

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

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

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

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

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

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



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

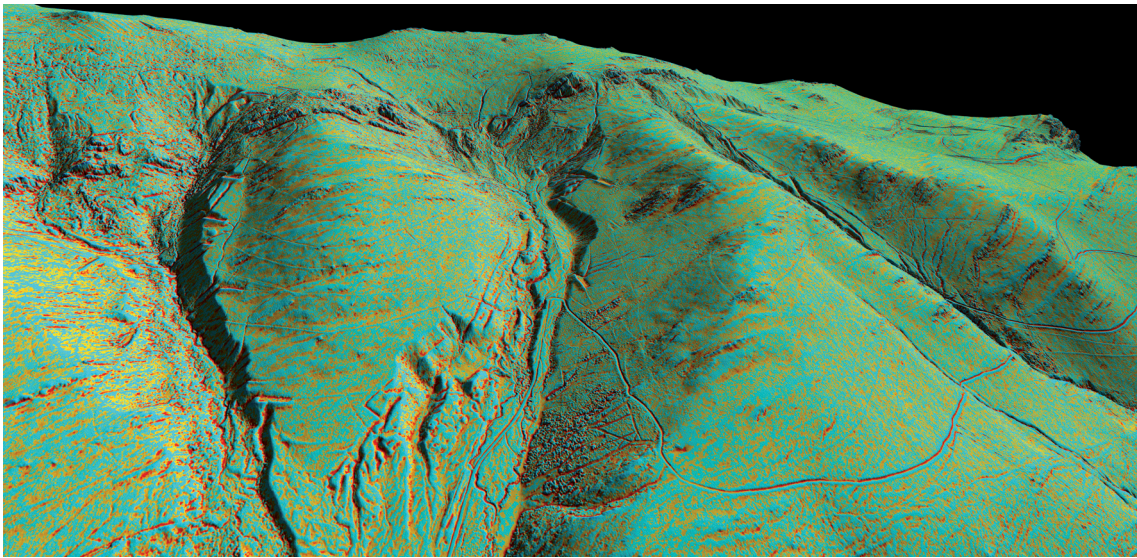


Fig. 2: Teleno massif (province of León, E): Mining zones, water reservoirs and aqueducts, seen from the south (tilted). Data: ALS of the Instituto Geográfico Nacional de España, processed by the Morphological Residual Model [MRM] method on the basis of 1 point per 50 cm².



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

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

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

Some of the most important indicators are

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

Both are directly related to

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

This entails the following problems

- of processing and smelting the metal ore.

Which leads to

- personnel costs and

- the cost of setting up the infrastructure.
- But it all ultimately hangs on
- the value of the product on the (world) market.

The Value of Gold in the Roman Empire

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

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

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

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

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

Deposits – Mining – Processing

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

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

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

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

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

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

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

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

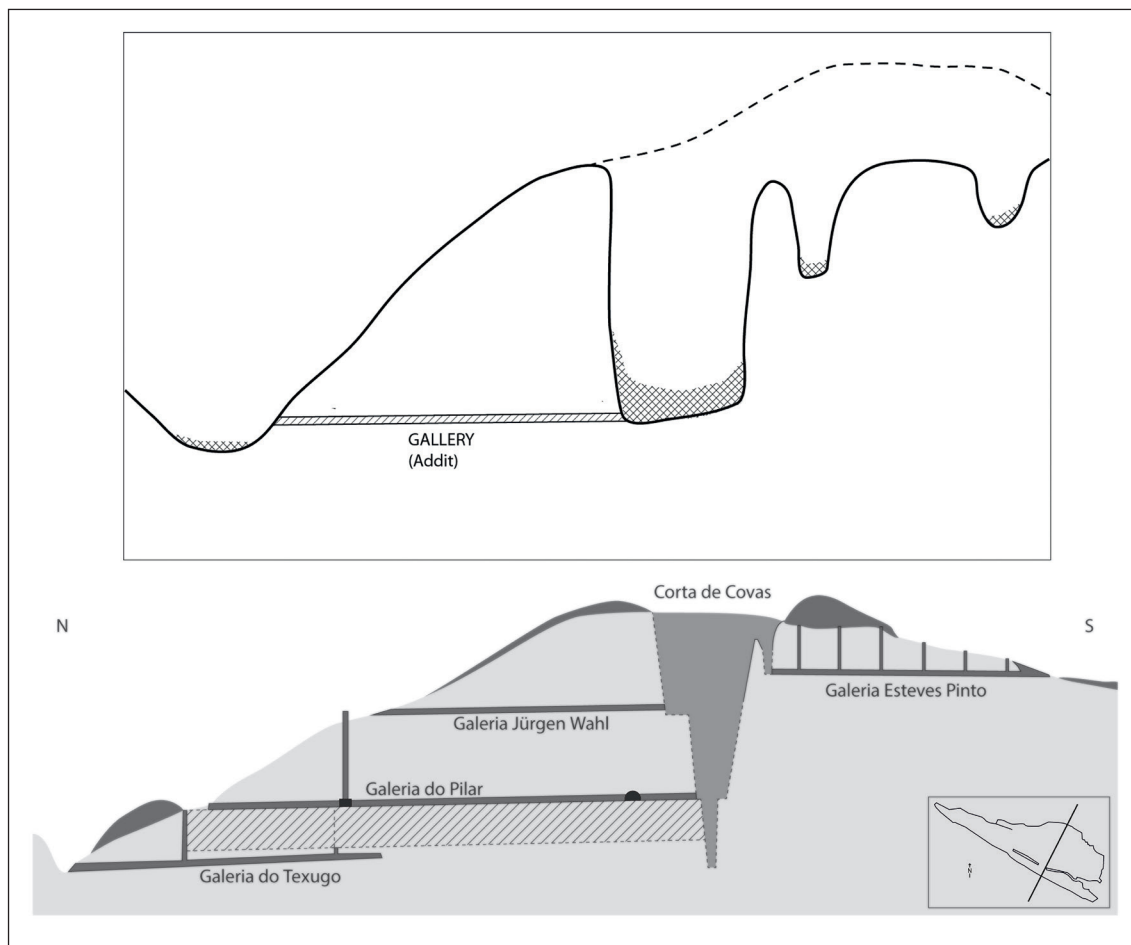


Fig. 4: a: *Territorium metallorum* Tresminas/Jales: Cut through the Corta de Covas. b: *Territorium metallorum* Tresminas/Jales: Cut through the Corta de Covas. c: *Territorium metallorum* Tresminas/Jales: Position of the cut through the Corta de Covas.

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

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

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



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

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

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

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



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

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

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

The consequences of these figures for the calculation of the profit margins in the gold mining areas in the Northwest of the Iberian Peninsula are noteworthy, as can be demonstrated with the example of Las Médulas. It is estimated that around 4.7 tonnes of gold²⁸ were mined here over a period of around 200 years, from which 574,000 aurei could be mined, corresponding to 57,400,000 HS. In other words, the total gold production of Las Médulas was at best sufficient to pay for the construction of not even all ten aqueducts. The purpose of this comparison is not to obtain any exact figures, but to draw attention to the proportionality between the profit and the investment costs.

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

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

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



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

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

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

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

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

Personnel Costs and Organizational Form

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

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

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

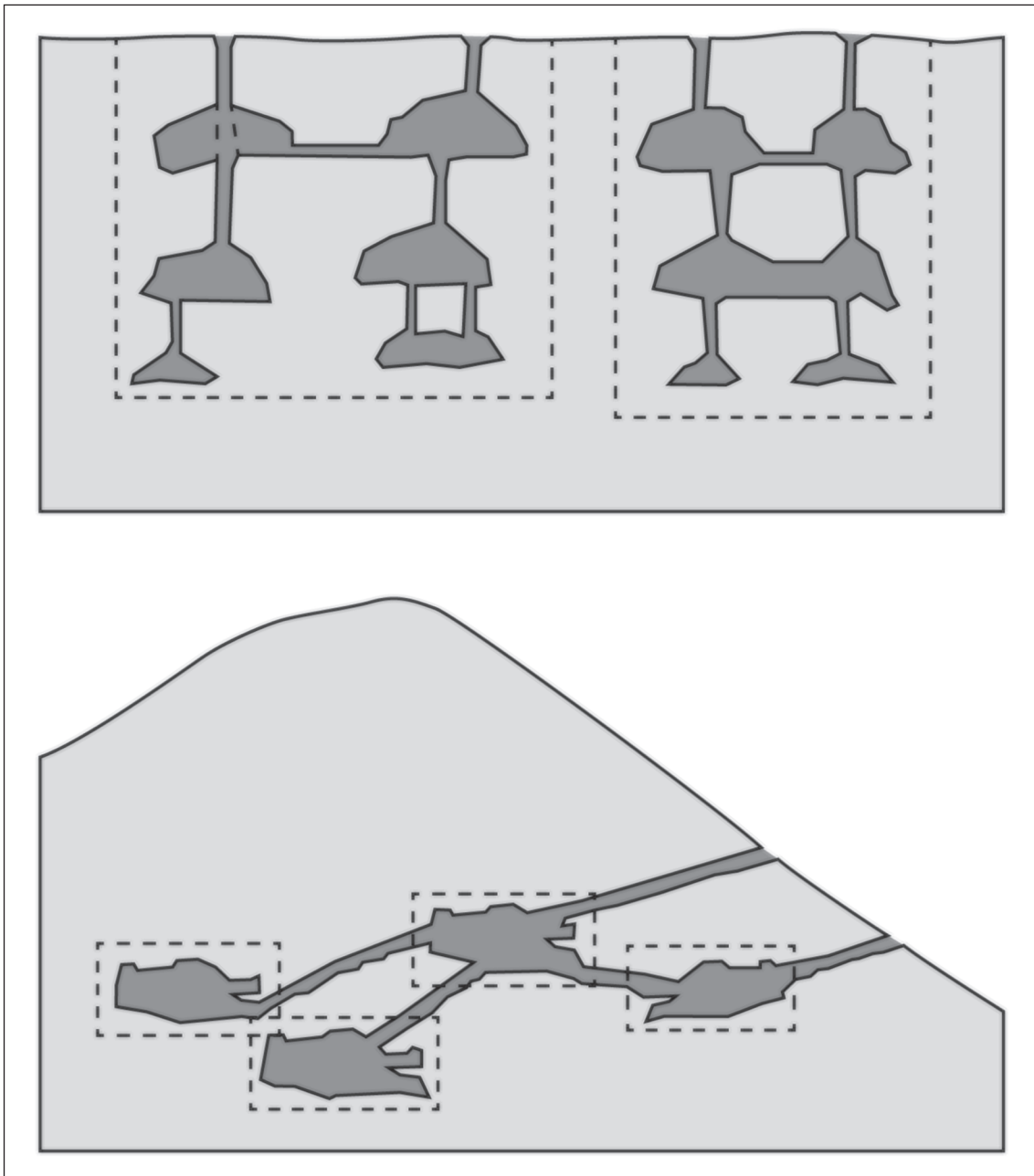


Fig. 8: a: *Vipasca* (Aljustrel, Distrikt Beja, P): Schematic cut through the mining zone with the concession boundaries. b: *Alburnus Maior* (Rosia Montana, Ro): Schematic cut through one of the mining zones with the concession boundaries.

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

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

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

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

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

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

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

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

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

Closing Remarks

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

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

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

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

Translation: Dr. S. Hoss

Notes

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

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

³ Domergue 2008, 190–240.

⁴ Von Reden 2015, 97.

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

<<http://www.elektroniknet.de/elektronik/power/das-ende-der-abhaengigkeit-146341-Seite-3.html>>
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⁶ Wolters (1999, 371–373) discusses the relation between gold and silver and the fluctuations in the value of these metals. The price of gold in Italy fell by a third within two months after the Taurisci had discovered a new gold vein (Polyb. 34,10,10–14 = Strabo 4,6,12). Similar distortions resulted from the looting of the Gallic temple treasures by Caesar (Suetonius, Caesar 54,2). The Romans were well aware that there was sometimes a discrepancy between the coin value and the metal value, as proven by Cassius Dio (78,14, 3–4): “Antoninus gave [the peoples at the mouth of the Elbe] full coins, while for the Romans he had only falsified silver and gold: one type was made of lead with silver, the other of copper with gold plating”.

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

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

⁹ Drexhage et al. 2002, 52.

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

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

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

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

¹⁴ Overview in Drexhage et al. 2002, 54.

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

¹⁶ Fernández Nieto 1970, 71.

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

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

¹⁹ Domergue 2008, 129–139.

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

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

²² Wahl-Clerici 2016 and 2017.

²³ Matías Rodríguez 2004, 181 f.

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

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