# The significance of the Lavrion mines in Greek and European Geoheritage

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*The Lavrion mines have had a prominent role in the social, economic and cultural development of Greece since ancient times. The income from the mines was the foundation of Athenian power during the 5th and 4th century BC, but conversely led to significant economic problems for the early modern Greek state. Many mineral specimens from the mines and the slags of the area are unique or were discovered there for the first time. In recent years, due to its significance the area has been proposed as a cultural and natural heritage site, with the mines and the general area being on the Tentative List of the UNESCO World Heritage Centre.*

*Les mines Lavrion ont joué, depuis les temps anciens, un rôle prépondérant pour le développement de la Grèce aux points de vue social, économique et culturel. Le revenu provenant des mines fut à la base de la puissance d'Athènes pendant les 5ème et 4ème siècles AC, mais, inversement, il a créé des problèmes économiques réels pour le récent et moderne Etat Grec. De nombreux échantillons minéralisés provenant des sites miniers et les scories propres à cette région sont uniques ou furent découverts ici, pour la première fois. Ces dernières années, liée à l'importance de sa signification, la région a fait l'objet d'une proposition de site à valeur d'héritage culturel et naturel, les mines et la zone globale faisant partie de la liste préliminaire d'admission au Centre UNESCO de l'Héritage Mondial.*

*Las minas de Lavrion han tenido un papel destacado en el desarrollo social, económico y cultural de Grecia desde la antigüedad. Los beneficios de las minas fue la base del poder ateniense durante los siglos V y IV a. C., pero de manera contraria, condujo a problemas económicos significativos para el estado griego moderno. Muchos especímenes minerales de las minas y las escorias del área son únicos o fueron descubiertos allí por primera vez. En los últimos años, debido a su importancia, el área ha sido propuesta como un lugar de patrimonio cultural y natural, con las minas y el área general en la lista provisional del Centro del Patrimonio Mundial de la UNESCO.*

## Introduction

The Lavrion - also spelled "Laurium" or "Laurion" - mines were of pivotal importance in shaping the socioeconomic framework and ultimately the history of ancient Greece and of the modern Greek state. Also undisputed is the mineralogical wealth of the area; the local ore deposits are the constant focus of research. This article aims to present Lavrion as a part of European geoheritage, both on account of its geological uniqueness and significance and of it being a major factor in the local and national economy and a catalyst for major historical events.

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## The Lavrion ore deposits

The area of Lavrion comprises many different ore deposits, including, but not limited to porphyry Mo-W, skarn Fe-Cu-Bi-Te, carbonate-replacement Pb-Zn-Cu-As-Sb-Ag ± Au-Bi, and vein/breccia Pb-Zn-Cu-As-Sb-Ag-Au-Ni-Bi ores (Voudouris *et al.*, 2018). The carbonate-replacement ores of the Kamariza district were mined in ancient and in modern times and are associated with the formation and exhuma-

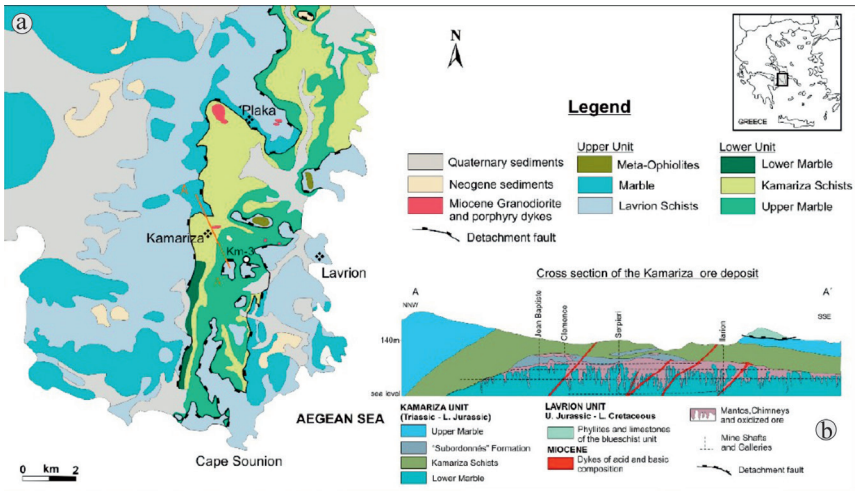


*Figure 1: (a) Simplified geological map of the Lavrion ore district; (b) Cross-section A-A' of the Kamariza deposit (after Voudouris* et al.*, 2018).*

tion of a metamorphic-core complex, in the Atticocycladic crystalline belt (***Figure 1***). The main minerals of this system are pyrite, arsenopyrite, sphalerite, galena and chalcopyrite. Galena is the principal carrier of Ag, whose maximum enrichment reaches up to 3000 gr/t (Voudouris *et al.*, 2008). Furthermore, Voudouris *et al.* (2018) mention high grades of Au (around 100 gr/t) in the nearby vein-type Clemence deposit, which could have been known and exploited in antiquity.

**Mining activities at Lavrion from ancient Greece to the present day**

While it is not possible to determine the date when mining activities began at Lavrion, it is commonly held that they began sometime around 3000 BC, during the Minoan Era. The 8th century BC was when organised mining most probably developed and the exploitation of silver must have started a century later, reaching its peak around the 4th and 5th century BC (Economopoulos, 1996).

The ancient galleries (***Figure 2a***) have an aggregate length of many hundreds of kilometres, and comprise six levels, interconnected with a multitude of shafts. The immense and intricate network of the ancient mining galleries is even more impressive considering that they were dug out, a few metres per month, using nothing but hand tools and, occasionally, fire. The mines were worked by slaves, who belonged to wealthy citizens of Athens. Each such citizen was in essence a contractor, to whom a section of the galleries was leased in exchange for a profit percentage. Ancient Athens had very strict mining laws and violators were severely punished (Katerinopoulos, 2010). The entrances of some of these shafts and galleries still dot the countryside of Keratea.

The conspicuous lack of water in Lavrion necessitated the building of a complex drainage system, which was then utilised – apart from the sustenance of the mining camps – in filling the ore washeries (***Figure 2b***) used for ore separation, before the smelting process. This drainage system also ensured that the water of the ore washeries was recycled, thus alleviating the need for constant transport of water from afar. It is truly a marvel of engineering, considering the era in which it was constructed.

The silver extracting procedure itself was a testament to the skill of ancient Greek metallurgists. When the ore came out of the galleries, it was crushed down to fine particles, which were then gravimetrically separated in the ore washeries, based on the fact that argentiferous ore in any mineral form (galena or cerussite) is heavier than the gangue minerals, and as such does not float. The first step in this process was to initially smelt the ore and extract the silver-rich lead. The remaining slag was discarded and subsequently cupellation was carried out, where the lead was ignited and burned within a furnace, aided by a constant influx of air. In the end, only pure silver remained at the bottom of the furnace, while the useless litharge was discarded. This two-stage procedure ensured that around 99 % pure silver was extracted. After 146 BC and the Battle of Corinth, the Romans continued mining activities at Lavrion, using more advanced techniques involving drainage procedures for extending the galleries below the water table (Periferakis & N. Paresoglou, 2019).

After Roman times, the mines of Lavrion were completely abandoned, despite the fact that during the 18th and early 19th century there were reports of the area's economic potential (Periferakis & Paresoglou, 2019). Only in 1860 would the Greek geologist Kordellas notice the ore minerals in the ancient slags, and his memo to the Greek state would incite a second fervent period of mining activity. In 1864 Jean-Baptiste Serpieri founded the Italian-French company Roux-Serpieri-Fressynet, which initially had permission to exploit only the ore deposit itself by expanding the ancient tunnels and creating new ones (***Figure 3***).

Soon, however, the company illegally bought heaps of ancient slag from the Municipality of Keratea, proceeding to extract silver which had been irretrievable using the ancient techniques, in turn leaving massive amounts of modern slag which remain still visible around Lavrion (***Figure 4***). This violated the license issued to the company by the Greek state, and Greek courts issued a condemning verdict, ordering the company to pay significant reparations. This prompted the ambassadors of Italy and France to intervene on behalf of the company and demand that the state drop the legal proceedings.

While initially it refused, eventually the Greek government relented due to the naval blockade imposed by French and Italian warships. In 1873, Andreas Syggros bought the company and renamed it the Lavrion Metallurgy Company. Syggros then tricked the public into buying worthless shares of his company and at the same time blackmailed the Greek state into lowering the annual taxes on his company, and on top of that decreased slag exploitation and silver production. Meanwhile, Serpieri founded the Compagnie Française du Laurium, which managed to obtain the sole right to exploit the underground mineral wealth of the area. The company closed in 1977, while the Lavrion Metallurgy Company


*Figure 2: (a) The entrance to an ancient mining gallery in the area of Thorikos; (b) A reconstruction of an ore washery with the ancient theatre of Thorikos in the background.*

*Figure 3: (a) The interior of the Esperanza tunnel, with the slope increasing rapidly towards greater depths; (b) The entrance of the same tunnel, in the countryside of Lavrion. Many of the most famous mineral samples of Lavrion have been extracted from this tunnel.*


*Figure 4: (a) Slag from the 19th and early 20th century by the port of Lavrion; (b) Massive heaps of slag from the turn of the previous century still define the contours of the area.*

had already shut down in 1917, having exhausted the slag supply (Dermatis, 1994).

**The social, cultural and economic consequences of Lavrion exploitation through the ages**

The wealth accrued by the mining activities at Lavrion had a profound effect on the course of the ancient Greek civilisation, and by implication, on European cultural heritage. The income generated – directly through the payment of leases and indirectly through taxation and general fiscal growth – enabled the city-state of Athens to build and maintain a vastly disproportionate – disproportionate to the expected financial capabilities of any city-state of the era – fleet of around 200 triremes, which were manned with trained oarsmen and hoplites. In the naval showdown with the Persian fleet in 480 BC the Athenian fleet constituted more than half of the Panhellenic fleet of 380 triremes. This naval power of the Greeks, with Athens at the forefront, checked the Persian advance, which, had it continued, would undoubtedly have altered the history of Europe.

In later years, during peacetime, Athens maintained an expanded fleet of 300 triremes, whose operating cost for the campaigning season - which was about 8 months - amounted to around 1600 talents. This great sum, which was more than twice the annual tribute of the whole Delian League, could not even cover the maintenance of the whole fleet. At all times, around one third of the Athenian triremes were held in reserve. During the Peloponnesian War, Athens fuelled its wartime economy using the silver of Lavrion, and only during the final phase of the war did the Lacedaemonians succeed in disrupting mining activities. So the income from Lavrion partly contributed to Athenian power, creating a precarious balance between the then-dominant city-states of Athens and Sparta. The balance of power could therefore be only tilted via war. Had the mines of Lavrion not been exploited, it is more than probable that Athens would not have achieved its status as one of the leading powers of ancient Greece.

Apart from military matters, the wealth accrued from the mines provided the funds for the construction of the temples at the Acropolis. Colonnaded temples like the Parthenon were probably the most expensive buildings of the Classical Era. The gold and ivory statue of Athena Promachos, the murals and the marble statues of the Acropolis where also paid for in part from the mines' revenue (Periferakis & N. Paresoglou, 2019; and references therein).

When Serpieri founded his company in 1864, during the years of the modern Greek state, Lavrion was an insignificant settlement, but within a year it was transformed into a thriving town of over 10,000 residents. The company built houses for its employees, and public buildings; most notably churches and schools, were also constructed (Dermatis, 1994). Operating under the auspices of the company, pharmacies and local infirmaries took care of the workers. When the company was bought by Syggros it began to use technologies innovative for their time, like electricity and telephones. Between 1882 and 1885 the company paid for and constructed the railway line linking Athens with Lavrion (Katerinopoulos, 2010).

Although there were fiscal and administrative benefits from the companies for the local societies, the bickering over the exploitation rights and the temporising policy of both foreign and Greek investors had detrimental effects on the national economic policy. In fact, the Lavrion crisis was a major factor leading to the financial collapse of the Greek state, which declared public insolvency in 1893.

**Lavrion as a unique geological monument**

The existence of many different ore deposits at the same area, which are linked temporally and spatially, makes Lavrion an ideal place for research and educational purposes. Indeed, many geologists visit the area to study its regional tectonic setting and the ore genesis processes. In addition, the mineralogical wealth of the area is remarkable, and in fact the mines and the slags of Lavrion are host to hundreds of different minerals, samples of which are on display in the two mineralogical museums of the area, in Kamariza (***Figure 5a***) and in the City of Lavrion (***Figure 5b***).

Around 15 % of the currently known minerals can be found in Lavrion (Katerinopoulos, 2010). A number of minerals, such as laurionite, paralaurionite and thorikosite, were discovered in the area, and in fact some of them cannot be found elsewhere in the world, like the recently discovered voudourisite (Rieck *et al.*, 2019) and others like nealite, georgiadesite, hilarionite, and fiedlerite. Finally, the slags contain crystallised compounds as a direct result of the smelting process and slags found underwater contain crystallised compounds resulting from the chemical reactions between the slag minerals and seawater. As such, Lavreotiki is an ideal place not only for mineralogical research, but also for geochemical and artificial crystallisation studies.

**Lavrion as a place of Geoheritage**

The mines of Lavrion have directly influenced the culture and history of the Hellenic Nation, both in the Classical Era and in modern history. They are thus tangibly associated with the formation of the sociopolitical and cultural framework of Greece and Europe. In addition, the mines of Lavrion are associated with the creation of the modern town of Lavrion and as such they have a local as well as a national historical value. Mines and quarries represent the way that people in the past lived and the needs of their society, which means they have strong links to the local folklore as well (Prosser, 2019).

The mines themselves provide "windows" onto natural mineral and ore forming processes, and since there are a large number of tunnels that are still structurally safe, they could be made suitable for visitors with relatively cheap structural upgrades. Being near to Athens and easily accessible, Lavrion could thus be made into a large thematic geopark, building upon the existing Lavrion Museum of Mining and Metallurgy and the Archaeological Museum of Lavrion. Some buildings of the French mining company have also been restored, and along with the ancient washeries and the Theatre of Thorikos, constitute interesting tourist sites.

While the administrative area of Lavreotiki has been declared a National Park, the area of Lavrion is also considered as having Outstanding Universal Value and

*Figure 5: (a) The Mineralogical Museum of Kamariza, in an old building of the French Company, with the Serpieri Well in the background; (b) The Mineralogical Museum of Lavrion, located in an old office building near the centre of Lavrion.*

fits the criteria for inscription on the World Heritage List (Migoń, 2018) of UNESCO. Currently, the mines of Lavrion are on the Tentative List of the UNESCO World Heritage Centre. As mentioned above, the Greek state has made some steps towards maintaining and promoting the rich history and material culture of the area, but further action is required. Ancient galleries are left locked but otherwise unguarded and unmaintained. Most alarmingly, trespassers enter the galleries and illegally extract rare and valuable mineral samples for personal gain. Apart from this, the dockside loading piers of the now closed companies have been left unmaintained, despite the fact that they too could be an interesting attraction if properly restored. Aside from these extensive restoration works, another step should be the complete mapping of the ancient tunnels utilising the most recent advances in exploration geophysics, most notably microgravity measurements. In short, despite some tentative steps taken over the years, there is still a need for extensive geoconservation efforts in the area of Lavrion.

## Conclusions

The mines of Lavrion have shaped history on a regional and European level, both in ancient and in modern times. They are proof of the intertwining of history and geology, and also they bear testimony to the way that natural resources influence society, economy and culture. Consequently, Lavrion is a major cultural landscape. Furthermore, the mineralogical wealth, along with the multitude of ore deposits in the area, ranks Lavrion as an important natural landscape.

It must be mentioned that the mines of Lavrion, despite being the best known site of its kind in Greece, are not unique in terms of sociocultural and economic significance. They are part of the rich geoheritage of Greece, which stretches from the emery mines of Naxos Island to the exploitation of Au + Ag ± (Cu, Pb) deposits in Macedonia. To summarise, the mines of Lavrion should be regarded as being a cardinal part of both the Greek and European geoheritage, and, if maintained and exploited properly, can constitute a valuable resource for research, education, training and recreation.

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