Humanities & Social Sciences Communications

ARTICLE

https://doi.org/10.1057/s41599-026-06556-x OPEN

Pliny the Elder's discourse on Roman gold mining: The ecological approach of his gold metaphor and the personification of Nature

Javier Fernández-Lozano[1]✉ & Enrique Ferrari[2]

Book XXXIII of *Naturalis Historia* by Pliny the Elder is the most comprehensive compendium of Roman gold mining in the 1st century. For an interdisciplinary in-depth study of the text, this work combines discourse analysis with a geological examination of the Latin author's references. First, it frames Pliny's allusions to mining through rhetorical devices—two figures of speech—that he uses to link them to his anthropology and the naturalist motivation of his treatise (in which mining references occupy only a minor part): the use of gold as a metaphor for greed, rather than merely for value or power, and the personification of nature, endowing it with the capacity for vengeance. Second, it supports most of Pliny's references with current geological and historical data to justify his ecological concerns, which also help shape the framework through which he understands mining.

[1] Departamento de Tecnología Minera, Topografía y Estructuras. Escuela Superior y Técnica de Ingenieros de Minas, Universidad de León, León, Spain. [2] Facultad de Artes y Ciencias Sociales, Universidad Internacional de La Rioja, Logroño, Spain. ✉email: jferl@unileon.es

Introduction

There is an initial framework for understanding Latin texts that refer to the gold mines of the northwestern part of the Iberian Peninsula. This framework is built around how the Roman Empire spread mining activities in these deposits using persuasive discourse to influence general perceptions of its technological capabilities and economic and political power. We have sufficient references to the development of mining activities during this period, which enabled the minting of gold coins—a policy promoted by Emperor Augustus to ensure the expansion of the Empire (Domergue 1990). There are also references in ancient text such as the Bible (BibleGateway 2026, 1 Maccabees 8: 1-4,): "Judas heard of the name of the Romans and marveled at how much they had accomplished in "Spain" through their wisdom and patience, becoming masters of the gold and silver metals." Most of these texts aimed to highlight the technical expertise behind mining projects and the richness of resources in certain territories, though some also serve as valuable compendiums and manuals on mineralogy, metallurgy, prospecting, and mining, such as *Geographia* by Strabo or *Naturalis Historia* by Pliny the Elder.

The objective of this study is to analyze the construction of one of these discourses that exalts Roman mining but with a broader scope—one that is critical of the causes of mining activity and concerned with its consequences. Pliny the Elder's discourse views Roman gold mining as a metonymy representing the Roman Empire in its various aspects. Within this framework, to which the metaphor "work of giants" lends dimension, there is room for admiration of the achievements of Roman engineering and justification of its excesses. However, the discourse also presents in the background the environmental and social impacts of mining, portraying it ambivalently: as an extraordinary feat of engineering but also acknowledging it as a "cause of excessive suffering." This anticipates a more critical understanding of mining, one with a greater sensitivity to its problems and inconveniences, a perspective that is very much present in our time.

Pliny is an essential source for documenting almost any Roman activity, including mining. His accounts are fairly precise in narrating exploitation systems, locations, labour force, tools, and mining administration. However, his references do not function independently of the broader framework of his work; they form part of his *Naturalis Historia*, a comprehensive project of 37 books conceived from a naturalist's perspective, encompassing everything that concerns humanity. At the beginning of his Book XXXIII, Pliny states that greed—the "damned hunger for gold"—is what drives the extraction of minerals, which he presents as an assault on nature (Pliny the Elder 1995). For Pliny, the use of gold for rings, clothing, and coins is a crime against humanity, a sin, although the perpetrator remains unknown, he writes (*NH*, Book XXXIII, §42 XIII). He condemns gold for spreading greed, calling it "a new source of pettiness through expenditure" (*NH*, Book XXXIII, §48 XIV). He even claims that gold's waste has value, and that this insatiable pursuit leads humanity to challenge nature (*NH*, Book XXXIII, §4 II) and to confront the evils that access to gold can bring (*NH*, Book XXXIII, §6 III): "The discovery of gold was the ruin of humanity!" he concludes.

Limited to the more technical or descriptive paragraphs (§66–§86 and §95–§111), Pliny's references to mining provide the most accurate, analytical, and didactic testimony of Roman mining activity. Within the larger context of Book XXXIII, these references form part of a broader discourse in which Pliny expresses his unease regarding the greed he perceives in his time. His text —closely aligned with the principles of Stoicism (cf. Wade 2023)— serves as both recognition and denunciation of the enormous impact of Roman civilization on nature (land excavation being a prime example), a result of population growth and the expansion of the Empire, which led to the ruthless exploitation of natural resources. He writes: "We follow all the veins of the earth, and people live within the excavations we make, yet we are surprised when it sometimes opens or trembles, as if indignation were not enough to provoke this kind of punishment from this sacred mother!" (Fig.1).

Fig. 1 Panoramic view of Las Médulas (León, Spain), a UNESCO World Heritage Site since 1997. Las Médulas, a prime example of Roman gold mining, where the interplay between human activity and natural landscape is strikingly evident.

There are already some studies in Latin literature addressing Roman gold mining in the northwestern part of the Iberian Peninsula (Plácido-Suárez 1988; Plácido-Suárez and Sánchez-Palencia 2014). However, a study is still needed that examines Pliny's analysis of this mining activity not by treating his technical references as independent analytical exercises on the mining industry but as part of his anthropological discourse, developed in Book XXXIII of *Naturalis Historia*, which leads to the root causes of mining exploitation. A deeper analysis is required to understand how, through recognizing environmental abuses (e.g., *NH*, Book II, 157–159), Pliny anticipates the contemporary perspective on mining, one that is deeply rooted in the collective consciousness due to the growing awareness of environmental concerns (Pliny the Elder 1995). Any broader harm to nature disrupts the natural order, and that disruption is not only detrimental to nature but will ultimately lead to partial or complete self-destruction, as Robertson and Pollaro (2022) note. His contemporary, Seneca, holds a similar view, stating that human beings have gone far beyond mere subsistence and, in Stoic terms, have acted without virtue, extracting not out of necessity but out of greed (Seneca 1979).

This study, incorporating discourse analysis supported by a solid geological examination of the area —the result of more than a decade of fieldwork carried out as part of several research projects—, explores this second contribution of Pliny as a historical product: how he contributes to shaping a more critical perspective on mining, structured along two main axes: social sensitivity and ecological sensitivity, which, in turn, divide into three key aspects or causes: deforestation, the effects of hydraulic works, and metal contamination.

To achieve this, we use constructivist rhetoric, Lakoff's theory of cognitive framing, and theories of metaphor that emphasize its epistemic function (Ricoeur and others) as our methodological framework. In very brief terms, constructivist rhetoric holds that reality (or our knowledge of reality) is discursively constructed, shaped by language: what George Lakoff has called "frames"—molds made of words (often metaphors) that shape the way we think about and perceive reality, and consequently, how we act upon it. We organize and study his references to mining in *Naturalis Historia* using two rhetorical devices that allow him to link his technical discussion of the mining industry with the core of his thought as a naturalist and anthropologist:

i) By shifting the general meaning of the gold metaphor from value to greed.

ii) By personifying nature or the mine, portraying it as capable of feeling indignation and taking revenge for the harm inflicted by human greed.

In his implicit—rather than explicit—use of gold as a metaphor, Pliny downplays the more obvious association of gold with wealth or power and instead intensifies another meaning, a secondary one derived from the first: from the very beginning of the book, he ignores the positive connotations of gold and focuses on its association with greed, particularly as it is turned into rings, garments, and other adornments. From this premise, he establishes a causal relationship that morally justifies the harmful effects of mining: because it unnecessarily harms nature solely out of greed, nature, in turn, reacts (through personification) with indignation and vengeance. At the beginning of this book, to precisely frame his Treatise on Metals and Their Nature (*NH*, Book XXXIII, 1), he writes:

> "We will speak of metal, the wealth par excellence, and the sign of the value of things. Industry, for various reasons, seeks it within the earth. Here, it is excavated to satisfy greed, and they will seek gold, silver, electrum, copper, and, to satisfy luxury, gemstones used to decorate walls or hands with colors […]".

By structuring his discourse with gold as a metaphor for greed, Pliny can shift between technical details of its extraction and the negative consequences of mining. It is as if two works are contained within one: i) a comprehensive and didactic compilation of mining knowledge, following the style of other treatises of his time, and ii) a broader narrative shaped by the conflict arising from human greed, from more general ethical coordinates:

We cannot overlook the lexical clues of the text itself. Pliny titles Book XXXIII as the "Treatise on metals and their nature", yet he writes the word gold 158 times, compared to just 25 instances of metal or metals (or 115 of silver, 28 of copper, and 23 of iron). He also mentions wealth and greed 10 times each, and ring 65 times, as a symbol of both. He refers to the mine, mining and miners 25 times. The book comprises 164 very short paragraphs (or chapters), barely 20 pages; the density of these references is therefore significant with respect to the authors's interest in focusing the more general subject of metals on gold as "the symbol of the value of things," as he himself writes.

However, to better understand Pliny's intellectual stance toward gold and its extraction, what matters more than the number of references is their arrangement and order in the text. By concentrating his core theses in the initial paragraphs, he shapes the reader's attitude, who assimilates the author's value system before encountering more technical or historical matters. In the first six paragraphs, Pliny outlines a general framework for his discourse on gold, structured along three main axes: (i) the association of the metal with wealth, as a synecdoche, with gold as the paradigmatic metal in this sense; (ii) the motivation for this interest in acquiring gold: greed, to satisfy luxury, and (iii) the consequences of extracting these metals from nature: the destruction of nature and, along with it, the risks and dangers for the mine workers.

Against other canonical readings, our interpretation of Pliny's approach to gold mining prioritizes: (i) his explicit identification of gold with greed (and the societal decline it entails for Roman society), and (ii) his concern for the consequences this has on nature and the miners.

Although it is not Pliny's central focus, he considers it important to provide a more human view of gold extraction and recovery—attentive both to what it entails for people (including the attendant hardships) and to its effects on the natural environment. Against this backdrop, the present reading analyzes the internal discourse of Book XXXIII of the *Naturalis Historia*, showing how the recurrent allegorical expressions 'hunger for gold' (§6) and its variant 'thirst for gold' (§§48, 72, 134) function as lexical isotopies in a text whose content is primarily technical and historical but whose interpretive framework is ethical: Pliny's moral understanding of human nature, marked by concern over the decline he perceives in Roman society as its appetite for luxury and greed grows. Pliny the Elder acknowledged that this form of "globalization" could entail tangible gains—particularly in the circulation and accumulation of knowledge—while also introducing significant challenges. Even in his *Natural History*, he urged his readers to preserve the natural world from destruction, outlining the benefits of doing so (Dunn 2021).

Hispania as an object of study

We owe to Strabo and Pliny the Elder the most detailed and precise description of the geographical and administrative situation of the Iberian Peninsula at the end of the Republic and the beginning of the Empire. Both authors followed one another in time: the first, a Greek geographer, born in Amasia in 64 BCE, and the second, a Latin naturalist, born in Como around 23 CE.

Strabo glorifies the Greek and Roman identities over the indigenous population, highlighting their negative aspects to justify the necessary Roman acculturation process of these people, whom he refers to as "barbarians"—individuals with strange customs and difficult communication, a situation exacerbated by distance and the lack of communication routes between the different peoples that made up the Peninsula. This was the prevailing image of Iberia from the 3rd century BCE, likely due to its remoteness from the main Greek centers of power (Blanco-Robles 2020). However, Strabo also provides an extensive inventory of the region's resources and wealth, with a particular focus on mining and its productivity. He describes geographical elements such as rivers and estuaries, detailing their features that allow ships to navigate inland (*Geog.* III, 3,4), and in some cases, providing access to gold-rich areas (Plácido-Suárez 1988). His detailed descriptions seem to prepare the ground for administrative control over the peninsula's resources. His accounts do not merely document the cultural and social characteristics of local populations but also their political implications, which are reflected in the rapid development of these societies under Roman rule. For example, he highlights urbanization and the increased fertility of the land due to improved agricultural techniques, as well as the integration of indigenous tribes, whose living conditions improved as they abandoned banditry-based economies.

Pliny the Elder, on the other hand, writes with a *stilus presus*, a light, subtle, and concise style, free of ornamentation and accessible to any Roman citizen (Ramos-Maldonado 2014). Eduard Norden referred to him as a "literary monster" because of his obscure and poor style (Norden 1954). As a Roman procurator, in the course of his duties in northern Europe and Hispania, he became familiar with different lands and civilizations, which shaped his encyclopaedic work, *Naturalis Historia*. In the prologue, dedicated to Emperor Titus (77–78 CE), Pliny expresses his intention to encompass all the knowledge of his time (i.e., geography, botany, mining, among others), synthesized into 37 books and more than 20.000 entries (Mata-Soler 2014; Dunn 2021). In these books, he also deals with the administration and resources of the Hispanic provinces, emphasizing the transformation they underwent once conquered. His descriptions include numerous detailed passages, even though he often relied on indirect sources to satisfy the curiosity of Roman readers eager to learn about the conquered territories. However, there are various passages in his *Naturalis Historia* where some of his judgments either remain

Fig. 2 Gold in Roman times. A Native gold hosted in a quartz vein from the "Cueva del Mouro" mine (Tabuyo del Monte, León, Spain), shown together with an obverse of an aureus of Augustus (c. 18 BCE) from the Spanish National Archaeological Museum (MAN) (**B**).

unclear or are not supported by solid arguments—for instance, in certain sections of Book XXXIII, where he presents partial or incomplete information regarding gold exploitation.

Both Strabo and Pliny rely on relatively contemporary sources to gain credibility and authority. Although Strabo never visited the Iberian Peninsula firsthand, his text incorporates accurate information gathered from Polybius, Posidonius, and Artemidorus, allowing him to construct a cohesive synthesis of the peninsula, its peoples, and its resources, such as its land and mineral wealth. Pliny, on the other hand, cites approximately four hundred authors, both Roman and foreign. For topics related to mineralogy and resources, he relies on Menas, Dio Cassius, Florus, Xenocrates, Archelaus, Theophrastus, Diodorus, and Polybius, among others (Blázquez-Martínez 1971; Mata-Soler 2014). However, both authors use geographical place names to locate the points of interest. Their approach is systematic and methodical, aiming to describe the natural world and mining activities. In fact, *Naturalis Historia* already outlines the main phases of modern mining processes: prospecting, exploration and evaluation, and extraction.

The role of gold in the Roman Empire

After the fall of Rome, there are no written records on Roman mining activities until well into the 19th century (Gómez 1989; Fernández-Mier 1996). In fact, it was these same Roman mines that served for much of the 20th century as indicators for locating new deposits (Sowerby 1885; Tuñas-Corzón 2022). The 1970s saw a renewed interest in gold mining that followed the decade's sharp increase in gold prices. Prices rose after the 1971 suspension of dollar–gold convertibility under President Richard Nixon and were further propelled by oil shocks and high inflation; it was this price signal—rather than the policy change per se—that stimulated exploration. From that point onward, a first wave of more systematic studies began to appear. (Domergue and Sillières 1977; Domergue and Herail 1978; Sánchez-Palencia 1984; Sánchez-Palencia 2000), followed more recently by the application of new technologies and artificial intelligence in the study of Roman gold mining (Fernández-Alonso and Gutiérrez-Alonso 2014; Fernández-Lozano and Gutiérrez-Alonso 2017a; Fernández-Lozano and Gutiérrez-Alonso 2017b; Fernández-Lozano et al. 2019; Fernández-Alonso et al. 2023). A significant part of our understanding of Roman mining techniques has been based on rigid and overly literal interpretations of Latin texts (Plácido and Sánchez-Palencia 2014).

According to Pliny the Elder, the mining sectors in Asturias, Galicia, and Lusitania produced approximately 20,000 pounds of gold in a single year (*NH*, Book XXXIII, 78), equivalent to about 6550 kg of gold per year. Of this, Las Médulas would have accounted for less than 1% of the total, with nearly 90–100 million cubic meters of excavated material (Sánchez-Palencia et al. 1998; Sánchez-Palencia 2000). This gold was highly significant for Rome, as it became the foundation of the monetary system from the time of Augustus (Fig. 2) (27 BCE – 14 CE). Gold financed the army and sustained the numerous military campaigns across the vast territory controlled by the Empire. The transition to a new era required the regulation of the Roman monetary system, maintaining the gold-based economic system centered around the minting of the aureus (Sánchez-Palencia 2000). For this reason, a geographical understanding of the available resources—particularly gold—was crucial for Roman rulers.

Knowing the resources available in Hispania was essential for continuing the rapid expansion of the Empire. The precise geographical descriptions of the Iberian Peninsula aimed to list all these resources—gold, malachite, cinnabar, and other valuable materials, as noted by Florus (2000, II, 33. 46–60). For instance, Strabo provides data on the climate and the unequal distribution of wealth across different regions of the Peninsula. He describes Iberia as "barely habitable," characterized by poor soils and vast forests, but he qualifies this statement by distinguishing two distinct regions: the northern region, isolated due to its rugged terrain and proximity to the sea, making its people less hospitable. The southern region, which benefits from better lands.

Strabo (1991) also discusses the mineral wealth of Iberia (*Geog.*, Book III):

> "This is a cause for admiration; for although all the land of the Iberians is filled with them, not all regions are equally fertile and rich. Even more so, those that have an abundance of minerals, as it is rare for both conditions to occur simultaneously, and it is also rare to find all types of metals concentrated in a small region".

Pliny also bears witness to the mineral wealth of the Iberian Peninsula (*NH*, Book XXXIII, 30): "Nearly all of Hispania abounds in deposits of lead, iron, copper, silver, and gold." The lands of Hispania, he states, are arid and barren, which is why gold is a necessary resource (*NH*, Book XXXIII, 67). Nothing else is more valuable: "[…] compelled by man to provide this precious product," he writes.

Pliny perceives the greatness of these mining works in the methods used for gold extraction (Fig. 3), which he describes as "a true work of giants." He details how galleries were extended over great distances (*NH*, Book XXXIII, 70) and how iron wedges and hammers were used to break through the hard clay deposits (*NH*, Book XXXIII, 72):

> "There is nothing in the world more difficult, but the thirst for gold is even harder".

Fig. 3 Roman gold mine. The Covas open-pit, part of the Roman gold mining complex of Tresminas (Portugal).

Fig. 4 Roman hydraulic system. Trace of channel to Las Médulas, cut into the rock and featuring a dry-stone retaining wall.

With an allegory (*NH*, Book XXXIII, 2, 3):

> "We enter its womb, seeking wealth in the thrones of the infernal gods; for it does not appear beautiful, pleasant, or sufficiently fertile where our feet tread. […] The substances hidden in its depths, which are not produced quickly, are what drive us and lead us to the infernal regions".

The scale of the work, Pliny writes, is so immense that the water used flows from the land to the sea. Large quantities of water are required for mining operations. Studies conducted to date suggest that the hydraulic infrastructure supplying Las Médulas and its "satellite mines" extended up to 1,110 km in length (Fig. 4), with some channels exceeding 100 km (Fernández-Lozano et al. 2025).

Gold extraction was not limited to mines; it was also collected from river courses and other dry areas where gold dust glistened, as Strabo (1991) describes (*Geog*., Book III, 8). Pliny was well acquainted with the process:

> "And by covering the dry areas with the water they carry, they make the dust shine. Then, by digging wells and devising other techniques, they separate the gold from the sand through washing. In fact, even more numerous than the gold mines themselves today are the so-called gold washing sites".

Describe the different mining phases (i.e., prospecting, evaluation, extraction). Break down the various prospecting methods used by miners to locate the mineral, focusing on the search for indicators that could help identify the deposits (*NH*, Book XXXIII, 67).

Fig. 5 Gold prospection in rivers. Prospection works were based on gold panning in rivers. A present-day example in the auriferous Eria River (León).

> "[…] Those who search for gold first remove the *segutilum*, a deposited soil that indicates the location of the vein. The sand is then washed, providing an estimate of the vein's richness based on the residue left after washing. Sometimes, gold veins are found at the surface— a rare stroke of luck […]. The soil beneath the gold found on the surface is called *talutium*".

Generally, gold, being a high-density mineral (19.3 g/cm^3), nearly seven times denser than quartz (one of the most common minerals on the Earth's crust), tends to accumulate with the denser fraction of minerals during alluvial prospecting using a gold pan (Fig. 5), a process known as "heavy mineral concentration" (Toscano et al. 2012).

When referring to another metal that accompanies gold (Fig. 6), Pliny writes (*NH*, Book XXXIII, 156, 157):

> "Next, the nature of lead, of which there are two types: white and black. White lead is very valuable, and the Greeks call it *cassiterum* […] It is found in Portugal and Galicia, above a black sandy soil, which is identified by its weight […] The water that washes the gravel releases black-colored grains with white specks, as heavy as gold. […] It is also found along with the metal in the baskets that collect the gold […]".

The prospecting tasks carried out by our research group, GeoInca, from the University of León, in the rivers of Los Ancares (León)—such as the Burbia and Ancares Rivers—and Las Médulas have determined that the lead-colored mineral found at the bottom of the gold pan, which Pliny refers to as white lead, may correspond to hematite or possibly tin (cassiterite, probably the *cassiterum* mentioned by the Greeks, a major tin ore). The latter is highly abundant in both Galicia and Portugal. In contrast, the mineral Pliny refers to as black lead could correspond to oxidized (rusty) pyrite or even magnetite and/or wolframite. We would like to note that Pliny may have misidentified certain minerals commonly found in auriferous river environments (Fernández-Lozano 2025), and that some of his references may be based on second-hand accounts of minerals known to occur in the northwestern part of the Iberian Peninsula. Nonetheless, it is true that some Roman-exploited areas—such as El Cabaco (Salamanca)—contain placer-like deposits situated near granitic and quartzite rocks, where both tin and gold are present. Given these recent observations at various gold-bearing sites in northwestern Iberia (Fig. 6), we wish to leave open the possibility of a reinterpretation of Pliny's descriptions. We propose it as a working hypothesis with the aim of fostering scientific discussion and opening up possible new avenues of interpretation.

Pliny describes a second method of gold extraction, carried out in wells known as *canalicium* or *canaliense* (*NH*, Book XXXIII, 68). What he refers to as marble is now known as milky quartz or

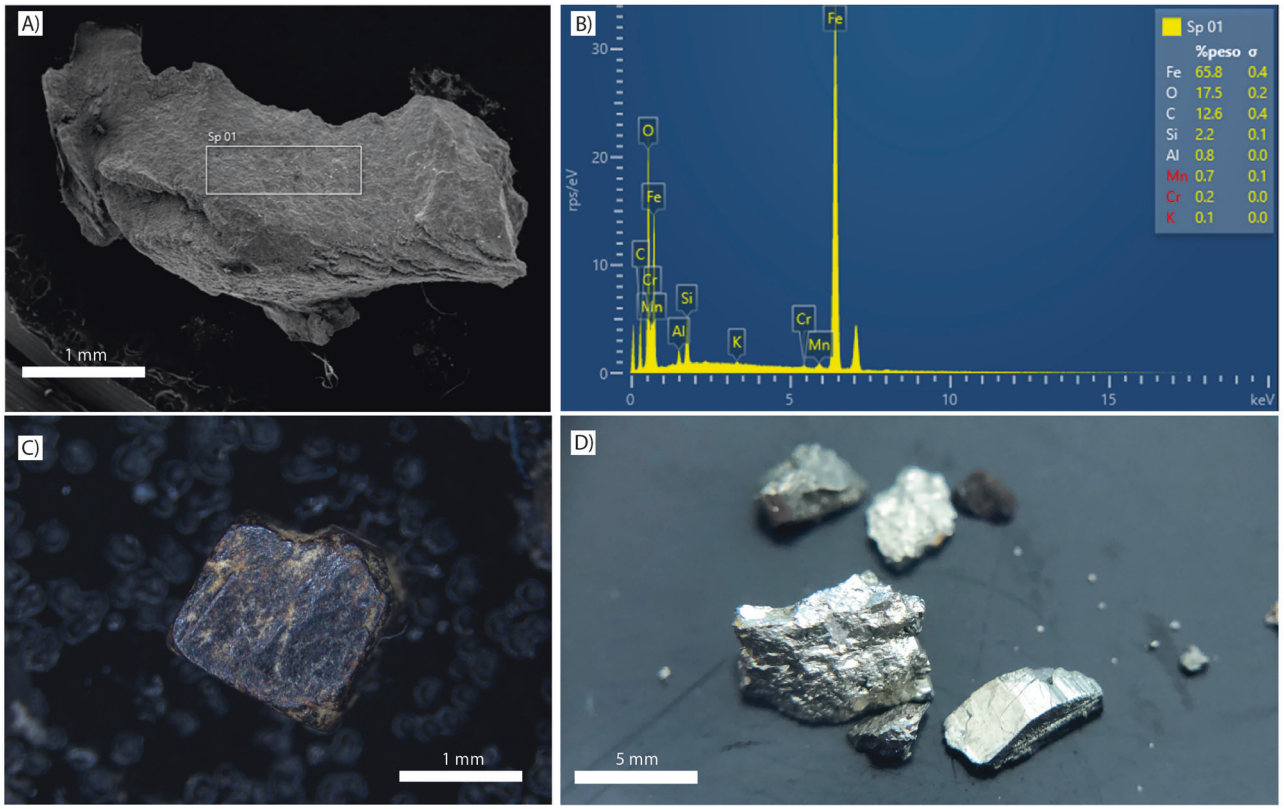

Fig. 6 Dense minerals associated with gold inriver basins. The prospecting works carried out in the "placer" gold-bearing deposits of El Bierzo (León, Spain) reveals fragments of dense metallic minerals that accumulate at the bottom of the gold pans. The grayish minerals (**A**) examined by scanning electron microscopy with energy-dispersive X-ray spectroscopy (SEM-EDS), show iron-rich compositions that suggest the possible presence of hematite (**B**) with no trace of arsenic or tin. **C** Shows other common minerals found in the panning concentrates associated with remnants of oxidized (rusty) pyrites. This suggests that the minerals referred to by Pliny as "white and black lead" could correspond to remnants of hematite and pyrite, which can take on lead-grey, black, and yellow hues (**D**).

white quartz. However, when he observes that "the marble contains gold particles," he effectively explains the trap formed by a quartz vein, where gold becomes embedded and retained.

> "[…] it is found along with pebbles and marble sand […] These are particles carried by the marble. These channels flow from the veins along the walls of the wells, which is why they are called *canalicium*. The galleries are supported by wooden pillars.".

He justifies the effort as a feat of great magnitude. He calls it, as we mentioned, "a work of giants," referring to the miners' labour and the exceptional ability of the Roman Empire to dominate nature. Through this hyperbole, he exaggerates the impact of the extraction technique used to demolish the mountain.

He states that channels were excavated into the rock to transport water to the mining sites, using iron picks. In the mining sites where the rock/sediment was too hard, fire and vinegar—mentions of vinegar probably reflect a transmission error (a misreading of Livy, 1919:21.37) rather than an actual practice; see the Hoovers' note in *De Re Metallica* (Agricola, 1950, pp. 118–19)—could have been used to open tunnels and underground galleries (*NH*, Book XXXIII, 27-4; *NH*, Book XXXIII, 71):

> "[…] Pouring vinegar to break the rocks, where even fire could not take effect".

Some of these channels transported water hundreds of kilometers to the mining sites (*NH*, Book XXXIII, 74) and was stored in reservoirs, from which the gold deposits were attacked (*NH*, Book XXXIII, 75):

> "Another task, even more costly, is to divert rivers from the mountain peaks, often a hundred miles away, to wash away the waste […] At the water's head, at the front of the mountain, two reservoirs are excavated […] Once the reservoir is full, the plugs are removed, and the rushing current surges with such force that it carries away entire sections of rock".

The rivers could not be diverted to flow directly into the mining areas. Still, their water was collected and channelled for hundreds of kilometers to the mining sites for mineral extraction. In this way, gold particles were released from the sediment, a process that remains active even today, although now mechanized through hydraulic jets or "*monitors*."

Pliny describes the gold recovery process in sedimentary deposits (*NH*, Book XXXIII, 76):

> "On flat terrain, there is yet another task: the excavation of pits called "*agogas*" to collect water, which are built in terraced steps. There is a shrub-like plant called ulex, similar to rosemary, which is rough in texture and helps retain gold. The sections are closed off with wooden planks, and these shrubs are hung over the cliffs".

He compares ulex (gorse, a spiny leguminous shrub) with rosemary (*Salvia genus*): although they are different species, they share a somewhat similar pattern in the way spines are distributed in the former and leaves in the latter. Through a

step-by-step enumeration, he describes the entire process of gold recovery in the *agogas* and their arrangement. His descriptions are simple, making it easier for his audience to visualize the process clearly.

The second framework: environmental and social impacts

Based on existing data (more than 500 mines have been identified in the province of León alone), we know that Roman gold mining had an enormous impact on the landscape of northwestern Iberia. The large-scale removal of vegetation cover for agriculture and livestock grazing facilitated the exposure and subsequent identification of mineral resources, a process that began with the Neolithic Revolution and quickly spread across the Iberian Peninsula, causing significant territorial transformations more than 6000 years ago (Morales-Molino 2014). This phenomenon intensified during Roman times, with the aim of promoting the systematic exploitation of the mineral resources present in Iberia (Hillman et al. 2017).

In a less anthropized landscape than today, particularly in northwestern Iberia, where annual precipitation exceeds 1000 mm (a transitional Atlantic-Mediterranean climate zone), we can assume the presence of dense vegetation. These conditions hindered access to resources, necessitating massive clearings and controlled burns to strip the soil of its vegetation cover. These operations were conducted over large areas, meaning that a primary mine like Las Médulas, which covered more than ~3000 hectares, would have required extensive deforestation before hydraulic mining (*arrugia*) could begin. Otherwise, the vegetation's stabilizing effect of the terrain would have prevented soil mobilization and the development of mining cuts. Numerous paleoenvironmental studies suggest that intense environmental changes occurred in antiquity as a result of mining and metallurgical activity (López-Merino et al. 2011; Silva-Sánchez 2015). Near Las Médulas, there are more than 500 mining sites spread across various valleys of the León mountains (Fernández-Lozano and Sanz-Ablanedo 2021). The sheer volume of excavated material—which at Las Médulas exceeded 90 million cubic meters (Pérez-García et al. 2000)—resulted in a large-scale transformation of the landscape.

The volume of extracted material was so immense that river waters turned red as sediment was carried downstream to the sea. This anthropization of the territory led to the formation of new valleys, reshaping the hydrological network by establishing new erosion cuts and channels. However, the extractive process was not the only factor generating a significant environmental impact —so too was the construction of the hydraulic network, which transported water over hundreds of kilometers to supply the mining operations (*NH*, Book XXXIII, 74–75).

The environmental impact was twofold. A project of this magnitude required modifying the terrain to ensure the correct gradient of the hydraulic network, which had to maintain slopes of 0.1–0.2% (Sánchez-Palencia 2000). The hydrological regime of river flows was altered to facilitate water collection, a process further exacerbated by seasonal reductions in river discharge during the summer months. Additionally, the excavation of large galleries and water reservoirs in the mining sites significantly altered the landscape, triggering massive earth movements (*NH*, Book XXXIII, 75). More than 150 water reservoirs have been identified in mining areas such as Sierra del Teleno (Fernández-Lozano et al. 2019). Finally, the construction of hydraulic works, including water diversions for gold-bearing sediment extraction in rivers, further modified natural watercourses (Fig. 7). These interventions caused major landscape transformations, disrupted fluvial regimes, and had a direct impact on local fauna.

Fig. 7 Anthropogenic river course modification. Montefurado tunnel (Montefurado, Lugo), built to divert the river to exploit the gold-bearing sands along the entire meander of the Sil River.

The exploitation of gold deposits required vast amounts of water for metal recovery, particularly in secondary ("placer") deposits. Strabo describes how the Salassi in northern Italy diverted the River Durias for mining, leading to the overexploitation and complete exhaustion of secondary deposits (Strab. *Geog*., 4.6.7), an episode generally dated to the mid-second century BCE (Davies 1935; Bird 2004). Placer-like deposits are geological formations that consist of sedimentary detrital materials, where gold, due to its high density, settles at the bottom of rivers, terraces, and other fluvial/alluvial sediments. Gold is transported hydraulically and accumulates in riverbeds, alluvial fans, and floodplains. Other natural placer deposits formed by glacial, aeolian, or coastal activity. Water was used to wash auriferous material (hushing), and gold was recovered by sluice boxes, a process comparable to the gold rush era of 19th-century California. The third type of gold mining, according to Pliny, involved obliterating entire mountains using water-driven collapse techniques. This process, known as *arrugia*, is now referred to as *ruina montium* (i.e., "the ruin of mountains"). The term *ruina montium* was exclusively used in Hispania to describe this specific mining method (Domergue, 1972; De Hoz 2003). Pliny describes this technique in *NH*, Book XXXIII, 71:

> "The third method surpasses even the labours of giants. Galleries are extended over long distances, deep into the mountain, lit only by oil lamps. The depth of these tunnels is measured in months, as miners work in darkness for extended periods. These mines, often called "*arrugiae*", collapse suddenly, and the shifting earth buries the workers. While it may seem reckless to seek pearls and coral in the depths of the sea, we have made the earth even deadlier than the water! […]".

In *NH* Book XXXIII, 72:

> "[…] Once the work is completed, the final blow is struck against the pillars of the arches, triggering the collapse, which is noticed only by the watchman at the top of the mountain".

He continues saying in *NH* Book XXXIII, 72:

> "He raises his voice and, with gestures, shouts to the workers, "Quick, flee!" The mountain breaks apart and collapses with a roar beyond imagination, unleashing an explosion of incredible force. The victorious look upon the ruin of nature".

Fig. 8 The scale of the mining works. Mining site of La Leitosa (León), exploited using the *arrugia* (*ruina montium*) method, with an associated fan of tailings resulting from the washing and recovery of the precious metal.

Fig. 9 The rugged topography traversed by channels. Section of channel to Las Médulas cut into a rock cliff, where workers may have hung from ropes to follow the channel's path.

With his account of miners fleeing before bringing down the mountain (Fig. 8), Pliny conveys to the reader the dangerous nature of these mines. He transmits the tension of the peril, describing miners perishing in the galleries, while also depicting the joy of those he calls victors, as they witness the defeat of nature. This was the effect of using water to extract gold (*NH*, Book XXXIII, 76): "And in this way, the water runs from the land to the sea, and the mountain collapses; this is how Hispania is exploited." The amount of water required for the *ruina montium* technique had to be sufficient to generate a flow capable of reaching the sea, over 150 km away in a straight line—a flow rate comparable to that of a river.

Beyond the immediate destruction of the landscape, mining's environmental impact extended to the metallurgical processes used to recover the metal. The mineral processing had well-known environmental consequences, mainly due to the waste and residues generated during ore treatment.

Pliny —shaped by Stoic ethics in his perception of nature as divinity— provides a meticulous description of these operations, which we now know had significant repercussions due to the release of toxic particles into the atmosphere, particularly heavy metals such as lead and bismuth (Martínez-Cortizas et al. 2013; Hillman et al. 2017). He writes (*NH*, Book XXXIII, 69):

> "The extracted mass is crushed, washed, burned, and reduced to powder […]. The impurities discarded by the dish, as with all metals, are called slag. This slag contains gold, so it is crushed again and heated in *tasconium* crucibles. This white-colored earth, similar to clay, is the only substance capable of withstanding the action of bellows and fire, allowing the material to reach boiling point".

The smelting and purification of ore in reduction furnaces, along with the use of substances such as mercury, have been recently identified in gold recovery processes in the placer deposits of the Eria Valley, in León (Fernández-Lozano et al. 2021). The mercury used in gold amalgamation is a highly polluting element, particularly due to mercury vapours or its methylation in water, processes that characterize the treatment, extraction, and use of this chemical element, leading to its accumulation in soils and natural waters (Ortiz-Villajo and Higueras 2017).

Alongside the severe environmental impact of these mining activities, there were also the harsh conditions faced by miners due to the extreme demands of working in the mines. Mining required a large workforce that included enslaved people; in northwestern Iberia, however, it relied predominantly on free workers who rendered tribute to Rome through their labour (Orejas-Saco del Valle et al. 2021).

Pliny also writes about the hardships of mining labour (*NH*, Book XXXIII, 71):

> "[…] Just as in caves, the steam and smoke suffocate the miners, they often have to break the rock with iron hammers […] then carry the fragments on their shoulders, day and night, passing them hand to hand through the darkness. Only those positioned at the entrance see the light […]".

We know that mining work was carried out by both free workers (*mercennarii*) and slaves (*servi*) until well into the 1st century CE. The situation changed from the 2nd century CE onward, when free labour became predominant due to the shortage and rising cost of slaves (Sánchez-Gómez 1989).

In one passage of his *Naturalis Historia*, Pliny describes how miners had to descend using ropes down the rugged slopes of the mountains (Fig. 9), where a vast system of channels, known as "*corrugos*", was built to transport water to major mines such as Las Médulas (León).

With the translation provided by Plácido and Sánchez-Palencia (2014):

> "There is another task, similar or even more costly: they have channeled water currents along the mountain peaks […] they call them "*corrugos*" […] The worker responsible for breaking them hangs from ropes, so that, to those watching from afar, he does not resemble any kind of beast, but rather a bird".

His account is similar to the one written a century earlier by the historian Diodorus of Sicily. However, Diodorus (2001) provides a more poignant depiction of the harsh working conditions in the mines and how miners sacrificed their lives under such adverse circumstances.

Diodorus of Sicily writes about the sufferings of the miners (Diod. *BH*, Book V, 38):

> "[…] Underground in the galleries, they wear out their bodies day and night, and many perish due to extreme hardships; they have no right to rest nor any pause in their labour […] they give their lives in utter misery, although some, thanks to their physical endurance and strength of spirit, manage to survive longer, only to prolong their suffering".

Classical authors portray mining labour as abhorrent, carried out under extremely harsh conditions, without rest. The suffering was so great that Diodorus even suggests that some miners preferred death to continuing their existence. Similarly, Seneca (1979), in his *Naturales Quaestiones* (V, 15), describes the mines

of Carthago Nova as true human anthills (Sánchez-Palencia and Orejas 2012).

From records concerning the mines of the Red Sea, we can infer how mining labour could be organised in other parts of the Roman world. Work was divided by age and gender (Diod. *BH*, Book III). Children and adolescents were often employed to enter narrow and remote areas of the mines, where they collected fallen rock and transported it to the surface (Arboledas-Martínez and Alarcón-García 2015). As a broader Roman parallel, the funerary stele of Quartulo depicts a four-year-old child miner from the Hispano-Roman province of Baetica; it is now exhibited in the Spanish National Archaeological Museum (MAN).

Sources from elsewhere in the Roman Empire suggest that adult workers carried out mineral extraction inside the mines, following the veins by striking with hammers and chisels. Women and the elderly were assigned to washing and recovering minerals. There was no mercy for the sick or disabled—those who were weaker could end up dying under mistreatment and torture.

During underground work, some miners were trapped by cave-ins (*NH*, Book XXXIII, 70). And for many, their suffering did not always bring profit or gain—for some, mining became their ruin (*NH*, Book III, 33; Book V; *NH*, Book XXXIII, 73).

Gold as a two-faced metaphor

Roman mining megaprojects, landscape transformation, and environmental impact went hand in hand. The development of a mining system like *ruina montium*, capable of removing more than 90 million cubic meters of material that made up the slopes of the Roman mine at Las Médulas, is today seen as a unique historical achievement. No one questions the artistic beauty of the mining landscape silhouette left by these ancient exploitations. In contrast, just a few kilometers away, the remains of other modern quarries opened for limestone extraction in the area have caused a significant negative environmental impact (Félix 2014). It seems to highlight humanity´s ability to carry out colossal engineering feats, piercing and dismantling an entire mountain with water power, transported through canals from distant locations. However, those majestic sedimentary rock formations that stand out in the mining landscape are the result of errors in execution, which prevented Roman miners from extracting all the gold.

From a historical discourse perspective, what we recognize in Pliny the Elder is his ability to frame the issue, to redefine a conflict or dilemma that his contemporaries overlooked. He approached the problem with a broader perspective, identifying both a cause—greed—and a consequence—the assault on nature and its potential vengeance. It is an exception, although other contemporary authors also approach the issue: Ovid, for instance, alludes to the dangers of gold ("more harmful than iron") in his Metamorphoses. He writes (*Metamorph*, I, 137–143):

> "[…] and not only did they demand from the fertile soil its crops and necessary food, but they also delved into the very bowels of the earth and unearthed what brings misfortune —the riches she had hidden near the gloomy Styx".

However, unlike Pliny, Ovid does not frame his approach from the perspective of environmental harm.

By employing gold as a two-faced metaphor, Pliny diminished its traditional association with value, power, or abundance (which many perceived as its primary meaning). It intensified its connection to greed, portraying it as the raw material for rings, garments, and other ornaments. Through this narrative strategy, he gave life to his discussion of gold mining, transforming what might have been a conventional analysis of pros and cons into a story of action and reaction, populated by protagonists and antagonists—with nature personified as a force that retaliates against human greed, endangering miners in response.

We know, thanks to rhetoric, that reality is constructed through discourse. A narrative structure arranges facts into a meaningful direction, creating significant relationships, which is what White refers to as an "integrated pattern of meaning" (cf. Pujante and Alonso Prieto 2022, 56). This reflects the mutual influence between discourse and society, where society both produces and responds to its impact.

According to Lakoff (2020), "frames" are the mental structures that shape our perception of the world. Thus, redefining the frame means changing the way we see reality. Faced with a complex issue such as natural resource exploitation, necessary to sustain or increase economic development, Pliny highlighted its dual nature: he understood that gold, as a global image, provided the two necessary perspectives for comprehending the problem.

A metaphor is an association of different meanings, the transfer of one meaning to another to create a new image. Different authors have described its mechanism as a rhetorical device in similar terms: i) Michel Le Guern sees it as the projection of a paradigmatic relationship onto the syntagmatic axis (1976, 26); ii) Bobes Naves defines it as a semantic interaction between two terms that share a syntactic relationship (2004, 119); iii) Ortega y Gasset describes it as the annihilation of two realities to create a new one (1983, VII, 460), and iv) Ricoeur considers it a continuous process of reconfiguration (2001).

Pliny's gold metaphor is implicitly embedded in the framework of Book XXXIII. He does not explicitly state "gold is greed", but he constructs a brief introductory thesis for his treatise on metals, which is effectively summarized by this metaphor. This shift in meaning transforms gold into a symbol of greed, as he presents it not as a mineral but as a product that best represents luxury and ornamentation, gold transformed into rings.

With this analogy as a premise, Pliny is able to better explain mining accidents as the culmination of a narrative. A personification or prosopopoeia attributes human qualities to inanimate entities. By personifying the mine or nature, Pliny transforms the physical and geological causes of mining accidents into a narrative, where the victim—the mine—seeks revenge after being harmed by an unjustified act, motivated solely by human greed (as men excavate the earth to satisfy their desire for luxury).

In the early paragraphs of Book XXXIII, Pliny uses metaphors to describe the mine as "the thrones of the infernal Gods" or "infernal regions". These expressions are intended to suggest both the extent of the desecration that nature suffers and its destructive power in carrying out its revenge. This new cultural narrative is less forgiving of Roman imperial power. In this way, he somehow anticipates the approach of some current critical readings of the history of mineral extraction (such as the very recent one by Yusoff [2024], though with a different focus and intensity).

Conclusions

Pliny the Elder´s contribution to the understanding of Roman gold mining in Book XXXIII of his *Naturalis Historia* can be analyzed on three levels, two of which have been more extensively studied, while the third remains less explored. The first contribution lies in the quality of his testimony, which is further validated by his citation of over 400 sources. The second contribution is his analytical capacity, as he provides a reasonably rigorous exposition of the minerals found in the Iberian Peninsula and the techniques used for their extraction—this very aspect, along with its artistic references, has recently been studied by Anguissola and Grüner (2021). The third contribution is his perspective, made possible by his ability to synthesise

information. Pliny frames his references to mining within a standard interpretative structure, which he constructs through the use of gold as a general metaphor: (i) a first, more evident and generalized meaning, in which gold is associated with wealth and power; (ii) a second, more nuanced meaning, derived from the first but carrying exclusively negative connotations, in which gold is understood as greed. This approach enables him to establish a second rhetorical connection with the core of his naturalist thought—namely, nature's vengeance in response to the aggressions it suffers, which he expresses through prosopopoeia or personification.

This study examines Book XXXIII of Pliny´s *Naturalis Historia* from both a close and distant perspective. To demonstrate the value of his analysis, it is contrasted with current and historical knowledge of the geology of northwestern Iberia and Roman mining engineering (drawing on highly detailed fieldwork). To highlight the importance of his synthesis and rhetorical approach, his discourse is situated within contemporary rhetoric and the broader context of cultural narratives.

Data availability

No datasets were generated or analysed during the current study.

Received: 8 March 2025; Accepted: 19 January 2026;
Published online: 28 January 2026

References

Agricola G (1950) De re metallica. Dover Publications
Anguissola A, Grüner A (2021) The nature of art: Pliny the Elder on materials (Vol. 1, Materiality). Brepols
Arboledas-Martínez L, Alarcón-García E (2015) Infantile Individuals: The Great Forgotten of Ancient Mining and Metallurgical Production. In Sánchez Romero M, Alarcón García E, Aranda G (eds), Children, Spaces and Identity, Childhood in the Past: An Int J 4, Oxbow Books, Oxford
Bible Gateway (2026) Biblegateway Online. https://www.biblegateway.com/
Bird D (2004) Pliny's arrugia water power in roman gold-mining. Min History: Bull Peak Dist Mines Historical Soc 15(4-5):58–63
Blanco-Robles F (2020) De Iberia a Hispania: la formación de una identidad en la Antigüedad (I). Hispania Antiqua, (XLIV), 316–338
Blázquez JM (1971) Economía de Hispania al final de la República Romana ya comienzos del Imperio según Estrabón y Plinio. Estudios de Historia Económica I Rev de la Univ de Madr 20(78):57–143
Bobes Naves C (2004) La metáfora. Gredos
Davies O (1935) Roman mines in Europe. The Clarendon Press, 304 pp
De Hoz J (2003) El léxico minero de Plinio y su posible origen hispano. *Palaeohispanica*. Rev sobre Leng y culturas de la Hispania Antig 3:73–100
Diodorus (2001) Biblioteca Histórica, Libros I-III (F Parreou Alasa, Trad.). Editorial Gredos, 576 pp
Domergue C (1990) Les mines de la Péninsule Ibérique dans l'antiquité romaine (Vol. 127, No. 1, pp. 0-0). Persée-Portail des revues scientifiques en SHS
Domergue C (1972) A propos de Pline "Naturalis Historia" 33, 70-78, et pour illustrer sa description des mines dór romaines dÉspagne. Arch español De arqueología 45(125):499–528
Domergue C, Herail G (1978) Mines d'or romaines d'Espagne.Le district de la Valduerna. Publications de l'Universite Toulouse Le-Mirail, series B 4
Domergue C, Sillières P (1977) Minas de oro romanas de la provincia de León. Servicio de publicaciones del Ministerio de Educación y Ciencia
Dunn D (2021) Bajo la sombra del Vesubio: Vida de Plinio. Vol. 120. Siruela
Félix M (2014) Piden 6 y 3 años de cárcel para Martínez Parra y el alcalde de Carucedo por la cantera de Catisa. Diario de León. https://www.diariodeleon.es/bierzo/140405/955560/piden-6-3-anos-carcel-martinez-parra-alcalde-carucedo-cantera-catisa.html
Fernández-Lozano J, González-Pérez I, González-Abajo Á, Sanz-Ablanedo E, Rodríguez-Pérez JR (2025) Absent Voices and Unwarranted Presences: A Combined Multi-Approach to Mapping the Roman Hydraulic System Supplying Las Médulas Gold Mine (NW, Iberia). Geosciences 15(1):13. https://doi.org/10.3390/geosciences15010013
Fernández-Lozano J (2025) La minería aurífera romana en la Reserva de la Biosfera de los Ancares Leoneses. *Revista Braña*. Cuad de Divulgación Científica en Reservas de la Biosf 1:8–25
Fernández-Lozano J, Sanz-Ablanedo E (2021) Unraveling the morphological constraints on Roman gold mining hydraulic infrastructure in NW Spain. A UAV-derived photogrammetric and multispectral approach. Remote Sens 13(2):291. https://doi.org/10.3390/rs13020291
Fernández-Lozano J, Palao-Vicente JJ, Blanco-Sánchez JA, Gutiérrez-Alonso G, Remondo J, Bonachea J, Morellón M, González-Díez A (2019) Gold-bearing Plio-Quaternary deposits: Insights from airborne LiDAR technology into the landscape evolution during the early Roman mining works in north-west Spain. J Archaeological Sci: Rep 24:843–855. https://doi.org/10.1016/j.jasrep.2019.03.001
Fernández-Lozano J, Gutiérrez-Alonso G (2017a) Geomática aplicada a la prospección y valoración arqueológica de yacimientos auríferos romanos en el noreste peninsular (Distrito Aurífero del Valle del Eria, León). In Minería y metalurgia históricas en el sudoeste europeo: nuestras raíces mineras. Sociedad Española para la Defensa del Patrimonio Geológico y Minero SEDPGYM, 105–111
Fernández-Lozano J, Gutiérrez-Alonso G (2017b) Uso de LiDAR y aeronaves no tripuladas para la cartografía y registro de zonas de interés geominero: un ejemplo de la minería aurífera romana en el valle del Eria (León, España). In Investigaciones arqueológicas en el valle del Duero: del Paleolítico a la Edad Media: actas de las V Jornadas de Jóvenes Investigadores del valle del Duero. Del Paleolítico a la Edad Media. Glyphos, 520–536
Fernández-Lozano J, Gutiérrez-Alonso G (2014) Aplicación de LiDAR aerotransportado para la cartografía de las antiguas labores mineras romanas en el noroeste peninsular. Mapping (167), 22–29
Fernández-Mier M (1996) Repercusiones de la minería aurífera romana sobre el poblamiento medieval: la trasformación del paisaje y su dedicación posterior. Fundación Hullera Vasco-Leonesa. In Minería y metalurgia históricas en el sudoeste europeo: nuestras raíces mineras. Sociedad Española para la Defensa del Patrimonio Geológico y Minero SEDPGYM, 649–658
Fernández-Alonso D, Férnandez-Lozano J, García-Ordás M T(2023) Convolutional neural networks for accurate identification of mining remains from UAV-derived images. App Intell 53(24):30469–30481. https://doi.org/10.1007/s10489-023-05161-8
Florus (2000) Epítome de la historia de Tito Livio (G. Hinojo Andrés e I. Moreno Ferrero, Trad.). Editorial Gredos
Gómez, JS (1989). De minería, metalúrgica y comercio de metales: la minería no férrica en el Reino de Castilla, 1450-1610. Universidad de Salamanca 65 (I)
Hillman AL, Abbott MB, Valero-Garcés BL, Morellon M, Barreiro-Lostres F, Bain DJ (2017) Lead pollution resulting from Roman gold extraction in northwestern Spain. Holocene 27(10):1465–1474. https://doi.org/10.1177/0959683617693903
Lakoff G (2020) No piensen en un elefante. Ediciones Península
Le Guern M (1976) La metáfora y la metonimia. Catedra
Livy (1919) History of Rome, Vol. VI (Books 21–22). Harvard University Press (Loeb Classical Library)
López-Merino L, Cortizas AM, López-Sáez JA (2011) Human-induced changes on wetlands: a study case from NW Iberia. Quat Sci Rev 30(19-20):2745–2754. https://doi.org/10.1016/j.quascirev.2011.06.004
Martínez-Cortizas A, López-Merino L, Bindler R, Mighall T, Kylander M (2013) Atmospheric Pb pollution in N Iberia during the late Iron Age/Roman times reconstructed using the high-resolution record of La Molina mire (Asturias, Spain). J Paleolimnol 50:71–86. https://doi.org/10.1007/s10933-013-9705-y
Mata-Soler J (2014) A propósito de la Laus Hispaniae de Plinio el Viejo (*NH*. 37, 77) y la economía de Calagurris iulia. Kalakorikos. Rev para el estudio, Def, protección y divulgación del Patrim histórico, artístico y cultural de Calahorra y su entorno 19:181–192
Morales-Molino C, García-Antón M (2014) Vegetation and fire history since the last glacial maximum in an inland area of the western Mediterranean Basin (Northern Iberian Plateau, NW Spain). Quat Res 81(1):63–77. https://doi.org/10.1016/j.yqres.2013.10.010
Norden E (1954) Die romische Literatur: Mit ANHang: Die lateinische Literatur im Ubergang vom Altertum zum Mittelalter. BG Teubner
Orejas-Saco del Valle A, Sastre-Prats I, Zubiaurre-Ibañez E (2021) Organización y regulación de la actividad minera hispana altoimperial. In Zarzalejos Prieto, M, Hevia Gómez, P and Mansilla Plaza, L (eds.). Paisajes Mineros Antiguos de la Península Ibérica: Investigaciones recientes y nuevas líneas de trabajo. Universidad Nacional de Educación a Distancia, 31–46
Ortega y Gasset J (1983) "Idea del teatro", Obras completas (tomo VII). Alianza Editorial
Ortiz-Villajos JAA, Higueras PLH (2017) Contaminación de suelos por mercurio. In Introducción a la contaminación de suelos. Mundi Prensa Libros, 75–85
Pérez-García LC, Sánchez-Palencia FJ, Torres-Ruiz J (2000) Tertiary and Quaternary alluvial gold deposits of Northwest Spain and Roman mining (NW of Duero and Bierzo Basins). J Geochemical Exploration 71(2):225–240. https://doi.org/10.1016/S0375-6742(00)00154-0

Plácido-Suárez D (1988) Estrabón III: el territorio hispano, la geografía griega y el imperialismo romano. Habis 18 y 19:243–256
Plácido-Suárez D, Sánchez-Palencia FJ (2014) La explicación de la minería de oro romana hispana en la Historia Natural de Plinio El Viejo, párrafos 66 a 78 del libro XXXIII. In FJ Sánchez-Palencia (Ed.), Minería romana en zonas interfronterizas de Castilla y León y Portugal. Junta de Castilla y León. Consejería de Cultura y Turismo, 17–32
Pliny the Elder (1995). Historia Natural (A. Fontán, Trad.). Editorial Gredos
Pujante D, Alonso Prieto J (2022) Una retórica constructivista. Creación y análisis del discurso social. Universitat Jaume I
Ramos-Maldonado SI (2014) De stilo presso: Plinio el Viejo en las controversias ciceronianas. Rev de Estudios Lat (RELat) 14:119–139
Ricoeur P (2001) La metáfora viva. Trotta
Robertson P, Pollaro P (2022) Ancient Greco-Roman Views of Ecology, Sustainability, and Extinction: Aristotle, Stoicism, Pliny the Elder on Silphium, the Modern Legacy in Cuvier, Humboldt, Darwin, and beyond. In Ecotheology-sustainability and religions of the world. IntechOpen, 1–19. https://doi.org/10.5772/intechopen.104989
Sánchez-Gómez J (1989) De Minería, Metalúrgica y Comercio de Metales. Tomo I. [Tesis doctoral]. Universidad de Salamanca, 415 pp
Sánchez-Palencia FJ, Orejas-Saco del Valle A (2012) Alcance e impacto de la minería provincial hispanorromana. Minería y metalurgia antiguas: Visiones y revisiones. Homenaje a Claude Domergue (Madrid: Casa de Velázquez), 261–272
Sánchez-Palencia FJ (ed.) (2000) Las Médulas, un paisaje cultural en la Asturia Augustana. Diputación Provincial de León, 362 pp
Sánchez-Palencia FJ, Fernández-Posse MD, Fernández-Manzano J, Orejas-Saco del Valle A, Pérez-García LC (1998) Las Médulas (León), la formación de un paisaje cultural minero. Boletín Geológico y Min 109(5–6):157–178
Sánchez-Palencia FJ (1984) La explotación del oro de Asturia y Gallaecia en la Antigüedad. Tesis doctoral, Universidad Complutense de Madrid
Seneca (1979) Naturales Quaestiones. Colección Hispánica de Autores Griegos y Latinos. Consejo Superior de Investigaciones Científicas, Vol. 1, 361 pp
Silva-Sánchez NS (2015) Mining and metallurgical activities in N Iberia and their link to forest evolution using environmental archives (centuries AD V to XI). Estudos do Quaternário Quaternary Studies, (12), 15–26. https://doi.org/10.30893/eq.v0i12.104
Sowerby W (1885) The Spanish Gold-fields and Mines of the Rio Sil. Suppl. Mining J, London
Strabo (1991) Geografía. Libros III-IV (Ma J. Meana y F. Piñero, Trad.). Editorial Gredos, 215 pp
Toscano M, Pérez-López R, Sáez R (2012). Concentración de minerales pesados mediante técnicas de batea y su interpretación. Enseñanza de las Ciencias de la Tierra, 20(2): 164–164
Tuñas-Corzón S (2022) Tras los pasos de Plinio: John Rosewarne y los inicios de la minería industrial en el noroeste peninsular. De Re Metallica 39:79–96
Wade M (2023) Stoic Pantheism and Environmental Ethics in Pliny the Elder. In: Valera, L (eds) Pantheism and Ecology. Ecology and Ethics, vol 6. Springer, Cham. https://doi.org/10.1007/978-3-031-40040-7_2
Yusoff K (2024) Geologic life: Inhuman intimacies and the geophysics of race. Duke University Press. https://doi.org/10.1215/9781478059288

Acknowledgements

Javier Fernández-Lozano, Ph.D., gratefully acknowledges partial funding from the Universidad de León (Ayuda a Proyectos de Investigación Ule-2024/00205/001). Enrique Ferrari, Ph.D., acknowledges partial funding from the International University of La Rioja (UNIR) through the Call for Grants for Scientific Publication in Prestigious Editorial Media.

Author contributions

JFL and EFN drafted and revised the manuscript. JFL prepared the figures. Both authors reviewed and approved the final manuscript.

Competing interests

The authors declare no competing interests.

Ethical approval

This article does not contain any studies with human participants performed by any of the authors.

Informed consent

The study does not involve human participants or their data.

Additional information

Supplementary information The online version contains supplementary material available at https://doi.org/10.1057/s41599-026-06556-x.

Correspondence and requests for materials should be addressed to Javier Fernández-Lozano.