URBAN LANDSCAPE SURVEY
IN ITALY AND THE MEDITERRANEAN

An offprint from

Urban Landscape Survey in Italy and the Mediterranean

Edited by

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In co-operation with
The British School at Rome
Academia Belgica
Koninklijk Nederlands Instituut Rome
Ghent University, Department of Archaeology
Universidade de Évora, CIDEHUS

Within the framework of
Programme 'People' – Marie Curie Action: 'Industry-Academia Partnerships and Pathways'
(FP7-PEOPLE-IAPP – 2008 – Grant Agreement n. 230679)
Project RADIO-PAST: Radiography of the past. Integrated non-destructive approaches to understand and valorise complex archaeological sites

ISBN 978-1-84217-486-9

www.oxboxbooks.com

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Ground Penetrating Radar Survey of Urban Sites in North Coastal Etruria: *Pisae, Portus Pisanus, Vada Volaterrana*

M. Pasquinucci, S. Ducci, S. Menchelli, A. Ribolini, A. Bianchi, M. Bini and S. Sartini

Introduction

The North Western Etruria Project is run by the University of Pisa, Dpt. Scienze Storiche del Mondo Antico, since 1982. It is an intensive 'total archaeology' research project (Darvill 2001; 36) with strong attention to 'climatic changes and impacts'.

All available sources and data provided by diagnostic techniques are critically examined, including geomorphology; palaeogeography; non-destructive techniques applied to landscape and settlement archaeology (remote sensing, geophysical surveys); archaeological researches (intensive surveys and monitoring of surveyed areas, stratigraphic excavations, underwater archaeology); archaeometric and archaeological studies of finds (metals and pottery wares); bioarchaeology; the study of ancient and medieval epigraphic, literary sources and toponyms, historical cartography.

The data are processed in a diachronic perspective from the late Bronze Age up to the early Medieval period, with main focus on the late Etruscan, Roman and Late Roman period. Participant institutions are the University of Pisa and the Soprintendenza per i Beni Archeologici della Toscana (Florence); scientific collaboration is provided by DipTeRis (Genoa), CNR-ISTI (Pisa) and CEREGE (Aix-en-Provence). The Project has been supported by European Programmes (HCM, INTERREG, MEDOCC), by the Ministero dell' Istruzione Università e Ricerca Scientifica, local and regional authorities, banks (in particular Fondazione Cassa di Risparmi di Livorno) and local firms. The palaeogeographic, archaeological and geophysical researches are overseen by several senior academic staff, plus many younger students.

In this paper we present the multidisciplinary results of three GPR surveys, respectively in the northern suburb of ancient Pisa (*Pisae*) and in two coastal settlements: *Portus Pisanus* (Livorno), the main Pisa ancient port, and *Vada Volaterrana* (Vada, Livorno)**,** the main Volterra harbour in Etruscan and Roman times.

State of the art

In the Etruscan period Pisa (*Pisae*) and Volterra (*Velathri*, *Volaterrae*) were the main cities in north-western Etruria. Their territories included a coastal strip (respectively from the Magra to the Fine and from the Fine to the Bolgheri rivers mouths) and large hinterlands (Figure 15.1). Along the coast were ports and landing places, in the hinterland minor settlements, workshop centres, and *villae*.

Volterra was conquered by the Romans in the first half of the third century BC and Pisa became *civitas foederata* in the mid-third century BC; in the second century BC it was a Roman military base during the wars against the *Ligures* and in 180 BC it granted part of its northern territory for the creation of the Latin colony *Luca* (Lucca). In 177 BC, when the *Ligures* were defeated in northwest Tuscany, the Roman colony *Luna* (Luni) was founded (Ciampoltrini 2004). Between 42 (*Philippi* battle) and 31 BC (*Actium* battle) or after *Actium* the cities and most plains in North Etruria were remodelled by veteran colonization (Ciampoltrini 1981).

In northwestern Etruria the Triumviral-Augustan colonization marked a notable economic growth both in farming, manufacturing and trade (Pasquinucci and Menchelli 2010) and had a strong impact on the cities and their territories. The landscape kept substantially steady in most areas till the mid sixth century (Cherubini *et al.* 2006).

Pisae

Recently the toponym (Greek: *Pisa/Pisai/Peisa/Peisai*; Latin: *Pisae*) has been interpreted as Indoeuropean, meaning a site rich in water, both stagnant and fluent (Dini 1994). In the late seventh–early sixth century BC the Etruscan town emerged based on a few settlements on low mounds separated by major and minor streams, in the area where the river *Auser* (an ancient branch of the Serchio) flowed into the Arno (Strab. 5.2.5; Plin. *N.H.*, 3.50; Rut. Nam.

1.566; Schol. Ptol. 3.1.4.), on the right bank of the latter (Pasquinucci 2003). The site was an important crossroad, where the North Tyrrhenian coastal itineraries intersected the road system following the Arno and Serchio valleys. The rivers were a natural defence, a resource and a risk**:** recurrent floods are archaeologically documented both in the ancient town area and in the territory.

The layout of the archaeological finds and the identification of necropoleis prove that the Etruscan settlement was scattered on several low mounds formed by previously deposited fluvial sediments and separated by river branches and streams. Most streams progressively silted up after the fourth–third century BC. Relevant evidence of the Etruscan and Roman town is provided by archaeological excavations in the city centre (via S. Apollonia; piazza Duomo; piazza Dante: Pasquinucci 2003). Around 480 BC a flood damaged large part of the town area (Bruni 1998: 137, 198: evidence in piazza Duomo, piazza Dante).

In the last decades of the first century BC the colonia *Opsequens Iulia Pisana* was founded. Intense town planning and building activities affected the town area; a vast *centuriatio* was constructed in the plain. The colony's imposition had a dramatic impact on the social and the economic structures.

Evidence of the late-Republican to late antique suburban landscape is provided by a few shipwrecks sunk in the *Auser* by floods, one of which is dated around AD 10 (Camilli 2005). The wrecks are dated from the second half of the second century BC to the late sixth–early seventh AD.
In Roman times the North suburb was dotted with *villae*, pottery workshops and necropoleis (Pasquinucci, Menchelli 2008).

Portus Pisanus

Pisa lay 20 *stadia* from the coast according to Strabo (5.2.5) and his sources (therefore in the late republican–early imperial period). The distance increased progressively because of the North Etruscan coast progradation, interpreted as a consequence of the colonization impact on the hinterland and possibly of a phase characterized by intense rainfall (Pasquinucci 2007; Pasquinucci and Menchelli 2009).

The town and its territory had a well integrated system of sea and river ports and landing places. The main port was situated north-northeast of present Livorno, as documented by literary and archaeological sources. It was protected by offshore shoals in the offing and by the Livorno shallow rocky promontory. The harbour was active since the archaic period; after the second–first century BC its location shifted progressively westwards due to coastline shift. In the early fifth century AD it was described as rich and safe by the poet Rutilius Namatianus (*de reditu*, 530 ff.). It was named *Portus Pisanus* at least since Late Antiquity (*Itinerarium Maritimum*: 501) and in the Middle Ages.

In the area notable Roman buildings were described by Targioni Tozzetti in the mid-eighteenth century; a large late Roman necropolis was excavated in the late nineteenth century (Targioni Tozzetti 1768; Pasquinucci and Menchelli 2010). Recent excavations have brought to light evidence of the port settlement and stretches of the adjacent seabed (Ducci, Pasquinucci and Genovesi 2007). Palaeogeographic and archaeological research proves that this stretch of shallow water could be navigated by appropriate crafts in order to load and unload cargoes at least since the late seventh–early sixth century BC (Stefaniuk *et al.* 2007). In the fourth–third century BC stone blocks and posts were set up either to reinforce the shoreline or to provide a dock (Pasquinucci and Menchelli 2010).

The area was progressively and rapidly silted up by alternate sand and *posidonia* layers from the mid-second century BC; in the late first century BC the port activities were therefore shifted westwards. *Portus Pisanus*, together with *Luna* and *Vada Volaterrana*, the main North Etrurian harbours, appears to have been strictly linked to the Mediterranean trading routes up to Late Antiquity.

Vada Volaterrana

Vada Volaterrana, main harbour of *Volaterrae* in Etruscan and Roman times, was located north of the ancient Cecina river mouth, along the coastal road (via Aurelia since the third century BC), 25 *milia* from Populonia and 18 from *Portus Pisanus* (*Itinerarium Maritimum* 1,501) (Menchelli and Pasquinucci 2006). Part of the ancient town lies under present Vada, which keeps the ancient toponym. On the grounds of geomorphologic and archaeological data, the harbour was located in the sheet of water in front of the town. It was protected by a large shoal system; its access was described by the poet *Rutilius Namatianus* (1, 453 ff.) in the early fifth century AD. Immediately north east of this area, in the San Gaetano di Vada site, since 1982 we have been carrying out stratigraphic excavations which brought to light a Roman quarter evidently related to the harbour.

Huts dated to the ninth century BC were identified under the Roman settlement, on the coastal dunes; they were abandoned because of a brackish water flooding documented by malacofauna. Two *thermae* (Figure 15.2, A and D), an *horreum* (B), an *aula* (C), a fountain (E), a *schola* (F), a triconch building (G) and a large complex (H) with tanks and a drying-kiln have been excavated so far.

This Roman quarter was built in a unitary project starting from the early decades of the first century AD; its activities continued up to Late Antiquity. The buildings underwent systematic renovations and functional changes in the middle Imperial Age. A crisis is documented by a necropolis partly covering the *horreum* (B) and the bath (D) in the late third–fourth century AD, as confirmed by

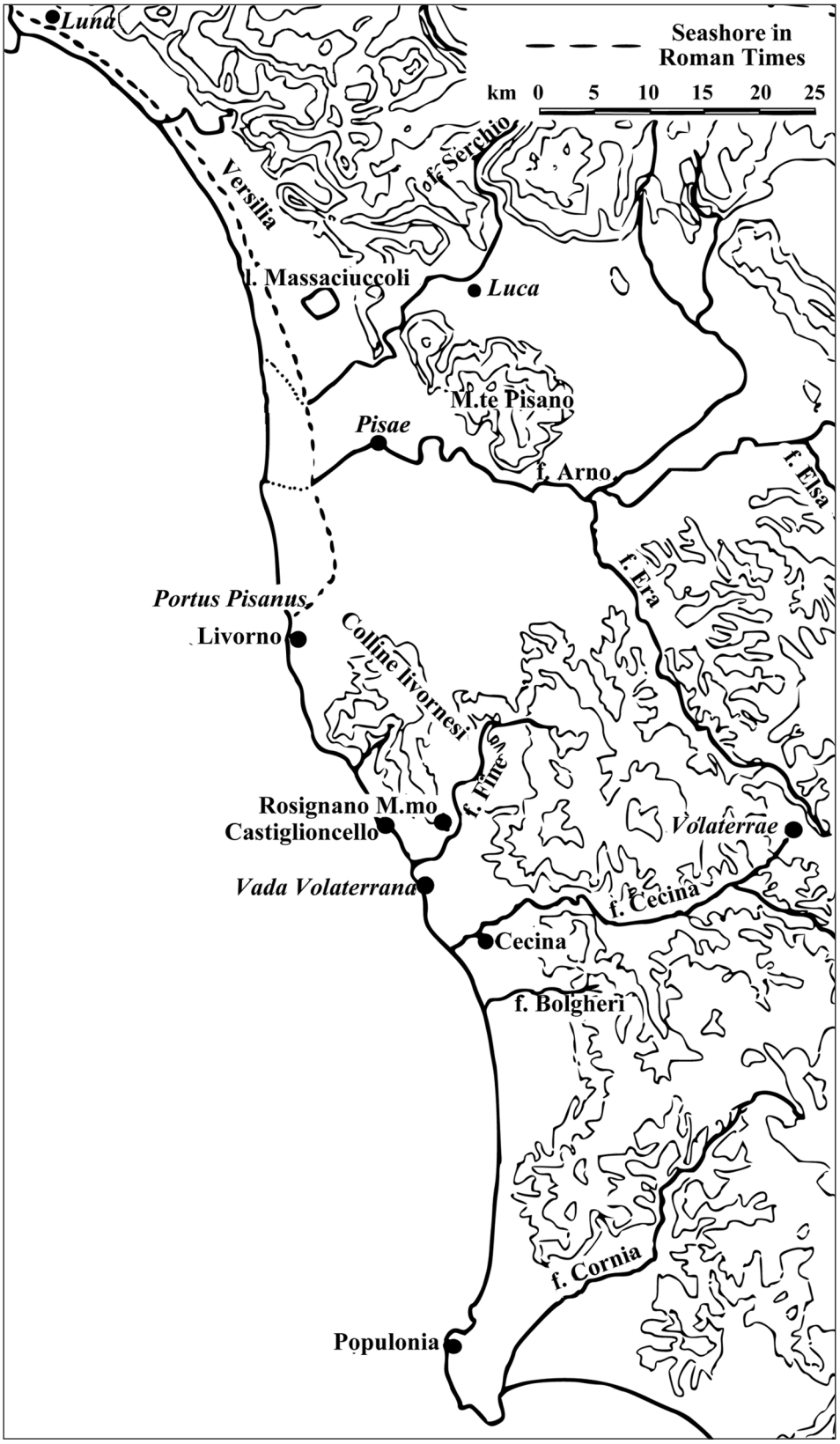

Figure 15.1 North coastal Etruria.

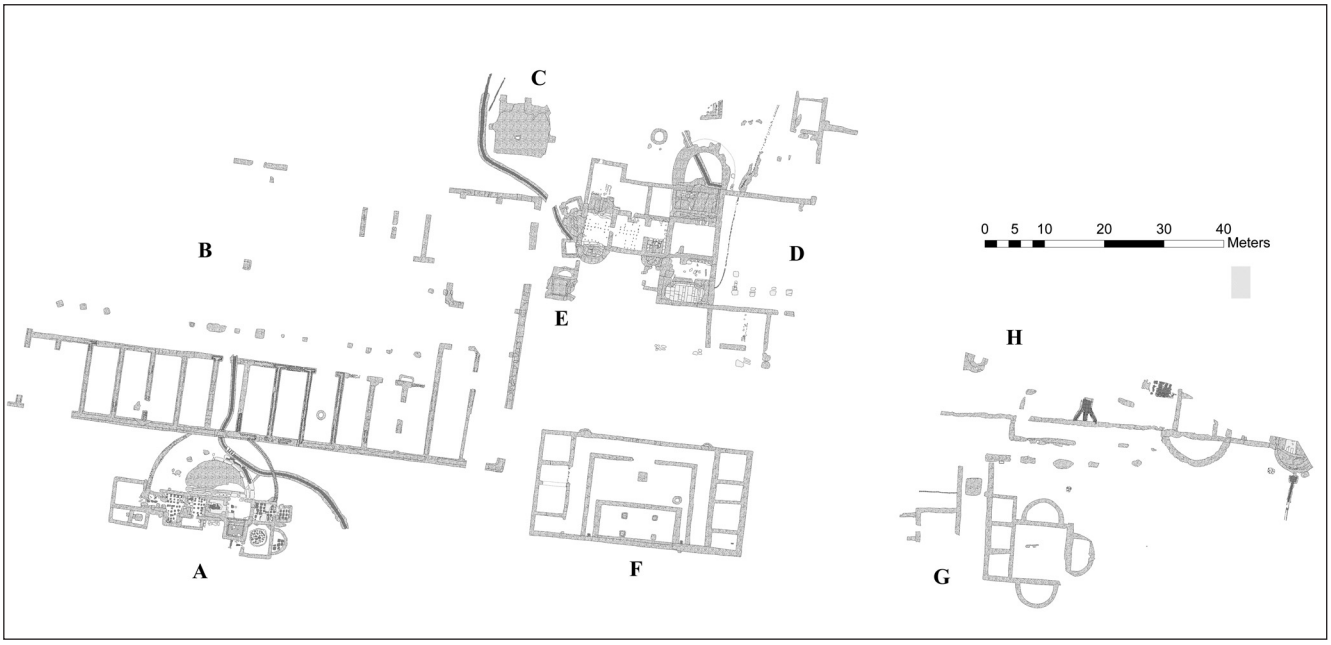

Figure 15.2 Vada Volaterrana. *Archaeological area in S.Gaetano di Vada (Rosignano M.mo, Livorno).*

the calibrated C14 dating of one of the skeletons (AD 267–377: analysis by ANSTO, Physics Division, Menai, Australia). Afterwards, the buildings were restored and intense import-export activities are documented up to the early seventh century AD.

From the archaeological data we can identify a close economic relationships among *Vada Volaterrana, Volaterrae* and their hinterland, which was rich thanks to agricultural, breeding, manufacturing and commercial activities and to many natural resources (copper; alabaster; sea- and rock-salt; timber) (Menchelli and Pasquinucci 2006).

Methodology

Ground Penetrating Radar (GPR) is a fast and cost-effective electromagnetic (EM) method providing relevant information on the shallow subsurface. Since it is based on the emission and reflection of EM waves, it is sensitive to variations of the EM parameters in the subsoil, especially the dielectric constant and the electric conductivity (Davis and Annan 1989; Smith and Jol 1995; Annan 2009). The lower the frequency of EM waves propagating into the subsurface, the greater their penetration depth. The capability to resolve targets vertically (vertical resolution) increases with the antenna frequency up to centimetre values, while lateral resolution depends on the geometry of acquisition (step size, i.e. the distance between each point where a measurement is made along a GPR profile) and can reach sub-centimetric resolution.

Moreover, further significant advantages are reached adopting a grid of radar profiles, allowing a 3D visualization of the subsurface, and facilitating the interpretation of geometric structures such as archaeological remains (Malagodi *et al.* 1996; Nuzzo *et al.* 2002). The area of grid cell must be dimensioned to properly resolve the dimensions of the targets in the subsurface. Eventually, 'time-slice' (or depth-slice) maps can be used to display the plan pattern of radar data at variable depths (Goodman *et al.* 1995).

Hence, the expected results generally drive the compromise between investigation depth and antenna frequency, as well as the acquisition geometry, i.e. step size and grid dimension.

Finally, GPR high resolution (lateral and vertical) and the modern techniques of data visualization (2D and 3D) make this method widely employed in archaeological investigations (Basile *et al.* 2000; Leckebush 2003; Grasmueck *et al.* 2004; Leucci 2006; Orlando 2007; Soldovieri and Orlando 2009).

In this study, the GPR survey has been performed using the Radar System device of IDS Company © (www.ids-spa.it), equipped with antennas of 200 MHz and 400 MHz of nominal peak frequency and HH polarized. The data were acquired in continuous mode, controlling the step size by means of an odometer wheel. In vertical direction, the subsurface was explored for 128 ns (range) adopting 512 samples per scan, while horizontally the radar source was triggered every 2.4cm.

A 0.5m grid cell was used to cover each of the surveyed areas. In some cases, the presence of obstacles on the surface limited the acquisition.

The raw data were processed adopting a standard sequence as follows:

- time-zero correction shifting the first arrivals by a constant;
- running average filter in order to filter the DC component (Dewow filter);
- linear and smoothed gain with window-length of 71 ns (5m depth);
- subtracting the mean trace in order to filter out the continuous flat reflections caused by the breakthrough between the shielded antennas and by multiple reflections between the antenna and the ground surface (Daniels 2004);
- vertical band-pass filter;
- determination of EM wave velocity for depth conversion using the method of hyperbolic shape of a reflection from a point source (diffraction hyperbola).

After the above sequence of processing and analysing 'time slices' at various depths, the areas of high back-scattered energy corresponding to reflections of EM waves (anomalies in the following) were archaeologically interpreted.

Results

Pisa, area Via Galluppi

The studied site is located a few hundred metres north of the medieval city walls (Figure 15.3); this segment of fortifications most probably coincided with the Roman ones.

The area belonged to the northern *Suburbium* of *Pisae*, at present almost completely urbanized. In recent years a series of random finds have been made there, and rescue and preventive excavations were carried out (Pasquinucci and Menchelli 2008).

In the Augustan period this district specialized in the production of *terra sigillata*: kiln wastes were found in via Santo Stefano, near via Galluppi. From here late Italian *terra sigillata* workshops were spread over a large part of the northern *ager Pisanus*. The medieval sources provide useful data to locate in this area both the course of the river *Auser*/*Oseris* and the bridge built across it near via S. Stefano (Garzella 1990: 57). Most probably in Roman times the topographic layout was very similar to the Medieval one, since the *sigillata* workshops identified in via S. Stefano

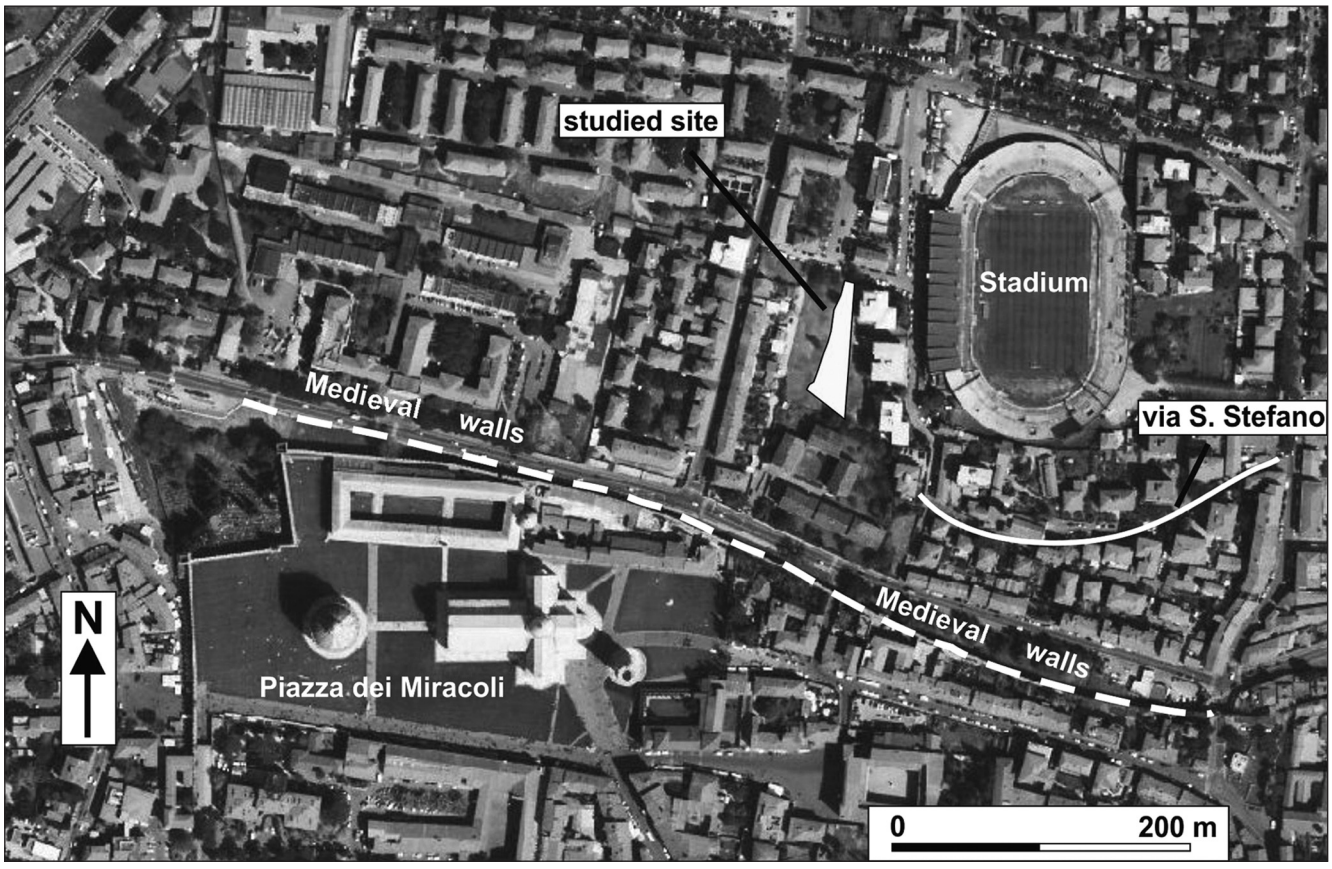

Figure 15.3 Pisa. An aerial view of the Pisae *North suburbium.*

used *Auser* clays, as shown by chemical and minero-petrographic analyses (Menchelli *et al.* 2001).

The GPR survey was undertaken subdividing the area in three irregularly shaped adjacent sectors (Figure 15.4). An acquisition network of 0.5m grid cell was adopted in each sector. The central sector (sector 1, Figure 15.4, A and B) shows areas of high backscattered electromagnetic energy, drawing slightly continuous geometrical elements locally consistent with the existence of subsurface structures at various depths. In detail, from the perimeter of the archaeological excavation an evident anomaly extends perpendicularly to the centre of the sector. Other reflections evident up to 100cm depth are visible in the southern part of the sector.

In the centre of sector 3, reflective areas were detected from 40–110cm depth drawing a north–south orientated plurimetric element, up to 30–40cm wide (Figure 15.4, C and D). Other minor reflective areas are visible at various depths, oriented both perpendicularly and in parallel to the geometrical element previously mentioned. In the northwestern corner of sector 3 the pattern of radar anomalies at 110cm depth seems to enclose spaces without reflections.

In sector 2 (Figure 15.4, E and F) a highly reflective area was detected at 30cm depth; in spite of the irregular limits, it assumes a sub-rectangular shape. Increasing the depth (70–80cm), it is evident that this area is bordered by a wide northwest–southeast anomaly, crossing the whole sector. The width of this continuous and high back-scattered energy area is about 200cm up to 110cm depth.

The excavations in progress in the site identified part of a Roman building (most probably a suburban *villa*) and a necropolis located southeast of it. The GPR results are consistent with this interpretation, showing elements interpretable as huge walls (at least 50–60cm wide) shaping regular rooms. In sector 2, the linear evidence can be interpreted as a street, continuing beyond the excavation area toward north east. Moreover, the round shaped reflective area in sector 3 can be referred to a kiln waste

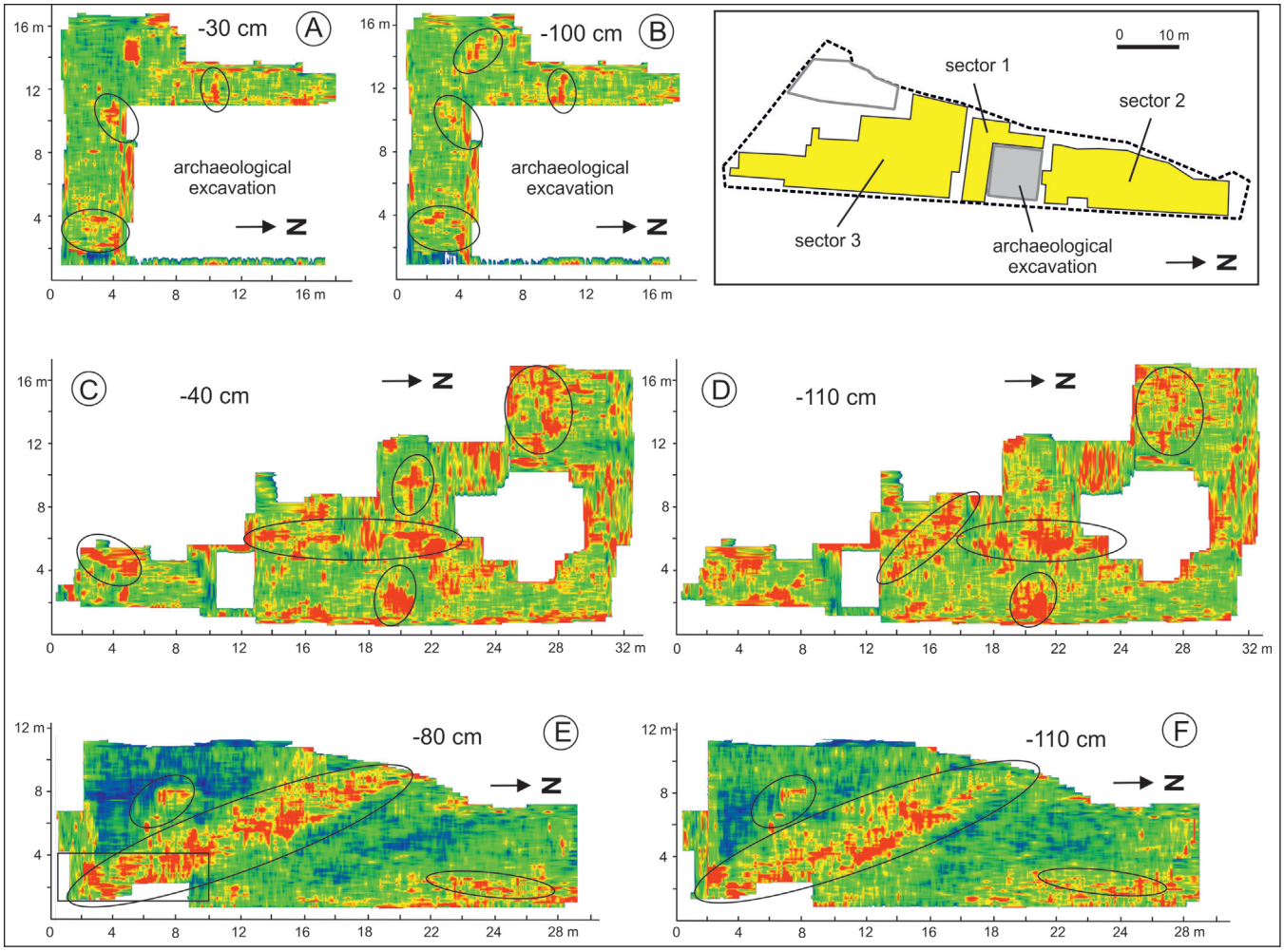

Figure 15.4 Pisa. Galluppi street. Time slices at various depths of the studied site.

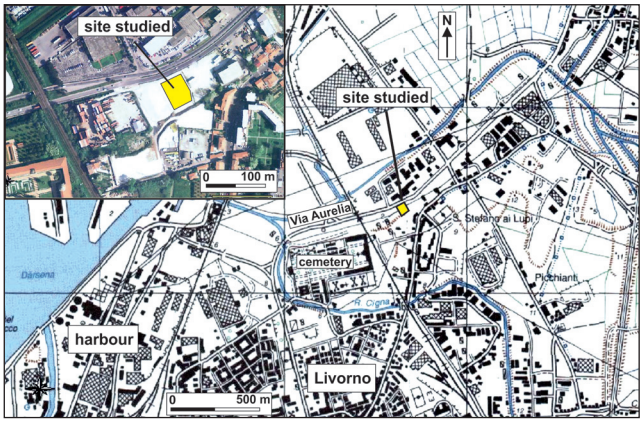

Figure 15.5 Portus Pisanus. *(Livorno). Map and aerial view (in the inlet) localizing the studied site.*

dump, in agreement with the acquired knowledge of the area (Pasquinucci and Menchelli 2008) and with the results of the excavations. Actually, during the excavations some mis-fired vessels were found, stamped by the Late-Italian potter L.S.M, who is well documented in the Santo Stefano kiln waste. Excavations have been scheduled for the future when we hope this interpretation will be verified.

Portus Pisanus

The survey was undertaken in the north-eastern periphery of Livorno, in the area of *Portus Pisanus* (Figure 15.5).

A sector of about 2000m^2 was prospected adopting a regular 0.5m grid cell network of acquisition. Differently from the previous cases, the radar system was acquired using contemporaneously a 200 MHz and 400 MHz antenna. The data elaboration corresponds to the processing of the two acquisitions.

Starting from 90–100cm depth in the eastern part of the surveyed area, several reflections are consistent with geometrical elements of variable shape and dimensions (Figure 15.6A). The reflections pattern is coherent with the regular shape of close polygons developing with a northeast–southwest trend (Figure 15.6B). The dimensions of the most evident polygons vary from about 15 to about 30m^2. The reflections preserve the characteristics of spatial continuity and coherency up to 130 cm depth (maximum depth of investigation).

GPR data show several linear elements variously oriented that can be interpreted as wide walls shaping a sequence of rooms. Other minor evidences seem not to be connected with the main building. According to the excavations carried out in the surveyed area, it was a commercial building (most probably a *horreum*) articulated in a central courtyard lined by a portico faced by quadrangular rooms. It is dated to the first century BC–sixth century AD and was constructed on a previous building (third–second century BC) (Pasquinucci and Menchelli 2010).

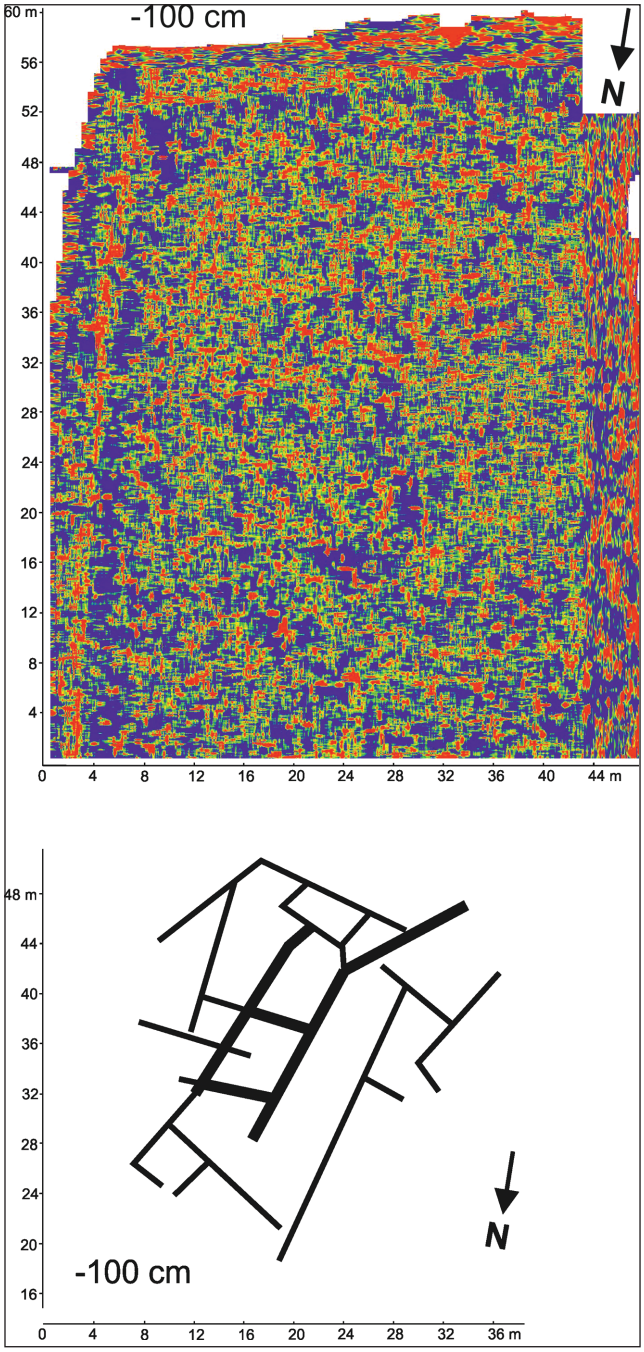

Figure 15.6 Portus Pisanus. *(Livorno). Time slice at 100 cm depth in the site. A) drawing of the main reflective areas discussed in the text; B) black geometrical elements are interpreted as walls.*

Vada Volaterrana (Vada)

The survey was undertaken immediately SE of the San Gaetano excavated area to test the potential prosecution of the archaeological finds toward the city of Vada (Figure 15.7A and B).

The time-slice at 110cm depth (Figure 15.8A) clearly shows the existence of geometrical elements whose general

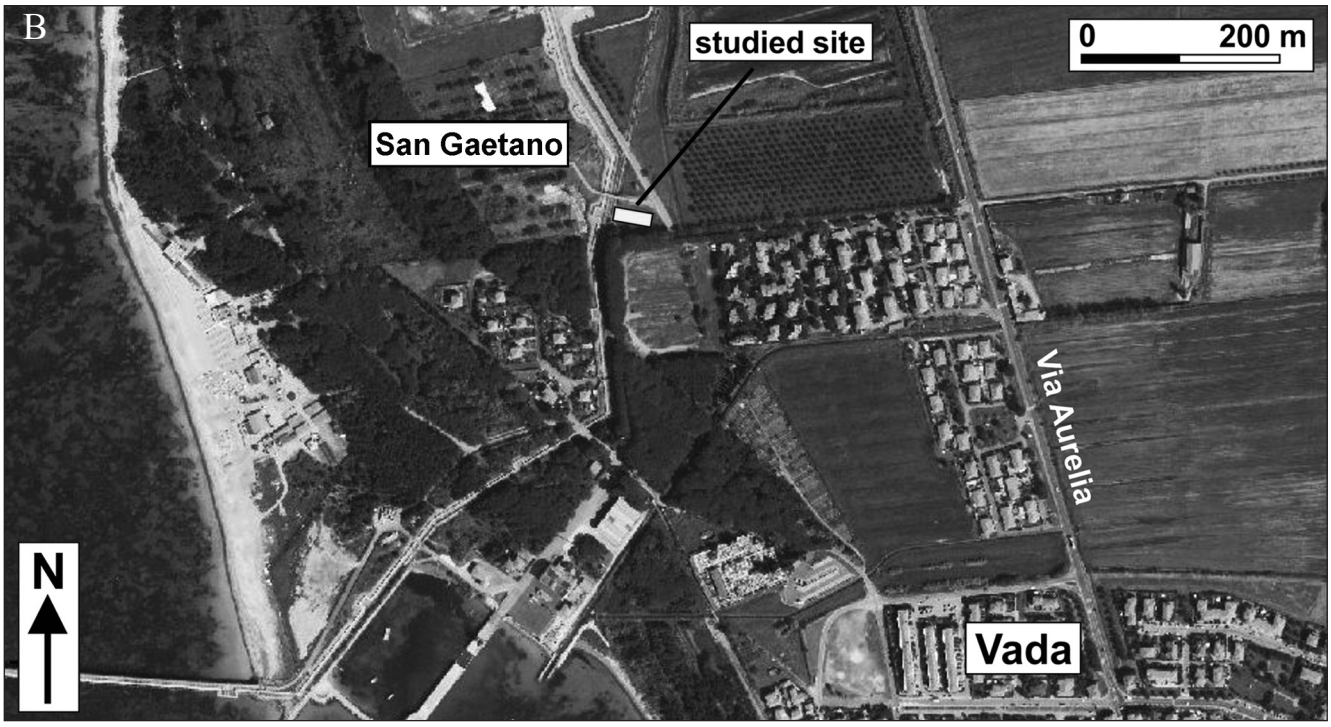

Figure 15.7 A) Vada (Rosignano M.mo Livorno) and the remains of Vada Volaterrana*. 1: S.Gaetano di Vada commercial quarter; 2: unspecified Roman findings; 3: harbour area; 4–5: dwelling quarter; 6–7: necropolis. B)* Vada Volaterrana*. An aerial view including S.Gaetano di Vada and the studied site.*

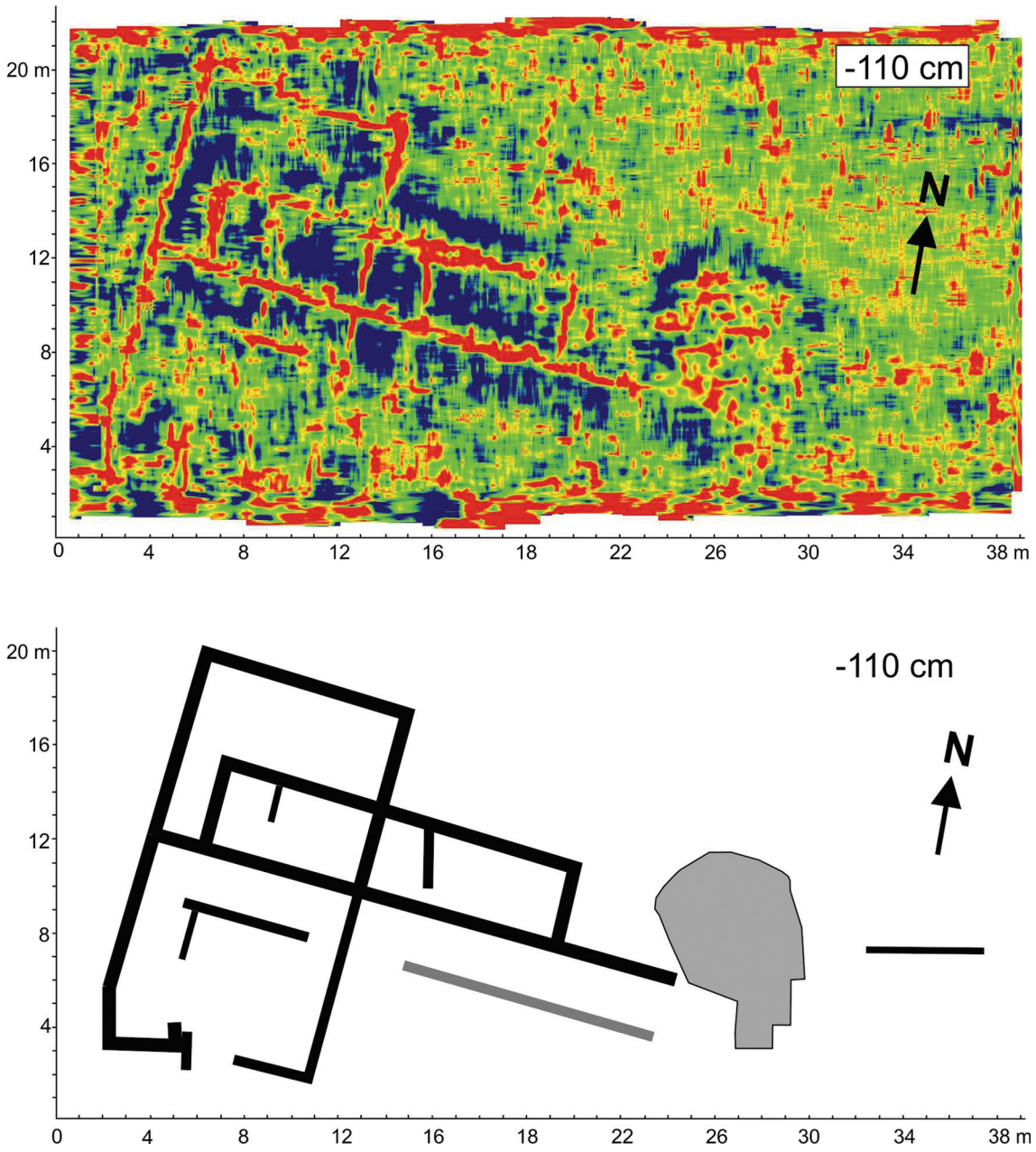

Figure 15.8 Vada Volaterrana. *Time slice at 110cm depth in the site.*

pattern is consistent with regular structure's of pseudo-rectangular shape, enclosing areas with no EM reflections. The structures dimensions are remarkable, with continuous and coherent EM reflections up to 100–130cm depth (Figure 15.8B). Near the eastern border of the rectangular structures, a wide and highly reflective area showing a curved limit toward north was detected.

The GPR data show regular evidence of a building formed by several rooms. The walls appear to be at least 60cm wide, accordingly with the evidence of the excavated complex in the area. The round reflective area can be interpreted as the pavement of a cistern, supplying water to the complex through a drainage system identified by the minor linear anomalies located south of the rooms. Excavations in the area are planned for September 2011.

Conclusions

The results confirmed the GPR efficiency in the archaeological research. In *Portus Pisanus* the excavations results matched the GPR data and their interpretation. In Pisa (Via Galluppi)

and *Vada Volaterrana* the data agree with the archaeological knowledge of the area. Moreover, locally the reflective sectors are self-evident, showing clear geometrical shapes, certainly due to human activities.

The results confirm the capability of the GPR method to explore ancient areas being a non- invasive, rapid and relatively cheap prospection.

The planned extensive use of GPR could provide further data to reconstruct the suburban landscape of *Pisae* and to better define the topographical features of *Portus Pisanus* site. Moreover, systematic GPR prospection in the area between San Gaetano site and the modern Vada could provide evidence to identify the actual extention of the *Vada Volaterrana* town. Most probably in this area public and private buildings should be expected, on the basis of previous excavations and other findings.

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