



LiDAR Datasets Applied to Roman Gold Mining Studies in NW Iberia. Response to Paper: Roman Gold Mining at “Las Miédolas” (NW Spain): Lidar and Photo Interpretation in the Analysis of “Peines”

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Abstract

Early LiDAR datasets in Spain are available since 2014 (5-m resolution), when the first works were carried out by our team (Fernández-Lozano and Gutiérrez-Alonso Mapping 167:22–29, 2014; Fernández-Lozano et al. J Archaeol Sci 2014:356–373, 2015). The implementation of LiDAR to 1-m resolution was subsequently used and compared by Fernández-Lozano and Gutiérrez-Alonso (J Archaeol Sci 5:509–520, 2016) in combination with UAV-derived (Unmanned Aerial Vehicles) photogrammetry. These works showed different Roman gold mining scenarios that were modeled providing outstanding results even with the poorest resolution LiDAR datasets. Moreover, the implementation of visual enhancement tools, widely used in different fields of archeology, geomorphology, and geology, such as Sky-View, Multi-hillside, Slope, LRM, Openness, and Principal Components have improved notably the interpretation of results in both mining and archeological works. This paper discusses the potential and insights provided by our methodological approach and shows that the results of its application to the study area of Las Miédolas can provide better results than those obtained by Matías and Llamas (Geoheritage 13(2):1–22, 2021).

Keywords LiDAR · Roman gold mining · Visual enhancement methods · UAV · Hydraulic network · Geomorphological features

Introduction

We welcome and acknowledge the work by Matías and Llamas (2021) for providing new data and interpretations on the “Las Miédolas” roman gold mining complex. Nevertheless, we disagree with several misleading statements in the text concerning our pioneering work using the LiDAR technology in nearby areas (Fernández-Lozano

and Gutiérrez-Alonso 2014, 2016; Fernández-Lozano et al. 2015) without providing adequate discussion. For instance, in their paper, Matías and Llamas (2021; pag. 5) wrote “Other authors made similar studies with scarce results in the Roman mining located in the Iberian Northwest (Fernández-Lozano and Gutiérrez-Alonso 2014; Fernández-Lozano and Gutiérrez-Alonso 2016).”

Nevertheless, the use of LiDAR technology in characterizing and documenting Roman gold works in NW Iberia was first done by Fernández-Lozano and Gutiérrez-Alonso (2014) and Fernández-Lozano et al. (2015), who were able to discover and describe new sectors of Roman gold mining in the Eria river area, where part of the hydraulic and mining infrastructure was unknown. This work improved the mapping of some sectors carried out to date with traditional aerial orthoimages. Subsequent works carried out by Matías and Llamas (2018, 2019, 2021) were all based on the methodological approach shown in the pioneering work developed by Fernández-Lozano and Gutiérrez-Alonso (2014) and Fernández-Lozano et al. (2015). On the other hand, the implementation of unmanned aerial vehicles (UAVs) and

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visual enhancement methods (VEM) shown in Fernández-Lozano and Gutiérrez-Alonso (2016) has demonstrated the potential of this methodology, lately used by different researchers in other archeological and geomorphological papers (e.g., Sonnemann et al. 2016; Poirier et al. 2020; Carrasco et al. 2020).

The Roman exploitation of secondary placer gold deposits of reduced thickness and extensive surface was based on converging furrows also known as “peines.” This method was a standardized practice between the first and third centuries A.D. as shown by the several examples recorded in Northwest Iberia (not only in the Province of León, as stated by Matías and Llamas 2021); Galicia and Portugal (Chá do Castro, Los Milagros de Monte Medo, As Covas, Avintes, etc., Sánchez-Palencia 1983); Salamanca (Ruíz del Árbol Moro and Sánchez-Palencia 1999; Ruíz del Árbol Moro et al. 2014); Zamora (Rio Negro, Andrés-Bercianos et al. 2021a); and León (Destriana, Las Murias-Tallares, Castro de Cepeda, Vallico La Escoba, Torneros de Jamuz, respectively, studied by Domergue (1973); Sáenz and Vélez (1974); González-Gutiérrez (1999); Fernández-Lozano and Gutiérrez-Alonso 2016; Fernández-Lozano et al. 2019). Some of them, like El Cabaco (<https://el-cabaco.com/cavenes/>), in the Province of Salamanca, represent an outstanding example of this exploitation method, having their own Interpretation Centre of the Roman Gold Mining Industry, which contributes to the promotion of geotourism.

Besides their impressive geometrical appearance, the interest of the convergent furrows exploitation method is supported by the comprehensive information that emerges from their complex infrastructure of water channels and drainage systems (evacuation channels). This type of exploitation is easily recognized from aerial imagery since their extension and magnitude are large enough to preserve the mining infrastructure remains. In the area of Las Miédolas, several systems of exploitation, comprising convergent furrows and trenches, trench-channels, and large trenches and simple trenches are combined to exploit the larger extension using the minimum hydraulic resources (Fig. 1). Therefore, their analysis using technologies such as LiDAR or UAVs can improve the results of the documentation works in these areas, unlike other mining sectors with minor works and more densely vegetated, developed also over the Raña deposits of the western Duero Basin (Fernández-Lozano et al. 2019; Andrés-Bercianos et al. 2021b).

In the light of the above, in order to correct the statement made by Matías and Llamas (2021; pg. 5) and to support our methodological approach, we present here an example of its potential as an application to the area studied by Matías and Llamas (2021), which can improve their results on deciphering the hydraulic and mining complex at Las Miédolas site. It is also interesting to note that using LiDAR in areas with reduced vegetation cover, or minor anthropic

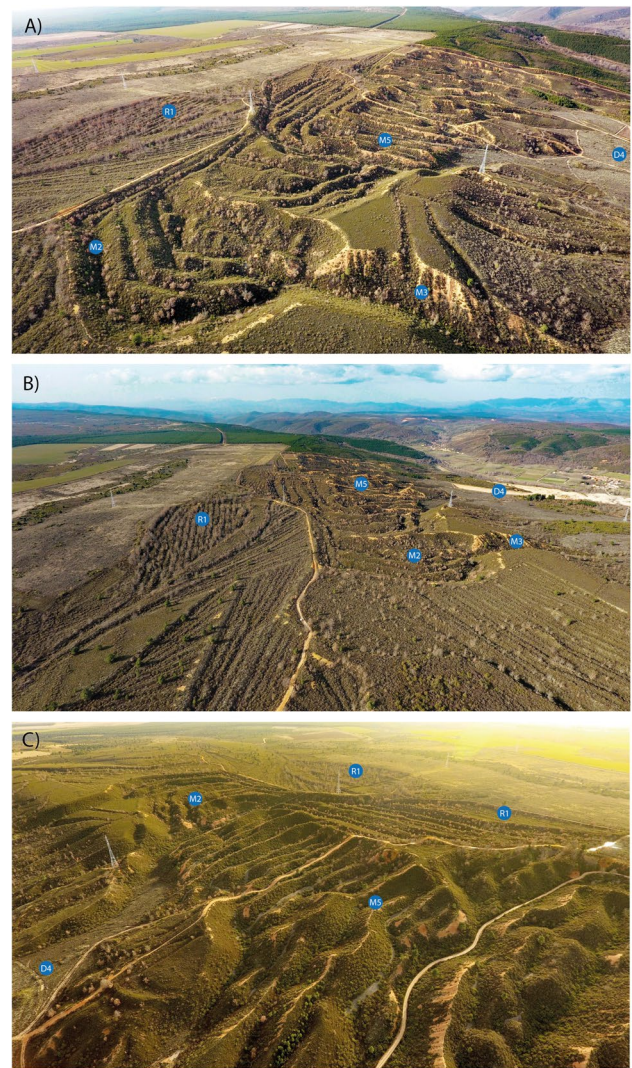


Fig. 1 A, B, and C comprise different exploitation sectors at Las Miédolas. Legend: R1, Raña deposits exploited in convergent furrows; M2, Miocene deposits exploited in convergent trenches; M3, Miocene deposits exploited in large trench systems; D4, Quaternary debris slopes deposits exploited in grooves; M5, Miocene deposits exploited in trench-channel structures

modifications, such as Las Miédolas, where the infrastructure can be directly observed from aerial images, provides little difference in the interpretation from previous works (see previous cartography presented by Sánchez-Palencia 1983).

The emergence of LiDAR and UAV technologies

The use of light detection and ranging (also known as LiDAR) in archeological and prospection works has grown lately. The high accuracy and resolution of LiDAR point

clouds datasets boosted the ability to investigate large areas in remote regions with dense vegetation cover. In Spain, the Instituto Geográfico Nacional (IGN; www.ign.es) provides first cover point clouds with density 0.5–4 points/m² and altimetric precision of 20 cm. The dataset provided by the IGN has multiple returns (4 per pulse), which are always used to obtain a more detailed and accurate interpolation of the ground surface. As explained by Fernández-Lozano and Gutiérrez-Alonso (2014), the DTM, depending on the LiDAR coverage, can be interpolated to different high resolutions, from 1 to 5 m. However, as these authors suggest in their subsequent paper in 2015, depending on the characteristics of the elements and landforms (i.e., channels, water tanks, and anthropic landscape modifications), 3 or 5 m LiDAR resolution may improve the prospection results (Fernández-Lozano and Gutiérrez-Alonso 2015). It is important to pinpoint that early public IGN datasets available and published in Fernández-Lozano et al. (2015) were 5-m resolution.

Unmanned aerial vehicles or UAVs also show promising results for the exploration of ancient mining sites. First implemented in the Roman gold mining of NW Iberia by Fernández-Lozano and Gutiérrez-Alonso (2016), the photogrammetric-based products (i.e., mdt, orthomosaics, and 3D texture maps) have contributed to improving the mapping of mining infrastructure and to the public diffusion and conservation of Roman remains (Fernández-Lozano et al. 2018; Fernández-Lozano and Sanz-Ablanedo 2021). The UAV pioneering work was systematically overlooked by the authors of the paper Matías and Llamas (2021) (and previous works, see García-Ramos 2017; Matías and Llamas 2018), the former carried out a similar study in the area without crediting. It is important to remark that UAVs are not geographic information systems as it is suggested from a poor precise title with no relation with the content of the technical document published by García-Ramos (2017), but it is an airborne geomatic technology that uses different sensors (i.e., LiDAR, RGB, multi-hyperspectral sensors) for exploration and mapping.

Recent work by Fernández-Lozano and Sanz-Ablanedo (2021) represents a step forward in the study of the Roman gold mining by implementing high-resolution UAV photogrammetry and multispectral analysis, which constitutes a promising method for exploration in extremely vegetated areas or where other technologies, such as LiDAR, do not offer enough resolution. This is the case of the Montealegre sector, near the El Bierzo Basin, where 1 m LiDAR data and PNOA orthoimages (Plan Nacional de Ortofotografía Aérea, IGN, www.ign.es) do not allow the accurate identification of the hydraulic network in certain sectors (Fernández-Lozano and Sanz-Ablanedo 2021). However, in those sectors, the implementation of UAV photogrammetric and multispectral flights efficiently highlights the location of the channels.

Thus, UAV-derived data allow the accurate location and morphometric analysis of these structures providing new insights into the magnitude of the Roman works in north-west Iberia. Even though complex areas with poor LiDAR data coverage are difficult to explore, generally, this technology provides outstanding results in regions with dense point clouds dataset (a high-resolution LiDAR coverage depends also on the type of vegetation and its density. For instance, pine trees provide better surface coverage than oak trees and dense scrub). Therefore, excellent areas for interpretation of Roman gold mining remains based on LiDAR data are, for instance, the Teleno Mountains (Fernández-Lozano et al. 2020), Las Miédolas Mine (Matías and Llamas 2021), or Las Murias-Los Tallares (Castrocontrigo; Fernández-Lozano and Gutiérrez-Alonso 2014; Fernández-Lozano et al. 2015), where a low vegetation cover enhances a better reconstruction of the terrain.

Visual enhancement tools for Roman gold mining documentation

Visual enhancement tools (VET) are widely used in archeological, geomorphological, and mining works due to their potential for improving the identification, description, and interpretation of different anthropic and natural landforms (Challis et al. 2011; Kokalj et al. 2011; Štular et al. 2012; Doneus 2013; Carrasco et al. 2020). These methods have been successfully implemented in the study of Roman gold mining remains by Fernández-Lozano and Gutiérrez-Alonso (2016) and Fernández-Lozano et al. (2018, 2019, 2020). These works have shown that VET is a powerful tool to explore complex settings where the anthropic signature hides most of the remains as a result of farming and other forestry exploitation activity. The different proposed methods have also contributed to improving the initial digital 5-m elevation models available from 2014 (Fernández-Lozano and Gutiérrez-Alonso 2015).

The low vegetation cover affecting Las Miédolas allows the rapid interpretation from aerial imagery, especially from the so-called *Vuelo Americano* (American Flight; from 1956–57). However, in areas with dense vegetation cover, the identification of mining infrastructure becomes complicated. In this case, the use of LiDAR and the processing techniques can efficiently improve the prospection results. Different techniques can be implemented at Las Miédolas mining sector following the methodology by Fernández-Lozano and Gutiérrez-Alonso (2014, 2016), which provide insightful information and details of the hydraulic system and mining infrastructure (Fig. 2). Besides the clear anthropic features observed from aerial imagery, the implementation of Sky-View Factor, SLRM, Slope, and Openness algorithms can provide useful details about the drainage

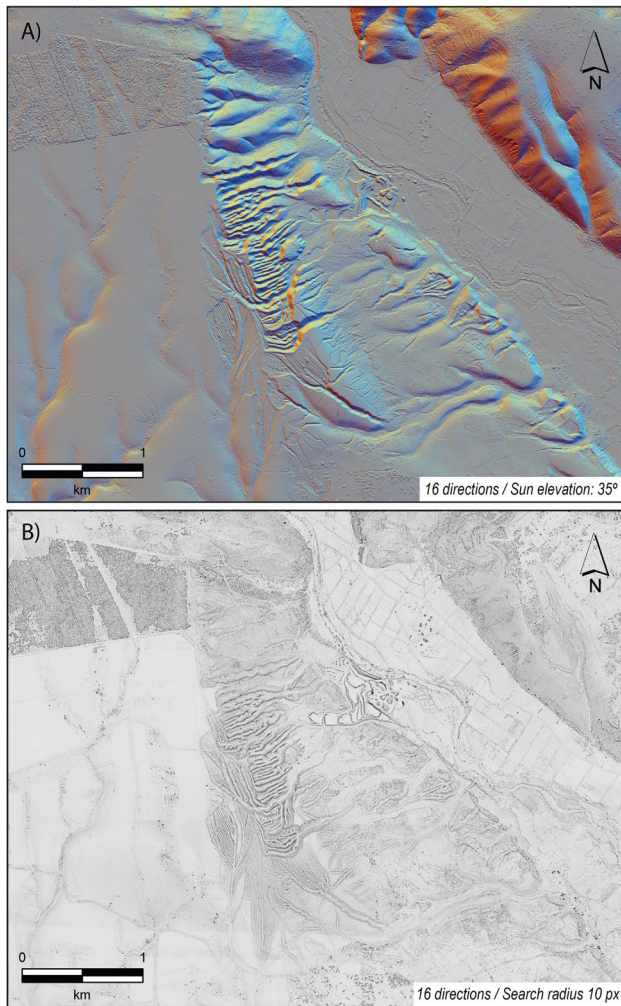


Fig. 2 LiDAR-derived digital terrain models. **A** Multi-hillside enhances slope gradients, while negative openness (**B**) allows the identification and mapping of the drainage system, which helps to understand and discriminate among different observed features of the hydraulic infrastructure (see the highlighted troughs in white marking the position of the drainage system)

system such as the presence of natural landforms and the hydraulic network. Among others, image enhancement facilitates the interpretation of a wide variety of hydraulic features in this type of mining contexts, such as disturbed natural channels, regulated natural channels, mixed channels, and anthropic or man-made channels, together with the interpretation of water tanks used for the mining tasks. A good example of this complex hydraulic system and the potential of the methodological approach was shown by Fernández-Lozano et al. (2020) in the Teleno Mountains, a nearby mountainous area. Additionally, the use of these methods would avoid misinterpretations on the location of water tanks and other remains, since, as it has been demonstrated by Bennett et al. (2012), the method of hill-shading used by Matías and Llamas (2021), despite they do not wish

to decipher their processing methods, provides important errors due to the used shading algorithms. A good example of this problem is shown in Fig. 23 (location of water tank D-16), which is, in fact, located at the bottom of a mining trench. Basically, these authors have only used the LiDAR-derived DEM as a cosmetic image to locate the Roman workings and not as prospecting and documenting tool.

Moreover, the work published by Fernández-Lozano and Gutiérrez-Alonso (2015, 2016), focused on different interpolation resolutions and datasets, has shown the importance of using different gridding resolutions and VET techniques depending on the type of feature that needs to be investigated and the landscape transformation (i.e., presence of a water tank, channel, mining feature, anthropic activity). In fact, the studied sector of Valdepinillos (Castrocontrigo, Eria Valley; Fernández-Lozano and Gutiérrez-Alonso 2015) was subsequently republished in the catalogue of Roman Gold Mining Inventory of Junta de Castilla y León (Page 49 in Matías 2017) without citation.

What do the Romans exploit at Las Miédolas?

Las Miédolas gold mine forms part of the eastward side of a large-scale alluvial fan developed from the mountainous region of the Cantabrian Mountains situated further to the NNW of the area (also known as Quintanilla del Monte alluvial fan; Moro-Martínez 2020). These sediments comprise boulder-like red conglomerates that represent the Plio-Quaternary Raña deposits (Fig. 1, R1) and do not correspond with the underlying Miocene conglomerates as stated in the Matías and Llamas (2021) paper. They represent the final stages of basin growth before the fluvial incision of the Orbigo and Omañas Rivers started. These deposits have been sampled by Moro-Martínez (2020), indicating gold grades over 120 mg/m^3 . Given that gold grades in such placer-like deposits may greatly vary across their length, more representative results are achieved if the whole sedimentary body is sampled and not only a few punctual locations (see Moro-Martínez 2020). The Miocene orange conglomerates underlie the Raña deposits (Fig. 1, M2, M3, M5). In addition, the formation of gold placers associated with the debris slopes (Fig. 1, D4) has been exploited in some sectors of the lower third of the mine. These materials can be considered secondary deposits recycled from the Raña and Miocene conglomerates and, in turn, both represent a paleoplacer deposit at Las Miédolas.

Some interesting remarks of the geological and geomorphological analysis are that the exploitation method selected for each sector of the mine depends on the main characteristics of the sedimentary materials. Thus, convergent furrows (i.e., “peines”) were developed in Raña deposits

(Fig. 1, R1), which are characterized by reduced thickness (0.5–10 m in the Quintanilla del Monte alluvial fan, Moro-Martínez 2020) and large extension, while trench-channel structures and large trenches were used to exploit thicker Miocene deposits (Fig. 1, M2, M3, and M5). In addition, minor trenches or grooves were carried out in the debris slope materials of reduced thickness and extension (Fig. 1, Quaternary debris, D4).

It is also noticeable that Fig. 30 in Matías and Llamas (2021) corresponds to a structured natural deposit, not anthropogenic since the remains of the mining activity produce two types of anthropic material: coarse tailing deposits (*urias* boulders) and unstructured fine-grained sediments (\approx mud flows) at the end of the evacuation channels. To understand such an interpretation, it is instructive to review the characteristics of the Roman debris accumulated from the Chao de Maseiros sector at Las Médulas gold mine (Sánchez-Palencia 2000). Therefore, the deposits shown in Fig. 30 are associated with debris slope materials (D4 in Fig. 1). These deposits, therefore, are unlikely to be related to different phases of exploitation as suggested by Matías and Llamas (2021). Recent works by Fernández-Lozano et al. (2020, 2021) have provided new insights into the interpretation of anthropic and natural deposits and landforms in other nearby Roman mining sectors.

Conclusions

Matías and Llamas (2021) misleading statements about previous studies based on LiDAR, UAVs, and visual enhancement methods by Fernández-Lozano and Gutiérrez-Alonso (2014), Fernández-Lozano et al. (2015), and Fernández-Lozano and Gutiérrez-Alonso (2016) are challenged. These geomatic technologies have provided in the last few years outstanding results in different fields of application worldwide. The Roman gold mining research is no exception. It has benefited from these methods providing researchers with insightful datasets to accomplish new and profitable results. As it has been shown, these technologies and the methodological approach we have shown in the Roman gold mine of Las Miédolas provide promising insights into the hydraulic and mining infrastructure. Besides, we highlight the importance of an accurate interpretation of the geomorphological features preserved on the landscape. Poor interpretations will lead to wrong conclusions as we demonstrate for the gold placer deposits exploited by the Romans in this sector. All in all, the future of the Roman gold mining studies lies in a correct interpretation of datasets derived from geomatic technologies (i.e., LiDAR and UAVs), remote sensing methods, the geological, and geomorphological analysis supporting fieldwork. Therefore, multidisciplinary studies will

be necessary to gain new insights into the recognition and interpretation of Roman gold mining activity in NW Iberia.

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Declarations

Not applicable.

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