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A brief survey of the development of silver mining in ancient Laurion

ABSTRACT: *The ancient silver mines of Laurion were already famous in antiquity being the backbone of Athenian economy in the classical period. During this time, south-east Attica developed into a densely inhabited, vivid mining area whose remains form the landscape until today. Various aspects of this silver-rush era have been studied intensively while other periods are less well examined. This paper tries to give an overview of the development of mining in Laurion from pre-historical times to late antiquity, considering the available archaeological and historical evidence and aspects of technological change as well.*

KEYWORDS: LAURION, ATTICA, ANCIENT GREEK MINING, ANCIENT TECHNOLOGY, MINING LANDSCAPE

Introduction

The Laurion is the most famous mining landscape of Greek antiquity and, from ancient literary sources as well as archaeometallurgical analyses, known to be the source of the famous Athenian owl coinage. As we know from Herodotus (7,144), the enlargement of the Athenian war fleet in 483 BC was financed with silver from Laurion. This undertaking, which Herodotus attributed to Themistocles, ultimately led to the Athenian's victory over the Persians and ended the period of war.

In the study of ancient mining, the Laurion has been a pivotal research topic. It has been studied intensively by geologists and engineers, as well as by archaeologists and historians since the early 19th century. Despite this long history of research, a number of open questions either remain or have successively evolved from the comprehensive academic works on this topic. The aim of this paper is to give a short overview of the development of mining in ancient Laurion based on the present state of research (see already: Lohmann, 2005). It also turns the attention to some associated aspects, thereby referring to some preliminary results of my doctoral thesis (Nomicos 2017).

Topography and Natural Environment

The Athenian silver mines are located in south-east Attica, approximately 30 kilometres south of Athens. The landscape is defined by a series of low hills, mountain ridges and dry stream beds. Covering an area of about 68

square kilometres in total, it is situated within the territory of the six ancient Athenian *demes* Amphitrope, Anaphlystos, Besa, Phrearrhioi, Sounion and Thorikos (Fig. 1). The natural landscape today is characterised by an almost total lack of water sources and a corresponding vegetation such as pine trees and garrigue. The geology is defined by three stratigraphic units which contain the polymetallic ore deposit and which are well-known for the silver-bearing lead ores galena and cerussite, exploited by the city-state of Athens. The mineralisations are located in three contact zones known as the "first", "second" and "third contact", the latter bearing the richest ore deposits (Marinos and Petraschek, 1956). According to modern-day estimations (Conophagos, 1980, p.145-152) based on 1,500,000 tons of ancient slag which were reprocessed in the 19th century, the total amount of extracted ore of argentiferous lead adds up to 13,000,000 tons, yielding 1,400,000 tons of lead and 3,500 tons of silver. Ancient mine works, galleries, shafts and open-cast mines have survived in great numbers, despite modern mining and reprocessing of ancient waste material between 1864 and 1977. Nevertheless, datable evidence from the mines is scarce, due to a lack of mining archaeological research that focuses on chronology. Moreover, stratigraphic sequences have often been destroyed by the modern industry.

A large part of the Laurion area is inaccessible today because of the installation of a restricted military zone at the beginning of the 1980s (Salliora-Oikonomakou, 1985, p.90). Rescue excavations (e. g. Salliora-Oikonomakou, 1985, pp.90-132) carried out beforehand revealed that the restricted zone lies in the very centre of the classical mining landscape. Measures in order to protect the area have

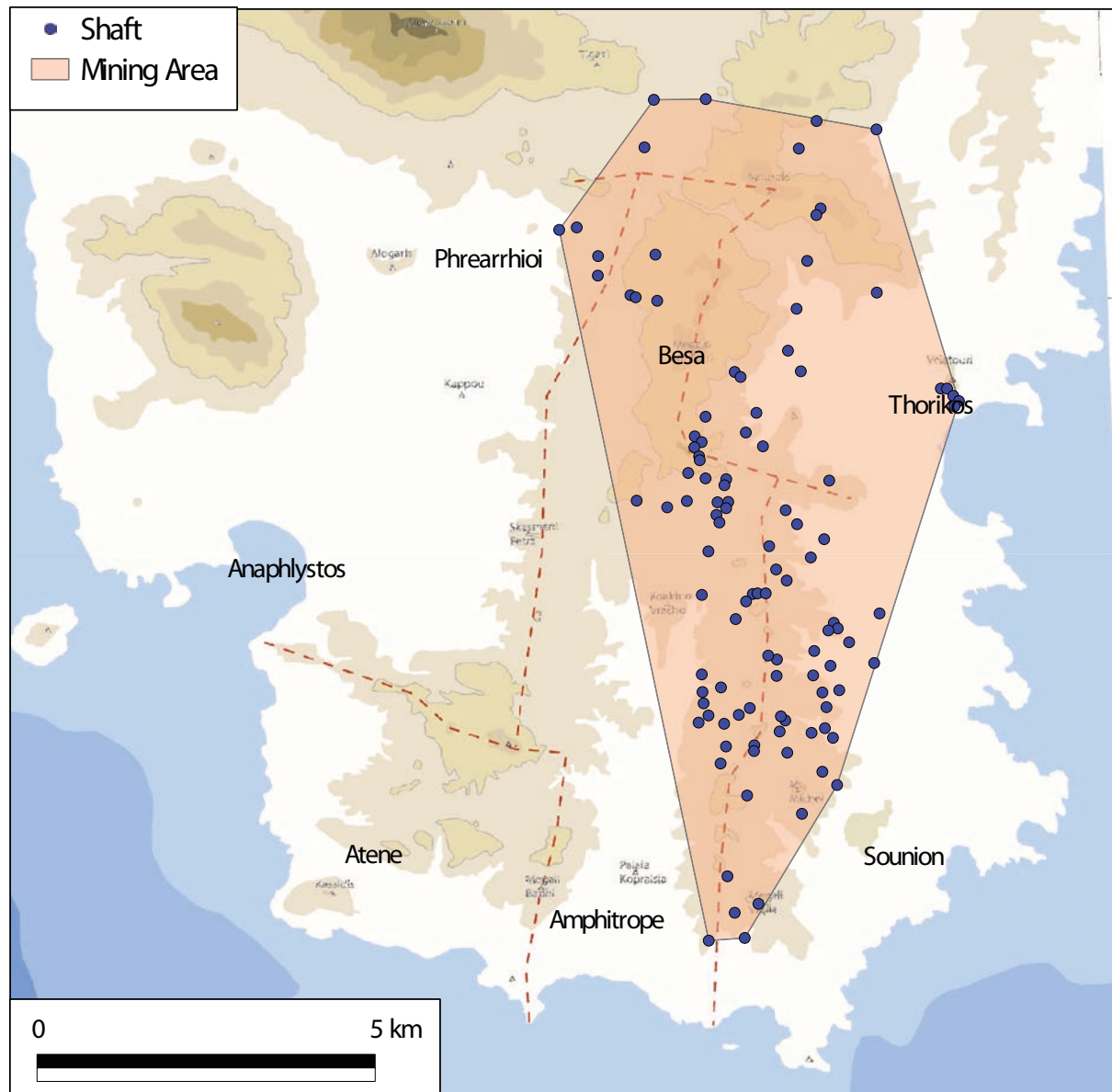


Fig. 1. Map of the mining area in relation to the ancient demes of Athens (graphic: Sophia Nomicos).

been undertaken by the Greek state and by the local community as well, and in 2014, the UNESCO has included ancient Laurion in the “tentative list” of World Heritage (UNESCO Tentative Lists 2014).

Prehistoric Laurion

The first evidence of silver mining dates back to the EH II period (Nazou, 2013; Spitaels, 1984) but even older mining activities can be assumed (Nazou, 2013) because several Early Bronze Age metallurgical workshops have recently been found only few kilometres north of the Laurion. One of these workshops, at Lambrika, dating to the EH I period, yielded several kilogrammes of litharge (Kakavoyanni, Michaelidi, Nezeri and Douni, 2009). Litharge is the by-product of the cupellation process, a

metallurgical procedure to extract silver from argentiferous lead ores. The high amount of waste material found in this workshop suggests a close familiarity with this process, and this leads to the conclusion that the introduction of this technology is even older. Late or final Neolithic mining had already been suggested by J. Maran (2000, p.187) on the basis of the lead isotope signature of two chalcolithic silver pendants which match the Laurion ores. The role of the pendants is problematic, however, because there is no other connection to the Laurion or Attica since one was found in the Peloponnesus and the other one on Crete. Bearing in mind that there is at least one ore deposit in Asia Minor, whose isotopic “fingerprint” can at present not be discerned from Laurion (Pernicka, 1987, p.693), final proof of their Attic origin is lacking. Nevertheless, Neolithic mining is not unlikely because a growing demand for precious metals such as silver and gold has

been deduced from an increasing number of such objects in the archaeological record of Neolithic sites in Greece (Zachos, 2007). This apparent interest in silver must have led to an intensive prospecting phase of ore deposits and corresponds to the situation on Siphnos, where the earliest known mining site has also been dated to the early Helladic period (Weisgerber, 1985). Moreover, late and final Neolithic pottery has been identified in "Mine 3" at Thorikos but its connection to early mining activities is not secure, due to lack of stratification (Nazou, 2013; Spitaels, 1984). Therefore, at present, a starting date of mining in Laurion in the late or final Neolithic seems probable, but final evidence is still missing.

Mining, probably in limited scale, continued from EH II to the Mycenaean period, the only proof of which is a lump of litharge from a middle Helladic context at Thorikos (Servais, 1967, p.23). During this period, the remote regions of the Laurion hills seem to be almost completely unoccupied, but several EH and only one MH contexts are known from the coastal area (Salliora-Oikononakou, 2004, p.32).

A major change at Thorikos took place in the Mycenaean period when the Velatouri hill was transformed into an acropolis (e. g. Laffineur, 2010), as can be deduced from the well-known tholos and chamber tombs which have been known for more than 100 years. Lead isotope studies suggest that Laurion silver played a distinct role in Mycenaean economy concerning the trade with the Minoans (Stos-Gale and Gale, 1982). The Mycenaeans used silver for precious objects and, as has recently been shown (Tselios, Filippaki, Bassiakos, Korres, 2011), also for the plating of bronze weapons which were given as grave goods to the deceased. The connection of the Mycenaean acropolis to silver mining at Thorikos is very plausible, although archaeological evidence for this is lacking. It may be assumed, however, that mining during this period was still limited to Thorikos because neither traces of mining nor traces of occupation have been identified in the rest of the Laurion. The only exceptions are several graves close to the Sounion coast at Limani Pasa (Salliora-Oikononakou, 2004, p.33) which point to the existence of a small coastal settlement in this area.

The Laurion in the Geometric and Archaic Period

The only evidence of mining during the geometric period is a piece of litharge from Thorikos (Bingen, 1967, p.25 ff.), that is why the role that Thorikos and the Laurion played in the Aegean economy of the geometric period remains elusive.

It can be assumed that mining was intensified during the archaic period, when the demand for silver must have grown exponentially, as a direct consequence of the introduction of coinage in the ancient world. It is during the late archaic period that an increase in finds, almost exclusively graves or gravestones, is to be noticed for the first time

in the hilly landscape of the Lavreotiki (Salliora-Oikononakou, 2004, pp.34–37). Secure archaeological evidence of 6th century mining is yet lacking, but due to the extremely unfavourable natural conditions for agricultural land use, it can be assumed that the expansion of occupation to off-coast sites is to be linked to mining operations in that area. Moreover, according to G. Weisgerber (1993) remarked, graves in close vicinity to the ore deposit are sometimes the only indicator of a mining period otherwise unattested, because of destructions caused by later mining.

Presumably, mining in Laurion underwent significant changes at some point before the classical period. As has been suggested, deep-shaft mining (Kalcyk, 1982, p.109) and stone-built ore washeries (Kakavoyannis, 2001) are likely to be technological innovations of the transitional period between the 6th and the 5th century BC. A major change must have been the introduction of large cisterns (van Liefferinge, 2013). These round, square or rectangular cisterns were built into the rock (either schist or limestone) and lined with a special kind of hydraulic mortar (Badeka, 1974) which contained litharge and was also used for the insulation of the washeries. Securing the access to water in the extremely dry area of Lavreotiki enabled the beneficiation of ores by the opportunity to use water all-year round and thus paved the way for large-scale mining operations, including comparatively poor ores that required enrichment. Conversely, this could mean that the beneficiation of galena and cerussite before the introduction of cisterns was possible only seasonally, during certain months when the streams carried water. It should also be kept in mind, though, that the hydrogeological situation could have been quite different in prehistoric times. Due to the lack of extensive hydrogeological research, it is uncertain if significant water sources, such as springs, ever existed in significant numbers in the Laurion. Nevertheless, it should be taken into account that the mining of native silver and other silver rich ores had been practiced too, and thus initially there was no need for complex beneficiation procedures.

The 5th century BC

Due to the lack of archaeological evidence, the situation during the 5th century BC remains nearly as elusive as the preceding archaic period. The ancient literary evidence (Herodotus 7,144) and the heavy output of Athenian silver coinage as well (Flament, 2007, p.68; van Alfen, 2012, p.93 f.) suggest intense mining activities during this period. In the overall archaeological record, however, this period is strikingly underrepresented. Outside of Thorikos, there are only few places which have yielded material from the 5th century BC. This phase is mostly represented by the existence of graves. Especially the large necropolis of Anemones which contains more than 200 graves of the 5th century (Salliora-Oikononakou, 1985) can give an insight into how densely the landscape

might have been inhabited during this phase. Apart from that, the evidence is scarce: in the heart of the mining region in Souriza, an ore washery has been preserved beneath the so-called Hilltop tower of the 4th century (Goette, 2000, p.86; Lohmann, 1993, p.105). This position and the uncanonical form of the washery suggest that it antedates the 4th century examples for which a “standardised” form is typical. Preliminary excavations in 1971 at Megala Pevka under H. Mussche and C. Conophagos (1969) furthermore suggest that the well-known Laurion smelting furnaces were a technological innovation of the 5th century BC or earlier.

The impact of mining on the landscape during the 4th century BC

Ancient mining reached its peak during the 4th century BC as can primarily be deduced from the more than 200 ore-processing workshops (Ellis Jones, 2007) which mostly date to this period. A significant increase in other 4th century finds and sites supports this view and contradicts the older opinion according to which, on the basis of the ancient literary evidence, saw the heyday of classical mining in the 5th century BC (Davies, 1935, p.249); this was already seen (e. g. Lohmann, 2005, p.125). Moreover, it corresponds well with the evidence from the mining leases from the Athenian Agora (Crosby, 1950; Crosby, 1957; Langdon, 1991) which date to the decades between 367/6 BC and ca 300 BC (Langdon, 1991, p.60).

The 4th century BC left an archaeological imprint on the landscape characterising it until today. Among the numerous amount of 4th century sites there are not only mines and workshops but the archaeological record also reveals a dense system of roads connecting the mines, workshops and smelting places as well as the different mining centres to each other. Apart from that, 4th century graveyards, farmsteads and sanctuaries, and the urban centres of Sounion and Thorikos as well define the heterogeneous character of the mining landscape of this period. This overall picture of a vivid landscape is further complemented by the mining leases which have yielded not only crucial information on how the mining “industry” of this period was organised but also on the historical topography of south-east Attica (Kalcyk, 1982, pp.57-98; Lohmann, 1993, pp.74-86; Kakavoyannis, 1977).

Technological innovation in ore grinding and the decline of silver mining in circa 300 BC

A model of a 4th century silver-mining district can be studied at Ari in the westernmost section of the Laurion. Although the area has been mined intensively during the 19th and 20th century by the company “Lauriotikos Olympos” (Milchhöfer, 1889, p.25), many of the ancient

workings and technical installations have survived. This district is currently being investigated in a joint project between the Greek Archaeological Service, the Ruhr-Universität Bochum and the German Archaeological Institute at Athens (Lohmann, 2016, p.88). During several excavations in this area, K. Tsaimou of the National Technical University of Athens had already uncovered four beneficiation-workshops of the Classical period (Tsaimou, n. d.). Notably, the excavations revealed – for the first time *in situ* – four circular installations of the type known as “helical washery” (Conophagos, 1980, pp.248-151), one in each workshop. Their *in situ* position allowed a re-examination of the traditional explanation as ore washeries, given by C. Conophagos (1980), and several details lead to the conclusion that this theory cannot be maintained any longer (Nomicos, 2013; 2017; Papadimitriou, 2016). Most importantly, they show no inclination of the surface without which gravity separation, as reconstructed by Conophagos, is physically impossible. Furthermore, the devices lack the characteristic hydraulic mortar and the water tank as well, which are also essential components of the reconstruction. Instead, their circular form and the existence of a pivot in the centre lead to the conclusion that the installations are to be reconstructed as edge-mills of the *trapetum* or *Kollergang* type (see Nomicos, 2017) known from agricultural contexts in Greek antiquity (see for example Foxhall, 2007, pp.165-177). Based on the fact that they are exclusively found in ore beneficiation workshops, they are to be explained best as mills for grinding ore.¹ Similar mills, so-called *arrastras*, have been used for example in South American mining of the 19th century (De Nigris, 2012, pp.14 f., fig. 21). Dating these devices in Laurion has been difficult because pottery from stratified contexts has not been found so far. Tsaimou’s excavation of such an ore-mill at Bertseko, however, has yielded sherds from the transitional period between the late classical and early Hellenistic era. This dating is supported by the fact that the example at Bertseko is built on top of a late classical wall (Tsaimou, 2001, p.402). Furthermore, the pottery from the workshops at Ari has apparently yielded no distinct Hellenistic or later ware (these results will be published in a subsequent paper by K. Tsaimou, H. Lohmann, and S. Nomicos). This dating to the end of the classical silver-rush suggests that the mills were introduced in order to make poor ores profitable. As modern parallels show, in beneficiation, the step of grinding is the most labour-intensive one. Thus, by mechanising this step, the processing of poorer ores can be made profitable (Lynch and Rowland, 2005, p.4). This explanation becomes probable when considering the reason for the end of the silver-rush: as has been shown (e. g. Lohmann, 2005, p.125), one significant reason for the decline of mining in Laurion around 300 BC was the exhaustion of the silver-rich ores (Strabo 9, 1, 21).

It is noteworthy that such ore-mills are obviously not limited to the Laurion, because installations of the same type have been discovered in the Egyptian Eastern Desert in Ptolemaic contexts (Klemm and Klemm, 2013,

pp.238-243, fig. 5, 182; Brun, Deroin, Faucher, Redon and Téreygeol, 2013, p.122, fig. 15, 16, 20). How is this to be explained? Historical documents, especially papyri from Egypt, show that during the Hellenistic period, Greeks from many different places emigrated to the Ptolemaic kingdom, because of economic reasons (Lewis, 1986). Bearing in mind that at this time, the Laurion was largely depopulated (see for example Goette, 2000, p.106) and that close political connections existed between Athens and the Ptolemies (Habicht, 1992), we can assume that the circular installations in Egypt can be linked directly to the Laurion and should be considered as proof of technological transfer between these two mining regions.

Post-classical mining

As mentioned above, the Early Hellenistic period apparently experienced a strong decline of mining, probably caused by the decreasing profitability of the attic mining industry. Apparently, mining had ceased largely and there was a process of depopulation in this area as, for example, the excavations at Thorikos have shown (Mussche, 1996, pp.64-65). Nevertheless, some activity can still be noticed. Evidence for metallurgy comes from the smelting sites on the coast and they are probably to be linked to the passage in the text of Strabo (9, 1, 23) who, in the 1st century BC, described that old tailings were re-smelted. It is possible that the Hellenistic Agora at Limani Pasa (Salliora-Oikononakou, 1979, pp.161-173, plates 66-78), excavated by the Greek Archaeological Service, played an important role in the "industry" of that period. Presumably, these smelting activities are to be considered in connection with the emission of the so-called New Style coinage of Athens which, according to M. Thompson (1961), was issued between 196/5 and 89/88 BC. The extensive output of this coinage testifies to a great demand of silver during this period, especially when the Delphic Amphictyony ordered in the last quarter of the 2nd century BC that all Greek *poleis* had to accept Athenian tetradrachms (Lefèvre, 2002, pp.316-322, No. 127; van Alfen, 2012, p.100). Therefore, the possibility of additional mining activities on a reduced scale at certain places in the Laurion should not be discarded. Final proof of the coin's attic origin, however, is lacking, and so it is equally possible that external silver was used for minting the New Style Coinage (Habicht, 1995, p.244).

From a numismatic point of view, the local silver of Laurion lost its importance when Athenian coinage ceased to be emitted. After the battle of Philippi in 42/1 BC, the lighter Roman denarius "has forced the drachm out of circulation", as Kroll has argued (1993, p.15; pp.89-91). This view is supported by the literary sources which lead to the conclusion that silver from Laurion was of no significance for Roman Imperial economy: as Pomponius Mela (II, 45-46), a Roman author of the 1st century AD, remarked: "Thoricos et Brauronia olim urbes iam tantum

nomina". Furthermore, Pausanias characterised the Laureion area in the first chapter (1,1) of his Description of Greece as the place where "the mines of the Athenian used to be".

This picture given by the ancient literary sources is in accordance with the archaeological evidence. Apart from some archaeological evidence of occupation in the coastal area (Salliora-Oikononakou, 2004, p.143), there are hardly any sites of Roman Imperial date, neither in Thorikos nor in the Laurion. The insignificance of the Laurion for the Roman economy is not surprising because the empire owned much more viable metal deposits (Davies, 1935, p.251) such as the famous gold mines of Las Médulas of which Pliny (hist. nat. 33, 78), who was curator of Hispania Citerior at the time, says: "According to some accounts Asturia and Callaecia and Lusitania produce (with the so-called *arrugia* mining method) 20,000 lbs of gold a year, Asturia supplying the largest amount." (Sánchez-Palencia, Orejas and Ruiz del Árbol, 2008, pp.427-452).

Mining in Laurion was taken up again – according to the available evidence – during the 5th and 6th century AD. The evidence of late Roman/Byzantine mining in Laurion is conclusive but not very well published. Already in 1935, O. Davies (1935, p.251) pointed out that a significant number of late Roman lamps had been found during the modern mining activity in the shafts and galleries of Laurion. This is supported by finds from Thorikos (Mussche, 1996, p.65) and new evidence found by D. Morin who has been investigating the Laurion mines in the last decade. According to Morin (personal communication, April 25, 2016), Byzantine lamps dating to the 5th and 6th century AD are still found in many secondarily widened classical galleris, which points to Early Byzantine exploitation.. Additionally, late Roman pottery has been found in a number of classical workshops, suggesting a second phase of use after the classical period. It has to be material born in mind, however, that we do not know exactly what was mined in the Laurion and if new mining technologies were used. This late mining activity is also testified by the Byzantine poet Paulos Silentiarios (Descriptio S. Sophiae, verses 678-681) who says that "the mines of Sunium opened their veins" for the decoration of Hagia Sophia at Constantinople after the earthquake of 558 AD. This renewed mining activity is also reflected by an overall increase of sites in the Laurion. A late Roman settlement existed at modern day Lavrio, which is proven by the existence of a three-aisled basilica and a nearby graveyard of the 4th-6th century AD (Salliora-Oikononakou, 2004).

A similar situation has been observed in Bir Umm Fawakhir, a mining region in Egypt. Here, renewed mining activity took place around 500 AD, too, after being stopped several hundred years before, due to the exhaustion of the deposits (Meyer, 1995). This indicates that, probably after the loss of the Iberian mines (Edmondson, 1989, p.90). and the consequent reduction of the empire, the Byzantine economy was apparently in short supply of precious metals (Davies, 1935, p.251; Mussche, 1996, p.65).

Concluding remarks

The focus on the long-term development of mining in Laurion reveals exploitation phases of different intensity.. It seems that these phases can be correlated with changes in the supply and demand structure concerning silver in the Aegean and more specifically the history of Athenian coinage. Furthermore, it can be observed that the development of occupation in the Laurion is directly linked to the development of mining (Nomicos, 2017). The invention of circular ore mills shows that the Laurion was a place where important technological innovations were made which, through technological transfer, later found their way to other parts of the ancient world.

Notes

- 1 This idea emerged during a discussion I had with Prof. H. Wotruba (Aachen, October 2011), whom I thank most sincerely. Without his decisive observations, I would not have been able to develop this theory.

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