







# DETECTION OF FUNERARY MONUMENTS IN THE NORTHERN NECROPOLIS OF *SEGOBRIGA* USING MULTISPECTRAL AND GEORADAR IMAGING

## DETECCIÓN DE MONUMENTOS FUNERARIOS EN LA NECRÓPOLIS SEPTENTRIONAL DE *SEGOBRIGA* A TRAVÉS DE IMÁGENES MULTIESPECTRALES Y GEORRADAR

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### Highlights:

- The application of GPR and multispectral remote sensing techniques has enabled the identification of an Italic-style grave road, referred to as *Gräberstraße*, situated along the route from Segobriga to the north.
- This is a critical analysis of the two non-invasive archaeological survey techniques and their results in calcareous soils.
- The archaeological verification of the anomalies has the potential to facilitate a more comprehensive understanding of the Segobrigian necropolis spatial structuring, obviating the need for extensive excavation.

### Abstract:

The existence of an extensive *Gräberstraße*-type necropolis in the Roman city of *Segobriga* is confirmed by the funerary-type structures located 2,400 m from the city and by the excavation of five funerary monuments located along its main entrance/exit road. The inscriptions, sculptures and architectural remains of funerary character exhumed prove, in addition, its use by members of the higher social classes, including wealthy freedmen. Until now we did not know the spatial structuring of the *monumenta* and their relationship with each other and with the road. This information is vital to know the internal topographic organisation and the constructive density of the necropolis. Geophysical surveys with ground penetrating radar (GPR) and multispectral images captured with unmanned aerial vehicles (UAV) have recently been carried out in order to improve our knowledge in this field. They have been developed within the framework of an ongoing research project to study the northern suburb. The objective of these surveys was to identify new funerary monuments not visible on the surface along the route of the road. This paper analyses the methodology and processing of the two techniques used. It also evaluates their comparative applicability to detect buried remains in calcareous soils. The data obtained indicate the presence of mausoleums on both sides of the roadway according to the Italic model of funerary *viae*. Those located in the first line form two continuous rows, while isolated monuments are located at the rear. This model prevailed in the cemetery areas of the Western Roman Empire from the end of the 1<sup>st</sup> century BC onwards.

**Keywords:** georadar (GPR); multispectral drone imaging; archaeological documentation; funerary structures; *Gräberstraße*; Roman period

### Resumen:

La constatación arqueológica de estructuras funerarias localizadas a 2400 m de la ciudad de *Segobriga* y la excavación de cinco monumentos sepulcrales alineados en uno de los costados de la vía principal de entrada/salida de la ciudad, junto a los hallazgos antiguos de inscripciones, esculturas y restos arquitectónicos de carácter funerario, confirman la existencia de una extensa necrópolis tipo *Gräberstraße* en *Segobriga*, utilizada por las clases sociales más elevadas, incluidos ricos libertos. Sin embargo, se desconocía la estructuración espacial de los *monumenta* y su relación entre sí y con la vía, necesaria para alcanzar conclusiones sobre la organización topográfica y densidad constructiva de la necrópolis. Por ello se han llevado a cabo recientemente, dentro del proyecto de investigación dedicado al estudio del suburbio septentrional, prospecciones geofísicas con georradar GPR y mediante imágenes multiespectrales capturadas con dron, con el objetivo de identificar nuevos monumentos funerarios, no visibles en superficie, a lo largo del trazado de

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la calzada. Este trabajo analiza la metodología y procesamiento de las dos técnicas empleadas y evalúa su aplicabilidad comparada para la detección de restos enterrados en suelos calcáreos. Como resultado, la interpretación de los datos ha permitido reconocer dos hileras continuas de mausoleos dispuestos, en primera fila, a ambos lados de la vía, así como otros monumentos en segunda fila pero aislados, siguiendo el modelo itálico de *viae* funerarias difundidas en áreas cementeriales del oeste del Imperio romano a partir de finales del siglo I a.C.

**Palabras clave:** georradar (GPR); imágenes multispectrales por dron; documentación arqueológica; estructuras funerarias; *Gräberstraße*; época romana

## 1. Introduction

Recent archaeological research in the Roman city of *Segobriga* (Cabeza de Griego, Saelices, Cuenca) has provided a substantial corpus of data on its periurban cemetery areas. There is also a wealth of information available from old discoveries and excavations that took place in the last decades of the 20<sup>th</sup> century. At the same time, studies on funerary inscriptions and the architecture of sepulchral monuments, including their architectural and sculptural decorative elements, have given us a complete picture of the layout of the burial grounds (Noguera, 2012; Cebrián, Trunk & Hortelano, 2022). Many different elements, including open-air funerary enclosures, plots delineated by cippi, monumental altars, aedicula-type mausoleums on podiums, funerary columns, circular monuments and stelae, compose this particular landscape. These elements are arranged according to a structured road system, forming extensive *viae sepulcralis* (Cebrián, 2019).

In 2015, ground-penetrating radar (GPR) was used to identify new monuments in the western and northern necropolis. Later, between 2016 and 2020, several mausoleums in this area were excavated. Both have shown the extent of funerary activity in the suburbs of the Roman city, where the funerary monuments are arranged as a continuous façade on one side of the *vía*, a phenomenon never recorded before. A new geophysical survey, using a combined georadar and multispectral unmanned aerial vehicle (UAV) imaging technique, has clearly identified the formation of an Italic-style grave road in the manner of the so-called *Gräberstraßen* in German literature. It runs along the route from the city to the north.

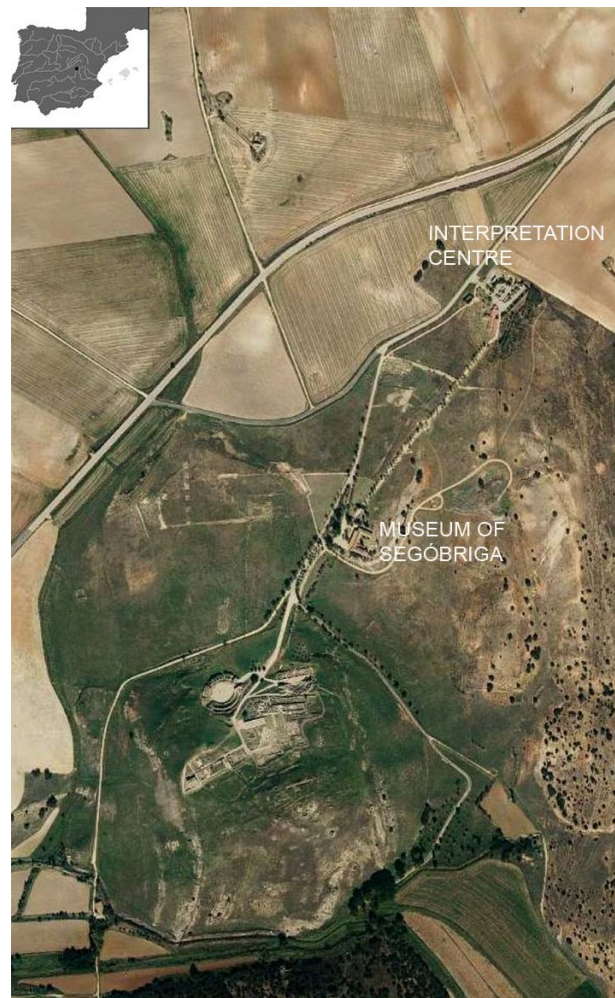
The area under consideration is located between the Museum of Segóbriga and the Interpretation Centre, which currently comprise the two museum facilities within the Archaeological Park (Fig. 1). This area of the site constitutes a section of the northern suburb of the Roman city, where archaeological evidence attests to the occurrence of intense funerary occupation between the 1st and 8th centuries. This encompasses the High-Imperial phase, characterised by the construction of mausoleums, the Late Roman phase, during which a martyr's church and a burial cemetery were erected, and the Visigothic phase, which saw the establishment of a monastery under the protection of the re-modelled temple (Cebrián, Hortelano & Panzram, 2019).

The planimetry of the burial structures surrounding the causeway was obtained from the aforementioned data, revealing a similar organisational structure to that observed in other necropolises in major cities across the Empire (von Hesberg & Zanker, 1987). The plan illustrates a series of funerary monuments positioned along the road, replicating the architectural model that was adopted in the other western provinces from the end of the 1st century BC onwards. This model was adopted by local elites to gain civic prominence and demonstrate

their adherence to Roman culture and power. The layout of the necropolis around the main routes into and out of the city has been thoroughly researched, as evidenced by the case studies of the provincial capitals of *Augusta Emerita* (Murciano, 2019), *Tarraco* (Remolà, 2008) and *Corduba* (Vaquerizo, 2010; Salinas, 2015).

The aim of this article is to present how non-invasive techniques can be used in archaeology to detect subterranean burial structures, and to discuss the archaeological interpretation of the radar and multispectral images obtained. This is set against the background of the excavation of a number of soundings and archaeological excavations carried out subsequently (2022-2024) with a view to contrasting and corroborating the results of the geophysical survey.

The presentation of the research findings includes new archaeological information about the size and layout of the necropolis along a 200 m section of the northern funerary road of *Segobriga*.



**Figure 1:** Location of the archaeological site of Segobriga on the aerial orthophoto PNOA-MA-OF-ETRS89-HU30-H25-0633-3.

## 2. A topographical and geological context of the northern Segobriga road

The northern road of Segobriga was 6 m wide and allowed traffic to go in both directions (Cebrián, Hortelano & Panzram, 2019, p. 198-200). On the western side, the road was marked by a kerb filled with a layer of small limestone rubble and river pebbles, which had been placed over the natural terrain. The causeway was made of a compact and uniform layer of pale earth with small and medium-sized pebbles. The remains of this road have been found in different excavation areas close to the Visigothic basilica, linked to several burial monuments (Cebrián, Trunk & Hortelano, 2022: fig. 4).

It has been determined that the route in question predates the layout of the funerary monuments situated on its margins. The last 100 m of the road connects to an entrance to the city that was in use from the middle of the 1<sup>st</sup> century BC until the time of Augustus, when it was no longer considered necessary (Fig. 2). An archaeological excavation at this side in 1987 revealed a series of severely compromised structures situated just west of the Baths near the Theatre, which were interpreted as the remnants of an elbow gate. Measuring 7 m in width, the entrance/exit to/from the city was facilitated via a gently sloping street whose base was the cut rock itself (Almagro-Gorbea & Llorio, 1989, p. 44-46). This access was later rendered unusable after the construction of a monumental access at the end of the Augustan period, known today as the North Gate.

The urban road from this gate went northwards until it reached a crossroads that was a centre of activity in Roman times. The route then followed a relatively straight line until it reached a narrow pass in the area known as La Pinilla, some 2000 m from the town. At 2600 m, the road forked, taking different paths. One route led towards the Ebro valley via *Ercavica*, another towards Valeria in the direction of the Levant, and a third, via a secondary road that had been in use since the Republican period, linked up with the road that led to *Carthago Nova* (Palomero, 1983, p. 254-257).

The level between this bifurcation and the northern gate of the town rises from 820 m to 825 m above sea level, with an estimated slope of approximately 1% in the last 700 m. The subsoil is composed of breccia, clay, and silt of reddish and limestone tones (Díaz Molina & Lendínez, 1992), which results in a relatively poor response of the terrain to episodes of intense rainfall, with the potential for sudden waterlogging. The impermeability of the terrain, together with its steep slope towards the west, made it necessary to implement drainage measures along the eastern edge of the road. The aim was to avoid the occurrence of flooding and the consequent loss of the road surface as a consequence of heavy rainfall. The introduction of these drainage measures allowed rainwater to be redirected towards lower areas, where it could be evacuated more efficiently by natural means.

We can assume that this solution was used in a section of about 40 m of the track, as evidenced by the 50 cm wide longitudinal anomaly detected by the georadar. We first thought that this trace could be related to the lead pipe that supplies water to the town of Segobriga from La Fuente de la Mar, near Saelices. Digging a test trench allowed us to document a deep channel with a triangular cross-section, aligned with the eastern side of the track, interpretable as a ditch.



Figure 2: The north road and a funerary monument next to the Theatre. Drone image: I. Hortelano.

## 3. Materials, detection methods and processing

For over two decades, new technologies have been used in the field of archaeological research. The development of enhanced, high-capacity software and the utilisation of UAVs for the acquisition of aerial images, facilitate the refinement and improvement of interpretations and, consequently, the non-invasive documentation of archaeological sites (Forte *et al.*, 2021; Sarris *et al.*, 2013; Monterroso-Checa *et al.*, 2019).

Previous geophysical surveys conducted in Segobriga (Cebrián, Hortelano & Panzram, 2019) have yielded promising results. The information provided by these preliminary data sets allowed us to define a specific study area for the experimental application of different non-invasive prospecting techniques, including multispectral image analysis and geophysical prospecting with georadar. Accordingly, the present work is structured in three successive phases of data acquisition.

In the initial phase of the study, remote sensing was employed to obtain multispectral images of the area under investigation. This methodology offers a high degree of capacity for the analysis of extensive areas in a relatively short time. However, the resolution of the data may be reduced, depending on the sensors employed (Brooke & Clutterbuck, 2020; Kalayci, 2019).

After analysis of the multispectral images, a geophysical survey was carried out with a three-dimensional (3D) GPR system. In this case, the capacity to analyse large areas is limited, while the process is inherently time-consuming. However, the acquired data are of high resolution, which significantly improves the information obtained in the preliminary survey. This allows us to determine the depth and quality of possible underlying structures (Trinks *et al.*, 2018).

Finally, a series of minor archaeological works have been undertaken to corroborate the inferences derived from the indirect methodologies. This approach aims to corroborate and establish a definitive correlation between them and the remaining anomalies.

### 3.1. Multispectral remote sensing as an effective tool for locating new monumenta

Archaeological surveys using remote sensing, especially multispectral imaging, have usually focused on finding possible buried structures under certain types of plants, like crops. Recent developments in telemetric

applications for vegetation analysis, particularly in precision agriculture, are based on the assessment of plant vitality and its examination using multispectral aerial photography (Ali et al., 2012; Bennett et al., 2012; Faltýnová et al., 2015; Fuldain González & Fuldain González, 2018; Gojda & Hejzman, 2012; Haboudane et al., 2004; Materazzi & Pacifici, 2022; Salgado Carmona et al., 2020). In this way, buried archaeological remains can be identified indirectly through the analysis of the characteristics exhibited by the flora that has grown on them (Agudo et al., 2018; Ronchi, Limongiello & Barba, 2020).

This method is also applicable to find buried structures in areas with different vegetation covers, like in the study area, where there are a lot of small plants, such as wild thyme, tamarisk, asparagus and seated thistle. The differential growth of these plants depends on the presence or absence of underlying elements, with depth being the most decisive factor.

Remote sensing by multispectral camera is a non-invasive survey technique based on the reflection, absorption, transmission and emission of electromagnetic energy from materials. The radiant energy given off by these substances is described in terms of wavelength or frequency, which allows the establishment of bands organised according to their wavelengths. These are known as electromagnetic spectra (Chuvieco, 1995). In this study, we used the visible spectrum (0.4 to 0.7  $\mu\text{m}$ ), which is the radiation that the human eye can detect, as well as two additional bands above its threshold: blue (0.4-0.5  $\mu\text{m}$ ), green (0.5-0.6  $\mu\text{m}$ ), red (0.6-0.7  $\mu\text{m}$ ), red edge (0.68-0.75  $\mu\text{m}$ ) and near infrared (NIR) (0.7-1.3  $\mu\text{m}$ ) bands.

The images were taken using a Sensefly Ebee X RTK fixed-wing drone (Fig. S1 & Fig. S2). The UAV was equipped with a Sensefly SODA sensor to obtain RGB images, and a Micasense Red Edge sensor for the multispectral images. Two flights with the RGB sensor covered an area of 250 ha and took 1071 photographs. Two other flights with the multispectral sensor covered an area of 258 ha by taking additional 13910 photographs.

### 3.1.1. Methodology

The images were processed and the data interpreted using ERDAS Imagine and ArcGIS software. As a preliminary step, the images produced for each of the five bands were consolidated into a single multiband image. This composite image was processed with necessary filters and transformations.

It is useful to first check the reflectance spectra of the area being studied (Fig. 3). In this context, reflectivity is defined as the ratio of reflected light to the total light incident on the object. Accordingly, given that each material exhibits a distinct reflectivity, it is feasible to delineate particular patterns or reflectance spectra.

An alternative method of representing colour is to consider not the components themselves, but rather the properties that they possess. This is the transformation known as Hue, Saturation, Intensity (HSI). Hue is defined as the wavelength at which the maximum reflectivity of an object is produced. It is equivalent to the colour that is perceived by the human eye. Saturation refers to the purity of this colour, to its degree of mixture with neighbouring colours. Finally, intensity is identified with brightness and is dependent on the percentage of reflectivity received.

This kind of transformation is of significant value in the field of archaeology, as saturation represents those locations where moisture is concentrated. These may include filled pits, silos, the interiors of structures, buried canals, old watercourses, and other features. In contrast to the shades of the surrounding soils, these features make it possible to document structures without the need for intermediate infrared.

Along with the HSI transformation, different extra indices can be used to get more information from the images. These transformations aim to generate supplementary artificial bands by combining them with the original ones. In this way we improve the interpretation of the multiband image and we can emphasise specific variables of interest. Most of these transformations are considered linear, whereby new bands are created by a linear combination of the original bands. This may involve additions, multiplications or weighted divisions (Chuvieco, 1995).

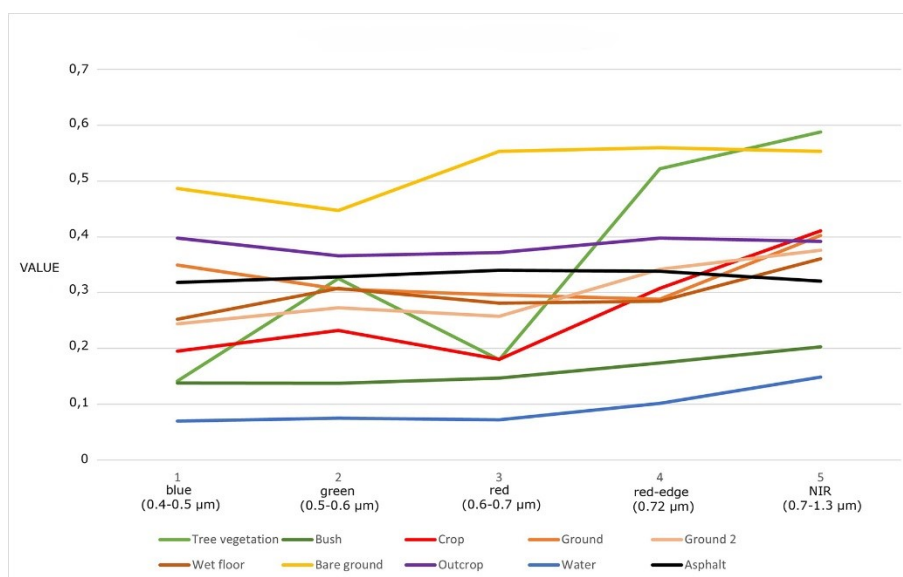


Figure 3: Spectral signatures in Segobriga. Image: Unidad de Arqueometría y Análisis Arqueológico. Complutense University.

The abundance of vegetation in a given area affects the spectral response of each pixel. This allows the estimation of vegetation density through the analysis of spectral data. The calculation is based on the response provided by the vegetation in the red and near-infrared spectra, with the premise that greater contrast indicates greater vegetation vigour. The application of this index in the field of archaeology employs the differential growth of vegetation over extensive areas to document the potential underlying structures responsible for these observed differences.

In this case, we have processed NDVI (Normalised Difference Vegetation Index) as an indicator of vegetation presence and condition. NDVI is sensitive to changes in the health of green vegetation. The combination of the normalised difference formulation with the regions exhibiting the highest chlorophyll absorption and reflectance renders it a suitable tool for a wide range of conditions. However, saturation may occur in areas of dense vegetation when LAI (leaf area index) values are high (Rouse *et al.*, 1973).

$$NDVI = \frac{(NIR-RED)}{(NIR+RED)}$$

Furthermore, the reliability of NDVI has been called into question due to its purported dependence on the underlying soil type (Huete, 1987). To address this limitation, we have incorporated a corrective parameter into the aforementioned formula, aligning the vegetation index with the SAVI (Soil Adjusted Vegetation Index) soil line.

$$SAVI = \frac{1.5 * (NIR-RED)}{(NIR+RED+0.5)}$$

In this equation, the L factor serves to mitigate the impact of soil presence through a range of values, spanning from 0 (denoting areas with high vegetation density) to 1 (representing areas with low vegetation density). Consequently, in the case of soils displaying vegetative development, the L factor is set to 0 without modifying the equation, thus rendering it equal to NDVI. In instances where the developing vegetation is significantly influenced by soil exposure, the L factor assumes a value of 1, which serves to dampen the initial NDVI index. In the final instance, moderately exposed soils are assigned an L-value of 0.5.

Other analytical techniques based on modifications of vegetation indices that have been investigated for decades provide visual representations of plant reflectance. The Modified Enhanced Chlorophyll Absorbance Ratio Index (MCARI2) is a modification of the original MCARI. It incorporates a soil adjustment factor while preserving the sensitivity of the LAI and the resistance to chlorophyll influence (Haboudane *et al.*, 2004).

$$MCARI2 = \frac{1.5[2.5(\rho_{800}-\rho_{670})-1.3(\rho_{800}-\rho_{550})]}{\sqrt{(2*\rho_{800}+1)^2-(6*\rho_{800}-5*\sqrt{\rho_{670}})-0.5}}$$

Consequently, it is considered a superior method for predicting leaf green area. The Modified Red Edge Simple Ratio (MRESR) is an adaptation of the previous Simple Ratio (SR) that employs the Red-edge bands and incorporates a correction for specular reflection of leaves. It offers high accuracy in agricultural, forest monitoring and vegetation stress detection applications (Datt, 1999; Sims & Gamon, 2002).

$$MRESR = \frac{\rho_{750} - \rho_{445}}{\rho_{705} - \rho_{445}}$$

### 3.1.2. Data obtained

Radiometric adjustments were made, and it was found that the only process that provided satisfactory results was inversion, whereby the image values are inverted. Additionally, false colour enhanced the visualisation of the vegetation (Fig. S3 & Fig. S4).

The vegetation indices used to document potential structures yielded disparate scores. The results obtained with the NDVI and SAVI indices were highly similar. Areas of more vigorous vegetation were represented in greenish tones, which turned yellowish as the vegetation became drier and almost reddish on bare or asphalted ground. In the images obtained, there are some square-shaped structures in the northern area, which are coloured in orange tones as the vegetation on them is unable to develop to its full potential (Fig. 4).

The MCARI2 and MRESR indices incorporate red-edge bands and ground-level corrections. The former allows the observation of structures represented by darker shades, as the chlorophyll of overlapping plants does not reflect. In contrast, the latter has not yielded significant results.

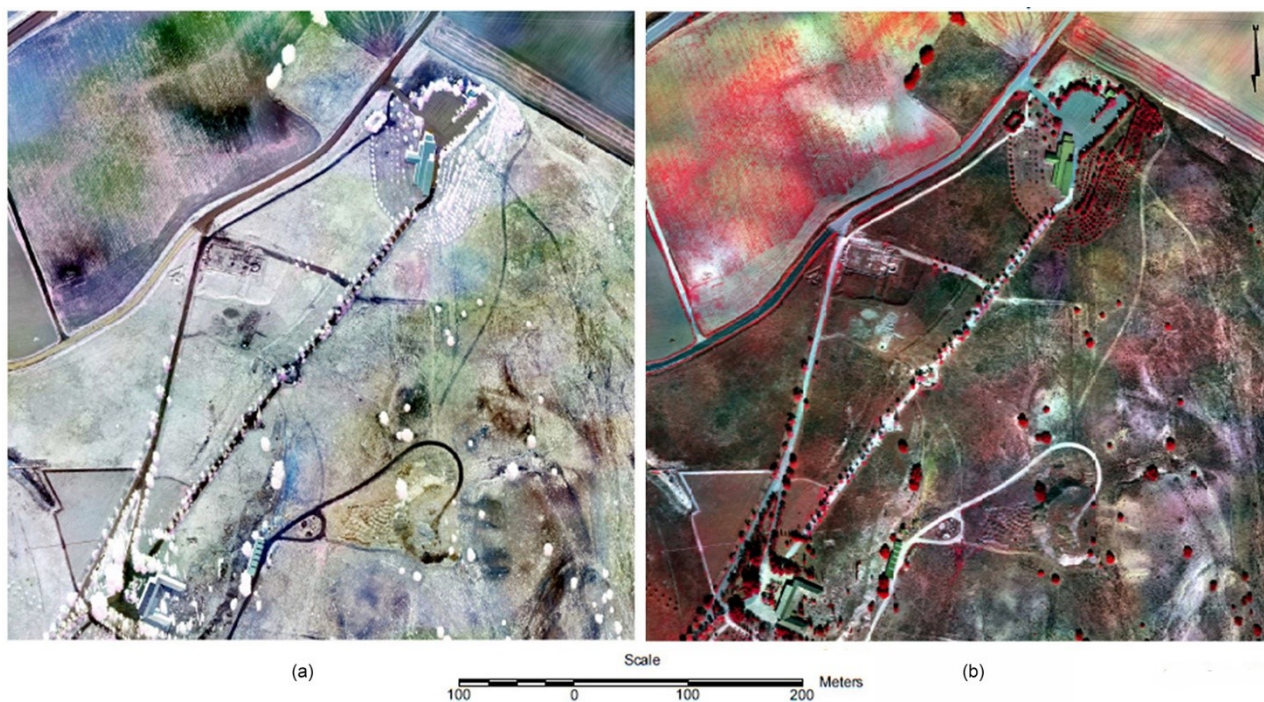
In the HSI transformation, the vegetation exhibits a magenta hue (saturation) that tends to purple in areas of higher vigour (saturation + intensity).

This method allows structures with lower moisture content (saturation) to appear yellowish, with buildings marked in shades of green (hue) and bare ground displaying yellowish and reddish tones (intensity + hue). Furthermore, bands in a north-south direction with purple tones can be discerned, which may correspond to the remains of ancient roads (Fig. 5).

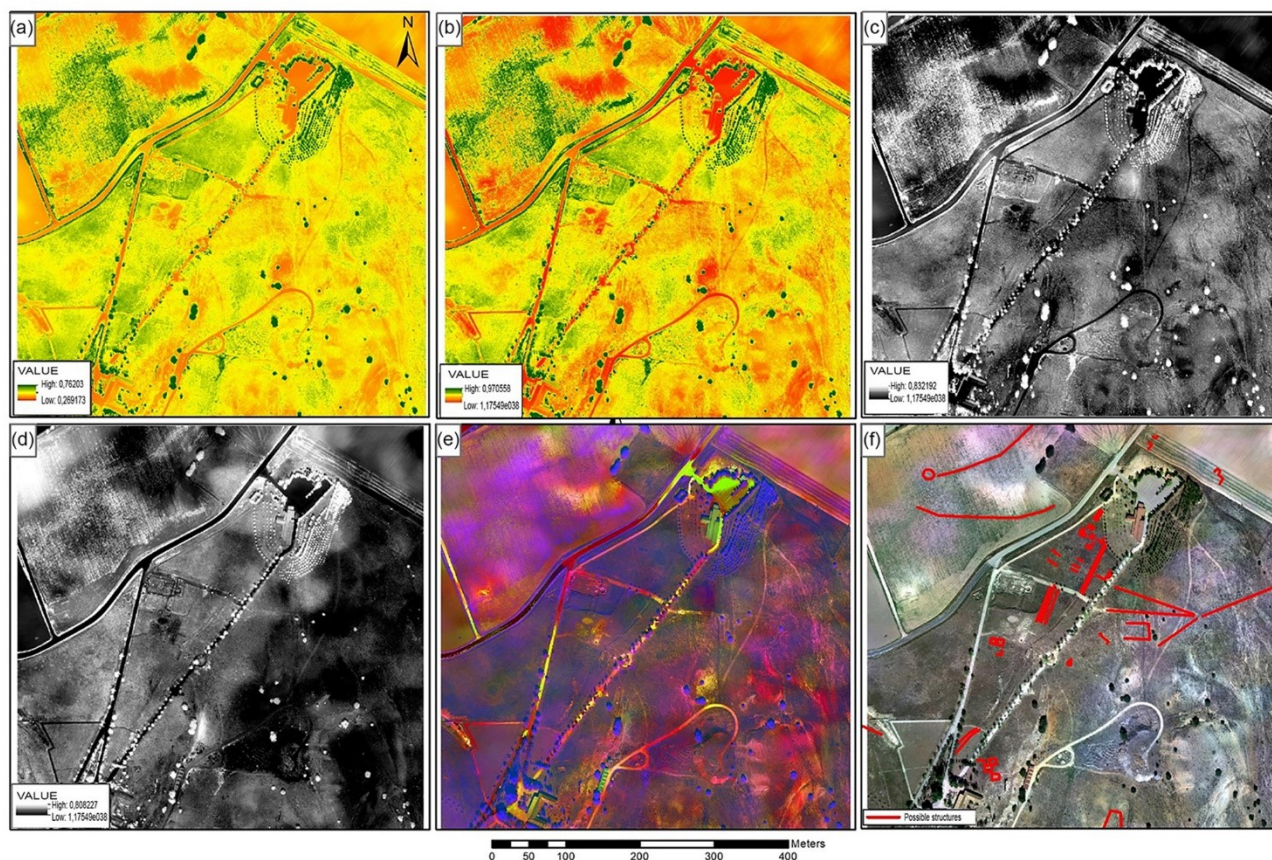
Using this technique, we tried to recognise rocks and stones grouped that could constitute the remains of walls or boundaries. Anomalies that may indicate the presence of underlying structures have been identified in the northern part of the study area (Fig. 6).

These structures may represent the external walls of square-shaped constructions. This area is the sector where the signs are most clearly discernible, likely due to its elevated topography, minimal substrate accumulation, and sparse vegetation (comprising wild thyme and asparagus).

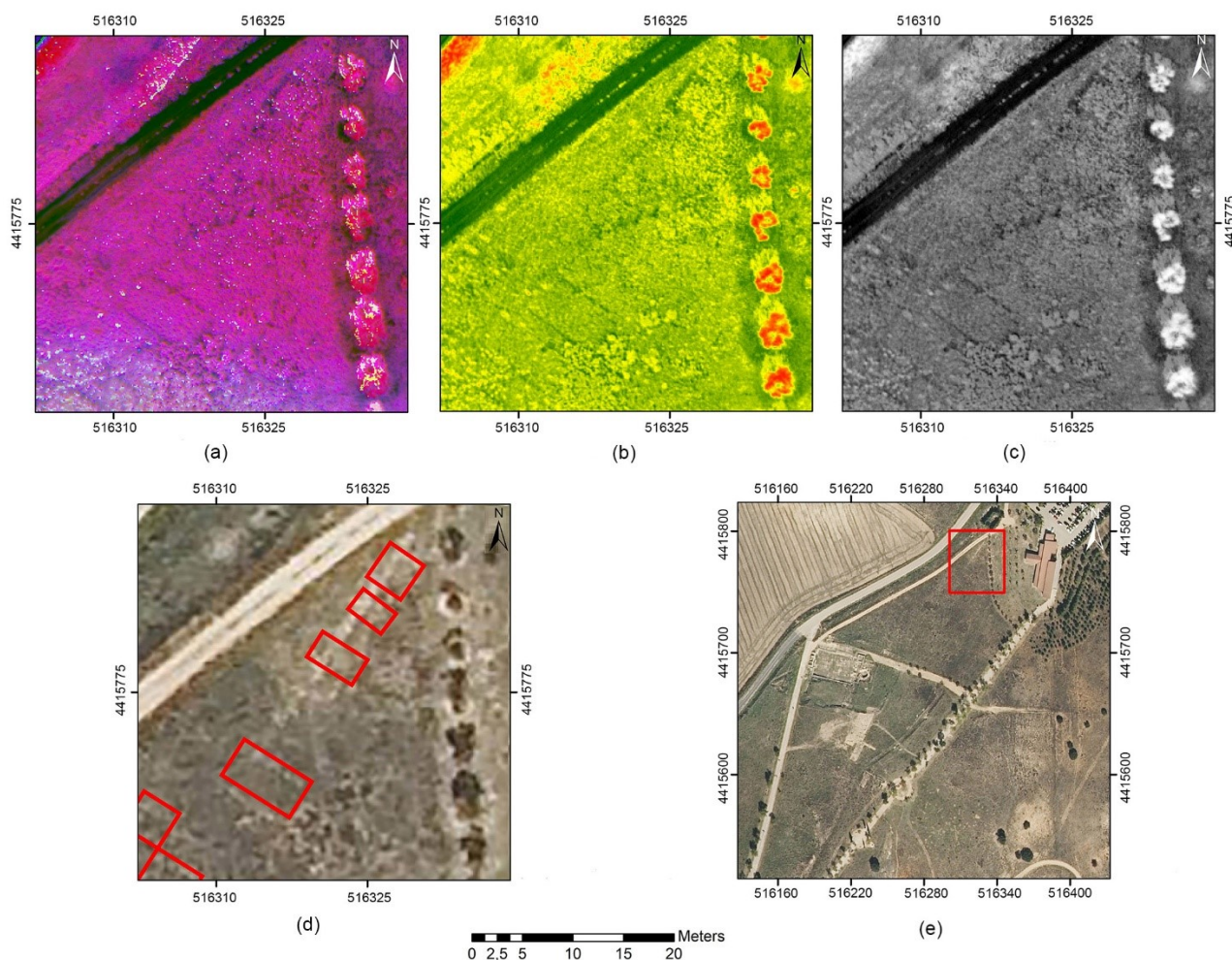
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**Figure 4:** Northern area: a) with colour inversion (RGB); b) with false colour (IR). Image: Unidad de Arqueometría y Análisis Arqueológico. Complutense University.



**Figure 5:** Detailed view of the northern area where square and rectangular structures have been located. a) NDVI; b) SAVI; c) MCARI2; d) MRESR; e) IHS; f) Orthophoto + possible structures. Image: Unidad de Arqueometría y Análisis Arqueológico. Complutense University.



**Figure 6:** Northern area detail with further definition of remote sensing findings: a) IHS Vision; b) NDVI; c) MCARI2; d) RGB and interpretations; e) General situation map. Maps in UTM ETRS89 30 N Projection. Image: Unidad de Arqueometría y Análisis Arqueológico. Complutense University.

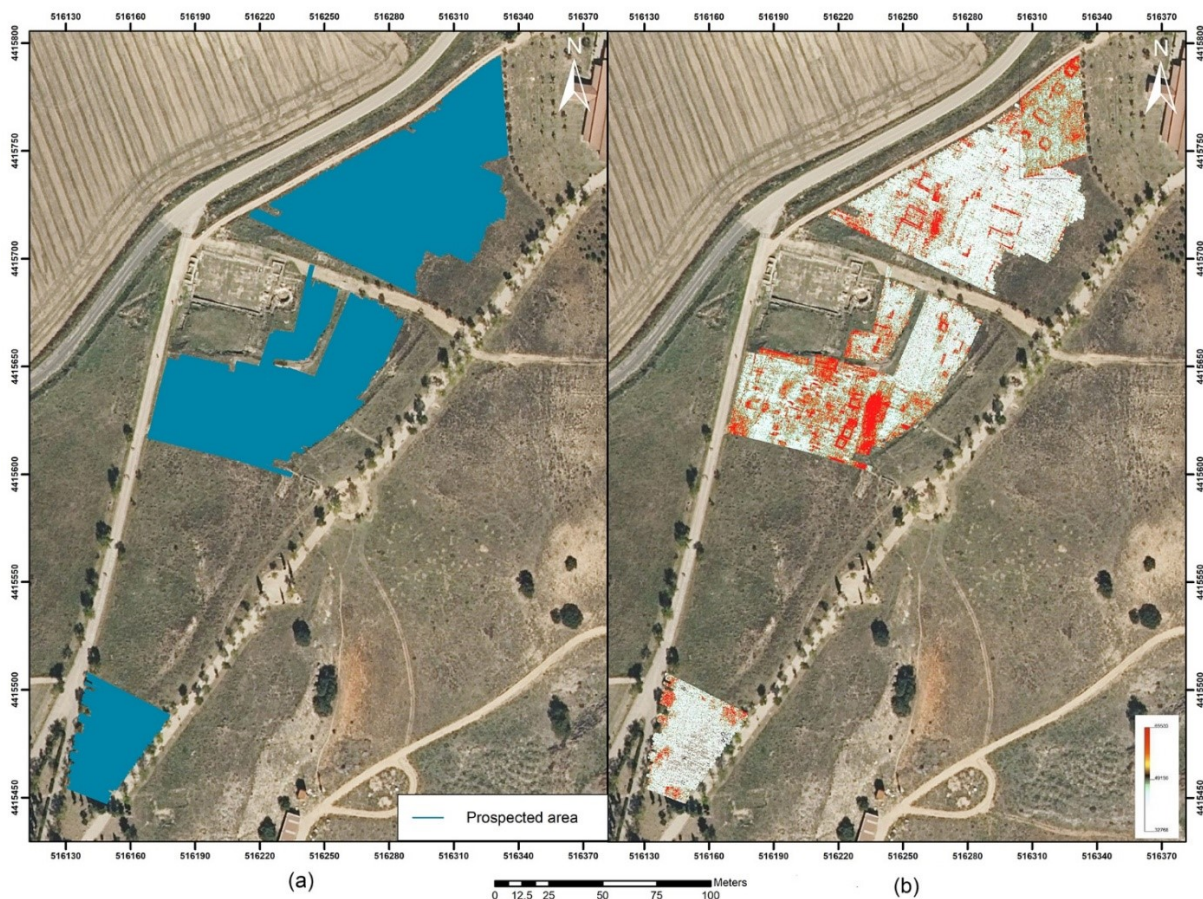
### 3.2. The use of georadar to identify funerary monuments

Following the archaeological interpretation of the multispectral images processed with the aforementioned indices, a smaller sector was delimited in order to carry out a more detailed georadar survey. The choice of sector was based on the likelihood of the existence of underlying structures. In this sector, there were some underlying structures that appeared to be arranged in accordance with a potential alignment. Given that these structures could be identified at the surface; it was assumed that their depth would be relatively shallow. Consequently, a multi-channel antenna with a nominal frequency of 600 MHz was selected. This frequency is not optimal for reaching great depths (its range of action is estimated to be approximately 1 m in clays), but it provides high-resolution readings, detecting elements of up to 1 cm in size (Lorenzo, 1994; Pérez García, 2001). The Stream X model antenna (IDS georadar), comprising 12 dipoles with an spacing, was used. It has been very effective in detecting stone alignments such as walls and foundations. Also for the identification of

anomalies associated with compact layers of gravels and river pebbles such as the remains of the roadway. It has as well allowed us to locate pits on the roadsides, corresponding to water drainage ditches.

The study focused on an area situated in proximity to the access road leading to the Roman city from the north. A total of 550 acquisition transects were conducted, yielding a total of 6050 radargrams at 8 cm intervals. The processing sequence varied according to each space since, due to changes in vegetation and surface rock content, different filters have been implemented with the GPR Slice processing software. The main filters applied were gain, background removal, bandpass, deconvolution, and, in some areas, migration. By employing a methodology for estimating the dimensions of hyperbolic anomalies, the velocity of the medium was determined to be approximately 0.093 m/ns. This enables the depths of investigation to be calculated. The shots were georeferenced using a Topcon GPS, model GR-5, with acquisition in Real Time Kinematic mode and GNSS satellites in GPS (USA) and GLONASS (Russia) systems. in the UTM projection system ETRS89, Zone 30N (Fig. 7).

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**Figure 7:** Area surveyed with GPR: a) Planimetry; b) Alterations identified. Maps in UTM ETRS89 30N projection. Image: Unidad de Arqueometría y Análisis Arqueológico. Complutense University.

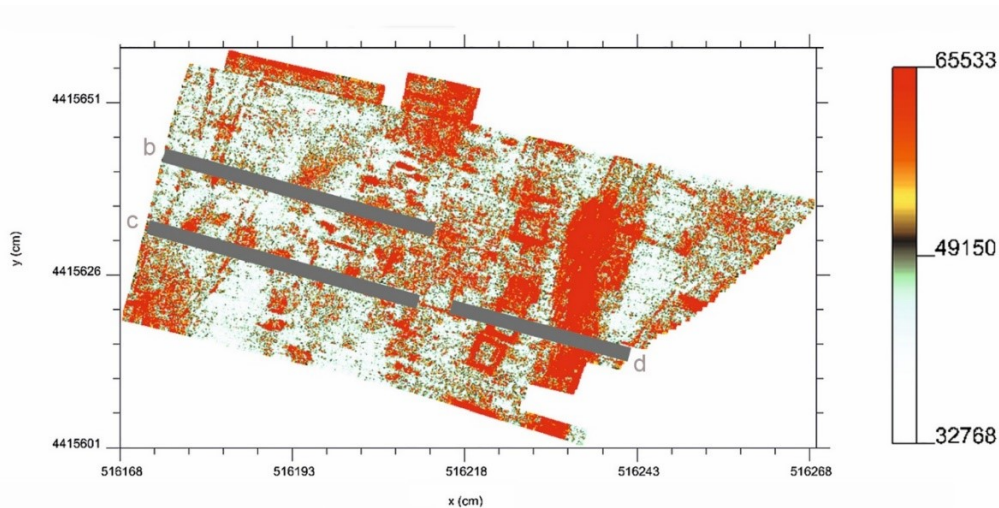
The processed data have been used to create a manipulable 3D block, with the objective of improving the quality of the interpretations. This enables a series of slices to be obtained with plan views at varying depths. These images demonstrate the accumulations of anomalies or reflections resulting from the presence of subsoil elements. In this instance, a plethora of anomalies with disparate topologies can be discerned.

The area exhibits a variety of alignments and morphologies. Some alignments are dispersed, while others are concentrated in specific locations. There is also a series of large buildings with regular morphologies. Additionally, there is a singular alignment with a large reflection.

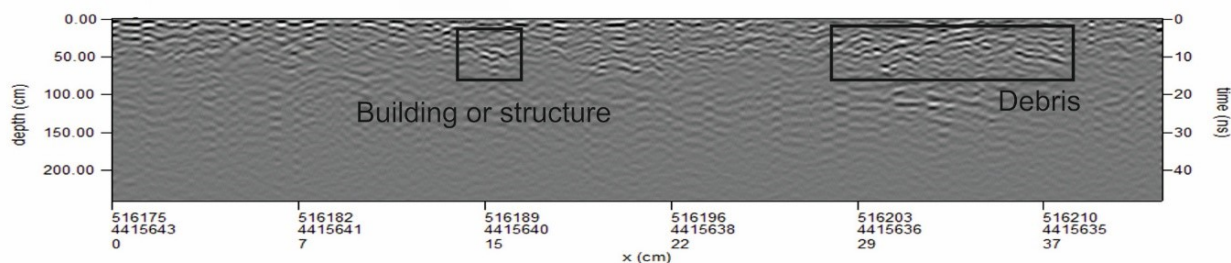
In one area, a series of small anomalies are discernible across the terrain (Fig. 8). In the radargrams, which represent the morphologies of the anomalies, they correspond to large-amplitude reflections, indicative of the presence of building rock. Some groupings of reflexions have been interpreted as areas of accumulation of materials, where each curve corresponds to one or more of the elements that

comprise the whole (Fig. 8a). Additionally, larger hyperbolas with a discernible horizontal and continuous reflection component have been identified as individual tombs, situated at a depth of 20 cm or more (Fig. 8b). The presence of minor reflections with discernible alignments in the 3D data block suggests the possibility of structures with minimal foundation thickness. Such features are observed between landslide accumulations and at approximately 15 cm depth.

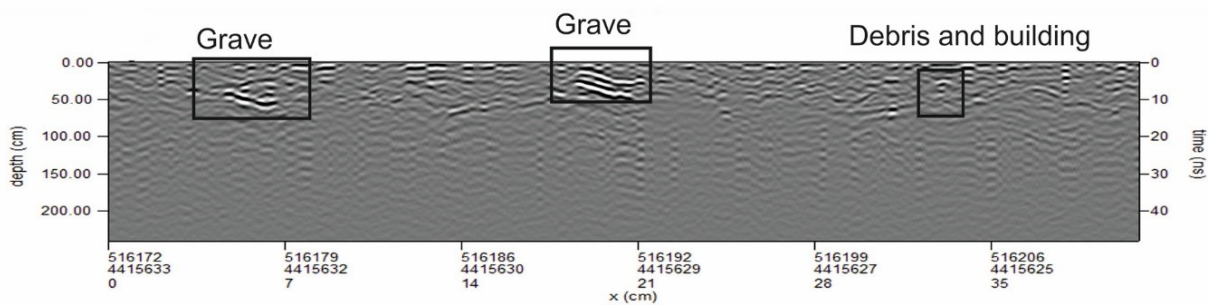
To the east of this area (Figs. 8c, 9, S5, S6 & S7), reflexions are observed to occur in a relatively regular pattern. In the 3D block and in the plan view, the morphologies are observed to be highly regular, exhibiting a quadrangular tendency. These structures are believed to be thin constructive formations comprising walls of a specific width. Additionally, a substantial, elongated, and continuous anomaly is evident, which, in the radargram section, exhibits varying degrees of compaction. On either side, there appear to be longitudinal channels. As illustrated in the interpretation map (Fig. 14), it is surrounded by the remaining anomalies, which correspond to singular rectangular-shaped constructions.



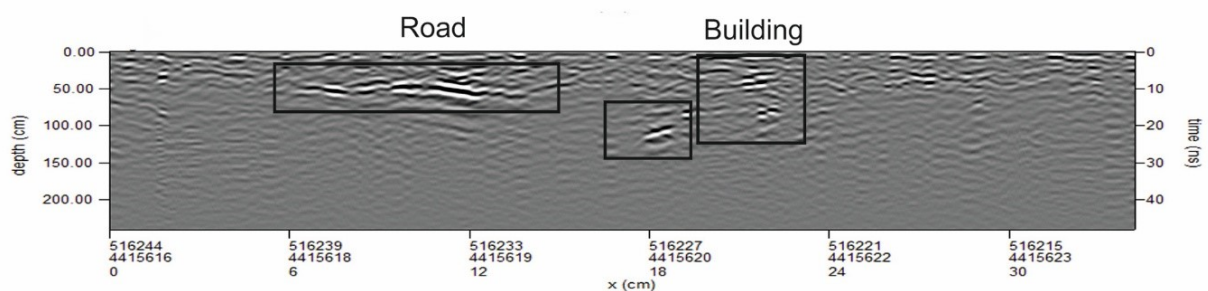
(a)



(b)

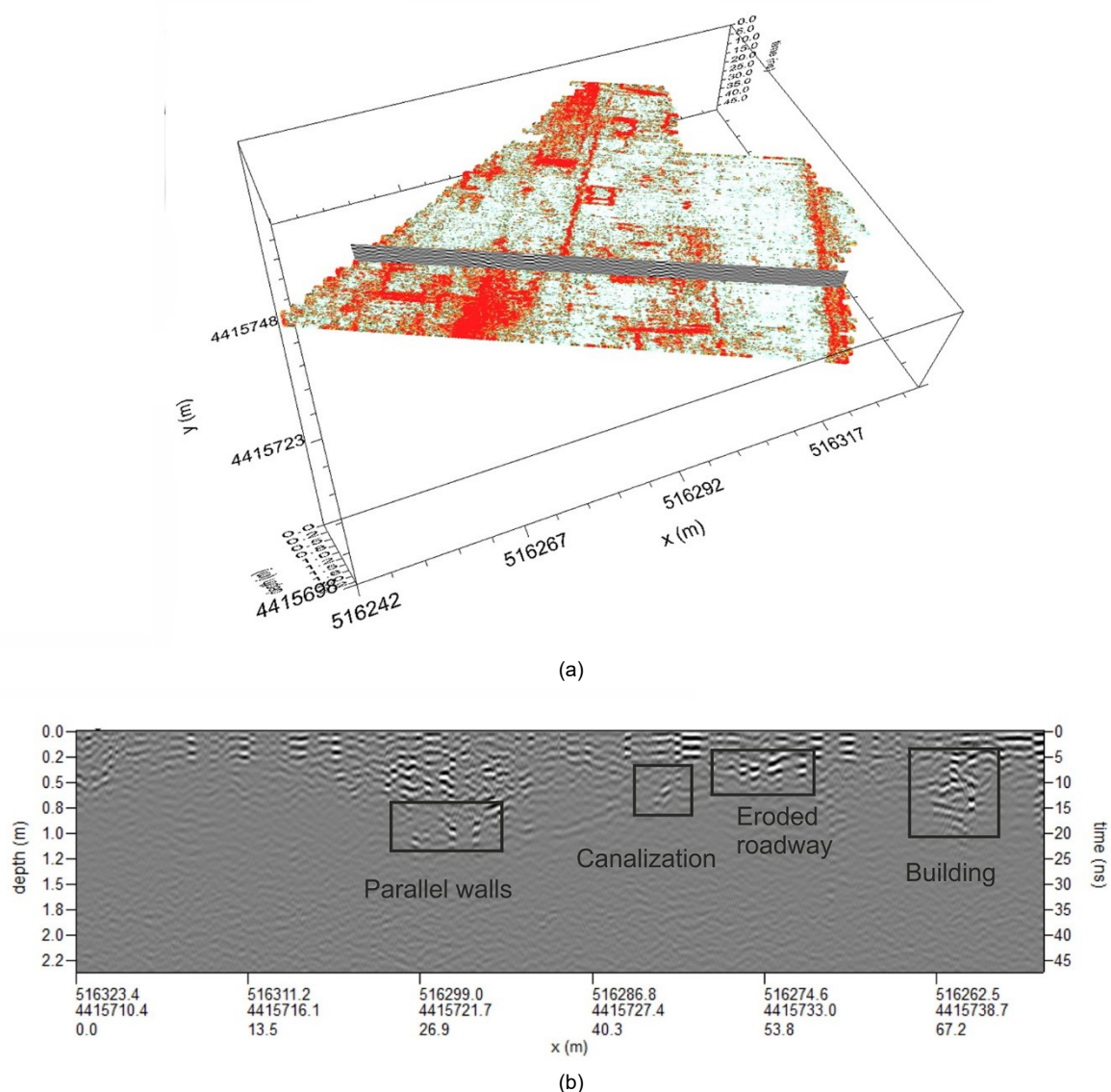


(c)



(d)

**Figure 8:** Sections 1: a) General plan and sections; b) Possible building or structure and debris; c) Graves, building and debris; d) Road and building. Image: Unidad de Arqueometría y Análisis Arqueológico. Complutense University.



**Figure 9:** Sections 2: a) Perspective view and section; b) Parallel walls, possible canalization, eroded roadway and building remains. Image: Unidad de Arqueometría y Análisis Arqueológico. Complutense University.

#### 4. Results: archaeological verification by open area excavation and stratigraphic soundings

We have excavated several archaeological soundings at different points in the study area to contrast the information obtained from the multispectral photography and the georadar survey. The initial excavation was opened in 2016 after the first geomagnetic survey in the area of the so-called Visigothic Basilica (Fig. 10). The results were sufficiently conclusive to justify the launching of successive extensive excavation campaigns, which are still continuing in short summer campaigns. The archaeological work allows us to trace the diachronic evolution of the necropolis, from its High-Imperial phase until its definitive abandonment in the 8<sup>th</sup> century AD. We have recorded a transversal section of the northern road, which constituted the origin and longitudinal axis of the funerary area. In addition, we have identified a total of six mausoleums of different typologies, located on the west side. Five of them

(mausoleums M1, M2, M3, M5 and M6) are located in the front row and face the road, while the sixth (M4) has a secondary position, potentially linked to a back road (Cebrían, Trunk & Hortelano, 2022) (Fig. 11e).

In the course of the archaeological excavations, we have exhumed several *busta* and cinerary urns, as well as evidence of the *silicernia* that followed the cremation of the corpses. Moreover, we have recovered architectural elements and epigraphic fragments that serve as a basis for formulating reconstructive proposals. On the other hand, we have documented the processes of transformation of this funerary space as a consequence of the widespread adoption of Christianity by the Segobrigian society from the 3<sup>rd</sup> century AD onwards. They involved the progressive expansion of burial practices that replaced the previous cremation rituals. The subsequent construction, in the middle of the 5<sup>th</sup> century, of the martyrial temple known today as the Visigothic Basilica, together with the new funerary area *ad sanctos* generated around it, meant the prolongation of funerary uses until the 8<sup>th</sup> century.



**Figure 10:** Virtual image of the funerary road and the so-called Visigothic basilica from the east. Image: Balawat S. L. based on data elaborated by R. Cebrián and I. Hortelano.

The convenience of establishing an exact correlation between the geophysical anomalies detected using GPR and their archaeological interpretation determined the excavation of new punctual soundings. The objective was not to create new excavation areas, but rather to provide definitive evidence regarding the efficacy of the employed methodology. Accordingly, the dimensions of these areas have been reduced, and only the strata affected by traditional agricultural work until the middle of the 20<sup>th</sup> century have been removed.

In the northern section of the surveyed area, a 19 m-long trench was excavated to investigate the potential alignment of three quadrangular mausoleums situated on the eastern side of the causeway (Figs. 11a & S8a). Two of them appeared to be adjoining each other, while the third, located at the southern end, remained separated by a distance equivalent to the average width of the three monuments, estimated at 5 m. The excavation provided the definitive evidence to corroborate the proposed interpretation, thanks to the unquestionable results yielded by the georadar. The fidelity of the interpretation is a consequence of the total razing of the structures, which have preserved only their foundations. The absence of associated levels of collapse, a probable consequence of the intentional dismantling of the pagan necropolis in the course of its Christianisation, offers greater clarity, as it further increases the contrast between the built and the natural terrain.

A comparable level of destruction was identified in the excavation of a second trench, measuring 27 m in length and situated 40 m to the southwest. This was intended

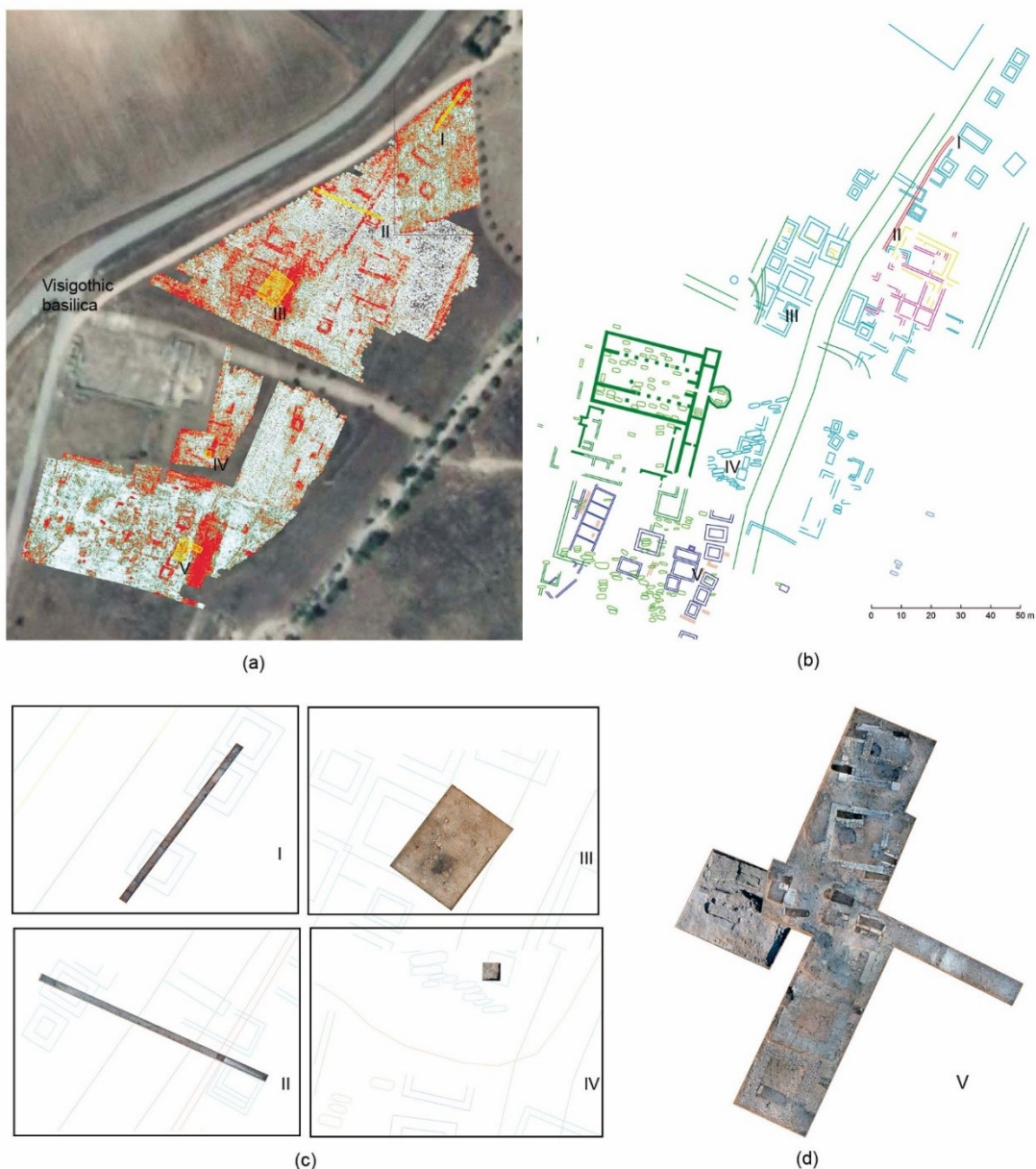
to provide a cross-section of the roadway that included the monuments on both sides. The location was determined by the presence of a 50 cm wide longitudinal anomaly detected by the georadar parallel to the eastern side of the road for a distance of approximately 40 m (Figs. 11b, S8b & 12). Initially, it was thought that this

line corresponded to the lead pipe for the supply of drinking water to the city. However, the excavation revealed that it was a deep ditch with a triangular section, intended for the collection and evacuation of runoff. We have also documented in this area the north foundation of a mausoleum situated on the eastern side of the thoroughfare and evidence of the front and rear walls of another mausoleum located on the opposite side of the road. Both structures were approximately 5 m on each side. The road surface, made of earth and cobbles on a base of gravel and river pebbles, had a boundary kerb on the western side.

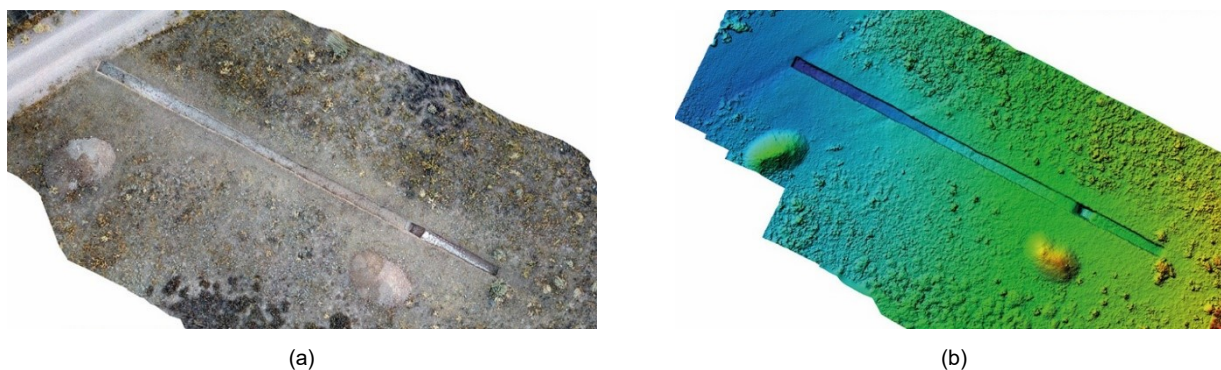
A small test pit excavated in close proximity to the apse of the suburban temple served to confirm the continuity of the High-Imperial necropolis to the north of the sector that had already been subject to excavation (Figs. 11c, S8c & S9). In this instance, the excavation was conducted on a quadrangular structure whose morphology was consistent with that of the other mausoleums already known, although it was somewhat smaller in size. The structure in question only retained the print of its implantation on the basal surface, showing a complete obliteration.

The excavation of a fourth test pit, situated to the northeast of the so-called Visigothic Basilica, has revealed a greater stratigraphic complexity. The initial objective was to test the georadar responses in a sector located to the west of the road, where the archaeological levels were visible to the naked eye. Removal of the surface level in this area revealed Late Period re-occupation structures whose masonry reused elements of one or more previously dismantled funerary monuments. The underlying High-Imperial sepulchral framework is evidenced by the presence of ruined walls belonging to two earlier mausoleums and an *ustrinum* (Figs. 11d & S8d).

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**Figure 11:** Verification of the outcomes of the GPR geophysical survey through the excavation of archaeological soundings: a) General plan of the surveyed area; b) Detailed planimetry with archaeological interpretation; c) Orthoimages of the soundings showing the remains of three aligned funerary monuments, of two other mausoleums located on each side of the road, which preserves the ditch, a cremation associated with a funerary monument and remains of a structure belonging to the Late Antique phase and the foundation of a single funerary monument; d) Monuments arranged on the western margin of the northern funerary road. Images: I. Hortelano. Archaeological interpretation: R. Cebrián and I. Hortelano.



**Figure 12:** Archaeological sounding carried out perpendicular to the axis of the north road in 2023 to check the state of conservation of the archaeological remains: a) Photogrammetric model; b) Digital Elevation Model (DEM). The two small mounds to the south of the trench correspond to the temporary stockpiles of earth extracted in its excavation. Images: I. Hortelano.

## 5. Discussion. Georadar survey versus multispectral drone imagery

The results obtained are largely determined by the survey technique applied. In contrast to remote sensing, a passive method in which data are obtained according to the reflection of sunlight, georadar surveying is based on the emission and reception of an electromagnetic pulse (active method).

The analysis of multispectral images is influenced by a number of factors, both intrinsic to the sensor and extrinsic to the imaging environment. These include the height of flight, the season of the year in which the images are taken, as well as the type and density of vegetation at the site. Furthermore, differential growth of the vegetation, determined by the depth of any buried structures, can also affect the analysis of multispectral images.

The GPR results are, however, influenced by a number of additional factors, including climatic conditions, the physical and compositional characteristics of the strata (such as humidity, compactness, and mineralogical composition), the degree of contrast between the underlying structures and the strata that host them, and the differences in the dielectric constant of the medium.

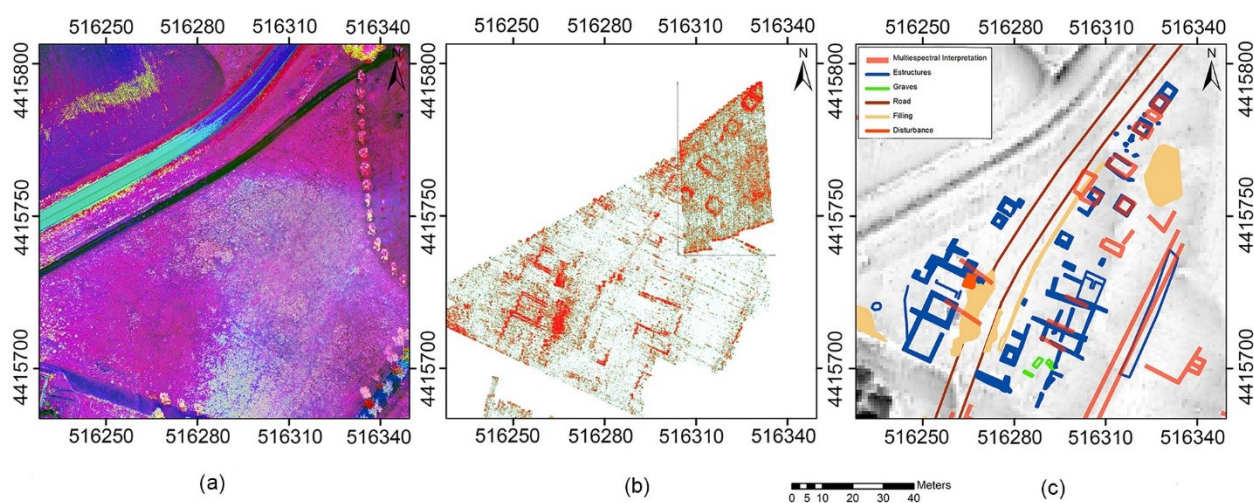
The utilisation of multispectral imagery for surveying purposes represents a highly efficacious methodology for the initial analysis of expansive areas, with relatively minimal investments of time and resources. It permits a rapid overview of the results, although the resolution is inferior. Georadar, however, provides exceptionally high-quality and detailed results, making it one of the most widely applied techniques in archaeology (Conyers, 2015; Goodman *et al.*, 2011; Goodman & Piro, 2013a, 2013b; Piro & Campana, 2012; Zhao *et al.*, 2015). Its use allows the evaluation of the state of the structures and their depth, although this process requires a significant investment of time due to the need to carry it out on foot or with low-speed motorized systems.

The combination of both techniques within the same framework enables a comprehensive assessment of their respective pros and cons. It also allows for an assessment of the quality of their results. In the remote

sensing survey, the interpretations are unambiguous and definitive, although not as numerous and detailed as those obtained by in this geo-radar study (Fig. 13). In the remote sensing context, the absence of cultivated or densely vegetated areas posed a challenge for interpretation using the indices. However, the application of the HSI transformation proved to be an effective solution for this type of terrain, with few, small and not particularly dense vegetation elements. The saturation of the image made it possible to differentiate areas with different degrees of humidity, providing results somewhat comparable to those obtained with the mid-infrared. In addition, the application of vegetation indices such as NDVI, SAVI and MCARI (Fig. 6) has been successful in documenting underlying structures in terrain that, a priori, and due to the type of vegetation present, would not be suitable for this purpose. However, the scarce and low flora of the terrain has been sufficient to provide information in the indices at spectral level, as is perfectly visualised in the area where the walls are buried and the vegetation is much less vigorous or almost non-existent. This case demonstrates the effectiveness of these indices and highlights their suitability not only for the analysis of crop fields but also for a broader range of applications.

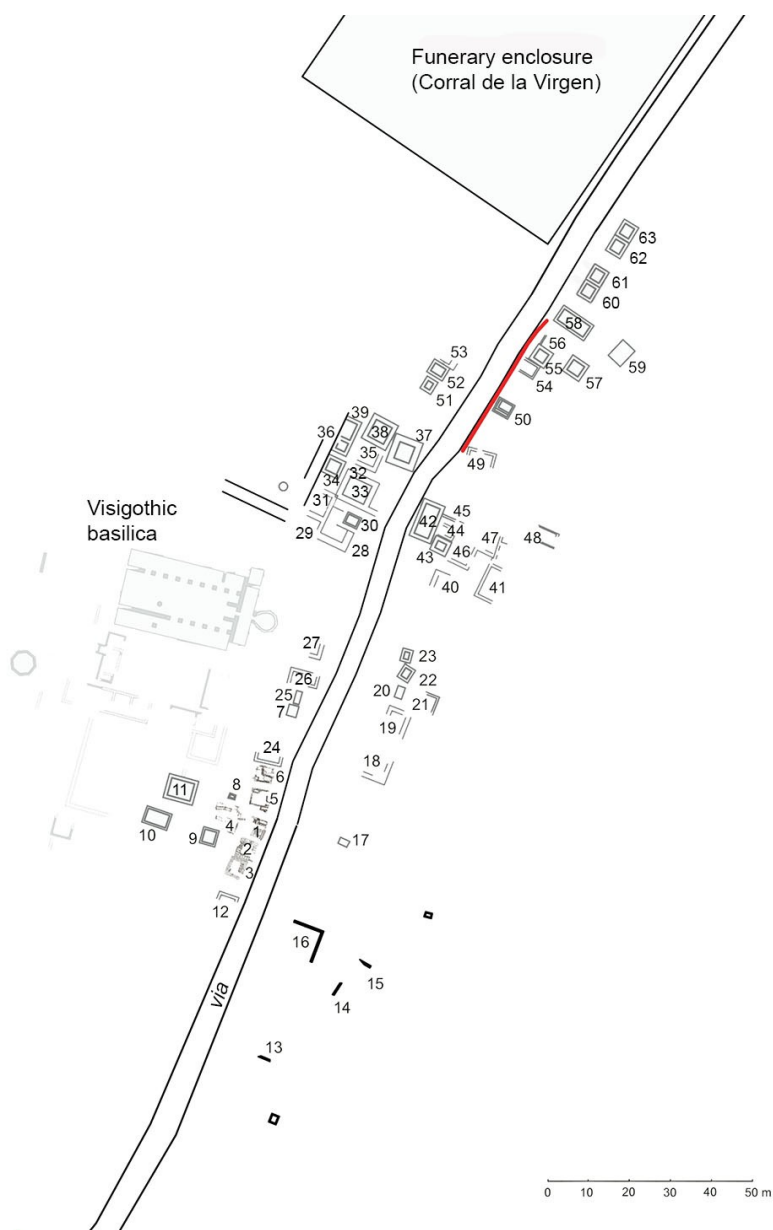
## 6. Conclusion. The organisation of the northern *via sepulcral* of Segobriga

The main funerary use of the northern road of *Segobriga* has been archaeologically confirmed. It is materially characterised by the discovery of monumental tombs and funerary enclosures of considerable dimensions, built to house burials of different types. The roadway extended immediately outside the city walls for a distance of at least 2400 m. This is demonstrated by finds from the sites of Los Vallejos and Pinilla, which are the furthest from the city (Abascal *et al.*, 2008). New data obtained using GPR and multispectral remote sensing techniques indicate the presence of a layout of monuments that follows the characteristics of 'funerary streets'. These *Gräberstrassen* were widespread from the late 1<sup>st</sup> century BC and Augustan times in Roman urban necropolises in Italy and the provinces (von Hesberg, 1992: 26-37).



**Figure 13:** Multispectral and georadar results: a) IHS Vision; b) GPR Vision; c) Overlay interpretations (multispectral and GPR). Maps in UTM ETRS89 30 N Projection. Image: Unidad de Arqueometría y Análisis Arqueológico. Complutense University.

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**Figure 14:** Planimetry of the section of the northern funerary road studied with non-invasive techniques, based on the interpretation of the data obtained. In black, structures visible on the ground. In red, the roadway ditch. Image and archaeological interpretation by R. Cebrián and I. Hortelano.

A total of 63 funerary monuments have been identified, including those already excavated (Fig. 14). Most of them were situated in the front row. They measured approximately 5 m on each side and are notable not only for their location, but also for their singularity and decorative apparatus. This is evident from the mausoleums already known, in which only one person was buried (Cebrián, Trunk & Hortelano, 2022).

The funerary area follows the pattern of a necropolis arranged on both sides of the northern road. The density of buildings can only be distinguished in specific areas. Here we can identify monuments in the second row, concentrated in isolated clusters, and a group of buildings located at a greater distance from the road. The available evidence suggests that the necropolis developed rapidly in length, extending along the road. The rear strips would later be occupied, as indicated by the fact that the only monument excavated in the second row is dated to the 2<sup>nd</sup> century (Cebrián, 2020).

The pre-planning and demarcation of the necropolis parcels was straightforward. The pre-planning and delimitation of the necropolis plots were straightforward. They were based on the demarcation of continuous 5 m deep strips subdivided into 5 m wide plots for sale. The final appearance was that of a continuous cemetery with its beginning at the city gates, where the first funerary district can be recognised. There, the podium of a funerary monument, preserved next to the theatre and on the eastern side of the northern roadway, must correspond to the earliest *monumentum*. Despite its proximity to the city, from which it is only about 30 m away, it did not invade the public space of the pomerium, which must have remained free of funerary structures (Campbell, 2015).

The scarcity of excavations means that there is a lack of archaeological data and some questions remain to be answered. We do not know the typology of the funerary monuments or the definition of the social environment of

the deceased and their patrons. Nor is the temporal sequence conclusive, although we know that the monuments lasted over time. We can therefore recognise a 'horizontal' stratigraphy in the structure of the necropolis, which determines relationships of juxtaposition rather than superimposition.

H. von Hesberg (1987: 50), who studied the arrangement of funerary buildings along the roads leading out of Rome, observed this phenomenon. In the late Republican or early Imperial period, monuments were aligned continuously with the roads or with roads parallel to them, while in a second period, dating from the 2<sup>nd</sup> century AD onwards, they were arranged in groups aligned with secondary roads. Furthermore, in this second phase the tombs were built at a great distance from the road, in contrast to those of the first period. These differences in the layout of the monuments reflect the funerary ostentation of the elite citizens.

The orientation of the façades of the monuments in *Segóbriga* towards the street is also related to their visibility to passers-by. The competition between the monument promoters is reflected in the front-row mausoleums and in their shape and decorative richness.

Considering the findings of the geophysical survey, the number of documented structures is remarkable. These partially overlap with those identified by remote sensing, in particular those of a shallower nature, whose depth, as indicated by the georadar data, does not exceed 10 to 15 cm. In the remaining regions, where the strength of the overlying soil is greater, remote sensing was either inoperative or provided poorly defined and inconclusive results.

The success of this model of funerary *viae* outside the *pomerium* is attested by its great extension. The example of the *Via Appia* is remarkable: from Rome, interrupted only by a few villas and sanctuaries, it continued as a funerary road near the Alban Mountains, 24000 m from the *Urbs*.

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In the provincial cities, necropolises of considerable size have been identified. In *Pola, Dalmatia* (Gnirs, 1930: 184-189), it reaches a length of 4000 m, while in the so-called *via* of the ocean, at *Lugdunum, Gallia Lugdunensis* (Goudineau, 2009, 94), its length is about 2800 m. In the province of *Venetia et Histria*, the necropolis of the *via Annia*, in Altino (Scarfí, 1990: 325), extended for a distance of 2000 m, whilst that of the city of *Camulodunum*, in *Britannia* (Scholz, 2012: Abb. 384), 1,736 m.

The most extensive necropolises in *Hispania* are located in the provincial capitals. In *Augusta Emerita*, funerary areas are situated more than 2000 m from the *pomerium* (Cortese, 2015: fig. 6.2), in *Tarraco* they reach to a similar extent along the *via Augusta* (Arrayás, 2005: fig. 43), and in *Corduba*, tombs have been identified 1700 m away from the city (Ruiz Osuna, 2010: fig. 166). The extension of the *Segóbriga* burial area, which reached a length of 2400 m along the northern road, makes it one of the most extensive of its kind known on the Iberian Peninsula.

The identification of funerary monuments in *Segóbriga* by remote sensing offers new and fruitful research prospects in the field of knowledge of *viae sepulcralis* in *Hispania*. It constitutes a significant advance in our understanding of the dissemination of a funerary model with Italic roots, which was employed by local elites as a vehicle for self-representation from the end of the 1st century BC.

## Supplementary files

This article contains supplementary files accessible via <https://doi.org/10.4995/var.2024.22738>.

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