; Hopkins 2014, 16.
[18] App. B Civ. 5.89; Dio 48.47–48; Hopkins 2014, 16
[19] Lane 1973, 49; Hopkins 2014, 15.
[20] Brummett 1994, 96; Hopkins 2014, 15.
[21] Hopkins 2014, 15.
[22] Lane 1973, 368; Zysberg-Burlet 1990; Hopkins 2014, 17.
[23] Hopkins 2014, 20.
[24] Marzano 2013a, 96.
[25] Marzano 2013a, 98.
[26] Marzano 2013a, 103.
[27] Marzano 2013a, 121.
[28] Marzano 2013a, 86.
[29] Marzano 2013a, 87.
[30] Meloni 1958, 93; See also Vegetius, 4. 31 on the fleet of Misenum during the period of the Late Roman Empire.
[31] López Sánchez 2012, 2014.
[32] Southern 2007, 112.
[33] Bouras 2016, 204.
[34] Bouras 2016, 216.
[35] Scapini 2016, 222.
[36] Res Gestae Divi Augusti 18.
[37] Scholars take different positions regarding this, and a few (such as Garnsey 1988, 255) claim that the main contributor of grain was the African provinces.

[38] Suet. Claud. 18.2.
[39] Garnsey 1988, 74.
[40] Ep. 77.1; Scapini 2016, 226. 228.
[41] Hist. 2.82; 3.8.
[42] Scapini 2016, 226, note 53.
[43] Buraselis 2013.
[44] Gabrielsen 2013.
[45] Jones 1964, 698; Durliat 1995, 19–33.
[46] Garnsey 1988, 256 f.
[47] Scapini 2016, 237.
[48] I Tralles 80 (=CIG 292); Scapini 2016, 232.
[49] I Ephesos 211, SEG LII 2002, nº 1132. On this document, see Wörrle 1971; Scapini 2016, 232.
[50] OGIS 389. There is evidence of such Imperial permits from the first decade of Augustus' Principate up until the early 3rd century.
[51] Ziegler 1977: the coins are described at 34 f. (pl. 3).
[52] Peter 2005, 112 f.
[53] Tacheva-Hitova 1983, 44–54.
[54] Lemke 2017.
[55] Marzano 2013a, 97.
[56] Marzano 2013b.

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Elba Deforested? – New Perspectives on the Ancient Bloomery Smelting Landscape of Elba Island (Tuscany, Italy)

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Ancient Iron Mining and Smelting on Elba Island

Elba Island hosts one of the largest iron ore deposits in Roman *Italia*.[1] Early evidence – however indirect – dates the onset of mining on the island to the 6th century BCE, when hematite from Elba was smelted in the furnaces at Populonia and Follonica-Rondelli on the Tuscan mainland.[2] Nearly all evidence of ancient mining activities on Elba got lost in the open pits of the modern mining period (1853 to 1981).

During the first centuries of mining on Elba, the raw ore was transported to the mainland; smelting on the island started most likely in the 3rd century BCE, as indicated by ceramic finds from different smelting sites.[3]

While iron production in Populonia continued until the 1st century CE,[4] it is commonly assumed that all smelting sites were abandoned in the mid-1st century BCE as indicated by the chronology of ceramic material.[5] Additionally, textual sources are interpreted as a description of the decline of production on Elba: Diodorus of Sicily (1st half of the 1st century BCE) describes mining and smelting of iron on Elba Island:

"For the island possesses a great amount of iron-rock ... those who are engaged in the working of the ore crush the rock and burn the lumps which have thus been broken in certain ingenious furnaces; and in these they smelt the lumps by means of a great fire."[6]

In contrast, Strabo (Augustan era), notes that iron was mined on Elba, but the raw ore was transported directly to the continent to be processed there.[7] Although Strabo gives no reasons why the ore could not be smelted on Elba, his observation is commonly interpreted as a description of deforestation and a lack of fuel resources – the 'deforestation narrative'.

Aims

In the following, we will contribute to the discussion on the end of iron smelting on Elba from a landscape archaeological point of view.
We discuss:

- the development of the so called 'deforestation' hypothesis;[8]
- published palynological data, own sedimentological cumulative probability functions of calibrated ^{14}C-dates to reconstruct the (mid- to) late Holocene landscape development on Elba;

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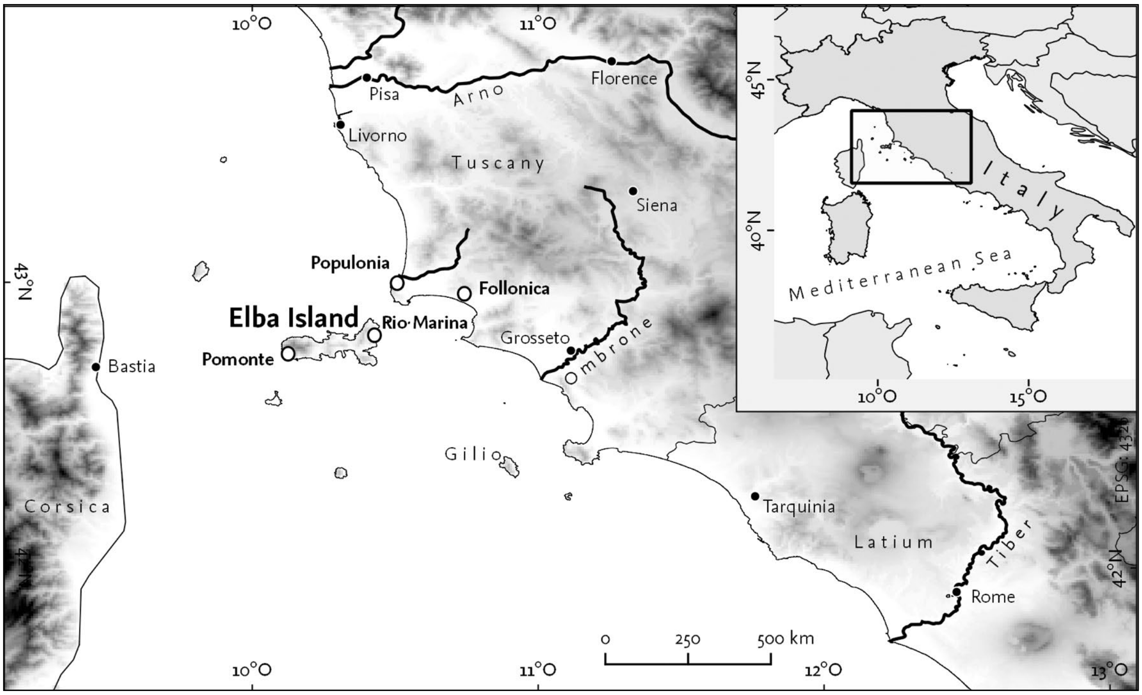

Fig. 1: Location of Elba in the Northern Tyrrhenian Sea.

- a model of the required and harvestable woodlot area on Elba; and
- the site pattern of ancient furnaces on Elba to evaluate if a 'forest management strategy' is visible.

In a synthesis we will integrate the evidence presented in a revisited chronological framework of ancient Elba and the wider economic development of the Roman iron industry between the 1st century BCE and 1st century CE.

Although the general discussion on ancient deforestation in the Mediterranean region is controversial and of wider interest, we do not give a comprehensive overview on the state of the art.[9] Further historic and more general views on iron and deforestation can be found in e.g. Lindsay;[10] Goucher;[11] and Iles.[12]

The 'Deforestation Narrative'

The 'deforestation narrative' dates at least to the 18th century. For example, in his travel narrative from 1775, R. Pococke refers to Strabo and states that "they [the Romans] could not melt the iron on the spot [Elba], but carried the ore immediately to the continent.", because there was not the "conveniency of wood for their foundry".[13] Also Täckholm cites Strabo: "We know from Strabo V 2.6 that ore was transported directly to the continent, without being melted. The reason is not indicated by Strabo, but might not have been any other than a lack of firewood."[14]

Fig. 2: View from the Volterraio castle over the Central Elban hills and plains and the Monte Capanne massif (August 2016).

Also, in recent literature on environmental and forest history, ancient Mediterranean deforestation, or ancient technology a lack of fuel on ancient Elba is discussed,[15] without citing evidence for deforestation.

The 'deforestation narrative' occurs contemporary to observations on fuelwood scarcity. E. Schweighardt mentions that in antiquity, iron was roasted on Elba, but further processed on the mainland. He records that "even now [in 1841], due to a lack of firewood, the ore is not processed on Elba, but on the mainland".[16] Landscape descriptions from the 18th and 19th century characterise Elba as an island with sparse tree cover; e.g., A. Thiébaut de Berneaud reports: "Wood for fuel is still more rare. The island affords nothing beyond a meager underwood [...] In a word, forest-trees are wanted throughout the island. [...] all the iron works in the island are destroyed; they have no wood [...] they are obligate to transport the ore to Corsica, the coast of Genua, and the shores of Tuscany, in order to have it manufactured."[17]

Similar narratives were taken down by Swinburne in 1771 and Barker in 1815;[18] from Napoleon's short stay on Elba (1814), the anecdote is delivered that he send a vessel with raw ore to the U.S.A. because of a lack of fuel.[19] In a record from 1771, Giovannelli notes that although it is believed that the ancients degradated the island, it is the construction of agricultural terraces for wine production that eliminate most of forest on Elba.[20]

Landscape degradation on Elba is stated even today: "Most scholars believe that this shift [of iron production from Elba to Populonia] took place after the island had become totally deforested. Elba today is still heavily marked by erosion and barren hills."[21]

Common impression of the island is quite different (fig. 2, 3); Elba is marked as the "Grüne Insel Elba" (Die Zeit, 01.03.1968 and 26.02.2016) – the green island of Elba. Only

Fig. 3: View from the sea on the Ortano valley (September 2015).

some hills on northeastern Elba are today covered with grassland.[22] Since the 1960s – when tourism on Elba was in its early development and the local economy mainly relied on the primary sector – woodland cover increased and agriculture use in the plains and the adjacent slopes declined.

We therefore think that the 'deforestation' hypothesis is rooted in that kind of 'uniformitaristic' view on the ancient environment on Elba; an idea that is similar to Grove and Rackhams' ruined landscapes theory or Rackhams' pseudo-ecology.[23]

Palynological Evidence

A palynological study by Bertini et al. uses pollen records from coastal plains to reconstruct the vegetation history on Elba from ca. 6000 BP to present.[24] Their data indicate an alteration of wetter and dryer climatic phases on Elba and occasional changes from dominant wetland vegetation to terrestrial species. At least since 4000 BP deciduous oaks and *Ericacea* spec. dominate the pollen record. Bertini et al. link a drop of oak pollen and the synchronous increase in *Ericacea* pollen around 2150 BP to metallurgical activities on Elba. However, the data do not necessarily indicate a lack of fuel: First, *Ericacea* species (E. arborea) was used as main fuel for iron smelting on the continent;[25] also in sediment sequences from Elba, the (sparse) anthracological record is dominated by *Ericacea*-species, *Arbutus* spec.[26] Second, pollen were recovered from lagoonal sediments, which do not necessary represent the entire vegetation cover of the island; today the plains are often used for agriculture, whereas the distant slopes are often characterised by tree cover (fig. 3). Third, the alteration of oak and *Ericacea* is observed also for periods prior to the Iron Age.[27] Fourth, although the oak cover is reduced, the pollen record does not indicate large scale deforestation on Elba.

Sedimentological Evidence

Sedimentological data obtained from the Campo plain by Becker et al.[28] cover a period from ca. 8000 BP to the present. The most obvious environmental change recorded in the sediment archives occurred between 7000 BP and 6000 BP and is strongly linked to increased sedimentation and a change in the depositional environment during late transgressive and early high stand conditions (i.e., the transition from a rapidly rising sea level to more or less stable sea level). The change from a lagoonal/lacustrine environment to an alluvial plain and the deposition of relatively coarse gravel in the lower part of the plain dates to ca. 2300 BP. In addition, slope deposits (c 2200 BP) and high-magnitude flood layers (between 2200 BP and 1900 BP) point on accelerated morphodynamics during the period of Roman iron smelting. Additionally, charcoal deposition tends to increase in the late Holocene sediments from the Campo plain and is relatively high between ca. 2700 BP and 1400 BP. The taxonomic identification of 14 samples representing the interval between c 2200 BP and c 1900 BP reveals that the charcoal record is dominated by *Arbutus* spec., a typical *macchia* shrub used for fuel production on Elba.[29]

Meta-Analysis

Preliminary results of the meta-analysis of ^{14}C-ages obtained from sediment sequences from Elba Island[30] indicate phases of increase/decreased depositional activity on Elba: For a first analysis of the data, we used the 'modelTest' in the *rcarbon*-package[31] in R[32] to analyse the Cumulative Probability Function (CPF) of the available ^{14}C-dates. The approach follows the assumption that the probability density of calibrated radiocarbon dates in a time span is related to fluvial (depositional) activity. As the actual CPF might be biased by the shape of the calibration curve and by random coincidences of several ^{14}C-ages, we tested our CPF against a null model of randomly uniformly distributed samples over the study period; only phases where the CPF exceeds the 95%-envelope of the simulated CPF, we assume accelerated activity. The CPF for the late Holocene as depicted in fig. 4 clearly show several phases of depositional activity. During the Roman smelting period, the curves show a significantly accelerated activity, between ca. 2200 and 2000 BP. This phase is followed by a phase of significantly decreased activity around 1800 BP.[33]

Resource Model

We set up a resource model to estimate both wood consumption for smelting and the harvestable woodlot area. As most of the data necessary for the model are subject to

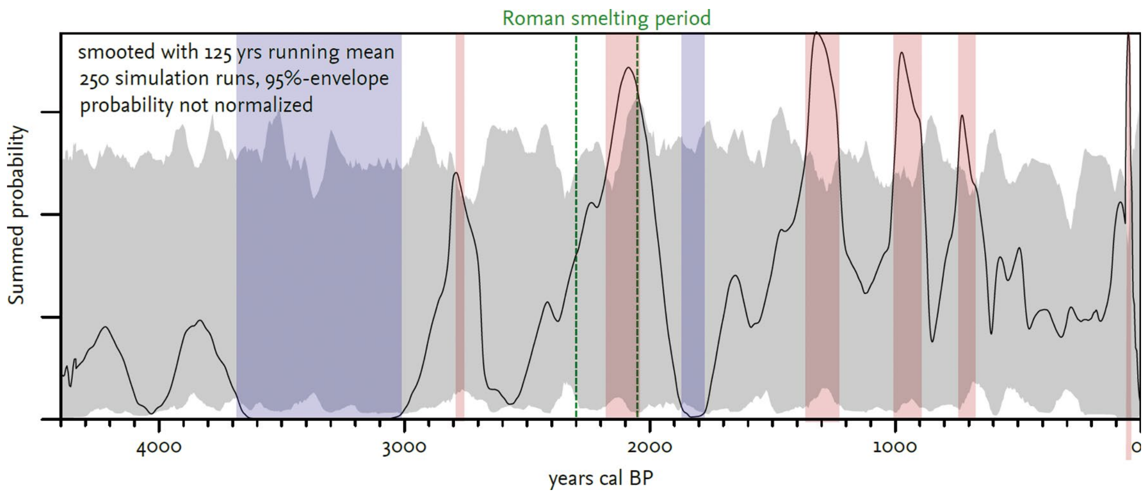

Fig. 4: Cumulative probability function of calibrated ^{14}C-ages from sediment sequences tested against a null model (95%-envelope, grey background); coloured bars indicate phases of significant high/low activity. Created using the *rcarbon* package in R.

uncertainties, we used a Monte-Carlo-simulation and propagated the uncertainty in the input parameter (i.e. a lack of detailed quantitative information on the conditions on ancient Elba and no specific information on the applied technologies, e.g. coppicing or clear-felling) to the model output by using randomly select values in the possible value range and repeated the calculation 1000 times; the result is therefore a probability function of consumption, production, and thus a possible scarcity of fuel wood. The model explicitly estimates potential deforestation by iron smelting; we are aware that also other economic activities and daily life have contributed to deforestation. The methodological approach is summarised as follows:[34] (i) We obtained information on the extend of iron production on Elba from the amount of ancient slag found on Elba; these data are available from statistics taken down by the re-smelting concessionaires in the first half of the 20th century,[35] reported extends of slag heaps, and published and own (field) data.[36] (ii) Based on the total amount of ancient slag form Elba we estimated the amount of charcoal to charge the furnace and the amount of wood to produce the charcoal using parameter obtained from experimental and ethnographic data. (iii) Using the present day vegetation cover and estimations of the ancient cover used in other calculations and forest yield tables as a baseline assumption, we were able to estimate wood availability and regrowth. (iv) As a time frame, we used a phase of intensive production in the 2nd century BCE, when most of the dating material was deposited on smelting sites.

We modeled a wood consumption ranging between 3,500 and 25,600 t a^{-1} in for the 2nd century BCE (at 95%-confidence); annual wood production on the island is estimated to be between 13,800–54,200 t a^{-1} (clear-felling) and 29,800–78,300 t a^{-1} (coppicing). The modeled total land area required to satisfy the wood consumption by smelting ranges

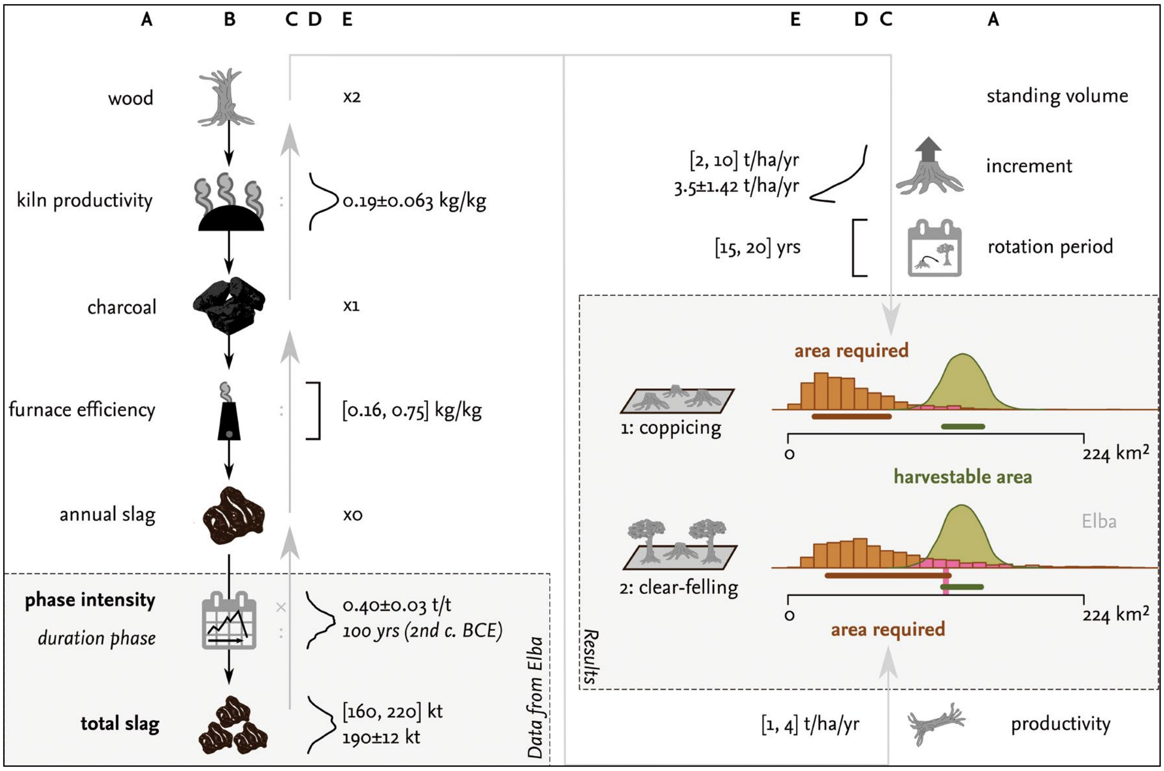

Fig. 5: Model of the required woodlot area (brown) on Elba for iron smelting in the 2nd c. BCE and the harbestable area (green). For details see Becker et al. submitted; columns: A = parameter, B = production steps, C = reconstruction steps, D = parameter probability, E = values ([range], median ± median absolute deviation).

between 7 and 89 km² (coppicing) or between 20 and 262 km² (clear-felling); the total harvestable area was potentially >138 km². Therefore, in 5.0% (coppicing) or 19.9% (clear-felling) of our simulation runs, the entire area of the island had to be under forestry to supply fuel for the furnaces, thus it is (very) unlikely that Elba had to be deforested to charge all the furnace.

Site Pattern

The ancient iron mines on Elba Island are characterised by (i) proximity to the coast, (ii) a disruption of the ancient structure by modern mining, (iii) (mainly) hematite deposits in shallow depth, and (iv) a location exclusively in eastern Elba. In contrast, the latter, ancient smelting sites are not only located in eastern Elba – in the vicinity of the mines – but spread over the entire Island. The most remote site at Pomonte is located in 42 km distance by sea to the Rio mines – the industrial quarter of Populonia is located about 13 km from the Rio mines. The furnaces are situated very close to the (ancient) shoreline, often at sandy pocket beaches which are suitable for landing – even today – and embayments that offer anchorages with some degree of protection. Especially in western Elba, a wider valley is located in the hinterland of the sites, where wood resources are easily accessible.[37] In the late 2nd – early 1st century BCE, most of the sites on Elba were active. We interpret the site pattern as a clear evidence for strategy to efficiently use the wood resources on the island.[38] The transport of ore to the location of charcoal is much more efficient than the transport of charcoal or even wood, as one can carry more amount of ore than charcoal at the same volume. The transport by land is hindered by (steep) hills and mountains (fig. 6).[39]

Synthesis and Conclusions

We used different approaches and data sets to discuss the hypothesis that Elba Island was deforested during the ancient period of iron smelting (4th/3rd century BCE to 1st century CE). The following points are our main conclusions:

- The 'deforestation' hypothesis cited in the relevant literature lacks a fundamental basis; the main evidence presented is an observation of Strabo, who only notes that iron is not smelted on Elba in the Augustan era – Strabo does not give any reasons for the observation. The hypothesis rather developed on the background of the 18th–20th century-landscape of Elba, which is marked by reduced forest cover and a scarcity of wood.[40]
- Palynological studies do not necessarily indicate a lack of fuel on Elba in the 1st century BCE. The percentage of e.g. oak pollen decreases during the ancient smelting period, but the percentage of other fuel wood species (*Ericacea*) increases.
- Sedimentological evidences obtained from the Campo plain in Central Elba shows that morphodynamics (potentially as a result of clearing and subsequent soil erosion) increased during the Roman Middle Republic to early Imperial period. Additionally, more charcoal was deposited in the sediments since then.
- Cumulative probability functions obtained from calibrated ^{14}C-dates support the interpretation of the detailed sedimentological analysis and shows several significant phases of deposition, one is related to the ancient smelting period in Elba Island; a phase of decreased deposition follows the Roman smelting period.
- Regardless of assumed silvicultural system and a possible phase of high production, our Monte-Carlo-based model of resource consumption and production clearly suggests that it is (very) unlikely that the demand of wood for iron smelting exceeded the regrowth of the woodland cover on Elba.
- The pattern of smelting sites on Elba Island is strongly related to the access of forest resources – an interpretation that Corretti describes with "the fullest exploitation of wood resources".[41] Smelting sites are located in considerable

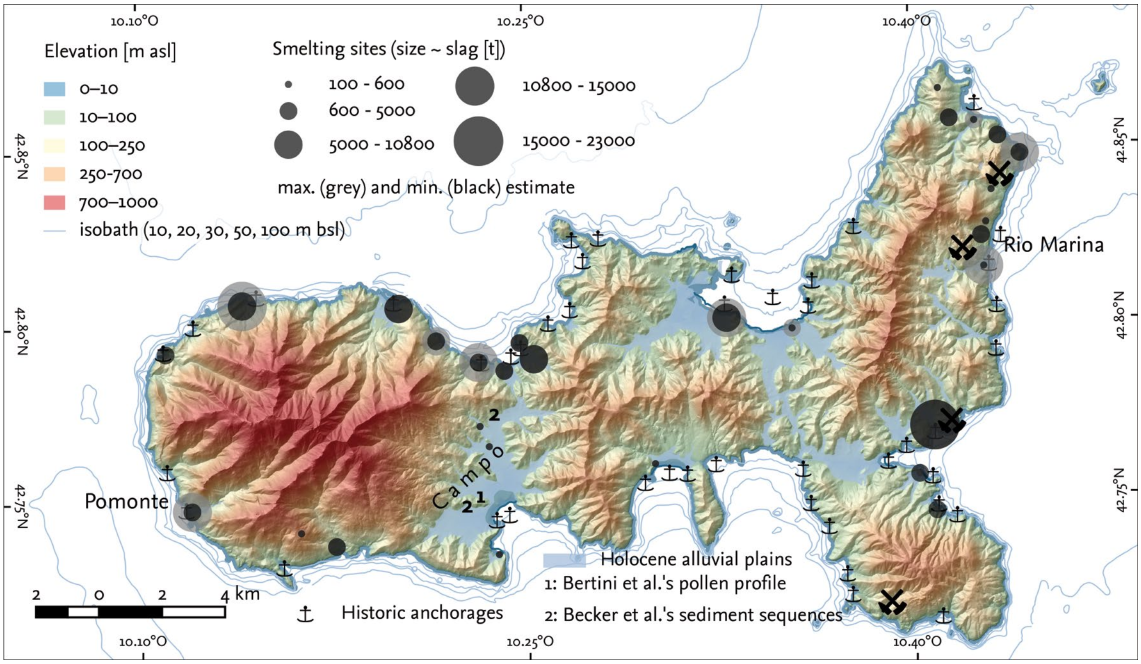

Fig. 6: Distribution of ancient smelting sites on Elba.

distance from mines in areas (where wood is available), in the direct vicinity of sandy beaches (where ships can easily land), and at the end of wider valleys (where forests are well accessible).

Other historical events might have triggered the decline of smelting activities on Elba:

- The proposed end of iron smelting on Elba in the mid–1st century BCE coincides with the Roman occupation of further iron mining districts in Europe, especially in as one can carry more amount of ore than charcoal at the same volume *Gallia*, *Hispania Tarraconensis*, and *Noricum*.[42]
- A possibly contemporary *senatus consultum* mentioned by Pliny HN, 3.138 and 33.78 might be interpreted as evidence for a strategy to conserve the ore resources in Italia.[43]

Additionally,

- a reinterpretation of published evidence on the chronology of iron smelting on Elba and newly obtained dating material (e.g. ceramic fragments and calibrated ^{14}C-dates) shows that smelting on Elba continued in the 1st century CE, most likely on a smaller scale than in the preceding centuries.
- The interpretation of the site pattern as a forest management strategy – together with the fact that smithing and refining of iron blooms took not place on Elba[44] – might indicate that resource management was an integral part of the production cycle of iron in the Elba–Populonia industrial area.

In conclusion, we assume that it is reasonable that Elba was not (completely) deforested in the 1st century BCE, but smelting activities had a significant impact on the environment.

Notes

[1] Tanelli et al. 2001.

[2] Cf. Corretti – Benvenuti 2001, 141 f.; Corretti 2017, 452.

[3] Corretti et al. 2014, 183 f.

[4] Chiarantini et al. 2018, 12.

[5] Corretti 1988, 27; Corretti – Firmati 2011, 232.

[6] Diod. Sic. 5.13.1. Translation by Oldfather 1993, 131.

[7] Str. 5.2.6.

[8] We understand the term deforestation as a (even temporal) absence of sufficient three cover; for a discussion of the terminology in the archaeological context see i.a. Iles 2016 and Harris 2013.

[9] The interested reader is referred to the relevant literature: Hughes – Thirgood 1982; Meiggs 1982, 371–403; Hughes 1983; Wertime 1983; Williams 1989; Hughes 2011; Harris 2013.

[10] Lindsay 1975.

[11] Goucher 1981.

[12] Iles 2016.

[13] Pococke 1745, 180 f.

[14] Täckholm, 1937, 21; in German: "Wir wissen durch Strabon V 2.6, dass das Erz direkt aufs Festlande transportiert wurde, ohne noch geschmolzen zu sein. Der Grund dafür wird von Strabon nicht angegeben, doch kann es wohl kein anderer als Brennholzmangel gewesen sein"; translation: by the authors.

[15] Forbes 1964; Meiggs 1982; Williams 2010, 78; Harris 2013; Sands 2013, 22; Penna 2014, 151.

[16] Schweighardt 1841, 23.

[17] Thiébaut de Berneaud 1814, 23 f.

[18] Swinburne 1814, 429 f.; Barker 1815, 4.

[19] Campbell – Maclachlan 1869, 4.

[20] Giovannelli 1771, 112.

[21] Wiman 2013, 17.

[22] Foggi et al. 2006.

[23] Grove – Rackham 2003; Rackham et al. 1996; see also the German ‚Holznotdebatte' (debate on wood shortage) and problems related to the understanding of deforestation in the 18th c. in e.g. Radkau 1986 and Schenk 2006.

[24] Bertini et al. 2014.

[25] Sadori et al.2010.

[26] Becker et al. 2019.

[27] Bertini et al. 2014.

[28] Becker et al. 2019.

[29] Cf. Brambilla 2003.

[30] Unpublished data; D'Orefice – Graciotti 2014; Becker et al. 2019.

[31] Bevan – Crema 2018.

[32] R Core Team 2016.

[33] It should be noted that the CPF results are preliminary and some biases in the data need further assessment and discussion.
[34] Becker et al. 2020a, Becker et al. 2020b.
[35] Pistolesi 2013, passim.
[36] Cf. Zecchini 2001.
[37] Cf. Corretti 1988, 25 f.
[38] Cf. Corretti 2017, 455.
[39] In the Middle Ages, transport over land is more often practiced.
[40] Interestingly, Chiarantini et al. 2018, 12, even state that the forest resources might be already exhausted in the 6st c. BCE, as iron was only mined on Elba and smelted in Populonia—far prior the onset of smelting on Elba in late 4th/3rd c. BCE.
[41] Corretti 2017, 455.
[42] Cf. Camporeale 2013, 206.
[43] Corretti 2004, 282 f.; Cambi 2009, 226 f.; Contra Camporeale 2013, 207.
[44] Only very scanty founds of smithing slag were recorded, see Corretti 2016. Corretti 2017, 455 f.

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Nouvelle étude d'un four à amphore dans le complexe artisanal de Loron (Tar Vabriga Torre Abrega, Croatie). Premiers résultats de l'étude archéologique et anthracologique

Christophe Vaschalde – Corinne Rousse – Benoît Brossier – Gaetano Benčić

L'atelier de production céramique de Loron (Tar-Vabriga, Croatie) fait partie d'une vaste propriété sénatoriale, puis impériale, implantée le long de la mer vers 10 ap. J.-C. sur le territoire de la colonie de *Parentium* (Poreč) (fig. 1). Les fouilles menées par plusieurs équipes internationales (1994–2011)[1] ont révélé le caractère hors norme de ce grand complexe artisanal, principalement dédié à la fabrication d'amphores à huile Dressel 6B exportées vers la plaine du Pô et le *limes* danubien.[2] Les timbres amphoriques donnent une liste de prestigieux propriétaires membres de l'ordre sénatorial avant que le domaine ne passe dans la propriété impériale.[3] Après Hadrien, les amphores ne sont plus timbrées, mais la production se poursuit jusqu'au début du IV^e^ s.[4] Le site est ensuite abandonné puis démantelé jusqu'à la fin du V^e^ s.

L'atelier de Loron se caractérise par l'aménagement particulièrement fonctionnel des édifices destinés à la fabrication, à la cuisson et au stockage des amphores. Il suit un plan d'architecte, défini dès sa fondation (vers 10 ap. J.-C.) et sans équivalent pour l'instant dans le monde romain (fig. 2). L'organisation repose sur deux modules de bâtiments alignés sur la ligne de côte, mesurant au total 171 m de long, d'est en ouest. Les deux modules sont séparés par une voie d'accès descendant vers la mer, qui relie l'atelier à l'intérieur des terres, tout en facilitant le transport des amphores par voie maritime. Le module occidental est interprété comme un quartier d'habitat modeste, accueillant le personnel, servile ou non, qui travaillait dans l'atelier.[5] Le module oriental correspond à l'unité de production. Long de 90 m est-ouest pour 80 m de large nord-sud, il est composé d'une terrasse inférieure, divisée en une série de caves ou espaces de stockage donnant sur la mer, et d'une terrasse supérieure occupée par l'atelier, constitué d'un vaste bâtiment en U centré sur une cour rectangulaire. Quatre grands fours en batterie occupent l'espace central de ce bâtiment (espace 45), encadrés par des préaux de séchages (espaces 48–49). Ils constituent les principales structures de cuisson identifiées de l'atelier.

Le fonctionnement des fours et les importants volumes de production ont nécessité de grandes quantités de combustibles. A l'instar de ce qui a été fait en Gaule narbonnaise[6] et en Bétique,[7] la fouille de Loron est l'occasion de comprendre les modalités de gestion des boisements associés à la production d'amphores.

Les premières fouilles des fours de Loron (2007–2011)

Les fours ont été partiellement fouillés entre 2007 et 2010 par une équipe italo-croate.[8] Trois structures ont été étudiées, laissant intact le quatrième four (FR ξ-8000), repéré

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Fig. 1 : Vue d'ensemble des sites : atelier de Loron et villa de Santa Marina sur le territoire de la commune de Tar-Vabriga/Torre-Abrega.

grâce à un sondage dans le *praefurnium*. Les fours sont installés dans une pièce de 24,6 × 18,6 m, ouverte sur la cour grâce à trois accès. Ils sont disposés par paire de part et d'autre d'un mur central en petit appareil régulier. Les façades arrière des fours se situent à 5 m du mur nord de la pièce (MR 3288), laissant un espace commun de manutention ouvert sur les deux préaux de séchages. À l'avant des fours, un espace large d'un peu plus de 5 m sert de fosse d'accès.

Selon cette étude, les fours, orientés nord-sud, présentent les mêmes caractéristiques : un long *praefurnium* (2 m), suivi d'une chambre de chauffe rectangulaire de 7×5 m. Des départs d'arcs identifiés sur les trois premiers fours étudiés suggèrent une chambre de chauffe à canal unique de type IIb.[9] La stratigraphie indique que l'implantation des fours remonte à la première phase du complexe (10–40 ap. J.-C.). Les deux fours orientaux pourraient être abandonnés dans le courant du IIe s., comme semble l'indiquer l'implantation d'un petit four plus tardif devant l'un des deux *praefurnia* ; le troisième grand four, situé à l'ouest du mur médian, a pu continuer à fonctionner durant le IIIe s.[10] Deux petites unités de cuisson, destinées à la production de céramique commune, ont également été installées dans les fosses d'accès du secteur oriental de l'espace 45 avec une production datée de la fin du IIIe s.-début IV^e^ s.[11]

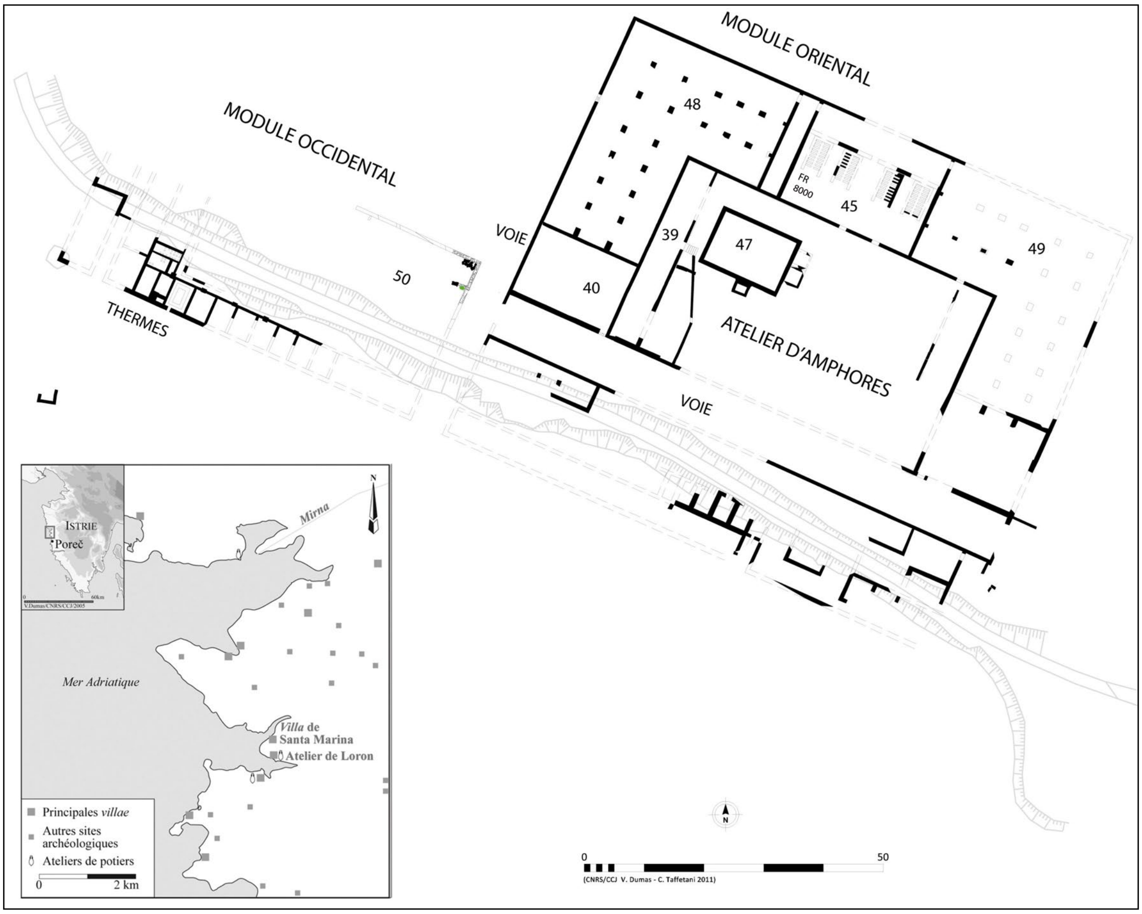

Fig. 2 : Loron. Planimétrie de l'atelier avec l'espace des fours (45) et localisation du four FR ξ-8000.

La fouille du four occidental FR ξ-8000

La fouille du quatrième grand four, à l'ouest de l'espace 45, avait pour principal objectif d'éclairer les stratégies d'approvisionnement en combustible en appliquant un prélèvement systématique des charbons de bois pour permettre une étude anthracologique et dendro-anthracologique, accompagnée de datations de laboratoire (archéomagnétisme et radiocarbone). L'opération a révélé la structure de cuisson la mieux conservée du site,[12] à la fois en plan et en élévation (fig. 3 et 4).

L'alandier et sa façade

Au sud, le four est doté d'un alandier long de 2,50 m et large d'1,35 m (fig. 3), bâti en briques crues en forme de claveaux liées à l'argile, qui ont cuit au cours du fonctionnement du four. L'alandier est en partie comblé par les cendres et les charbons de bois (US 8085) issus de la dernière fournée. Ce comblement comprend même des

Fig. 3: Four FR ξ-8000 vu du sud. Au premier plan, l'alandier et sa façade.

bûches carbonisées intactes. Un mur de façade s'appuyait sur l'alandier, constitué à la base de moellons calcaires liés au mortier de chaux puis, au-dessus, de fragments de *tegulae* liés au mortier de chaux.

La chambre de chauffe

Le four FR ξ-8000 forme un quadrilatère (9 × 5,10 m), œuvre et alandier compris (fig. 4 et 5). Conservée par endroit sur près de 2 m de hauteur, cette structure révèle une organisation des maçonneries complexe, permettant de gérer la nécessité de reconstruire périodiquement certaines parties dégradées par la chaleur, ou d'en pérenniser d'autres. Parmi les éléments permanents (*tegulae* ou moellons calcaires, tous liés au mortier de chaux), on reconnaît des bases de piliers (MR 8141 ; MR 8144) aux angles nord-est et sud-est du four, le mur ouest de la pièce (MR 3301) et la fondation des élévations arrières du four (MR 8151). Sur ces éléments permanents s'appuient des parois peu exposées à la chaleur : ce sont les murs est et ouest de la chambre de chauffe (MR 8075 et MR 8125), construits en *tegulae* liées à l'argile. À l'intérieur et à l'arrière du four, des murs de briques portent des traces d'une importante exposition à la chaleur, et ont sans doute été reconstruits plus souvent. Le mur arrière témoigne d'une réfection, avec un doublement de la paroi en briques, qui réduit la longueur de la chambre de chauffe de 40 cm et pourrait correspondre

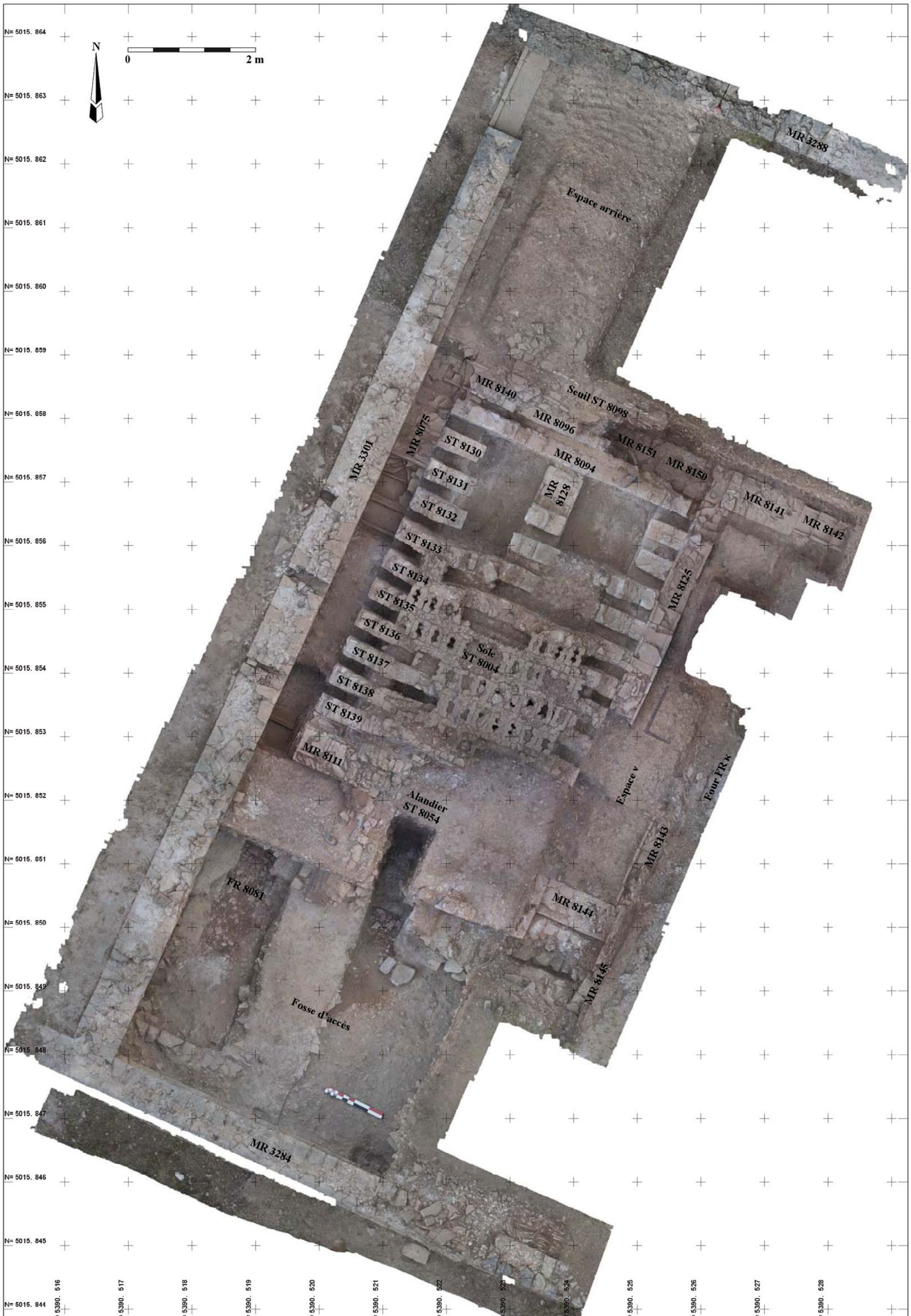

Fig. 4: Orthophotographie du four FR ξ-8000.

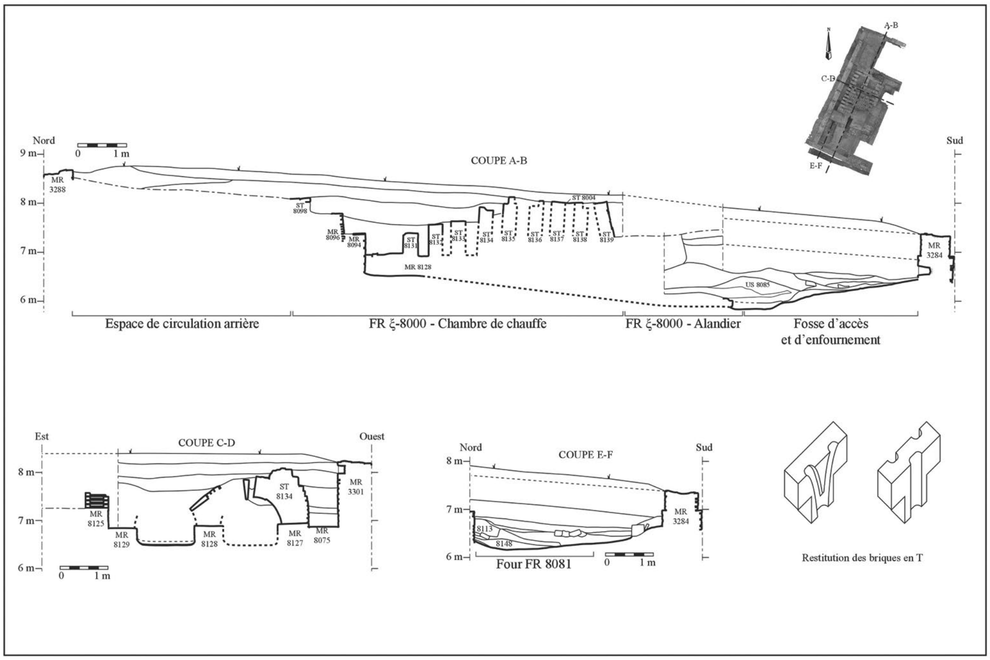

Fig. 5: Coupes des fours FR ξ-8000 et FR 8081, et restitution schématique des briques en T.

à un changement de plan. L'observation des techniques de construction suggère que le four a pu fonctionner, à l'origine, avec un seul couloir, avant d'être équipé de deux couloirs. Au-dessus de la paroi arrière, un seuil ST 8098 de 75 cm de large marque l'emplacement de la porte arrière du four, qui permettait d'accéder à la chambre de cuisson depuis l'espace arrière nord.

La chambre de chauffe mesure 6,50 × 5,10 m. Elle est occupée par deux couloirs parallèles nord-sud et délimités par des murs en briques. Le dernier état de la structure appartient donc à un type différent de celui identifié pour les trois autres fours de type IIc.[13] Ces murs soutiennent dix séries d'arcs qui supportent la sole. Ils mesurent 60 cm de large pour 45 cm de hauteur. Le mur central porte la trace d'un changement de disposition des arcs de la sole, permettant de restituer un état antérieur avec neuf séries d'arcs, au lieu des dix du dernier état.

La sole

Le tiers avant de la sole ST 8004 est conservé en place (fig. 3, 4 et 5). Elle est construite avec des briques en T dotées d'un système complexe de demi-carnaux qui sont posées entre chaque arc, face à face, de manière à former des carnaux complets (fig. 5). Une chape d'argile d'environ 2 à 3,5 cm d'épaisseur est présente par lambeaux sur la sole, et conserve les traces d'un dallage en fragments de *tegulae*. Plusieurs carnaux sont obstrués par des pierres plates posées à plat servant de bouchon. Enfin, le laboratoire de cuisson mesure 5,20 × 3,90 m hors œuvre.

Fig. 6: Vue du four FR 8081 depuis le sud-ouest.

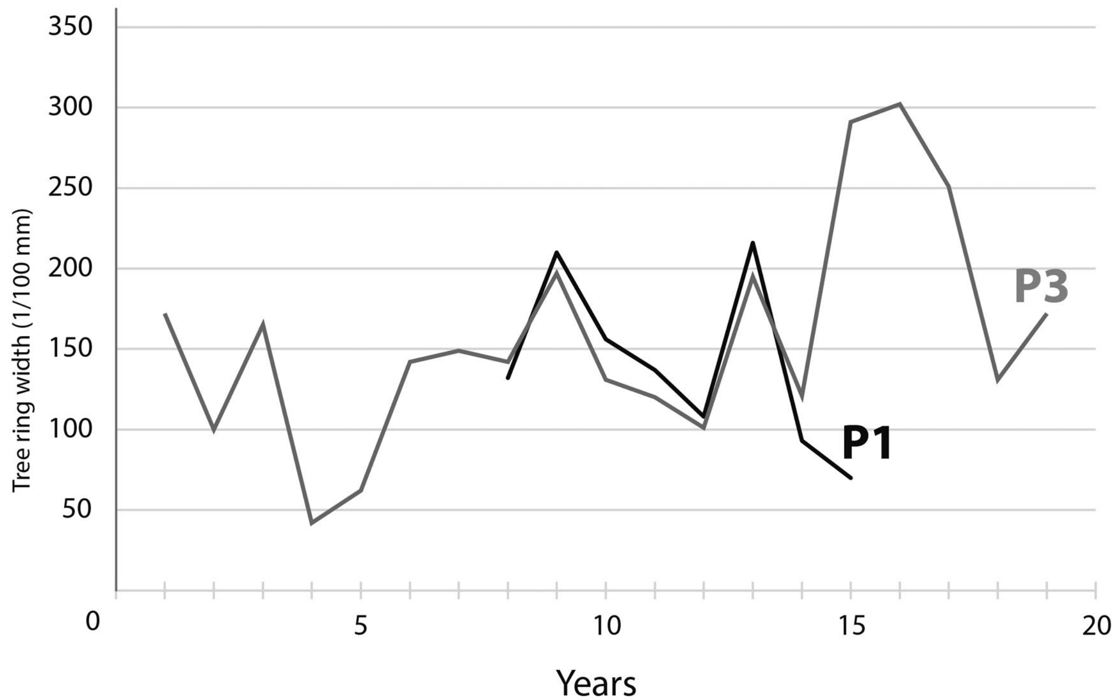

Fig. 7: Interdatation de deux bûches (P1 et P3) issues de l'US 8085 du four FR ξ-8000, obtenue par l'analyse dendro-anthracologique.

La fosse d'accès du four et le petit four secondaire FR 8081

Au sud du four FR ξ-8000 s'étend la fosse d'accès à l'alandier (fig. 4 et 5), mesurant 5,40 × 4,40 m, (environ 24 m2). Le niveau de circulation, sur lequel l'alandier et les parois du four sont fondés, présente un pendage en direction de l'entrée de l'alandier. La fouille complète de la fosse d'accès (couches de démolition datées des IVe–Ve s.) n'a pas révélé de dépotoir de production.

Dans la partie occidentale de la fosse, un petit four FR 8081 bien conservé est accolé à la paroi ouest de l'alandier (fig. 5 et 6). De plan quadrangulaire (2,30 m × 70 cm hors œuvre), il est conservé sur 65 cm de hauteur. Ses parois sont construites en briques d'adobe cuites lors du fonctionnement du four. Elles conservent les traces de deux états, avec un premier four large de 70 cm, puis un second de 50 cm de large. La stratigraphie témoigne de ces deux états, avec deux niveaux de couches cendreuses (US 8118 et 8143) séparés par un comblement argileux. Le mobilier associé est composé de bouchons d'amphore et de pesons de pêche.

La datation des fours FR ξ-8000 et FR 8081

Le four FR ξ-8000, daté par radiocarbone (Poz-100663 : 1735 +/- 30 BP), archéomagnétisme et typochronologie du mobilier retrouvé dans les niveaux de fonctionnement, s'est arrêté de fonctionner autour de la fin du IIIe s. Cette datation est cohérente avec la chronologie admise pour les dernières productions de l'atelier (dites amphores tardives). Quant au four FR 8081, les deux datations 14C fournissent des intervalles calibrés compris entre la fin du Ier s. ap. J.-C. et le premier quart du IV^{e} s. (Poz-100664 : 1835 +/- 30BP ; Poz-100788 : 1875 +/- 30 BP). Il est donc possible que les deux fours aient cessé de fonctionner en même temps.

L'étude anthracologique et dendro-anthracologique
Matériel étudié et présentation des résultats

Plusieurs niveaux charbonneux et cendreux ont été mis au jour dans les fours FR ξ-8000 et FR 8081. Dans le four FR ξ-8000, deux types de prélèvements ont été effectués dans l'US 8085 : un prélèvement des buches carbonisées restées en place, accompagné d'un échantillonnage en masse des couches charbonneuses. Dans le four FR 8081, aucune buche n'étant conservée, seul un prélèvement en masse a été effectué sur deux niveaux charbonneux (US 8118 et 8143). Au total, 125 litres de sédiments et 8 bûches ont été prélevés. Les prélèvements en masse ont été tamisés sous eau sur une colonne de tamis (maille : 4, 2 et 0,5 mm). L'étude des charbons de bois (détermination taxinomique et analyse des paramètres morphologiques et taphonomiques) a été effectuée à l'ISEM UMR 5554 de Montpellier. L'étude a porté sur 270 charbons de bois, permettant d'identifier sept taxons différents (Tab. 1). L'analyse dendro-chronologique repose sur l'application d'une méthode de traitement des charbons de bois qui vise à les consolider pour créer les conditions optimales à l'observation de la succession des cernes de croissance.[14] Il est possible de développer trois niveaux d'analyse et d'interprétation : interdatation des bûches (ont-elles été coupées la même année ?) ; datation dendrochronologique de l'abattage ; lecture anthropo-écologique de ces courbes (techniques de coupe, rythmes d'exploitation des boisements). Le résultat de l'étude dendro-anthracologique de deux des bûches (P1 et P3) de l'US 8085 est présenté sur une figure synthétique (fig. 7).

Une gestion raisonnée de l'exploitation du bois ?

L'étude anthracologique montre une très nette différence entre le combustible du four FR ξ-8000, uniquement alimenté avec du Chêne caducifolié, et le petit four FR 8081, dont le spectre anthracologique est plus diversifié. Des rejets cendreux du Ier s. étudiés dans l'officine[15] ayant livré uniquement du Chêne caducifolié, tout porte à croire que le Chêne caducifolié est privilégié pour les grands fours, le petit four étant alimenté par un combustible plus diversifié. Les anthracologues ont montré que la composition du spectre est éminemment liée à un état de la végétation environnante.[16] Le choix du Chêne ne s'explique donc pas par une éventuelle propriété combustible, d'autant que son pouvoir calorifique n'est pas forcément plus important que celui des autres bois lorsqu'on le compare à d'autres types de combustible.[17]

L'approche dendro-anthracologique peut renseigner les modalités de gestion des boisements. En Gaule narbonnaise à Saint-Pargoire, elle a permis d'identifier une

		Structure	FR ξ-8000	FR 8081		TOTAL
		Unité stratigraphique	8085	8113	8148	
		Prélèvement		T2		
		Volume (L.)	45	20	15	
		Nature	Fireplace of kiln	Fireplace of kiln	Fireplace of kiln	
		Chronologie	[245; 405] AD	[80; 325] AD		Occ.
Déterminations taxinomiques	*Fraxinus*	Frêne		10		**10**
	Ostrya carpinifolia	Charme-Houblon		20	20	**40**
	Quercus f. c.	Chêne caducifolié	98	31	19	**148**
	Rosaceae maloïdeae	Rosacées maloïdées		1		**1**
	Rosaceae prunoïdeae	Rosacées prunoïdées		5		**5**
	Tilia	Tilleul		3		**3**
	Ulmus	Orme		49	8	**57**
		Ecorce	1			**1**
		Nœud	1	1	2	**4**
		Indéterminable			1	**1**
		TOTAL	**100**	**120**	**50**	**270**
Autres observations		Fentes de retrait	78	53	37	**168**
		Vitrification, stade 1	5	17	1	**23**
		Vitrification, stade 2	49	51	45	**145**
		Vitrification, stade 3	34	25	0	**59**
		Vitrification, stade 4	12	27	4	**43**
		Vitrification, stade 5	0	0	0	**0**
		Zones colorées	7	2	0	**9**
		Nœud	3	3	2	**8**
		Moelle	1	0	0	**1**
		Ecorce	1	0	0	**1**
		Bois de compression/tension	0	0	0	**0**
		Thylles	60	14	1	**75**
		Diamètres mesurables	1	0	0	**1**
		Cernes très courbés	10	1	0	**11**
		Cernes peu courbés	14	8	0	**22**
		Cernes rectilignes	5	10	0	**15**
		Saison d'abattage	1	0	0	**1**
		Champignons	0	0	0	**0**
		Traces d'insectes	0	1	0	**1**

Tab. 1: Résultat de l'étude anthracologique, en valeurs absolues.

gestion en taillis avec une rotation régulière des coupes.[18] Qu'en est-il à Loron ? L'allure des courbes montre que les boisements exploités n'ont pas été gérés en taillis. Un autre mode de gestion est à envisager (émondage, étêtage…) mais son identification nécessite de disposer de courbes de comparaison. L'analyse dendro-anthracologique a montré que les bûches, dont le diamètre est compris entre 3 et 8 cm, ont été coupées entre 7 et 19 ans, et que ces coupes se sont échelonnées sur quatre années, notamment entre les bûches P1 et P3. Les bûches provenant toutes d'un même foyer (US 8085), témoin d'un évènement unique, alors que leur coupe s'échelonne sur quatre ans, un stockage du bois pendant plusieurs années est donc à envisager.

Composition des boisements exploités

L'étude anthracologique montre des variations de la diversité et des proportions entre espèces, en partie imputables au faible effectif étudié pour l'US 8148. Toutefois, le spectre anthracologique du four FR 8081 donne l'image d'une végétation dominée par des taxons caducifoliés, du type *Ostryo-Quercetum pubescentis* qui, actuellement, s'étend sur une grande partie du karst istrien.[19] Dans le four FR 8081, la forte proportion d'Orme mérite un développement. Actuellement, la *Flora Croatica Database* recense six espèces d'Orme en Croatie, parmi lesquels seul l'Orme champêtre (*Ulmus minor* Mill.) est recensé sur les côtes du nord de l'Istrie.[20] L'Orme champêtre, taxon héliophile et pionnier,[21] peut être considéré comme un indicateur d'ouverture du milieu. Ayant une bonne capacité à rejeter de souche,[22] l'Orme peut prendre une place importante dans un boisement régulièrement coupé. Toutefois, l'Orme ne dominait probablement pas, puisque le Chêne est très présent, notamment dans le four FR ξ-8000 et dans les rejets cendreux de l'officine.[23] En coupant régulièrement le Chêne caducifolié pour alimenter les grands fours, les potiers permettent à la lumière de pénétrer dans les boisements exploités, favorisant le développement de l'Orme qui ne devient toutefois pas majoritaire. Ailleurs dans l'empire, notamment en Gaule narbonnaise, l'exploitation sur le long terme de taillis de Chêne caducifolié[24] aboutit à un changement de la composition des boisements, qui est souvent plus radical.

Conclusion

La fouille complète d'un four à amphore de l'atelier de Loron, combinée avec l'étude anthracologique et plusieurs méthodes de datation, renouvelle les connaissances sur le fonctionnement de l'atelier. Il est désormais démontré que ce grand four fonctionne jusqu'à la fin du IIIe s.-début du IV^e^ s., avec une production qui doit correspondre au type « tardif » des amphores Dressel 6B de Loron, bien qu'aucun dépotoir n'ait encore été mis à jour à proximité du grand four. Cette datation vient également confirmer la longue durée de fonctionnement de l'atelier, jusqu'ici induite par la stratigraphie des niveaux d'abandon.[25]

L'étude des charbons de bois révèle une gestion raisonnée et originale du combustible, fondée sur l'utilisation exclusive du Chêne caducifolié pour le four à amphores, et d'un combustible plus diversifié pour le petit four, sans utilisation de taillis. Le maintien d'une quantité suffisante de bois après plus de trois siècles de production intensive de l'atelier, indique une stratégie de gestion de la forêt à l'échelle de la propriété. Ce constat ouvre une réflexion nouvelle, dans un champ encore peu traité par la bibliographie, sur la gestion des ressources en combustible, l'espace qui leur est dédié au sein de la propriété, et la capacité des différents propriétaires à maintenir ces ressources dans la longue durée de fonctionnement de l'atelier.

Notes

[1] La fouille 2001–2011 de l'atelier de Loron a été conduite dans le cadre d'une convention associant le musée territorial du Parentin Zavičajni muzej Poreštine (V. Kovačić), l'Institut Ausonius – université de Bordeaux Montaigne (F. Tassaux), l'université de Padoue (G. Rosada, A. Marchiori) et à partir de 2007, l'Ecole française de Rome (C. Rousse). Depuis 2012, un nouveau programme franco-croate entre le musée (D. Munda, G. Benčić) et le centre Camille Jullian – Aix Marseille université (C. Rousse), ainsi que l'Ecole française de Rome, développe des recherches sur la villa de Santa Marina, qui appartient à la même propriété, et sur l'environnement du littoral. Les études archéobotaniques et la fouille du four à amphores FR 8000 se rattachent à ce programme (2017–2020).

[2] L'atelier de Loron est un des grands ateliers connus du nord de l'Adriatique avec plus de 1800 timbres recensés sur les amphores Dressel 6B. Une production secondaire d'amphores vinaires, de céramique sigillée et commune, et de matériaux de construction est également attestée.

[3] Tassaux et al. 2001.

[4] L'activité de l'atelier jusqu'au IVe s. est suggérée par la stratigraphie, la typologie des productions locales (dites « amphores tardives » de Loron : Marion – Starac 2001 ; Maggi, Marion 2011, complétées par une production tardive de céramique commune : Mondin 2017) et la chronologie des contextes de diffusion dans le nord de l'Adriatique (Maggi – Marion 2011 ; Degrassi – Maggi 2011 ; Auriemma et al. 2012; Gaddi – Maggi 2017, 286–308). Elle est désormais confirmée par les datations par le radiocarbonne effectuée sur le four FR 8000.

[5] Tassaux et al. 2001, 57–85.

[6] Chabal 2001; Chabal et al. 2012 ; Vaschalde – Chabal accepté; Bigot – Vaschalde 2017–2018.

[7] Bourgeon et al. 2018.

[8] Sous la direction de V. Kovačić, G. Rosada, A. Marchiori et C. D'Incà: Kovačić et al. 2011; Marchiori – D'Incà 2014.

[9] Cuomo di Caprio 1972.

[10] Kovačić et al. 2011; Marchiori – D'Incà 2014.

[11] Mondin 2017.

[12] Rousse et al. 2018.

[13] Cuomo di Caprio 1972.

[14] Brossier – Poirier 2018.

[15] Vaschalde et al. accepté.

[16] Chabal 2001, 98.
[17] Chabal et al. 2017, 88.
[18] Vaschalde – Chabal accepté.
[19] Quézel – Médail 2003, 171 ; Fouache 2006.
[20] <http://hirc.botanic.hr> (26.08.2020).
[21] Rameau et al. 2008, 999.
[22] Quézel – Médail 2003, 314.
[23] Vaschalde et al. accepté.
[24] Chabal 2001; Vaschalde – Chabal accepté ; Bigot – Vaschalde 2017–1018.
[25] Rousse et al. 2018.

Crédits photographiques

Fig. 1: P. Ružić. – Fig. 2: CAO V. Dumas, C. Taffetani, AMU-CNRS, CCJ; Ch. Vaschalde. – Fig. 3: Ch. Vaschalde. – Fig. 4: ortho photographie: V. Dumas, AMU-CNRS, CCJ; CAO: Ch. Vaschalde. – Fig. 5: DAO: Ch. Vaschalde. – Fig. 6: cliché: Ch. Vaschalde. – Fig. 7: les auteurs. – Tab. 1: les auteurs.

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Stone Supply for Carnuntum and Vindobona – Provenance Analysis in a Historico-Economical Context

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This paper presents selected results of the interdisciplinary Austrian Science Fund project "Stone Monuments and Stone Quarrying in the Carnuntum – Vindobona Area".[1] Conducted from 2014 to 2018 at the Institute for the Study of Ancient Culture (Austrian Academy of Sciences) in cooperation with the Vienna University of Technology, the Geological Survey of Austria, the Wien Museum, the Department of Urban Archaeology and the University of Vienna, the project was focused on the stone monuments from Carnuntum and Vindobona, two important military centres on the Pannonian Limes, and their respective hinterland (fig. 1).[2]

The project idea is based on the recent inventory of stone monuments realised within the framework of Corpus signorum imperii Romani[3] as well as on a former project centred on settlement development and stone quarrying in Vindobona.[4]

Apart from a detailed archaeological recording of the objects in their historical context, the project's main aims are a petrographic characterization of the locally and regionally quarried stone material used in antiquity,[5] consequently a detailed provenance analysis of the stone monuments and a discussion of mainly logistical, chronological and economical questions related to these results.

This approach is based on detailed geological methods:[6] The Roman period stone objects originating from the project area were petrographically analysed mainly by macroscopic investigation, but also by comparative thin-section studies. In certain cases, X-ray fluorescence spectrometry was used for investigating the chemical composition of fine-grained rocks. This enabled the development of a hierarchical classification of relevant lithotypes as a basis for the provenance analysis of the monuments. At the same time, following the evaluation of historical documents and maps, high-resolution airborne laser scanning (ALS) topographic data and geological databases and maps, presumable ancient quarry sources were investigated through surveys, during which important outcrops were logged and samples were taken.

Thus, as a major result, a number of quarry areas and higher ranked quarry regions, which are relevant for the region and period under investigation could be identified (fig. 2). These quarry areas are defined by hosting one or more of the lithotypes found among the monuments, provided the bedding thickness suited the production of sculptures and architectural elements.

Due to the geological and geographical investigation the quarry areas were grouped into seven quarry regions, located in the Leitha Mountains (regions I/II), the Rust Hills (region III), the Hainburg Mountains (region IV) and along the western rim of the Southern Vienna Basin (regions V–VII). These results form the basis for the evaluation related to

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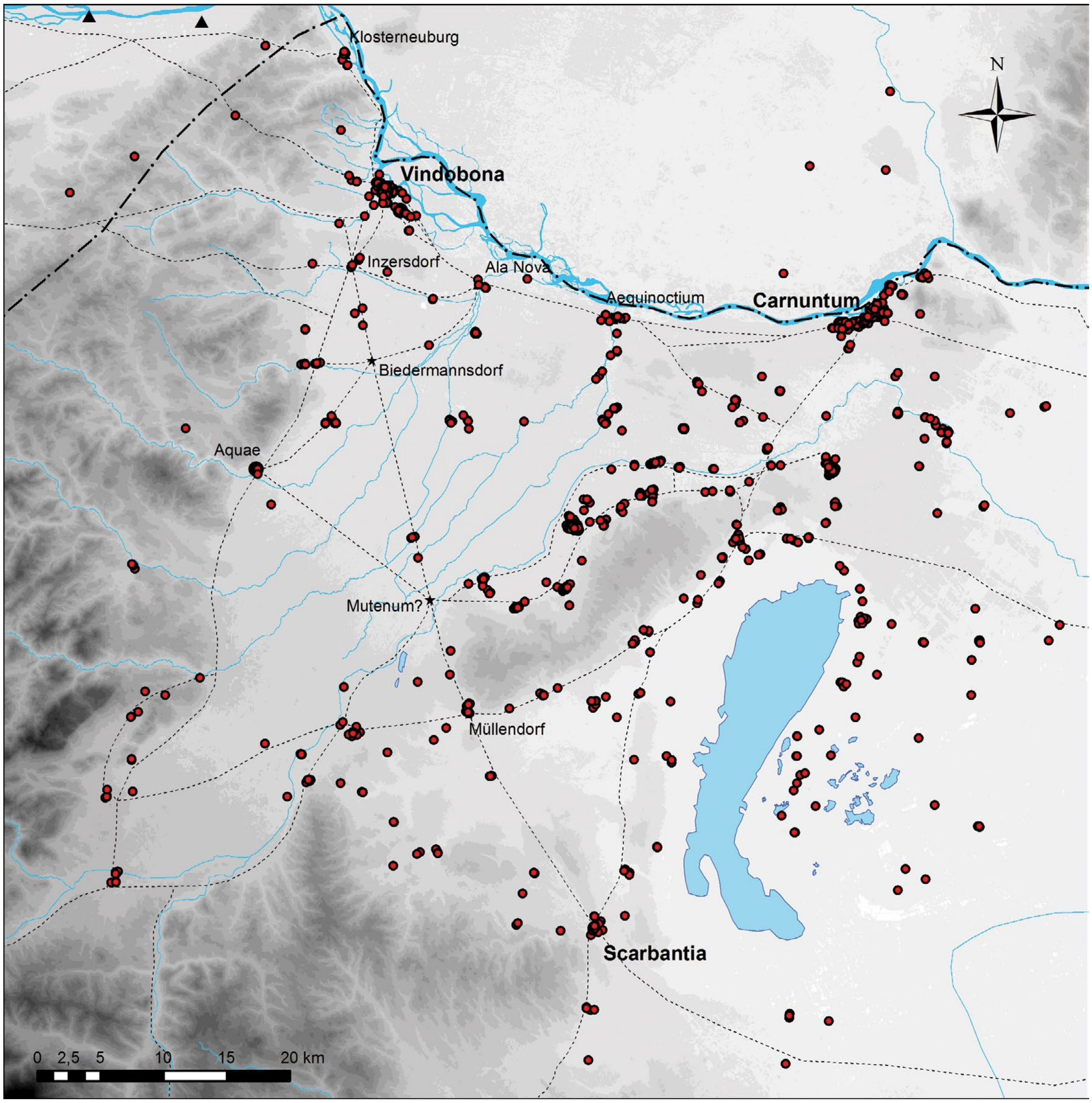

Fig. 1: Find-spots of stone monuments in the Carnuntum – Vindobona area.

the raw material resources, the qualification of certain lithotypes for the different end uses as e.g. sculpture production and the issues of provenance and transport.

The local and regional importance and the range of size of the quarries vary: Lithological investigation of more than 900 stone objects from the entire project area has shown that, while the quarries of the regions IV, V and VI are of mainly local importance for either Carnuntum (IV) or Vindobona (V, VI), the different lithotypes of Leitha Limestone[7], quarried in the Leitha Mountains (regions I/II) were used as material for monuments both in Carnuntum and Vindobona as well as in their respective hinterlands. Because

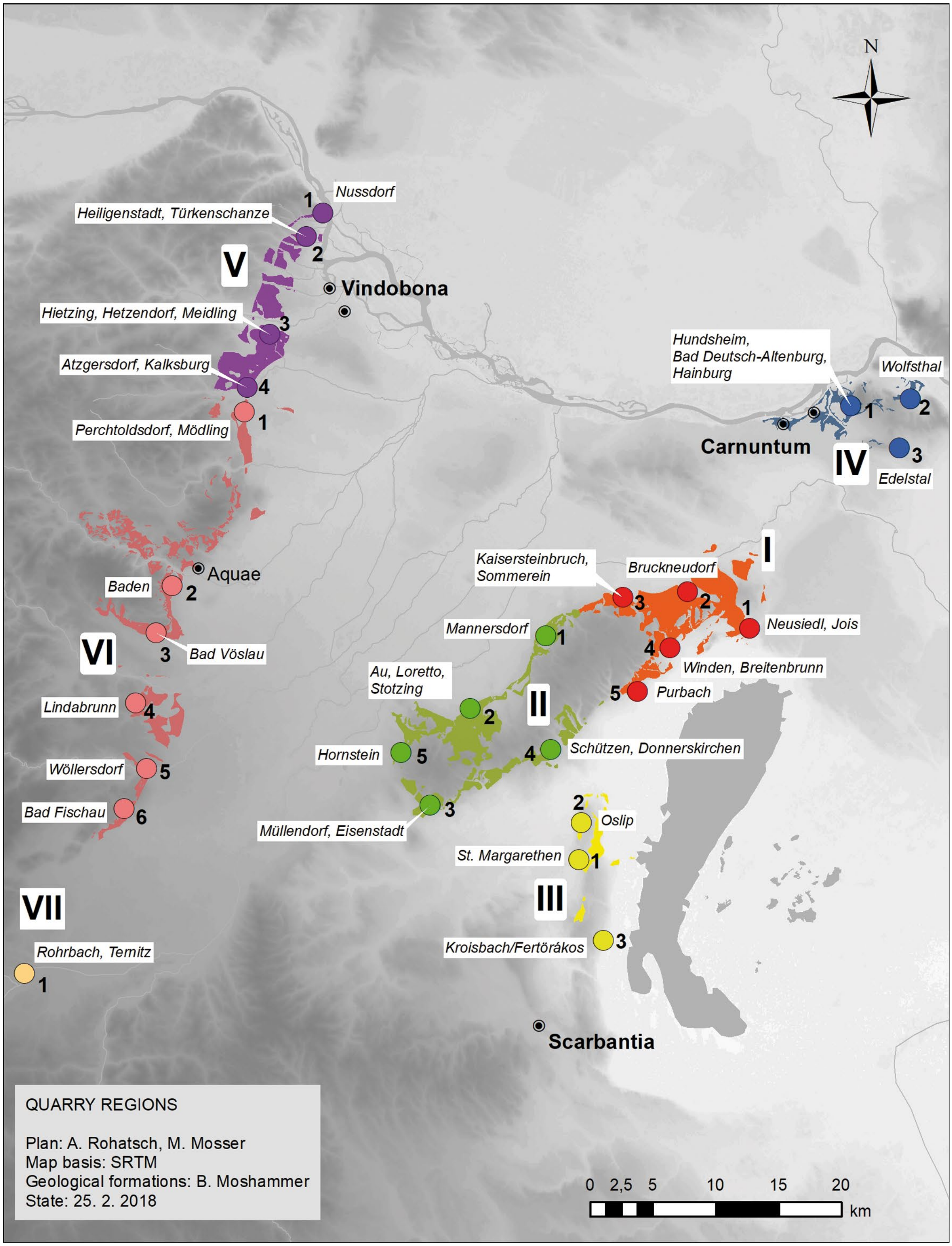

Fig. 2: Quarry regions (Latin numbers) and quarry areas (Arabic numbers).

Fig. 3: Presumptive ancient quarry near the reconstructed mithraeum in Fertőrákos.

of this, when analysing the distribution pattern of Leitha Limestone lithotypes, not only the questions of lithological properties, suitability and transport logistics, but also aspects such as workshop organisation, trade mechanisms and chronology have to be taken into consideration.

Furthermore, the situation in the two project areas differs in an important point: On the one hand, the relevant Badenian[8] and younger sedimentary rock resources used in Vindobona occur on the margin of the Vienna Basin near Vindobona and further south. They provide locally distinctive deposits of Leitha Limestones (recognizable by their clasts from the Flysch and Northern Calcareous Alps), breccias and conglomerates passing into this hinterland, siliciclastic coquinas and furthermore important resources of quartz rich sandstones. On the other hand, the stone artefacts made of Leitha Limestone used predominantly in Carnuntum, but in Vindobona too, have been quarried from around the name giving Leitha Mountains. Very important and large resources for this kind of freestone are found there and in the Rust Hills. In general, Leitha Limestones represent strata composed mainly of particles of calcified red algae (Corallinaceae) and other shallow marine biota, which were deposited on flat marine shelves in the Central Paratethys Sea, especially in the Badenian but were resedimented in younger times up to the Pannonian age/stage. Because of the partly very similar limestone successions in different parts around this low mountain range, from which high quality stones were

Fig. 4: Potential ancient toolmarks in a former quarry at Hundsheimer Berg near Carnuntum.

extracted, the exact provenance determination is much more difficult and more often open to several alternatives.

No Roman quarry has been verified with certainty in the area under investigation, nor have any inscriptions related to quarry organisation and administration been found in this area up until now. Since the Roman period, the landscape has undergone continuous and severe changes, which have caused ancient quarry faces to disappear by subsequent exploitation or become inaccessible without the use of heavy equipment. Moreover, without the presence of additional finds such as inscriptions, unfinished blocks or archaeological features, quarry faces and tool marks are still very difficult to date.[9] A certain number of possible and probable ancient quarries have however been identified, such as the quarry remains near the mithraeum of Fertőrákos[10] (belonging to quarry region III) (fig. 3), or certain outcrops located among the baroque and modern quarries on the Hundsheim Mountains (region IV), in the near vicinity of Carnuntum (fig. 4).[11]

As a next step, the different situations in Vindobona and Carnuntum have to be examined in detail.

About 600 Roman-period stone objects found in Vindobona itself as well as in its surrounding region have been preserved in different collections. This comparatively small number of objects enables the petrographic examination and archaeological recording of various different object groups, ranging from architectural ornamentation, inscriptions or sculpture to infrastructural elements, construction material or quern stones.[12]

Results of the examination of approximately 300 of these objects demonstrate that Vindobona obtained its raw stone material from three different sources: About two thirds of all analysed monuments were made from rocks in the area of present-day Vienna (region V) and further south along the western rim of the Vienna Basin (region VI), while one third can be allocated to quarries in the Leitha Mountains (regions I/II).

The use of quarries situated along the western rim of the Vienna Basin can be attested from the earliest known point of military presence in Vindobona onwards: The funerary stele of T. Flavius Draccus (fig. 5),[13] a soldier belonging to the auxiliary unit ala I Flavia Augusta Britannica, which was stationed in Vienna during the reign of Domitian, was made from stone quarried in Perchtoldsdorf (region VI.1). About eight years later, in 98 AD, a legionary garrison was stationed in Vindobona and the construction of the legionary fortress began.[14] For certain infrastructural elements of the fortress, in particular the manhole cover stones, as well as for parts of the architecture of the legionary thermae and the fortification wall, stone from Perchtoldsdorf was used again.[15] This demonstrates a transfer of knowledge between the different branches of military units. Petrographic analysis of 23 architectural elements and building stones belonging to the enclosing wall of the legionary fortress have shown that a major part of these objects can be allocated to quarries from region V, namely Heiligenstadt/Türkenschanze (V.2) and Nußdorf (V.1).[16] This implies the use of close-by resources with short transport routes in order to ensure a continuous supply of construction material.

In contrast to this pattern of obtaining raw material from nearby quarrying areas, for other types of stone objects, like votive monuments, different tendencies can be observed. For these, stones quarried in the Leitha Mountains (regions I/II) were favoured and imported to Vindobona despite the longer transportation time.[17] This fact could be related to varieties of Leitha limestone with softer quality and finer texture being more suitable for the sculpting of reliefs and inscriptions than the local material. Since the exploitation of these quarries can be proved from the mid-1st century onwards, another possibility are pre-existing workshops in the Leitha Mountains region or the Carnuntum area whose market extended to Vindobona.

In Vindobona's hinterland, similar patterns concerning the stone deliveries can be detected.

Petrographic analyses of stone monuments found within small-scale settlement centres along the western rim of the Vienna Basin reveal that a large part of their stone material was acquired from very local individual quarries, which were more easily accessible. Simultaneously, the practice of importing stones for special monuments, like altars, from extraction areas situated further away in the Leitha Mountains can also be assured here.

Fig. 5: Funerary stele of Titus Flavius Draccus, 91–96 AD (Wien Museum, Inv. MV 670; CIL III 15197).

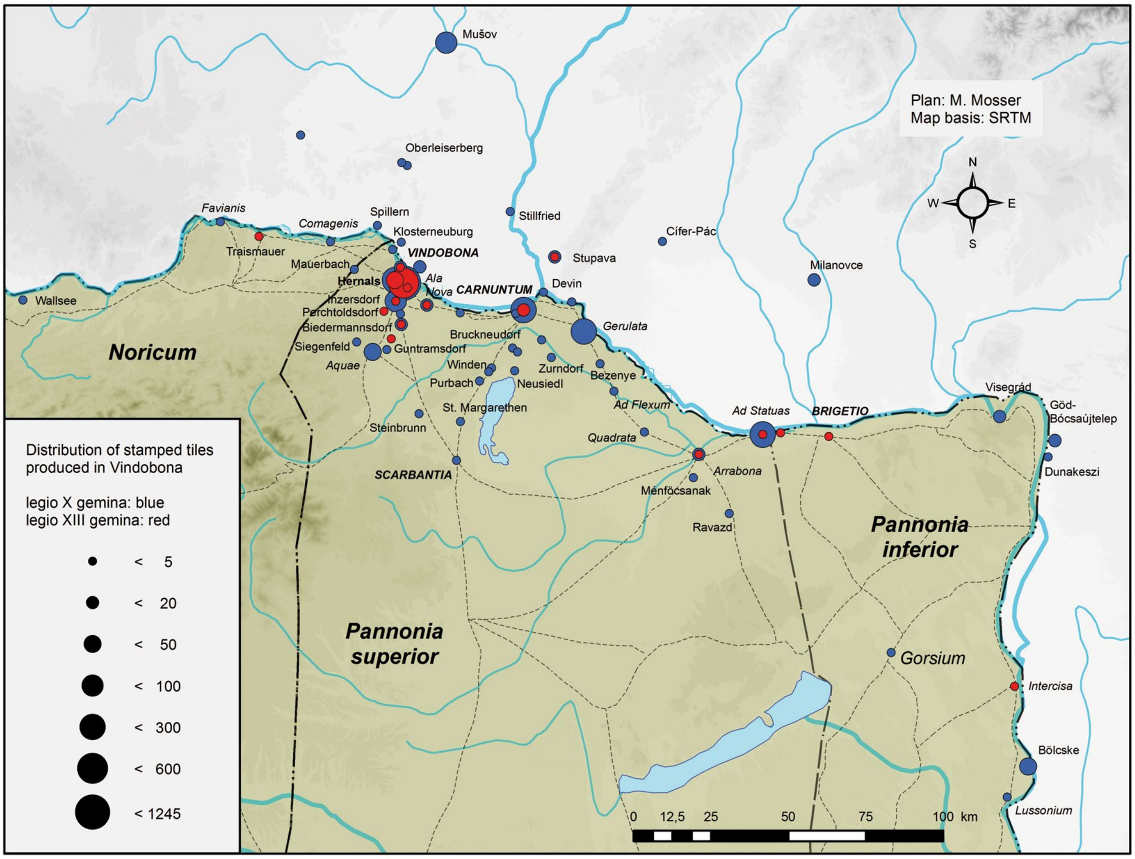

Fig. 6: Distribution of stamped military tiles produced in Vindobona.

In order to better approach questions related to the localisation of the ancient quarries and problems of transportation, a cross-linking of geological, archaeological and historical data is crucial. Since there is a strong possibility that the quarries, which were important for Carnuntum and Vindobona were opened and exploited by the military units stationed there, the localisation of finds related to the military is of relevance to the project. The most important object group connected with military activities are stamped tiles manufactured by the Roman legions.[18] Distribution maps of these objects show the existence of clusters of stamped tiles along the western rim of the Vienna Basin, which suggests a strong military presence in the same areas used as sources of raw stone material for Vindobona (fig. 6). Roads as transportation routes were vital for the delivery of this material; this is also evidenced by the existence of the two nearby Roman road stations Inzersdorf and Biedermannsdorf.[19] Within the framework of the project, least-cost path analyses were conducted[20] with the objective of reconstructing possible routes between the potential quarries and the settlement centres Carnuntum and Vindobona, thereby constituting a valuable contribution to the goals of the project.

In the project area of Carnuntum, research is facing a slightly different situation, as evidence from early large-scale building activities is hardly available today. Petrographic analysis had to concentrate on a careful selection of the far more than 2000 carved stone artefacts from Carnuntum made of Badenian and Sarmatian calcareous sandstone and limestone as well as on a selection of the objects found in the surrounding area. About 600 representative monuments have been analysed, such as for example building and votive inscriptions indicating the names of the consuls or providing other epigraphical clues for exact dating, military funerary stelae or sculptures and architectural elements out of specific archaeological contexts.

The results of the petrological analysis show that rocks from the Leitha Mountains (regions I and II) account for about two thirds of the limestone monuments in Carnuntum, one third being provided by the local quarries (region IV). According to the results obtained in Vindobona, this ratio would probably shift significantly in favour of local quarries if building material could be analysed extensively. The Leitha Limestones and conglomerates of the Badenian at the northern slope of the Hainburg Mountains in the immediate vicinity of Carnuntum – today's Bad Deutsch-Altenburg – have been nearly completely removed by mining activities or overbuilt from the Roman period onwards. At least since the Severan period (193–235 AD) the use of lithotypes from the Leitha Mountains is attested in considerable quantities for building stones and non-decorated architectural elements as well, for example in the auxiliary fort (stone period II)[21] and in the city wall of the civil town.[22]

It has been established that local stones from region IV were used for all kinds of carved monuments as well as for building activity in Carnuntum. Also the quarries in the Leitha Mountains provided material for both private funerary stelae and official sacral monuments and for architectural elements as well. This lithological inventory was primarily used for monuments in the hinterland of Carnuntum, too. Stone material from region III (Rust Hills) appears to have sparse presence in the investigated area and supplied mainly Scarbantia-Sopron and surrounding areas.

A precious evidence for the chronological evaluation of stone monuments and stone provenance in Carnuntum and surroundings is related to the consecutive presence and deployment of military troops (fig. 7). The Legio XV Apollinaris arrived at Carnuntum under Tiberius and built the first permanent fortress under Claudius before it was moved to the east in 63 AD, taking part in the first Jewish-Roman war (66–71). The early fortress was built of timber and earthworks, and only in the early 2nd century, it was replaced by stone buildings.[23] But the members of the 15th Legion already erected funerary slabs during the first period of their stationing and these are the earliest securely dated stone monuments of Carnuntum.[24] It seems evident that larger scale limestone-quarries started to be exploited when the 15th legion arrived, although we do not have any inscription or document related to a military quarry activity comparable to the votive inscriptions for Hercules Saxanus found in the limestone-quarries of Norroy-lès-Pont-à-Mousson in Gallia Belgica,[25] or in the tuff-quarries of Brohltal in Germania inferior.[26]

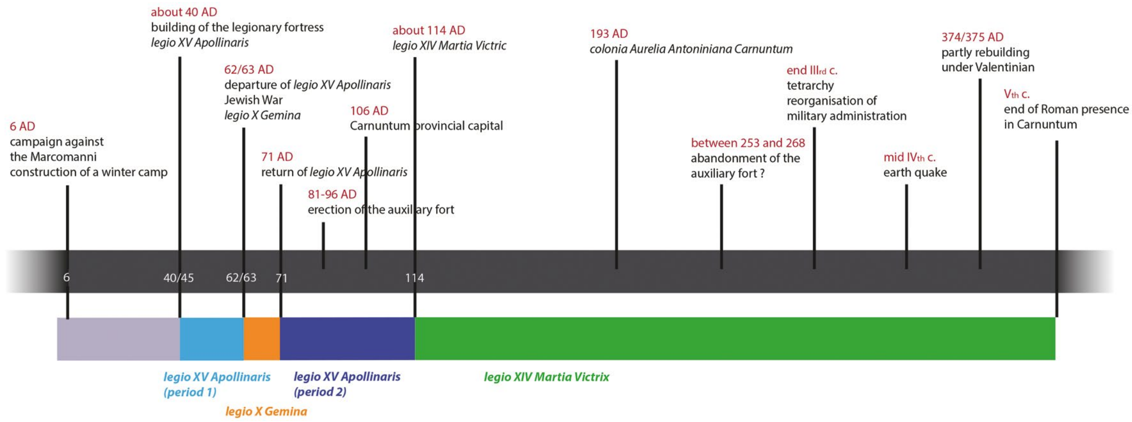

Fig. 7: Timeline of Roman military presence in Carnuntum.

The petrographic analysis of about 40 military stelae from this early period (40–63 AD; fig. 8) shows the following provenance pattern: Stone supply came mainly (60 %) from the region IV, namely the Leitha Limestone from the immediate vicinity of Carnuntum and furthermore from oolite quarries at Wolfsthal, located about 10 km east of Carnuntum. A considerable number of slabs (30 %) from this period were however made of Leitha Limestone from the Leitha Mountains, which means that these outcrops were already known and exploited before the large-scale military building activities started in Carnuntum.

Comparing the military stelae from Carnuntum according to the provenance of material shows that products made of stone material from one quarry region do not necessarily show the same stylistic characteristics. Very similar products have instead been carved in material of different provenance. One possible interpretation of this fact is that one (or several) workshop(s) located in Carnuntum used stones from different outcrops and also from different quarry regions. The work steps carried out in or near the quarries does not seem to have had a decisive impact on the shape and ornaments of the stelae in these cases. Typology and iconography of these early stelae is closely related to northern Italian products,[27] and we may assume that the sculptors working in these workshops were of Italian origin, as were the legionaries themselves in this period.

The following chronological marker is given by the short stay of the Legio X Gemina in Carnuntum, which replaced the 15th legion detached to the military campaigns in the eastern part of the Empire (63–71 AD). The six stelae of this period which have been analysed are stylistically very homogenous and have been made of stone material of the Leitha Mountains exclusively.

Nevertheless, also here different lithotypes have been established, probably originating from the regions I and II.

The next chronological group again contains monuments erected by members of the 15th legion, which came back to Carnuntum after the Jewish war in 71 AD and stayed

Fig. 8: Left: Funerary slab of Marcus Herennius, 40–57 AD (AMC Inv. CAR-S-900; AE 1992, 1403) made of corallinacean calcarenite (region I.2); right: funerary slab of Caius Vibius Secundus, 40–63 AD (KHM Inv. III 63; CIL III 4488) made of oolite (region IV.2).

until 114 AD. The analysed 54 objects of this period show a clear predominance of material from the northeastern Leitha Mountains, but material from the nearby quarries of the region IV was still used. Material from the local quarries around Carnuntum has been used until the very end of freestone carving in Carnuntum, as is shown by a series of votive monuments and building inscriptions of the 2nd half of the 3rd century.

Some conclusions concerning the main questions related to producer-resource dynamics of stone supply in our regions may be drawn:

Short distance transport seems to be the main factor for the choice of building material in the Vindobona area, and probably also (but less well documented) in the Carnuntum area.

Stone quality – and possibly related to it workshop organisation – may have been the crucial factor for the choice of material with fine carving products.

Workshops with military background from Carnuntum were using from the beginning material from different quarry regions and outcrops at the same time.

The quarries established in the earliest period of military presence in the Carnuntum area continue to deliver until the 3rd or even 4th century, but the relation moves away from local towards regional sources from the 2nd century on.

Further evaluation will show if stylistic or typological characteristics may be related to quarries – or even to workshops – located in the Leitha region in the hinterland of Carnuntum and how the transport routes between the quarry regions and the distribution areas may have functioned.

Notes

[1] FWF P 26368-G21 (project leader Gabrielle Kremer).

[2] Kremer 2016; Kremer – Kitz 2016; Kronberger et al. 2016; Rohatsch et al. 2016; Kitz – Insulander 2018; Rohatsch et al. 2018; Kremer et al. 2018; Insulander et al. 2018.

[3] Kremer 2012. – For the further inventory see Neumann 1967; Krüger 1967; Krüger 1970; Krüger 1972; <www.lupa.at> (5.11.2020).

[4] Kronberger et al. 2010.

[5] For the examination of imported marbles used in Carnuntum, see Kremer et al. 2009; Ch. Uhlir – M. Unterwurzacher, in: Kremer 2012, 421–430.

[6] Cf. Rohatsch et al. 2016, 177–184.

[7] See Rohatsch 2005; Rohatsch 2012; Bednarik et al. 2014.

[8] In the local time scale of the Para-Tethyan, the Badenian is a stage/age of the Miocene, lasting c. from 16–13.3 Ma.

[9] See e.g. Kurapkat – Wulf-Rheidt 2017.

[10] For the *mithraeum* see Gabrieli 1993.

[11] For the recent history of quarrying in this region see Lachmayer 1999; Geng-Sesztak et al. 2000.

[12] Kronberger et al. 2016, 87.

[13] CIL III 15197; Kronberger 2005, 27–30. 49–53; Lupa 627.

[14] Kronberger – Mosser 2015, 242.

[15] Kronberger et al. 2016, 92–93.

[16] Kronberger et al. 2016, 92.

[17] Kronberger et al. 2016, 93.

[18] Gugl et al. 2005.

[19] Talaa – Herrmann 2003; Kronberger – Mosser 2013, 114–116.

[20] Performed by the company Crazy Eye, Geoinformatics and Digital Archaeology, Vienna. <https://crazyeye.at/> (5.11.2020).
[21] Kandler 1997.
[22] Maschek 2012.
[23] Gugl – Kastler 2007.
[24] Mosser 2003.
[25] Boulanger – Moulis 2018, 247–263.
[26] Schaaff 2015.
[27] Beszédes – Mosser 2002; Weber-Hiden 2014.

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Stone Resource Economy during the 1st Century BC and 1st Century AD in Aeduan and Lingon Territories

Florent Delencre – Jean-Pierre Garcia

Stone is a major element in Roman construction and its systematic use contributed to the complex process of economical and cultural changes known as romanization.

These problems allow us to discuss the appearance and the subsequent diffusion of Roman building materials in central-eastern Gaul as much as their role as cultural and identity markers.[1] Indeed, they can be considered witnesses of intercultural relationships between the Mediterranean world and Gallic tribes, before and after the Roman conquest.

It is clearly shown that the appearance of monumentalized and petrified towns, mostly during the first decades of the 1st century AD and before, is irremediably linked to changes in building design. Thus, Gallic construction methods, which are characterized by perishable resources such as wood, thatch or unbaked clay, are gradually replaced by new architectural forms with materials of Roman origins (involving stones and architectural terracotta). These materials can be recorded in multiple contexts, belonging to private houses, institutional structures and also temples.

The analysis of building stone supply appeared as relevant for several archaeological sites, dated from the 1st century BC to the 1st century AD, belonging to two territories located in central-eastern Gaul: Aeduan and Lingon *ciuitates* (fig. 1a). We aim to describe the use of stone resources in the buildings of these territories to shed light upon the plurality of supply sources, the economy and the management of construction. These aspects can be approached by the description of the natural resources, their origins, the implementation and the shaping of the materials.

Analyses applied to the corpus are based on macroscopic identifications of stone materials compared to local and regional geological data. The correlation with the outcrops, which were the most likely to have been exploited, allows us to characterize supply perimeters following a classification system into five categories.[2] They define origin scales (immediate, adjacent, local, regional and extra-regional perimeters) according to the distance between outcrops and construction sites.

Stone Materials Analysis on the Aeduan Territory

Our interest for the Aeduan territory lies in two sites, which are chief towns. They are integrated in a vast area focused on the Morvan region. This Hercynian massif, made of granitic, volcanic, metamorphic and sandstone rocks, is surrounded by calcareous and chalky plateaus. The position of the towns of Autun-*Augustodunum* and Bibracte

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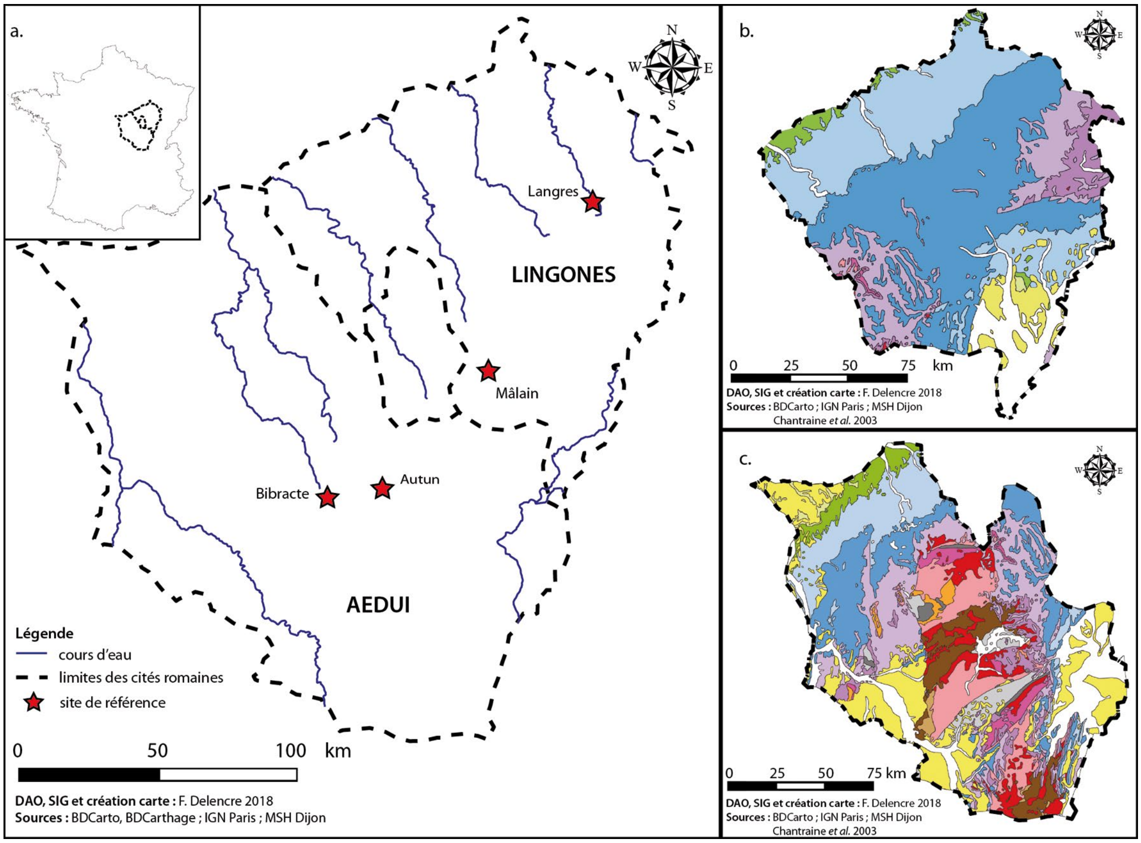

Fig. 1: Spatial and geological frameworks for the Aeduan and Lingon territories.

is central in this area (fig. 1c): they are well served by communication routes and give access to three catchment areas of importance. They correspond to argillaceous plains and valleys: "la Loire" in the south, "la Seine" in the north and "la Saône" in the east.

The *oppidum* of Bibracte

Regarding stone building materials of the *oppidum* of Bibracte, the earliness in the appearance of new construction methods is remarkable. It seems to be the result of long-term contacts established with the Mediterranean world. Indeed, this *oppidum* occupied since the end of the 2nd century BC is the chief town of the Aedui, a Gallic tribe considered by the Roman Senate as "brother of the same blood".[3] The petrographic analysis of stone materials is therefore relevant to characterize the modalities of integration for the construction techniques and the know-how.

A substantial corpus has been collected in different excavations of the *oppidum*[4] and the forensic record for the petrographic nature turns out to be preliminary to determine the stone's resources origins.[5]

The most abundant facies correspond to volcanic rocks (mostly rhyolite) and stones from sills of microgranite and microdiorite.[6] These precise facies are involved in the

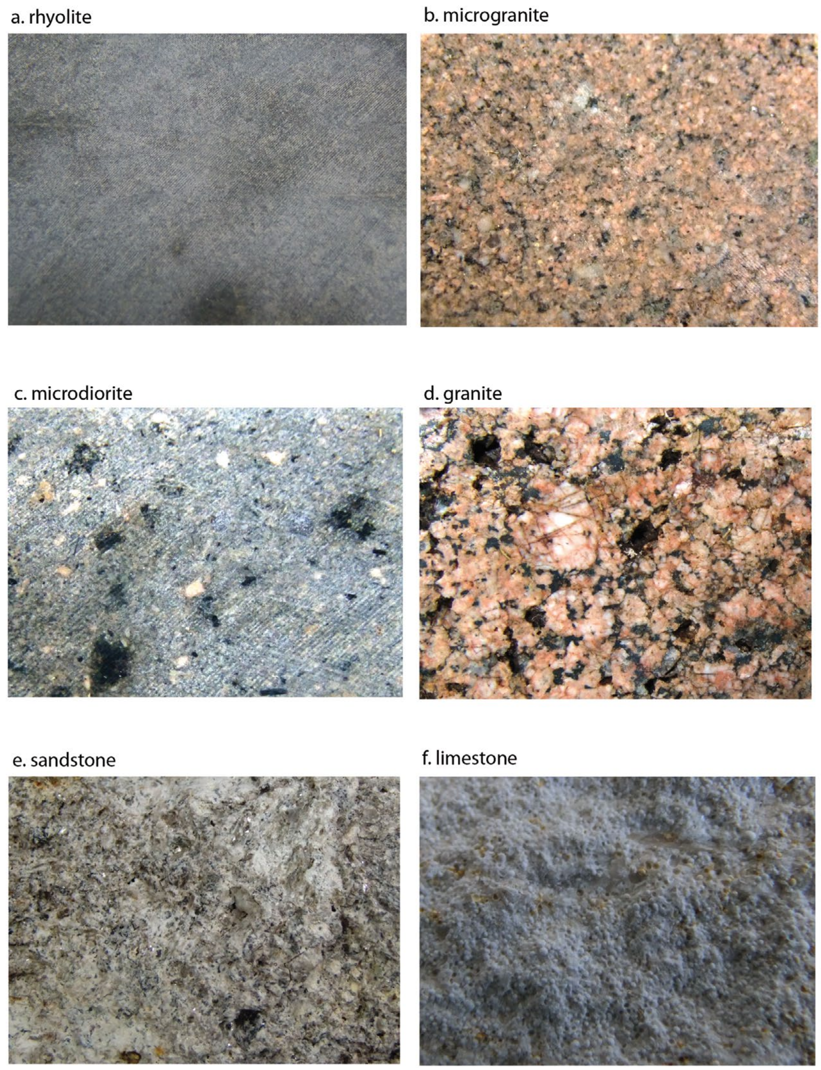

Fig. 2: Petrographical corpus for building materials used in Bibracte.

appearance of Roman building methods and by the introduction of lime mortar in the masonries of Bibracte (fig. 2 and 3). This is achieved as soon as the middle of the 1st century BC when a building so-called "with basilica floor plan" was erected. This building turns out to be the earliest example of the implementation of Roman techniques in the construction for central-eastern Gaul.[7]

A few stone resources, imported from far away areas (fig. 2 and 3), experienced a more specific use. For this reason, several facies of granite recognized in Bibracte are shaped into architectural elements of great dimensions such as stones for stairways and quoins. We can also see them mobilized in a monumental basin construction. These different facies of granites are successively exposed on about a five-kilometer distance in the east of Bibracte.

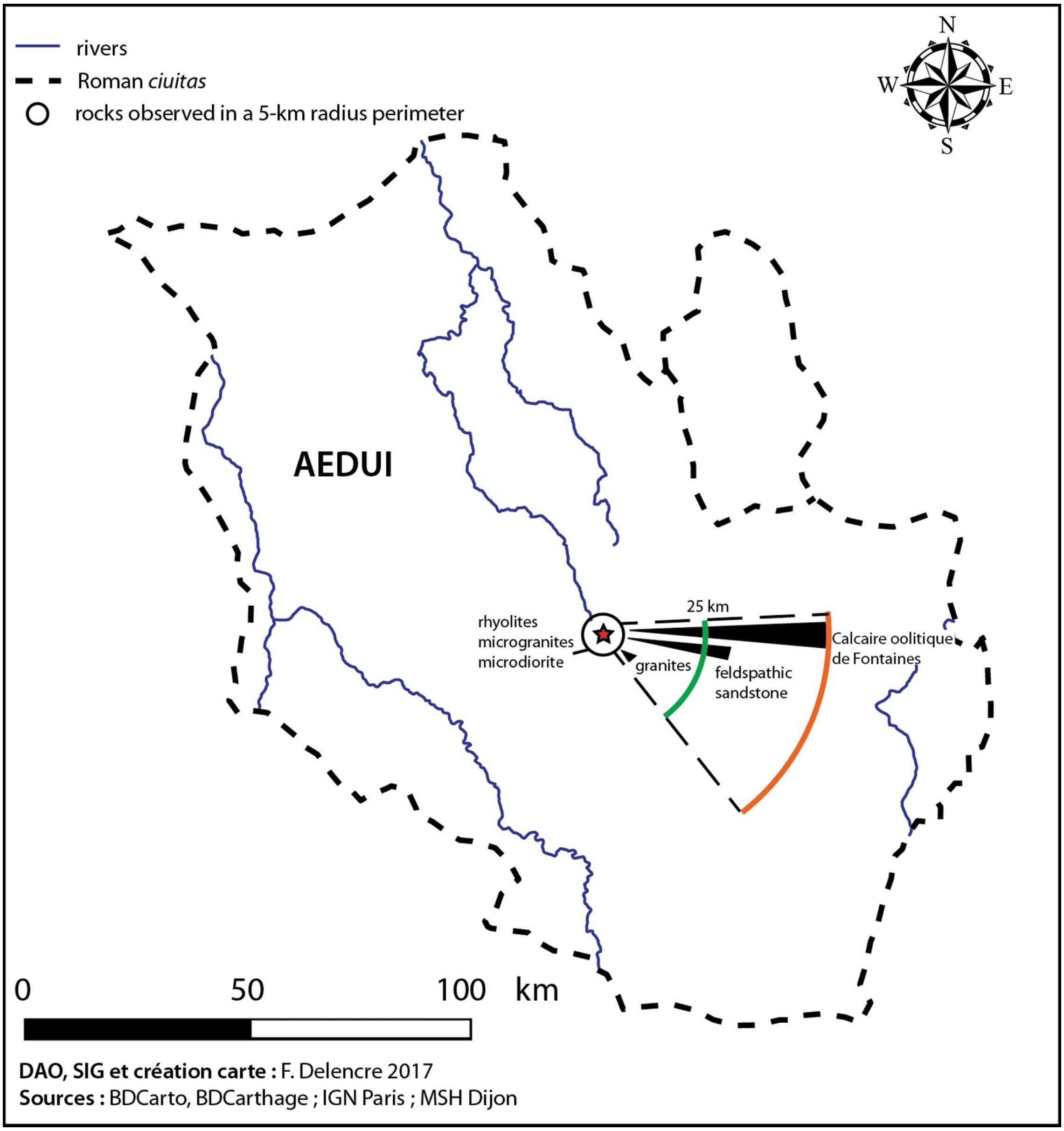

Fig. 3: Stone resources supply in Bibracte.

Resources from further beyond are used to shape the columns of the building with a basilica floor plan (fig. 2 and 3). A triassic feldspar sandstone outcropping about 30–40 kilometers from Bibracte is mainly implemented with the facies of granite for disc sections composing column shafts.

The choice of a limestone named "Calcaire oolitique de Fontaine" does not seem to be a coincidence either as it is exploited in the regions of Beaune and Chalon-sur-Saône, at a distance greater than 50 kilometers. If our first deduction is the easiness to shape those stones, other solutions can be evoked due to the distant origin and the Roman norms, which seem to rule the elaboration of columns capitals and bases. Moreover, this rock is naturally white and catches the eye by comparison with the darker colors of the local stones.

The study of these materials confirms the variability of stone supplies. Local stones mobilized within a 25-kilometers perimeter are widely used and can be observed in the masonries. Some petrographic natures, belonging to regional perimeters, are however specifically employed in construction to fulfill architectural needs.

The chief town of Autun-*Augustodunum*

As all the "*caput ciuitas*", Autun-*Augustodunum* reveals a great diversity regarding functional buildings, in which construction areas are characterized by Roman techniques and a very important stone resources supply.[8]

The Gallo-Roman town is surrounded by a 6 kilometers-long fortification[9] and one of its four main gates leaving access to the city still exists today, known as the "Porte de Saint André" (fig. 4a). It has been studied for its historical, architectural or archaeological aspects and the question of building material has obviously been considered for this typically Roman monument.[10]

The fortification wall on each side of the gate is quite well preserved and made of local granite and gneiss stones. The outcrops of these rocks are recognized at the limits of the Permian basin of Autun, in the south and west of the town (fig. 4b and 5).

The substructures supporting the gate jambs and the superior arcatures are made of feldspar sandstone. It can be seen on the plateau of Antully-Planoise,[11] about 10 and 20 km east of the town (fig. 4b and 5).

The exterior facings exhibit oolitic calcareous slabs of great dimensions, which is exactly the same stone used for the columns of Bibracte.[12] As we saw earlier, this limestone can be found near the region of Beaune and Chalon-sur-Saône, more than 30 km away from Autun (fig. 4b and 5).

The rubble stone walls forming the towers inserted on each side of the gate are made of sandstone named "Grès blond du Rhétien". It can be found in a 10 km –perimeter from Autun (fig. 4b and 5).

Stone resources engaged in the construction reveal different origins that can be retraced thanks to the characterization and the recognition of rocks. Various distance scales can be defined, even if the precise quarries have never been located. As in the example of Bibracte, local stones seem to be mobilized for the construction requiring important volumes. In the same time, distant resources are sought to fulfill specific architectural needs.

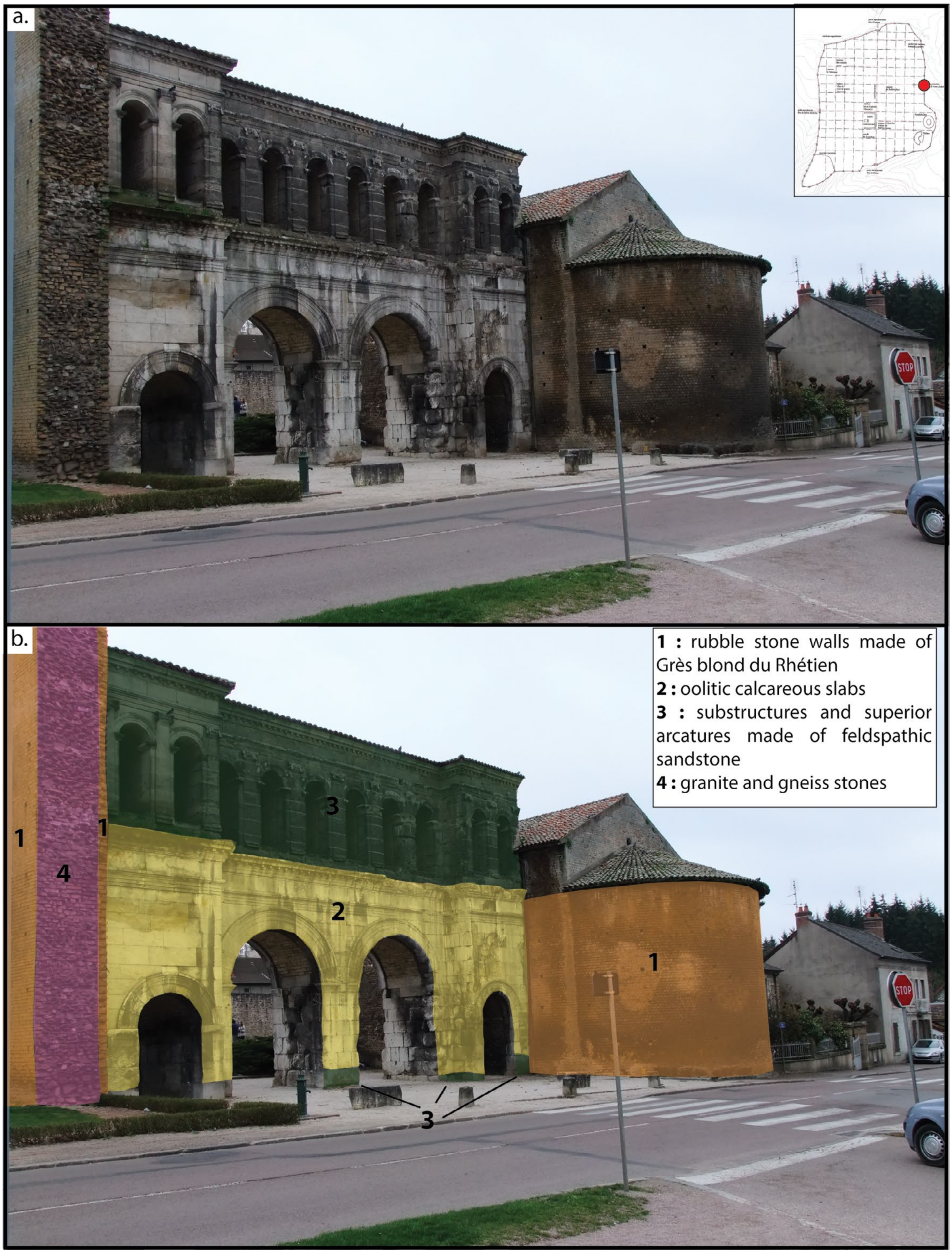

Fig. 4: Petrographical identification of building materials implemented in the “Porte de Saint-André” of Autun-*Augustodunum*.

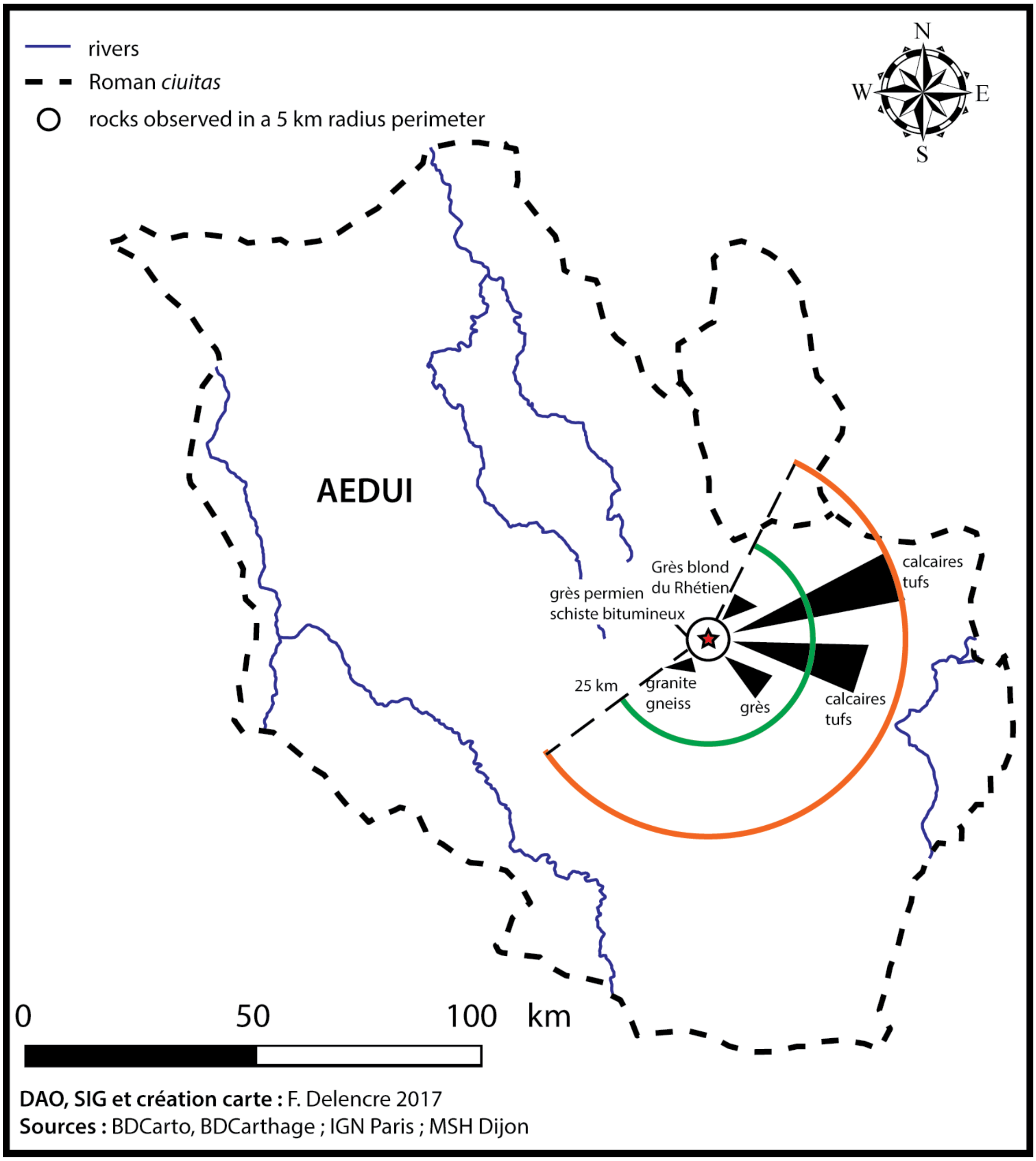

Fig. 5: Stone resources supply in Autun-*Augustodunum*.

Stone Materials Analysis on the Lingon Territory

The Lingon territory, located north from the Aedui, is spread on an area where geological resources are mostly formed by calcareous plateaus. Two argillaceous and marly regions can also be found in the west and south of the *ciuitas*. Concerning stone building materials, here we can focus on two peculiar sites: a secondary agglomeration and the *caput ciuitas* (fig. 1b).

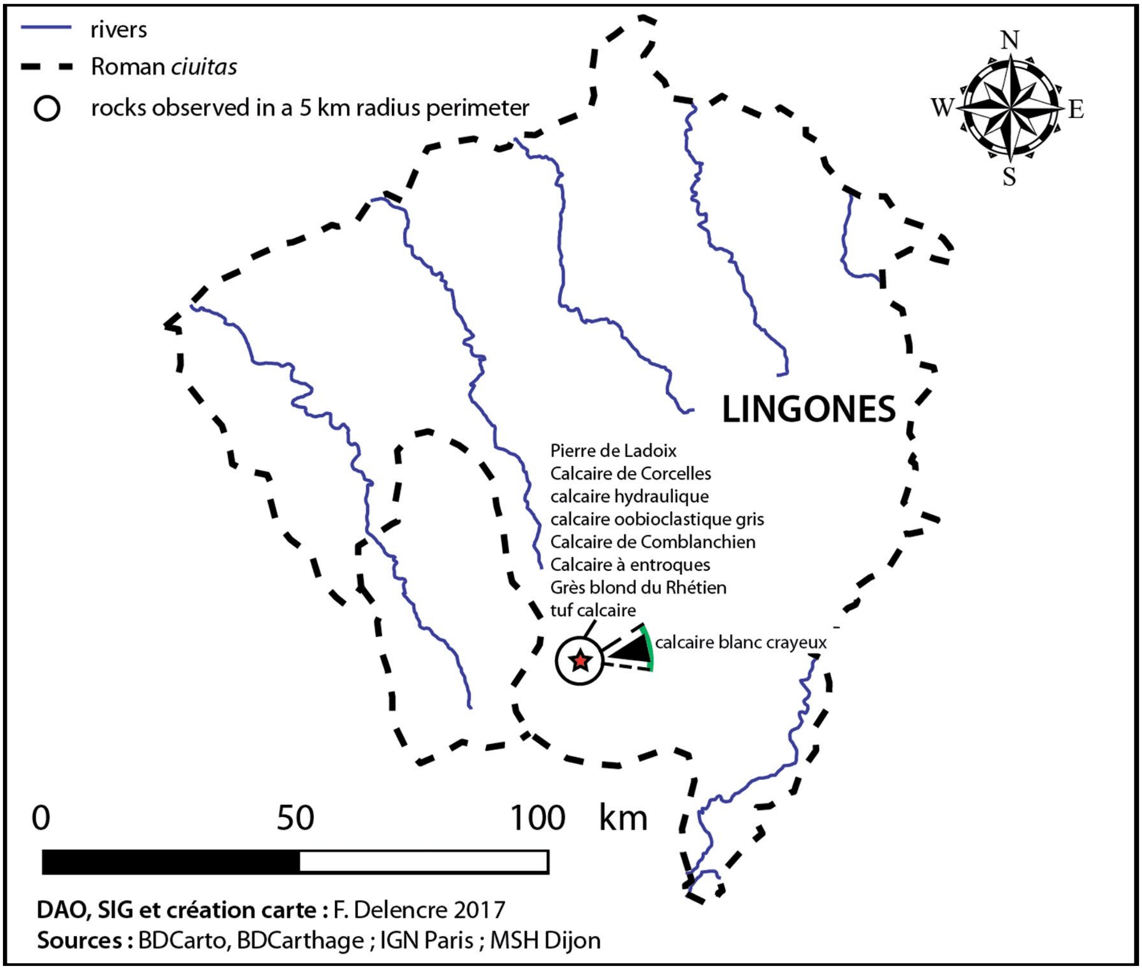

Fig. 6: Stone resources supply in Mâlain-*Mediolanum*.

Mâlain-Mediolanum

The excavations in Mâlain-Mediolanum, which took place in the locality of "La Boussière", revealed structures composing the urban center, including a portico along a rectangular square that could be interpreted as the forum.[13] The studied corpus has been gathered by the remaining masonries, stairway elements, columns and various blocks of great dimensions that add to the selected materials during the archaeological excavations.

Several petrographic facies were defined, helping in finding the precise geological formations they were extracted from. All the stones that can be found used in a construction context are described as various calcareous rocks. Furthermore, the recognition of building stones sheds a light on the fact that the exploited resources all belong to the local perimeter, meaning in a 25 km radius around the site (fig. 6). Regarding the masonries, stones can be found immediately very near to the site, less than 1 km away. Such variability on the use of stone resources seems to be linked with the availability of local geological environment. Local stones are thus employed for

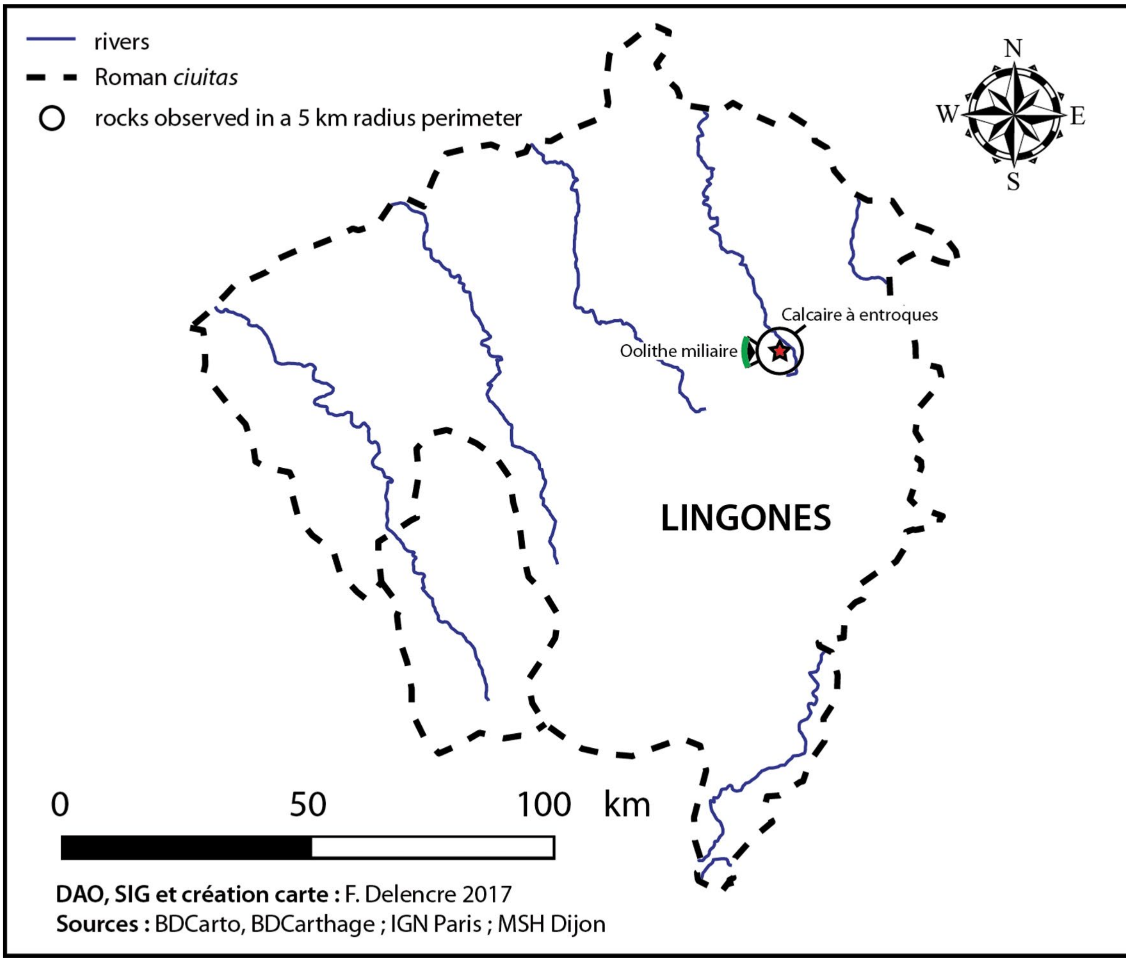

Fig. 7: Stone resources supply in Langres-*Andemantunum*.

specific architectural needs, contrary to what we could observe in Aeduan examples. This characterization for the selection of materials therefore defines a maximal mobilization of the close environment to fulfill specific requirements of construction.

Langres-*Andemantunum*

Regarding the *caput ciuitas* of the Lingones' territory, Langres-*Andemantunum*, it is not very well documented because of the scarcity of large-scale excavations.[14] Despite this, some recent archaeological activities give us information concerning the origin and the occupation of the agglomeration.

That is the case, for instance, for two *insulae* established on each side of a *decumanus*, excavated between 1968 and 1981, revealing structures and artifacts, which date the site back to the beginning of the 1st century AD.[15] The collected corpus for stone building materials is very partial. Indeed, only a few observations could be undertaken on the masonries and a sampling has been realized for stoned-roof elements.

Therefore, it is difficult to appreciate supply variability for the construction sites in the Lingones *caput ciuitas*. The most employed facies concern the masonries, involving consistent volumes, correspond to a calcareous rock with crinoid fossils. It is interesting to notice that this very stone constitutes the geological substrate on which the agglomeration is established.

In contrast, stoned-roof elements are made of a distinctive petrographic nature clearly different from this substrate. The first outcrops of this oolitic calcareous rock are located at a distance of 10 kilometers west of Langres. We can also notice that this geological formation can be found further to several tens of kilometers. We can deduce, from these information and the lack of knowledge about ancient quarries, that the supply sources can be located in several points belonging to the local perimeter (fig. 7). The analysis of stoned-roof elements shows that when a peculiar stone resource is wanted for a construction, only the local environment is mobilized.

Identification of Two Distinctive Behaviors in the Use of Roman Building Materials

It is not a surprise that stone resources observed in constructions have very little in common for each site, apart from a few exceptions. This can be easily explained by the diversity of geologic formations in the considered territories.

However, stones of various petrographic natures can be found sometimes very far from the construction site where they are shaped and implemented. By these observations, we can put in evidence a common feature with the use of substantial local rocks in the masonries. All these stones belong to the local perimeter and can be found in a 25-kilometer radius around the considered site to produce rubble stone, quoins, etc.

Specific needs related to the construction have led the builders to seek stones bearing particular qualities. Compact and isotropic rocks are selected to create the elevations with stones arranged following regular bedrocks bound with lime mortar. Oolitic limestones are particularly wanted to shape architectural elements such as columns as they are easily carved, etc.

The highlighting of different origins of stones according to construction needs marks precise selections depending on economical, technical, and aesthetic criteria.[16]

These last aspects are materialized by searching geological origins, by bringing out supply organizations or by identifying the inherent properties of the rocks for their shaping and implementing.

The analysis of materials for several Aedui sites emphasizes a typical supply pattern, first seen with Bibracte and Autun (fig. 8). Thus, most of the stones used for each construction site are extracted from less than a 25-kilometer distance. However,

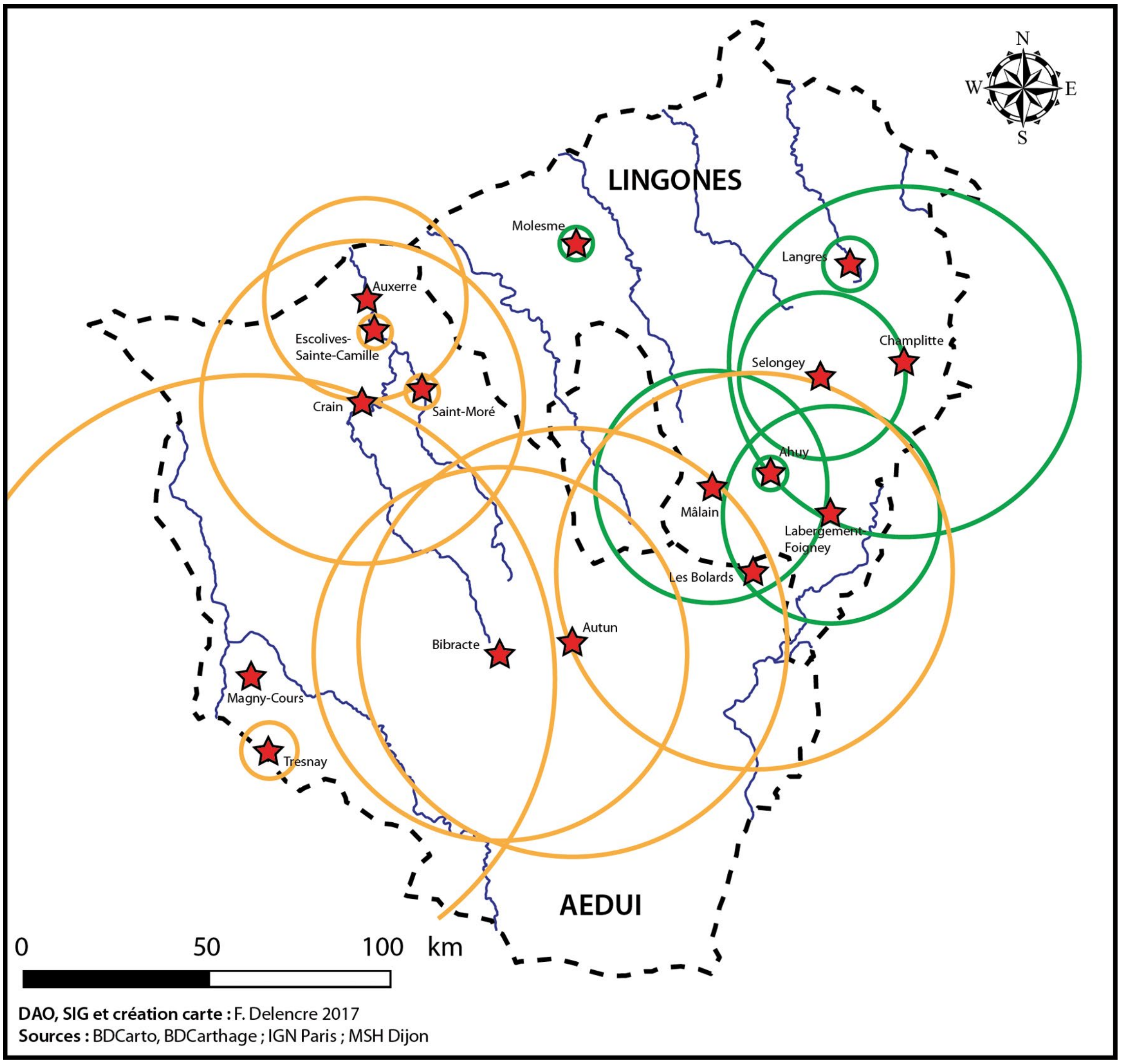

Fig. 8: Stone resources supply in Aeduan and Lingon territories

concerning construction, some petrographical facies are particularly sought to meet specific architectural needs. This implies selecting and carrying stones, which are found inside a 50-kilometer perimeter. The Aedui therefore are prone to have a peculiar form of independence to the natural resources.

Buildings on Lingones' territory, described with Langres and Mâlain, are characterized by an exclusive use of local stones, never exceeding a 25 kilometers distance (fig. 8). The choices made for these materials draw a maximum mobilization of the surrounding environment to meet required architectural needs. A building in the Lingones' territory reflects *de facto* its geological environment.

The overview of the results that we have presented finally highlights two different behaviors concerning the relationship to building natural resources. This can be observed by the supply of construction sites inside these territories with an important variety of geological resources.

A very remarkable pattern emerges by the recognition of each *ciuitas* in its construction methods linked to the local geology and to be able or not to carry materials over great distances. These observations confirm our research results concerning the integration (appearance and subsequent diffusion) of Roman building materials in these territories.[17]

Concerning the Lingones, the variety of construction methods testifies for strictly localized supplies. Lingones' roofs are made of *tegulae* and *imbrices* only where argillaceous formations are prone to be exploited for terracotta. The use of lime mortar is limited to calcareous regions.

On the contrary, the Aedui buildings are defined by the use of Roman building materials, even if local resources are not able to properly produce them. Lime mortar and tiles are widely used, no matter the geological context.

There is no valid argument allowing us to think that the Aedui are more able than the Lingones to transport goods. Indeed, the road and fluvial networks are almost identical for both Gallic tribes. Moreover, these two territories are characterized by important catchment areas and the Roman roads have been established regardless of the *ciuitates*. The issues of resources availability can be considered, if we take territorial legislation into account insuring with the administration the coherence of Roman *ciuitates*.[18] We have to keep in mind that a large portion of these territories belongs to the *ager publicus* and the exploited resources can be located in areas that cannot be assigned to a private owner.[19] However, if this point could be mentioned to explain the choice of specific stones, it does not quite explain this neat differentiation between Lingones and Aedui, all the more when both *ciuitates* are considered as *foederati* in the same way by Rome.

It would be compulsory to shed light on other specifications that could differentiate those two areas to explain these underlying mechanisms. Those two distinct managements of natural resources in each *ciuitas* we have analyzed seem to be consistent. They appear to be based on specific cultural aspects, religious beliefs and/or institutional frameworks that can explain this neat differentiation.

Conclusion

These discrepancies raise a question concerning the insertion of various building sites in economical and architectural problems. Our results show that the use of stones in construction is not only an issue of material conditions but they also show that building materials can be considered cultural markers, just like more classical ones, linked to a global transformation of construction and perception of material resources in the environment.

To conclude, the search and the implementation of basic materials essential to produce these building materials are motivated by several parameters. Nonetheless, we have to be careful about the fact that the characterization of stone resources is different from ours. Indeed, ancient texts teach us that stone workers have their own classification guided by a pragmatic recognition of the technical properties specific to the crafted stones.[20] The plurality in the arrangement of building materials, the way to conceive natural resources, the persistence of new integrated construction methods, etc. express changes that can be linked to the cultural acquaintance between these two Gallic tribes and Rome. These changes are supported by an important knowledge of the more or less local natural environment to correspond to practical, technical and even aesthetic aspects, which are developed throughout construction programs.

Notes

[1] Delencre 2017.

[2] Fronteau et al. 2014.

[3] Goudineau – Peyre 1993, 171.

[4] Delencre 2017, 130–140.

[5] Delencre – Garcia 2012.

[6] Gradeler 2018.

[7] Szabó et al. 2007.

[8] Labaune – Kasprzyk 2015.

[9] Labaune 2011, 42.

[10] Blanc et al. 1985 ; Delencre 2017.

[11] Rat 1996, 475 f.

[12] Delencre et al. 2014.

[13] Roussel 2003.

[14] Joly et al. 2015, 218.

[15] Menec 2008, 103 f.

[16] Delencre 2017, 143–147.

[17] Delencre – Garcia 2014 ; Delencre – Garcia 2016 ; Delencre 2017.

[18] Chouquer 2010, 93.

[19] Chouquer 2010, 144.

[20] Dessales 2011, 47.

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Beyond Health. The Exploitation of Thermomineral Sources in Artisan Activities

Maddalena Bassani

Introduction

In recent years, the study of thermomineral sources exploited during the Roman age has led to a large critical output mostly related to their use for curative activities.[1] At the Department of Cultural Heritage of Padua University thanks to a complex database for the census of all the archaeological, literary and epigraphic records attested in the Italian area[2] and in the northern Roman provinces of *Germania* and *Gallia*,[3] the research team has proposed an in-depth analysis of the different contexts attested from 2nd century BC to 4th century AD. Because of the wealth of evidence, we have defined some methodological starting points,[4] for recognizing the types of settlements,[5] the healing structures built close to the sources,[6] the worship places and the offerings dedicated to the deities,[7] the social and the legal aspects, as well as the geological, chemical and curative elements.[8]

But besides the clearer data of public buildings for healing purposes and of luxurious structures such as the Roman *villae*, useful to cater for all the needs of the pilgrims and ancient users, further archaeological contexts strictly linked to the thermomineral springs have been appearing and they cannot be classified as curative pools, worship places or villas, but probably rather as artisan buildings.

Indeed, there are few studies for the Roman period aimed at identifying places and structures/infrastructure built to use all the by-products extracted from the mineral springs themselves,[9] in other words the minerals, salts and concretions that normally accumulate where the waters exit. These hydrothermal deposits are a sub-category of the products derived from geothermal phenomena, for which a general classification has been proposed. Hydrothermal by-products include silica, borax and boric acid, iron oxides and sulphur, alongside sedimented carbonates such as travertine. The secondary uses of hydrothermal derivatives also include the exploitation of thermal heat for heating purposes and the driving force of the water itself, for example to power mills.

Starting from a general classification of the most common mineral salts attested at known Italian curative springs and their secondary uses, which can be compared with similar ones in other sites of the Roman Empire, this paper will therefore present some archaeological features discovered in Italy with specific markers of the mining of mineral concretions from thermomineral waters. Furthermore, an overview of both some ancient literary sources and some testimonies from the previous centuries will contribute to propose new elements for attempting to understand the multiple exploitation of the mineral sources in the Roman age.

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Distribution of Springs in Italy and Classification of the Principal Hydrothermal By-Products

As is known, to be described as mineral or thermomineral a water must be rich in dissolved salts.[10] The enrichment process starts with rainwater: after falling on the ground the water descends by percolation into the deep layers of the subsoil and comes into contact with mineral-rich rocks, which vary from place to place. Here it is mineralized and then rises back to the surface along specific underground paths. The water is classified as hypothermal (< 30°C) if it does not encounter sources of heat, whilst if it comes into contact with geothermal phenomena it may be described as homeo/hyperthermal (> 30°C).

The painstaking work to catalogue archaeological features in the vicinity of the thermomineral springs of ancient Italy, with further in-depth studies currently in the final stages on the larger and smaller islands, has made it possible to identify over 150 ancient contexts georeferenced in a web-GIS environment. As noted in the introduction, most of these are public bathing facilities of differing size and complexity, cult places, private villas and even, in some cases, probable *hospitia*; a less well represented, but no less interesting, group are smaller structures of uncertain function that may therefore, in some cases, be spaces for processing the hydrothermal by-products.

Cataloguing these settlements has also allowed us to propose a subdivision of the principal typologies of waters attested. Examining Table 1, we see that around a dozen mineral waters can be listed on the basis of their saline component: those rich in sulphur, sodium, calcium, magnesium and iron, alongside those containing traces of substances of plant or organic origin such as bituminous waters. The same table also contains a general outline of the main uses for the various types of water to treat various ailments of human and animals.

SALT TYPE	FIXED SOLIDS (mg/l)	THERAPEUTIC PURPOSES
bicarbonate	> 600	For digestion (contrasts acidity)
sulphate	> 200	As a laxative for hepatobiliary problems; also effective for dermatological, respiratory and articular problems
chlorine	> 200	For intestinal, biliary and liver problems; as a laxative
calcium	> 150	For calcium deficiency (pregnancy, menopause, osteoporosis and hypertension)
magnesium	> 50	For digestion
iron	> 1	For anaemia and iron deficiency
sodium	> 200	For sporting activities (to replenish mineral salts)
hypo-sodium	< 20	For arterial hypertension

Table 1. Principal salts present in thermomineral waters and their therapeutic purposes (as proposed by A. Bassani).

GEOTHERMAL BY-PRODUCTS	SECONDARY USES (AS BASIC INGREDIENTS OR ADDITIVES) FOR:
Various hydrothermal compounds and fumarolized vulcanites	Ordinary pottery and fine ceramics; concrete mortars and construction materials; fuller's earth and the treatment of textiles
Borates, oxides of iron and sulphur (sulphur dioxide)	Slips and glazes for fine ceramics; colorants; medicines (weak acids, pomades, unguents)
Sinter (hydrothermal silica)	Abrasives
Travertine	Construction blocks or cladding slabs for important buildings (columns, palaces, temples)
CaCo3 from hot waters saturated with CO2	Waterproofing of small channels in earth or bricks
Igneous rocks	Construction materials; millstones; road surfaces
Obsidian/natural volcanic glass	Stone tools; mirrors

Table 2. Classification of geothermal by-products for which some uses have been found (as proposed by R. Cataldi).

Referring those interested to the published studies on these issues mentioned above,[11] here I wish to focus instead on the minerals making up the hydrothermal by-products, either dissolved within the waters or present in solid form at the springs. Remembering that these hydrothermal derivatives represent a sub-category of geothermal products, summarily listed in Table 2, Table 3 shows that for a given product present in the vicinity of springs one or more uses in manufacturing, construction, agriculture or in the home are documented.

I will then present some archaeological contexts that can be analysed in the attempt to understand if, based on the indicators that they present, these can be interpreted in light of what we have said so far.

Archaeological Contexts near Sulphur Springs

As is known, the presence of sulphur salts in thermomineral waters (in which they were dissolved) and in the mineral concretions formed at these springs (where they took the form of yellow-ochre coloured crystals) was recognised already in the Greek world, which used the term *theion* for this precious material.[12] It can indeed be described as a precious substance both for its numerous curative uses and for its domestic and artisanal purposes, as well as its use in religious ceremonies: it is no surprise that in Greek the same word is used both for sulphur and for the divine.

Turning our attention to the identification of settlements in the vicinity of sulphur springs used for non-therapeutic purposes during the Roman period, an instance that

HYDROTHERMAL BY-PRODUCTS	SECONDARY USES (AS BASIC INGREDIENTS OR ADDITIVES) FOR:
Borax and boric acid (R. Nasini)	Slips and glazes; treatments in the textile industry
Sulphur (Pliny the Elder; modern authors)	Whitening and softening substances; flammable substances; purification of spaces; treatment of wool; maceration of linen and hemp
Iron oxides (modern authors)	Pottery
Calcium carbonate (Vitruvius, Pliny the Elder, Seneca)	Stone encrustations; canals in agricultural and rural areas
Sodium chloride/rock salt (Arrian; Herodotus; Synesius; Claudian; modern authors)	Dietary uses; religious uses (sal hammoniacus-Siwa); use for construction in arid areas
Bitumen (Pliny the Elder)	Oil for lamps; cladding of water conduits; coating of bronze or iron objects; cementification
Thermomineral muds (modern authors)	Potential uses in pottery
Thermal heat (Pliny El.; Cassiodorus; S. Mandruzzato)	Cultivation of some plants even during the cold season; distillation of alcohol; maceration of linen; extraction of silk from cocoons; hatching of eggs in incubators; facilitated cooking of legumes, pasta, fruit
Driving force (J. Dondi, A. Vallisneri; S. Mandruzzato)	Mills, spinning wheels

Table 3. Classification of hydrothermal by-products for which both ancient sources (Pliny the Elder, Vitruvius, Seneca etc.) and modern sources (J. Dondi, A. Vallisneri, R. Nasini etc.) indicate a non-therapeutic secondary use (with case-by-case variations depending on the individual springs).

merits detailed analysis is a private context in Lazio discovered at Acqua Zolfa, on a promontory that now forms part of the Tor Caldara Nature Reserve (Ardea, Lazio)[13].

Like most thermomineral archaeological contexts in Lazio, this site too has numerous mostly hot springs, with a prevalently sulphuric salt composition; around the springs are extensive banks of yellow sands and numerous quarries for the extraction of sulphur, attested at least from the modern period to the mid-19th century.

This type of extractive and perhaps also productive activity, as we shall see shortly, must have far more ancient origins, going back to the Roman period. In this same area, behind a small portion of a maritime villa built on terraces, of which a *nymphaeum* and a few other rooms are known (fig. 1, site L),[14] the soundings undertaken in the 1980s identified a series of quarries and tunnels for the extraction of sulphur, alongside basins for collecting the spring water, rich in its derivatives, and some rooms that seem to have been intended for the production of sulphur cakes. The map in Fig. 1 shows some sites (in particular A–G) with large deposits of particular ceramic objects: here there was an abundance of large jars with a hole on the shoulder, in addition to numerous

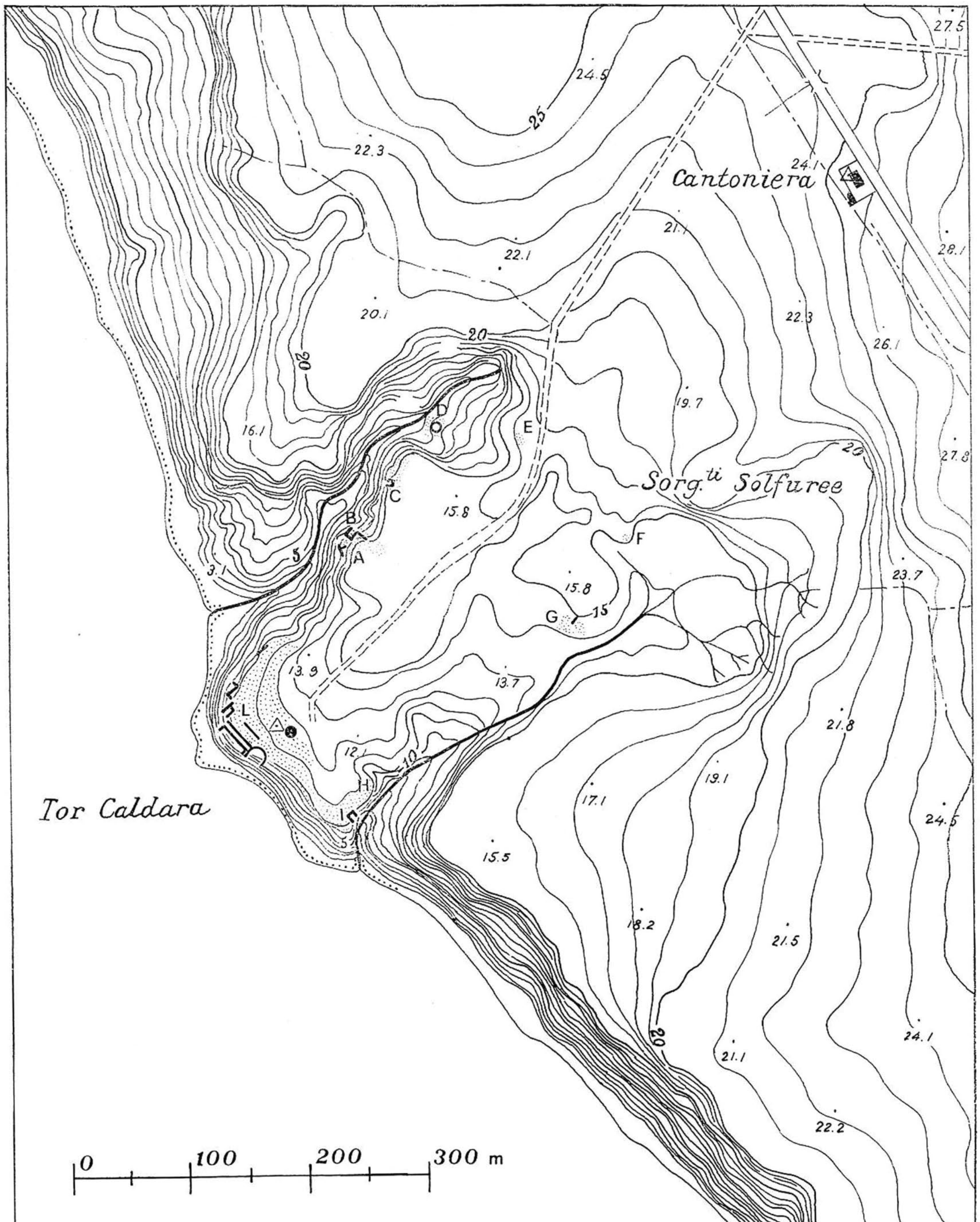

Fig. 1: Ardea, *Latium*. Topographical map of the Roman *villa* with its production places.

remains of tubes that must have been inserted into these (fig. 2). Thanks to a helpful comparison with the extraction processes used in the 16th century (fig. 3, 1–3),[15] and on the basis of more recent evidence,[16] the authors suggested that the various stages

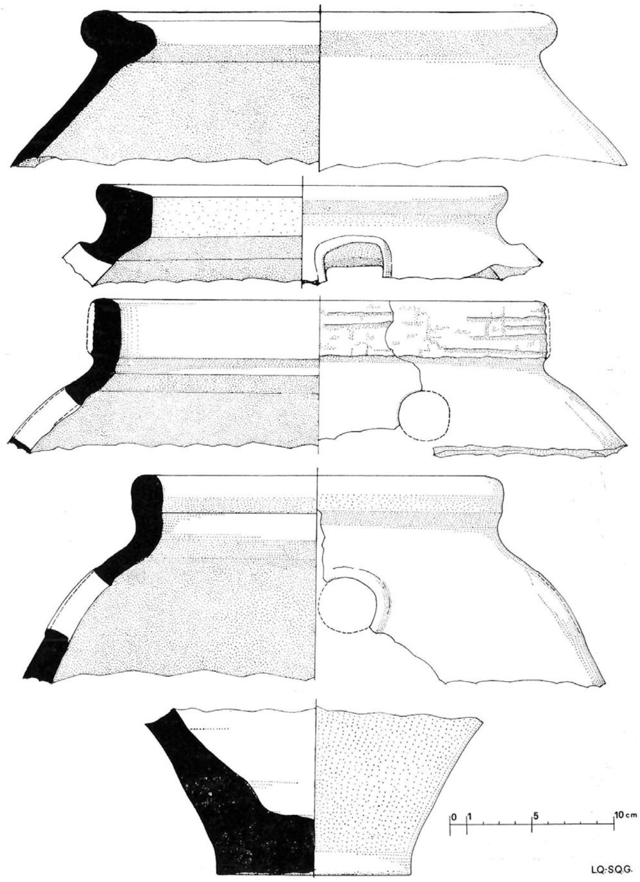

Fig. 2: Ardea, *Latium*. Photo and drawing of some *ollae* for the sulphur extraction.

of sulphur processing might have taken place here. More specifically, in the quarries/tunnels identified as sites A–B, the sulphur could have been extracted still unrefined, not separated from the gangue, the waste product usually associated with the mineral intended for use. At F the remains of basins for channelling the springs that abounded in the vicinity could be seen whilst at site G, as at D, it is likely that the procedure aimed at obtaining pure sulphur, in use until the last century, took place. The unprocessed mineral was placed in large ceramic containers with lids and tubes placed over a boiler (fig. 3, 1), and heated to 112-114°C; after liquidising, it vaporised, separating from the gangue. The sulphur fumes passed through the tubes into another container (fig. 3, 2), where they cooled and liquefied; at this point the pure sulphur was then collected in other vases or moulds, from which the cakes destined for trade could then be made (fig. 3, 3).

That the villa of Tor Caldara was built here not just to enjoy the splendid views over the Tyrrhenian Sea but above all as a control centre for the operations to extract and process sulphur, intended for a wide variety of uses, seems a fairly plausible hypothesis and indeed the continuity *in situ* of the same extraction techniques over the centuries supports this theory.

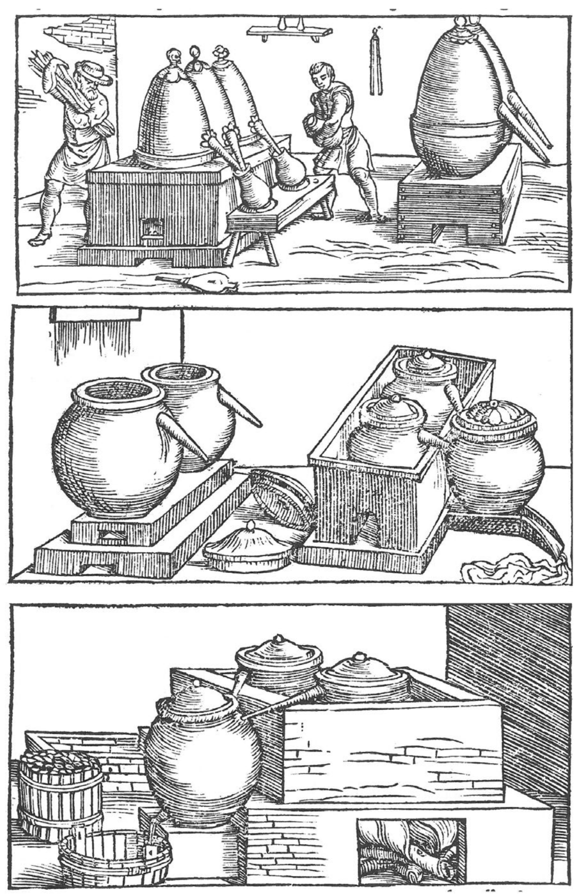

Fig. 3: The extraction process of the sulphur in some illustrations of Agricola, 1563.

Naturally, this is not an isolated instance, and it is clear that elsewhere too, where sulphur was abundant, there must have been installations of this type, mostly privately run. A representative example is the eastern area of Agrigento, famous for its wealth of springs and sulphur quarries. It has been the subject of a very recent research project devoted to studying the production of this mineral from the Hellenistic to the Byzantine period:[17] 35 sites were identified, some used for production and others of a residential type, and yet others used as a necropolis, but all lying near the springs and the sulphur quarries (fig. 4). Whilst it was already known in the 19th century that the *tegulae sulphuris* obtained using the procedure described above came from this area,[18] the project made it possible in many cases to identify the production places of these sulphur cakes, since fragments of *tegulae* identical to those already known were found directly on site. From the topographical map provided we see that in this case, too, as at Tor Caldara, there must have been residential areas, in other words *villae*, which functioned as a control and management centre for the entire production process between the II to the IV century AD, in all likelihood entrusted to slaves.

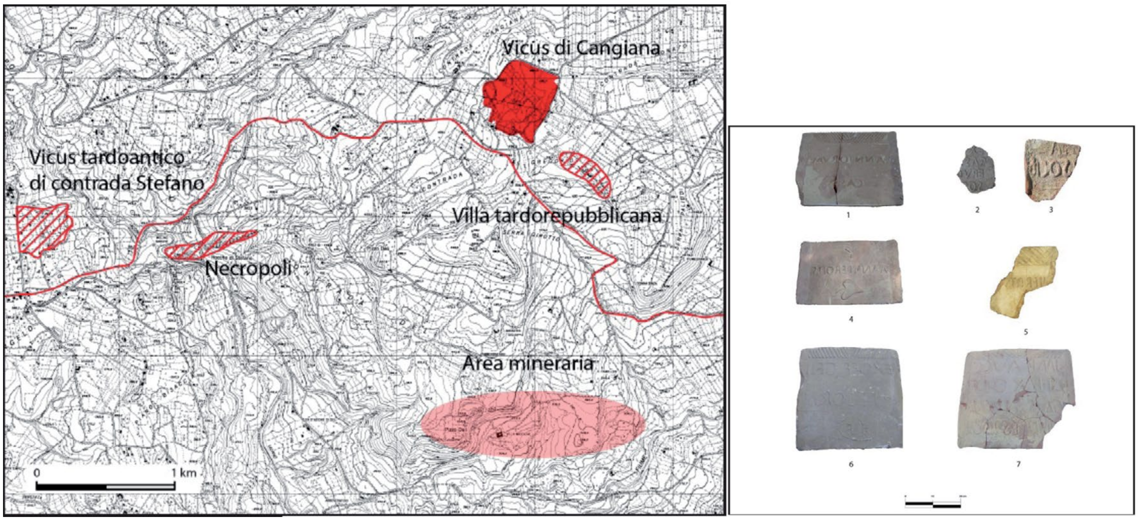

Fig. 4: Agrigento, Sicily. Topographical map of the Roman private contexts, where some *tegulae sulphuris* were found.

Archaeological Contexts for Pottery Production

Different issues with respect to those connected to the processing of sulphur emerge in the case of the identification of the chemical components derived from thermomineral waters used for the production of terra sigillata pottery and in particular of the so-called Arretine ware.[19]

As is known, this particular ceramic class became established in the area of Arezzo in the second half of the 1st century BC[20] and became extremely popular, spreading through Italy and Gaul before being partially supplanted by African red slip ware.[21]

Already in the early 20th century, some chemists from the University of Padua had suggested the presence of boric acid in the glaze of the Arretine vases,[22] undertaking a series of analyses also performed by German colleagues.[23] Even at this time it was clear that borax and boric acid were used to obtain the sheen and red slip typical of these vessels. These materials were widely available at the hydrothermal springs of Larderello, an area famous precisely for its 'borax fumaroles' and only a short distance from *Aretium* itself. It was thus proposed with a good margin of certainty that these substances came from this borax-rich region, and were brought to Arezzo along the trade networks of the metal route; at this production centre they were then mixed with other components to obtain the red slip peculiar to this ceramic class.

The Aretine workshops are archaeologically attested in various areas of the city,[24] but a certain ground plan is available only for one of them, perhaps belonged to *M. Perennius* (fig. 5). Beneath the space occupied by the church of Saint Maria in Grandi were production facilities arranged around a porticoed area A, including two basins for clay, a larger one, C (8.6 × 3.8 m, depth 1.2 m) lined with terracotta blocks, and a

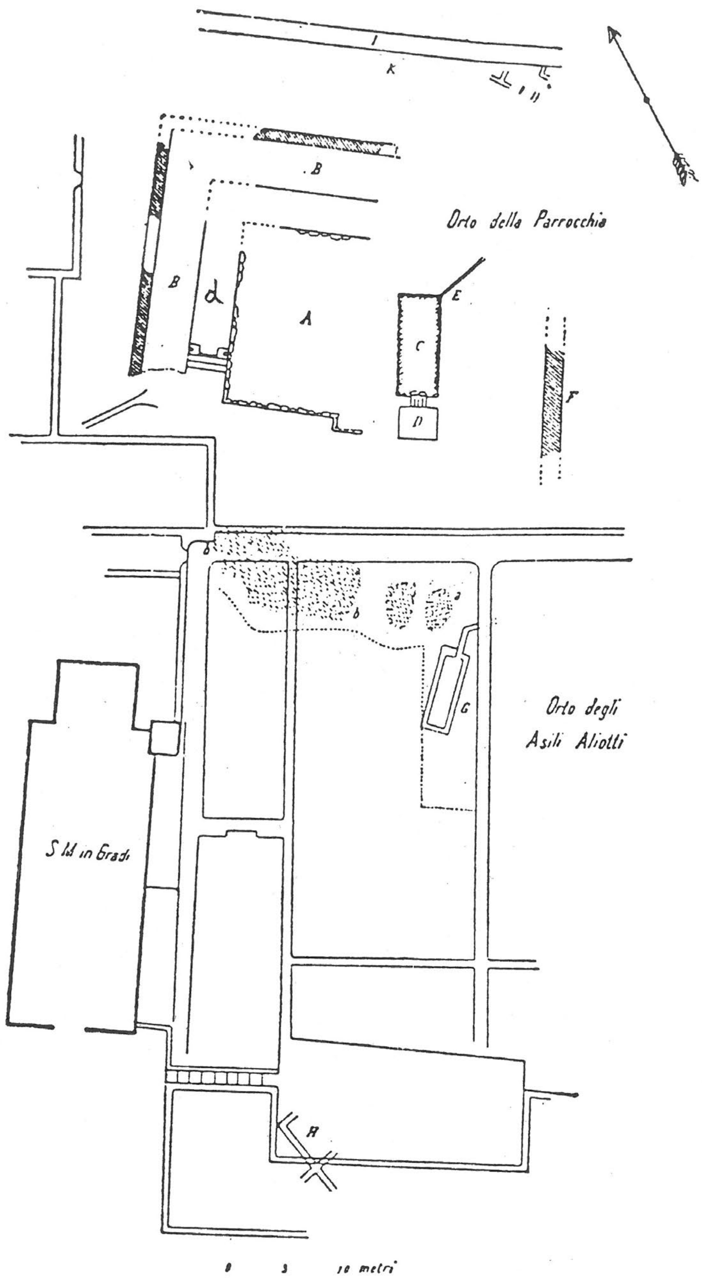

Fig. 5: *Aretium*, Tuscany. Plan of the workshop for the production of *Aretina vasa* close to a *domus*.

smaller one D (2.8 × 3.5 m) lined with plaster, and a small channel E; annexed to this first group were some rooms interpreted as the *ergastula* of the *figuli*, who worked for a *dominus* whose probable *domus* was identified nearby. Observing the same map, further south we find other basins for clay, including basin G (4.7 × 1.8 m, lined with

Fig. 6: Santa Venera-Acireale, Sicily. View of the manufacturing area near the *Thermae Xifoniae*.

concrete on the inside), near a large pottery dump marked on the plan with the letter *A*. Though the location of the kilns belonging to this facility is unknown, as they were not found during the excavation, they must have been in the immediate vicinity in order to optimise the time needed and the various production phases.

Besides the resumption of this manufacturing tradition in the modern period,[25] the use of a specific by-product such as boric acid in the slip of Arretine ware suggests that we may be able to identify other thermomineral sites with a potential artisanal vocation. Thus, for example, we can note that near Pomarance at Bagno al Morbo,[26] not far from Arezzo and Larderello, a thermomineral context of the Roman period is known that may be the *Aquae Volaterranae* shown on the *Tabula Peutingeriana*.[27] This area is rich in cold but mineralised waters, classified as rich in carbon, iron and sulphur salts, but also in gas emissions identical to those of Larderello, in other words containing borax. The structures at this site have been interpreted generically as belonging to a settlement identified in the 19th century and may also turn out to be closely connected to the production of pottery and specifically of red slip ware. This is true particularly considering that during the Middle Ages when the area hosted a flourishing ceramic industry making a brightly coloured type of pottery known as 'ingobbiato-graffito' (slipped-incised).[28]

To broaden the range of production centres that may potentially have used hydrothermal by-products, we could recall that in Sicily a late antique district where bricks were produced has been brought to light near Santa Venera-Acireale, believed to be the ancient *Thermae Xifoniae*.[29] This area, built in the vicinity of a settlement established near sulphur springs

Fig. 7: Montirone-Abano Terme, Veneto. *Rhytà* in *terra sigillata* from a Roman context.

containing radioactive bromine and iodine salts was home in the Roman period to a thermal curative facility with a small annexed temple. From the 4th century AD onwards, in an earlier Hellenistic district, a large area hosting 37 rooms connected to warehouses and three kilns was built, where bricks, pottery and tiles were made (fig. 6): it is highly likely that for manufacturing these products local clays were used, for which some basins have been identified in the immediate vicinity of the complex.

Based on the data hitherto proposed it is therefore not arbitrary to assume that at the *Aquae Patavinae*, too, in the Euganean area there may have been workshops that used the clays present there, obtained by maturing the muds from the springs containing

Fig. 8: Montirone-Abano Terme, Veneto. Vases in *terra sigillata* from a Roman context.

radioactive bromine, iodine and lithium salts that gush out, as is known, at 87°C. In this context, the mind immediately turns to the very rich ceramic deposit discovered near Abano Terme at Montirone,[30] in 1951: it is believed to have belonged to an *emporium* aimed at those seeking a cure at the *aquae* patronised by Apollo and *Aponus*, to whom various inscribed panels discovered in the vicinity were dedicated.[31] The deposit is an accumulation of numerous refined drinking vessels, including 12 glazed *rhytà* in purified clay (fig. 7), mostly with antelope heads, alongside around a hundred fine-walled beakers in a gray or orange fabric (fig. 8), signed by some known potters of the early imperial period (including *Aco*, *Norbanus*, *Clemens* etc.).

The only information on structures and infrastructure found in the vicinity of the deposit are those noted in 1986, when walls and amphorae used for drainage were discovered.[32] Perhaps more interesting are the two plastered basins found just to the east at the 'Trieste property' in 1874:[33] one was fairly large (22.7 × 10.05 m) and one smaller (6 × 2.4 m), both accessed by steps, dating, like the vases in the deposit, to the Augustan period. Whilst some scholars believe that these basins may have been used for bathing, although without any certain evidence of this, a different part of the same context yielded other artefacts (some inscriptions, a trachyte weight, an antefix, two male busts, alongside materials belonging to a funerary context) that suggest this sector should be identified as a unitary context.

Some scholars believe that it should be interpreted as a funerary area,[34] whilst in my opinion it seems more likely that this was a residential and artisanal district like that at Arezzo mentioned above. According to this second hypothesis, the area may have developed precisely thanks to the production of objects to be sold to the patrons of the baths, such as the aforementioned vases and beakers, which may have been used for drinking the thermal waters and/or for dedication to the divinities presiding over these waters, *Aponus* and Apollo. The presence of busts of high-ranking individuals like that of an old man, now lost, alongside the antefixes might suggest that near the basins and the *emporium* there was a villa belonging to the owner as at Arezzo and Agrigento, equipped with the usual decorations such as the *imagines maiorum*, but also serving as a control centre for the economic activities of the rich Euganean area.

It would thus be interesting to undertake chemical and physical analyses of the clays used for the vases from Montirone, to clarify whether these were made *in situ* by specialised artisans or elsewhere – which would obviously make little economic sense.

Concluding Remarks

Examining the use of some thermal by-products in the Roman period on the basis of the archaeological and literary sources, where possible compared with the treatises of the modern period, has made it possible to pinpoint the potential offered by hydrothermal resources aside from their better known and more studied use for curative purposes. It goes without saying that numerous ancient thermal spas were and continued to be famous and renowned for the healing properties of their waters, but the importance of understanding and identifying the settlement system around the *aquae* is also evident.

The latter certainly consisted of hotels, residential or rustic villas, but – I believe – also of production facilities, including those structures and infrastructure that exploited the by-products of which an initial sample was discussed here. Ongoing research will certainly provide opportunities to broaden our approach and deal in greater detail with the wide-ranging production potential of these natural resources. However, the information set out here already seems to open up unprecedented prospects for interdisciplinary research, combining economic, market and artisanal motivations but also new interpretations of very well known archaeological artefacts.

Notes

[1] Annibaletto et al. 2014; Peréx Agorreta – Alaix i Miró 2017; Guérin-Beauvois 2015; Scheid et al. 2015; Matilla Séiquer – Gonzálo Soutelo 2017.

[2] For the Montegrotto Terme context, see Bassani et al. 2011; Bassani et al. 2012; Bassani et al. 2013.

[3] See the PhD theses by M. Marcato (Marcato 2014–2016) and C. Zanetti (Zanetti 2014–2016).

[4] Annibaletto – Bassani 2013; Ghedini – Bassani 2014.

[5] Annibaletto – Basso 2014.

[6] Annibaletto 2014.

[7] See the works on the subject by the present author, with ample reference bibliography (Bassani M. 2011–2017); cfr. also Costa Palahí – Vivó 2011.

[8] Several articles on all these topics in the book edited by Annibaletto et al. 2014.

[9] Information in Burgassi 2005; Bassani M. 2016a; Bassani M. 2017a; for the protohistorical period cfr. Grifoni Cremonesi 2005; for the medieval period cfr. Dallai – Francovich 2005. The reference volume on mines and metallurgy in the Greek and Roman world is Healy 1993 (Italian translation).

[10] Pola et al. 2014.

[11] See above, note 1.

[12] Bassani M. 2011.

[13] Bassani M. 2016b. News recently emerged of the discovery, by the Nucleo dei Carabinieri per la Tutela del Patrimonio Archeologico, of clandestine excavations inside the reserve, stopped in a timely fashion, <http://www.romatoday.it/cronaca/furti-villa-romana-tor-caldara-.html> (26.08.2020).

[14] On the excavation Quilici – Quilici Gigli 1984; for an initial reconsideration Bassani M. 2016b.

[15] Agricola, *De re metallica*, 1563 (Macini – Mesini 1994); Biringuccio, *De la pirotechnia*, 1540 (Carugo 1977).

[16] Pace 1935, I, 392–399.

[17] Zambito 2014.

[18] Salina 1900; Salina 1901.

[19] Goudineau 1968; Pucci 1985; Burgassi 2005.

[20] The principal study of the Roman vases produced in the Arezzo area is Paturzo 1996. It is thought that there were around 100 workshops, large and small, at Arezzo. For a very detailed overview of the various types of terra sigillata, cfr. EAA, s.v. Aretini, vasi <http://www.treccani.it/enciclopedia/terra-sigillata_%28Enciclopedia-dell%27-Arte-Antica%29/> (26.08.2020).

[21] For a general overview cf. Comfort – Paribeni 1962.

[22] Nasini 1939; it is worth recalling that Nasini began his research on Larderello when working at Padua and continued these subsequently, after moving to Pisa. For a biography of this famous lecturer in chemistry cfr. Bassani A. 2009, 418–450, in particular 448–450 for his research on Larderello.
[23] Miller 1916.
[24] Paturzo 1996, 104–107; Paturzo 1997, 382–384.
[25] According to Vasari, only a few people in the late medieval and modern period knew the secret to recreating the sheen of this particular type of Roman pottery: Vasari 1906, 557–558 (cited in Burgassi 2005, 76 and note 7, with bibliographical references).
[26] Chellini 2002, 177–178; Groppi 2006.
[27] Ghedini 2014, 113.
[28] Burgassi 2005, 78.
[29] Cfr. the website <https://termediacireale.wordpress.com/storia/enciclopedia-dellarte-antica-treccani/> (26.08.2020); See also Braciforti et al. 2006; Amari 2007.
[30] Lavizzari Pedrazzini 1995; for an analysis of the area of Abano Terme cfr. Zanovello 2012.
[31] Zanovello et al. 2010, with ample preceding bibliography.
[32] Bressan – Bonini 2012, 93, AT 14.
[33] Bressan – Bonini 2012, 94, AT 20.
[34] Bressan – Bonini 2012, 94, with preceding references.

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Fig. 1: Quilici – Quilici Gigli 1984, 234 fig. 4. – Fig. 2: Quilici – Quilici Gigli 1984, 240 fig. 13; 243 fig. 16. – Fig. 3: Carugo 1977, images at the cartae 25v, 26v, 27. – Fig. 4: Zambito 2014b, fig. 2. 3. – Fig. 5: Paturzo 1996, 104 fig. 16. – Fig. 6: Branciforti et al. 2006, 94 fig. 11. – Fig. 7: Lavizzari Pedrazzini 1995, 156. – Fig. 8: Lavizzari Pedrazzini 1995, 149.

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Compared to other pre-modern economies, the Roman world stands out for having developed a highly specialised and very productive manufacturing sector. This development led to the widespread and large-scale extraction of raw materials. Even in a territory as large as the Roman Empire, such activities put major pressure on the land. Strategies of resource exploitation and conservation were thus essential in dealing successfully with the limited availability of these resources in the medium or long term, and to ensure the sustainability of the Roman exploitation model. This volume deals with the various ways in which natural resources were exploited and managed in the Roman world. It focuses on if, when, where and how the Romans pursued a harmonious balance between the limited availability of a particular resource and the law of supply and demand. The case studies in this volume cover various key areas of the Western Roman world – from Italy and the island of Elba, over coastal Croatia to Central-Eastern Gaul and the Pannonian limes – and discuss in particular the fish industry, iron smelting, deforestation and forest management, the stone trade and the exploitation of thermo-mineral resources.

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