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Non-Invasive Prospection Methods in the Roman City of Balsa (Luz de Tavira-Portugal): Revealing the Real Townscape †

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Abstract: Ever since Estácio da Veiga, at the end of the 19th century, identified the ruins of the Roman city of Balsa under Torre d'Aires estate (Luz de Tavira-Portugal) and its surroundings, the scientific questions about this Roman city have been constantly increasing. Despite the historical importance of this city, referenced in classical literature, the archaeological knowledge about it remains very scarce due to the difficulties around implementing any durable scientific research projects. Therefore, much of that written about the topographical features and configuration of the city has no unequivocal scientific support. Finally, 2019 saw the launch of this ongoing project "Balsa, searching for the origins of the Algarve", which aims to ascertain the main features concerning the city's extent and configuration, mainly through non-invasive methods. Since 2017, geomagnetic and geo-radar surveys have spanned several hectares and successfully identified many traces of the Roman city while discarding the existence of others in certain locations. In the last two years, the geo-radar surveys have intensified and established the boundaries to the Roman city as well as parts of its layout, remnants of buildings, and even fossilised agricultural crops in addition to other geophysical anomalies, whether or not they are subsequently confirmed by diagnostic pits.

Keywords: geophysical surveys; GPR; Roman maritime town; Lusitania province

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1. Introduction

Balsa was a Roman port city in the south of Lusitania (current Algarve) referenced on various occasions in the classical literary sources (Figure 1). The name and the memory of the site were lost over the course of the Middle Ages and, during the Renaissance, the site was identified as the current city of Tavira. Only in 1866, based on the epigraphy and the abundant remains surviving on the lands making up the Torre d'Aires and Antas estates, located in Luz de Tavira, 6 km away from the city, did Estácio da Veiga correctly locate and define the Roman city in those estates [1]. In 1887, this pioneering Portuguese archaeologist carried out wide reaching excavations on the Torre d'Aires estate, specifically in the necropolis in the north of the city, where he collected some very significant finds [2] (pp. 219–280).

There have since been multiple finds of artifacts and structures that range from the 1st century BC (with only very little evidence) through to the 7th century, a chronological framework established according to the ceramics recovered from these sites [3] (261 and seq.). Even while commonly cited in bibliographies, above all, due to the quality of the finds here, Balsa remains a very underexplored and unknown archaeological site, with only rare fieldwork/research. Since the digs of Estácio da Veiga, over a century past before new archaeological excavation took place on the site of this major Roman settlement. The scarcity of fieldwork stemmed in large part due to the city having been steadily abandoned over the course of the second half of the first millennium AD, giving way to private agricultural terrains.

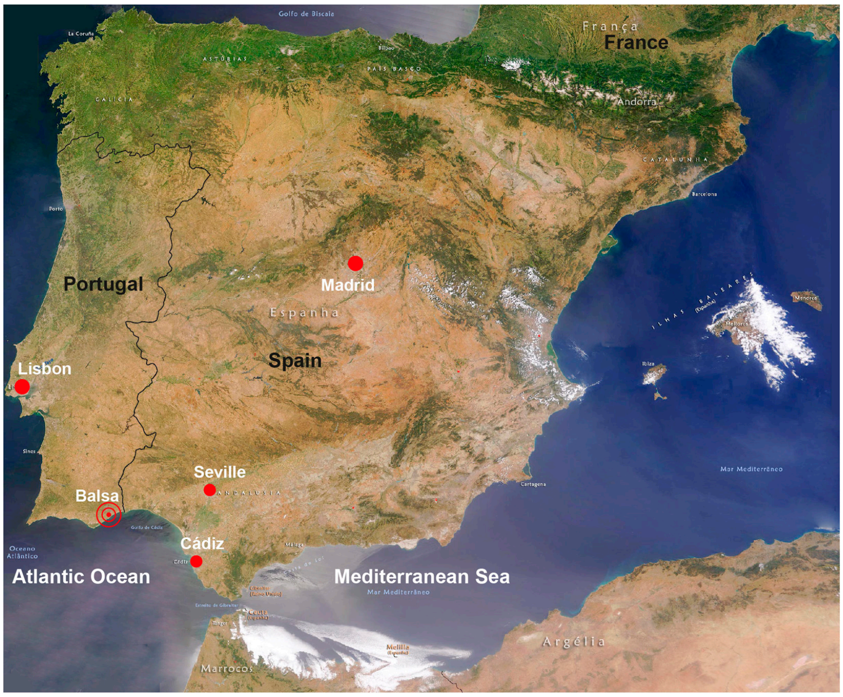

Figure 1. Location of Balsa, Luz de Tavira (Algarve, Portugal).

Among the few digs carried out in the 20th century, the prospecting completed in 1977 by Fernando Bandeira Ferreira, Manuel Maia, Maria Maia, and Victor Gonçalves stands out for having enabled the location of various structures and significant amounts of ceramic materials. In this same year, there was an archaeological excavation campaign that detected some poorly preserved ruins of the former city, such as "a water pipe in *opus incertum*, ... and rectangular tanks established by walls in *opus incertum* ... ." [4]. In the following decade, a survey and recording of all archaeological surface occurrences was carried out by Cristina Garcia, the archaeologist of the Ria Formosa Natural Park, with reports that many of the previously identified structures had since been destroyed [5]. These works enabled the collection of a considerable volume of finds deposited with the National Museum of Archaeology, which have since been subject to successive studies [6–9].

The sheer importance and prosperity of Balsa, even in keeping with the standards of Roman society, are unquestionably demonstrated by the quality and diversity of the archaeological materials recovered there [10–14]. The epigraphic sources also provide diverse reference to the daily life of the city between the first and third centuries [15], highlighting the occurrence of events that would have required the building of public infrastructures and facilities as well as confirming its statute as a municipality. Furthermore, study of the diverse materials, in particular the ceramics, return insights into the ongoing economic activities and commercial dynamics of this port city with its strong connections with the Mediterranean world between at least the 1st century BC and the 6th–7th centuries AD [16].

Throughout the closing decades of the 20th century, simultaneous to advances in the studies of the materials stored in museums, the site was particularly affected by earth moving and, allegedly, at the behest of real estate interests. The city of Balsa, according to the accounts arriving in the public domain, was being subject to destruction, camouflaged to a greater or lesser extent, and increasingly associated with an archaeological site given over to abandonment and a poor example of heritage preservation.

The study and rising number of publications on its materials, which portrayed a dynamic and prosperous provincial city, especially in the early centuries of the Roman

Empire, contrasted with the absence of systematic field studies. This situation drove a great number of hypotheses and conjecture over the city's past reality, scale and size, topography, and urban structure. Thus, a highly fictional, and even mythical, image was built up around Balsa, a great city for discovery and subject to successive destruction due to economic interests. The construction of this reality became so frenzied that it resulted in the publication of a book "Balsa, Cidade Perdida (Lost City)", by Luís Fraga da Silva [17]. This very well-documented publication, featuring attractive illustrations and highly successful online, gained widespread acceptance among the general public, and even serves as a reference in scientific works given the absence of any concrete facts about the former reality of this Roman city. The reconstruction of an idyllic city on an enormous scale as was then put forward, even while more speculative than based on actual scientific fact, generated the enormous merit of attracting regional level attention as regards the need to preserve these ruins. Hence, this led to the establishing of an area of special protection in 2011 that underwent expansion in 2017.

This reflects the context that, under the auspices of mitigating the potential heritage impacts of a large agricultural project planned for terrain hosting remnants of the city, the fieldwork began with prospective surface studies, through field walking, alongside geophysical means accompanied by some soundings undertaken by a private company but under the scientific coordination of the University of the Algarve [18]. These studies led to the launching of the project "Balsa, *Searching for the Origins of the Algarve*" that, in sum, sought to deploy non-invasive geophysical methods and archaeological soundings in order to ascertain the size of the city and level of preservation of its remains.

The accumulation of information ever since the 19th century, testifying to the heritage importance of the site, but also of the surrounding region with a set of *villae* existing on the city's periphery, alongside the scant field research findings, led to the proposition that Balsa was an enormous provincial city spanning 47 hectares, characterised by numerous public buildings, in particular, the port and lighthouse [17] (pp. 94–100), [19] (p. 88), [20] (p. 36). The enormous area attributed to the city, coupled with the need to unequivocally scientifically prove the boundaries of the city's *pomerium* and the still existing archaeological remains, led to the beginning of extensive non-invasive prospecting work under the auspices of the project "Balsa, *Searching for the Origins of Roman Algarve*", involving recourse to geomagnetic and geotomographic devices and especially through means of geo-radar. These surveys were carried out by the Geo Detection Unit of the University of Cadiz and other teams within the scope of agricultural projects in recent years. This set of surveys, which enables the coverage of over a dozen hectares, and the mechanical soundings and excavations in the terrain that have been ongoing brought about some very significant advances, in particular, establishing the boundaries and scale of Balsa as well as a better understanding of its urban layout. The most extensive field surveys were the responsibility of the Geo Detection Unit of the University of Cadiz that primarily applied the geo-radar equipment that we shall approach below.

2. Methodology and Equipment

On the site of Balsa, we carried out geophysical surveys with two different teams. The criterion for the application of georadar explorations [21,22] was the distinction between three areas of the municipium in accordance with the data provided by the historiography detailed above: the urban area, the western necropolis, and an area considered suburban (Figure 2).

The georadar explorations spanned two different campaigns, in 2020 and 2021. We deployed two different devices, even if displaying similar characteristics, not only for operational and logistical reasons, but also to methodologically compare the results of two different systems applied to the same site.

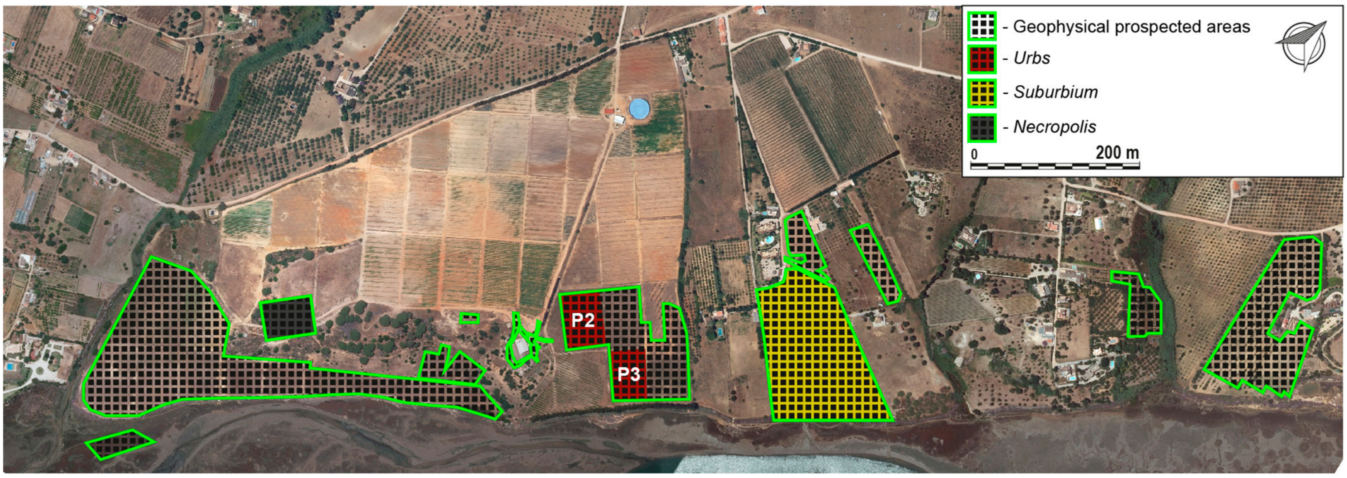

Figure 2. Total areas subjected to GPR geophysical surveys in the city of Balsa and plots analysed in this paper.

In addition, one of the main objectives in advancing with these surveys was to document, at least partially, the planimetry of the ancient city of Balsa, and so we also applied some image processing methods to the plans and tomography scans of the GPR results. These simple processing methods, which will be developed further below, aim to optimise the visualisation at certain levels in order to digitise and interpret eventual locations, especially urban contexts, in Balsa.

In the case of the urban area, we deployed GPR Stream × equipment produced by the Italian company IDS (*Ingegnieria dei Sistemi*, Pisa, Italy). This is a multi-channel georadar consisting of an array of 16 antennas spaced 12 cm apart. The antenna array consists of two modules, 8+8 dipoles oriented in parallel to the sampling direction (vertical polarisation). The sensors work with a core frequency of 200 MHz. The total number of antennas provides the equipment with a size of 2 m, although the effective scanning width is relatively smaller, a transect width of 1.80 m. The antennas are connected to a Central Unit (DAD) that records all scan data. The specific parameters for data acquisition were 80 ns in terms of depth with 512 samples per scan and with an average wave propagation speed of 10 cm/ns. The equipment is carried on a motorised vehicle, in this case a 4 × 4 vehicle fitted with a crane system operated by the pilot, which allows the device to broadly adapt to the surface characteristics of the terrain under exploration. The maximum data acquisition speed with these parameters is 15 km/h. We made recourse to ONE VISION (Albuquerque, NM, USA) for data acquisition software and with GRED HD (Wymondham, UK) providing data processing and three-dimensional visualisation software.

For the geophysical exploration by georadar, we deployed Mk IV equipment, model DXG2528 produce by 3DRadar. This is a multi-frequency, multi-channel georadar consisting of an array of 28 antennas spaced 7.5 cm apart. Unlike the Stream × equipment, also multichannel, the MK IV is characterised by the use of step-frequency technology which consists of the practically simultaneous emission of electromagnetic pulses at different frequencies covering a much wider bandwidth than traditional systems. The frequency range that this equipment can cover in its data acquisition ranges from 30 to 3000 MHz and thereby ensuring the maximum resolution at all depth levels. This covers an effective scanning width of 2.10 m. The 28 antennas are connected to a central unit (GeoScope) that records the data. We sourced data acquisition software from GEOSCOPE CONTROL while Kontur Examiner (Trondheim, Norway) provided data processing software.

Both devices acquire data simultaneously via GNSS GPS systems with RTK correction. Due to the proximity of the Spanish border, we connected to the Andalusian Positioning Network (RAP) to correct the GPS data. Stream × adopts the Leica Geosystems model GS14 (antenna) and CS15 (controller) the GPS system while the MkIV applies the TOPCOM produced HiPer SR (Figure 3).

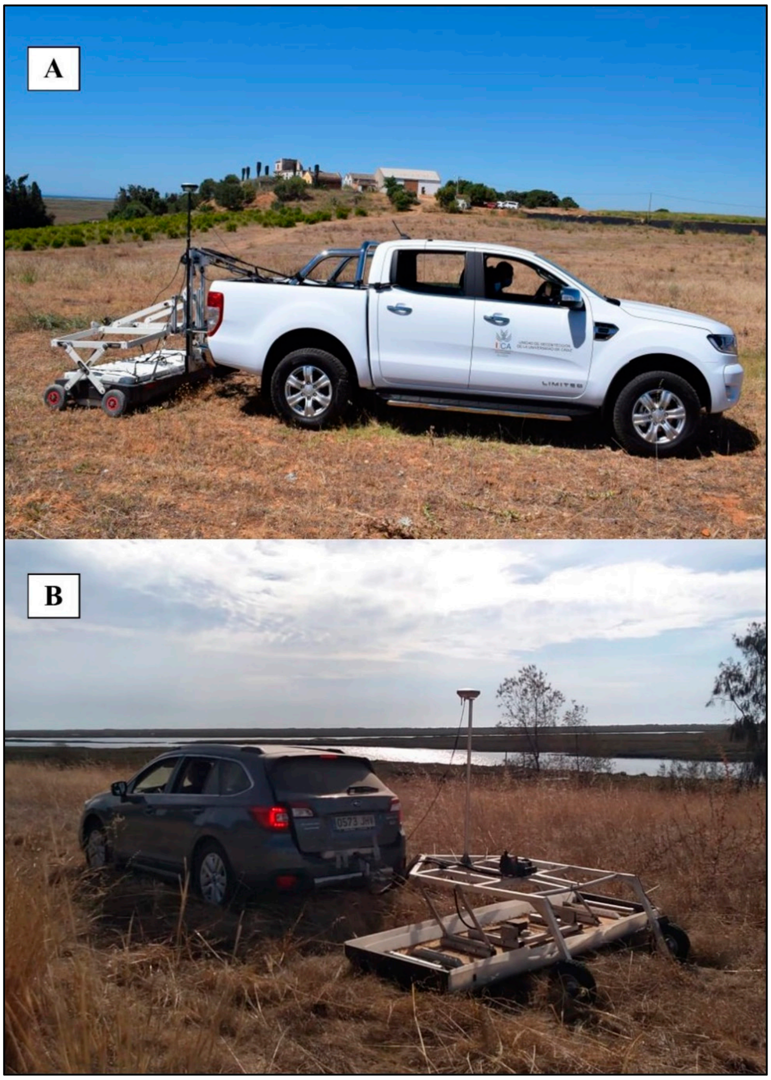

Figure 3. The GPR equipment used: (**A**) GPR Stream X; (**B**) GPR MkIV.

In general terms, the working conditions and the type of soil were optimal for the use of this technique, with the exception of some areas already subject to excessive intervention, such as roads, or heavily disturbed by agricultural work. Therefore, during data processing [23] (pp. 141–146), we opted not to apply an excessive number of filters or overly manipulate the parameters (Figure 4).

	STREAM X	MK IV
PARAMETERS AND FILTERS GENERALES	Vertical Bandpass	Interference Supression
	Time Zero Correction	Fourier Inverse Transform (ISDFT)
	Gain Smooth (GainSTC)	Background removal
	Background removal	

Figure 4. Filter packages applied to both GPR equipment.

3. Main Alterations Detected in the Three Study Areas

In the following, we describe and analyse the main sets of geophysical alterations documented in the three areas of the city.

3.1. Urban Area

In this area, in the vicinity of the Torre d'Aires estate farmhouse, we carried out a total of five projects covering an area of 1.6 ha. Each project was defined by the usual obstacles encountered in agricultural terrains; groves, ditches, etc. The main alterations were documented in that entitled projects 2 and 3.

Starting with project 2, we can distinguish at least four sets or groups of reflections that are orthogonal in layout (Figure 5).

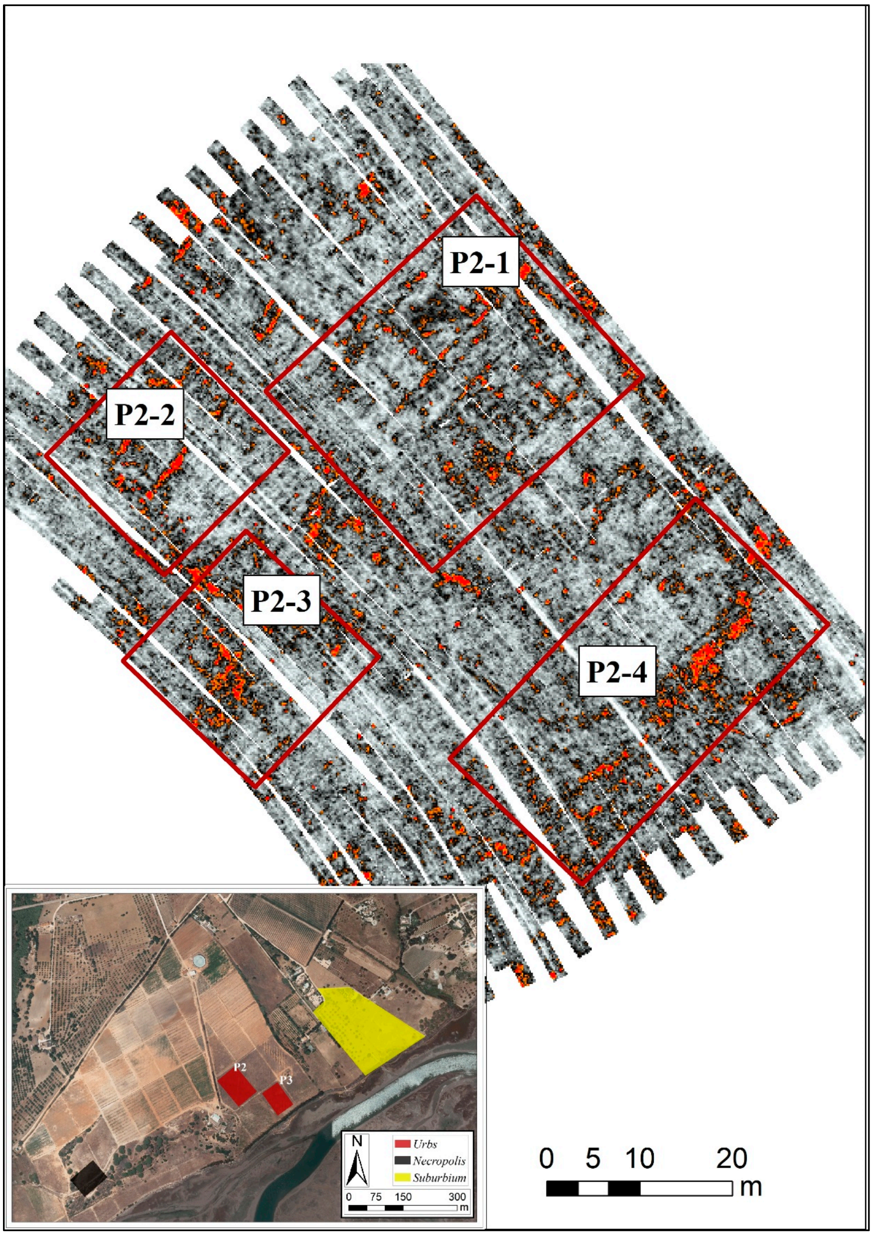

Figure 5. Groups of alterations in project 2.

Analysing them from north to south and from east to west, the first group of anomalies (P2-1) emerges as orthogonal linear alterations, forming, in the layout view, rooms distributed in an orderly spatial fashion. Although they begin being detected at around

−0.40 m in depth, a general characteristic of this project, their best visualisation levels are found at a lower level. This reflects the deterioration and destruction suffered by the most superficial layers. At a depth of −0.70 m, this complex becomes two groups of regular rooms separated by an "empty" space of about 4 m. The average dimensions, in spite of the deterioration and destruction of the most superficial layers, are as follows. The average dimensions, despite the different layout views, are around 8 × 5 m and the building alignment orients northwest-southeast.

A similar group (P2-2) is documented at the northwest end of the project, some 13 m from the group described above, in this case the remains are better visualised at a relatively lower level, −1.10 m. At least two rooms are documented in the layout view, in this case more quadrangular, about 6 × 6 m, and displaying the same orientation.

To the southwest, about 14 m from the previous site, we can identify P2-3, in this case with a different morphology to the general trend hitherto described. We may distinguish two differences: the first anomaly has an almost rectangular morphology, measuring 2 × 3 m, with a layout depicting some kind of strong structure separated into two containment spaces; and, in the second, with a clear relationship to the previous, another group with an irregular layout shape is documented, without walls or enclosures except for one powerful anomaly, which the radargrams portray as a horizontal stratigraphy with an approximate dimension of 5 × 6 m.

To close this general description of Project 2, alterations are also documented further south (P2-4). In this group, a strong northeast-southwest linear anomaly stands out which, despite being documented at higher levels, is projected at deeper levels, reaching up to 2 m. At the depth of −0.90 m, orthogonal continuations southwards seem to be present. This linear alteration, interpreted as a major wall feature, reaches a width of 1.70 m at −1.50 m (Figure 6).

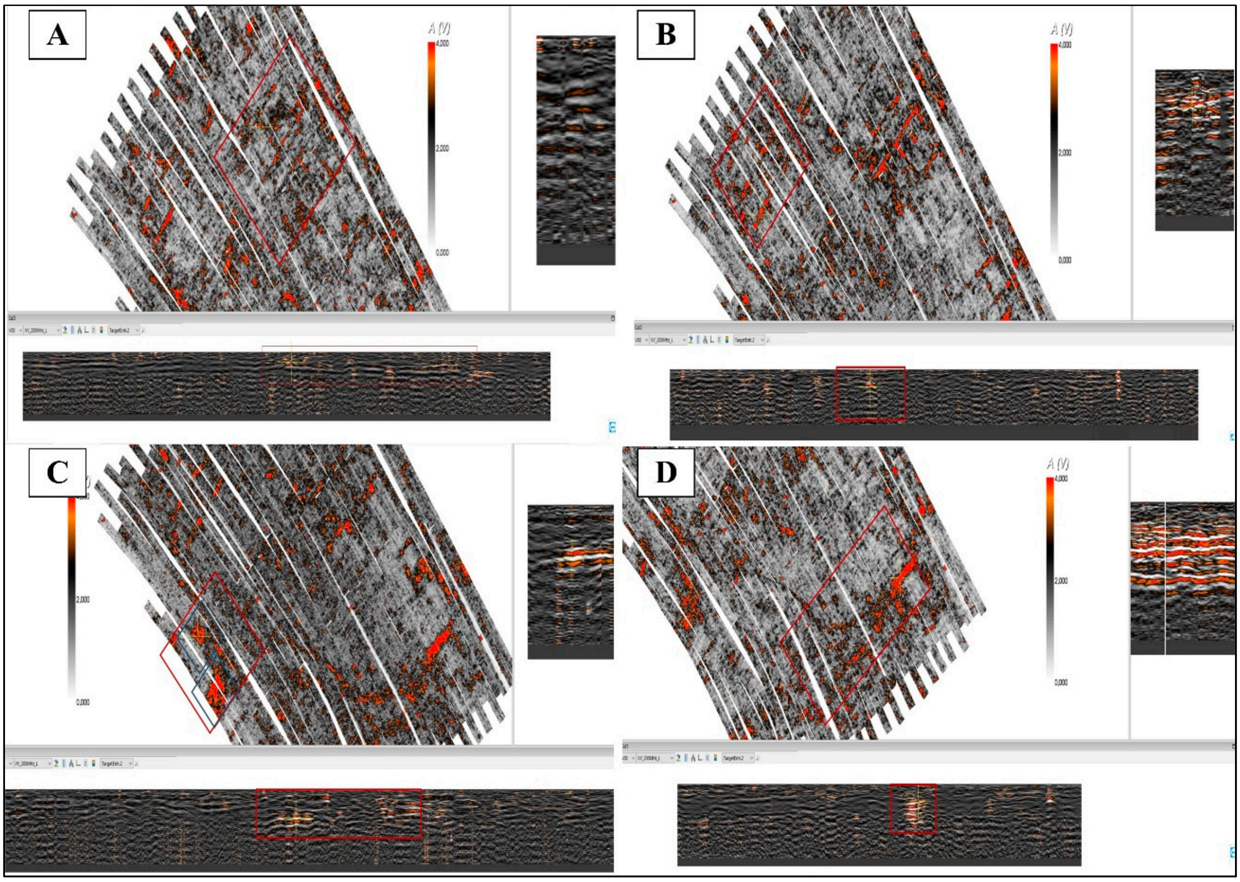

Figure 6. Main alterations of project 2 in GRED HD: (**A**) P2-1; (**B**) P2-2; (**C**) P2-3; (**D**) P2-4.

Project 3 documents similar alterations to those of project 2 even though more irregular in their visualisation. This probably occurs because this terrain is at a lower level, where earth movements and filling seem to have taken place in recent years. In general terms, we identified three groups of reflections of interest (Figure 7).

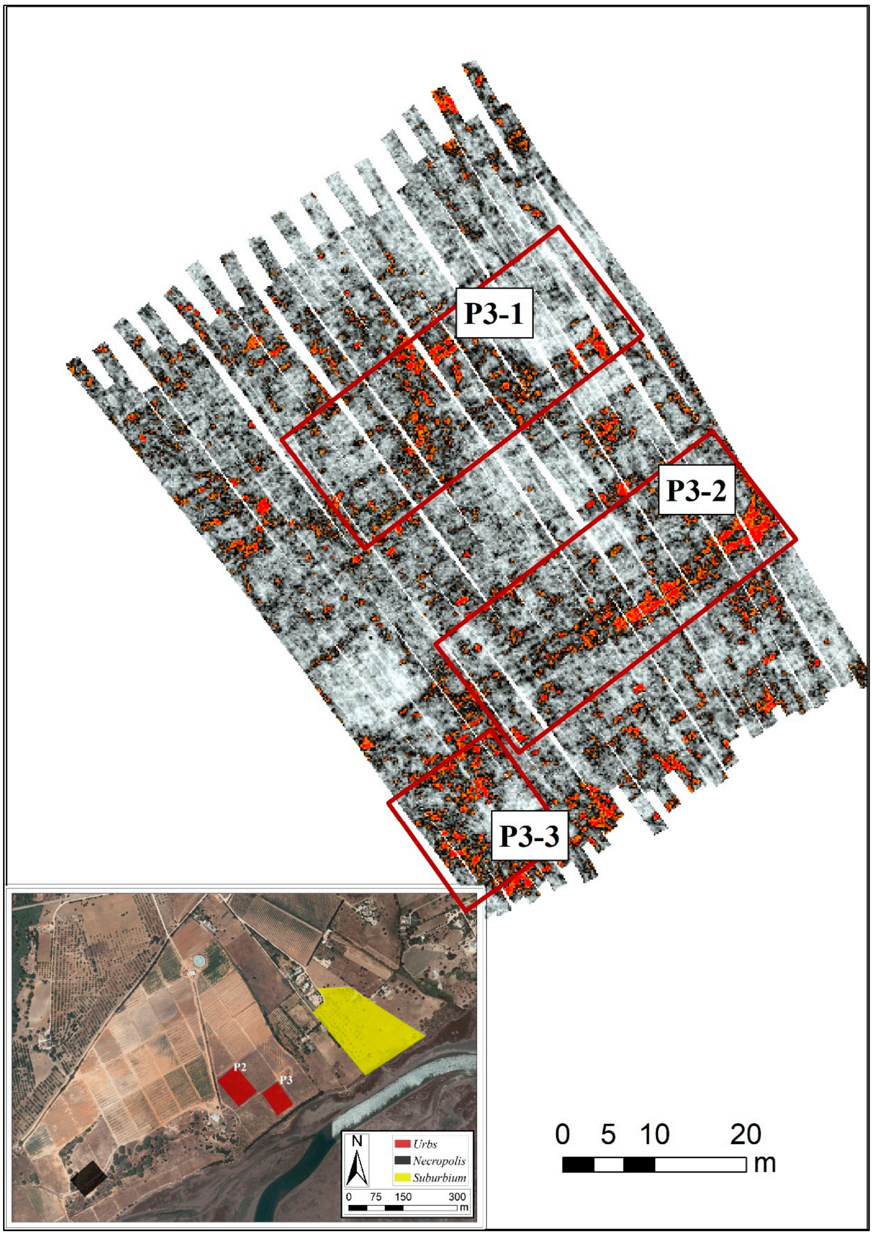

Figure 7. Groups of alterations in project 3.

At the northeast end, the first group (P3-1) stands out with the linear alteration running around 31 m in a northeast-southwest direction to which other features of a constructed nature seem to be attached. In other words, this seems to correspond to a feature for the arrangement and separation of space. The layout view depicts a massive feature, 4 × 3 m on average, whose best viewing height lies at around −0.40 m. Its radargram configuration leads to our interpretation of a possible floor or pavement.

About 25 m to the south, a group of reflections with a similar morphology emerge (P3-2): a very powerful linear anomaly stands out which appears to be the spine for organising this space, a possible island, or important public building. The power of the alteration ranges from −0.20 m to −1.20 m, with a width of 1.60 m. At shallower levels, we detected other orthogonal alterations towards the north.

Finally, the P3-3 set, in the southwest of this project area. While the uniformity or orthogonality described thus far does not appear, the visualisation of the longitudinal and transversal profiles reveals a negative clogged feature, interpreted as a possible containment structure (Figure 8).

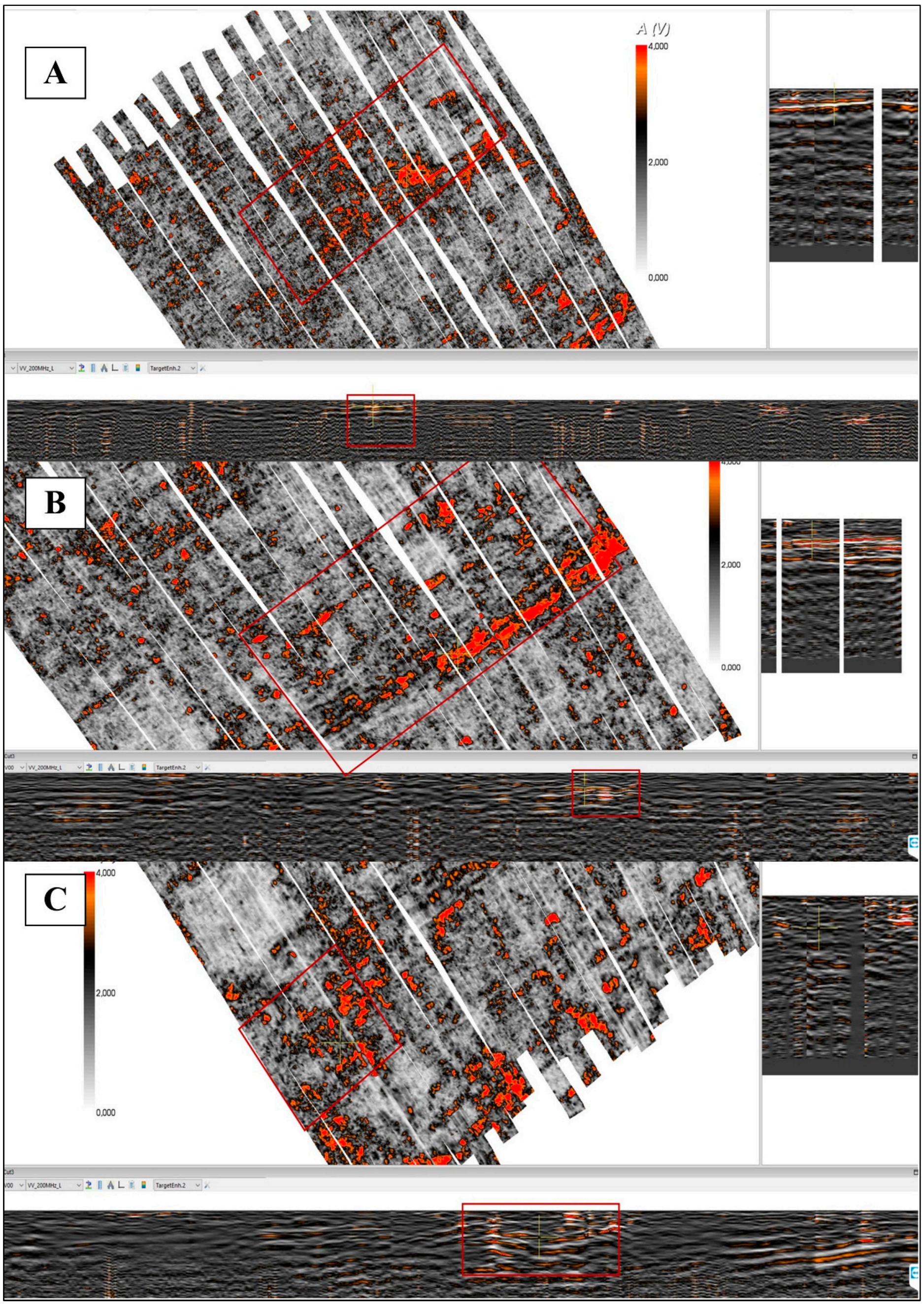

Figure 8. Main alterations to project 3 in GRED HD: (**A**) P3-1; (**B**) P3-2; (**C**) P3-3.

3.2. Western Necropolis

Two Roman burial sites have been documented in this area, with a 3rd–4th century chronology [24] (p.365). The GPR exploration of this area was limited by certain surface features, such as ditches, trees, and fences. Furthermore, the site is located on a road with very compacted soils.

Despite this, the visualisation or layout view identifies up to four sets of alterations interpreted as the eventual remains of burial sites (Figure 9).

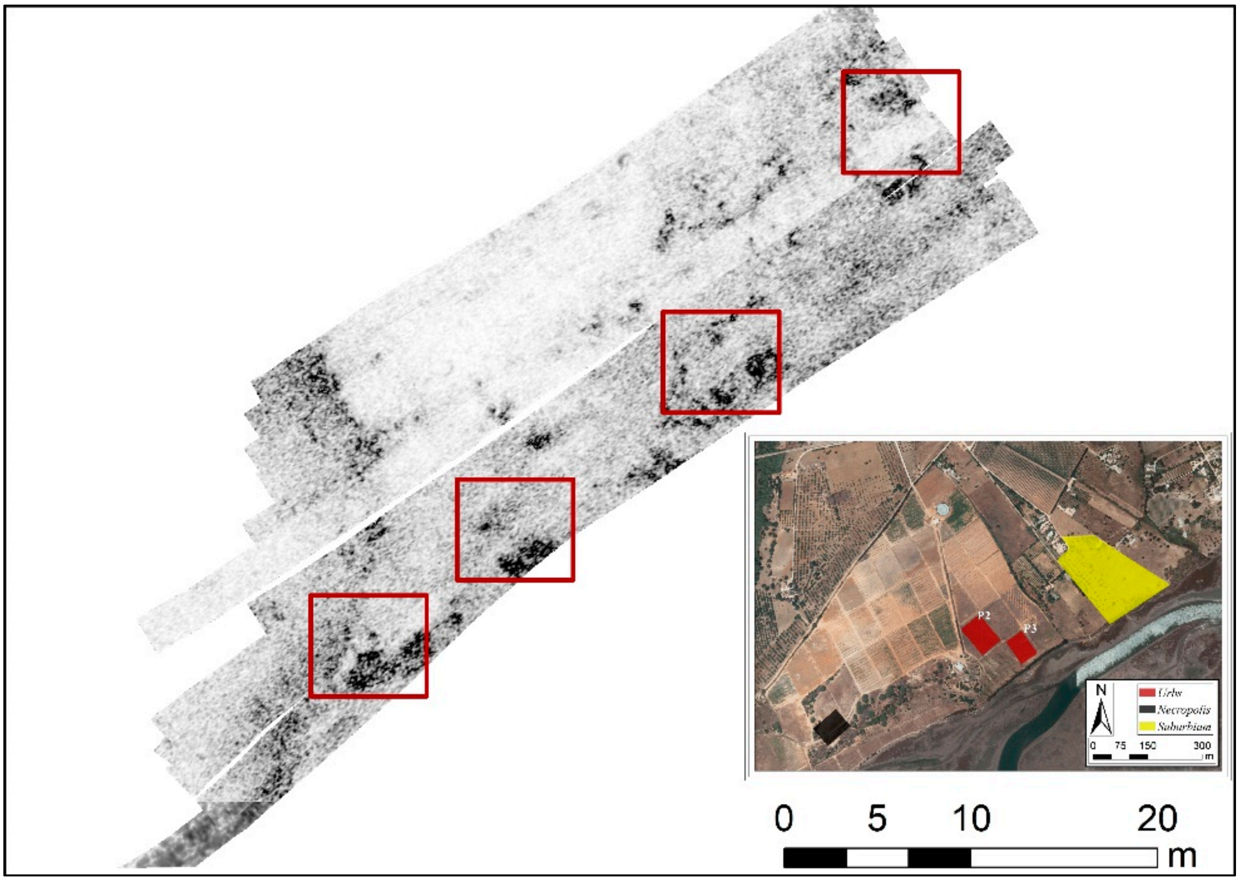

Figure 9. Groups of alterations in the GPR survey of the necropolis area.

The project dimensions and the type of anomalies documented underpin an overall description of the whole. In this case, the views of the longitudinal sections and radargrams best characterise the anomalies. In general terms, a sort of trough is documented, running from −0.30 m to approximately −1 m. Between −0.40 m and −1 m, the longitudinal radargrams best depict these anomalies. However, the radargrams effectively document the level between −0.40 m and the base of the geologic layer and, while in some cases it would seem there are worked anthropic features, hyperbolas of similar dimensions are documented, with some more irregular than others, but defining a general pattern. We interpret these features as likely remains of inhumation or burial sites organised in a space (Figure 10).

3.3. Suburban Area

In the area identified a priori as the Balsa suburban space, a single project explored a 2.6 ha area occupying a complete private plot and the eastern section of the neighbouring plot.

This large-scale project distinguished four groups with different morphological and functional characteristics (Figure 11).

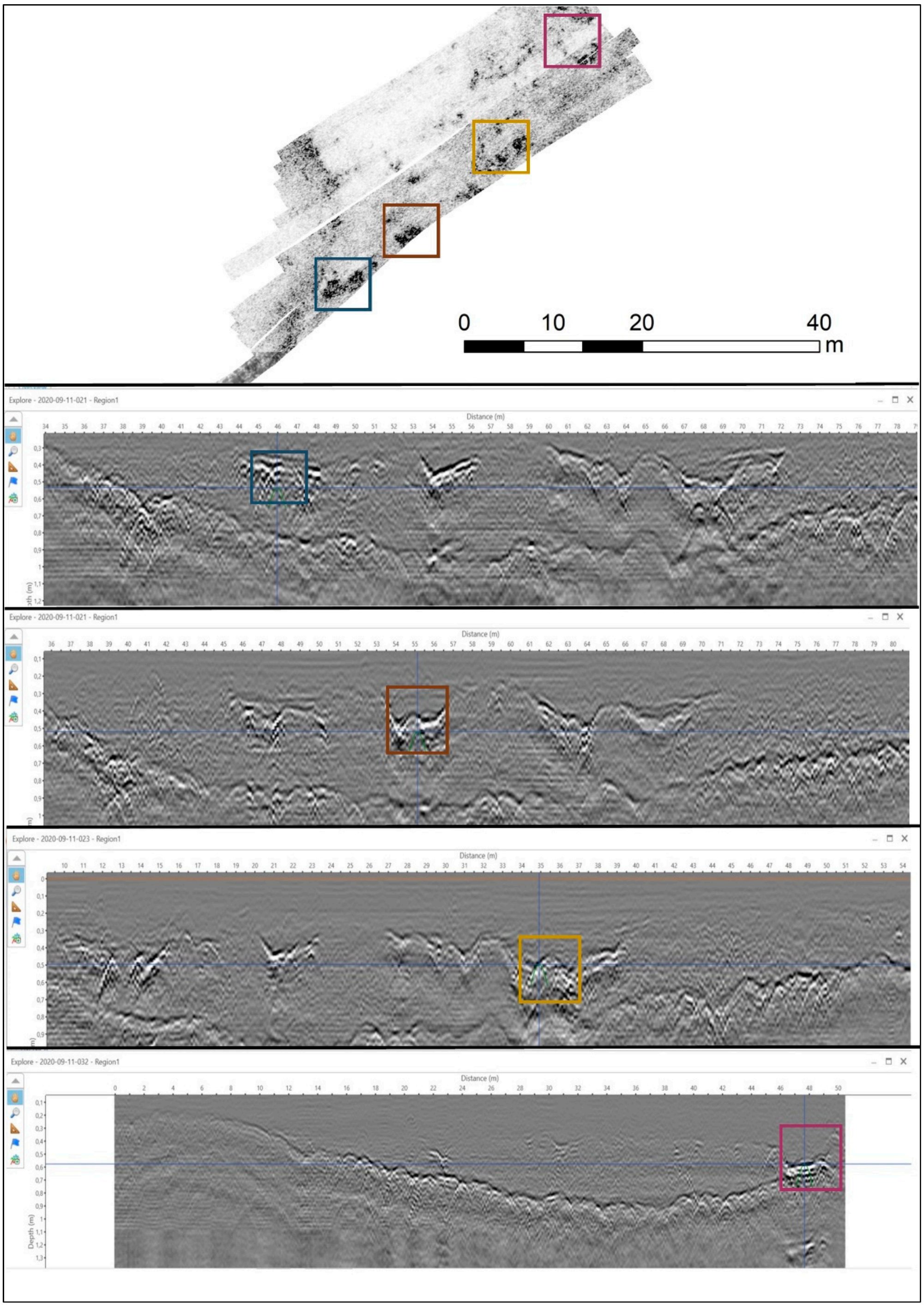

Figure 10. Main alterations of the GPR survey of the necropolis.

The group identified in the north (P1-1) contains a series of linear anomalies running orthogonally to each other. The reflections take on a northeast-southwest and northwest-southeast orientation, hence the same as the urbanism interpreted in the area described above. The anomalies are visualised very subtly and, according to the radargrams, at a shallow level of little over 20 cm. Following detailed analysis, there emerges a subset to the north with a rectangular morphology and outlining a space of 7 × 8 m. We may highlight a possible floor or pavement in this area, and another space about 30 m to the south, the main construction, which presents internal subdivisions forming practically square 4 × 4 m rooms, and finally, to the southwest, already in the neighbouring plot, another group at a greater depth and which seem to form the perimeter closure of the set or building on this flank. We therefore interpret this group as a peri-urban building, possibly the remains of a suburban villa.

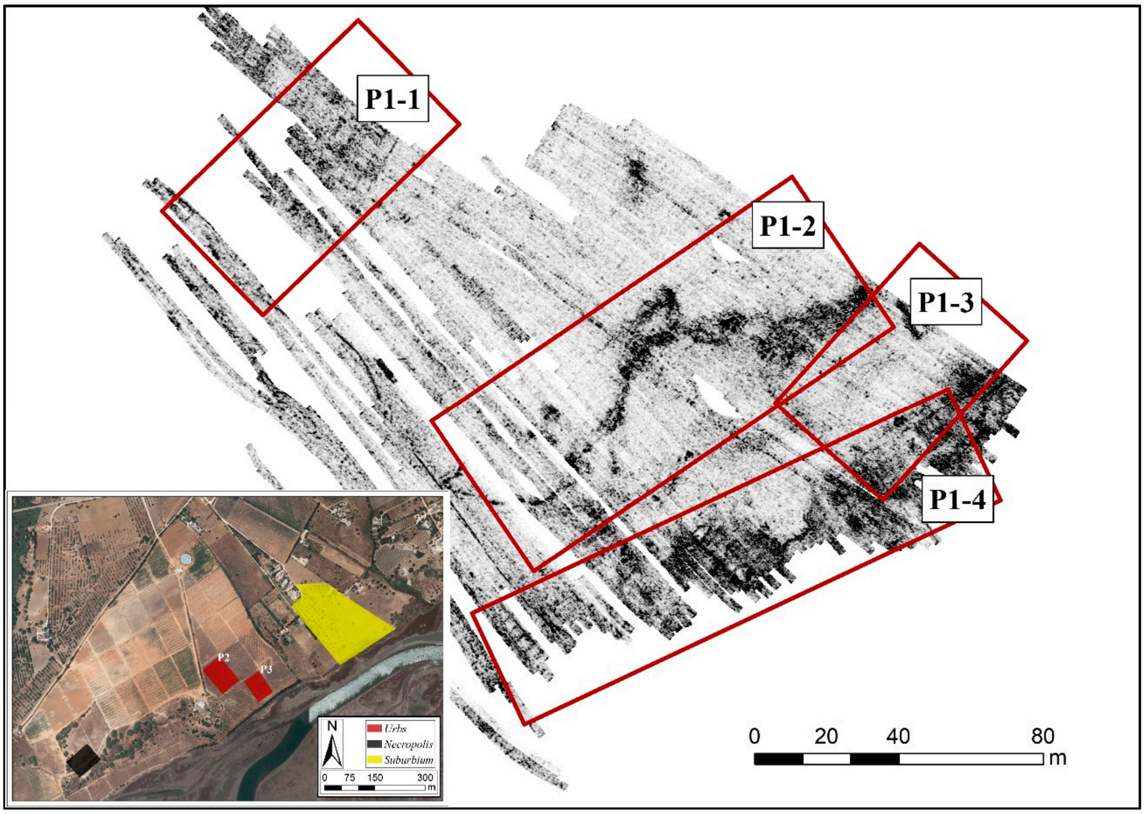

Figure 11. Groups of alterations in project 1.

In the central project area, P1-2, a large alteration runs through the entire project, from east to west and with an irregular morphology. Depending on the elevation at which we visualise the whole in layout, this takes on either one form or another. A priori, this idea and analysis of the radargrams lead us to interpret this as a change in the geological structure that causes this type of reflection. However, we also cannot ignore the fact that, at very specific and relatively deep levels, rectilinear cuts appear to be visible in the substratum, appearing to be aligned at the level of −1.30 m.

The third group of alterations (P1-3) appears on the southeast side of this plot. In layout, this area stands out for its spatial configuration in the form of small punctual signs organised and distributed uniformly within a defined space. They are documented at around −0.30 m in depth with some of them about 40 cm in thickness. In the layout view, the reflections form an organisation in lines, spaced 3 m and 2 m apart and approximately 40 cm in diameter. In the radargrams, they appear as hyperbolas without any significant echo at depth [25]. We correspondingly interpret them as the remains of planting pits, a relict cultivation framework. The materials making up this pit may eventually be features with high amplitude values, such as some metals or the remains of materials subjected to combustion.

To close this analysis, we have unified the alterations emerging in the P1-4 group, which occupies the entire southern fringe of this project. This group of structures displays a series of common characteristics:

- They are organised in a specific space.
- They are visible from relatively shallow levels, from −0.30 m upwards.
- The perimeter features, interpreted as walls, attain a significant height, over 1.20 m.
- The width of these walls is also relatively large, spanning around 80 cm on average.

– In the visualisation of the sections and the radargrams, a different material filling can be identified as possibly sand, and, at the deepest levels, the pavement of the archaeological structure was documented.

Although morphologically, from the ground layout perspective, not all these alterations are visualised with the same morphology or size, this entire space is interpreted as a set of tanks (*cetariae*) dedicated to the production and preservation of fish sauces. In other words, a *cetariae*, a prominent feature of the Balsa *suburbium* (Figure 12).

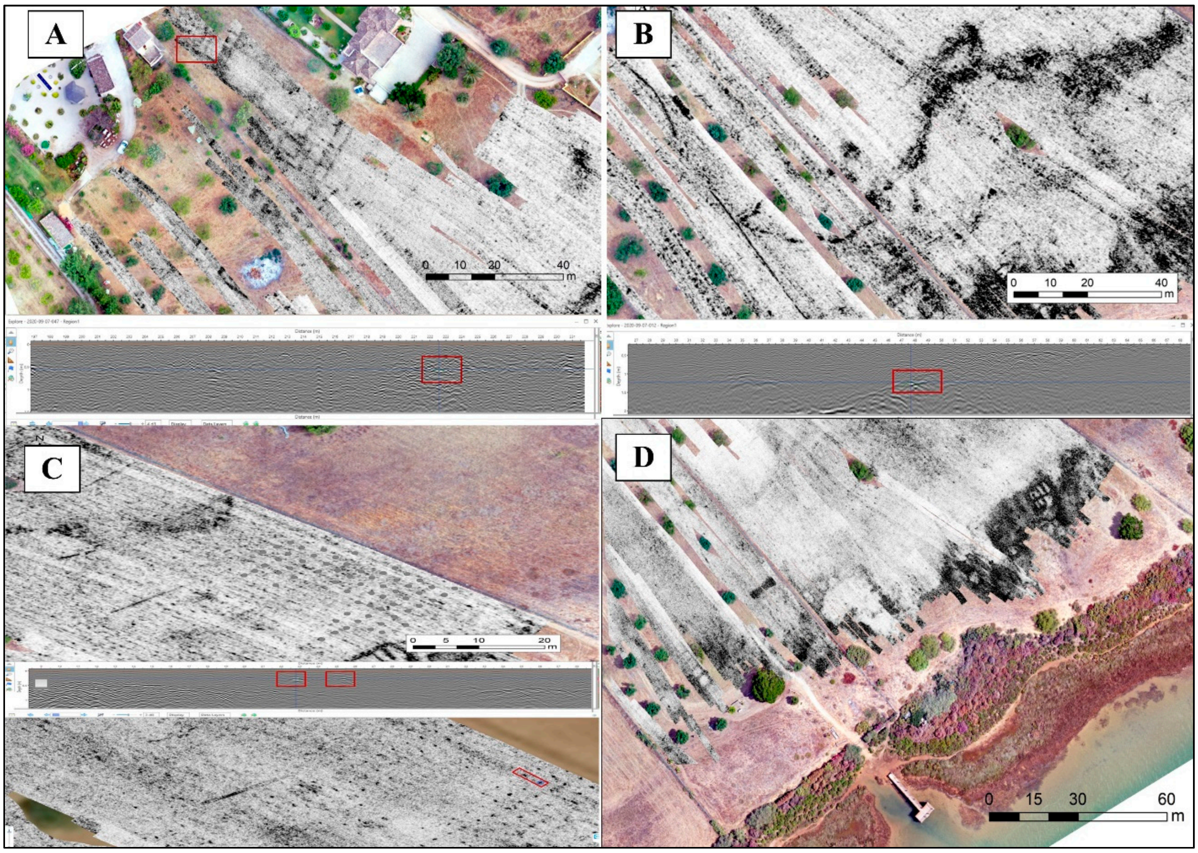

Figure 12. Main alterations to project 3 in GRED HD: (**A**) P1-1; (**B**) P1-2; (**C**) P1-3; (**D**) P1-4.

4. General Interpretation of the Results

In the previous section, we described and analysed the main alterations detected by the GPR geophysical surveys. The insights into the different zones of the city of Balsa have been important to launching the first interpretations of the geophysical results.

In the so-called western necropolis of Balsa, despite the limitations of the space being explored and the general conditions of the terrain, we have documented a space with alterations that are interpreted as possible inhumation or burial sites, similar to those excavated, in the geological formation, or worked into the substratum. The site of Balsa in general, but especially its necropolis areas, has been very badly damaged by intense looting, hence the relevance of this non-invasive technique in helping to document these damaged areas [25] (p. 361).

The maritime connection of the Balsa *municipium* must have constituted one of its main features. For this reason, in this section, we wish to focus on the city's other two areas:n the one hand, the *suburbium* and, on the other hand, the urban area of Balsa.

4.1. The Balsa Suburbium: Combined with Archaeological Findings

In the georadar prospecting project carried out in the plots where at least part of the suburban area of the city appears to be located, we have described four different archaeological groups. One of the general objectives in carrying out these explorations and other non-invasive techniques applied to the site was the delimitation of areas of interest for the opening of archaeological probes within the framework of the "Balsa, searching the origins of the Algarve" project.

The complex to the north (P1-1—Figure 12A) was analysed and interpreted as a peri-urban building with its configuration suggesting it was formerly a *villa* or a suburban *domus* with its structural features appearing to have been badly damaged due to subtle alterations in the ground level and the lack of strength in the reflections corresponding to walls in relation to the other archaeological structures analysed. In addition, we would also note that the findings seem to identify possible remains of pavements or floors at certain heights despite a lack of overall clarity in the radargrams. In this sense, one of the open surveys, which is still under study with its results still unpublished, partially confirms these interpretations. In particular, the latter approach has led to the excavation of some wall remnants, with only a low level of elevation, which would delimit an *opus tessellatum* or mosaic (Figure 13).

Figure 13. Mosaic documented in an archaeological sounding (P1-1).

The second group described in the *suburbium*, P1-2 (Figure 12B) has also since been probed. In this case, it had been interpreted as a potentially strong feature brought about by a change in the geology although this does not rule out that the site was worked on in some specific areas. However, although not contrary to the interpretations of the geophysical data, this seems to correspond to intrusions of more compacted clays in a sandy context (Figure 14).

Thirdly, the point anomalies distributed in an orderly manner and interpreted as the remains of a planting pit for a relict crop (P1-3; Figure 12C). Once again, the archaeological sounding confirms a similar line to the previous interpretations in documenting rounded dark patches composed of crystallised materials. The levels at which they emerge in relation to Roman archaeological structures suggest closer chronologies in time. Carbon 14 testing is currently under planning to ascertain their origins (Figure 15).

Figure 14. Sounding opened in P1-2. In this case, the geophysical alterations were caused by the diverse nature of the sediments.

Figure 15. Sounding opened in P1-3, with the remains of planting pits visible.

Finally, the entire southern strip of the surveyed suburban area, which we have interpreted as part of Balsa's salting quarter (P1-4; Figure 12D), this salting factory, with numerous documented pools, reflects an important component in the city's link to the sea and productive activities in coastal contexts. A test pit was opened to document part of the structures located to the east of the strip and resulting in the excavation of extremely robust walls, preserving the *opus signinum* (Figure 16).

Figure 16. Sounding opened in P1-4 with a vat dedicated to the production of fish sauces.

4.2. The Balsa Urbs: Data Processing for Digitalising the Urban Planimetry

In this area, given the absence of the archaeological surveys made of the suburban areas, exploring by GPR has returned a series of orthogonal alignments, spatially linked, interpreted as the remains of the urban network and the insulae of the Balsa *municipium*.

In order to effectively digitalise the anomalies, we consider make up part of this network, we carried out some post-processing via Geographic Information Systems (GIS, hereafter). We have described how changes in the topography of this plot, as well as the agricultural work itself, have meant that not all the structures are documented at the same level. For this reason, we resorted to exporting and working with point clouds in the depth range of interest, hence, every slice from −0.30 m to −1.70 m. The aim here involves unifying all these slices before undertaking some statistical calculations with the intention of obtaining a 2D summary image of the data package. Specifically, we calculated the mean squared values in order to intensify the lowest and highest values, thereby "cleaning" the image. Once we have obtained this summary file, which contains coordinate values (X,Y) and the amplitude value, we move on to its rasterisation in GIS. In this final file, we may single out the most interesting anomalies by means of raster queries and then reclassifying [26] the file to enhance these anomalies [27] (pp. 170–172) (Figure 17).

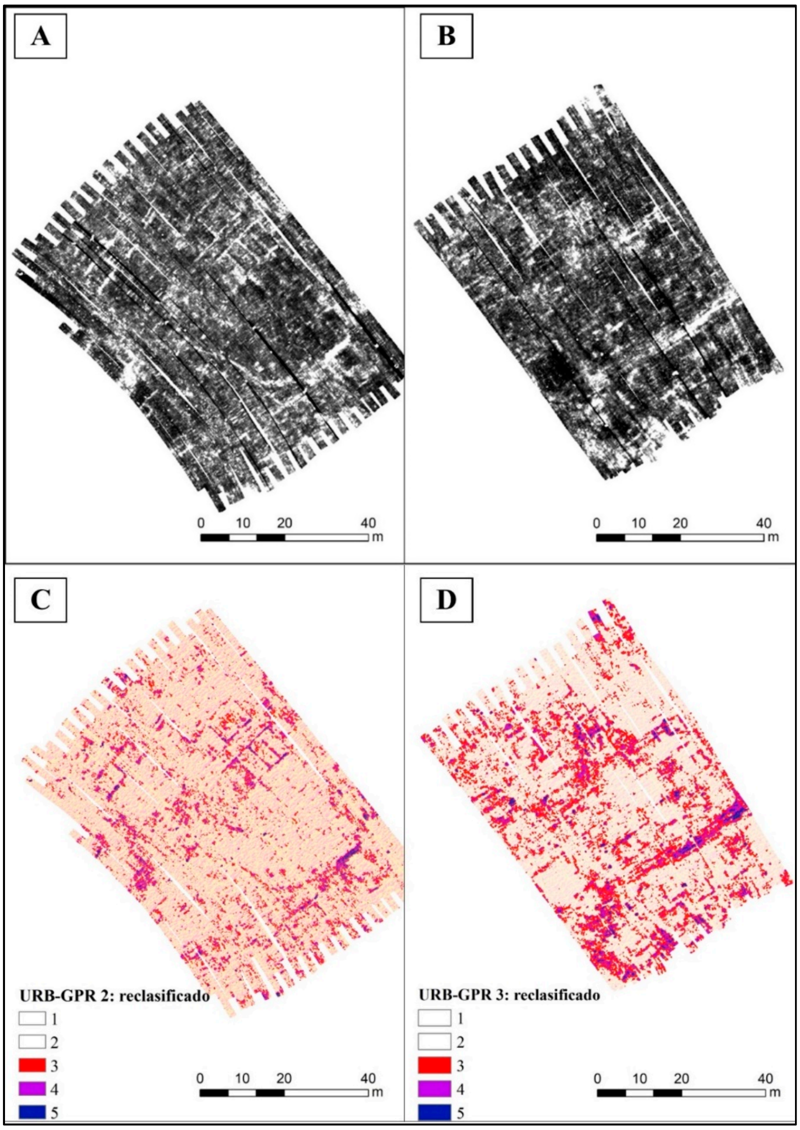

Figure 17. Post-processing and improving the visualisation of the data from projects 2 and 3 in the urban area: (**A**) Mean squared of project 2; (**B**) Mean squared of project 3; (**C**) Reclassification of project 2; (**D**) Reclassification of project 3.

Through this procedure, we have been able to document other orthogonal anomalies, which has resulted in the digital quality of these alterations and, correspondingly, of the knowledge on this section of the urban extent and buildings of Balsa.

In order to be able to draw some initial conclusions about the urban planning of Balsa, the data obtained from project 3 and its subsequent analyses have provided us with a considerable amount of information.

As demonstrated in the image above two *cardines* and two *decumani* have been identified (Figure 18). The first *decumanus*, located to the north, features a width of 3.5 m, 11 Roman feet. It is unusual in that it is porticoed at the end closest to the *cardine* identified towards the west. This portico would have had dimensions of 1.2 m, or 4 Roman feet, on either side of the *decumanus*. The second *decumanus*, located in the project's southern area, and with more irregular boundaries than the previous case, displays a maximum width of 3.8 m or 13 Roman feet.

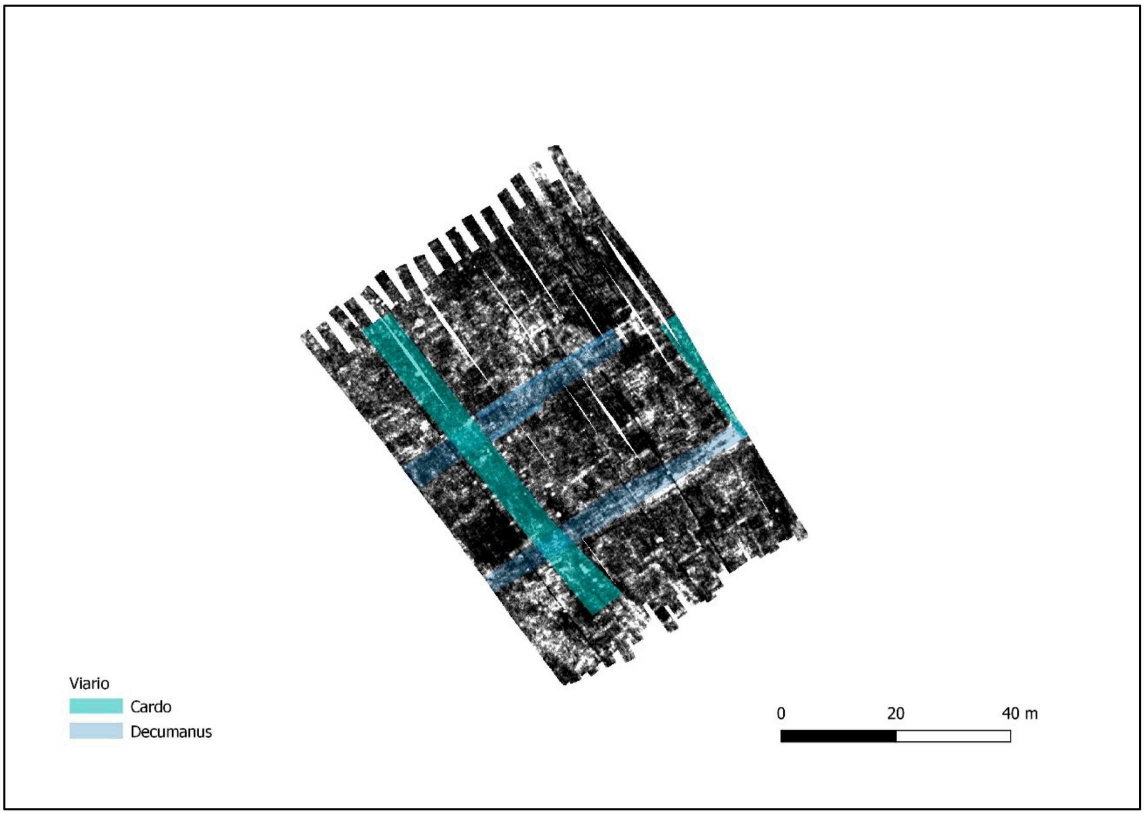

Figure 18. Post-processing of project 3 and road representation.

As for the two *cardines* identified, we have not been able to obtain the maximum width of that located to the east of project 3 as this not yet fully surveyed, thus extending beyond the limits of the project. The westernmost *cardo* attains a maximum width of 4.2 m, or 14 Roman feet.

Although the easternmost *cardo* could not be identified in its entirety, it did, however, provide us with a complete delimitation of what we identify as an *insulae*. After obtaining the dimensions of the latter, we may report a width of 18 m and a height of 35 m, which would be about 60 by 118 Roman feet. We thus encounter an insula that represents an almost perfect rectangle in a 1:2 proportion.

All of this information generates insights into the possible module applied in the urban planning of Balsa, the possible layout of the road and its orientation, running northwest-southeast for the *cardines* and northeast-southwest for the *decumani*.

5. Conclusions

From the methodological perspective of geophysics using GPR, we have been able to deepen our historical knowledge of the municipium of Balsa. We have focused on three areas of the city, the necropolis, *urbs*, and *suburbium*, and we extracted data of interest in all three zones. This approach limits the hitherto proffered speculations, as detailed in the first section, about the large areas and buildings supposedly identified at Balsa without scientific evidence.

In addition, comparison with the first results returned by the archaeological surveys coincides with and complements the interpretations made of the geophysical data alone, which enhances the quality of the results obtained using non-invasive techniques, in this case geophysical prospecting with georadar, whenever duly interpreted according to historical postulates, knowing the working space and previous research.

We have also deepened our knowledge on the city, from the perspective of its relationship with the sea, and on coastal productive activities. In fact, the geophysical results obtained in the eastern section of that traditionally considered a section of the city's pomerium (area P1–4), configure this as more of an industrial area dedicated to the transformation and preparation of fish and sited the city's periphery.

Finally, there is a need to emphasise how an extensive area, beyond our scope here, located above all on the riverbank in the western section of the Torre d'Aires estate, turned out to be archaeologically empty despite being assumed as the location for a series of important structures, which includes the wharf and lighthouse of this port city [28]. The geophysical survey largely discarded the bulk of these hypotheses and with this, subsequently confirmed by archaeological soundings. Due to the geologic nature of these soils, especially the intrusion of lodes and sediments and clayey sediments in otherwise predominantly sandy soils, the geophysical results were not always entirely clarifying as regards the absence or presence of archaeological structures in a few of the sites subject to exploration. Nevertheless, over three dozen mechanical and manual soundings have enabled the clarification of the main outstanding doubts.

The geophysical surveys, especially those deploying the highly productive GPR, contributed decisively to achieving the objectives of the ongoing project that fundamentally aims to grasp the true urban area of Balsa as well as evaluating the level of preservation of its ruins. Given the amount of existing speculation and conjecture, these objectives, now obtained, seek to respond fully and scientifically to that which has long since prevailed in the knowledge about Balsa, one of the Roman port cities in the south of the Province of Lusitania.

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