Der Anschnitt, Beih. 50, pp.153 – 174, 2023, https://doi.org/10.46586/DBM.264.399

Hans Lohmann

Laurion – The present state and future scope of research

ABSTRACT: *The mining district of Laurion in Attica (Greece) was doubtless the largest and most important industrial area of ancient Greece. Due to the density, diversity and partly excellent state of preservation of the remains it is also one of the most fascinating mining landscapes of the ancient world. The silver mining at Laurion formed one of three pillars of the Athenian public economy. Although the geological and archaeological exploration of the Laurion has made significant progress over the last few decades, numerous questions concerning its history and topography, as well as its mining archaeology and archaeometallurgy remain unsolved. This paper tries to offer a brief general overview of the outstanding problems and questions, in order to define research fields and to formulate tasks for the future as a matter of priority. The most important task, however, is adding the Laurion to the list of UNESCO World Cultural Heritage sites and to protect it from further destruction.*

KEYWORDS: LAURION, MINING LANDSCAPE, MINING, BENEFICIATION, ARI

Introduction

Attica, comprising about 2,500 km², has already for a long time and for good reason been regarded as a 'central' landscape of Greece – 'central' not in a geographical sense but for the cultural history of Greece as a whole, and likewise 'central' for the entirety of ancient studies: Archaeology as well as Ancient History and Classical Philology (Lohmann and Mattern, 2010). There is no other historical landscape of Greece providing a similar quantity of literary and archaeological evidence. It is therefore not surprising that no other landscape and its urban centre were the object of comparable intensive historical and archaeological research from prehistoric to modern times, as Athens and Attica. Not only the number of publications is impressive, but also the number of excavations, mainly by the Archaeological Service, but by the foreign schools as well. Thanks to the substantial works starting already in the 19th century on the Athenian Acropolis, the Athenian Agora and the Kerameikos, Athens stands out as a lighthouse. With the long-term excavations of V. Petrakos at Rhamnous, published only recently in six extensive volumes (Petrakos, 1999a-b; 2020a-d), and the likewise substantial publications of the Belgian School at Thorikos (Docter and Webster, 2018, pp.58 – 69, with ample bibliography) two important country towns, each of them displaying a completely different character, have enormously enriched our knowledge. It is to be hoped that in the future the regrettably much degraded town and sanctuary of Eleusis will gain more attention and a reassessment of the outdated excavation results, especially with regard to the chronology of its fortifications (Hülden, 2020, pp.370 – 377; Lohmann, 2021, pp.78 – 89). The beautifully situated country town of Sounion also deserves further research and it is to be hoped that funds will be found for the restoration of its marvellous 5th century BC city wall before it will collapse entirely (Lohmann, 2021, p.98, fig.54).

On the other hand, there are also enormous deficits. After the Second World War the unrestrained growth of Athens has turned large parts of Attica into an archaeological desert. Hundreds and thousands of ancient sites and monuments – including well-known and published ones – were destroyed in an uncontrolled manner. The vast majority of rescue excavations by the Greek Archaeological Service has never been fully published (Μαλούχου, 2017, p.7). Where the Prussian maps of Attica from the late 19th century[1] show thousands of archaeological sites, concrete is now spreading across the once lovely Attic countryside.

Since the reforms of Kleisthenes Attica was divided into rural and urban demes ('villages'), which in the 4th century BC numbered 139, and disposed of a differentiated settlement structure, comprising thousands of single farmsteads, as well as hamlets, villages, country towns and an urban centre – Athens –, which itself consisted of approximately 40 'city' demes (Traill, 1975; 1986). According to Thucydides (2,16) down to the outbreak of the Peloponnesian War in 431 BC, the majority of the Athenians lived as farmers in the countryside, which so far has been the object of no more than four survey projects: in Southwestern Attica, in a region identified as

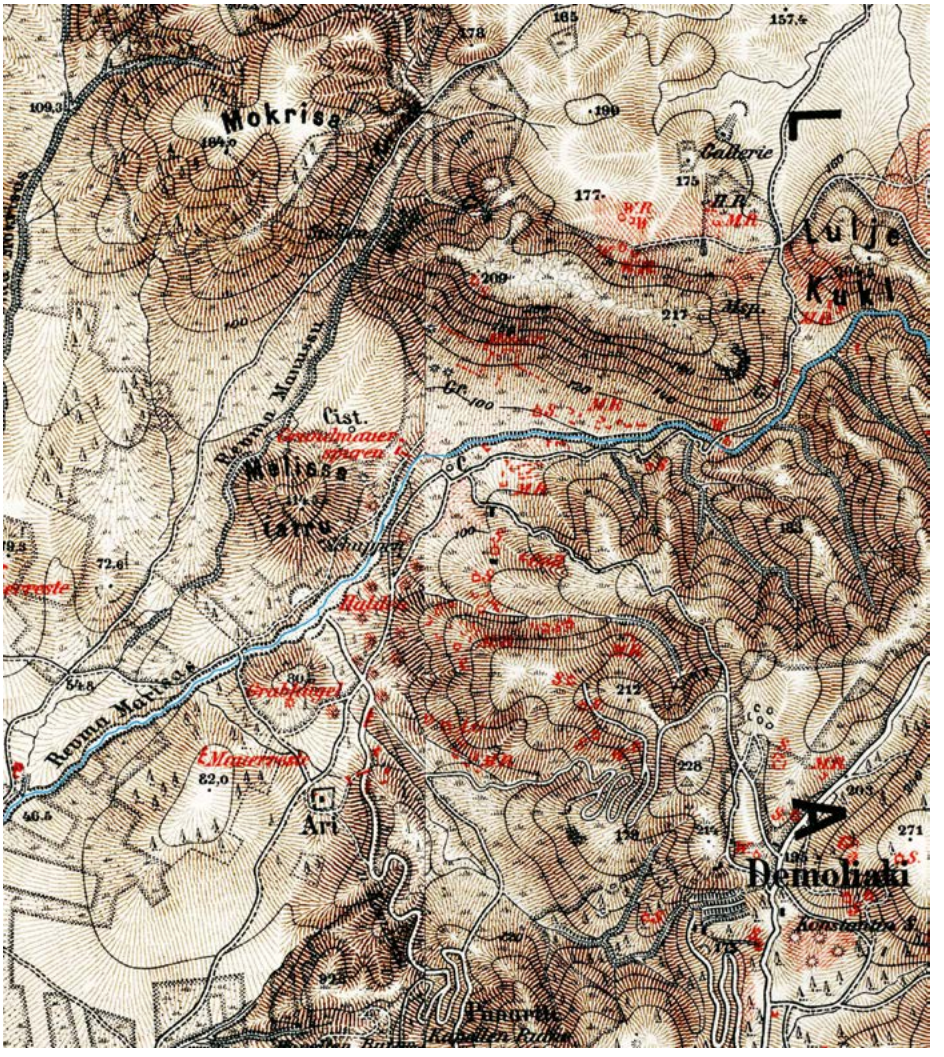

Fig. 1: Map of Ari. Sections of the maps 16 (Lavrion) and 17 (Olympos) of the Prussian Maps of Attica, prepared by Friedrich von Bernhardi from survey in 1882.

the rural deme of Atene (Lohmann, 1993), in the Skourta plain (Munn and Munn 1990; Munn, 2010), in the Oropia (Cosmopoulos, 2001) and only recently in the Mazi plain in Northwestern Attica (Knodell, et al., 2017). Despite the mountainous structure of vast parts of Attica, the land contributed considerably to the wealth of Athens through the efforts of the Athenian farmers, cultivating even the last corner of their homeland (Thuk. 1,82,4; Hell. Oxyrh. 17 (12),5; Audring, 1977, p.20). The extensive exchange of goods between the urban centre and the countryside as well as the mass production of different goods in the town, contradicts the notion of economic historians of the 'primitivist school': During the Classical period Athens was instead beyond any doubt the highest developed polis of Greece, economically, politically and culturally.

The second pillar of the Athenian Empire was formed by the contributions of the allies organized in the First Athenian League. While the percentage of the tribute that flowed directly into Athens' treasury seems rather modest (Flament, this vol.), the tribute going into the construction of the Athenian fleet stimulated its economy enormously. The hundreds of shipsheds and shipyards in the Piraeus are witness to this. This vividly calls to mind the USA forcing European states to spend 2% of their gross national product on defence, mainly of course on weapons purchased in the USA.

The third pillar of the Athenian state economy in addition to agriculture and to the Athenian League were the silver mines at Laurion (Flament, this vol.). Although their contribution to the economy of Athens and its hegemonial role during the 5th century BC and at least also during parts of the 4th century BC has regrettably been extremely underrated by many historians, it can – to the contrary – hardly be overestimated. Not to speak of the building of the fleet before the fateful naval battle at Salamis in 480 BC, when the Athenians prevented Greece from becoming just another province of the Persian empire. European history might have taken a completely different turn then. It, therefore, cannot be stressed often enough, that the Laurion in Southeastern Attica was by far the largest and most important industrial area of ancient Greece. It comprises no less than 80 or 90 km² stretching from Cape Sounion in the South, to Plaka in the North, and from Thorikos in the East to Ari near Anavysso in the West. Because of its

enormous wealth of ancient remains, comprising mines, workshops, smelting places, sanctuaries, graves, towns and farmsteads, it forms a unique fossilised industrial landscape, mainly of the Classical period, the 5th and 4th century BC. It will hopefully finally be listed as world cultural heritage by UNESCO (Voudouris, et al., 2021) – despite the immense damage that, after a first wave of destruction by the mining activities of the 19th and early 20th century, uncontrolled summer house construction and industrial projects have caused since the 1960s.

History of research

The most recent and thorough treatment of the research on ancient Laurion is that by S. Nomicos (Nomicos, 2021, pp.17 – 24). Within the framework of this paper, I can only highlight some of the milestones of past academic research, which started in the early 19th century, more than 200 years ago, when in 1815 A. Boeckh published his paper "Über die Laurischen Silberbergwerke in Attika" (Boeckh, 1815). Only two years later followed his comprehensive work "Die Staatshaushaltung der Athener" (Boeckh, 1817), which made him the father of Economic History as a historical discipline of its own. Due to the great impact of this work, it was translated into English in 1828 (Boeckh, 1842). His writings were created exclusively on the basis of the extant ancient sources. He never personally visited the Laurion.

Early pioneers of the Laurion mining district were the mineral geologist K. G. Fiedler (1840, pp.36 – 79) and the Greek mining and metallurgical engineer A. Kordella (Cordella, 1869). In 1864 the Roux-Serpieri-Fressynet & C.E. started to rework the ancient slags, while since 1870 the ancient mines were reopened. But the mining history of the Lavriotiki during the 19th and 20th century remains still to be written.[2]

Shaped by a foresight in research policy that is all too painfully missing today, were the Prussian maps of Attica of the late 19th century, when modern mining in the Lavriotiki advanced rapidly. For the first time these maps sought a systematic inventory of the whole of Attica, including all ancient remains in the Laurion. In 1882 and 1883 Friedrich von Bernhardi, then Lieutenant in the Prussian army, mapped the whole of Laurion at the scale of 1: 25 000 (Curtius and Kaupert, 1891 – 1900, maps 14, 15, 16 and 17; Fig. 1), within seven months – an almost unimaginable effort (von Bernhardi, 1920, pp.157 – 164; 1927, 92 – 100; Lohmann, 2010, pp.259 – 275), especially regarding the high precision of these maps. More detailed maps of parts of the mining area are to be found in the archive of the CFML (Compagnie Française des Mines du Laurium) and the later Hellenike Hetaireia Lavriou (Ελληνική Εταιρεία των Μεταλλουργείων Λαυρίου) in the Technological Park at Lavrio (Τεχνολογικό Πολιτιστικό Πάρκο Λαυρίου). To date there is no recent mapping of the ancient remains, instead up to the most recent publications maps of the 19th century are reproduced (v. *exempli gratia* Kapetanios, 2010, p.162, fig.27). The maps published by K. Konophagos (Conophagos, 1980) are copied from maps of the CFML. The envisaged project of the Belgian School at Thorikos to map the entire Laurion by means of a LIDAR-drone was, unfortunately, never accomplished.

The scientific commentary on the Prussian maps concerning the mining area by A. Milchhoefer (1889) lags far behind the enormous number of entries they display. Obviously, completely on his own, A. Milchhoefer was overwhelmed with the task of describing the vast area comprehensively. The attempt of W. Wrede, director of the German Archaeological Institute at Athens during inglorious times (Petrakos, 1994), to provide a new commentary, got stuck at the beginning.[3] Plans of some ancient mines made by the Saxon geologist Baldauf in 1935 were lost during the Second World War, before they were published (Wilsdorf, 1952, p.112; Hopper, 1968, p.312, n.159). Among the first authors who tried to provide an overall picture of the ancient mining district of Laurion were A. Kordella (Cordella, 1869) and E. Ardaillon (1900). After the Second World War, interest was primarily directed towards the organization of mining in Classical times, which we are informed about in the ancient mining leases from the Athenian Agora (Crosby, 1941; 1950; 1957; Langdon, 1991; Aperghis, 1997/98). The paper of R.J. Hopper of 1953, working on the extant literary and epigraphical sources is still much appreciated and indispensable for the study of the Laurion mining industry, but is lacking intimate knowledge of the region and the ancient remains existing there. Many publications followed, H. Kalcyk lists in his PhD no less than 180 books and articles (Kalcyk, 1982, pp.226 – 235). But only with the seminal work of K. Konophagos (Conophagos, 1980), former director of the metallurgical plant at Lavrio, then director of the renowned EMP (Εθνικό Μετσόβιο Πολυτεχνείο) / NTUA (National Technical University of Athens) and industry minister of the first democratic government of Greece after the Junta, did there commence a new era of research on the ancient mines at Laurion. His book, therefore, marks in some respects a turning point. It is certainly no coincidence that several attempts to take stock of previous research appeared in the early 1980s (Jones, 1982; Weisgerber and Heinrich, 1983). Since then, the number of publications has more than doubled (Nomicos 2021, pp.139 – 159). Although some ideas of K. Konophagos are now out-of-date, his greatest merit is the stimulation of new research.

Indeed, research on the Laurion has made tremendous strides over the past four decades. The geologists solved essential questions of orogeny and the formation of the polymetallic ore deposit (for an overview see Voudouris, et al., 2021; Ross, et al., this vol.). In the beginning of the 21st century D. Morin, A. Photiadis and their team explored the ancient shafts of Laurion with modern equipment (Morin and Photiades, 2005; Morin and Herbach, 2008; Morin, et al., 2012; Herbach, et al., 2013; Morin, et al., 2020). Only recently the "Lavrion Shafts Project", a sur-

vey project by a team headed by M. Vaxevanopoulos (Vaxevanopoulos, et al., this vol.), has for the first time located all shafts in the Laurion area, the number of which has been tremendously exaggerated in former publications: Estimates have reached from 1,000 to more than 2,000.[4] The aforementioned project has put an end to this debate by determining that there were approximately 300 shafts, as I had already suggested long ago on the basis of the mining leases from the Athenian agora and the entries in the Prussian maps nos. 14–17 (Lohmann, 2005, p.118). No less than 10 ancient mines were speleologically explored and topographically mapped by M. Vaxevanopoulos and his team. More plans of ancient mines will be provided by D. Morin (Morin, et al., forthcoming). Other plans together with thousands of important documents and maps in the archive of the Technological Parko at Lavrio await intensive study and publication.

Since the 1970s dozens of workshops, so-called *ergasteria*, have been uncovered. K. Konophagos excavated the Asklepiakon of Simos in the Soureza valley (Conophagos, 1980, pp.375–389), others were unearthed by the Belgium School at Thorikos, by E. Kakavogiannis and O. Kakavogianni, by K. Tsaïmou and by M. Salliora Oikonomakou, the former director of the Archaeological Museum at Lavrio which opened to the public in 1999. But so far none of these workshops has ever been fully published. Only the publication of a large *ergasterion* on the southern slope of Mt. Michali by E. Photos-Jones and J.E. Jones stands out as an important point of reference (Photos-Jones and Jones, 1995).

Several conferences on the different aspects of the history and technology of the ancient mines in the Laurion at Keratea and elsewhere have brought about many pieces of new evidence and contributed considerably to improve our knowledge and our understanding of this important part of Attica. During the last two decades the question of prehistoric mining in Laurion has gained special attention. Only recently J. Maran has strongly advocated, that in the Aegean the use of silver "can be traced back to the early 4th millenium BC and possibly even earlier" (Maran, 2021, p.197). Thanks to recent findings in Lambrika, Keratea and elsewhere (Andrikou, this vol.; Kakavogianni and Douni, this vol.) it can now be stated safely that mining in the Laurion goes back to the Final Neolithic and Early Helladic I period, although it still remains difficult to pinpoint traces of such early mining works. The discussion of the findings in the famous Mine 3 at Thorikos gives an impression of the problems involved (Nazou, 2018; Nazou, this vol.).

On the other hand, there are also heavy losses to report. Since the 19th century much damage occurred to the Laurion area, first by reworking the ancient slags since 1864, than by reopening the mines since 1870 and within the last decades by various building activities and industrial projects like the EBO (Ελλενική Βιομηχανία Όπλων), which devastated senselessly the valley of Botsari most probably identical with the ancient mining district of Thrasymos, one of the largest and most important ones in the whole Laurion, being part of the deme of Sounion.[5]

Pending problems

Historical topography

The questions of the historical topography of ancient Laurion have been scrutinized by H. Kalcyk (1982) and the author (Lohmann, 1993, pp.98–110) with partially diverging results. Since no significant progress on the issue has been made since then, there is no need to go into any detail here. In only six out of the 139 Classical demes of Attica did mining took place. These are (in alphabetical order) Amphitrope, Anaphlystos, Besa, Phrearrhioi, Thorikos and Sounion. Thanks to the discovery of several rock-cut horos-inscriptions in the region, we are able to draw borders between at least some of these ancient demes. In addition to the already known series of horoi on Megalo Baphi and on Spitharopoussi (Lohmann, 1993, p.109, fig.12, pp.447–448, PH 62 no.1–5; Fig. 4), only recently a rock-cut horos inscription already mentioned by K.G. Fiedler in 1840 has been rediscovered by M.K. Langdon (Fig. 2. 3).[6] Although this inscription to the north of Plaka, in a saddle a little northeast of the Mousaki (H 359), is somewhat smaller than the horoi on Mt. Megalo Baphi

Fig. 2: Rock-cut horos inscription situated North of Plaka (photo: Hans Lohmann).

Fig. 3: Rock-cut horos inscription situated North of Plaka (photo: Hans Lohmann).

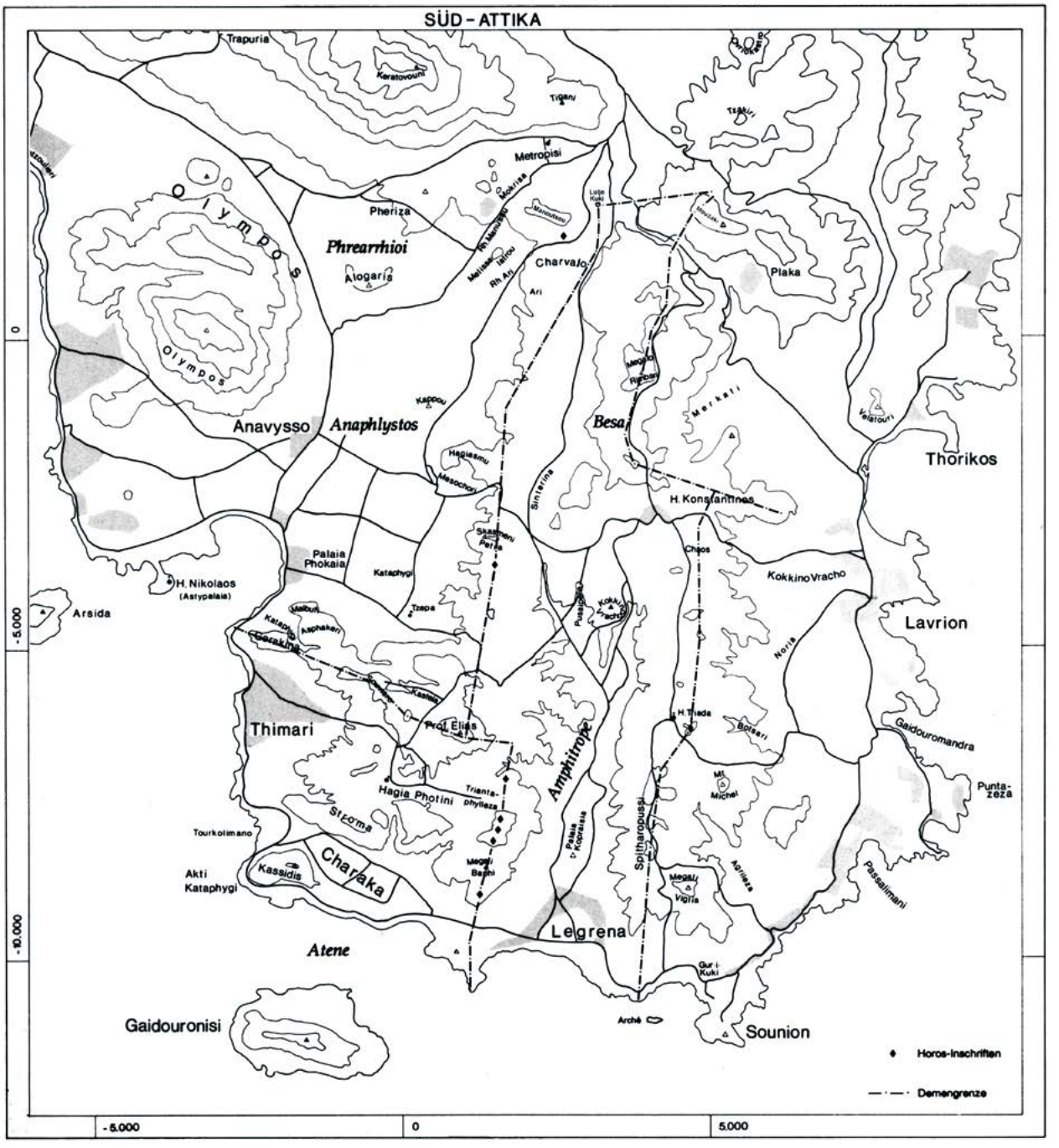

Fig. 4: Map of South Attica with borders of demes (by Hans Lohmann).

and on Mt. Spitharopoussi, it might well mark the border between the demes of Kephale (Keratea) to the north and Thorikos to the south. At the same time, the discovery of four ancient shafts in the northeastern part of the Manoutsou or Koumarodiasello discovered by M. Vaxevanopoulos (this vol.) raises the question, where the valley of Metropissi (miswritten as "Μητροσπίτι" in the Greek Topographical Map Sheet Lavrion, Fig. 5) north of the Manoutsou belonged in antiquity. Since it is by no means identical with the ancient deme of Amphitrope (Lohmann, 1993, p.80) and no mining leases are attested for the closely adjacent deme of Kephale (more or less identical with modern Keratea), it was evidently part of Phrearrhioi.

It is not particularly surprising that in antiquity the mining landscape of the Laurion was made accessible by a dense network of mule tracks and driveways, some of them being the same ones we still drive on today. 'Roads' (ὁδοί), perhaps not always in the strict sense of the English word as driveways but as mule tracks, are often mentioned as borders of mining concessions in the

Fig. 5: Map of district of Ari. From Athenai-Koropion 1 : 50 000 (edited by the Geographiki Hyperessia Stratou, 1976; modified by Hans Lohmann).

mining leases from the Athenian Agora. The few remains still existing have been studied previously by J. Young (1956b) and more recently by O. Kakavogianni (2008).

What has been mined?

The question what has been mined in prehistoric and ancient times in the Laurion has been discussed for some time (see Ross, et al., this vol.). For my part I can only offer an archaeological point of view on the topic. Although the Laurion is primarily famous for its silver deposits, it is indeed a polymetallic ore deposit. No less than 700 different minerals are attested there.[7] A significant by-product of the silver was lead, which was obtained in large quantities. But there are also copper minerals. Although the quantitative relationship between copper and lead ores in the Laurion is difficult to ascertain, the copper ores were obviously mined primarily in the bronze age (Gale, et al., 2009). In this context it should be noted that one of the largest Early Bronze Age sites of Southwestern Attica is located on a hill called Mokriza, only about 1.5km Northwest of Mt. Charvalo at Ari.[8] The hill is situated on the 'Phrearrhian' side of the torrent Ari (Fig. 1. 4). On the hilltop traces of a sanctuary were found and remains of a settlement of the Classical period were discovered in the much overbuilt slopes (Lohmann, 1993, pp.75. 505, AN 25. 26). D. Parras discovered fragments of crucibles,

slags and litharge, which have not yet been published (Andrikou, et al., this vol; A. Kapetanios, pers. comm.).

Besides, copper zinc minerals may have played a certain role (Hanel and Bode, 2016, p.174). The existence of large zinc deposits has already been pointed out by K. Fiedler (1840, p.71) and A. Cordella (1901, p.353), while the Compagnie Française Minière de Lauréotiké (CFML), founded in 1876, was the first to realize the potential of the deposits of zinc carbonate (calamine) in the Laurion and to mine it. Zinc sulfide (sphalerite, from Greek σφαλερός), which was recognized as zinc mineral only in 1735 (Lüschen, 1979, p.191) and could not be melted before the 18th century seemingly prevails in the Laurion. While it is unclear, to what extent zinc sulfide was mined in modern times in Laurion, since there are still large amounts of it, its use cannot fully be excluded for pre-industrial times. Likewise, there is no evidence for the mining of zinc carbonate (calamine) in ancient Laurion (Nomicos, 2021, p.34). But since brass (Greek ὀρείχαλκος, Latin aurichalcum), an alloy of copper and zinc (Hammer, 2001, pp.609 – 615), was not produced by mixing melted copper and zinc, but by adding zinc ores like calamine or sphalerite to melted copper (Hauptmann, 2020, pp.402. 404), it would be surprising, if brass should not have been produced in the Laurion – be it by experiment or by chance. But once again evidence is totally lacking, especially, since on the basis of the data available, it cannot be decided whether and to what extent the numerous Classical or Hellenistic 'bronzes' in the museums around the world are actually brass.[9] It would, therefore, be fully speculative to claim that the brass ingots from a shipwreck sunk on the Southern coast of Sicily near Gela, allegedly dating back to the 6th century BC,[10] or those from another wreck found near the island of Embiez (Dép. Var, France), vaguely dated between the 4th and the 2nd century BC (Dumas, 1972, pp.181 – 185; Parker, 1996, pp.252 – 252; Hauptmann, 2020, pp.402 s.), originated in Laurion. The Romans, for whatever reasons, did not mine calamine at Laurion, but on Sardinia (Boni and Large, 2003; Boni, et al., 2002; Valera and Valera, 2005; Valera, et al., 2005).

Another major problem is the question, if iron was produced in the Laurion (see Ross, et al., this vol.; Nomicos, 2021, p.34). Certainly, the need for iron in the largest Greek polis besides Sparta was enormous: in architecture, agriculture and warfare as well as for the shipyards and last but not least in the mining district itself. Although iron ore does exist in the Laurion, clear archaeological evidence for mining and smelting of iron is totally lacking. Iron slags are very large and usually occur in huge quantities. So far, no such slag heaps have ever been reported from Laurion, but only forging slags, which sometime were erroneously reported as smelting slags. Huge slag heaps as relics of iron smelting are found in Etruria instead. Was iron the commodity exchanged against Athenian Black Figure and Red Figure vases, which are found in Etruscan tombs in their thousands? But is it even thinkable, that a polis of the size of Athens could cover its need for iron by import only? Unfortunately, the 'fingerprint' of the iron clamps of the Erechtheion (Conophagos and Papadimitriou, 1986, pp.129 – 42) does not point unambiguously to a provenance from Laurion. The methods of analysis applied to them in the 1980s do however not cope with today's standards of provenience studies.

Regarding Laurion, there is much talk about silver in the extant ancient sources, rarely and only in rather unreliable ones about gold, as already A. Boeckh (1842, pp.627 s.) had clearly seen.[11] Only B. Rieck in a regrettably confused passage of his dissertation has claimed the contrary.[12] Still little is known about gold production in 5th century BC Greece. But the literary testimonies do not have Laurion among the few places in Greece where gold was mined in the 5th century BC (Eddy, 1977, pp.108 – 109). This silence of our sources is difficult to explain, since thanks to recent research of P. Voudouris (Solomos, et al., 2004; Voudouris, 2005; Voudouris, et al., 2008; 2018; Rieck, 2012) there are evidently gold containing minerals in Laurion.

In the middle of the 5th century BC Phidias constructed the chryselephantine statue of Athena Parthenos, whose garment consisted of 1.5 mm thick sheet gold weighing 1.150 kg or 44 talents, thereby forming an important part of the state treasury.[13] Where did this huge amount of gold come from? S. Eddy (1977) argued that the major part consisted of melted coins of different, also Persian, origin mainly paid as a tribute by Athens' allies. But in the light of the new evidence mentioned, one wonders if at least part of this gold might originate from Laurion. Unfortunately, so far there is not the slightest piece of evidence for this.

In a polymetallic ore deposit like Laurion, offering hundreds of different minerals, pigments should have been an important by-product of mining. Since the Archaic period a growing need for pigments was fuelled by the practice to colour lavishly not only marble sculpture but whole temples. Pliny (n.h. 33,46) praises the ochre (Greek ὤχρα) of Laurium and indeed in a modern mine at Plaka ochre of the finest quality is present and ready for use without any further processing (Nomicos, 2021, p.34 n.287). Likewise, Vitruvius (7.7.1) describes Attic ochre as the best, thereby stating that it is currently not available. His formulation seems to imply that the supplies are exhausted, which is evidently wrong. The real reason might well be instead that in his times the mines had been long shut down and the Southern part of Attica was depopulated. Presumably for the same reason the extant literary sources offer no explicit evidence on cinnabar (Greek κιννάβαρι) and red chalk (μίλτος) from Laurion, which are to be expected as other significant by-products of lead-silver mining (Lauffer, 1979, p.44). But so far archaeometry and archaeology cannot fill this gap.

Mines and shafts

As already stated above, the "Lavrion Shafts Project" of M. Vaxevanopoulos and his team has clarified the number of ancient mine shafts in the Laurion district. The general correlation between the number of mines rented out, the number of shafts in the Prussian maps and the number

of shafts located by the "Lavrion Shafts Project" should not distract from the fact that although almost every shaft indicates a mine, not every mine necessarily disposed of a shaft. The number of mines should, therefore, be higher than the number of shafts.

In times when explosives were not available and galleries as well as shafts had to be hewn into the native rock by hand only, it was more economic to access the ore deposit by a shaft than by a gallery – especially under the aspect, that later on, a shaft allowed for easier access to the mine as well as easier hoisting of the ore by simple lifting devices (Conophagos, 1980, p.163). In a series of articles D. Morin has convincingly shown how the ventilation of a shaft was enabled during the process of sinking it (Morin and Herbach, 2008; Morin, et al., 2012).

The absolute and relative chronology of the ancient mining shafts at Laurion is open to debate. K. Konophagos differentiated nine different types of shafts (Conophagos, 1980, pp.163–165. 205–207, fig.9–32). Since none of the hundreds of shafts can be dated more precisely and since we do not know the reason why different types of shafts exist, it is obviously impossible to establish a relative chronology (Nomicos, 2021, pp.36–41). With respect to absolute chronology, so far it is totally unclear when the first shafts were sunk in the Laurion. Some connected the 'invention' of sinking a shaft with the mention of the discovery of an extremely rich ore deposit in 483 BC by Aristotle (Kalcyk, 1982, p.106). This is purely speculative (Nomicos, 2021, pp.90–91). An approximate date could perhaps be obtained if one knew the precise age of the oil lamps, which were found in the shafts. Contrary to the 'normal' evaluation of a stratigraphy, in this special case the oldest find dates the shaft. Unfortunately, so far, no evidence of this kind is available.

As far as we know, during the Hellenistic period, when the New Style tetradrachms were emitted, mining was not resumed, but the silver was exclusively won by reworking ancient slags (Lohmann, 2005, p.126; Nomicos, 2021, pp.112–113). This is, why in some of the slag heaps in the Laurion, meticulously mapped by Greek mineral engineers Vouyoukas and A. Kordella (Conophagos, 1980, pp.134–135, fig.7-3; 7-4) amphora stamps of the first half of the 2nd century BC were found (Lohmann, 2005, p.126; Börker, 2018).

Starting with the Early Byzantine era in the 4th century BC, but especially under the reign of emperor Justinian (527–565 AD), a remarkable revival of the Attic countryside can be observed (Mattern, 2010). In many parts of Attica Early Christian churches were established, in their majority rather modest ones, but also some larger three-aisled basilicae like at Brauron, Olympos and Lavrion. In Southwestern Attica a remarkable increase in pastoralism is evident by the number of Late Roman or Early Byzantine sheepfolds, so-called mandras (Lohmann, 1993, pp.254–261). Besides these, some of the larger Classical farmsteads have been reoccupied – at Hagia Photini (Lohmann, 1993, pp.145, 207, 431–433, PH 33) as well as at Charaka, where a Classical grave precinct served as backwall to a modest house (Lohmann, 1993, pp.126–128, 362–367, CH 14, CH15). Mining was resumed to some extent too.[14] We are informed that "the veins of Laurion were opened" (Paul. Sil., Ecphr. 678–681; Nomicos, 2021, p.121), in order to cover the enormous costs of the Hagia Sophia at Constantinople.

S. Nomicos in her comprehensive work (Nomicos, 2021) has thoroughly collected all available direct and indirect evidence for the revival of the mining district which occurred since the 4th or 5th century AD (Nomicos, 2021, pp.121–128). While the large 5th century AD basilica at Lavrio, providing clear indirect evidence for an economic upswing had to give way to modern houses (Nomicos, 2021, pp.126. 206, Kat. 182), a large mosaic from this church is preserved in the archaeological museum at Lavrio (Salliora Oikonomakou, 2007, p.45 fig.49; Nomicos, 2021, pl.40,1). Only little, and sometimes doubtful, direct evidence for Early Byzantine mining in the Laurion has so far been published. A. Milchhoefer (1887, p.302) mentions grafitti "aus christlicher Zeit" (from the christian era) in a shaft at Berseko, K. Konophagos (Conophagos, 1980, p.385) reports coins of the 4th century AD from the Asklepiakon of Simos and in an unstratified context in Mine 3 at Thorikos lamps of the 5th century AD were found (Butcher, 1982). D. Morin saw Late Roman oil lamps in some of the Laurion mines he investigated and a piece of burned wood, dated to the 5th century AD by C14-analysis (pers. comm.).

Evidence that new shafts were sunk during this period is lacking. The hundreds of Classical shafts provided ample and easy access to the mines. But what about enriching and smelting? A single Late Roman water jar found in the workshop at Mt. Michel, excavated by J.E. Jones and E. Photos-Jones (Jones 1984/85, pp.122–123), does not testify to any metallurgical activities of the time (Lohmann, 1993, p.260 with n.1810), nor do the few fragments of Late Roman pottery which W. Wrede collected at Megala Pefka (Lohmann, 1993, p.95; Grigoropoulos, 2009, pp.431–432 no.11, 15, p.478, FO 070). Among the pottery from the large *kaminos* at Ari excavated by K. Tsaïmou, were some few fragments of the typical Late Roman 'combed ware'. Moreover, in one of the eight furnace chambers (φ 5) charcoal dated by ^{14}C to the 5th century AD might testify to metallurgical activities there (Tsaïmou, 2007, pp.221–225; Nomicos, 2021, pp.169–170 Kat. 18; Tsaïmou and Nomicos, in prep.).

107 ancient shafts are marked in the map of the CFML published by K. Konophagos (Conophagos, 1980, map). Only a fraction of them was re-used in modern times, some were widened or repaired in order to enable machine hoisting like the Puit Damianos and the Puit Skouzès at Ari, while others were deepened like the Puit Serpieri 1 at Kamareza. But no precise statistics are available for the time being. However, to the best of my knowledge, no new shafts were sunk after the resumption of mining in the 19th century. Many galleries were enlarged by the CFML too. Obviously, a closer study of modern mining in the Laurion and of the archival materials in the Technologico Parko at Lavrio, would contribute considerably to our understanding

Fig. 6: Edge-mill, so-called 'crushing table', in the Asklepiakon of Simos at Soureza (photo: Hans Lohmann).

Fig. 7: Ari, site no. 85. Depressions in the living rock, most probably created by crushing the ore (photo: Hans Lohmann).

of the ancient remains. Unfortunately, interest in this topic seems regrettably low, while the economic policy aspects of 19th century mining at Laurion have been masterly elucidated by K. Schönhärl (2017, pp. 166–213).

Besides the questions already mentioned, more research is needed on the tools used for mining in the different periods of exploitation. Obviously, the geology of an ore deposit determines to a certain extent the shape of the tools required for mining. But which tools exactly had been used for the exploitation of the ore deposit and for winning the ore, has not satisfactorily been clarified. Differing from the former view expressed by G. Weisgerber (1988, pp.203–205), G. Körlin and G. Weisgerber in a more recent paper hold (2004) that hammer and wedge have been invented in the Middle Ages and were not used in Greek or Roman mines. A closer study of toolmarks might be helpful to solve this question. A pick from Laurion is in the collection of the Bergakademie at Freiberg (Weisgerber, 1988, p.208, fig.249). K. Konophagos published three hammers from Laurion, two of them still preserving their wooden handles. Another one with a wooden handle is said to be in his private collection (Conophagos, 1980, pp.176–177, figs.9-8. 9-10). It would doubtlessly be a great advance if the age of these tools could at least approximately be determined by ^{14}C-analysis.

The beneficiation of the ore

At all periods, the workflow from the mine to the metal takes three fundamental steps: mining, beneficiation and smelting or extractive metallurgy.[15] After sorting the mined material roughly underground, the ore underwent a process of beneficiation, which, even after decades of research, still raises many questions. Since the ore was extracted by hand, no large chunks were brought to the surface, only small ones. Nevertheless, these had to be crushed further. Therefore, the beneficiation of the ore before smelting likewise took three steps, namely crushing, grinding and washing.

1. Mining
↓
2. Beneficiation
↓
a. Crushing
↓
b. Grinding
↓
c. Washing
↓
3. Smelting (extractive Metallurgy)

Crushing

The crushing above ground did not take place on the so-called crushing tables consisting of big blocks of limestone, which K. Konophagos discovered in the Asklepiakon (Conophagos, 1980, pp.220, 227, 233, figs.10-3, 10-4, 10-15) and which are also well attested for many other workshops (Fig. 6). They served instead for grinding, most probably under the addition of water, because in most instances the surface of these blocks is extremely smooth and has a shallow circular depression. It is most likely, therefore, that these blocks are to be identified as the stone beds of saddle querns, on which the grinding was achieved by circulating movements with a rounded stone tool (Nomicos, 2021, pp.47–48). Since limestone is rather soft compared to basaltic lava, the preferred material of the so-called Olynthian mills, the question arises whether these saddle quern-like mills served for grinding ore or more probably for something else – for instance slags or litharge.

But where did the fine crushing take place instead? At two sites at Ari for the first time groups of round depressions in the living rock have been observed (Fig. 7). I hold that these are not natural. The living rock served here as a processing floor (Nomicos, 2021, p.46 pl.7,1). Similar depressions were found by D. Morin within the mines (pers. comm.). But the date of their use is unclear. Any period from prehistoric times to the Byzantine era and beyond can be

considered, as is exemplified by an old postcard (Nomicos, 2021, pp.46 pl.7,2; Nomicos, this vol., fig.2).

Grinding

Compared to the edge-mills (Fig. 6), which are known since Neolithic times, the so-called Olynthian mills mark a significant advancement in grinding technology. They belong to the category of lever mills. K. Kourouniotis (1917) was the first to acknowledge their true function. They owe their name to Olynthos, the destruction of which by Philip II. in 348 BC marks a clear *teminus ante quem* for their invention. Indeed, they existed at least since the early 5th century BC (Amouretti, 1986, p.142). Although at Olynthus these mills served exclusively for grinding grain, K. Konophagos was most probably right in assuming that those found in large numbers in every *ergasterion* of the Laurion, served for grinding ore – be it cerussite or galena (Conophagos,

Fig. 8: Quadrangular block of limestone with recess in the Asklepiakon of Simos at Soureza, serving as support for an Olynthian mill (photo: Hans Lohmann).

Fig. 9: Quadrangular block of limestone with recess at Thorikos, serving as support of an Olynthian mill (photo: Hans Lohmann).

Fig. 10: Ari, site no. 32. Pan grinder or kollergang, excavated by K. Tsaïmou (photo: Hans Lohmann).

1980, pp.220, 228–229, figs.10-6/8; Nomicos, 2021, pp.48–49). Their material, a basaltic lava not available in Attica, is harder than both types of ore. But it is also evident that they likewise served for grinding grain for the nutrition of the numerous workers. Most probably the stator of the mill was positioned on blocks with a rectangular recess, in order to prevent the stator from slipping. Such blocks have been found within the Asklepiakon (Fig. 8) as well as at Thorikos (Fig. 9) and elsewhere. Fragments of Olynthian mills from a recently excavated washery at Ari, which were tested by A. Hein (NCSR Demokritos) by means of an XRF-diffractometer, displayed no traces of lead higher than the surrounding ground, which should instead be the case if they had served for grinding ore (Hein, in prep.). These tests should be continued on as many samples as possible, especially since they are non-destructive. However, the large number of fragments of Olynthian mills found in the workshops clearly hints to their use in metallurgical processes, because by grinding grain only not as many would be broken as by grinding the much harder ore.

It is crucial for our understanding of the enrichment process, if the grist was afterwards ground to a powder-like substance by the saddle quern-like mills, or if they served other purposes as indicated above. There is obviously a need here for clarification.

The claim of M.I. Finley and his school that there was no substantial technological progress made during antiquity (Greene, 2000) is disproved by an even greater technological advancement which was achieved during the second half or near the end of the fourth century BC, when the pan grinder or *kollergang* was invented. They were probably driven by animals. K. Konophagos (Conophagos, 1980, pp.248–252) erroneously identified them as 'helicoidal washeries'. S. Nomicos first argued that they are neither helicoidal nor washeries, but large *kollergangs* or pan-grinders (Nomicos, 2013; 2021, pp.50–57). Her new interpretation has immediately gained much approval.[16] These *kollergangs* are made from large blocks of limestone which is much softer than the basaltic lava of the Olynthian mills.

It can therefore hardly be assumed that ore such as galena was ground on them. Rather, as G. Papadimitriou has suggested and as analyses of grinding residues confirm, one should think of litharge. Litharge is a by-product from the smelting of lead ores. It still contains high percentages of lead and silver. In order to recycle it, it had to be grounded first before it could me smelted again together with a fresh batch of ore. If the grinding of the litharge happened on these kollergangs, which are attached to the ore-concentrating plants, not to the smelting works, an important conclusion can be drawn about the economic relationships between the operators of the processing plants and the smelter sites. Because it would mean that the lessees or operators of the processing plants did not sell the enriched ore to the operator of the smelter, but that he worked against payment.

And this would also explain, why these pan grinders are so numerous in Ari, where no less than five of them have been found: Three have been excavated in an excellent state of preservation by K. Tsaïmou (Fig. 10), two more are testified by fragments: The smelting place at Ari evidently produced large amounts of litharge which had to be recycled in the nearby ore-concentrating plants. Since the surroundings of the other huge smelting place at Pountazeza excavated by K. Konophagos (1974) was already overbuilt by summerhouses in the 1970s, no evidence for a similar accumulation of *kollergangs* is available there. But at least two of these were testified close to the well-known furnace at Bertseko-Megala Pevka (Mussche and Conophagos, 1973, pp.66–71; Nomicos, 2021, p.178 Kat. 50, for the Kollergang ibid. p.175 Kat. 34).

With regard to the discussion on gold above, it should be noted here, that similar *kollergangs* or pan-grinders served in Egypt for grinding gold-bearing minerals.

The mechanisation of fine crushing by means of a *kollergang* would have brought about a substantial increase in productivity, while additionally saving manpower. This fits perfectly well with the economic situation of the second half of the 4th century BC, when the output of the mines decreased and slave labour was less available. Almost at the same time, the *kollergang* for milling olives was most probably invented by the Athenian mathematician Aristaios (Lohmann, 1993, p.215).

Washing

With respect to washing, it must be emphasized, that under pre-industrial conditions there was no other choice for enriching the ore than by gravity separation with water. The total number of ancient washeries in the Laurion is not

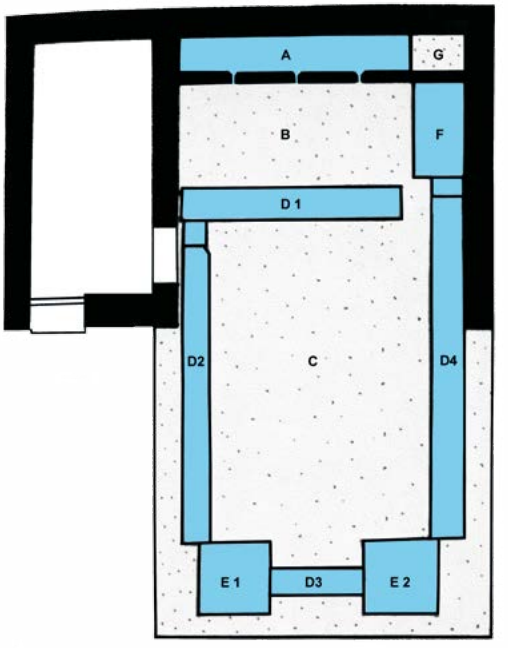

Fig. 11: Canonical type 1 washery at Agrileza, after Travlos (1988, p. 208, fig. 260) (modified by Hans Lohmann).

exactly known, there might have been over 250 (Nomicos, 2021, pp.63 s.), almost as many as shafts. In the mining leases they appear as '*ergasteria*', a general noun for workshops of all kinds.[17] The *ergasteria* or workshops of the Laurion all differ in terms of the arrangement of the rooms, but all have a washery as a central component. These washeries are surprisingly homogenous (Fig. 11). Almost all examples known to date are of a rectangular plan and consist of a tank (A) with four to eight jets in its front, a slightly (8%) inclined area (B) in front of it, and between two and four round or rectangular basins (E1-E4) at the corners connected to each other by water channels (D1-D4). A distinction can be made between type 1 and type 2 washeries, whereas the type 1 washeries form the overwhelming majority. The principle of both types is similar (Nomicos, 2021, pp.63 s.). While the tank and the area in front of it were roofed, the rectangular area (C), surrounded by the channels, which evidently served for drying the enriched ore after washing, was open to the sky. All parts exposed to water are covered with the same hydraulic mortar which was used to seal the cisterns. Because of their homogeneity we call these washeries 'canonical'. They seemingly belong in their majority to the 4th century BC. But what about their forerunners?

Fig. 12: Ari site no. 76, uncanonical washery, probably early 5th century BC (photo: Hans Lohmann).

Fig. 13: Ari site no. 76, uncanonical washery, probably early 5th century BC, detail of channels and tanks (photo: Hans Lohmann).

Fig. 14: Kamareza-Vrissaki, uncanonical washery, most probably unfinished, 6th century BC (photo: Hans Lohmann).

Only very few examples differ from this 'canonical' ground plan by displaying a totally irregular arrangement of tanks and channels (Nomicos, 2021, p.182, no.64, pl.31; p.186, no.77, pls.32, 2. 33). To the already known examples another one excavated in 2016 at Ari (site no.76) might be added (Fig. 12. 13). Of special interest is the example E. Kakavogiannis excavated on the edge of the gorge of Vrissaki below Kamareza, because he dated it back to the 6th century BC (Kakavogiannis, 2001, p.374, fig.8; Nomicos, 2021, p.182, no.64, pl.31; Fig. 14). Unfortunately, he passed away, before he was able to fully publish this most important finding. Tanks and channels have been cut into the extremely hard cemented alluvial fan, but are not coated with hydraulic mortar, even though the ground is permeable to water. Moreover, no remains of any walls have been found. The likewise irregular washery found at Ari (site no.76) is cut into the native bedrock, but channels and tanks display clear remains of mortar, although the washery has been seriously damaged by the activities of the CMFL. The bottom of the tank (Fig. 13 right below) was carved out by treasure hunters, most probably in the Byzantine period. The pottery found in connection with this washery points to a date in the 5th century BC. Another pre-canonical ore-washery was discovered underneath the fourth-century Hilltop Tower at Soureza (Young, 1956a, 129–131; Goette, 2000, 86; Lohmann, 2005, 118). The basins and tanks are likewise coated with mortar. The installation at Kamareza-Vrissaki, therefore, seems to be unfinished. Another explanation was kindly brought to my attention by F. Hulek (pers. comm.). He holds that regarding the finds of fine ware of the Archaic period it might be a totally plundered and devastated grave precinct of the time. Be that as it may: evidently an experimental phase preceded the invention of the 'canonical' washeries.

Four different models as to how the 'canonical' washeries were run have been discussed. It seems that already in 1881 Ph. Negris has given the correct answer (Negris, 1881). His model of the functioning of the rectangular washeries is based on Agricola. In his work "De re metallica libri XII" of 1556 he describes seven different types of washeries. The so-called "short herd" equals the 'canonical' rectangular washeries of Laurion in almost every detail (Fig. 15). The tank has several adjustable jets, which can be regulated according to the amount of water needed. In front of them there is a relatively short wooden box, in which the ore is enriched by stirring it by means of a brush. In front of the box runs a channel, gathering the sandy debris. In the rectangular washeries of Laurion such a wooden box was not required, since the ore could be swayed on the slightly inclined area in front of the tank.

As H. Morin-Hamon (this vol.) has convincingly shown in her paper this model was generally accepted until the publication of K. Konophagos (Conophagos, 1980, pp.224, 241–247, who suggested sluices in front of the jets instead). Many arguments advocate against this, archaeological ones as well as technical (Lohmann, 2005, pp.114, 130; Nomicos, 2021, pp.64–66). Empirically the best results are obtained when the sluices are approximately 2m long (Nomicos, 2021, pl.24,1.3). Should we really assume that over decades the skilled ancient workers never achieved this by experiment? Should we really assume that in all washeries the slightly inclined surface in front of the nozzles is incorrectly oriented because they are always wider than they are deep, allowing for a maximum length of the sluices of 1,10 m? Why, in a period, which displays even in modest buildings or technical installations the highest standards of stonemasonry, was an abutment for the sluices never hewn into the retaining

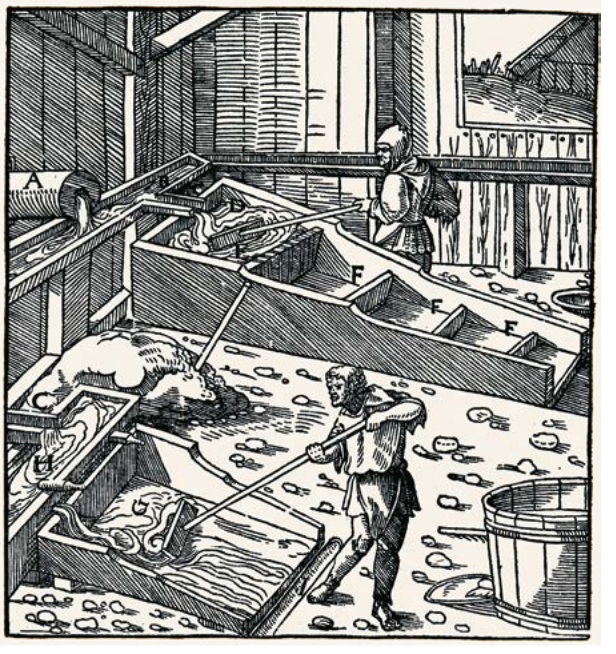

Fig. 15: Georg Agricola (1556, Reprint 1977, p. 261 fig. 11) (modified by Hans Lohmann).

wall with the nozzles? Why, then, were never any sluices found made of stone? Why among dozens of washeries there never occurred any stone support for the sluices, but we are forced to postulate wooden stands instead, although in the 4th century BC the Laurion was already largely deforested and wood as fuel for the furnaces had to be imported?

Ockham's razor or law of parsimony perfectly applies to this finding: This problem-solving principle postulates that "entities should not be multiplied without necessity" – or the simplest explanation is usually the right one (Schaffer, 2015).

The model of C. Domergue (1998; 2008, pp.66–67), who holds that the ore was agitated within the tank behind the nozzles, does not stand up to any critical examination. When excavating a washery at Ari in 2016 (Lohmann and Kapetanios, in prep.) it became totally obvious, that the hydraulic mortar within the tank, especially its floor, was

in excellent condition, just as if it had been made yesterday, while the mortar on the area in front of the nozzles was much worn and displayed clear signs of wear, as we should expect, if the ore is moved in front of the nozzles by means of brushes or wooden pushers.

Likewise panning by means of *lekanai* as prosposed by E. Kakavogiannis (2005) can be excluded. As experiments with modern replicas by K. Tsaïmou have shown, these clay bowls are far to brittle for the heavy ore and far too deep (Tsaïmou and Fragkiskos, 2001; Nomicos, 2021, p.66). For panning, as the name indicates, flat metal pans are required. The considerable number of fragments of lekanai found in every workshop can easily be explained by the often large number of workers, the one-sidedness of nutrition (mainly barley groats with olive oil) and the fragility of clay vessels in general, which are much less durable than modern porcelain, fired at 1400° C.

While the use of sluices in the 'canonical' washeries can safely be excluded and should no longer be discussed, on the basis of the data available it seems uncertain whether the separation of different grain sizes of ore in the channels D1 to D4 and the basins or tanks E1 to E4 respectively was intended and what it might be good for. Anyway, the main purpose of the basins and the connecting channels was to purify and to recycle the scarce water.

Large quantities of water were required to wash the ore. Although according to H. Wotruba, a worldwide renowned expert in beneficiation at the RWTH Aachen, seawater might do (pers. comm.), no ancient washeries are ever found at the coast. In the notorious semiarid climate of Attica with a precipitation of 377 mm per year only, the enrichment of the ore could only be continued during the dry season if enough rainwater was stored in large tanks during the more humid months, i.e. mainly in the winter from December to March. Nowadays – but this situation might slightly differ from antiquity – there is usually no rainfall between mid-April to mid-October. No wonder, therefore, that large to huge cisterns were found all over the Laurion.[18] Every cistern indicates more or less an *ergasterion*, since only very few metallurgical sites are known that had springs, as at Vrissaki near Kamareza or at Palaiokamareza, or groundwater wells as at Ari and at Demoliaki (Nomicos, 2021, p.62). A waterproof mortar was required to seal the cisterns as well as the tanks, channels and basins of the washeries. But when and where was it invented? The enormous boom of mining in the 5th century BC Laurion would not be possible without the construction of the numerous cisterns. As F. Schön has shown in his PhD (Schön, in prep.) there are no cisterns with hydraulic mortar in the Western Mediterranean before the 5th century BC. But what about the Near East?

Thanks to new evidence from Tell el-Burak in Lebanon it has become evident that the Phoenicians, already in the 7th century BC, were able to produce a water-resistant plaster or mortar which closely resembles the mortars of the cisterns at Laurion (Orsingher, et al., 2020, pp.1233–1241) – especially by adding grog (crushed pottery or tiles).[19] Maybe in the Near East the technological achievement of water-resistant mortars goes back to the Bronze Age (Yadin, et al., 1958, pp.118–140, pls. CLXXXII. CLXXXIV). At Hazor in the period LB II (Late Bronze Age II) cisterns nos. 9024 and 9027 have been secondarily used as graves and the burial within cistern no.9027 contained two imported Mycenaean LH II B-pyxides as grave goods. The cisterns, therefore, are undeniably older. The inner lining of the cisterns is described by the excavators as 'plaster'. But to my knowledge no archaeometric analyses were made. Whether and to what extent this 'plaster' was water-resistant and if it contained grog is, therefore, totally unclear. Be that as it may: The mortar used in Tell el-Burak in the 7th century BC fulfils all requirements for water resistance. Since so far, no securely dated cistern of the 6th century BC lined with water-resistant mortar is known in Greece, it remains an open question when this technology was brought to Greece and where it was first applied there.

The cisterns each had sediment traps and a sophisticated rainwater catchment system, remains of which are only seldom preserved, as for instance in the Soureza Valley where a channel served a whole chain of cisterns sunk into the valley bottom (Ardaillon, 1897, pp.66s., pl.3; Nomicos, 2021, pl.21, 23,2). Such catchment systems were not limited to the mining area. They can, for instance, also be found in a purely agrarian environment like for instance in the Mikro- and Megalo Kriftis Valleys in the Megaris (Van de Maele, 1984), which are totally void of springs.

A most interesting phenomenon about the cisterns in the Laurion, is that despite its hilly nature, the cisterns are regularly sunk into the ground at the same level as the washeries. Only in very few instances are they built higher up the hillside so the water could flow by gravity to the washery, while normally their tanks had to be filled by manpower. The operators or *epistatai* of the washeries apparently feared that otherwise the slaves would simply open the tap for convenience and waste the precious water.

Evaporation is another problem connected to the cisterns because of their wide openings and the climatic conditions in Attica. Obviously, roofs were indispensable in order to avoid too much evaporation, which would consequently have lead to an untimely end of the beneficiation process. Burnt-clay roof tiles are heavy and would, therefore, require strong wooden supports. So far, only very few cisterns with a central support pillar are known (Nomicos, 2021, p.61, pl.22), but to my knowledge there have never been found any large amounts of roof tiles within any of the numerous cisterns of Laurion. Many of these are circular and would, therefore, require conical roofs, but the manufacturing of these as a clay roof is extremely demanding. Neither these nor fabric sails are an option for covering, considering the frequent strong storms in Attica. The best thing to think about might, therefore, be thatch roofs (Kakavogiannis, 2005, p.226; Nomicos, 2021, p.61). These may often have been used to roof simple rural buildings and properties, workshops, stables and the like, because too few roof tiles were found during excavations of such buildings. This also applies to the *ergasteria* themselves.

Fig. 16: Megala Pefka in the upper valley of Legrena. Washery, excavated in the 19th century (photo: D-DAI-ATH-Attika-0062. With kind permission of the German Archaeological Institute at Athens).

Smelting

As far as smelting is concerned, I cannot go into any detail here, because the problems involved are far too many. I wish, instead, to touch upon some selected points only. First, the number of furnaces. I am convinced that the number of furnaces existing during the Classical and perhaps the Hellenistic period in the Laurion might be rather precisely calculated on the basis of the slag heaps thoroughly mapped by A. Kordellas and M. Vouyoukas (Conophagos, 1980, pp.134 – 135, figs.7-3. 7-4). Before the ancient slags were reworked at Lavrio during the 19th and 20th century, nobody took the pain to carry slags in large quantities from one point to another. It is, therefore, most likely that the number of slag heaps coincides more or less precisely with the number of furnaces once existing. Although both maps are much distorted and not to scale, they consistently display two slag heaps at Ari-Charvalo, which fits the results of the survey there (see below). A third heap on Manoutsou, shown on the map of Vouyoukas, has completely vanished as well as the furnace, which is indicated by the heap.

The remains of the ancient furnaces became particularly victims of the raging of modern mining companies. So far only at four sites have the remains of furnaces been excavated. All of them had already been looted. The size of the

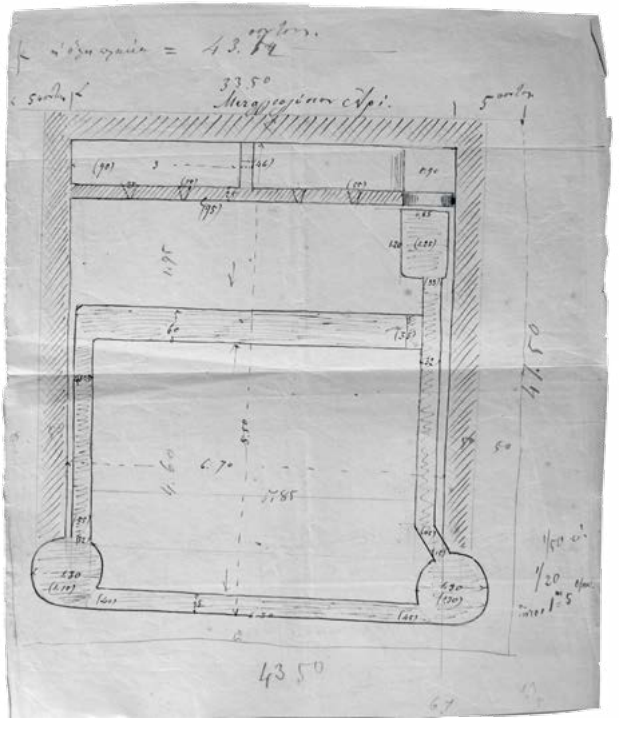

Fig. 17: Rough sketch of an otherwise unknown washery at Ari by A. Kordella (?) in the copy of Cordella (1869), owned by O. Kakavogianni.

smelting works ranges from small ones such as Asimaki or Passa Limani (Nomicos, 2021, pp.178 s., nos.49, 51), to medium-sized ones such as Berseko and Ari (Nomicos, 2021, p.169 s., no.18; p.178, no.50), to very large ones such as Pounta Zeza (Nomicos, 2021, p.179, no.54, pl.27). There might have been another one at Megala Pefka in the upper valley of Legrena, where in the 19th century an excavation took place, which is nowhere documented except for an old photo in the archive of the German Archaeological Institute at Athens (Fig. 16).[20] The most southwestern furnace of Laurion at the bay of Charaka is indicated by a huge amount of slags, sherds of both Classical and Hellenistic age and several Hellenistic amphora stamps (Lohmann, 1993, pp.243–246, 248, 396 s., pl.131, 1. 2). This testifies to activities there when during the first half of the 2nd century BC the New Style tetradrachms were emitted.

A survey at Ari

In 2014 at Ari North of Anavysso, ancient Anaphlystos, a survey was started as a *synergasia* or joint venture between the Ephorate of East Attica, represented by Dr. Eleni Andrikou, the German Archaeological Institute at Athens and the Ruhr-University at Bochum. Since a full report on the survey will be published together with A. Kapetanios in a forthcoming volume, devoted exclusively to Ari, I wish to report here only shortly on the topic, thereby highlighting only some of the peculiarities observed there.[21]

Ari is located in the north of the littoral embayment of Anavyssos and forms the westernmost ore deposit of the whole Laurion. It has been chosen for a survey because there, within a limited area comprising no more than 5 to 6 square kilometres, the whole workflow from the mine to the furnace can be studied, especially thanks to the excavations there by K. Tsaïmou between 2005 and 2008 (Tsaïmou, 2005; 2006; 2007; 2010). The enormous density of mining galleries, shafts and workshops at Ari becomes already obvious from the map of F. von Bernhardi, who mapped the region during the winter 1883/84, and was fully confirmed in the course of the survey (Fig. 1). The project at Ari might, therefore, contribute to solving at least some of the questions still pending, although there has been much devastation by the mining companies during the 19th and early 20th century. Another important peculiarity of Ari is its proximity to the important prehistoric site on Mokriza hill.

In antiquity the small mining district of Ari belonged partly to the large ancient deme of Anaphlystos, partly to the deme of Phrearrhioi. Anaphlystos was represented in the *boule* of Athens by no less than ten councillors. But only five to six mining leases out of 289 are testified for Anaphlystos, even less for Phrearrhioi, sending nine councillors to the *boule*. It is evident, therefore, that mining played only a minor role there, while agriculture was predominant. Despite their Greek appearance, the names of both demes derive from the pre-Greek language substrate. “Phrearrhioi”, for instance, has nothing to do with the Greek φρέαρ “well”. The name of Arí (Ἀρί, stressing the last syllable) derives by iotacism from the locative of Phrearrhioi φρεαρροῖ, as I have argued elsewhere (Lohmann, 1993, p.74 with n.568). Since then, this has been confirmed by the best connoisseur of Arvanitic toponymy of Attica T. Jochalas (pers. comm.). All ancient maps of the 19th century as well as a sketch by A. Kordella (Fig. 17), a copy of which I owe to the kindness of O. Kakavogianni, have Ἀρί, not Ary (Ἀρύ).

The torrent Ari, marked in blue in the map Fig. 1, once formed the borderline between the two demes of Phrearrhioi and Anaphlystos. In 1979 students of the American School found a horos-inscription within the rhevma Ari, correctly identified a marker of the border between Anaphlystos and Phrearrhioi by J.S. Traill (Traill, 1986, pp.117. 146, pl.16,4). And in 1970 E. Vanderpool reported finding a cult calendar of Phrearrhioi at km 48 of the road from Anavysso to Kalyvia (Vanderpool, 1970). Although the inscription was not found *in situ*, it was evidently not much dislocated.

Have the rich ore deposits at Charvalo already been mined in the EBA or even earlier? Are among the hundreds of outcrops some of prehistoric age? As already mentioned, there are fragments of crucibles and slags on nearby Mokriza hill. But at Mt. Charvalo prehistoric pottery is almost totally lacking. A total of four fragments of FN-pottery does not make up for intensive prehistoric activities there. Also, the typical grooved mallets are lacking throughout, while in the 1980s a hundred of them were heaped up in front of Mine 3 at Thorikos. They leave very typical tool marks. Whether any of these may be found within the dozens of ancient and modern underground-workings at Ari, is not yet clear.

With the Puit Skouzès and the Puit Damianos two shafts, both originally 80 meters deep, now filled with waste, are still prominent and had in modern times been improved for hoisting by means of a steam or diesel engine (Conophagos, 1980, map). In antiquity, Puit Damianos gave access to one of the largest mines of the whole Laurion, mine Ari 3, which was visited by D. Morin. He will present the results of his research in a forthcoming volume of the present series.

Without going into much detail, it should be emphasized that no less than 17 workshops have been identified on both sides of the rhevma Marisas / rhevma Ari. Some of them are already destroyed and are indicated by a large cistern on the surface only. O. Kakavogianni kindly send me a rough sketch of a washery at Ari she found in her personal copy of the publication of A. Kordella (Fig. 17). It does not display any of the washeries excavated there by K. Tsaïmou and has, therefore, to be considered as destroyed.

Some of the workshops at Ari evidently did not have a cistern. Due to a special geological phenomenon, groundwater wells were used as in Demoliaki. Others may have drawn water from the rhevma, which was retained by a dam. It cannot be ruled out, that in the Classical period at least some streams and rivers like for instance the Ilissos were perennial (Lohmann, 1993, pp.20–21). With the discovery of four ancient shafts in the northwestern part of the Manoutsou by M. Vaxevanopoulos (this vol.) it has become evident that the workshops on the east

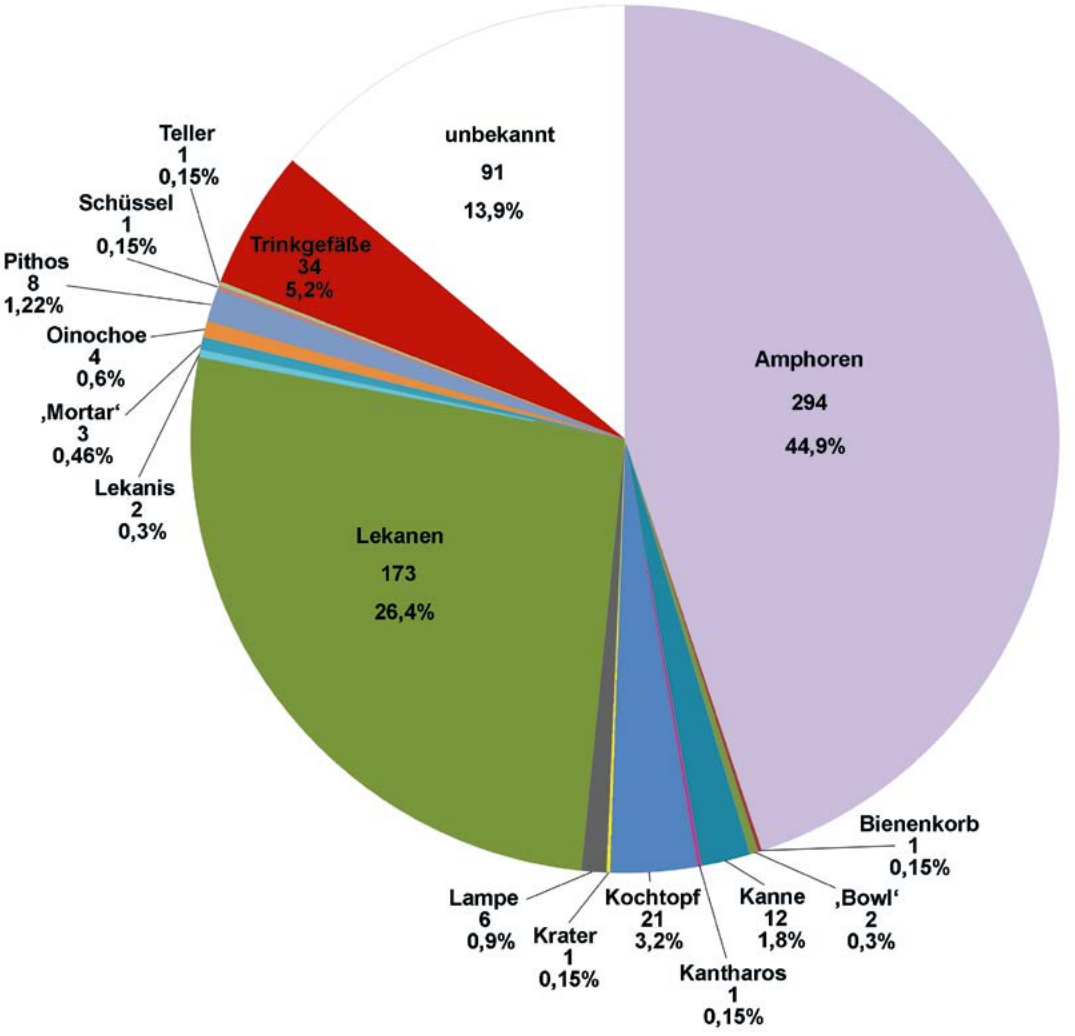

Fig. 18: Pie chart of the shapes of the ancient pottery and their respective percentage found in the survey at Ari. Prepared by Marta Korczyńska.

bank of the rhevma Marisas / rhevma Ari processed ore from these, belonging to Phrearrhioi, while those on the East bank processed ore from Mt. Charvalo.

Besides the local concentration of pan-grinders or *kollergangs* at Ari already mentioned, another important discovery was a stone which looks exactly like the anvil stones, hundreds of which have been found in the Roman mines at Tres Minas in Northern Portugal (Nomicos, 2021, pp.57–58, pl.18,1). We should not be too much surprised if the invention of a mechanical driven stamp mill has already been made much earlier in Greece.

The majority of the pottery from Ari dates to the Classical and Early Hellenistic period. It covers the same time span from the early 5th to the early 3rd century BC as the pottery from a Classical workshop at Ari excavated by K. Tsaïmou between 2005 and 2008 (Tsaïmou and Nomicos, in prep.).

Moreover, workshops can clearly be distinguished from farmsteads and other kind of settlements by the percentages of the shapes of vessels. The *ergasteria* of Ari show a very limited range of shapes, dominated by *amphoras* and *lekanai* (Fig. 18). Cooking vessels and Black Glaze drinking vessels are extremely rare, and there are no loom weights or beehives. This does not testify to what we might call a balanced nutrition for the many slaves working in the Laurion. But it might help us in the future, even in cases of much destroyed sites, where only a scatter of pottery can be found on the surface, to distinguish between rural settlements and workshops.

Conclusions

What conclusions can be drawn on the basis of this short overview?

First of all most urgently needed is a record of all surface remains in the Laurion, a complete atlas of the

mining area, at least at the scale 1 : 10,000, especially with regard to the entry of the mining area into the list of UNESCO World Cultural Heritage. Together with this inventory, detailed surveys of at least some areas of the Laurion are needed. An initiative should be taken to publish former excavations which so far are only known through preliminary reports or short find notes in Greek periodicals like the Archaiologikon Deltion.

The open questions are numerous and not only concern the whole workflow from the mine to the furnace, starting from the question which tools were used and when sinking of shafts was introduced in the Laurion. But also, the question what has been mined, when and by what means. As has been exemplified regarding gold and pigments, the extant ancient sources are sketchy. Other open questions concern the beneficiation and enrichment of the ore, the precise date of the invention of the pan-grinders or *kollergangs*, as well as the development from the 'non-canonical' washeries to the 'canonical' and their respective functioning.

Hopefully the close cooperation between geologists, archaeometrists and archaeologists practiced successfully for many decades, will be continued in the future and will help to solve at least some of the problems addressed here.

Acknowledgements

First, I wish to thank Dr. Eleni Andrikou and Prof. Andreas Kapetanios who were my partners in the Ari-Project and supported it more than can be expressed here in a few words. I also wish to thank the members of my team, Frank Hulek, Sophia Nomicos, Hans-Peter Klossek, Hans Marg (†), Achim Dombert and Dietmar Gansera for their constant help. The last-named provided the fabulous aerial photos. Special thanks go to Professor Adonis Fotiadis for providing a new and more detailed geological map of Ari and to Denis Morin and his team for studying at least some of the shafts and galleries within the survey area. Andreas Hauptmann as well as Norbert Hanel, Gabriele Körlin, Sophia Nomicos, Panagiotis Voudouris and F. Schön provided me with helpful information and some of the articles quoted here. Special thanks go to Sophia Nomicos for her constant help in all questions discussed here. Last but not least I wish to thank Theresa Stewart and John Bintliff for improving my English.

Notes

1 Curtius and Kaupert, 1891 – 1900; reprint Korres, 2008.

2 For now, see the overview in Conophagos (1980, pp.35 – 54) and Manthos and Dermatis (2017). For short accounts see also Kalcyk (1982, pp.214 – 219), Rieck (2012, pp.12 – 24) and <https://el.wikipedia.org/wiki/Λαύριο>.

3 His handwritten diaries and notes are, unfortunately, privately owned and currently not accessible.

4 Lauffer, 1979, p.22: "mehr als 2000 solcher Schächte und Stollen sind in einem Gebiet von 2000 ha nachgewiesen" (without testimony); Kalcyk, 1982, p.161; Goette, 2000, p.97. Critically Lohmann (1993, p.80 with n. 617).

5 For Botsari see Ardaillon (1897, pp.66 s., pl. 3), Kakavogiannis (1989a; 1989b), Lohmann (1993, pp.107 – 108); Goette (2000, p.12) and Nomicos (2021, p.176, no.36; p. 193, nos. 110. 111, pl. 21).

6 Pers. communication. geogr. coor. (WGS84): 37° 46' 28,0" N; 24° 01' 25,3" H 265 mamsl. – Fiedler, 1840, p.63; Curtius and Kaupert 1891 – 1900, sheet 16 (Laurion): "Villia, H 285, H.R.". The inscription is cut into a flat, triangular rock slab near a dirt road about 50 m northeast of an abandoned house. Length: 0.445 m. Its position is not on Mouzaki as presumably indicated in Lohmann (1993, p.109, fig.12) but a little bit further to the northeast (see Fig. 4).

7 For a list see Rieck (2012, pp.177 – 180), for brilliant photos see Voudouris, et al. (2019).

8 The name derives from Albanian mókrëze, diminutive of mókërë, hand mill (Lohmann, 1993, p.303). – Early Bronze Age pottery but no architectural remains were discovered during road construction work at the southern foot of the Mokriza hill (Parras, 2010, p.143, fig.4). This confirms Lohmann (1993, p.505, pl.72,1. 2 [AN 25]).

9 For the use of zinc in antiquity see Craddock (1990, pp.1 – 6).

10 So far, only preliminary reports on this shipwreck have been published (Hanel and Bode, 2016, p.168; Caponetti, et al. 2017a; 2017b; Hauptmann, 2020, pp.402). The date seems far from certain: The ship sank while mooring, i.e. close to the harbour of Gela. Pottery of the 6th century BC is said to be found "nearby", whatever this means. During geomorphological drillings in the harbour of Miletus enormous amounts of pottery of all periods after ca. 50 AD have been found. At this date, the harbour basin had evidently been dredged, but afterwards served as a garbage dump again.

11 Boeckh 1842, 627 n. 37; Hesych. s. v. Λαύρεια; Schol. Arist. Eq. v.1091; Souidas s. v. γλαὺ ἵπταται; Harpokr. and Suidas s. v. χρυσοχοεῖον.

12 Rieck, 2012, p.43. He claims that the mining leases explicitly define gold finds as Athenian state property. But such a contract term is nowhere found in the leases. Furthermore, he quotes from a non-existing inscription that a lessee named Hipponikos delivered two talents of gold in addition to the rent. His remarks on several golden statues of Athena in the Parthenon are totally confused, too. – I thank P. Voudouris for providing me a copy of the dissertation of B. Rieck.

13 Paus. 1.25.7 and Plut., Isis et Osiris 71 report that the tyrant Lachares in 296 BC stole the golden robe of Athena. That he minted coins from it is a mere assumption based on a gold coin of Lachares in the collection of the University of Glasgow: <http://collections.gla.ac.uk/#/details/enarratives/311>. King George III of England (not King Otto III of Greece as Rieck, 2012, p.43 holds) presented it to his personal physician William Hunter, who was a famous numismatist. The golden coin published by Rieck (2019, fig.7), had already been recognized as modern forgery by A. Boeckh .– I wish to thank here Frank Hulek once more for his invaluable help.

14 The remarks of Vryonis (1962, pp.1 – 17) on this point are purely hypothetical. On him relies Lilie (1976, p.260 with n. 224).

15 For the terminology see Weisgerber (2005, p.40). Very helpful is also the multi-lingual dictionary of Venator (1905).

16 Papadimitriou, 2016; see also <https://ntua.academia.edu/georgepapadimitriou> (Presentation 8 November 2015) [accessed January 2017].

17 For ample discussion of the term see Hopper (1953, pp.203 – 207).

18 A dissertation by K. van Liefferinge dealing with the cisterns of Laurion has, unfortunately, not been published. So far see Nomicos (2021, pp.59 – 63).

19 The authors are clearly wrong in stating (Orsingher, et al., 2020, p.1240) that "The tradition of mixing crushed ceramic (or tiles) with lime to produce hydraulic plasters … is rarely attested prior to the third century BC", because almost all Classical cisterns and washeries in the Lavriotike are using exactly that kind of mortar.

20 The site has been mentioned as 'fortified deme' by Löper (1892, pp.381 – 382), who does not mention either its name "Megala Pefka" nor the excavation, the photo of which shown

in Fig. 16 has been taken there according to the data in the archive of the German Archaeological Institute at Athens (D-DAI-ATH-Attika 0062). For Megala Pefka see Nomicos (2021, p.173, no.26 [with bibl.]).

21 For a first preliminary report see Lohmann (2015).

Bibliography

Agricola, G., 1977. *Zwölf Bücher vom Berg- und Hüttenwesen* (*De re metallica libri XII*, 1556). Reprint München: DTV.

Aperghis, G.G., 1997/98. A Reassessment of the Laurion Mining Lease Records. *Bulletin of the Institute of Classical Studies*, 42, pp.1–20.

Ardaillon, E., 1897. *Les mines du Laurion dans l' antiquité*. Paris: Thorin.

Audring, G., 1977. Zur wirtschaftlichen und sozialen Lage der attischen Bauern im ausgehenden 5. Und im 4. Jahrhundert v. u. Z. In: H. Kreißig, ed., 1977. *Studien zur athenischen Sozialstruktur und römischen Wirtschaftspolitik in Kleinasien*. *Jahrbuch für Wirtschaftsgeschichte, Sonderband*. Berlin: Akademie-Verlag, pp.9–86.

Boeckh, A., 1818. Über die Laurischen Silberbergwerke in Attika. *Abhandlungen der Königlichen Akademie der Wissenschaften in Berlin*, pp.85140.

Boeckh, A., 1842. *The Public Economy of Athens*. London: John W. Parker.

Boerker, Ch., 2018. Amphorenstempel aus dem Laurion. *Zeitschrift für Papyrologie und Epigraphik*, 207, pp.61–72.

Boni, M. and Large, D., 2003. Nonsulfide Zinc Mineralization in Europe: An Overview. *Economic Geology*, 98, pp.715–729.

Boni, M., Gilg, H.A., Aversa, G. and Balassone, G., 2003. The "Calamine" of Southwest Sardinia: Geology, Mineralogy, and Stable Isotope Geochemistry of Supergene Zn Mineralization. *Economic Geology*, 98, pp.731–748.

Butcher, S., 1982. Late Roman Lamps from a Mine Gallery at Thorikos. In: P. Spitaels, ed., 1982. *Studies in South Attica I. Miscellanea Graeca V*. Ghent: Belgian Archaeological Mission in Greece. Pp.137–148.

Caponetti, E., Armetta, F., Chillura Martino, D., Saladino, M.L., Ridolfi, St., Chirco, G., Berrettoni, M., Conti, P., Bruno, N. and Tusa, S., 2017. First discovery of orichalcum ingots from the remains of a 6th century BC shipwreck near Gela (Sicily) seabed. *Mediterranean Archaeology and Archaeometry,* 17(2), pp.11–18.

Caponetti, E., Armetta, F., Brusca, L., Chillura Martino, D., Saladino, M.L., Ridolfi, St., Chirco, G., Berrettoni, M., Conti, P., Bruno, N. and Tusa, S., 2017. A multivariate approach to the study of orichalcum ingots from the underwater Gela's archaeological site. *Microchemical Journal*, 135, pp.163–170.

Conophagos, C., 1980. *Le Laurium antique et la technique grecque de la production de l'argent*. Athen: Edotiki Athinon.

Conophagos, C. and Papadimitriou, G., 1986. La métallurgie du fer et de l'acier en Grèce. In: H. Kalcyk, B. Gullath and A. Graeber, eds., 1986. *Studien zur Alten Geschichte I. Festschrift Siegfried Lauffer*. Rom: Bretschneider. Pp.129–142.

Cosmopoulos, M.B., 2001. *The Rural History of Ancient Greek City-States. The Oropos Survey Project*. BAR Int. Series 1001. Oxford: Archaeopress.

Cordella, A., 1869. *Le Laurium*. Marseille: Cayer.

Cordella, A., 1901. Das Berg-, Hütten- und Salinenwesen Griechenlands. *Zeitschrift für das Berg-, Hütten- und Salinenwesen im Preussischen Staate*, 49, pp.351–382.

Craddock, P.T., 1990. Zinc in Antiquity. In: P. T. Craddock, ed., 1990. *2000 Years of Zinc and Brass*. British Museum Occasional Papers 50. London: The British Museum. Pp.1–6.

Crosby, M., 1941. The American Excavations in the Athenian Agora: Nineteenth Report (Jan.–Mar., 1941). *Hesperia*, 10, pp.14–30.

Crosby, M., 1950. The Leases of the Laureion Mines. *Hesperia*, 19, pp.189–312.

Crosby, M., 1957. More Fragments of Mining Leases. *Hesperia*, 26, pp.11–24.

Curtius, E. and Kaupert, J.A., eds., 1881–1900. *Karten von Attika*. Berlin: Reimer.

Docter, R.F. and Webster, M., 2018. *Exploring Thorikos*. Ghent: Dep. Of Archaeology, Ghent University.

Domergue, C., 1998. Remarques sur le fonctionnement des laveries planes du Laurion. In: *Αργυρίτις γη: χαριστήριο στον Κ. Κονοφάγο*. Αθήνα: Πανεπιστημιακές Εκδόσεις Ε.Μ.Π. pp.33–42.

Domergue, C., 2008. *Les mines antiques: la production des métaux aux époques grecque et romaine*. Paris: Picard.

Dumas, F., 1972. *Trente siècles sous la mer*. Paris: Famot.

Dumas, F., 1976. *30 centuries under the sea*. New York: Crown.

Eddy, S., 1977. The Gold in the Athena Parthenos. *American Journal of Archaeology*, 81, pp.107–111.

Fiedler, K.G., 1840. *Reise durch alle Theile des Königreiches Griechenland im Auftrag der Königlichen Griechischen Regierung in den Jahren 1834–1837*, I. Leipzig: Fleischer.

Gale, N.H., Kayafa, M. and Stos-Gale, Z.A., 2009. Further evidence for Bronze Age production of copper from ores in the Lavrion ore district, Attica, Greece. In: A. Giumlia-Mair, P. Craddock, A.B. Hauptmann, J. Bayley, M. Cavallini, G. Garagnani, B. Gimour, S. La Niece, W. Nicodemi and T. Rehren, eds., 2009. *Proceedings of the 2nd International Conference: Archaeometallurgy in Europe*. Aquileia, Italy, 17–21 June 2007. Milan: Associazione Italiana di Metallurgia, pp.158–176.

Greene, K., 2000. Technological innovation and Economic Progress in the ancient world: M.I. Finlay reconsidered. *Economic History Review*, 53, pp.29–59.

Hammer, P., 2001. *Hoops Reallexikon der Germanischen Altertumskunde*, 19, s. v. Messing. Berlin: De Gruyter, pp.609–615.

Hanel, N. and Bode, M., 2016. Messingbarren aus einem römischen Schiffswrack bei Aléria (Korsika). In: G. Körlin, M. Prange, Th. Stöllner and Ü. Yalcin, eds., 2016. *From Bright Ores to Shiny Metals. Festschrift A. Hauptmann*. Der Anschnitt, Beih. 29. Bochum: DBM, pp.167–181.

Hauptmann, A., 2020. *Archaeometallurgy – Materials aspects sciences*. Cham: Springer International Publishing.

Herbach, R., Morin, D. and Rosenthal, P. 2013. La géométrie des puits du Laurion. Traces et indices des technologies minières de l'Antiquité. *Actes du Colloque Indices et traces: la mémoire des gestes. Nancy, juin 2011*. Nancy: PUN. Editions universitaires de Lorraine, coll. Archéologie, Espaces, Patrimoines, pp.171–185.

Hopper, R.J., 1953. The Attic Silver Mines in the Fourth Century B. C. *Annual of the British School at Athens*, 48, pp.200–254.

Hopper, R.J., 1968. The Laurion Mines: A Reconsideration. *Annual of the British School at Athens*, 63, pp.293–326.

Hülden, O., 2020. *Das griechische Befestigungswesen der archaischen Zeit. Entwicklungen–Formen–Funktionen*. Wien: Verlag der Österreichischen Akademie der Wissenschaft.

Jones, J.E., 1982. The Laurion Silver Mines. A Review of Recent Researches and Results. *Greece and Rome*, 29, pp.169–183.

Jones, J.E., 1984/85. Laurion, Agrileza, 1977 - 1983. Excavations at a silver-mine site. *Archaeological Reports*, 31, pp.106 – 123.

Kakavogianni, O., 2008. Αρχαίες οδοί στα νότια και δυτικά Μεσόγεια και τη Λαυρεωτική. In: M. Korres, ed. *Αττικής οδοί: αρχαίοι δρόμοι της Αττικής*. Athens: Melissa, pp.182 – 197.

Kakavogiannis, E., 1989a. Ελληνική Βιομηχανία Όπλων. *Archaiologikon Deltion*, 38(B1), pp. 55 – 57.

Kakavogiannis, E., 1989b. Ελληνική Βιομηχανία Όπλων στην κοιλάδα Βότσαρι. *Archaiologikon Deltion*, 39(B), pp.51 – 55.

Kakavogiannis, E., 2001. The Silver Ore-Processing Workshops of the Lavrion Region. *Annual of the British School at Athens*, 96, pp.365 – 380.

Kakavogiannis, E., 2005. *Μέταλλα εργάσιμα και συγκεχωρημένα. Η οργάνώση της εκμετάλλευσης του ορυκτού πλούτου της Λαυρεοτικής από την Αθηναϊκή δημοκρατία,* Suppl. *Archaiologikon Deltion*. Athens: Ταμείο Αρχαιολογικών Πόρων και Απαλλοτριώσεων.

Kalcyk, H., 1982. *Untersuchungen zum attischen Silberbergbau: Gebietsstruktur, Geschichte und Technik*. Frankfurt a. M.: Lang.

Knodell, A.R., Fachard, S. and Papangeli, K., 2017. The Mazi Archaeological Project 2016: Survey and Settlement Investigations in Northwest Attica (Greece). *Antike Kunst*, 60, pp.146 – 163.

Körlin, G. and Weisgerber, G., 2004. Keilhaue, Fimmel, Schlägel und Eisen im mittelalterlichen Bergbau. *Der Anschnitt*, 56, pp.64 – 75.

Konophagos, K., 1974. Fours de fusion et technique de la fusion des minerais de plomb argentifère du Laurium par les anciens Grecs. *Annales Géologiques des Pays Helléniques*, 26, pp.338 – 366.

Korres, M., 2008. *Εκτέλεσι, περιεχομένο και άξια των χαρτών της Αττικής του Κάουπερτ* [Entstehung und Bedeutung der Karten von Attika von J. A. Kaupert], Athens: Έκδοτικός οΐκος Μέλισσα.

Kourouniotes, K., 1917. Κίναιδοι μυλοθροί. *Αρχαιολογή Εφημέρις*, 3/4, 1917, pp.151 – 157.

Langdon, M.K., 1991. Poletai Records. In: *The Athenian Agora. Results of Excavations Conducted by the American School of Classical Studies at Athens*, vol. 19, *Inscriptions. Horoi, Poletai Records, Leases of Public Lands*. Princeton, N.J.: American School of the Classical Studies at Athens, pp.55 – 143.

Lauffer, S., 1979. *Die Bergwerkssklaven von Laureion*. 2nd ed. Wiesbaden: Steiner.

Lilie, R.-J., 1976. *Die byzantinische Reaktion auf die Ausbreitung der Araber. Studien zur Strukturwandlung des byzantinischen Staates im 7. und 8. Jh. München*: Institut für Byzantinistik und Neugriech. Philologie.

Lohmann, H., 2005. Prähistorischer und antiker Blei-Silberbergbaus im Laurion. In: Ü. Yalçın, ed., 2005. *Anatolian Metal III*. 18. Beih. Der Anschnitt. Bochum: Deutsches Bergbau-Museum. pp.105 – 136.

Lohmann, H., 2010. Die preußischen »Karten von Attika«. In: H. Lohmann and T. Mattern, eds., 2010. *Attika – Archäologie einer ‚zentralen' Kulturlandschaft*. Wiesbaden: Harrassowitz, pp.259–275.

Lohmann, H. and Mattern, T., eds., 2010. *Attika – Archäologie einer ‚zentralen' Kulturlandschaft*. Wiesbaden: Harrassowitz.

Lohmann, H., 2021. *Teichos. Vom endneolithischen Wehrdorf zum spätosmanischen Tambouri: 5000 Jahre Festungswesen in Attika*. Wiesbaden: Harrassowitz.

Lüschen, H., 1979. *Die Namen der Steine. Das Mineralreich im Spiegel der Sprache*. 2nd ed. Thun: Ott Verlag.

Μαλούχου, Γ.Ε., 2017. *Αρχείον των μνημείων των Αθηνών και της Αττικής*, 7. Βιβλιοθήκη τῆς ἐν Ἀθήναις Ἀρχαιολογικῆς Ἑταιρείας ἀρ. 312, Athens. Η εν Αθήναις Αρχαιολογική Εταιρεία.

Manthos, K.G. and Dermatis, G.N., 2017, *Λαύριο η βοή του χρόνου – Lavrio the Rumble of Time*. Lavrio: Society for the studies of Lavreotiki.

Maran, J., 2021. Attica and the Origins of Silver Metallurgy in the Aegean and the Carpatho-Balkan Zone. In: K. Kalogeropoulos, D. Vassilikou and M. Tiverios, eds., 2021. *Sidelights on Greek Antiquity. Archaeological and Epigraphical Essays in Honour of Vasileios Petrakos*. Berlin-Boston: DeGruyter. pp.197 – 226.

Mattern, T., 2010. Eine »skythische Wüste«? Attika in spätantiker und frühbyzantinischer Zeit. In: H. Lohmann and T. Mattern, eds., 2010. *Attika – Archäologie einer ‚zentralen' Kulturlandschaft*. Wiesbaden: Harrassowitz, pp.201 – 230.

Milchhoefer, A., 1887. Antikenbericht aus Attika, 2. *Mitteilungen des Deutschen Archäologischen Instituts, Athenische Abteilung*, 12, pp.277 – 330.

Milchhoefer, A., 1989. Erläuternder Text III-VI. In: E. Curtius and J. A. Kaupert, eds., 1881 – 1900. *Karten von Attika*. Berlin: Reimer.

Morin, D. and Herbach, R., 2008. Antique Laurion shafts: first investigations and problematic of ventilation. Archaeological and archaeometrical approaches. In: Y. Facorellis, N. Zacharias and K. Polikreti, eds., 2008. *Proceedings of the 4th Symposium on Archaeometry of the Hellenic Society of Archaeometry. Archaeometry Studies in the Aegean: Reviews and recent developments*. Athens, Greece 28 – 31 May 2003. BAR S1746. Oxford: BAR Publishing, pp.499 – 506.

Morin, D., Herbach, R. and Rosenthal, P., 2012. The Laurion shafts, Greece: ventilation systems and mining technology in antiquity. *Historical Metallurgy*, 46(1), pp.9 – 18.

Morin, D. and Photiades, A., 2005. Nouvelles recherches sur les mines antiques du Laurion (Grèce). Mines et métallurgies dans l'Antiquité. Etat des recherches. *Pallas*, *Revue d'Etudes Antiques*, 67, pp.327 – 358.

Morin, D. and Photiades, A., 2012a. Les techniques d'exploitation en gisements métallifères profonds dans l'Antiquité: Approche géologique et technologique. In: E. Olshausen and V. Sauer, eds., 2012. *Die Schätze der Erde: natürliche Ressourcen in der antiken Welt*. Stuttgarter Kolloquium zur Historischen Geographie des Altertums 10. Stuttgart: Steiner. pp.281 – 335.

Morin, D. and Photiades, A., 2012b. Les mines antiques du Laurion (Attique / Grèce). Techniques minières et stratégies d'exploitation. In: A. Orejas Saco del Valle and Chr. Rico, eds., 2012. *Minería y metalurgia antiguas. Visiones y revisiones. Homenaje a Claude Domergue*. Madrid: Casa de Velázquez. pp.9 – 26.

Morin, D., Rosenthal, P., Herbach, R. and Jacquemot, D., 2013. Les techniques minières de l'Antiquité grecque: approche tracéologique. Les mines du Laurion (Grèce). In: F. Janot, G. Giuliato and D. Morin, eds., 2013. *Indices et traces: la mémoire des gestes; actes du colloque international, 16, 17 et 18 juin 2011, UFR d'Odontologie de l'Université de Lorraine*. Nancy: Presses Universitaires de Nancy, Éditions Universitaires de Lorraine, pp.147 – 169.

Morin, D., Rosenthal, P., Photiades, A., Delpech, S. and Jacquemot, D., 2020. Aegean mining technologies in Antiquity: a traceological approach: the Laurion mines (Greece). In: K.A. Sheedy and G. Davis, eds., 2020. *Mines, Metals, and Money: Ancient World Studies in Science, Archaeology and History*, *Metallurgy in Numismatics, vol. 6.* London: Royal Numismatic Society, pp.23 – 41.

Munn, M.H. and Munn, M.L.Z., 1990. On the frontiers of Attica and Boiotia: The results of the Stanford Skourta Plain Projekt. In: A. Schachter, ed., 1990. *Essays in the topography history and culture of Boiotia, 3*. Suppl. Teiresias. Montreal: Dep. of Classics, McGill University, pp.33 – 40.

Munn, M.H., 2010. Panakton and Drymos: A Disputed Frontier.

In: H. Lohmann and T. Mattern, eds., 2010. *Attika – Archäologie einer ‚zentralen' Kulturlandschaft*. Wiesbaden: Harrassowitz, pp.189–200.

Mussche, H.F. and Conophagos, C., 1973. Ore-Washing Establishments and Furnaces at Megala Pevka and Demoliaki. In: H.F. Mussche, J. Bingen, C. Conophagos, J. de Geyter, G. Vandenven and D. Deraymaeker, eds., 1973. *Thorikos 1969, VI. Rapport préliminaire sur la sixième campagne des fouilles*, pp.61–72.

Nazou, M., 2018.The end of the Neolithic in East Attica: new data from Kontra Gliate (Kiapha Thiti) and Thorikos Mine 3. In: S. Dietz, F. Mavridis, Ž. Tankosić and T. Takaoğlu, eds., 2018. *Communities in Transition: The Circum-Aegean Area During the 5th and 4th Millennia BC*. Oxford: Oxbow Books, pp.289–295.

Negris, F., 1881. Laveries anciennes du Laurium. *Annales des Mines*, 20, pp.160–164.

Nomicos, S., 2013. Laurion: Some remarks on the settlement pattern and the "helicoidal washeries". *Metalla*, 20, pp.25–27.

Nomicos, S., 2021. *Laurion. Montan- und siedlungsarchäologische Studien zum antiken Blei-Silberbergbau*,Der Anschnitt, Beih. 44 (= Veröffentlichungen aus dem Deutschen Bergbau-Museum Bochum, Nr. 244). Bochum u. Rahden/Westf.: Marie Leidorf.

Orshingher, A., Amicone, S., Kamlah, J., Sader, H. and Berthold, Chr., 2020. Phoenician lime for Phoenician wine: Iron Age plaster from a wine press at Tell el-Burak, Lebanon. *Antiquity*, 94 (377), pp.1224–1244. [online] Available at: <https://doi.org/10.15184/aqy.2020.4> [Accessed 28 November 2021].

Papadimitriou, G.D., 2016. The so-called helicoidal ore washeries of Laurion: their actual function as circular mills in the process of beneficiation of silver and lead contained in old litharge stocks. In: E. Photos-Jones, ed., 2016. *Proceedings of the 6th Symposium for the Hellenic Society for Archaeometry*. BAR International Series 2780. Oxford: British Archaeological Reports, pp.113–118.

Parker, J. 1996. *Ancient Shipwrecks of the Mediterranean and the Roman Provinces*, BAR 580. Oxford: Tempus Reparatum.

Parras, D., 2010. Λαυρεωτική: αρχαία τοπογραφία και νέες έρευνες (Ι). *Πρακτικά ΙΓ' Επιστημονικής Συναντησης ΝΑ. Αττικής, Παιανία, 29–31 Οκτωβρίου & 1–2 Νοεμβρίου 2008*. Kalyvia: Εταιρεία Μελετών Νοτιοανατολικής Αττικής, pp.141–147.

Petrakos, V., 1994. *Τα αρχαία της Ελλάδος κατά τον πόλεμο 1940–1944*. Athens: Η εν Αθήναις Αρχαιολογική Εταιρεία.

Petrakos, V., 1999a. *Ο δήμος του Ραμνούντος Ι. Τοπογραφία*. Athens: Ἐπιμέλλεια ἐκδόσεως Ἠλέκτρας.

Petrakos, V., 1999b. *Ο δήμος του Ραμνούντος ΙΙ. Επιγραφές*. Athens: Ἐπιμέλλεια ἐκδόσεως Ἠλέκτρας.

Petrakos, V., 2020a. *Ο δήμος του Ραμνούντος. ΙΙΙ. Το φρούριο*. Athens: Ἐπιμέλλεια ἐκδόσεως Ἠλέκτρας.

Petrakos, V., 2020b. *Ο δήμος του Ραμνούντος. IV. Το Νεμέσιον*. Athens: Ἐπιμέλλεια ἐκδόσεως Ἠλέκτρας.

Petrakos, V., 2020c. *Ο δήμος του Ραμνούντος. V. Τα νομίσματα, οι λύχνοι, τα γλυπτά*. Athens: Ἐπιμέλλεια ἐκδόσεως Ἠλέκτρας.

Petrakos, V., 2020d. *Ο δήμος του Ραμνούντος. VI. Οι επιγραφές, τα χαράγματα, τα σταθμία, οι μαρτυρίες*. Athens: Ἐπιμέλλεια ἐκδόσεως Ἠλέκτρας.

Photos-Jones, E. and Jones, J.E., 1994. The building and industrial remains at Agrileza, Laurion (fourth century B.C.) and their contribution to the workings at the site. *Annual of the British School at Athens*, 89, pp.307–358.

Psarros, M., 2016. Αγροτεμάχιο Κόκκορη–Δήμου. *Archaiologikon Deltion*, 67(B1), 2012 [2016], pp.59–63.

Rieck, B., 2012. *Neue Minerale aus dem Lagerstätten-Bezirk Lavrion/Griechenland und den Kalahari Mangan Feldern/ Republik Südafrika*. PhD. University of Vienna.

Rieck, B., 2019. The Mines and Minerals of Lavrion–Ancient Mining History (II). *Greek Mineral Wealth–Ελληνικος Ορυκτος Πλουτος*. [online] Available at: https://www.oryktosploutos.net/ 2019/03/the-mines-and-minerals-of-lavrion_14/ [Accessed 21 December 2020].

Σαλλιώρα-Οικονομάκου, Μ., 2007. *Lavreotiki. The Lavrion Museum*. Athens: Archaeological Receipts Fund.

Salliora Oikonomakou, M., 2007. *Lavreotiki. The Lavrion Museum*. Athens: Archaeological Receipts Fund Publications Department.

Schaffer, J., 2015. What Not to Multiply Without Necessity. *Australasian Journal of Philosophy*, 93, pp.644–664.

Schön, F., 2014. Insulare Wasserversorgung: Antike Regenwassersammel- und –speicheranlagen auf Pantelleria und Linosa (Italien). In: Th. Schäfer, ed., 2014. *Antike und moderne Wasserspeicherung, internationaler Workshop*. Pantelleria, Italy, 11–14 May 2011. Tübinger Archäologische Forschungen 12. Rhaden/Westf..: Marie Leidorf, pp.103–118.

Schönhärl, K., 2017. *Finanziers in Sehnsuchtsräumen: Europäische Banken und Griechenland im 19. Jh.* Göttingen: Vandenhoeck & Ruprecht.

Solomos, C., Voudouris, P. and Katerinopoulos, A., 2004. Mineralogical studies of a bismuth-gold-antimony mineralization in Kamariza, Lavrion. *Bulletin of the Geological Society, Greece*, 36, pp.387–396 (in Greek with English Abstract).

Traill, J.S., 1975. *The Political Organization of Attica*. Hesperia Suppl. XIV. Princeton, N.J.: American School of Classical Studies.

Traill, J.S., 1986. *Demos and Trittys. Epigraphical and Toporaphical Studies in the Organization of Attica*. Toronto: The Coach House Press.

Tsaïmou, K., 2005. Αρύ Λαυρεωτικής. Καμάριζα. Μπερτσέκο Λαυρεωτικής. *Αρχαιολογικόν Δελτίον*, 60(B1), pp.183–190.

Tsaïmou, K. and Fragkiskos, A., 2001. Σύγκριση εμπλουτισμού με ρείθρα ή λεκάνες στο αρχαίο Λαύριο. In: Y. Bassiakos, E. Aloupi and Y. Facorellis, eds., 2001. *Archaeometry Issues in Greek Prehistory and Antiquity*. Athens: Hellenic Society of Archaeometry, pp.699–712.

Tsaïmou, K., 2006. Θέση Αρύ. *Archaiologikon Deltion*, 61(B1), pp.179–183.

Tsaïmou, K.G., 2014. Αρύ Λαυρεωτικής. *Archaiologikon Deltion*, 62(B1), pp.221–227.

Tsaïmou, K., 2010. Αρύ Λαυρεωτικής. *Archaiologikon Deltion*, 56–59, pp.360–362. 364–366.

Valera, P.G. and Valera, R.G., 2005. Outline of geology and mineral deposits of Sardinia. In: Lo Schiavo, F., Giumlia-Mair, A., Sanna, U. and Valera, R., eds., 2005. *Archaeometallurgy in Sardinia from the origins to the Early Iron Age*. Monographies instrumentum 30, pp.35–42.

Valera, R.G., Valera, P.G. and Rivoldini, A., 2005. Sardinian ore deposits and metals in the Bronze Age. In: Lo Schiavo, F., Giumlia-Mair, A., Sanna, U. and Valera, R., eds., 2005. *Archaeometallurgy in Sardinia from the origins to the Early Iron Age*. Monographies instrumentum 30, pp.43–87.

Vanderpool, E., 1970. A Lex Sacra of the Attic Deme Phrearrhioi. *Hesperia*, 39, 1970, pp.47–53.

Venator, M., 1905. *Deutsch-Spanisch-Französisch-Englisches Wörterbuch der Berg- und Hüttenkunde sowie deren Hülfswissenschaften*. Leipzig: A. Twietmeyer.

von Bernhardi, F., 1920. *Eine Weltreise 1911/1912 und der Zusammenbruch Deutschlands*. Leipzig: S. Hirzel.

von Bernhardi, F., 1927. *Denkwürdigkeiten aus meinem Leben*. Berlin: E.S. Mittler & Sohn.

Voudouris, P., 2005. Gold and Silver Mineralogy of the Lavrion Deposit, Attika, Greece. In: J. Mao and F.P. Bierlein, eds., 2005. *Mineral Deposit Research: Meeting the Global Challenge. Proceedings of the Eighth Biennial SGA Meeting. Beijing, China, 18–21 August 2005*. Berlin: Springer, pp.1089–1092.

Voudouris, P., Melfos, V., Spry, P.G., Bonsall, T.A., Tarkian, M. and Solomos, Ch., 2008. Cabonate-replacement Pb-Zn-Ag±Au mineralization in the Kamariza area, Laurion, Greece: Mineralogy and thermochemical conditions of formation. *Mineralogy and Petrology*, 94, pp.85–106.

Voudouris, P., Mavrogonatos, C., Rieck, B., Kolitsch, U., Spry, P.G., Scheffer, Chr., Tarantola, A., Vanderhaeghe, O., Galanos, E., Melfos, V., Zaimis, S., Soukis, K. and Photiades, A., 2018. The Gersdorffite-Bismuthinite-Native Gold Association and the Skarn-Porphyry Mineralization in the Kamariza Mining District, Lavrion, Greece. *Minerals*, 8, p.531. [online] Available at: <https://doi.org.10.3390/ min8110531> [Accessed 21 December 2020].

Voudouris, P., Photiades, A., Tarantola, A., Scheffer, C., Vanderhaeghe, O., Morin, D. and Vlachopoulos, N., 2019. The Lavrion and Serifos mining centers: two worldwide unique mineralogical and geological monuments and perspectives for their protection. In: *The Value Framework for the Protection and Management of Sites and Monuments Extracted during the Antiquity: Current Uses and Future Synergies*. *ICOMOS Conference*. Athens-Lavrion, Greece, 29–30 November. [online] Available at: <https://doi.org. 10.13140/ RG.2.2.10668.82564> [Accessed 21 December 2020].

Voudouris, P., Melfos, V., Mavrogonatos, C., Photiades, A., Moraiti, E., Rieck, B., Kolitsch, U., Tarantola, A., Scheffer, C., Morin, D., 2021. The Lavrion Mines: A Unique Site of Geological and Mineralogical Heritage. *Minerals*, 11, p.76. [online] Available at: <https://doi.org/10.3390/min11010076> [Accessed 21/12/2020].

Vryonis, Sp., 1962. The Question of Byzantine Mines. *Speculum*, 37, pp.1–17.

Weisgerber, G., 1988. Bemerkungen zur antiken Bergbautechnik auf Thasos. In: G. A. Wagner and G. Weisgerber, eds., 1988. *Antike Edel- und Buntmetallgewinnung auf Thasos*. Der Anschnitt, Beih. 6 (= Veröffentlichungen aus dem Deutschen Bergbau-Museum Bochum, Nr. 42). Bochum: Deutsches Bergbau-Museum Bochum. pp.198–211.

Weisgerber, G., 2005. Montanarchäologie–Archaeology of Mining. *Bergknappe*, 29, fasc. 2, pp.40–43.

Weisgerber, G. and Heinrich, G., 1983. Laurion und kein Ende? Kritische Bemerkungen zum Forschungsstand über eines der bedeutendsten antiken Bergreviere. *Der Anschnitt*, 35, pp.190–200.

Wilsdorf, H., 1952. *Bergleute und Hüttenmänner im Altertum. Bis zum Ausgang der Römischen Republik*. Berlin: Akademie-Verlag.

Yadin, Y., Aharoni, Y., Amiran, R., Dothan, T., Dunayevsky, I. and Perrot, J., 1958. *Hazor I. An Account of the First Season of Excavations, 1955*. Jerusalem: At the Magnus Press, Hebrew University.

Young, J.H., 1956a. Studies in South Attica. Country Estates at Sounion, *Hesperia*, 25, pp.122–146.

Young, J.H., 1956b. Greek Roads in South Attica. *Antiquity*, 30, pp.94–97.

Author

Hans Lohmann – Ruhr University Bochum, Faculty of History, Institute of Archaeological Studies, Bochum, Germany, hans.lohmann@rub.de

Correspondence and material requests should be addressed to: hans.lohmann@rub.de