Archaeological Prospection
Archaeol. Prospect. **23**, 243–256 (2016)
Published online 30 September 2016 in Wiley Online Library
(wileyonlinelibrary.com) DOI: 10.1002/arp.1537

Magnetometer Survey at the Newly-discovered Roman City of Auritz/Burguete (Navarre). Results and Preliminary Archaeological Interpretation

EKHINE GARCIA-GARCIA[1,2]*, JUAN MARI MTZ. TXOPERENA[2], ROGER SALA[3], ARANTZA ARANBURU[1] AND JUANTXO AGIRRE-MAULEON[2]

[1] *Euskal Herriko Unibertsitatea (UPV/EHU), Mineralogia eta Petrologia, Leioa, Bizkaia, Basque Country Spain*
[2] *ARANZADI Society of Science, Donostia, Gipuzkoa, Basque Country Spain*
[3] *SOT Archaeological Prospection, Sant Cugat del Valles, Barcelona, Catalonia Spain*

ABSTRACT This paper summarizes the principal geophysical results obtained at a recently discovered Roman city at Navarre. Prior to the survey, the extent of the affected areas and the characteristics of the settlement were unknown. The authors describe the field strategy applied and focus their discussion on the archaeological interpretation of the fluxgate gradiometer data. The results allowed for a detailed description of the layout in the main area revealing a city organized along the Roman road, which would have preceded the buildings. On the contrary, the results show important differences in magnetic contrast in the surveyed areas. Whilst the walls of the main area are well resolved, other areas do not show a discernible magnetic contrast even though their existence has been proven by other sources. The origin of these differences is discussed and preliminarily attributed to waterlogging or to differences in the thickness of the archaeological deposits. The magnetic survey, therefore, has shown itself to be a suitable technique for obtaining a preliminary assessment of the archaeological characteristics of the settlement, but cannot be used to definitively assess the affected areas. The results allowed zoning based on the contrast differences that will be used to guide further investigations. Copyright © 2016 John Wiley & Sons, Ltd.

Key words: Magnetic; fluxgate gradiometer; Roman city; archaeological interpretation; Navarre

Introduction

In recent decades, geophysical prospection has proved to be a useful tool in helping archaeologists delimit and characterize unknown sites, and as a consequence, specialized literature has been developed (eg. (Scollar *et al.*, 1990; Clark, 1996; Gaffney and Gater, 2003). Among the available techniques, magnetic surveying has yielded satisfactory results at a reasonable cost and within a reasonable timescale (Fassbinder, 2010) and has been extensively used in Roman contexts (e.g. Neubauer and Eder-Hinterleitner, 1997; Gaffney *et al.*, 2000; Fassbinder, 2010; Vermeulen *et al.*, 2012).

This system is suitable for an initial survey as it can identify a wide range of archaeological features (Linford and Canti, 2001; English Heritage, 2008). Anomalies can be originated by induced magnetism due to differences in magnetic susceptibility (Aspinall *et al.*, 2008). This is the case of ditches or pits if they are in-filled with topsoil, which tends to present greater susceptibility than the subsoil (Le Borgne, 1955; Clark, 1996). Walls can clearly be resolved when the material shows enough magnetic contrast with the surrounding soil. In some cases, however, they can be obscured by large anomalies created by collapses, fires or highly magnetized materials such as bricks or tiles (Neubauer and Eder-Hinterleitner, 1997). In addition, anomalies can be generated by permanent magnetization (Aspinall *et al.*, 2008). In particular, this method responds particularly well to

* Correspondence to: Ekhine Garcia-Garcia, Euskal Herriko Unibertsitatea (UPV/EHU), Mineralogia eta Petrologia, Leioa, Bizkaia, Basque Country, Spain. E-mail: ekhinegarcia@yahoo.com

Received 10 July 2015
Accepted 8 January 2016

anomalies caused by combustion, due to the thermoremanent magnetization produced by the firing process (Clark, 1996; Linford and Canti, 2001). Hence, kilns and furnaces can be detected, as well as areas of industrial activity (Aspinall *et al.*, 2008; English Heritage, 2008). Iron materials produce strong anomalies that can mask others of archaeological interest. For this reason, they are typically a source of noise in magnetic surveys (Aspinall *et al.*, 2008).

With limited prior information on both the extent and characteristics of the settlement, the magnetometer survey was considered as the best available technique for a preliminary assessment in a newly-discovered Roman city. The geophysical survey was designed with the aim of taking into account three principal aspects: the objectives (delimitation and characterization); the characteristics of the site (rural area with little modern contamination) and the economic resources available (project with very limited funding, based mainly on volunteer work). Initially, a multi-disciplinary approach was chosen to assess the archaeological potential. Indeed, a combination of more than one geophysical technique provides more information than the combination of the information obtained by each one independently (Boucher, 1996; Clay, 2001; Hesse, 1999; Sala *et al.*, 2012). Nevertheless, given the area of the settlement (estimated at 15 ha at the time), and the economic limitations on the project, one system had to be favoured.

In order to assess the contrast of the magnetic system, in autumn 2012, an initial survey was conducted on a test area of 60 m × 120 m. The results were very promising; the Roman path and several anomalies interpreted as walls showed good contrast. The magnetic gradiometer was therefore definitively chosen for surveying the whole area in the main campaign, which was carried out in 2013.

Geographical and archaeological context

The site is located in the northeast of Navarre, on the southern side of the Pyrenees crest line. It is placed

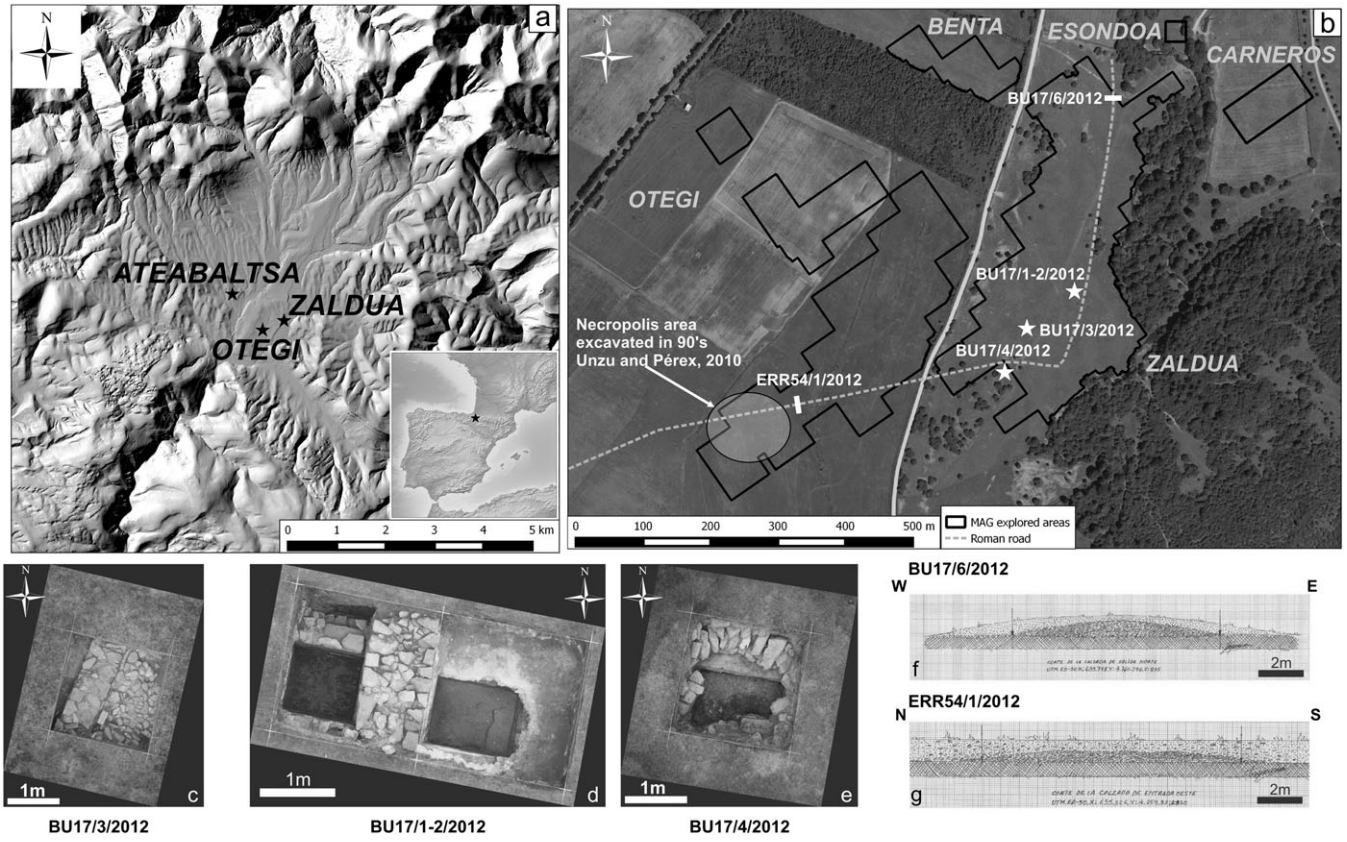

Figure 1. (a) Geographical location of evidence found on an elevation map created from the LiDAR data (5 m cell). (b) Location of archaeological trenches conducted in 2012 and the surveyed areas over the orthorectified aerial photograph in 2013. (c), (d) and (e) Orthorectified photograph of the results of the trenches BU17/1–2/2012, BU17/3/2012 and BU17/4/2012, respectively. (f) and (g) Sections of the Roman road at the trenches BU17/6/2012 and ERR54/1/2012, respectively. LiDAR data and aerial photography ceded by the © Instituto Geográfico Nacional de España.

DOI: 10.1002/arp

on a high plateau at an elevation of approximately 890 m, between the crestline and one of the valleys leading to the hinterland of the province (Figure 1a). The climate is temperate and characterized by abundant and well-distributed rainfall throughout the year. In the highest parts, snow can be persistent in winter. Vegetation is dense except on grasslands, and consists mainly of extensive beech and oak forests.

The settlement is positioned on the terraces of the Urrobi River, which flows north–south, bordering the terrace to the east. The steps of different terraces can be clearly distinguished and there is an additional slope descending to the east. There is no detailed geomorphological study of the Urrobi basin but it is known to be formed of Quaternary deposits of clay, silt, and gravel (geological map of Navarre http://geologia.navarra.es, Figure 2).

This region is particularly interesting from an archaeological point of view. Auritz/Burguete is one of the natural passes in the western part of the Pyrenees and has been used in all historical periods (Blot, 1978). The existence of Roman remains in the proximity of the site has been known since at least the early twentieth century. There is documented discussion (Altadill, 1922) of the prior existence of a Roman road, dismantled in 1878 for the purposes of reusing the material, and the possible location of the Roman *mansio* Iturissa to the north of Auritzberri/Espinal. This mansion is mentioned in classic bibliography

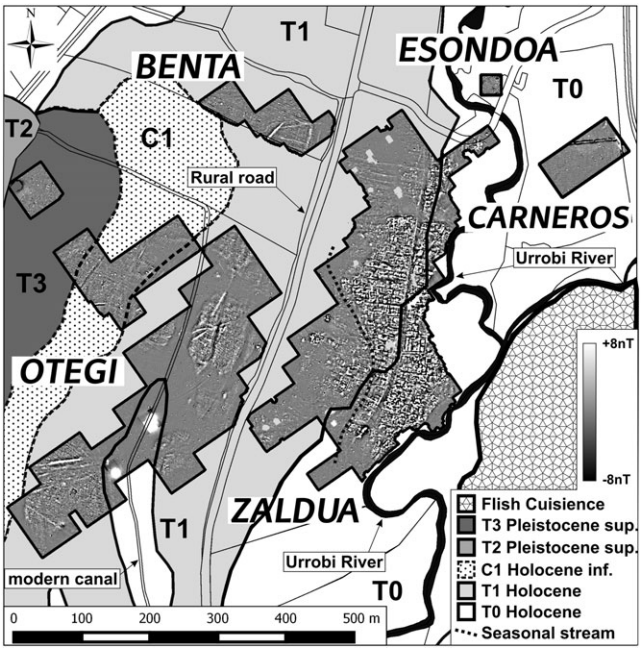

Figure 2. Magnetic response map in the overall explored area (-8nT black, +8nT white). The available geological information is displayed. Reproduced by permission of ARANZADI Society of Science.

(Ptolemy; Antonine Itinerary; Ravenna Cosmography) and its exact location has been extensively debated in the literature (e.g. Altadill, 1922; Peréx and Unzu, 1990; Canto, 1997). However, no hypothesis has been verified by indisputable archaeological findings.

In the 1980s, new evidence was discovered due to work by the restorer Juan Mari Mtz. Txoperena, who systematically collated information on materials that rose to the surface when the fields were ploughed. In 1985 he had noticed Roman pottery and metals at *Ateabaltsa* (Figure 1) and informed the local authorities. In three campaigns directed by M. J. Peréx and M. Unzu, a necropolis and a settlement in a poor state of conservation were partially excavated. Based on the materials found, the two occupations were dated to the first to the second centuries AD (Peréx and Unzu, 1997–1998).

A few years later, Txoperena observed more Roman pottery in Otegi (Figure 1), which is another field located 900 m from the first site. Excavation results showed a second necropolis with similar characteristics to the first, except for the presence of two mausoleums. A stone pavement was also located, but no interpretation of its function was made at that time (Unzu and Peréx, 2010). Owing to their contemporaneity, the two necropolises where attributed to the partially excavated settlement, which had been associated with Iturissa.

There had been no other intervention in this area until 2008, when the Aranzadi Science Society initiated a project to trace Roman roads. This research has centred on the route through the Pyrenees at Orreaga/Roncesvalles, and has produced new evidence that suggests some variation from the route known so far. During the course of the project, field investigations have detected many areas of archaeological interest, in particular a roadside settlement in the Zaldua area. In 2011 and 2012 a number of archaeological interventions were performed in these areas. The trenches excavated at Zaldua revealed substantial Roman masonry building foundations of unexpected significance and size (Agirre-Mauleon *et al.*, 2012; Figure 1c–1e). The location is next to the second necropolis excavated in the Otegi area, and the two are linked by the Roman road. Two trenches dug to verify the path of the suspected Roman road were also positive, one at Zaldua and the other at Otegi (Figure 1f and 1g).

At this point, the archaeological evidence suggested the existence of a large archaeological area with substantial masonry structures and several occupation levels, although the actual extent was unknown. In this context, geophysical intervention was proposed to delimit the affected area and characterize the site as far as possible.

DOI: 10.1002/arp

Data acquisition and explored areas

Data acquisition was performed by two independent teams using Bartington G-601-dual fluxgate gradiometers. Wooden stakes were placed at the nodes of a 60 m × 60 m mesh over the explored areas using a differential global positioning system (GPS). The data were acquired in 30 m × 30 m grids that were easily projected by the prospectors using the georeferenced stakes. Measurements were taken every 0.25 m along the traverses, 0.5 m apart, and reading in zigzag mode, using marked measurement tapes for positioning.

The areas for exploration were designated on the basis of the prior information compiled by the Aranzadi team. Results were checked on the end of each day to decide the new areas to be surveyed. The overall area explored was 18.9 ha (Table 1). It was divided into five areas to make the process and interpretation easier (Figures 1b and 2).

Zaldua corresponds to the area where trenches dug in 2012 showed Roman occupation, which was presumed to be the main area of the settlement. This area is known not to have been cultivated for centuries so any remains were expected to be well preserved. In this zone, an area of *c.* 8.65 ha was explored. The aim was to delimit the occupation and to describe as far as possible the distribution of archaeological remains. The site consists of grazing land covered in low grass and some scattered trees, bounded to the east by the Urrobi River and woodland and to the west by a rural road. The area is mainly flat except for the steep steps of various river terraces descending to the east. A seasonal stream and cow paths have caused visible erosion in some parts. In addition, local topographical variations attributed to archaeological remains are visible on the surface.

Table 1. Magnetic survey parameters.

Equipment	Bartington G-601 dual
Resolution	0.1 nT
Transept separation	0.5 m
Sample separation	0.25 m
Scan mode	Zigzag
Total area	189,048.56 m^2

The Otegi area is located on the eastern side of the rural road separating it from the Zaldua area (Figures 1b and 2). The Roman road was presumed to connect the two parts leading to the necropolis partially excavated in the 1990s in the southwest of the Otegi area. The lowest part is traversed by a modern water channel (Figure 2), and the area slopes gently towards it. In addition, linear topographical variations and some small elevations are visible in the field, and cropmarks are visible in aerial images, both attributed to possible archaeological remains. The goal was to check these irregularities and identify a precise location for the road connecting the Zaldua area with the excavated necropolis.

The Otegi area has been cultivated for years with frequent changes in field distributions as can be seen in historical aerial imagery. These works have affected the archaeological levels, as observed during excavation of the necropolis area (Unzu and Peréx, 2010). At the time of the data acquisition, the fields were being used for grazing and were covered in grass and low vegetation. An area of *c.* 8.46 ha was explored in three separate parts.

To verify possible continuation and check cropmarks visible in aerial photography, three minor areas were designated during the campaign. The Carneros and Benta areas are both located in agricultural fields that were not under cultivation at the time of data acquisition, but were covered in low vegetation. Carneros is a flat area, while Benta has a medium slope descending to the east. Esondoa is a small flat area next to the river, covered in grass (Table 2).

The data were processed using GEOPLOT 3.0 software following typical processing techniques (Aspinall *et al.*, 2008). Some minor areas affected by modern items such as fences or lamp posts were eliminated from the data. Before homogenizing the contrast using Zero Mean Traverse and Zero Mean Grid corrections, a despiking algorithm was applied to minimize the effect of surface metal items. Positioning problems due to the zigzag mode were corrected with destagger and the data were interpolated into a 0.25 m × 0.25 m pixel. The processed data were then georeferenced and incorporated into a QGIS project for interpretation.

Table 2. Characteristics of explored areas.

Area name	Area	Surface	Objectives
Zaldua	86,570.19 m^2	Pasture. Flat with terraced steps	Delimit and describe occupation
Otegi	84,611.81 m^2	Pasture. Sloped.	Discriminate occupation areas
Benta	9701.25 m^2	Low vegetation. Sloped.	Verify occupation.
Carneros	8155.31 m^2	Low vegetation. Flat.	Verify occupation
Esondoa	900 m^2	Pasture. Flat	Verify occupation
Total	189,938.56 m^2		

DOI: 10.1002/arp

Results and interpretation

The results show very different magnetic responses depending on the area (Figure 2). It is clear that the main occupation, as expected, is located within the Zaldua area. Here, the linear negative magnetic anomalies forming rectilinear pattern have been interpreted as walls. This attribution is supported by the comparison with the excavated trenches as shown in the enlarged area in Figure 3. In the Otegi area, the evidence of anomalies of archaeological origin is ambiguous, and the data appears to be affected by modern interventions. The continuation of some linear anomalies detected in Otegi can be traced in the Benta area, situated to the north. In the Carneros and Esondoa areas, the data shows no evidence of archaeological remains.

Zaldua area

In the central part of Zaldua a densely-occupied area of *c.* 4.5 ha is observed. The evidence of boundaries is ambiguous; at the western and southern limits the density of anomalies falls notably and they fade in strength, but no clear limit is detected. The east side is bounded by the river and a forest. Because the anomalies appear to continue outside the explored area, no evidence of any eastern limit has been detected. Moreover, data show areas where river flooding appears to have affected the archaeological remains, indicating that the river is an element of risk for site conservation. The only clear interruption of anomalies is detected in the northern section, where the main area is bounded by a negatively contrasted linear anomaly (Figures 3 and 4, number 1). It is interrupted by the route of the road, which widens slightly at this point. Based on this evidence, it might be conjectured that a gate to the city was situated at this point. However, this boundary does not show as an intense anomaly as might be expected for a massive stone city wall. Hence, any definitive interpretation is impossible without the support of excavation evidence.

The road is detected as a linear magnetically quiet zone which is easily identifiable when is surrounded by other anomalies, but difficult to discern in other areas. Two possible ditches showing up as positively-magnetized linear anomalies have been detected on either side of the road, but the anomaly is only continuous on the western side. A similar anomaly crosses the road next to the northern boundary of the main area (Figures 3 and 4, number 2) and may correspond to a drainage ditch or to a pipe.

Inside the densely occupied area, the urban grid is not reticular in pattern but structured in relation to the road traversing the settlement. Indeed, this is the only clear street shown in the magnetic survey. Possible secondary pathways are identified as positively contrasted linear anomalies or as linear areas without other anomalies (Figures 3 and 4, number 3). They are not easily identified due to their narrowness and the superimposition of anomalies, and sometimes only the intersection with the main road has been interpreted. Based on this partial information, it seems that they are principally perpendicular to the main road and arranged at irregular intervals. On this basis, the buildings are also arranged perpendicularly to the main road leading to an urbanization not organized in regular *insulae*.

Because the path is not straight, polygonal areas are generated between different building units. Some of them show a magnetic response that is quite distinct from the surrounding areas (Figures 3 and 4, number 4), showing up as areas without evidence of masonry structures. These were perhaps used as open spaces, or at least occupied by structures made of perishable materials, rather than stone.

Besides the irregular urbanization, different kinds of buildings are clearly distinguishable in the data. In some areas, there is clear evidence of masonry structures but no clear building plans can be discerned. This is the case in the southeast part of the main occupied area, where the intense magnetic anomalies might indicate industrial activity (Figures 3 and 4, number 5). In other cases, the magnetic survey revealed some high-status buildings with a typical Roman floor plan, such as some buildings on the main road (Figures 3 and 4, number 6). On the western side, the anomalies are arranged consistently in long strips suggesting construction units (Figures 3 and 4, number 7).

Some of the rooms show a high positive magnetic contrast that might be explained by the existence of mortar floors (Neubauer and Eder-Hinterleitner, 1997), but also by an accumulation of magnetically-enhanced archaeological sediments. Indeed, processes related to human occupation influence the soil composition and increment the magnetic susceptibility (Aspinall *et al.*, 2008). A definitive interpretation is difficult without the support of other geophysical methods or excavation evidence.

It is striking that in general no clear boundary has been detected between the buildings and the road. It might be conjectured that the facades facing onto the road were porticoed, but the magnetic survey did not provide any evidence confirming this supposition.

Many combustion anomalies have been detected in the main area, but there is no evidence of a massive conflagration suggesting some violent action. Most such anomalies are inside the dwellings and are interpreted as hearths. However, some of them show a different

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Figure 3. Magnetic response of the Zaldua area (-8nT black, +8nT white). A comparison of the archaeological and geophysical results is shown in the enlarged area. The numbers indicate the location of the anomalies mentioned in the text. Reproduced by permission of ARANZADI Society of Science.

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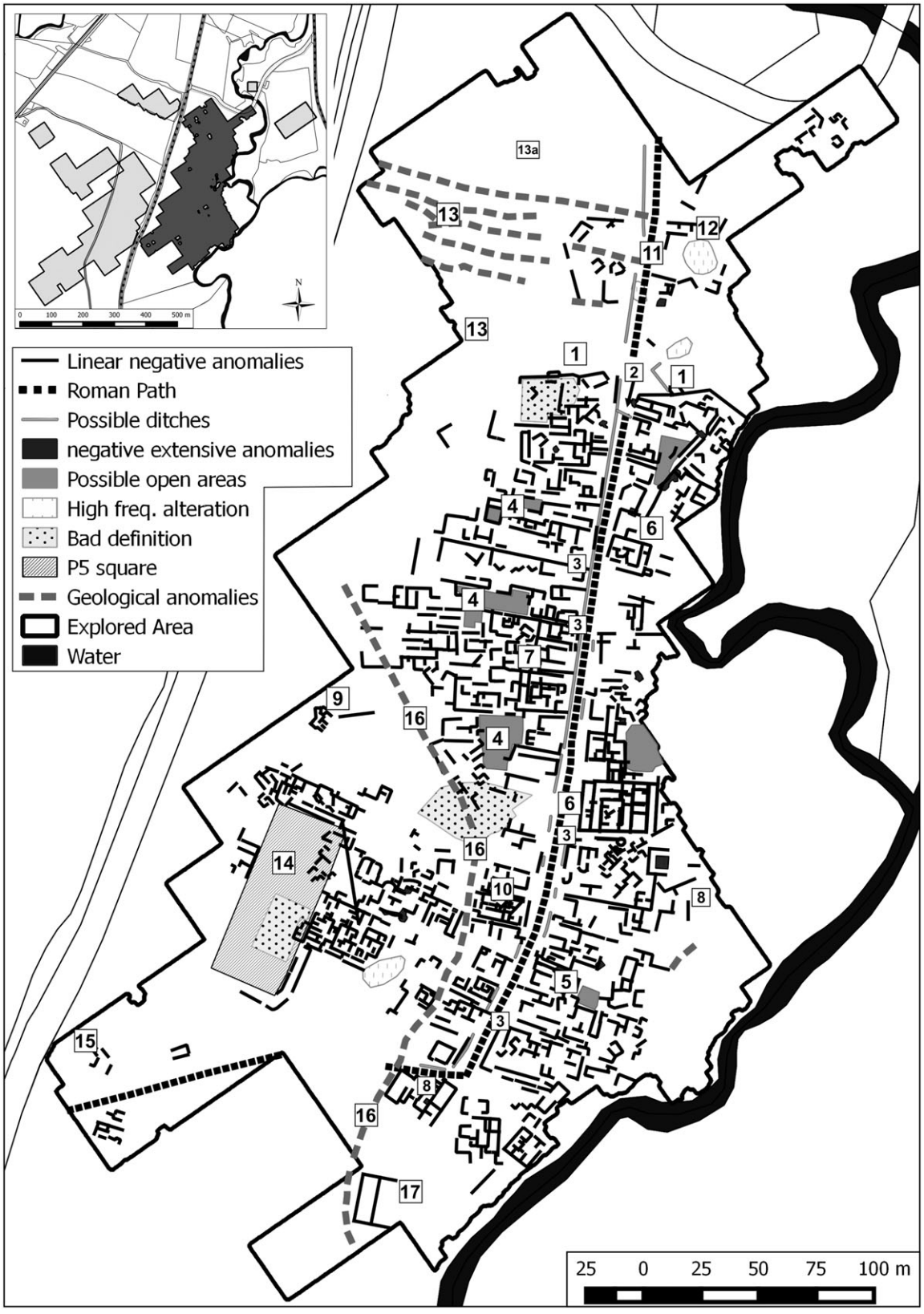

Figure 4. Archaeological interpretation of the Zaldua area. The numbers indicate the location of the anomalies mentioned in the text. Reproduced by permission of ARANZADI Society of Science.

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pattern and have been interpreted as kilns (Figures 3 and 4, number 8) or burnt areas (Figures 3 and 4, number 9). Some buildings show a singular magnetic signature that might perhaps be related to a specific use (Figures 3 and 4, number 10).

To the north of the main area, a fringe of 13 to 15 m with no relevant magnetic anomalies separates the possible city boundary from another area with clear evidence of occupation (Figures 3 and 4, number 11). It is important to note that the lack of anomalies does not necessarily mean a lack of remains. Indeed, the road does not register any magnetic anomaly in this strip although it is visible in aerial photographs. It has been pointed out that this area may have been seasonally waterlogged in the past, and this may have caused a difference in soil properties in this strip (Le Borgne, 1955; Weston, 2004). More research will be required before any definitive explanation can be given.

This secondary area shows a distinct magnetic signature on both sides of the road. To the west, there is an evident magnetic alteration but no structure is clearly defined. There are some linear, negatively magnetized anomalies, preliminarily attributed to masonry remains, although no clear building plans can be discerned. Slight positively-contrasted ditch-like anomalies were also detected and it might be conjectured that the ones in a west–east direction, at least, might be caused by the local geology.

In contrast, on the east side a more erratic magnetic signal is detected. The existence of masonry structures is evident but the combustion signatures are superimposed making proper definition of the building plans difficult. A circular area with high-frequency variations has been detected, which might indicate the accumulation of magnetic material such as tiles or slag (Figures 3 and 4, number 12). The separation from the main area and this magnetic behaviour might indicate that this area was used for an industrial activity. However, the prevailing winds in the region are from the north and northwest. Siting an industrial area to the north of the main settlement would therefore seem an unsuitable choice.

To the north-western part of the surveyed area, no relevant anomalies have been detected, except for linear and positively contrasted ditch-like anomalies, running mainly east–west (Figures 3 and 4, number 13). Because this is the main direction of the geological fractures in the area, observed in the river-bed strata, it can be conjectured that they were caused by stratigraphic differences and not by archaeological remains. They are positively contrasted in the north, and become denser and sometimes negatively contrasted to the south, opposite the main area. The background magnetic signal is exceptionally stable in the central part of this area (Figures 3, number 13a). As explained earlier, this might be related to soil differences due to the influence of moisture.

To the south of that area, a singular arrangement of anomalies has been detected that deserves special attention. Unlike the main area, the data show different groups of anomalies with subtle contrast but consistent orientation. Furthermore, they are arranged around a rectangle of about 78 m × 32 m (Figures 3 and 4, number 14; Figure 5, P5). This rectangle is situated on a topographic high-point and shows up as a comparatively quiet magnetic zone.

On the east side, it is bounded by a building complex and by two weak parallel linear anomalies that partially continue as a southern limit (Figure 5, B1). The linear anomalies are 4 m apart, and the gradiometer reveals

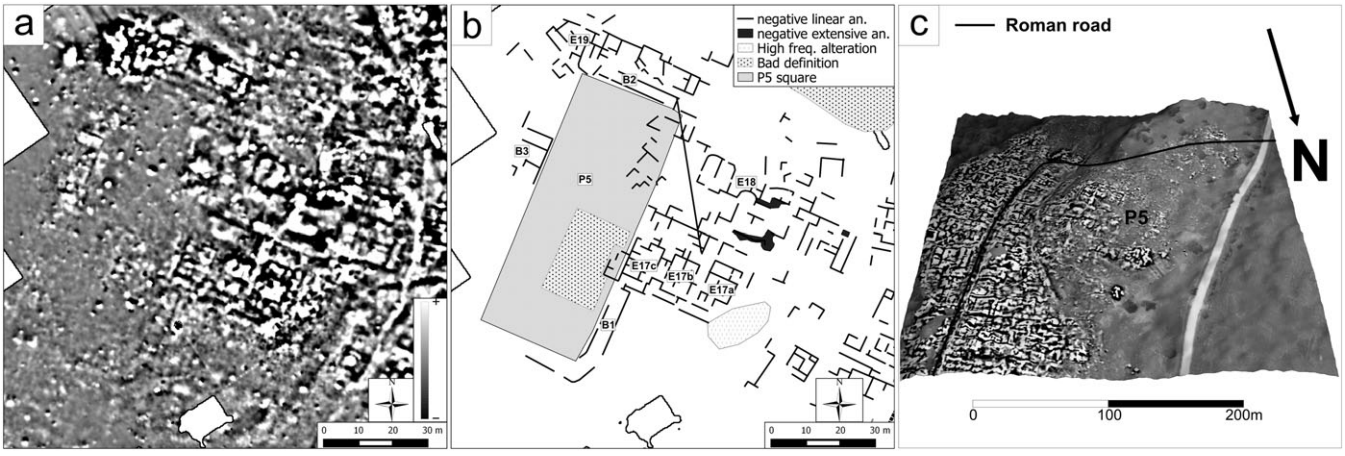

Figure 5. Detail of the P5 area. (a) Magnetic response (-3nT black, 3nT white). (b) Interpretation of the magnetic data. The numbers indicate the location of anomalies mentioned in the text. (c) Three-dimensional context of the P5 area. Reproduced by permission of ARANZADI Society of Science. LiDAR data ceded by the © Instituto Geográfico Nacional de España

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subtle evidence for internal subdivision, but not enough for a proper description. It is noteworthy that the corner between the eastern and southern boundaries is circular, as seen in many legionary camps (e.g. Fassbinder, 2010). The building complex is formed by three similar modules (Figure 5, E17a, E17b and E17c) and some adjacent spaces, showing high symmetry. Wall 103 excavated in Trench BU-17/3/2012 is the same as the western wall of E17a, showing that there is good correspondence between the geophysical data and the archaeological evidence (see the enlarged area in Figure 3). Immediately to the north there is an area with more contrasted and less-defined anomalies, with wide positively contrasted areas. One striking anomaly shows a circle-shaped northern boundary (Figure 5, E18), the only one of its kind in the area explored. Still further to the north, several combustion signatures were detected.

Coming back to the P5 rectangle, on the northern boundary two weak parallel negatively-contrasted linear anomalies have been detected (Figure 5, B2). Just to the north, further evidence for masonry structures is visible, although no clear building plans can be made out. The intense magnetic contrast detected on the western sector of that strip is interpreted as evidence of fire (Figure 5, E19). The western limit is not continuously defined but evidence of at least one masonry structure is visible in the data (Figure 5, B3).

These characteristics are singular in the explored area, where in general the orientation of the buildings is adapted to the path of the road. Furthermore, the area occupied by P5 is on a local elevation that provides a strategic position overlooking the road. Indeed, the expected trajectory shows an abrupt change surrounding this elevation from the mostly straight segment in the main area of Zaldua to the necropolis excavated in Otegi, although the reasons for this shape are not known (Figure 5). Based on this evidence, it is conjectured that this area had a specific function inside the settlement, the main hypothesis being that it may have been the public area of the town.

Due to scattered trees, a small area was available for survey in the south-western part of Zaldua. The reason for including it on the survey was that archaeological remains – walls and pavements – had been observed during installation of a water channel. It is visible in the data as a negatively contrasted linear anomaly (Figures 3 and 4, number 15). Contrary to expectations, weak magnetic anomalies were recorded, although the existence of some masonry structure is evident. Some of the parts surveyed were uneven during data acquisition. This resulted in some significant differences in the distance between the sensors and the ground, which may have affected the data. It is therefore considered advisable to repeat the data acquisition before making any more interpretations in this zone.

Analysis of aerial images revealed the existence of a building in the southern part of the surveyed area, which cannot be distinguished in the magnetic response (Figures 3 and 4, number 17). The existence of the walls was proven simply by removing the grass surface layer. These were confirmed to be of the same red sandstone that appears in the excavations in the main area. The lack of contrast should therefore be explained by differences in background magnetism or conservation, rather than the building material. This is a topographically lower area which is seasonally waterlogged, and this may cause differences in the mineral composition and fabric of the soil which could lead to a lower susceptibility of the background. Nevertheless, more research is needed to clarify the processes resulting in that lack of magnetic contrast.

Otegi and Benta areas

Linear topographical anomalies suggested occupation in the Otegi area. However, the results do not show clear archaeological evidence. Large areas have no relevant magnetic alteration. Other areas show background magnetic disturbance that has been preliminarily attributed to geological origins. These areas match the uncultivated areas in the historical records of aerial imagery. This is typical for areas where the bedrock is near the surface, because traditionally they were considered unsuitable for agricultural use. It may therefore be inferred that the difference in the magnetic response is caused by differences in soil thickness, but without further verification this inference must remain conjecture.

In addition, many of the anomalies detected have been identified as field boundaries (Figures 6 and 7, number 1) or plough marks (Figures 6 and 7, number 2). Erosion caused by water streams and linear anomalies attributed to geology are also visible (Figures 6 and 7, number 3). Plenty of anomalies identified as iron objects are also visible in the data, probably related to agricultural work.

The road shows no striking contrast but its route can be followed using the slight negative contrast detected in some stretches (Figures 6 and 7, number 4) combined with excavation information. Results suggest a junction with the tributary road continuing on to the Benta area (Figures 6 and 7, number 5) but this might not be contemporary. Indeed, a medieval road known as the 'Royal Road' crossed this area and might be the origin of this anomaly.

In the necropolis area excavations showed poorly conserved small urns (Unzu and Peréx, 2010). Therefore,

DOI: 10.1002/arp

Figure 6. Magnetic response in Otegi and Benta areas (-8nT black, +8nT white). The numbers indicate the location of anomalies mentioned in the text. Reproduced by permission of ARANZADI Society of Science.

individual burials were not expected to be detected. However, it was supposed that the extent of the affected area could be established using the magnetic alteration. On the contrary, anomalies of modern origin and, in particular, the variations in background magnetic disturbance were too significant and made delimitation difficult.

Nonetheless, some interesting anomalies were detected. A mausoleum excavated in the 1990s and still not covered is clearly visible in the data (Figures 6 and 7, number 6). In contrast, the second mausoleum excavated, which was not complete and had been covered over again, is not distinguishable. Instead, anomalies caused by metal objects are visible in this area, possibly as a consequence of the excavation work (Figures 6 and 7, number 7). Other possible unknown mausoleums are visible to the south of the road (Figures. 6 and 7, number 8). However, a similar quadrangular anomaly is visible in the western area excavated in the 1990s, where no mausoleum had been observed (Figures 6 and 7, number 10). The attribution is therefore uncertain and complementary geophysical survey or archaeological information would be necessary to confirm the origin of these anomalies.

One of the most intense anomalies was detected next to the road, showing up as a positively contrasted

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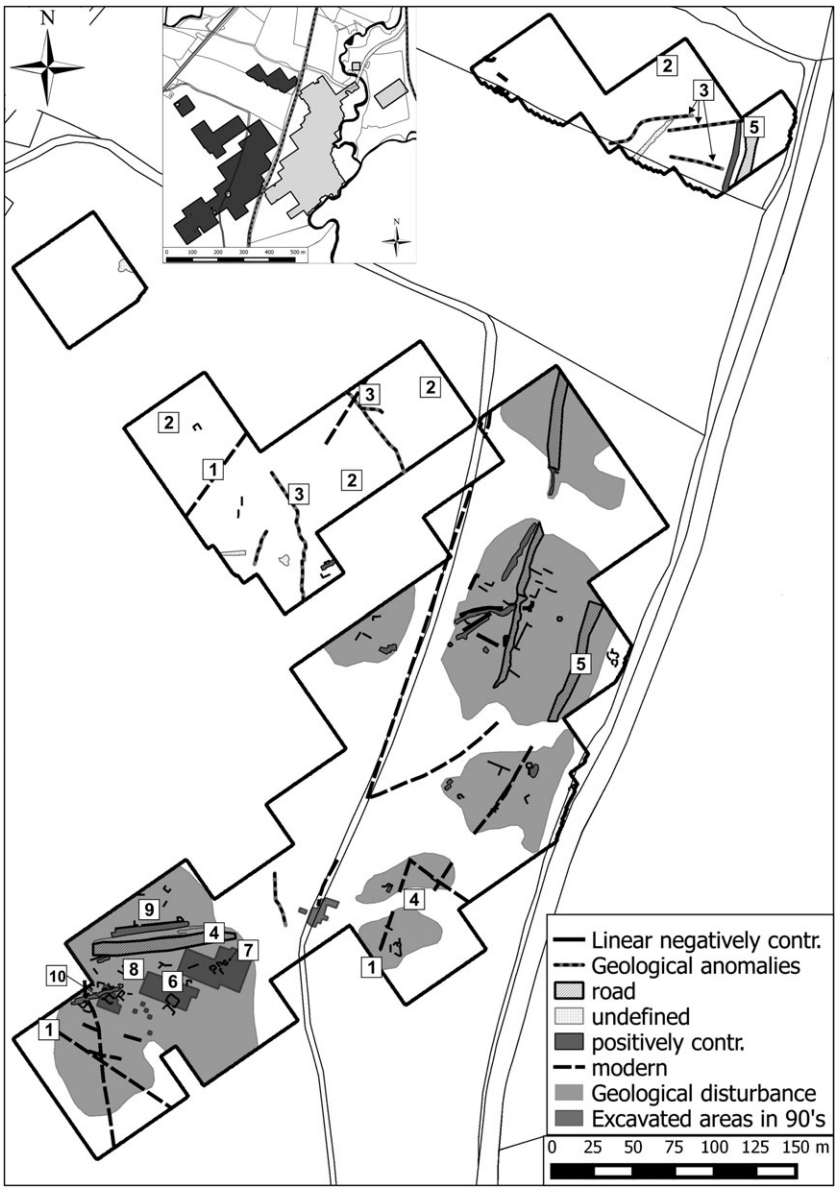

Figure 7. Interpretation of Otegi and Benta areas. The numbers indicate the location of anomalies mentioned in the text. Reproduced by permission of ARANZADI Society of Science.

linear anomaly (Figures 6 and 7, number 9). Because it runs parallel to the route of the road and is located next to it, this anomaly has been considered an interesting subject for further investigations.

Carneros and Esondoa areas

In those areas, the results do not reveal significant anomalies (Figure 8). Esondoa is characterized by an erratic magnetic response, attributed to combustion and iron objects. Later research indicated that this area had been used by the military as a camp. The anomalies detected are therefore attributed to modern fires and metal waste. The Carneros area mainly shows plough marks and metal interference. Thus, no evidence of archaeological impact was collected, although the absence of geophysical contrast does not necessarily imply an absence of archaeological remains.

Discussion and conclusion

The geophysical survey results have considerably improved knowledge of the newly-discovered Roman city. In particular, the map and extent of the main area

DOI: 10.1002/arp

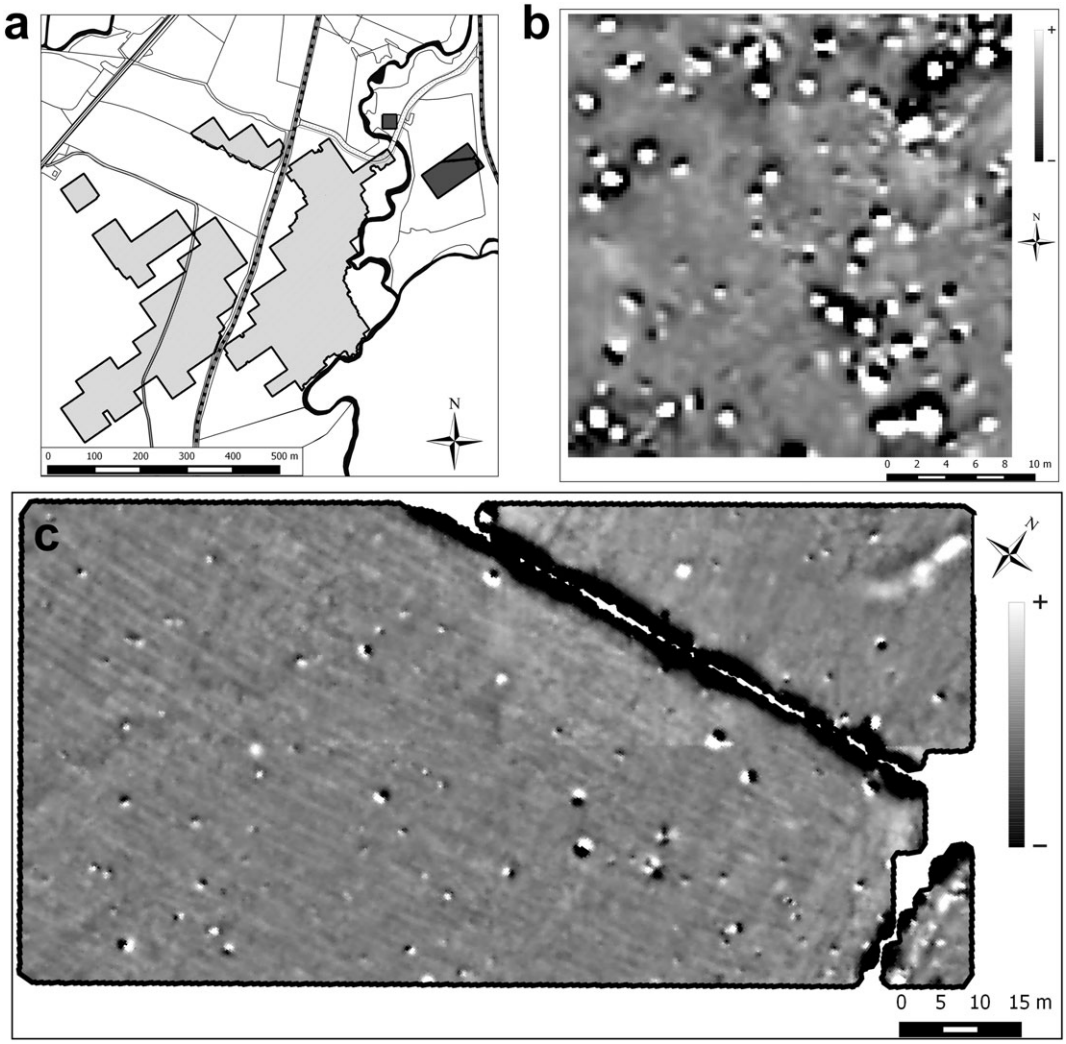

Figure 8. Magnetic response in Esondoa (b) and Carneros (c) areas (-8nT black, +8nT white). The location of those areas is illustrated in the image at top left (a). Reproduced by permission of ARANZADI Society of Science.

have been determined. The evidence for boundaries is, however, ambiguous and it was impossible to detect any clear limit, with the possible exception of the northern one. With nearly 18 ha surveyed, the results showed important differences in the magnetic response that made it difficult to delimit the affected area.

In some areas, the results appear to be affected by background differences. This is the case of the large anomalous areas in Otegi, where the magnetic disturbance has been preliminarily attributed to differences in soil properties or thickness. Intensive agricultural work has also affected the area, producing linear anomalies due to ploughing. In that erratic context, it has been difficult to determine the existence of archaeological remains. In particular, the extent of the necropolis area could not be established.

In addition, one known building in the south of Zaldua does not register a discernible magnetic contrast. This area is permanently waterlogged during winter. Previous researches have shown that waterlogging affects negatively the enhancement of magnetic susceptibility and, if persistent, can diminish it by leaching the iron oxides (Weston, 2004). This may explain the differences in the detected magnetic contrast. Similarly, the fringe that delimits the north of the main area might coincide with a seasonal stream in the past. The lack of relevant magnetic anomalies could be, therefore, related to differences in soil properties due to high moisture. Nevertheless, there is no evidence of archaeology in this fringe, therefore the lack of anomalies could also reflect a limit of the city.

In the south-western part of Zaldua results show poor evidence of archaeological occupation, whilst

DOI: 10.1002/arp

it had been proven otherwise during the installation of a water-pipe. However, this area is located in a high-point and waterlogging is unlikely to be produced. Instead, the differences might be explained by poor data quality combined with thin archaeological deposits.

These evidences suggest that other areas without magnetic contrast might host archaeological remains. It has therefore been shown that the magnetic survey cannot be used as the sole system for establishing the archaeologically affected area.

Despite these circumstances, the survey provides a firm basis for a preliminary archaeological assessment of the site. In particular, it has been possible to describe the arrangement of the buried remains in detail in the main area. Because walls have been well resolved, it can be conjectured that there is no great amounts of collapsed bricks or tiles. Based on the orientation of the buildings, it may be inferred that the road preceded them and acted as the axis around which the city grew. Identification of secondary streets, however, has proved more difficult. The partial information collected appears to suggest that they are perpendicular to the main road and not situated at regular intervals. This disposition mirrors the actual cities of Auritz/Burguete and Aurizberri/Espinal, also organized along the actual road and with narrow and irregular spaces between the houses. Some of the buildings show a high rate of magnetic contrast and it was possible to describe their interior layout, whereas in other areas the anomalies detected were not well defined enough for this purpose. Furthermore, some buildings show large floor plans. These differences could be related to the status of the inhabitants.

The intense magnetic contrast and shape allow some anomalies to be attributed to kilns or burnt areas. However, most of the combustion anomalies were detected inside the dwellings and are interpreted as hearths. The southeast part of the main area and the secondary area to the north show intense magnetic anomalies, but no area of industrial activity has been clearly identified from the magnetic survey.

Finally, the western area of Zaldua has been suggested to be a special area which might host some of the city's public buildings. Indeed, the coherent orientation is singular and leads to consider it as an archaeological unit. However, the weak magnetic contrast in this area renders definitive interpretation impossible without the support of other evidence. The difference in contrast compared to the main area has not yet been explained, and might correspond to differences in background magnetic susceptibility. Indeed, the archaeological evidence revealed a wall made of the same imported red sandstone as that used in other areas where the magnetic contrast is greater (Agirre-Mauleon *et al.*, 2012). However, the archaeological deposit found was thinner, which might also affect the magnetic contrast generated.

Based on the differences in the magnetic response, three kinds of areas have been established (Figure 9): (1) areas where archaeological features were well described, (2) areas with partial description of remains and (3) areas without relevant magnetic contrast but where the existence of remains has been proven by other sources. The first category comprises the main area of Zaldua. The secondary area located in the north and the possible public area in the west have been included in the second one. Finally, the third group encompasses the necropolis area and the minor areas of Zaldua with previous archaeological evidence. The road path has also been added to this category in the areas where it is not visible from the data. The areas outside of this classification correspond to magnetically stable areas and those where the anomalies have been attributed to geological or modern origins. These could also be affected by archaeological remains, but there is no evidence for this possibility.

The magnetic survey, therefore, has shown itself to be a suitable technique of investigation for obtaining a preliminary assessment of the archaeological characteristics of the settlement, but cannot be used to definitively assess the affected areas. Further research will be designed based on the magnetic data, allowing better management of the available resources.

Figure 9. Classification of the surveyed areas based on their magnetic response.

DOI: 10.1002/arp

Acknowledgements

This survey was made possible by the volunteer work of a great number of people from the Aranzadi Science Society. In particular, the authors would like to thank all those who contributed to data collection: Rafa Zubiria, Enrique Lekuona, Itsaso Kondearena, Gotzon Berjerandi, Joxe Etxegoien, Euken Alonso, Rafa Ballano, Isabel Olaortua, Eric Dupre and Cristian San Arroman. The authors would also like to thank those involved in the wider project to trace Roman roads, particularly Haizea Arrazola, Marta Berraondo, Ramón Ruiz Cabestany, Eneko Iriarte and Javier Puldain. The team from SOT Prospecció Arqueològica participated in the survey campaign and provided support with data analysis. The authors would especially like to thank Robert Tamba for his support during the project and for his helpful corrections of the text. Armin Schmidt made helpful comments on the text of this paper. Finally, the authors wish to thank the Arrobi Society, which owns part of the lands explored, for giving permission to conduct the geophysical survey.

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