

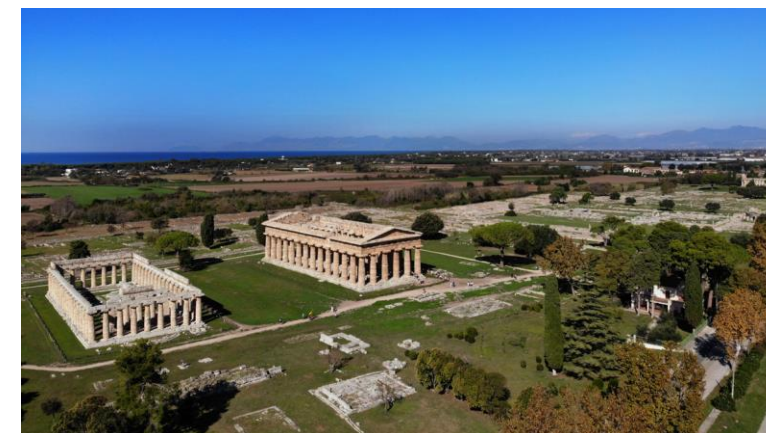
# COOPERATIVE USE OF NON-INVASIVE SENSING METHODOLOGIES FOR THE GEOPHYSICAL MONITORING OF THE ARCHAEOLOGICAL PARK OF PAESTUM



**Luigi Capozzoli**, Francesco Soldovieri, Enzo Rizzo, Ilaria Catapano, Giovanni Ludeno, Gianluca Gennarelli, Gregory De Martino, Francesco Uliano Scelza, and Gabriel Zuchtriegel



Paestum, originally called *Poseidonia*, represents one of the most major ancient Greek cities located on the coast of the Tyrrhenian Sea in the Magna Graecia territory. The city was founded by Greek colonists coming from the near city of Sybaris, in the VII century BC. The favourable position in the Terranean coast and the presence of fertile soils bathed by rivers and streams provided a rapid growth of the city that became a fundamental crossroads for the Greek settlers, the Lucanian people and finally by Romans.



The site is characterized by the presence of three Greek temples dated between the V and VI century BC in optimal conditions.

Only a little part of the area is excavated and a new impetus for archaeological activities in the last years is providing significant information about the ceremonial and social life of the fortified city.

## ARCHAEOLOGICAL AND GEOLOGICAL CONTEXT



The ancient city presents a fortified structure with four gates corresponding to the four cardinal points. A comb regular shape characterizes the ancient settlement with three main streets oriented in direction EW and a dense network of secondary streets perpendicular to the first ones oriented towards the NS direction.

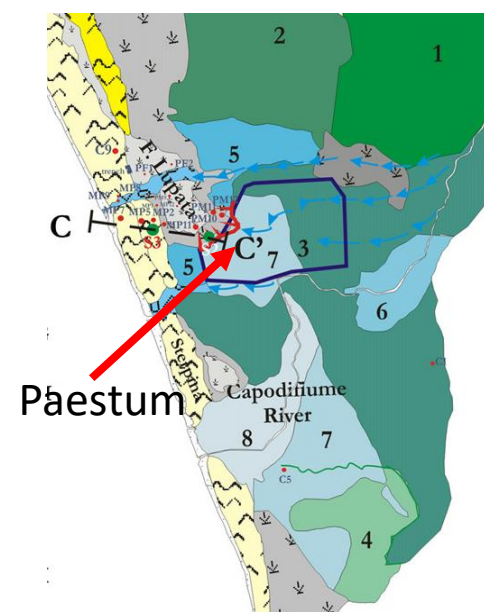
The temple of Athena is placed on the north of the three main streets, while the temples of Neptune and Hera are placed south of the agora.

The archaeological area is characterized by peculiar geological conditions that have strongly influenced the evolution and conservation of the site, and whose understanding is crucial for its protection in the course of the time. The city is placed in the alluvial coastal plain of the Sele River on terraced deposits forming the travertine platform. Some studies have permitted to identify the presence of different travertine units, that can be distinguished between the lower units, used for the construction of the city, and the upper units that, in the last two millennia have "partially buried" the city preserving its structures.

### Paestum Travertines depositional system:

- 1) Cafasso Unit (Middle-Late Pleistocene, before 50 ka BP)
- 2) Gaudo Unit (late Middle Pleistocene Late Pleistocene)
- 3) Paestum Unit (Late Pleistocene- early Holocene)
- 4) Mancone Unit (middle Holocene)
- 5) Arcione Unit (middle Holocene: before 2.5 ka BP)
- 6) Spinazzo Unit (Holocene: 2.5-1.7 ka BP)
- 7) Linora and Fossa Lupata Unit (Holocene: after 1.7 ka BP)

Modified from V. Amato et al. / Quaternary International 288 (2013) pp.112-128





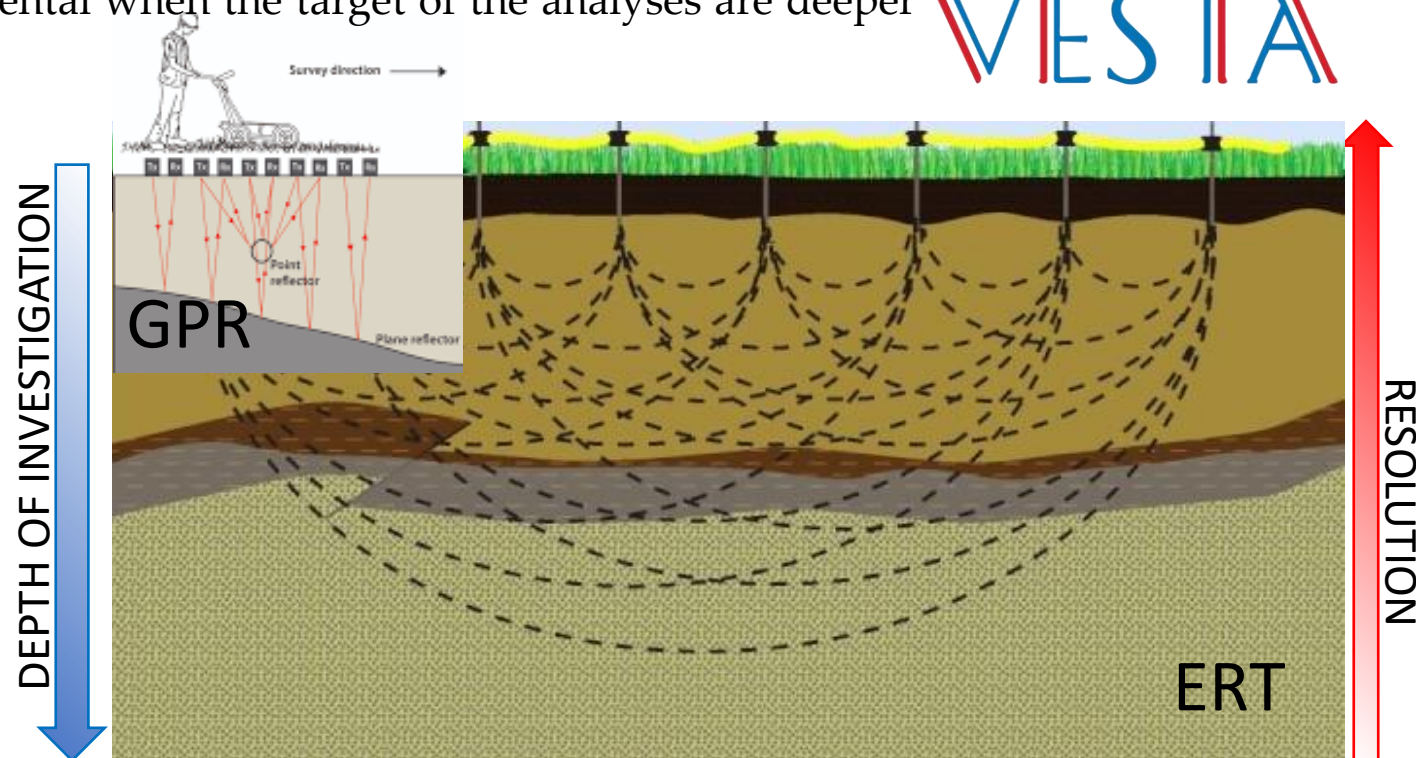
# COOPERATIVE USE OF NON-INVASIVE SENSING METHODOLOGIES FOR THE GEOPHYSICAL MONITORING OF THE ARCHAEOLOGICAL PARK OF PAESTUM

- Ground penetrating radar in the active geophysical method that provides the most high-resolution information about the subsoil and its use in archaeology is well known. However the depth of investigation is often limited and when hydrogeophysical aspects have to be analyzed, the use of other technique is strongly required.
- ERT is less used in archaeology for the limited resolution, but the greater depth of investigation and the high sensitivity to the water, make its use fundamental when the target of the analyses are deeper or paleo-morphological studies are necessary.



VIESTA

Integration of the two methods, also with other surface geophysical methodologies (magnetometric analyses) is the key for effective detecting new archaeological structures or monitoring Cultural Heritage.





# ON-GROUND TECHNOLOGIES

## DATA ACQUISITION

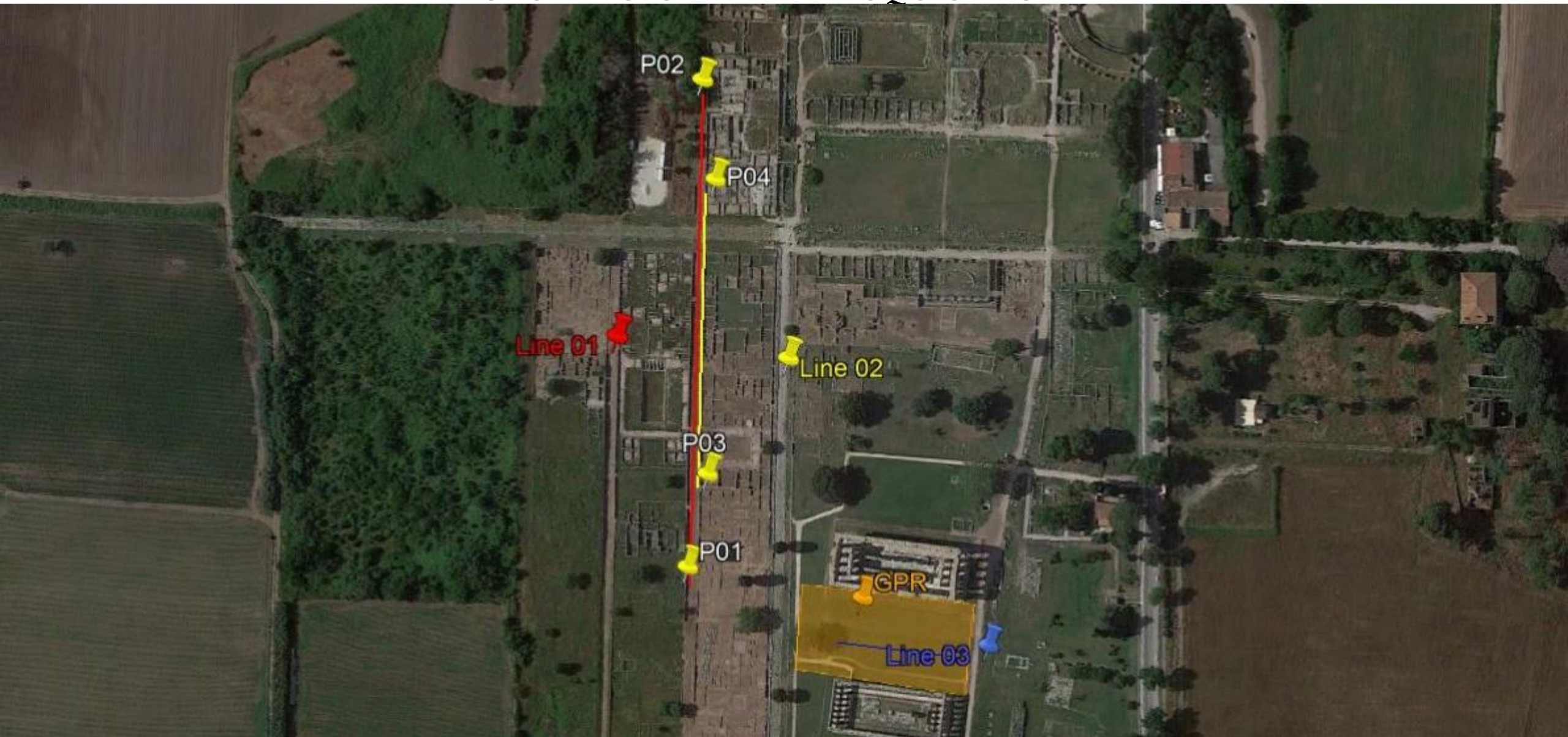
### EQUIPMENT

- Ground penetrating radar TH DUAL-F HI-Mod (IDS-Ingegneria dei Sistemi S.p.A) coupled to two bi-frequency monostatic antennae operating to the frequencies of 200 and 600 MHz
- Georesistivimeter Syscal Pro with 96 Channels (Iris-Instruments)
- G-858 MagMapper Magnetometer (Geometrics), connected to an external Smart 1 Novatel GPS antenna



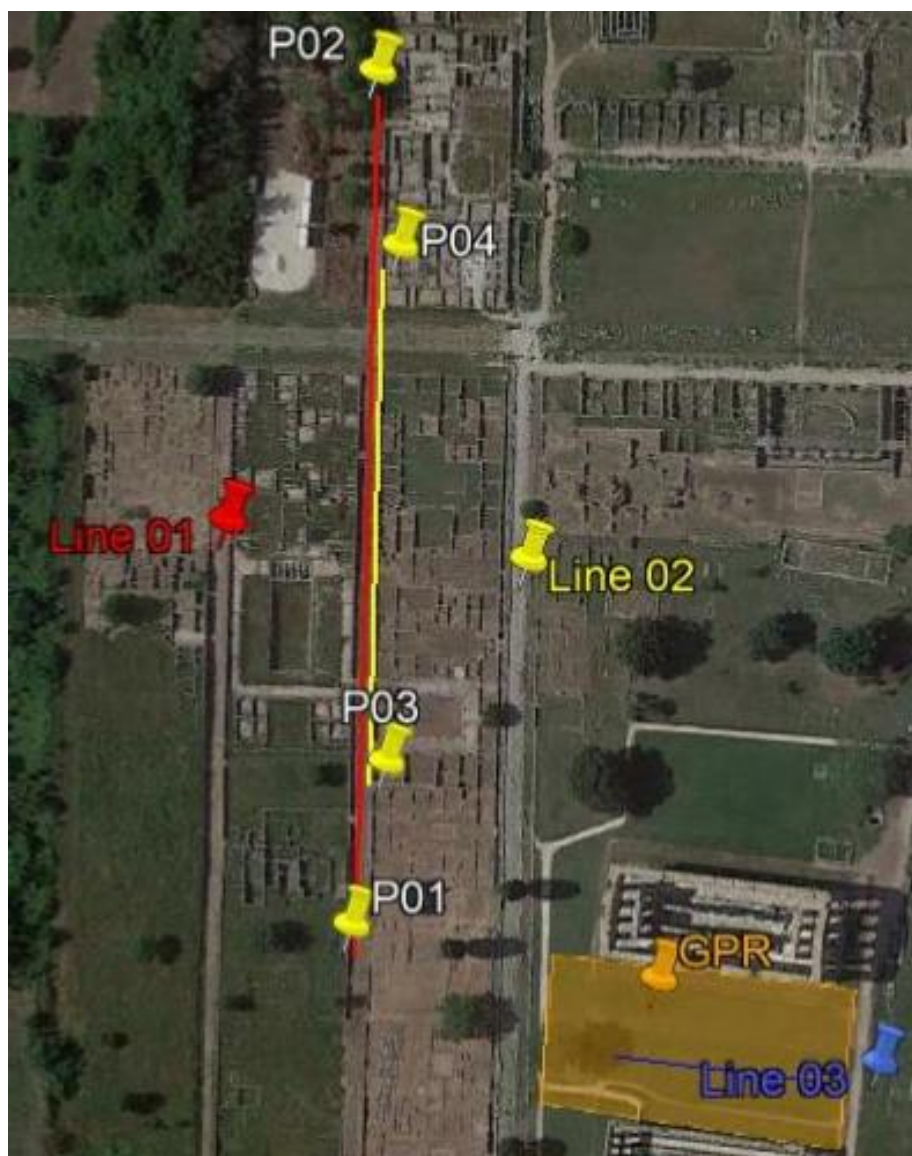


# GEOPHYSICAL DATA ACQUISITION





## ERT DATA ACQUISITION



Three transects are acquired: the first two corresponding to the lines 1 and 2, that are overlapped. Line 01 is long 235 meters between line 02 is 141 meters. ERTs according to the two arrays Dipole-Dipole and Wenner-Schlumberger are adopted for the measurements.

Electrodes are placed every 5 and 2 meters, for line 1 and 2, respectively.

The third profile is placed between the temples of Neptune and Hera. This line is long 47 meters and 48 electrodes placed every meter are used. Only the array Wenner Schlumberger is used. In this area also GPR measurements are performed.

## GPR AND MAG DATA ACQUISITION



Three areas are investigated with GPR:

- a. S1 and S2 with sizes of 8.5mx70m and 10.5mx70m, respectively;
- b. S3 with sizes of 16mx26m.

GPR radargrams are acquired every meter in only one direction, according to the axis NS for S3 and EW for the other two areas

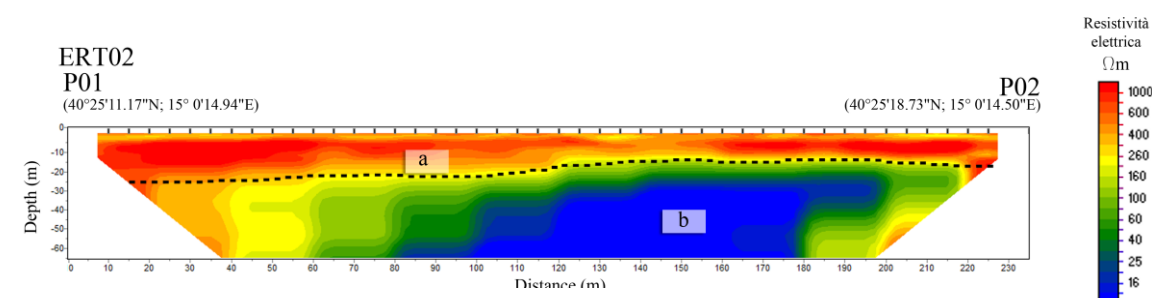
The entire area is also investigated with magnetometer coupled to a GPS antenna

The presence of some obstacles has limited investigations. The area investigated is flat and characterized by the presence of four pits (red circles) covered by metallic grids used in the past, supposedly, for collecting or storing the water.



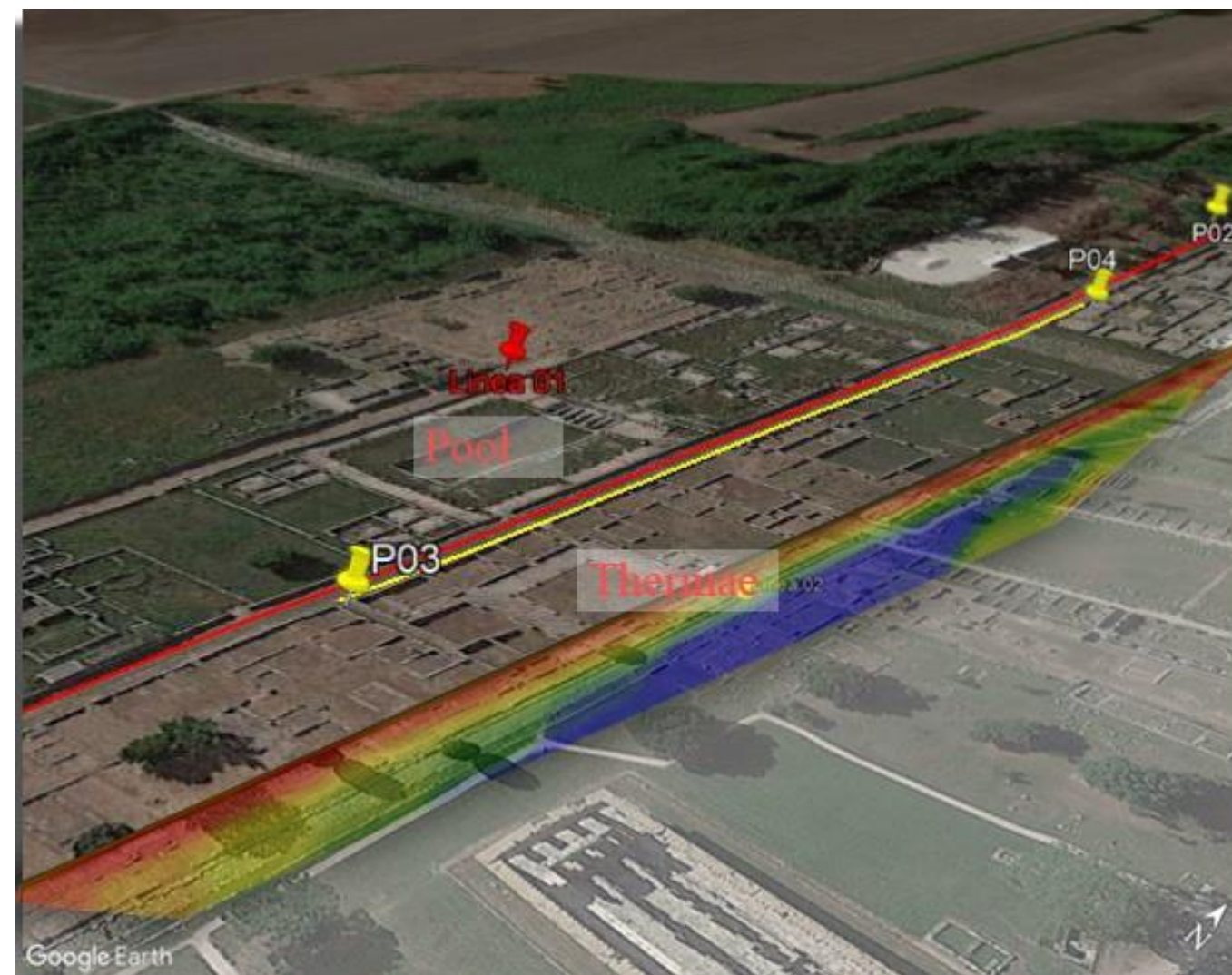
# Line 1

## Dipole-Dipole Array Electrode spacing 5 m



Two levels are distinguishable:

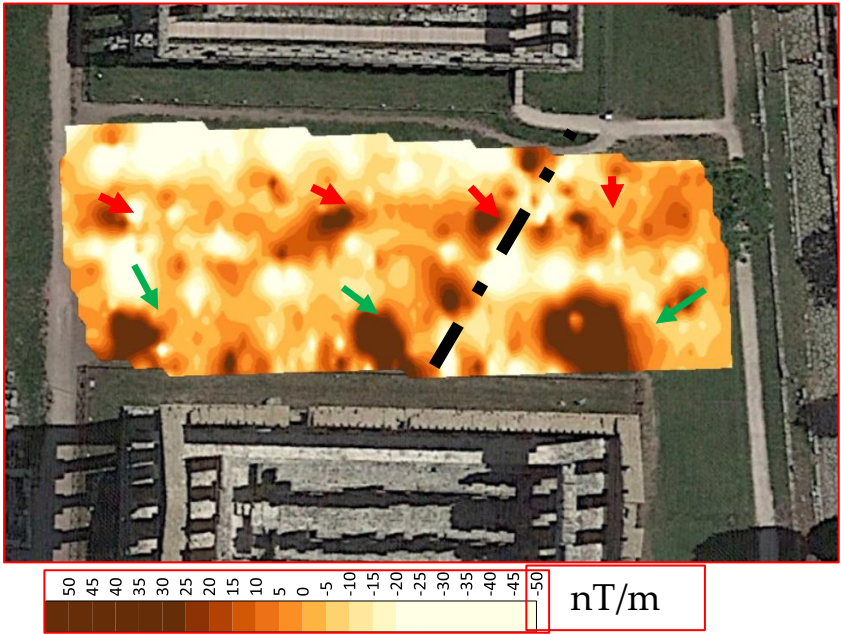
- Level “a”, more resistive, corresponds to the unsaturated travertine;
- Level “b”, more conductive, is located where alluvial units and seawater-saturated soils are expected.



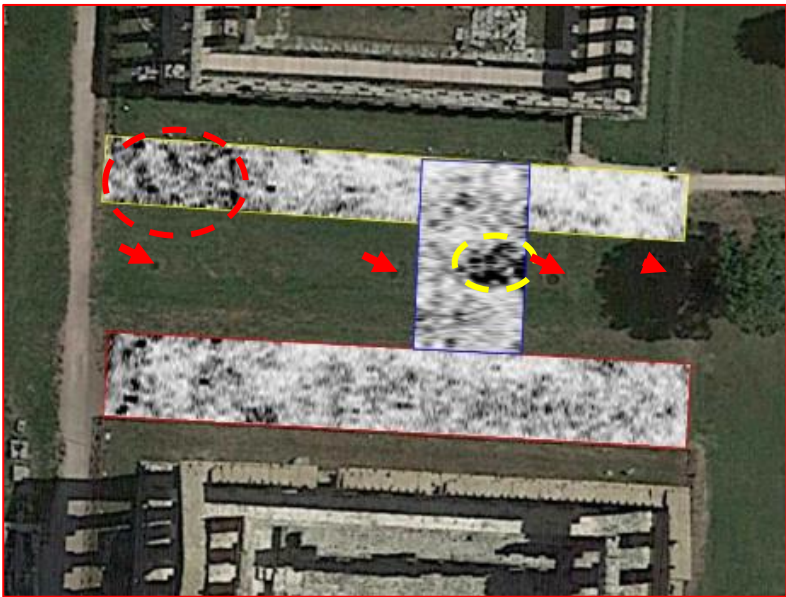


# BETWEEN THE TEMPLES

## MAGNETOMETRIC MAPS

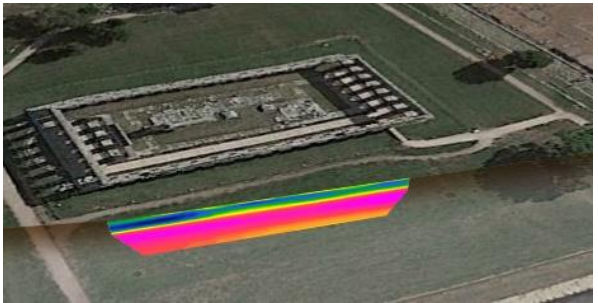
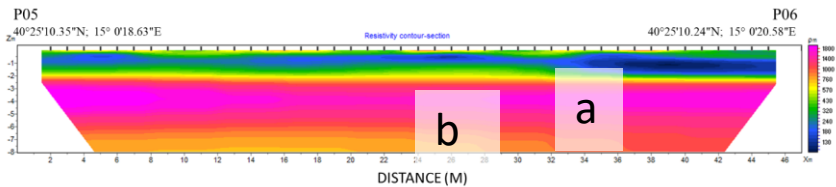


## GPR DEPTH SLICE (1M)



## WS- ERT (EL. SPAC. 1M)

“a” is characterized by low values of electrical resistivity imputable to a greater water content in the subsoil;  
“b” is characterized by high values of electrical resistivity due to the presence of the travertine geological unit.



Covered manholes

Pits

Modern irrigation system

reflections associable to the waters gathering and disposal system serving the area

Link (conduit) between the pipe



## RESULTS

- ERTs of lines 1 and 2 have identified the thinning of the upper unit of travertine characterizing the site, in correspondence of this anomaly it is possible to identify the presence of the thermae and a great pool. It is hypothesized that the geological conditions provide favourable conditions for the water supply.
- Dipole-dipole and Wenner Schlumberger arrays have provided similar results. The maximum depth reached was 40m for WS and 65m for DD. Two main electro-layers are found; the shallowest one is linked to the presence of unsaturated travertine, the deeper is maybe due to the presence of the seawater. The more resistive layer shows some parts characterized by lower values of resistivity due maybe to a greater presence of alluvial deposits.
- ERT acquired between the temples has identified the archaeological level placed at the depth of 2-2.5meters and a not homogeneous electrical behavior of the subsoil. Some more conductive zones are detected on the eastern edge of the line near the structure called “water clock” whose exact function is unknown and could be associated to the entry of the water supply system of the area.
- GPR has identified some reflections in the first centimeters due to the presence of pipes or underground utilities (depth lesser than 30 cm), also confirmed by magnetometry acquisition.
- At depths greater than 1 meter, some reflections seem to confirm the presence of archaeological structures, supposedly connected to the water storage and distribution system where the pits of the area are connected.



## FINAL REMARKS

- The deployment of novel strategies for monitoring the conditions of the archaeological sites represents a fundamental step for the conservation/preservation of the cultural heritage, especially for those located in areas characterized by high levels of environmental and anthropic risks.
- VESTA project deals with the experimental integration of advanced technologies designed for safeguarding and prospecting sub-soil and ancient structures as well as the management of the information derived from the carried-out investigations. The final goal is to support the end users regarding their conservation, safeguard and discovery activities.
- The geophysical surveys based on the combined use of geoelectrical surveys and ground-penetrating radar measurements with different resolution and depth of investigations, and the use of tomographic methodologies for the data processing, have allowed collecting interesting data for the identification of anomalies useful both to respond to the questions of the archaeologists and to give new perspectives for managing the site. Further some interesting information are collected for characterising the paleo-morphological context in the areas immediately close to the temples of Hera and Neptune and behind the ancient Forum.

## Acknowledgments

The authors would like to thank the VESTA project “Valorizzazione E Salvaguardia del paTrimonio culturAle attraverso l’utilizzo di tecnologie innovative” by which the present work has been financed. The VESTA project is co-founded by the Campania Region within the POR-FESR 2014-2020 program.