Journal of Archaeological Science: Reports 53 (2024) 104361

Contents lists available at ScienceDirect

Journal of Archaeological Science: Reports

journal homepage: www.elsevier.com/locate/jasrep

Salt in Late Iron Age Italy. A multidisciplinary approach to the exploration of Italy's coastal exploitation sites: Piscina Torta (Ostia, Rome) case study

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A R T I C L E I N F O

Keywords:
Iron Age Italy
Briquetage
Magnetometry
Corings
Intensive survey
Salt production in antiquity

A B S T R A C T

During the Copper Age and onwards, unique archaeological sites emerged throughout Europe. These sites exhibit distinct features such as the absence of typical household pottery, the presence of kilns, and extensive layers composed solely of fragments of reddish-brown jars. Scholars generally interpret these sites as specialized locations for salt production through the technique of boiling saltwater, known as briquetage. In Italy, many of these sites are found along the Tyrrhenian coast and span from the Middle Bronze Age to the Roman era, with a particular concentration during the early Iron Age. However, the archaeological evidence in Italy differs from that of other European sites, suggesting that these Italian sites were not solely dedicated to salt production but also involved other economic activities. To delve deeper into the understanding of these sites and their socio-economic context, the University of Groningen initiated the Salt & Power: Early States, Rome and Resource Control project in 2021. The project aims to comprehensively analyze these sites and shed light on the production of salt within their broader societal and economic framework.

In this contribution, we present preliminary findings derived from intensive surveys, coring campaigns, and geophysical investigations conducted at one such site, Piscina Torta. This site is believed to be connected to the city of Rome and dates back to the 7th and 6th centuries BCE. Furthermore, we propose a multidisciplinary workflow for studying specialized sites, incorporating various research methodologies and disciplines.

1. Introduction

In this paper, we present the results of a geophysical and intensive artefact survey carried out in April and July of 2022 on the archaeological site of Piscina Torta, near Rome (Fig. 1). The site had already been surveyed for surface artefacts in the 1980 s (Figs. 2, 3) and interpreted as a specialised site, perhaps devoted to salt production and/or fish processing and preservation. In the framework of the recently started 'Salt and Power' project of the University of Groningen (Alessandri and Attema, 2022), we decided to further study the site since the material evidence corresponded to the remains usually associated with the ancient briquetage technique to obtain salt (Alessandri et al., 2019; Harding, 2021). Thus, the aim of the surveys was two-fold: to better understand the sités chronology and spatial organisation and to obtain

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https://doi.org/10.1016/j.jasrep.2023.104361
Received 18 October 2023; Accepted 14 December 2023
Available online 19 December 2023

data on where to conduct the ensuing excavations. Finally, we also took the opportunity to test a new grid survey approach, implemented with a new low-cost GPS RTK device. We argue that in order to eventually understand the scale, productive complexity and chronology of specialised sites along Italy's Tyrrhenian coast a holistic landscape approach combining large scale geophysical prospection, intensive artefact survey, palaeoenvironmental studies and excavation, as implemented by our team at Piscina Torta, is a precondition for the contextualisation of the many so called 'reddish potsherd' sites known to exist along the Tyrrhenian coast of Italy. Our hypothesis is that these sites represent early productive areas linked to the formation of the Etruscan and Latin population centres, among which early Rome the economy of which has been recently re-considered, with special attention for the importance of coastal and lacustrine areas (Cifani, 2021).

1.1. Location and geological framework

The archaeological site of Piscina Torta is located in the southern part of the Tiber delta, where due to relative sea level change and variation in sediment supply a series of shore-parallel beach ridges and a coastal lagoon had formed during the Holocene (Bellotti et al., 1994; Giraudi, 2004; Milli et al., 2013). In particular, the fast post-glacial sea level rise between 14 and 6 kyr BP led to the drowning of the Tiber river valley, forming an open lagoon-barrier island system. During this period, the entire system migrated inward, displacing the delta inside the lagoon (Bellotti et al., 2018). Around 6 kyr BP, due to the reduced rate of sea level rise (Lambeck et al., 2004), the resulting bay-head delta started a fast progradation, which in combination with the high sediment load triggered the development of a wave dominated delta (Galloway, 1975), still present today. Based on artefact and sediment dating, eight phases of delta progradation with associated beach ridge formation and coastlines have been identified (Giraudi, 2004; 2011; Giraudi et al., 2009). These time intervals are reported in Table 1 (Belluomini et al., 1986; Carboni et al., 2002). The OSL (Optically Stimulated Luminescence) based chronology of coastal dune systems south from the Tiber delta (Castelporziano) revealed comparable ages (dune phases CP I to CP IX), even though two more phases of progradation are identified around 888 BCE and between the 13th and 14th century CE (Bicket, 2009). These data suggest that at the time of the supposed site activity at Piscina Torta the shoreline must have been much more inland than today: approximately around 1.3 km (Bicket, 2009).

Throughout these progradation pulses, on both sides of the Tiber delta coastal lagoons existed: the Maccarese lagoon in the north and the Ostia lagoon in the south (Bellotti et al., 2018 and references therein). The Piscina Torta site is located adjacent to the southernmost strip of the ancient Ostia lagoon, on the beach ridge most probably dated between 910 and 800 cal BC (5th phase; Giraudi, 2004; 2011; Giraudi et al., 2009) and 2888–2400 yr BP (CPV and beginning of CPVI phases; Bicket, 2009). Historical maps and paleoenvironmental studies of the northern sectors of the palaeo-lagoon (e.g. Vittori et al., 2015) suggest how the latter must have been connected through an inlet to the open sea, originating in the 9th or 8th century BCE, when it changed from a freshwater to a brackish environment (Di Rita et al., 2010; Giraudi, 2011). The exact location of such tidal inlet is still unknown, but considering a depression perpendicular to the beach ridge located at Piscina Torta (Pisani Sartorio and Quilici Gigli, 1984) (Fig. 4) and the vicinity of the contemporary coastline, it is very likely that the tidal inlet indeed connected the Piscina Torta site with the sea.

1.2. Previous research

In 1984, G. Pisani Sartorio and S. Quilici Gigli (1984) reported twelve scatters of potsherds over a large area South-East of Rome, in the

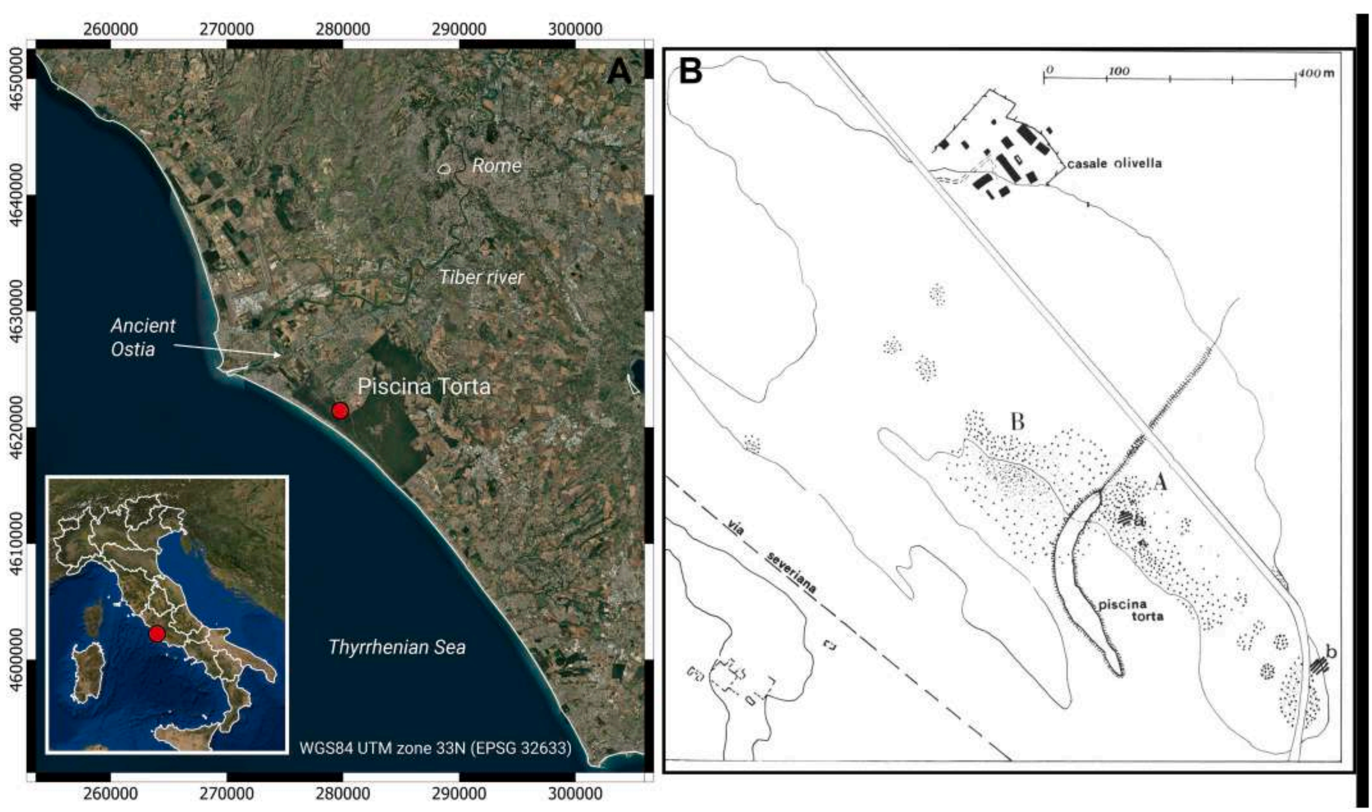

Fig. 1. A, location of Piscina Torta site; background ESRI satellite imagery (Esri, DigitalGlobe, GeoEye, i-cubed, USDA FSA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community). B, original sketch of the surface materials from Pisani Sartorio and Quilici Gigli, 1984 (a and b, Roman materials; A and B, high density of materials).

Castel Fusano pinewood (Rome), in an area indicated by the toponym Piscina Torta. The pine forest is the result of an afforestation that started in the 18th century by the Sacchetti and Chigi families for the production of wood and pine nuts. At the moment, the dominant tree species is Stone Pine while the subcanopy consists of Holm Oak and other typical broadleaf maquis. The area is now part of the Natural Reserve of the "Roman coast" (*Latium*) (Mazza and Manetti, 2013; Marcelli and Carta, 2022).

The twelve scatters detected in the 1980s (Fig. 2) ranged in size from 554 m^2 to 69440 m^2. Empty areas between scatters may be the result of the visibility conditions, which can be quite poor below the trees. A minimum estimate of the site area including empty zones reaches 145300 m^2, i.e. almost 15 ha, excluding the westernmost concentration which is at a considerable distance (220 m) from the others. In two small scatters, "A" and "B" in the original publication (Fig. 1, b), Roman late republican and imperial materials were recorded. Scatter "A" contained marble fragments, triangular bricks, and Terra Sigillata (*Aretina* and *Chiara*, dating between the I c. BCE – II c. CE) potsherds. The surface scatters in all the remaining portions of the site were characterised by the almost exclusive presence of reddish potsherds belonging to jars from the pre-Roman period, dating between the second half of the 7th c. BCE and the 6th c. BCE (Fig. 3). As the scatters are located along the shore of a former lagoon (Pannuzi, 2013), the location and the typology of the potsherds both led Pisani Sartorio and Quilici Gigli to hypothesise that the location might have been dedicated to a specialised activity: the production of salt as described in Cato the Elder's *De Agri Cultura* (Cato, 88) and/or preservation of fish (Alessandri et al., 2019).

1.3. Research context and objectives

The surface evidence from Piscina Torta consists of dense distributions of protohistoric reddish potsherds mainly belonging to jars. Similar 'reddish potsherd sites' are found along the central Tyrrhenian coast and are generally interpreted as debris from salt production sites employing the so-called briquetage technique and/or from possibly related activities such as fish preservation in jars (Pacciarelli, 1991; Mandolesi, 1994; 1996; Belardelli and Pascucci, 1996; Attema and Alessandri, 2012; Alessandri et al., 2019; 2021; Sevink et al., 2020; 2021; Belardelli et al., 2021). The briquetage technique is attested all over continental Europe: the earliest Chalcolithic occurrences come from Romania after which the technique became widespread in central and northern Europe, especially during the Iron Age and the Roman ages (Harding, 2013; 2021). It involves boiling a brine (seawater previously subjected to evaporation) in jars specially produced for the purpose. Following crystallization of the salt, the jars had to be broken to obtain the salt cake. The necessity to break the containers to extract the salt would explain both the almost unique presence of jars and the huge number of potsherds. However, the type of ceramic containers used in central Tyrrhenian sites is different from those used elsewhere in Europe for briquetage, which suggests a broader scale of activities at the central Tyrrhenian sites than salt production alone. In the framework of the 'Salt and Power' project hosted at the Groningen Institute of Archaeology, we investigate the scale, productive complexity and chronology of the specialised sites now known along Italy's Tyrrhenian coast with the aim to understand their socio-economic role in the protohistoric economy of Late Bronze Age to Archaic Italy (Alessandri and Attema, 2022). During this period, the number of specialized sites increases and, based on the pottery record, their productive capacity rose exponentially. We link this development to the formation of the large Etruscan and Latin population centres, among which Rome. Each of these urban centres would have controlled part of nearby coastal resources. However, to date the evidence consists predominantly of unsystematic surface collections and

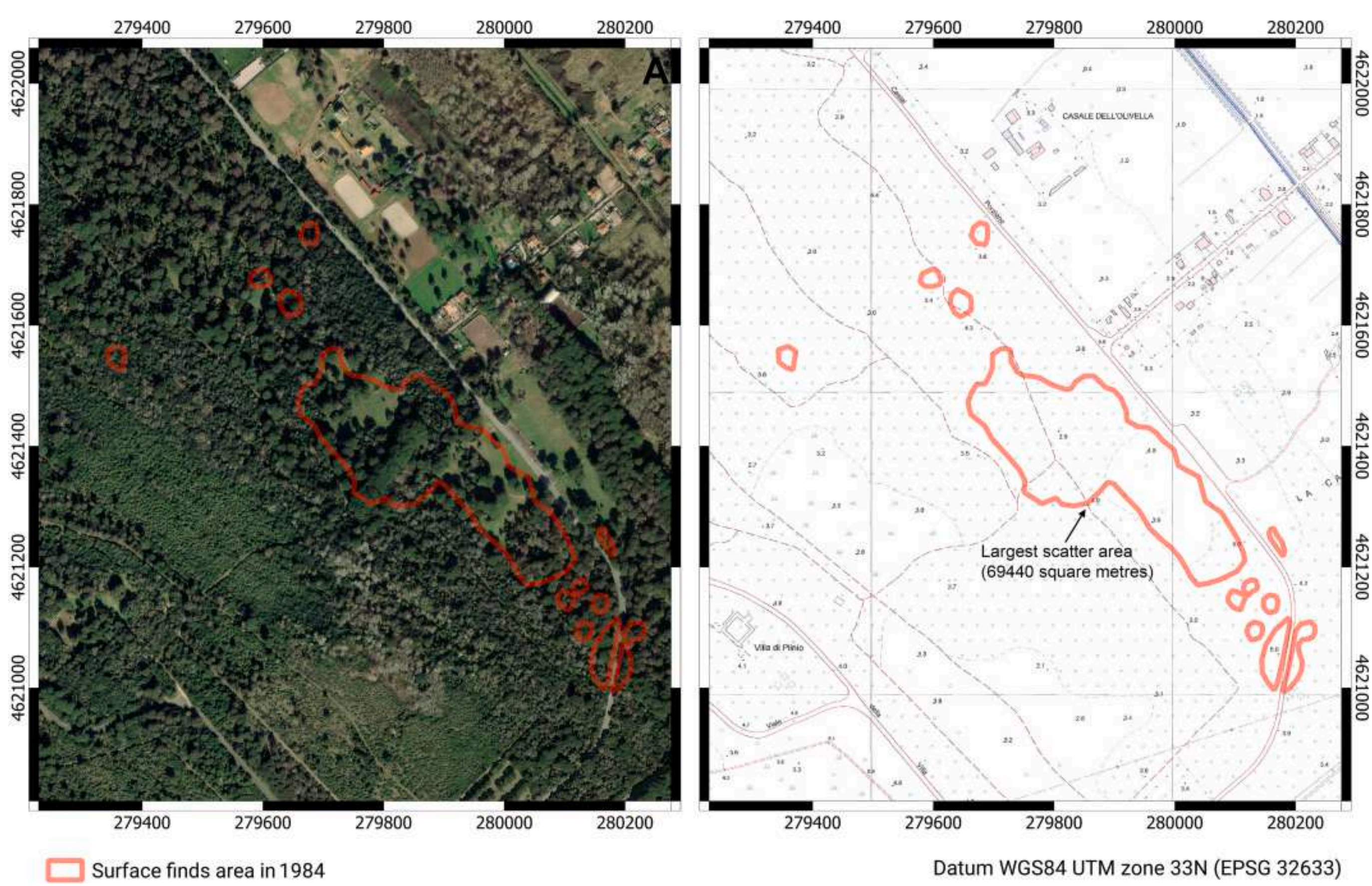

Fig. 2. Areas where surface materials were found, in the 1980s. A, background ESRI satellite imagery (Esri, DigitalGlobe, GeoEye, i-cubed, USDA FSA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community). B, background Carta Tecnica Regionale 387053 (1:5000).

single excavations, hampering the interpretative potential of this rich archaeological record to obtain insight in the nature, scale and chronology of what we think were veritable ‘protoindustrial coastal areas’ (the bibliography about these sites has been collected in Alessandri et al., 2019). To validate this hypothesis, the Salt and Power project team applies an integrated landscape archaeological methodology to substantiate the economic importance of these extensive coastal production zones for the inland urban centres. In this context, geophysical prospection, intensive artefact surveys and landscape archaeological contextualization at Piscina Torta was adopted to gain more insight in the spatial organization of the site and the character of subsurface traces, and to guide the ensuing excavations. This approach was first pioneered by us on a smaller scale at the site of Puntone in coastal Etruria (Aranguren et al., 2014), where it was successfully applied to unravel the operative chain of salt extraction from leached lagoon sands at the site of Puntone Nuovo (Sevink et al., 2020; Sevink et al., 2021).

2. Material and methods

To map the scale of the site and the density of potsherds over the surface, an intensive artefact survey was designed following recommendations described in Attema et al. (2020). Not all surface scatters of potsherds published in 1984 and the supposed empty spaces in between them could be covered in the artefact survey, as a great portion of the area under the tree canopy had quite poor surface visibility. The artefact survey therefore concentrated on the central portion of the larger scatter, covering an area of 17725 m^2 (17,725 ha) Afterwards, we also decided to carry on geophysical prospections in the same area and in a small northern zone which was suitable for magnetometry, but not for intensive survey. Prior to both surveys, a drone flight was carried out to produce a high resolution orthophoto image of the central part of the site.

Table 1
Tiber delta progradation phases and attributed ages (Belluomini et al., 1986; Carboni et al., 2002).

Beach ridges	Attributed age
I phase	3792–4042 yr cal. BC
II phase	3375–2930 yr cal. BC
III phase	2930–2140 yr cal. BC
IV phase	2140–1920 yr cal. BC
V phase	910–800 yr cal. BC
VI a) phase	4th century BCE
VI b) phase	10th century CE
VII phase	15th-16th century CE
VIII phase	16th-19th century CE

2.1. *The drone flight*

Before the start of the survey, an orthomosaic and a DEM were realised using the imagery obtained by a drone flight. The areas free from forest canopy were covered by a 2.5D transect flight using a DJI Mavic Pro drone and the mobile application Pix4Dcapture. In total, 597 orthographic images were collected at an altitude of 40 m with 80 % overlap, covering a surface of approximately 45000 m^2 (4,5 ha). The photos were then elaborated and georeferenced using the Agisoft Metashape software.

2.2. *The survey grid*

The cross points of the grid were indicated on the ground using simple white and red plastic sticks. We started by placing sticks every 40 m using a recently developed device: a low-cost RTK (Real-Time

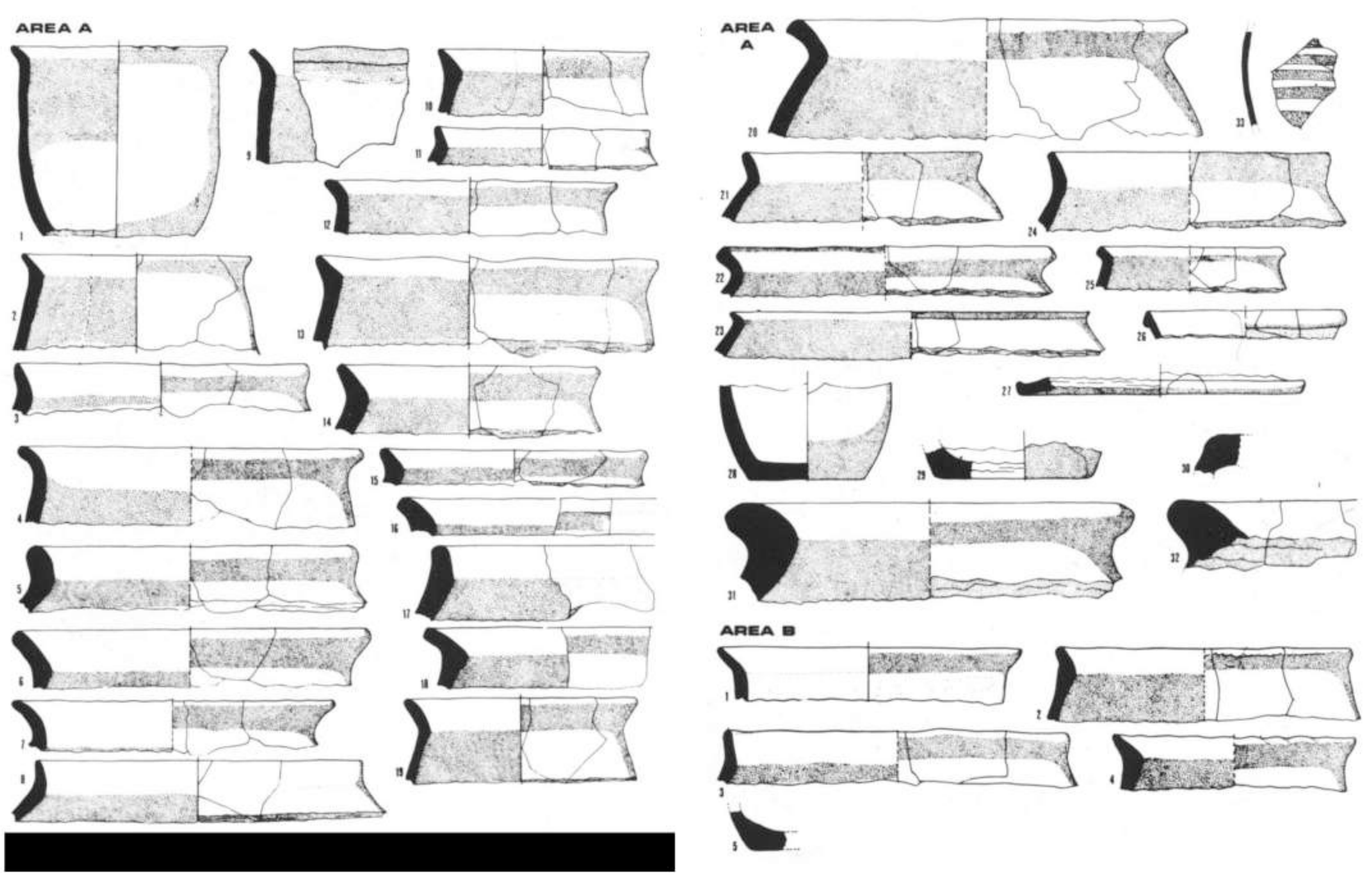

Fig. 3. Already published potsherds from Pisani Sartorio and Quilici Gigli 1984.

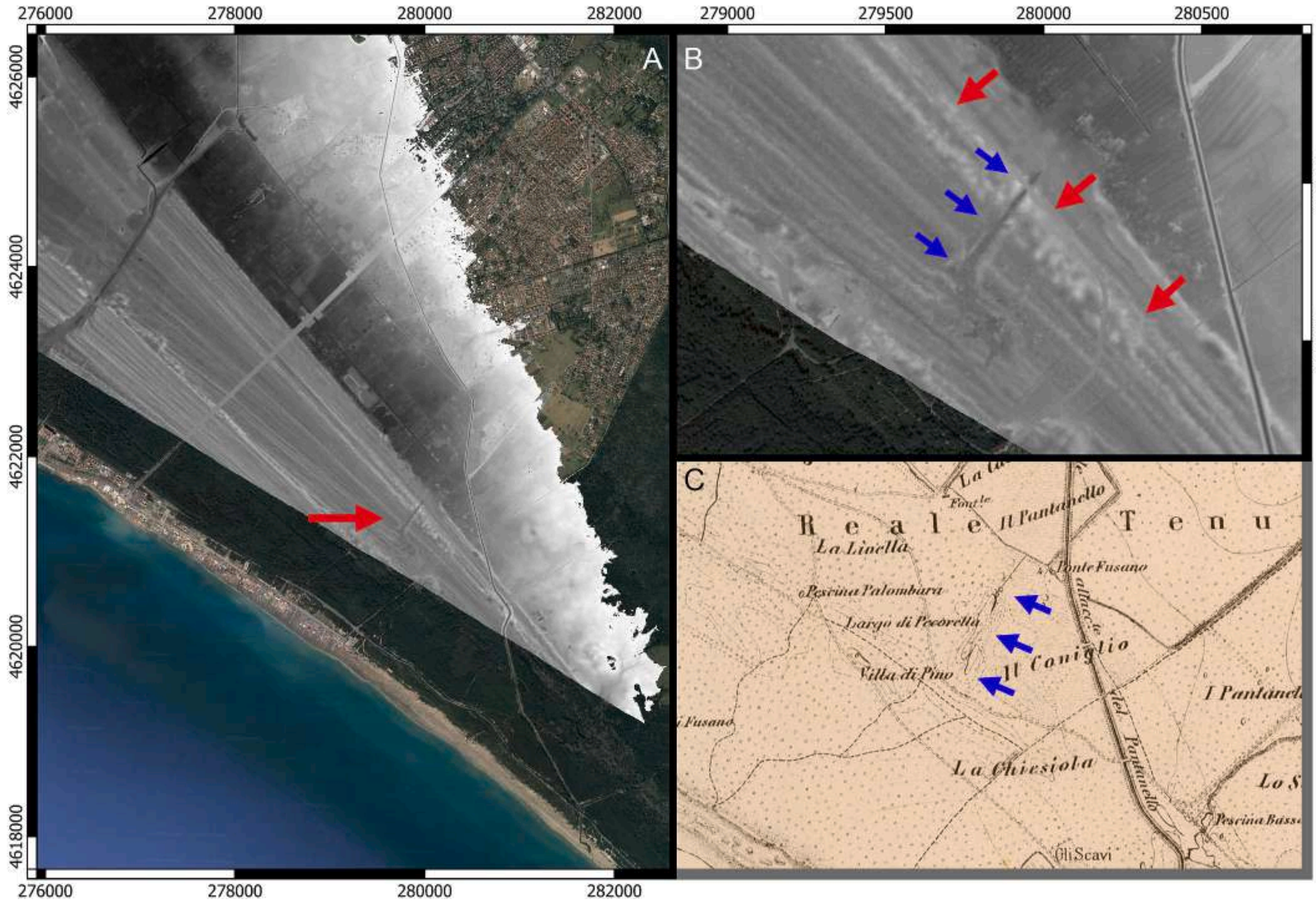

Fig. 4. The site and the probable tidal inlet visible in the LiDAR (A and B) and in the 1895 map made by Istituto Geografico Militare in 1895, Foglio 149, II SE, Castel Porziano (C). LiDAR from Ministero dell'Ambiente e della Sicurezza Energetica (Italy).

Kinematic) GPS/GNSS receiver from Ardusimple, which included a ZED-F9P RTK receiver and a u-blox ANN-MB-00 antenna for GNSS Dual Band. The device was connected to a smartphone Samsung Galaxy A52 via a USB port. To manage the data we used the free app SW Maps 2.9 which turned out to be straightforward to use even by non-experienced users. To achieve cm level positioning we acquired NTRIP data from the recently updated Regione Lazio permanent station network (Longhi, 2015; Regione Abruzzo, 2023). The intermediate sticks were placed using metric tapes. The survey grid was predefined in QGIS 3.22 and based on the WGS84 UTM grid (zone 33 N, EPSG 32633) (Barbarella, 2014). The use of grids based on absolute geodetic reference system, as opposed to the local systems, has many advantages:

Absolute and accurate georeferencing makes it possible to compare survey results with all other georeferenced spatial information such as: lithological maps, land use cartographies, visible and multi/hyperspectral photogrammetric images, geophysical data;

A number of permanent stations with known coordinates is essential for the maintenance of coordinate grids over time. In a national or international system, such as WGS84, they are maintained by state geodetic mapping agencies. This implies extreme precision, accuracy and a very long-life expectancy. In the case of local coordinates, unless these have been subsequently converted to other coordinates, it is up to the fieldwork team leader to create and maintain over time the permanent stations. This implies a significantly increased risk of losing data in the near future;

The grid and every single cell can be immediately placed in the right position by almost everyone, knowing only the unit extension and the coordinate reference system;

Using the coordinates as the name of the units (and of the associated bag of collected materials) is sufficient to place the finds on the world system. This implies no need to prepare and keep printed maps (which can be lost).

Before the survey, we tested the Ardusimple device against a much more expensive professional RTK GPS/GNSS receiver. The aim was to check if such a low-cost and easy-to-use device could be reliable (accurate and precise) in defining the spatial organisation of the finds, to be able to compare its data with the results of geophysical and geological surveys and, in general, with data that have the same high accuracy. The results of this comparison are presented in the Supplementary materials

2.3. *The intensive survey*

Since one of the aims was to detect intrasite functional areas, the dimension of the single unit (5x5m square cell) was a balance between the dimensions of the average expected features (ceramic dumps, kilns, groups of pits) and the available resources (mainly time) (Fig. 5, A). The ID of the unit is the coordinate of its northwest point (Fig. 5, B).

The single unit was walked by one (40 % surface coverage) or two people (80 % surface coverage). We used the former in units with low find density but in high visibility conditions as a means to save time. The collected archaeological materials were stored in bags labelled with the ID (coordinate) of the unit. Materials below 'thumbnail-size' were not collected. In total, we surveyed 709 units collecting 14,709 finds. More than 99 % of the finds consisted of protohistoric and Roman ceramic fragments. Additionally, there were occasional finds of Roman building materials (marble fragments, mosaic tesserae, cubilia, fragments of roof

Fig. 5. A, the established grid, based on WGS84 UTM zone 33 N (EPSG 32633), background ESRI satellite imagery (Esri, DigitalGlobe, GeoEye, i-cubed, USDA FSA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community). B, the procedure to assign the name to every single unit, background aerial image from our drone flight.

tiles and plasters). No bones were recovered during the survey. The surface-discovered charcoals are assumed to have originated from fires lit in the modern era and were thus left uncollected. For each unit, we recorded contextual information in the field using the app Epicollect 5 which was installed on the smartphone of each participant. The app directly uploads all entered information to the cloud. A copy of the updated data was downloaded and stored daily, for safety reasons. Following the suggestion made in De Haas, 2011 and Van Leusen, 2002, we registered: unit number; location (based on the smartphone internal GPS, for a rough control); date and time; photos; weather (sunny, cloudy, rain); vegetation (scale from 1, low presence, to 5, heavy presence); stones (scale 1–5); shadow (scale 1–5); overall visibility (scale 1–5; 1 is low, 5 is very good); ploughing (yes/no); coverage (40 % or 80 %); number of bag(s); number of potsherds; notes. In the laboratory we used the same app to register: the weight of the materials (per unit); the number of protohistoric materials that consisted of reddish potsherds only, in Italian archaeology called *impasto* ware); the number of Roman materials; diagnostic pieces (base, rim, handle, decoration); box (the final storage place of the bags).

Despite all the procedures put in place to avoid errors, some issues still arose both during the usual control at the end of the day and in the laboratory post-processing (Fig. 6). Most of them could be solved quite easily but a few were irreversible. In total, five bags went missing (0,007 % of the total bags) which account for 95 potsherds (0,006 % of all finds). The data from Unit 2,799,874,621,261 (78 potsherds) could still partially be used since the unit falls in an area in which only large amounts of impasto potsherds were found, so we considered all the finds as protohistoric with a high degree of certainty. Unit 2,799,224,621,401 (seven finds) could also still be used since in the field we already recorded that all the materials were Roman. In the end, only the data from three bags could not be used (units 2799824621341, 2,799,174,621,321 and 2800274621311) for a total of 10 finds. In the density calculation, these units were considered holding zero finds since we could not distinguish between protohistoric and Roman finds.

Finally, it must be noted that the area has never been ploughed. However, each year a disc harrow is used by the local Garden Service over the entire area to keep it free of weeds. Since the harrow usually does not go deeper than 20 cm, the surface materials can only be considered as representative of the layers above that depth.

2.4. The density calculation

It is well established that a number of biases affect the representativeness of the collected sample, almost all of which can be traced back to visibility (but also, for example, the experience of the walkers) (Schon, 2000; Van Leusen, 2002; Banning et al., 2006; Attema et al., 2020). The visibility is mostly influenced by vegetation cover, the state of tillage, shade, the presence of stones and other minor factors. Thus, to calculate the density of the surface materials, we used the algorithm from De Haas (2011), that accounts for coverage and overall visibility biases. We did not take into account the experience of the walkers, which was almost the same for everyone.

To account for the visibility bias, the visibility score has been translated in absolute retrieval rates using Schon's (2002) data (chart 5).

$D = N*(100/C)*(100/R)$.

D = number of estimated materials per unit; N = number of collected materials; C = coverage; R = Retrieval rates. D has been rounded off to the nearest integer.

The results (see Supplementary Table S5.txt) have been interpolated using the SAGA 7.8 Ordinary Kriging function in QGIS (Fig. kriging). Kriging is an interpolation technique that models spatial correlations between point values, widely used in archaeology (James et al., 2022; Wheatley and Gillings, 2002; Gillings, Hacıgüzeller, and Lock 2020).

Fig. 6. Different steps of the survey. A, placing the sticks with the low-cost device. The survey pole turned out later not to be essential. B, placing the intermediate sticks with the measuring tapes. C, plastic bags to collect the materials with the name of the site, the name of the unit (coordinates of the stick) and the data were immediately placed over the sticks. So, we could recognise if a unit had already been surveyed by the presence/absence of the bag. After surveying the unit, walkers had to upload the ancillary data on Epicollect with their smartphones. D, at the end of the day, a matching control between the Epicollect entries and the bags was always performed.

2.5. The chronology

The chronology of the site is based on known pottery types. From all the collected potsherds, only thirty potsherds (rims, decorations, handles) were diagnostic. These were manually drawn (see Supplemental material, chapter 2). Their chronology has been established using ceramic parallels from other dated contexts. The minimum duration of the site was subsequently calculated based on the dating of each diagnostic fragment.

2.6. The geophysical prospections

The geophysical work consisted of a magnetic gradiometry survey. We used a hand-pushed LEA-MINI system with four Sensys FM650 fluxgate gradiometer probes mounted at 0.5 m distance. Each probe measures the vertical difference in the vertical component of the Earth magnetic field (the so-called 'gradient') with a sensitivity of 0.1nT.The data were positioned using a Leica GS15 GNSS system mounted on the cart with real-time RTK corrections, resulting in a positioning accuracy of ca. 2 cm. The recorded variations were subsequently visualized as 2D-maps with a resolution of ca. 0.25 x 0.25 m. The technical details of the magnetic gradiometry surveys at the three sites are presented in Table S3.

The survey results were interpreted according to the amplitudes, dimensions, and configuration of magnetic features. The interpretation follows the classification scheme presented in Table S4

2.7. The geological fieldwork

Detailed geological fieldwork was carried out to investigate the type of deposits and sediment cover both at the site itself as well as in the area once occupied by the Ostia ancient lagoon. Where possible, exposures of older sediments were analysed and described. From the outcrops and from the archaeological site, the different sediments were then sampled and analysed for mineralogical and micropaleontological content under a stereomicroscope at the laboratories of the University of Groningen. Additionally, a preliminary surface coring program was executed at the Piscina Torta site in order to check whether the deposits were in situ or reworked.

3. Results

3.1. The survey grid accuracy

We performed two accuracy checks, both using a Geomax Zenith-10 (GZ10) GPS as a comparative device.

1. Using GZ, we measure the coordinates of the sticks placed using the metric tape. We recall here that these sticks were placed between a 40 m line whose ends were placed with the Ardusimple device;
2. We measure the difference between the grid nodes (which were supposed to be integer numbers) and the coordinates of the sticks placed with the Ardusimple.

In both cases, the accuracy turned out to be centimetric and thus we could achieve a high-resolution integration of surface archaeology with the other datasets (for details, see Supplemental material, chapter 1).

3.2. The intensive survey and the density calculation: Spatial organisation

The result of the interpolation (Fig. 7) for the protohistoric data shows two potsherd concentrations, both with two density peaks (Fig. 8, A, D). Both concentrations are near a small mound elevated a few metres above the average ground level (Fig. 8, A-C).

The interpolation of Roman material shows two concentrations as well (Fig. 7). In the larger and western one, tiles and *cubilia* were noted on the surface. A dense vegetation carpet prevented further investigation towards the East. The second concentration is unfortunately located right next to the modern road, which therefore makes it impossible to

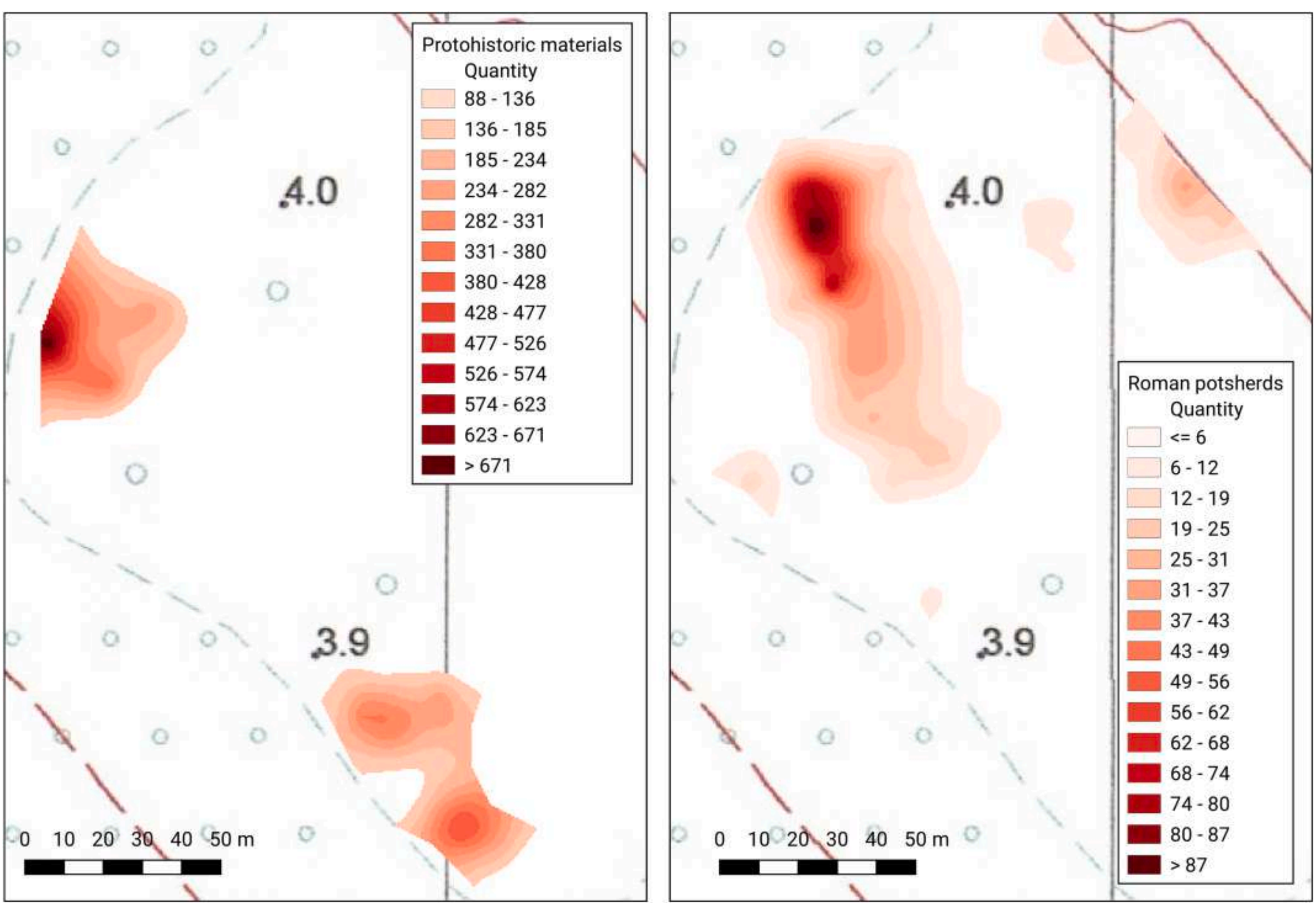

Fig. 7. The interpolated (Ordinary Kriging) density of Protohistoric and Roman materials, background Carta Tecnica Regionale 387053 (1:5000).

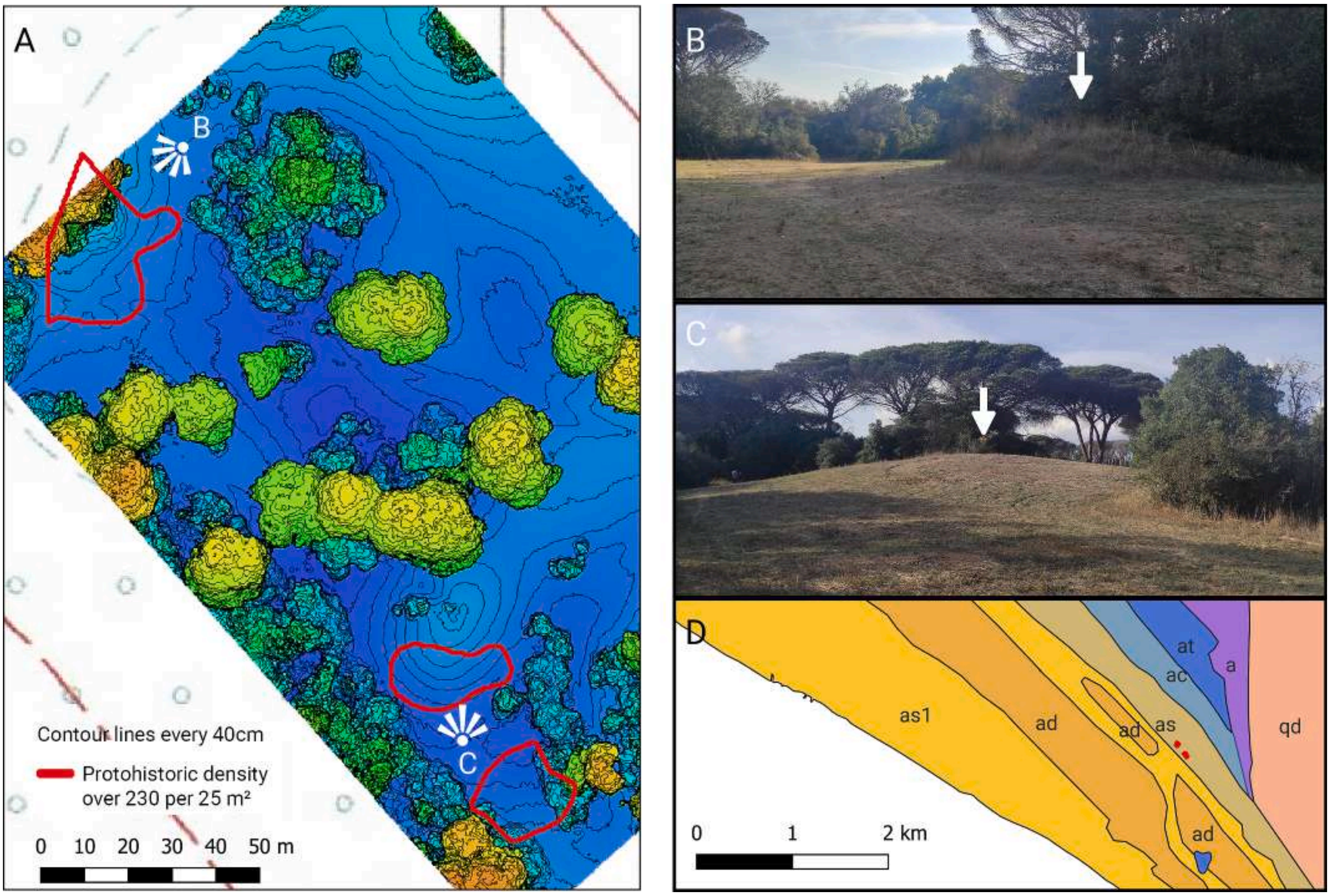

Fig. 8. A, the protohistoric materials density over 230 potsherds per 25 m^2; background, contour lines every 40 cm extracted by the drone flight. B and C, the mounds: refer to figure A for the viewpoints; D, the two concentrations of materials over the geological map. a, Terreni palustri di colmata; torbe, limi, terre nere; ac, Argille grigie e depositi salmastri con molluschi; ad, Dune interne; as, Sabbie fini di spiaggia; as1, Sabbie e depositi interdunari; at, Alluvioni deltizie antiche: riempimento di limi e argille gialle; qd, Sabbie gialle e rosse, eoliche, sciolte (Duna rossa antica).

estimate its true extent. Here no further diagnostic materials were found. Very small concentration spots are also visible in the north-western survey area.

3.3. The chronology

All the collected potsherds belong to so-called *ollae* (medium-sized jars) or *dolia* (large storage jars) (see Supplemental material, chapter 2). These types of vessels have always been difficult to precisely date, both because their morphological evolution is quite slow (e.g. much slower than in the case of bowls, cups and decorations) and because they have received little or no attention in previous publications. The jars from Piscina Torta have parallels from contexts dated between 675 and 525 BCE. This time frame should be understood as the shortest possible; indeed, the site life could have been slightly longer. These data substantially confirm the chronology which was proposed in 1984 (Pisani Sartorio and Quilici Gigli, 1984, p. 22): second half of the 7th century and 6th century BCE. This is in line with the ages obtained for the formation of the beach ridge on which the site is located (Giraudi, 2004; 2011; Bicket, 2009; Giraudi et al., 2009): between the 9th and 4th century BCE. The chronological distribution of the artefacts is homogeneous on the surface, meaning that no chronological clusters can be derived from the potsherd dataset.

3.4. The geophysical prospections: Interpretation of anomalies

Two areas were investigated at Piscina Torta: a large open field in which the two known accumulations of protohistoric pottery are situated (area I in Supplemental material, Fig. S6) and a smaller field with higher vegetation in the forest (area II in Supplemental material, Fig. S6). The interpretation of the data collected in these two areas is presented in Fig. 9. The magnetic contrasts between the natural background and the anthropogenic features detected are relatively high, including a number of structures with high amplitudes.

Area I (Fig. 9, A) is characterized by several clusters of archaeologically relevant magnetic features. The most conspicuous is a rectangular structure of ca. 8 x 16 m with high magnetic amplitudes, possibly caused by thermoremanent magnetism (burnt materials) or ferromagnetism [feature 1]. 12 m to the SE of this feature is a horseshoe-shaped anomaly [feature 2] that may be caused by a burnt structure such as a kiln. Features 1 and 2 are spatially linked to an area with multiple smaller magnetic features indicative of human impact [area 3]. No materials were seen on the surface during the survey; therefore, the date of these features remains uncertain. One of the known pottery heaps [feature 4] is spatially linked to a cluster of linear features and single deposits with positive magnetic amplitudes [cluster 5]. These are likely to be produced by pits and ditches related to the pottery heap. The second pottery heap [feature 6] is located directly north of a large magnetic anomaly (ca. 12 x 7 m) with strong dipole amplitudes, probably caused by burnt materials. During the survey, a patch of orange ceramic fragments was seen here that may pertain to a kiln or accumulation of strongly burnt material [feature 7]. Some 20 m to the east is another cluster of anthropogenic features including pits and fills [features 8 and 9]. Approximately 40 m north of pottery heap [6] is a round dipole anomaly

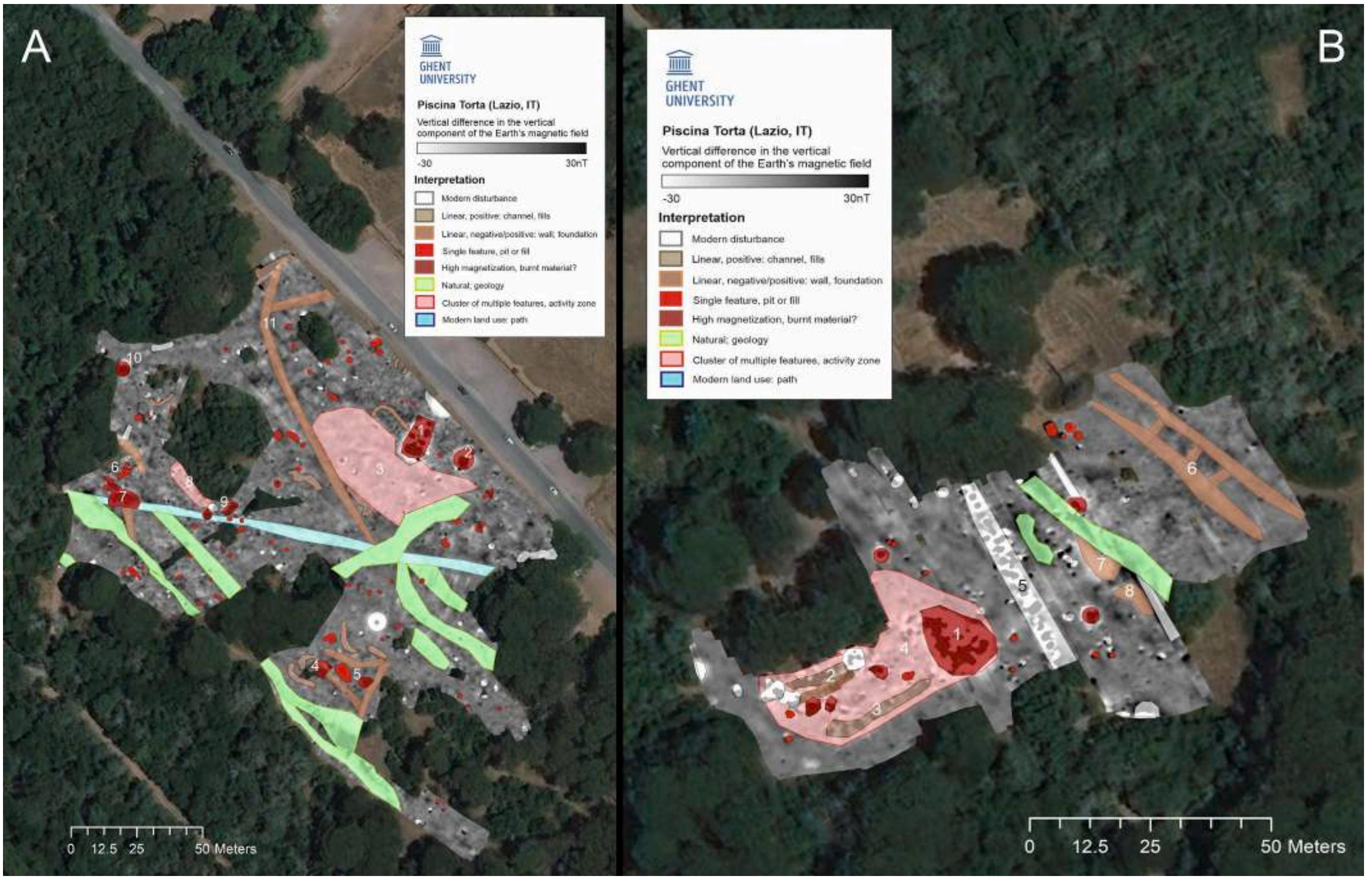

Fig. 9. Interpretation of the magnetic gradiometry data. A, area I. B, Area II. Numbered features are discussed in the text.

with strong amplitudes and a diameter of ca. 5 m. The shape and dimensions of this feature suggests that this is a kiln or other burnt feature. Crossing the field of area I is a long N-S oriented linear feature with a secondary branch, which may be related to an old path [feature 11]. This path is not visible on the surface.

Area II (Fig. 9, B) is divided by the present-day path with a pipeline underneath [feature 5]. To the west of this is a small elevation which holds a cluster of anthropogenic magnetic anomalies with strong amplitudes [cluster 4]. Conspicuous are three parallel linear features related to walls [features 2, 3] and a rectangular anomaly with very strong dipole amplitudes most likely caused by burning [feature 1]. Strong dipole disturbances are caused by cement blocks seen along the field edge but cut tuff stone blocks seen on the surface indicate an archaeological character of these traces.

To the east of the path is a series of weakly positive linear features that seem to be caused by walls or stone foundations [feature 6]. Parallel to this are two linear structures with an opening that may also relate to walls [features 7, 8]. Single magnetic features with positive amplitudes in the general area may be caused by pits or fills, but this should be verified.

3.5. *The geological fieldwork: Paleoenvironmental reconstruction*

The preliminary geological fieldwork enabled to distinguish two realms: the first one located inland from the archaeological site and the second at the site. A 1.6 m outcrop was identified in the area of the palaeo-lagoon of Ostia and sampled at a regular interval (10 cm). The samples mainly consisted of clayey sand (~70 % sand and ~30 %), with abundant calcium carbonate concretions. Shells or microfossils were absent. Regarding the surface sediments cored at the archaeological site, the first 20 cm consisted of recent, fine and well sorted sand, probably reworked by the harrow. Below this, deeper, older and undisturbed sand deposits were present.

4. Discussion

The surface artefact distribution and the magnetometry data provide complementary information on the presence and character of archaeological traces. The surface artefacts are related to the harrowed top 20 cm of soil, while the magnetic gradiometer records a total value for the body of soil between the surface and an estimated depth of 1–2 m.

4.1. *The Roman evidence*

Although the pottery surface carpet covers almost all of the area surveyed, the data showed a differentiation in the distribution of the Roman materials, which mostly does not overlap with the Late Iron Age potsherds. As a discussion of the Roman evidence is outside the scope of this paper, we limit ourselves to mentioning that these scatters may relate to the presence of the so-called Villa della Palombara (Villa di Plinio in Fig. 2), a Roman villa dated between I century BCE and III century CE, about 600 m SW of the site (Buonaguro et al., 2012; Marcelli and Carta, 2022). The distribution of the Roman materials suggests the presence here of a road with a NW-SE orientation diverging from the Severiana and going inland, which may replicate older paths.

4.2. *The Late Iron Age evidence, insight into the spatial organization of the Piscina Torta site*

The Late Iron Age potsherds are concentrated in two areas with an extraordinary pottery density and the presence of presumably man-made heaps (Fig. 8, B and C). Furthermore, the two protohistoric areas both coincide with some geophysical anomalies which have been hypothetically interpreted as kilns, pits, ditches and canals with positive magnetic amplitudes and structures with negative magnetic amplitudes such as walls, terraces, and stone foundations. At present, the distribution of these pieces of evidence suggests the presence of multiple work areas organized around the furnaces, like in the cases of the French ateliers de briquetage in Bretagne (Daire and Le Brozec, 1991; Daire et al., 2001) or in the Seille Valley (Laffite, 2002; Olivier, 2003; 2006). This hypothesis is currently being tested in our ongoing archaeological excavations, which are taking place in the northern concentration (Fig. 8, B). In this way, evidence from a single area can be used to interpret similar ones (from the intensive survey and magnetometry perspective) thus providing a plausible picture of the site's internal organization.

4.3. The origin of the surface deposit: Some alternative hypotheses (to the salt one) and their socio-economic framework

While the specialized vocation of Piscina Torta and that of comparable "reddish pottery sites" along the Tyrrhenian coast is undeniable due to the almost total lack of domestic finds and features, the actual activities taking place at these sites remain to be established. In our research project "Salt and Power" both the fieldwork activities, as at Piscina Torta, and the laboratory analyses are geared to exploring a number of hypotheses all or only some of which may in the end be validated based on new archaeological evidence. The hypothesis that salt production took place at all or some of the "reddish pottery sites" is under pressure as the comparison with European briquetage contexts, where salt production has been attested with certainty, is problematic on account of the nature of the ceramic record found on reddish potsherd sites such as Piscina Torta. Rather than simple and crudely made small open shapes, characteristic of the northwestern European "ateliers de briquetage", reddish potsherd sites yield open and closed shapes of different sizes, often with outcurving rims, which exhibit excellent workmanship and often carry notched cord decorations (Alessandri et al., 2019; 2021) These are all features that are not logical for essentially disposable ceramic vessels designated for brine evaporation. The ceramic debris record of the reddish pottery sites should therefore not be related to salt production but maybe rather to the storage and preservation of salted foodstuffs. In this vein, it has been suggested that fish processing took place at the"reddish pottery sites" (Belardelli and Pascucci, 1996; Alessandri, 2013; Belardelli, 2013; Belardelli et al., 2021). However, indications for salt production do exist, as we have shown in the case of Puntone (Sevink et al., 2020; 2021), while also our recent excavations at Piscina Torta have yielded so-called pedestals, used in kilns dedicated to salt production. It is thus possible that salt production took place in combination with other, archaeologically much more visible activities linked to the processing of fish. This latter hypothesis can be supported by the pivotal role salted fish and its byproducts, particularly fish sauces, had within the Late Republican and Imperial Roman food economy because of its central role in the Roman diet across all social strata (Marzano, 2013; Grainger, 2021). Independent evidence that such production took place at the "reddish pottery sites" is however still lacking. An argument in favour of this hypothesis is the sheer number of "reddish pottery sites" along Italy's Tyrrhenian coast and the huge quantities of broken vessels found there. In fact the heaps of broken vessels at Piscina Torta recall the famous heap of sherds composed of fragments of amphorae that formed the Monte Testaccio in Rome, along the bank of the Tiber. There, at the nearby river harbour, amphorae from Betica (80 %) and Africa filled with olive oil were brought ashore which, after extraction of their contents, were shattered, preventing them from being fraudulently refilled later on with low-quality oil (Remesal Rodríguez, 2018; 2019a; 2019b; 2022). While the size of the Monte Testaccio (ca. 35 m high with a circumference of about 1 km) is many times larger than the debris heaps at Piscina Torta or any comparable "reddish pottery site" elsewhere, and the trade of olive oil in imperial Rome was regulated by the State (Remesal Rodríguez, 2019b) we see possible parallels between the two contexts, in spite of chronological distance, differences in size of the phenomenon and diverse political and socio-economic context. Firstly, both heaps formed as a result of bulk production and trade in which the value of the vessels apparently was inferior to its contents. Secondly both contexts are found in a harbour context, well established for Monte Testaccio, possibly for Piscina Torta which was situated on a lagoon connected to the sea. In principle, the archaeological evidence from Piscina Torta may thus fit recent insights in the upscaling in the Iron Age Mediterranean of overseas trade networks with indication for the existence of bulk production and trade (Hodos, 2020). It would also fit the scenario of significant population growth of central Italy's early city states that would have required an efficient and to some extent regulated food economy (Pacciarelli, 2010b; 2010a; Cifani, 2021). In such a constellation, the role of coastal harbours, as discussed, for instance, in Demetriou (2012) for the Archaic period, was pivotal. The above scenario adds yet another perspective on the function of "reddish pottery sites". Apart from locations where pottery and salt were produced and fish and foodstuffs were salted in ceramic vessels to be transported to the inland early city states, the "reddish pottery sites" may also reflect rudimentary commercial and trading hubs linking inland city states with (nearby) overseas locations, where outgoing ships were provisioned and loaded with cargo, as convincingly described and tentatively quantified in terms of ceramic vessels needed by di Gennaro et al. (2023) for Etruscan coastal sites during the Villanovan period (10th/9th centuries BCE) (Amicone et al., 2020). In this sense Piscina Torta may prove to be an excellent case study in the context of Rome as the fastest growing city state of Central Italy. In sum, the existence of (bulk) production of salted fish and fish sauces already during the Late Iron Age and Archaic period is feasible but still hypothetical. In the current Salt and Power project our goal is to explore the nature and scale of the 'reddish pottery sites" within the context of the growing economic and geopolitical complexity of Late Iron Age and Archaic Central Italy. To this end we invest in the reconstruction of the palaeogeography of the locations of the "reddish pottery sites". The first analyses of the sediments of the lagoonal environment at Piscina Torta show that the site was located on the shore of a now vanished lagoon. The brackish lagoon at the time constituted an evaporative environment suitable as a primary source for brine production. Being connected with the open sea by an inlet, the conditions for fishing may have been excellent (Marzano, 2013). Our current palaeogeographical work is geared at reconstructing the suitability of the lagoonal environment for salt production, fishing and as a natural harbour or possibly artificial one. Next, we will try to establish the number of functions of the site based on the evidence from our on-going excavations that is revealing kilns and providing thousands of diagnostic artefacts that give quantitative information on the vessel types and their provenance, local and/or imported, for which we use XRF analyses. Also, we invest in aDNA analysis from the ceramic paste, apart from other archeometrical techniques, to establish what the broken jars exactly contained. The above components of our research programme are fundamental to explain why at the "reddish potsherd sites' such vast amounts of broken pottery accumulated. Finding this out at Piscina Torta may offer the key to understanding similar coastal sites characterized by the presence of massive dumps of reddish jar potsherds. These include the Salterns of Tarquinia (Mandolesi, 1999; 2014), Nettuno Depuratore (Alessandri and Tol, 2007; Alessandri, 2013) and La Fibbia (Piccarreta, 1977; Alessandri, 2013) in Latium, Puntone di Scarlino (Aranguren et al., 2014; Sevink et al., 2021; Sevink et al., 2020) in Tuscany, which from the 7th century BCE onward may have served the economies of the large inland protourban centres like Tarquinia, Veii, Satricum and Vetulonia respectively. A number of these sites will be investigated in the Salt and Power Project.

5. Conclusions

In this paper we have presented a methodological approach and its first results towards understanding the occurrence of the phenomenon of the numerous so-called ‘reddish potsherd sites’ that characterize the protohistoric archaeological record of Italy’s Tyrrhenian coast, as is currently being applied in the recently started ‘Salt and Power’ project. We have argued that paleoenvironmental reconstruction in tandem with geophysical prospection, artefact surveys, and excavation including the subsequent study of the pottery record, is suited to validate our hypothesis that the early Tyrrhenian city states in Central Italy in the later Iron Age and Archaic period disposed of extended protoindustrial areas dedicated to salt and food production to feed the growing cities. Furthermore, future interdisciplinary work at Piscina Torta and similar sites may clarify to what extent these sites were also engaged in overseas trade. For now it seems most relevant to establish in how far landscape processes had a direct impact on the growth of these coastal economic activities, more specifically the possibility to use sites as Piscina Torta as landing places and productive areas and when exactly they started to develop in trade hubs linking the Tyrrhenian seaboard with inland Central Italy.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data are available in the Supplementary

Acknowledgments

We would like to thank the Soprintendenza Speciale Archeologia Belle Arti e Paesaggio di Roma and in particular Dr. Barbara Rossi and Dr. Alba Casaramona, for the assistance and support they provided us during the investigations. This work was supported by the Netherlands Organisation for Scientific Research (NWO), grant 406.20.HW.013.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jasrep.2023.104361.

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