5

Archaeological Geophysics – From Basics to New Perspectives

Roger Sala, Ekhine Garcia and Robert Tamba
SOT Prospecció Arqueològica
ERAAUB
Spain

1. Introduction

The chapter aims to show a wide overview of the more used archaeological geophysics techniques and their last improvements and challenges. This will be done through two parts.

The first 5 tittles are dedicated to definitions, technical principles and a brief introduction of how the different geophysical techniques are used to answer archaeological questions.

In this first part we will also treat other methodological questions such as data interpretation or information exchange with archaeological teams, which are critical points to extract the maximum benefit from the results of a survey.

In the second part we will concentrate on the new perspectives offered by the last technological and methodological improvements in Archaeological Geophysics.

Since early 2000 decade, instrumentation manufacturers have enhanced the precision of systems, but what really meant a revolution are the stacks of sensors in GPR, magnetics or resistivity survey systems. This has brought to geophysicists a dramatic improvement in time and resolution of area surveys, in some cases multiplying by 5 or 10 the area explored in a single day, and enhancing spatial resolution of measurements by factors of 5.

Obviously these enhancements have a lot of implications in terms of cost or accuracy, but they have also created new technical problems, such as how to locate accurately the measurements at high speed or how to manage and process large amounts of data in reasonable times.

A last title will be dedicated to expose short examples of geophysical surveys.

These examples correspond to the highlights of the previous tittles, exposing the results and interpretations of seven survey cases.

The case studies shown will illustrate a wide range of sites and casuistic, from basic surveys based in one single technique, multi-system surveys or the new multi-sensor platforms. In addition, some of these cases will include excavation data to explore problems related to interpretation.

2. Basics. Imaging the subsoil with non destructive methods

The geophysical imaging techniques applied to archaeology are acquiring a growing weight in nowadays archaeological projects.

Although aerial imaging was the traditional way to open the focus to explore large areas or landscape evolution, the first generations of geophysical survey instruments in the 1980's, which were thought specifically for archaeological uses, revealed the potential of these techniques.

British, German, French and North-American geophysicists promoted an increasing specialization in survey techniques, data processing and interpretation that resulted in a well defined discipline called Archaeological Geophysics.

But in the last ten years, the capabilities of the sensors used have increased their quality, resolution and speed (and decreased their application cost) in a factor that has placed Archaeological Geophysics as one of the most valuable tools in the hands of Archaeologists.

The use of geophysical surveys to delimitate, describe or image cultural remains at low costs and in a non-destructive way allowed conceiving Archaeological projects in a different way. On the one hand, Archaeological Geophysics had dramatically enhanced the real area covered by a single project, helping archaeologists to explore large areas and to understand the sites in wider points of view, and not only by the material objects or remains. On the other hand, the information obtained in a single survey allows archaeologists to select the location of their excavation with previous information that helps optimizing their resources and increase the effectiveness of excavations.

2.1 Definition

There could be a lot of valid definitions; one of them is that Archaeological Geophysics is the non-invasive description of archaeological objects and facts by measuring the vatiation of their geophysical proprieties in the space, and interpreting them.

Out from this kind of never exact definitions, usually, Archaeological Geophysics are understood as extensive explorations made with instruments that create maps of proprieties of subsoil to obtain information of archaeological remains. But as we will see, the latest applications could go far away from this conception.

2.2 Measures, data formats, 2D/3D

As geophysics are a group of techniques that work in measuring different magnitudes of soil contents, every one of these magnitudes have their specific characteristics and a specific methodology to measure it.

Measures are taken by electronic devices that usually use a spatial reference (X and Y relative positions or geographical absolute coordinates) to record every measurement.

Geophysical techniques are also divided in the kind of spatial information that are being handled. Although magnetism could be measured in 3D, the most common applications use a single level of measurements to create an image or dataset with no direct information on depth. We call this kind of techniques as 2D. That is, single measurements placed in two space coordinates.

2D techniques also include the acquisition of profiles. The result is a vertical section similar to a stratigraphical section displaying the variations of a geophysical property. The graphical expression of this process represents the space in the X axle and the depth or time in the vertical axle. In resistivty acquisitions a profile is called pseudosection, in GPR prospection a profile is named radargram.

3D techniques are those that use multiple measurements in every X and Y points to obtain additional Z axle information. They can be built by the integration of several 2D profiles in a unique 3D block. They are commonly used in resistivity and GPR prospections.

Other techniques, such is 3D tomography use a real 3D technique, placing multiple sensors over a surface and combining them to obtain a real 3D ERT model.

In some techniques as GPR time-slice the 3D dataset is generated from the integration of several 2D datasets (GPR profiles). For example, GPR uses a directional, electromagnetic pulse that is emitted through the soil by the emitter antenna and measures his reflections with the receiver antenna to obtain information from subsoil.

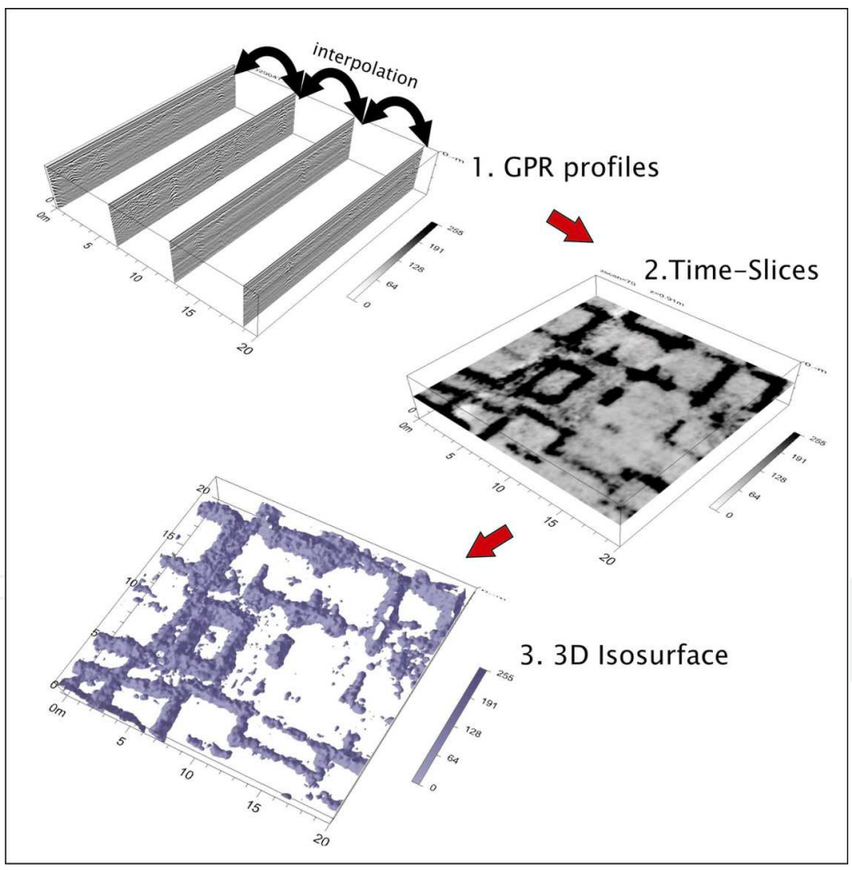


Fig. 1. 2D and 3D data. Example from Empúries Roman city site. A GPR extensive survey as an example of a 3D dataset built from 2D data. 1. Single GPR profiles are combined in order to obtain a 3D block which is represented in Z cuts (2).3. The entire information of the 3D dataset could be represented in an isosurface, establishing an opacity threshold of detected anomalies (in this case 70% of amplitude).

Measuring the amplitude of the reflections we can obtain dielectric proprieties of the soil. Measuring the delay from the emission time and the arrival time of the reflections, and knowing the velocity of propagation of the emitted pulse we locate the depth of the measurement in the depth axis. The graphical expression of this process is the radargram, which represents the space in the X axle and the depth or time in the vertical axle.

Finally, we can generate a 3D data block by integrating several GPR profiles of known position and represent it in the three axles (See Figure 1).

2.3 Typical applications

The geophysics has been applied in a very wide range of archaeological investigations, sometimes in imaginative or unusual ways.

But we can trace the gross lines of a short classification of most common surveys by their objectives.

Landscape archaeology

In combination with aerial and satellite multi spectral imagery, geophysics have been applied to study large areas of land. The speed of application of magnetic survey systems allowed projects that aimed to describe old agricultural divisions, gardens or other landscape features buried by time.[1]

Other techniques such as extensive phosphate measurements or soil or conductivity helped to carry other studies about land uses in the past[2].

Exploration and delimitation of archaeological sites

For the last 15 years it has been common for archaeological research teams involved in long term projects to use geophysics to raise again their investigations. Taking in mind that the complete excavation of some archaeological sites could be a work of decades, the possibility to explore the complete area of the site and have a clear delimitation of remains, is definitely a better way to take decisions about where to dig and why to do it.

Architectural analysis and description of specific archaeological elements

Some geophysical survey techniques, more sensible to the morphology of objects such as GPR or resistivity are used at shorter scales.

Using sensors and methodologies specifically thought for the building and engineering industry, the geophysicists have applied these techniques to solve the problems related to the architecture restoration or to obtain images from specific archaeological objects.

The capabilities of high frequency GPR are commonly used as a diagnostic tool in restoration architecture, since the use of 3D analysis could help to obtain information from hidden or non accessible objects and structures of a heritage building.

---

[1] An example of these large-scale surveys is the South-Cadbury Environs Project (UK) that has used geophysics to map extensively the Cadbury Castle area. The main aim of the project is to study the transformations of the landscape and human occupation patterns from the Neolithic to the Late Saxon periods.

[2] Magnitudes as phosphat contents or magnetic susceptibility could be mapped extensively as a complementatry layer to add information to the data obtained with other systems

Using antennas from 600MHz to 2.2GHz, the GPR could be used to image the hidden structure of a building, detect cracks on stone blocks or detect small cavities or voids. Other advanced applications use separated emitters and receivers to obtain higher resolutions.

Applications of high resolution resistivity have been used successfully to detect or delimitate cracks or to test the integrity of building materials, also using small-scale 3D configurations.

2.4 Using geophysics from an archaeological point of view

A single geophysical anomaly in a given space, it's no matter if it's magnetic, electromagnetic or electrical, could have a long list of plausible interpretations. That is because subsoil is a very heterogeneous media and there are a long number of other factors involved in measuring geophysical magnitudes that we use to characterize the contents of the soil.

There's no doubt that archaeological geophysics is a scientific discipline. But it is important to remark that a dataset obtained from a survey needs to be processed and interpreted to have a real use.

As we will see, geophysicists manage objective information (data) and must interpret it to bring relevant archaeological information. Taking in mind that anomalies could have more than one explanation, the interpretations are always uncertain in a variable degree.

But this degree of uncertainty must be pointed from an archaeological view. Thanks to the work of generations of archaeologists we have detailed descriptions of a lot of cultural remains, studies about their characteristics, building materials, and finally a growing bibliography of archaeological geophysics with hundreds of case-studies. Taking into account all this knowledge when we interpret is what makes the difference between geophysics and archaeological geophysics.

3. Overview of common survey techniques applied on archaeology

Under this heading we introduce the more usual survey techniques applied to Archaeology in a synthetic way, avoiding their physical and mathematical basements. The comprehension of these geophysical methods requires a basic knowledge in natural sciences and mathematics but they are not so far from the Archaeology as it could seem at first sight. Demonstrations of this are some good books specifically addressed to archaeologists that introduce these techniques and that will be recommended in each sub-section.

3.1 Magnetometry

The earth has a magnetic field that can be measured from the surface. This technique uses devices that measure extensively the local variations of this earth's magnetic field to describe the subsoil of a given area. The geologic materials contain iron particles in different degrees and with different magnetic behaviours. These iron particles can be magnetized by natural or human processes, creating local magnetic fields that can be measured[3]. The surface layers of earth tend to show higher magnetism than deeper materials due his

[3] A good guide for magnetic methods is *Magnetometry for Archaologists* (Aspinall et alii, 2008)

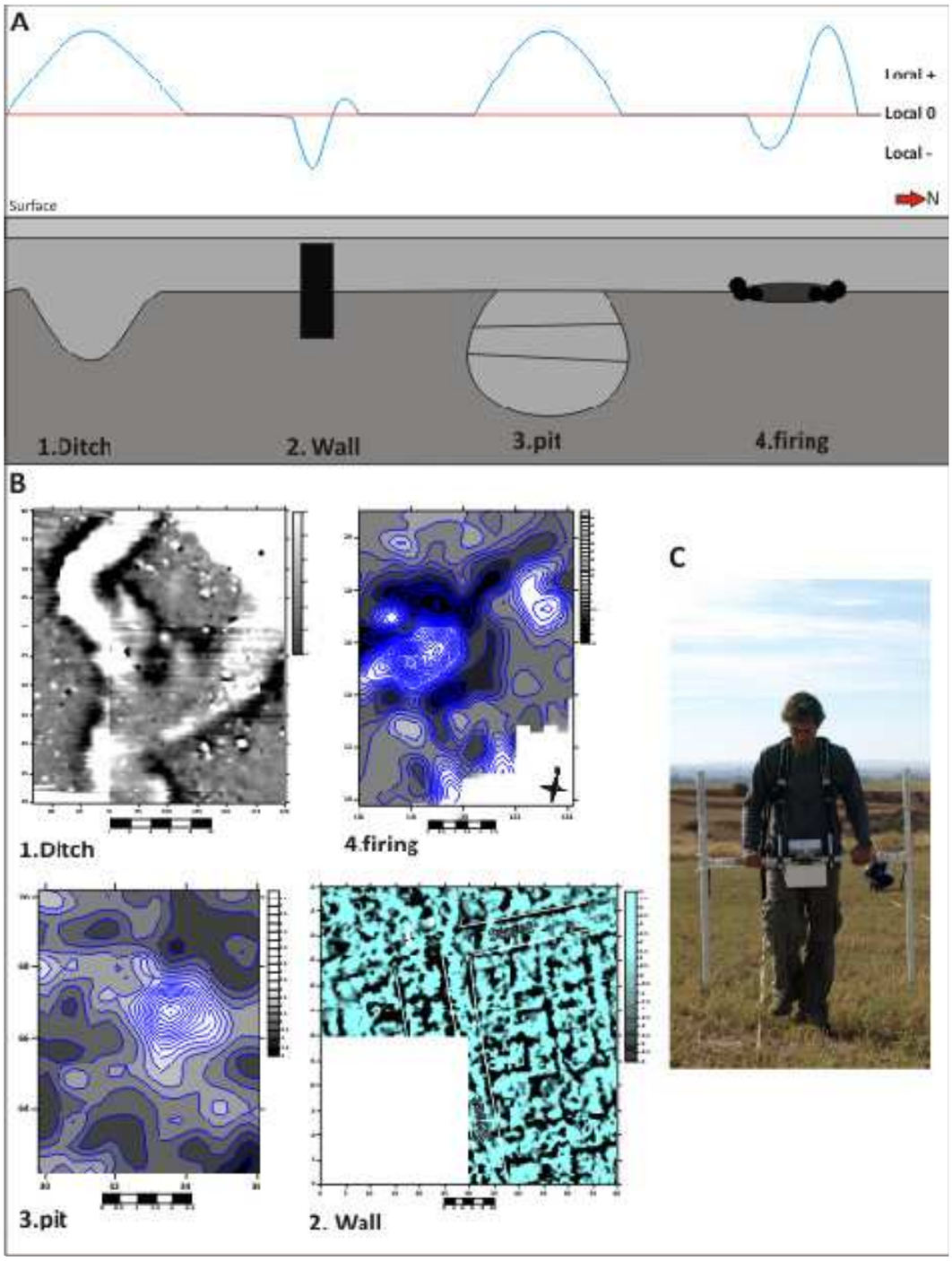


Fig. 2. Magnetism. Magnetic survey devices allow to detect some of the most important archaeological objects. At A there's a diagram showing the usual magnetic traces of tipicall arcaheological objects when using a magnetic gradiometer. B show data from real cases. An Iron Age ditch in Sant Esteve d'En Bas (Girona, Catalonia). A building mapping example from Empúries Roman City (Girona, Catalonia). A pit and a fired house at Puig Ciutat Roman Republican site (Oristà, Catalonia). C Fluxgate gradiometer Bartington G-601-

exposition to the sun, to the atmosphere and to human activity. Rocks could also have very different magnetic proprieties depending on his forming conditions and composition.

Applied to archaeology, this means that we can detect magnetic anomalies produced by the alteration of a sedimentary structure (a ditch excavated in a plain) or the anomaly produced by the rocks used in the building of a buried house. But it will always depend on the contrast between the magnetic proprieties of the archaeological materials and the media where they are laying.

That's why a pottery kiln or a burned house generates high contrast anomalies. The iron particles of the kiln building materials get polarized every time the kiln is fired, since temperatures of near 700ºC are enough to modify the magnetic structure of them. By the same reason, bricks or ceramic materials are also detected as high contrast anomalies, since they have coherent magnetic fields acquired during the firing.

The iron objects generate big anomalies according to his size and weight. This has a consequence that is one of the handicap of magnetic survey techniques. The abundance of iron in the actual urban environments, does not allow the use of magnetic systems, where the anomalies produced by these iron objects could be hundreds or thousands of times bigger than the trace of a buried wall.

The devices used in magnetometry are divided in two families depending on the method that they take measures. The total field magnetometers read the entire value of earth's magnetic field with a single sensor. Since this magnetic field has diurnal variations, geophysicists could use an additional magnetic sensor placed in a reference location to correct the survey data by this diurnal variation.

The gradiometers use at least two opposed magnetic sensors, which are calibrated in a same location. The value of earth's magnetic field in this calibration location will be taken as a conventional 0 value. The two sensors of a gradiometer measure the variations from this reference value, by recording in the memory of the instrument the difference between values measured by the two sensors in each reading point.

The depth of investigation and the resolution of magnetic acquisitions depends the distance between the ground and the sensors and of the distance between the sensors in the case of gradiometers.

These two kinds of magnetometers have a wide range of applications in archaeology, depending on the purposes of the survey. In cases of large area exploration, related with landscape archaeology, total field magnetometers are used to describe the archaeological features in relation with his geological context. When the objective is just to map archaeological remains lying near the surface, gradiometers are more used, since they describe better the local variations produced by near objects.

3.2 Resistivity

The electrical resistivity method consists in the measure of the electrical proprieties of the soil. Injecting a current in to the ground and measuring how this current gets altered we can calculate for every measuring point a value of apparent ground electrical resistivity[4].

[4] The resistivity techniques are exposed in a clear and simple way in the book *Seeing Beneath The Soil: Prospecting Methods in Archaology* (Clark, A. 1996)

There are multiple ways to inject current and measure the soil resistance depending on which depth or kind of anomalies we want to map. The most used in archaeology mapping is the extensive survey, since the resistivity variations produced by buried archaeology could give precise and geometrically consistent maps of these features. Other common application of resistivity measurements is earth resistivity tomography (ERT), where, the electrodes are disposed in a line to generate a single section of electrical proprieties of the soil. A number of systematically positionned ERT sections could also be combined to generate 3D models of earth resistivity.

The depth of investigation of a resistivity measure is directly conditioned by the relative position of electrodes that inject current and the ones that measure the resulting variations by his pass in the ground. After this, the modern resistivitiy survey systems take multiple measurements in the same location by activating sequentially the measurement of electrodes with different spacing. Thanks to this, we can obtain several maps resulting from every electrode configuration.

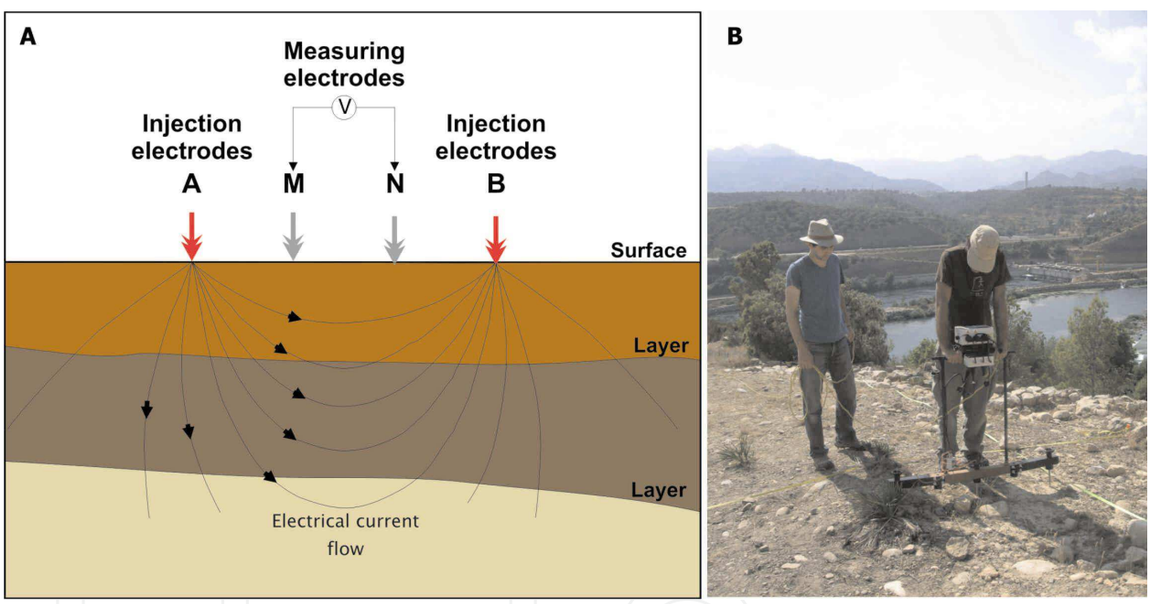


Fig. 3. Resistivity. A. A diagram of an ideal resistance measure (wenner array). B. RM-15 resistivity meter during data acquisition. This popular instrument uses a specific array called "twin" array. This electrode system places a pair of electrodes (A, B) fixed away from the survey area and uses a mobile pair (B,N) to take the resistance readings in every measuring position in the grid.

A significant part of buried human activity remains could be mapped with a resistivity survey. Walls and building materials tend to be more resistive than sedimentary soils as well as cavities, ashes or paved floors. But as other methods, resistivity surveys have his specific handicaps. The humidity and mineral composition of the soils could determine the success of an electrical survey in dry conditions, since the conduction of electricity could get more or less stable depending on these factors. In addition, the quality of the measurements is also influenced by the contact between the electrodes and the ground surface, and by the time spent in take every reading.

Although manufacturers as Geoscan Research have recently put on the market a new wheel electrode system that enhances the speed and resolution of area surveys, one of the traditional problems of resitivity extensive surveys was the time spent in the fieldwork. The operator must introduce the electrodes in the ground at every reading position manually, which can be a slow and hard work for large area surveys.

Other high speed resistivity systems as ARP are actually used in Europe in archaeological mapping of large extensions.

3.3 GPR

The Ground Penetrating Radar (GPR) is a survey method based on the principles of electromagnetism. An electromagnetic, directional pulse of known proprieties is generated by the system and transmitted into the ground by an emitting antenna. The changes in the propagation media of this pulse (the ground) generate reflections that are recorded by the antenna receiver sequentially depending from their arrival time. The memory of the GPR system records a sequence of amplitude values for every reading position in a time lapse. Knowing the velocity of the pulses into the ground we will be able to calculate the depth of the objects that produced the reflections recorded at a given time[5].

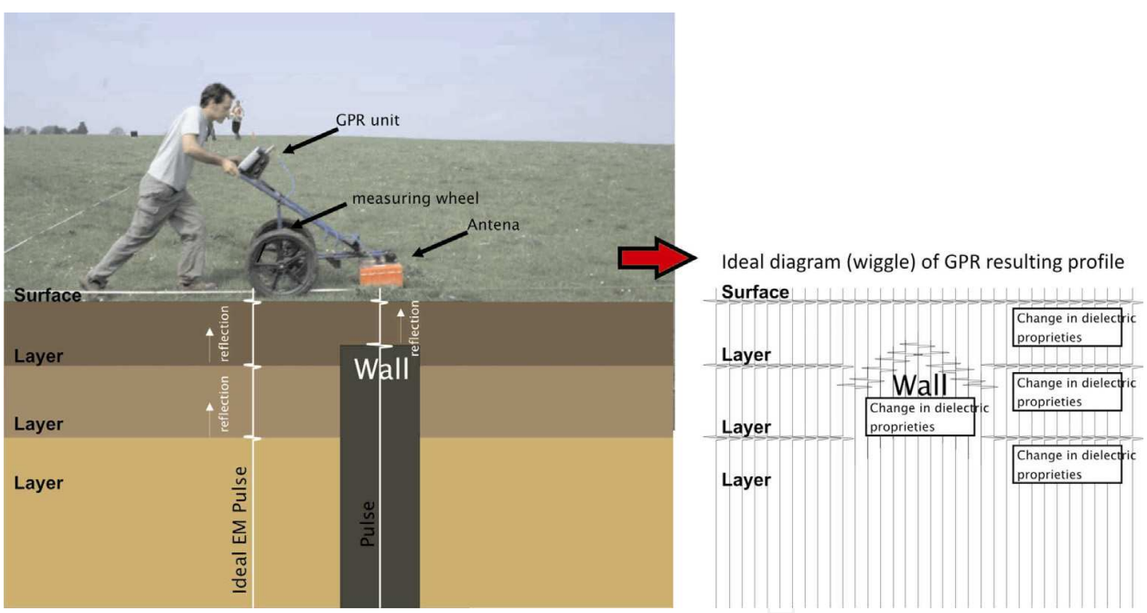


Fig. 4. GPR. A GSSI SIR-3000 GPR system. The system generates electromagnetic pulses that are emitted by the antenna. The pulses reflect a part of their energy with every change in dielectric conditions. These reflections are received by the antenna and saved in the memory of the instrument according to his arrival time and his amplitude. The result of this operation is a GPR profile, where every pulse is represented vertically, and the motion of the system is represented by the horizontal axis.

[5] A good manual of GPR adressed to Archaeology is *Ground Penetrating Radar: An Introduction For Archaologists* (Conyers & Goodman, 1997)

The electromagnetic pulse generated by the GPR system get modified in his travel into the ground attending to the dielectric proprieties (conditioned by proprieties such as conductivity, porosity or humidity) of the media. Every change of these parameters generates a reflection of a part of the pulse energy, and therefore an attenuation of the power of the original pulse that continues his travel on the ground. The depth range is determined by this loss of energy and directionality of reflections, as the returning pulses from the ground can not be discriminated from noise.

Another important factor in the GPR operation is the frequency of the emitted pulses. The usual frequency range of GPR antennae is located between 24MHz and 2.1 GHz (2.100MHz) in most of commercial systems, but the most applied in archaeology varies from 100MHz to 900MHz.

Lower frequency pulses could travel deeper into the ground than higher frequencies. In the other hand higher frequency pulses loss his energy in short depth ranges, but they get modified by smaller objects.

Applied to archaeology, this means that lower frequency antennae allows us to reach greater depths but could not describe small objects. Higher frequency antennae are more efficient in describe shallow and complex objects.

The result of GPR measuring files are usually represented in radargrams. the radargrams are diagrams of reflection strenght where the motion of the antenna is represented in the horizontal axle and the vertical axle represents the increase of time from the pulse emission or calculated depth.

One of the challenges for the use of GPR in archaeology is the complexity of results, since the shape of anomalies described in the radargrams does not correspond necessarily with the real geometry of buried objects. One of the last improvements in the GPR methodology is the *time-slice* technique which has introduced a visualisation method of area surveys that meant a decisive step in the information exchange between geophysicists and archaeologists.

The GPR area surveys consist in the covering of an area with profiles of known position. The time-slice technique uses these profiles integrating them mathematically to obtain a single 3D file that can be examined in the three axes. The use of time-slice cuts (plain views of data at the same time or depth) is a powerful tool to explain the results of a survey, since they represent buried objects in a similar way that archaeologists express their work.

Consequently, the results of a GPR area survey could be expressed in a sequence of time slices at increasing depths. This way, the archaeologists can obtain an overview of the subsoil contents and locate and plan the excavation areas or study the shape of archaeological features according to his depth.

3.4 EMI and other techniques

The geophysics apply a long list of other methods to study the geology which are based in the measure of other magnitudes. These methods are less usual in archaeological works by reasons of scale of measure or by their application methodologies. Techniques as gravimetry, or seismic refraction are methods designed for civil engineering, mining or geology imaging and are used at resolutions that exceed the size of archaeological objects.

Other methods, as thermography or LIDAR can also be applied to solve multiple questions related with geophysics although they come from other scientific and professional fields[6]. The EMI (Electromagnetic Induction methods) are another family of geophysical methods. They have been applied intensively in agriculture and in metal detection. The EMI are survey techniques based in the emission of magnetic fields by a coil of wire (transmitter) and the measuring of the electromagnetic reaction of the ground with another coil of wire (receiver). The system is based in the principle that a time-varying magnetic field could generate a time-varying, induced electrical current and vice versa. The transmitter coils of the instruments generate a time-varying magnetic field of a given frequency, which induces time-varying currents in the ground objects, in more or less intensity depending on his electric proprieties. These induced time-varying currents are measured by the receiver coil by the magnetic field they induce giving a value of the apparent conductivity of the soil. The frequency and phase of these induced currents are also measured to obtain additional data relative to magnetic susceptibility. The distance between the transmitter and the receiver and their orientation define the depth of investigation and the resolution of the measurements. Equipemnts with several receivers allow simultaneous acquisitions of several depth levels.

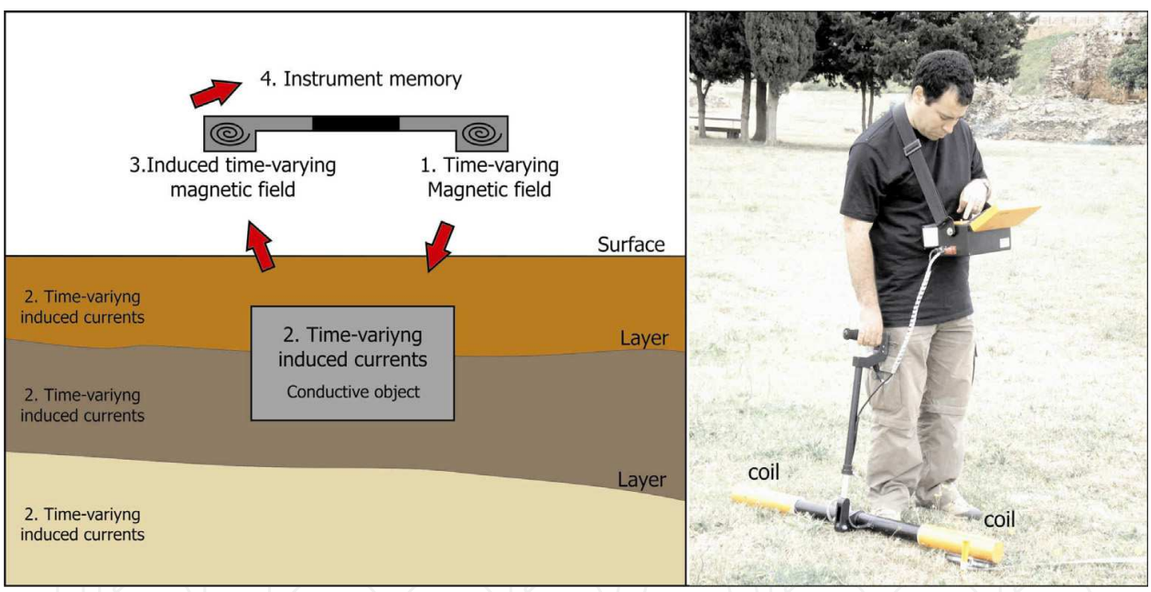


Fig. 5. A EMI instrument function diagram. At right, the geophysicist Mahjoub Himi taking readings with the GISCO CMD conductivity meter in the site of Ciutadella de Roses (Girona, Catalonia)

The archaeological applications of EMI instruments are wide if we think in terms of applicability: it is a fast method wich can be used to survey large areas and in some conditions the conductivity maps could give relevant information about buildings, metals or stratigraphyc alterations. Unfortunately, maybe because of the complexity of data interpretation, maybe because of tradition, systems such as EM-38 or EM-31 are less usual in archaeological works than magnetic or GPR methods.

[6] An exhaustive presentation of the preceeding techniques and gravimmetry, seismics or EMI methods could be found at *Handbook Of Geophysics And Archaology* (Witten, A., 2006)

Other EMI devices are metal detectors. Even if they are maybe the most popular geophysical instrument, their applications to archaeology are restricted to some specific fields. Most of these devices do not allow recording data since they are conceived as a tool to locate objects without spatial references. The Archaeology of Conflict uses metal detectors in combination with GPS to locate and map metal objects related with battles, military camps or other human activities that could leave a dispersion of metal objects in the shallower layers of the soil. The objects obtained and their positions are studied statistically in order to locate and map a conflict area or a battlefield.

Besides this recent applications, the use of metal detectors is well known by archaeologists since it is one of the most destructive tool in hands of "treasure hunters". Illegal excavators use metal detectors to locate valuable objects which they remove from archaeological sites, destructing their archaeological context. A sad reputation for what should be just another tool.

4. The first step. Adapting methodologies to each project and to each site

The investment of a survey comes most of times from an archaeological "problem". An archaeologist could need help from geophysics in the situations where a previous knowledge about buried features could help to take decisions, or to interpret his own work.

4.1 The archaeological questions

In order to reach its objectives, a geophysical survey must be planned from the begining placing the archaeological questions to be solved as the main axis of the work. It is no the same to delimitate a site of 16 hectares (where resolution should not necessarily be high) and to obtain a precise diagram of a specific room in a building to locate a mosaic

In a singular site, let's say a Roman pottery factory, if the main archaeological question is to locate a group of kilns, then a magnetic survey should be applied. But if the aim of the survey the structure of pottery workshops, in that case it would be better to use GPR, Resistivity or EMI.

But what if the Roman Pottery Factory was placed in a Field in the south of England? Or if it was in Sicily? Or buried in a Mediterranean forest in Girona? External conditions influence the viability of archaeological geophysics and sometimes are decisive.

For that reason it is always recommended to obtain the more information as possible about the site characteristics, chronology, geology and environment conditions or accessibility.

Therefore, it's important to adapt the survey strategy to a clear objective, selecting the right system and using it in the right parameters to obtain relevant information.

4.2 A complex media and unknown targets

To understand why archaeological geophysics is sometimes so complex, we can take a look to the media where it takes place.

The soil, and in particular the archaeological soils are a heterogeneous media. The most of archaeological projects where geophysics are used work in a lapse of 3-4m under the

surface. This first layer of the geology is variable by definition, since is the part of the soil involved in erosion phenomena and human activity. In consequence, the geophysical methods applied to obtain information of the subsoil can detect a long range of anomalies, sometimes not related with human activity.

A good archaeological definition of the targets and his context will be always helpful to design a good survey strategy and to interpret rightly the obtained data.

4.3 Measuring the right magnitude (if it's possible)

An archaeological object, let's say a burned, medieval house buried under a modern cultivation field, has several measurable physical characteristics. It could have a particular magnetic trace if the fire that destroyed the house has reached high enough temperatures to modify magnetism of building materials and his context. If the basement walls were done in stone, we probably can obtain images of them with area surveys of resistivity or GPR , and even describe the debris areas.

Indeed, we can obtain different views from the same object, measuring different magnitudes with the right sensors at the right resolutions. But, unfortunately, things are not always so simple.

The external conditionings are most of times a decisive factor. The first and most important is local geology. The geological context of a site could determine which method will give us more information or even eliminate some of them. For example, we can't pretend to detect a ditch in a site with magnetics if it's located in the downtown of your city. If we try to obtain a plan diagram of a roman site in a desertic context, it could be easier to do it with GPR or magnetics, since the low humidity of the soils could complicate the use of resistivity.

Another decisive factor is the resources or time we could spend in the survey. This could condition the area that we can explore, the data resolution that we can expect to obtain or the number of different sensors we want to use.

4.4 Resolution

Spatial resolution of the surveys could be a very complex matter, but it's reasonably simple in what is essential. In area surveys we can not expect to image correctly objects smaller than our measure spacing. The data should be collected in a resolution or in lapses smaller than the size of the archaeological object we want to describe.

A building of 40cm thick walls could not be well imaged in a GPR area survey using a space between profiles of 80cm.

Also, there's a structural limit for the resolution in survey systems, over which it has no effect in the sharpness of the images to increase the real data resolution[7].

Some investigators have reached spectacular results increasing the resolution of 3D GPR surveys until few centimetres.

[7] This is the case of traditional GPR systems, where our spatial resolution depends not only on our reading resolution, but also the frequency of the antenna used.

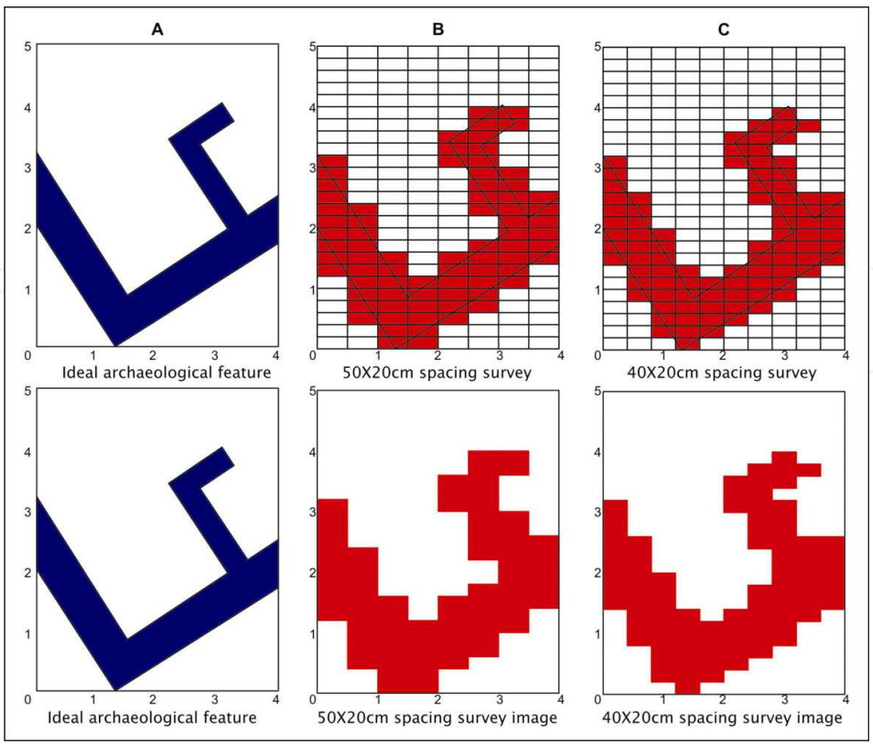


Fig. 6. Survey Resolution. At top-left, an ideal plant of an archaeological feature. The upper right diagrams show grids representing a 50X20cm and 40X20cm data resolution, respectively. Assuming that the feature was detected at every measuring position, the resulting representations are shown in the lower row with the ideal archaeological feature.

The new GPR antenna arrays or the gradiometer stacks that some manufacturers are putting in the market from 2000's, offer the possibility to survey large areas in spacing between profiles of 6 to 12cm, and it seems that this could change the way that geophysics are applied in archaeology.

All this could suggest that more resolution is always better, and possibly it is. But in cases that we just need to locate an object or to delimitate a settlement, resolution is not as important as the accuracy of measurements.

After all, the area covering and the spatial resolution of a survey will be one of the main components of the survey costs for its implications in terms of field work (data collection) and the further data analysis works.

4.5 Multiple factors. A survey plan questionnaire

Once the archaeological questions are exposed, we have seen how multiple aspects influence the methods and instruments that we use and how we use it. All this aspects, from the archaeological targets to the local geology or the external conditionings should be cleared at the start of every project.

In the figure 7, we reproduce a questionnaire created by Ekhine Garcia as a list of basics to create a survey project from zero.

Some of the information collected from the archaeological teams to plan the survey will be also used in the data process and interpretation of the surveys to understand the data. It is also recommended to collect and organize additional documentation. Counting on aerial imagery of the site of different chronologies, stratigraphic sections of previous archaeological works, geological analysis of soils or simply the archaeologists experience in the site's period could make the difference of a successful survey.

1. Previous information availability.
   Excavation reports
   Aerial imaging
   Preliminary delimitation of the site
2. What is the extension subject to exploration?
3. What is the geologic context of the site? (clay, sands, limestones, silt)
4. What kind of archaeological features are expected to locate/map?
5. What building materials are expected?
6. Is it expected to find burning structures (pottery or metal kilns, fired areas)
7. At what approximated depth are the structures expected, what is their expected depth range?
8. Could the site contain overlaying building levels?
9. Which detail level is needed?
10. Is it a dry or humid location? Could it be stationally? Which are the extreme seasons (rain, hot, etc..)
11. Is the site placed in an urban area? Vicinity of airports, electric facilities, communication antennae?
12. Are there metal objects fixed near the survey area (litters, enclosures, informative displays.
13. Is there any building in the survey area?
14. How is the surface covering? Vegetation (how high is it)? Sand? Concrete pavement? Cultivation field?
15. Is it a flat area or are there slopes in the survey area?
16. Are there obstacles in the survey area. Could we have images of the condition of the survey area.
17. Accesibility. Could vehicles arrive to the survey area?
18. Must the survey results be included in a GIS project?

Fig. 7. A simple questionnaire designed by Ekhine Garcia to plan a survey. It resumes in a short document the questions relative to the previous documentation available, the archaeological characteristics of the site, and the ambiental and logistic conditionings to trace a first survey strategy.

5. Data processing and interpretation

After a survey, the data collected are analyzed and processed in order to correct errors or to enhance quality or visualization. The objective of data processing is to extract as much information as possible from the datasets to be used in the further interpretation process.

But the interpretation will not be done just over the geophysical data, since there will be necessary to take in mind the previous archaeological information collected.

5.1 Data processing

Once the data are collected, they should be processed to remove undesired "noises" or positioning errors caused by the systems or field operators. After this the data could be statistically analyzed or enhanced in order to obtain the most information as possible from it.

Usually, the data resulting from a survey consists in a numeric file that contains a magnitude value for each spatial coordinate measured.

A first step in the data processing is to evaluate the quality of the acquired data. The objective of this step is to correct the errors in the position of measurements or to eliminate the wrong readings that could create artefacts if they were taken as real anomalies.

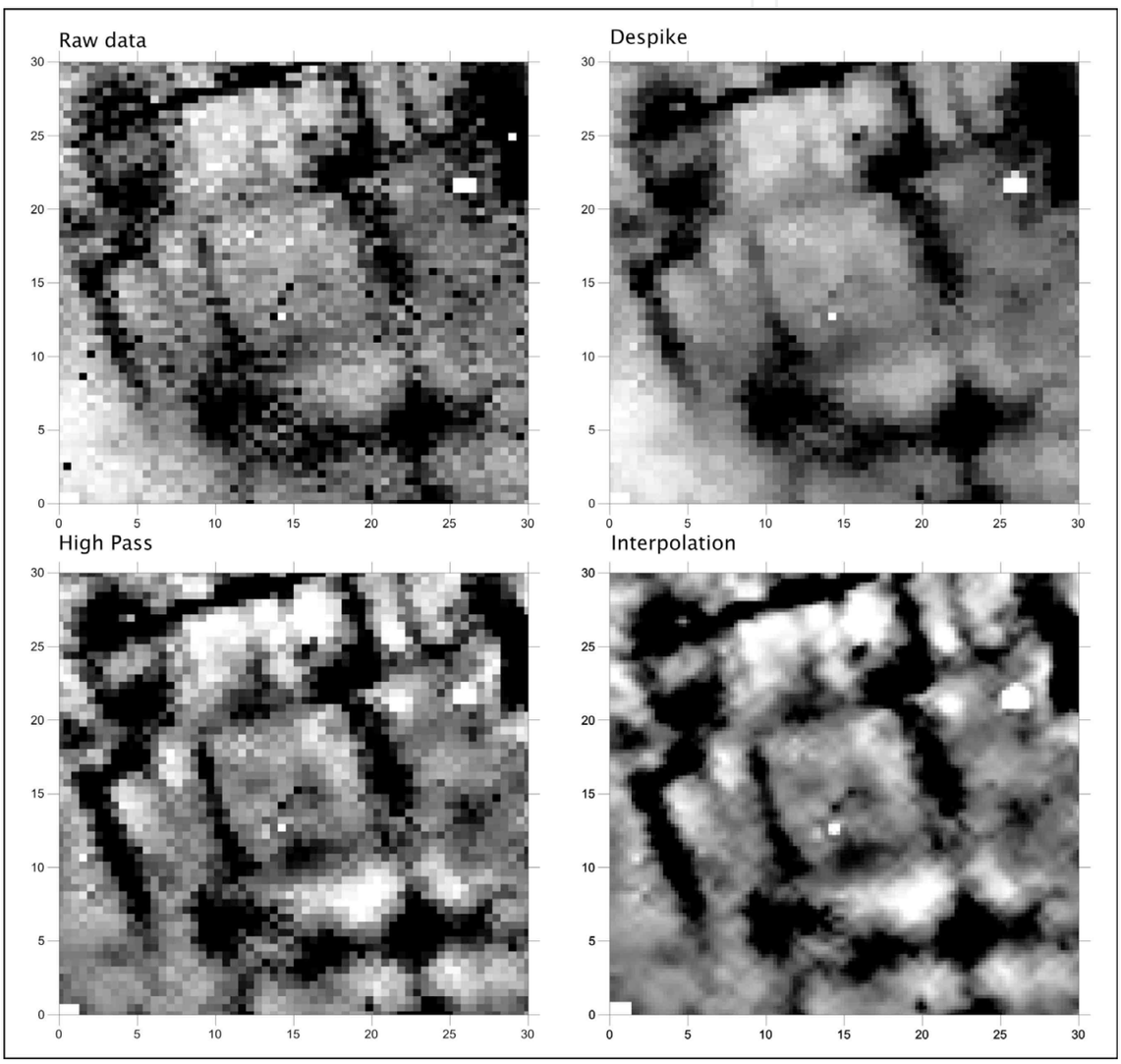


Fig. 8. Data processing. An example from a resistance survey (RM-15) at the archaeological site of Irulegi (Lakidain, Basque Country). The images show the same dataset with different processes applied. The raw data are despiked, in order to eliminate over-range readings. A High-Pass filter enhances the view of local anomalies. The interpolation increases the resolution artificially to achieve a smoother image of anomalies.

Some geophysical survey systems, as magnetics or EMI could need other additional statistical corrections to obtain clearer views of the data or to create a single, consistent dataset.

These data files are treated with statistical/mathematical tools called filters, used to enhance the contrasts of features, smooth the shape of detected anomalies or to study a specific kind of anomalies.

The data files could be also processed to extract other statistical information that could bring qualitative information that is not evident in the original data. In data processing, geophysicists start the data interpretation. A correct use of available information will be helpful to understand how to process data, and also a well processed data could be basic to reach a good interpretation.

5.2 Visualising data

The creation of data representation is a sensible point in the further data interpretation and communication. The 2D methods like magnetometry or extensive resistivity are usually represented as plan, colour or monochrome plots, where every data location is assigned to a single pixel. The colour of this pixel will depend of the measure obtained in its position.

The imaging of GPR data is more complex because of the special characteristics of his data.

A GPR profile could be represented as a single profile or vertical section called radargram. The GPR 3D imaging techniques start with the integration of a group of profiles which are

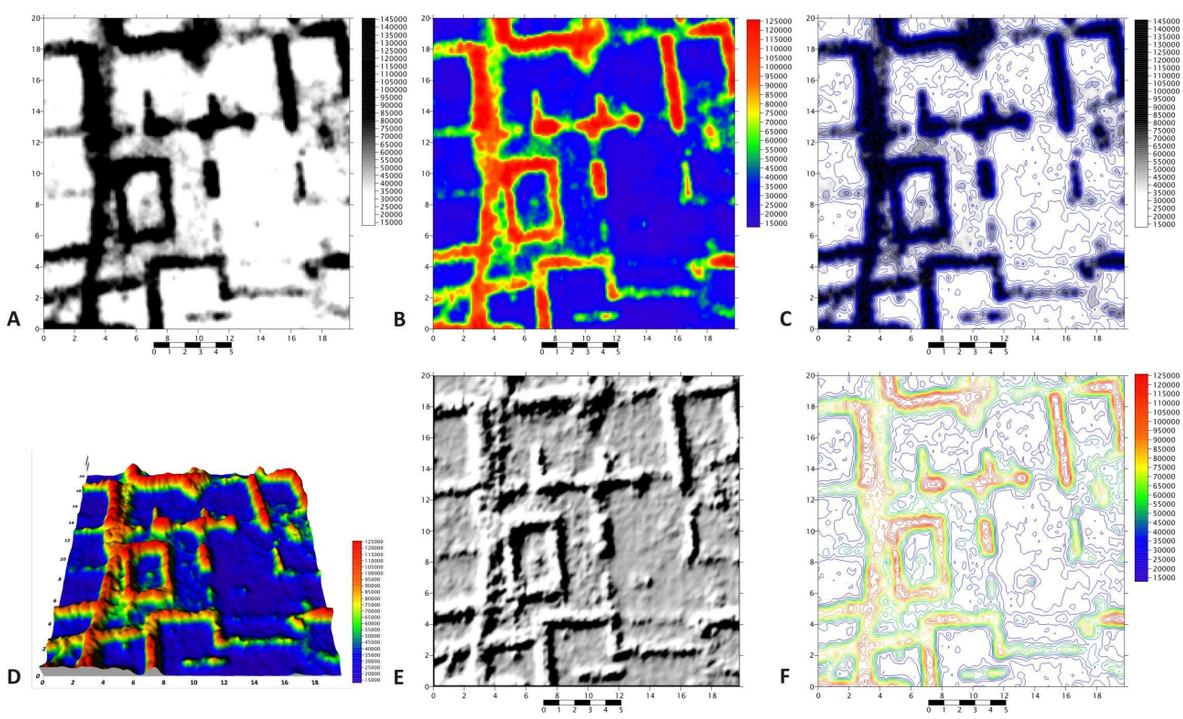


Fig. 9. Data visualization. Some examples of plots of the same time-slice (Empúries Roman City, Girona, Catalonia). A. Greyscale plot, B. Multiple colour plot, C. Greyscale with overprinted contour lines. D. Pseudo-3D relief plot. E. Shaded relief plot. F. Coloured contour lines.

collected under the same spatial references. The data of all this profiles could be resampled in a single 3D data cube to generate views in the three axles, allowing the visualization of the data from different perspectives.

One of the most used view tools in archaeological geophysics GPR is the time-slice technique, which generates sequences of plants representing different depths (or times in the pulse travel into the ground). Although it could be considered as an imaging technique, it requires a specialized processing of data that could generate spectacular images of archaeological features.

The use of 3D visualizations is a help to understand the position of anomalies and to show images of subsoil features to archaeologists in a visual language.

Although there is many ways to plot a dataset, the main objective of this kind of graphics is to communicate, to show which part of the data we are interested in.

5.3 Data interpretation. A team work

Although in some particular cases the interpretation of high-resolution datasets could look like a geometry question, the work of translating archaeological geophysics to archaeological information is not always so easy (see figure 16).

In essence, the interpretation of the data consists in offering plausible explanations for geophysical anomalies. The hypothesis or interpretations should be based on a previous given information and the results of the survey. To systematize this process, the problem is that no one of these two factors is predictable or constant.

There's a long list of factors involved in the final quality of data obtained in a survey. The ones that we can know or control are the particular system used, the local geology and the condition of the surface of the survey area, the field technique applied, the resolution of the acquisition and the ambient or weather conditions.

Another group of factors are the ones that we ignore. They are also determining the data quality in some cases: the conservation degree of the archaeological elements that we are trying to describe, the existence of other more recent features over the ones that we expect to find, the geometry of the features to describe and the materials used to build them.

Once the data have been examined and processed taking into account all these criteria, starts the interpretation itself.

As seen before, the information and experience of archaeologists in their own fields could be crucial in the right planning of geophysical surveys. For the same reasons, in the interpretation process, the geophysicists must hold a dialogue with the archaeologists and take into account the previous information available about the site, and all the factors exposed above.

A good way to start this dialogue is to share preliminary reports with the archaeologists or the research team. This could help to introduce the visual language of geophysical plots, and to obtain first interpretation suggestions. A geophysicist could take the magnetic trace of a buried trench filled of debris materials as a building wall, since they could generate similar images. An archaeologist that is familiar with his own site could discard it as a wall by the orientation or depth of the anomaly that is generating in the data.

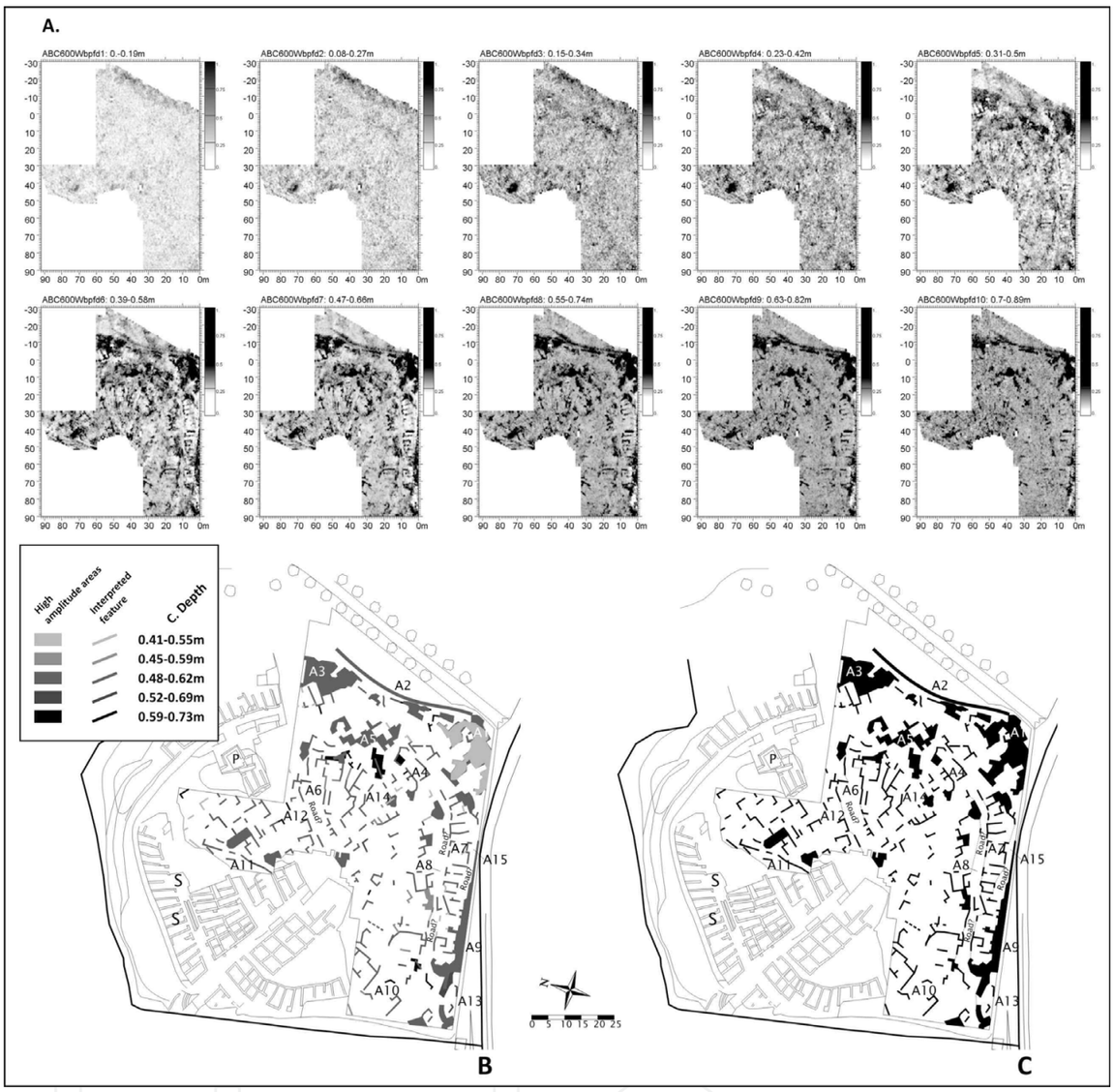


Fig. 10. Interpreting data. GPR survey at Molí d'Espígol Iron Age site, Tornabous (Lleida, Catalonia). A shows a time-slice sequence from 0 to 1m depth. B is a coded diagram with detected features in a scale of greys according to their calculated depth. C Represents all the detected features in black.

Taking the results of this dialogue and the survey results, geophysicists create the survey report, containing the representation of the results and their interpretations. The results could be exposed in different kinds of plots, but the interpretations are usually represented in coded diagrams (Figure 10).

At this point, the question is what should we explain in the interpretation and how should we explain it. If we only describe the shape and position of anomalies, we will get a simplification of the survey results. If we take too much "risks" suggesting detailed geometries for the buried features from ambiguous anomalies, we will generate to much expectative from uncertain informations. In front of this, common sense is the best ally: it's recommended to let clear in

the text and graphics of the report which are the most consistent information extracted from the survey and which are just possible or probable explanations.

For the same survey area, all this process could vary depending on the previous information available, the quality of the data and the system used. But in multi system surveys, when we combine and compare more than one magnitude obtained in the same survey area, the interpretation could be more complex.

The aim of this kind of surveys is to obtain two or more datasets from the same area which will give us complementary information about the subsoil contents. The building remains of a roman villa could be described in a GPR or resistivity survey and complemented with a magnetic survey to locate fired areas, high contrast building materials or iron objects in the same context. The result of multi system surveys could bring more information and, this is the main point, more consistent, since it will come from a cross validation of more than one survey technique and the sum of qualitative information extracted from each of those techniques.

6. Multi-system surveys. Solving archaeological questions from multiple points of view

Multi system surveys are used in some cases to describe the same survey area from the different physical points of view. The combination of datasets resulting from several survey magnitudes could bring us different information that could be combined to obtain a sum of subsoil proprieties which is not possible to reach applying just one kind of measures.

There are two main cases where multi-system surveys are usual. In cases where the objective of a survey is to delimitate and describe a site, the delimitation of the archaeological remains could be determined using a fast method as magnetics or EMI. After this first approach, the most interesting areas could be explored with higher resolution or more effective techniques to obtain detailed descriptions of specific features.

The other typical group of cases where multi-system surveys are applied is when a project aims to obtain detailed descriptions of buried remains to locate a specific target or to draw an excavation strategy for the survey area. In these cases, the use of multiple survey techniques are a way to obtain maps of different proprieties brought by each survey.

Combining these maps we can create a single diagram that relates the geometry and position of detected features with other measured proprieties. These final maps bring additional criteria to understand the function or the condition of detected features, and therefore are useful in to focus the attention of further excavations over one or other area of the site.

7. Towards high resolution. Large scale surveys, ultradense surveys

The technological evolution of survey systems in the last ten years has pointed three basic aspects: sensor accuracy, resolution and speed of acquisition. As the technological advance has ran in parallel with the computing and electronics revolution, the capabilities of the survey systems have been enhanced also in terms of size and versatility.

These evolution factors are condensed in the trend to create systems based on arrays of sensors. GPR, magnetics and resistivity have been the fields where the manufacturers and research teams have made the most remarkable advances.

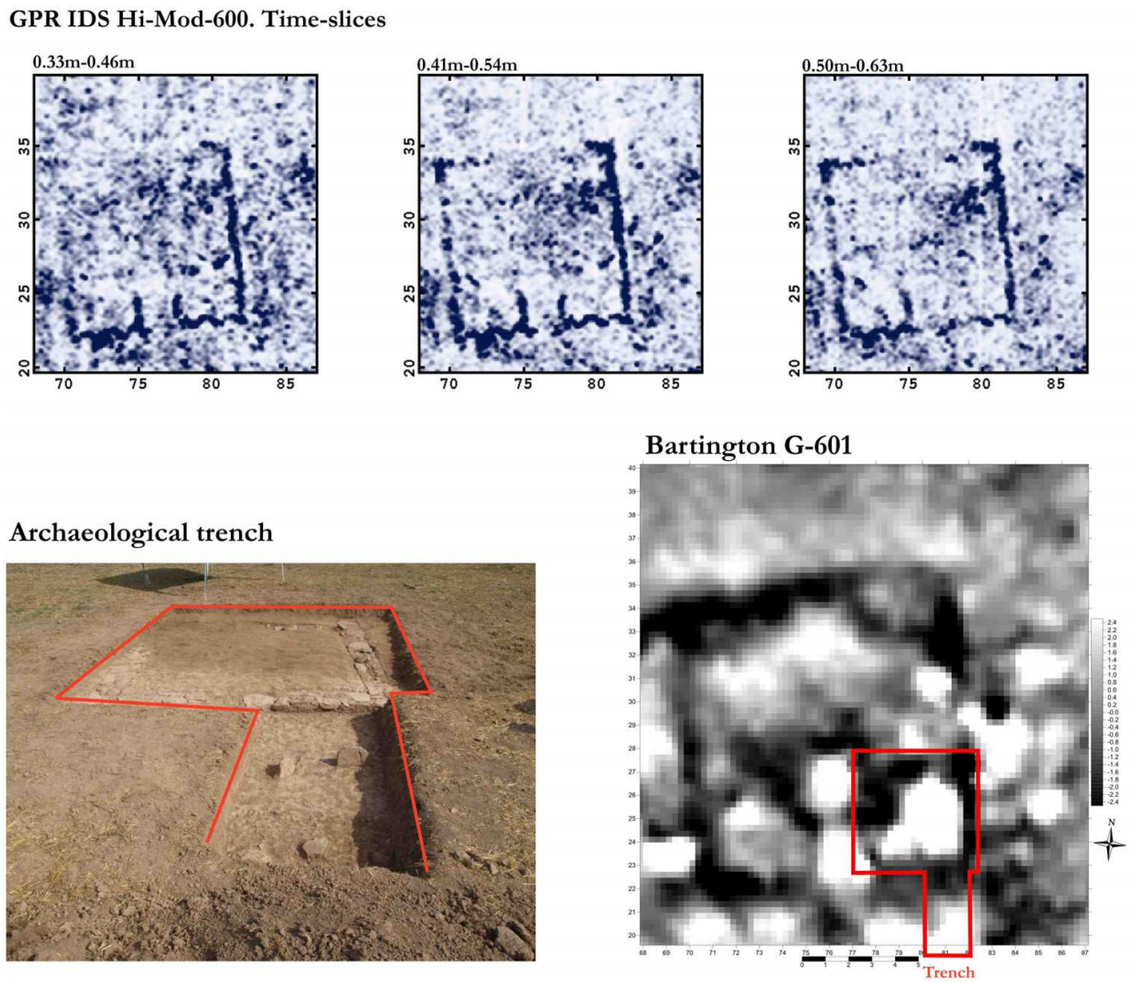


Fig. 11. Multi-system surveys. An example of Puig Ciutat Roman site (La Torre d'Oristà Barcelona). At the top, a sequence of time slices allows to distinguish clearly the building perimeter. The magnetic survey (bottom-right) shows a similar perimeter, but other internal anomalies reveal an increase of contrast in fired areas as the excavated room (bottom-left).

In the case of GPR, the creation of antennae stacks that "read" simultaneously, allow geophysicists to survey large areas at high resolutions at speeds that would be not possible applying the 1980's and 1990's single channel systems. Although this has been a technological challenge -not yet completely solved- the high costs of these systems are restricting his use to large scale projects. In some cases, the spectacular results reached in the surveys, especially in the description of building remains, show such detail that archaeologists start their own interpretations at first sight.

The magnetic surveys have been from the 1980's the fastest way to survey a large area. Even working with a single fluxgate gradiometer system is possible to survey from 7.000m² to 1Ha in a working day when the survey area has no obstacles. The last improvements in these systems allowed creating arrays of sensors that could be carried by vehicles, enhancing the survey speed until area coverings of several hectares per day. Once again, these systems are most used in large-scale surveys, to map the subsoil in the placement of

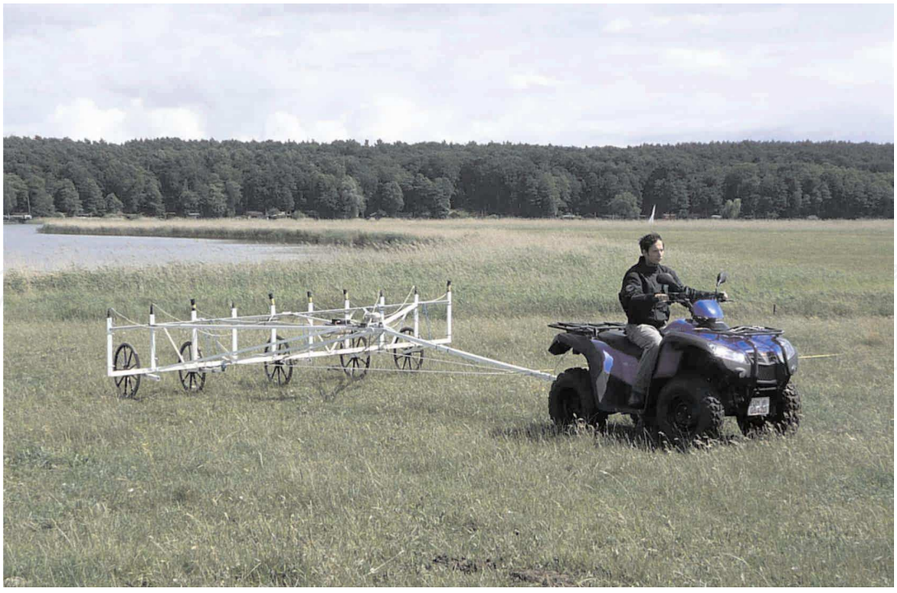


Fig. 12. A stack of magnetic gradiometers built by Eastern Atlas for large area surveys. Image courtesy of Cornelius Meyer.

future civil engineering works (railways, highways, building complexes, etc.) or to study a specific archaeological site in relation with his hinterland (mapping ancient agriculture or old field divisions).

Something similar happens with multiple resistivity systems than can survey large areas with two or more levels of depth. The high speed of measurement and the resolution of these devices could be useful in context with low magnetic contrast or in areas with rugged surfaces that are not the best environment for GPR surveys.

Another interesting trend is the exploration of high resolution limits. The speed and size of modern GPR systems allowed carrying experiments that used centimetric spacing to obtain high density 3D datasets of a survey area. Although there's a theoretical limit for the resolution of every technique, the results of these experiments reached spectacular and sometimes unexpected results.

8. New techniques and new problems. Positioning and data management

All this intensification in terms of data density or survey speed has generated problems that are common for these new systems. Sensors based on electromagnetic phenomena could influence other sensors placed in his vicinity. One of the major problems with this kind of systems is to avoid the influence between sensors placed very closely. This influence has been solved in multiple ways such are triggering the readings in alternative sequences or modifying the architecture and the relative position of the sensors.

One of the important problems that the manufacturers are facing is the accurate positioning of data. Since the multiple sensor systems tend to use high resolutions in wide areas, they need an accurate system to relate every reading with its real position.

The actual satellite positioning systems (GPS) have a military origin in the 1970's. The accuracy level of the GPS ground receivers is not enough accurate to monitor in real time the

motion of a survey system. Further evolution of the GPS systems has used other additional ground references or radio positioning to enhance the accuracy and speed of measurements. Even with the most advanced positioning devices the matching between GPS and GPR is not yet completely solved. Nevertheless, in urban survey environments the GPS loses a significant part of his precision. To solve this, manufacturers as IDS are working in the adaptation of optical positioning systems that are not affected by the electromagnetic contamination of modern cities.

The datasets resulting from large scale surveys or ultradense grids are files that can be several hundred Gigabytes or even Terabytes. They are also related with positioning files that should be processed, examined and interpretated. The results of large scale surveys are studied in GIS environments to relate it with other archaeological or geographical information. The management of such volumes of data generate computation problems, since in 3D surveys the processing sequences could result in enormous files, not easy to study in his integrity with a common computer.

9. Data analysis. From high resolution to regional archaeology

GIS environments have become the way to systematize study and analyze information in archaeological projects in a spatial view. The ability to dispose and analyze in one single work environment relevant information from multiple fonts (topographic, geophysical, aerial and multispectral imaging, paleoecologic or historic) is a trend that is changing the way how archaeology integrates and analyzes scientific information. One of these fonts is archaeological geophysics data which acts as one more layer of information in GIS-based projects. In fact, geophysical surveys are used in regional studies as another information layer that could be correlated with the rest of georeferenced data and maybe that is one of the most interesting new vectors of investigation of GIS works. The use of mathematical processes in order to correlate and integrate the different geophysical surveys with each other and with other space-referenced magnitudes also used in archaeology looks like an open field for new investigations.

While computers and software are not yet ready (or just not completely) to assume interpretation roles, the work of geophysics in archaeology is still a kind of artisan's work. Every time that a surveyed area is excavated, geophysicists should be interested in having as much information as possible to understand "what was really down there" and close the circle with their surveys. This drives us to another interesting field of investigation: the systematic comparison between collected data and real objects and the generation of synthetic models of archaeological features to understand why they show this magnetic trace or why they reflect GPR pulses that way. The use of modern computing techniques in these analysis are a promising, since they could help to understand much better the behavior of geophysical sensors in relation with archaeology and to develop new interpretation criteria.

10. Survey examples

This last section contains a group of survey examples that could be illustrative from what's exposed in the chapter.

10.1 Large-scale magnetic prospection with multi-channel gradiometer arrays (Germany)

By Cornelius Meyer and Burkart Ullrich (eastern atlas, Berlin, Germany) info@eastern-atlas.com

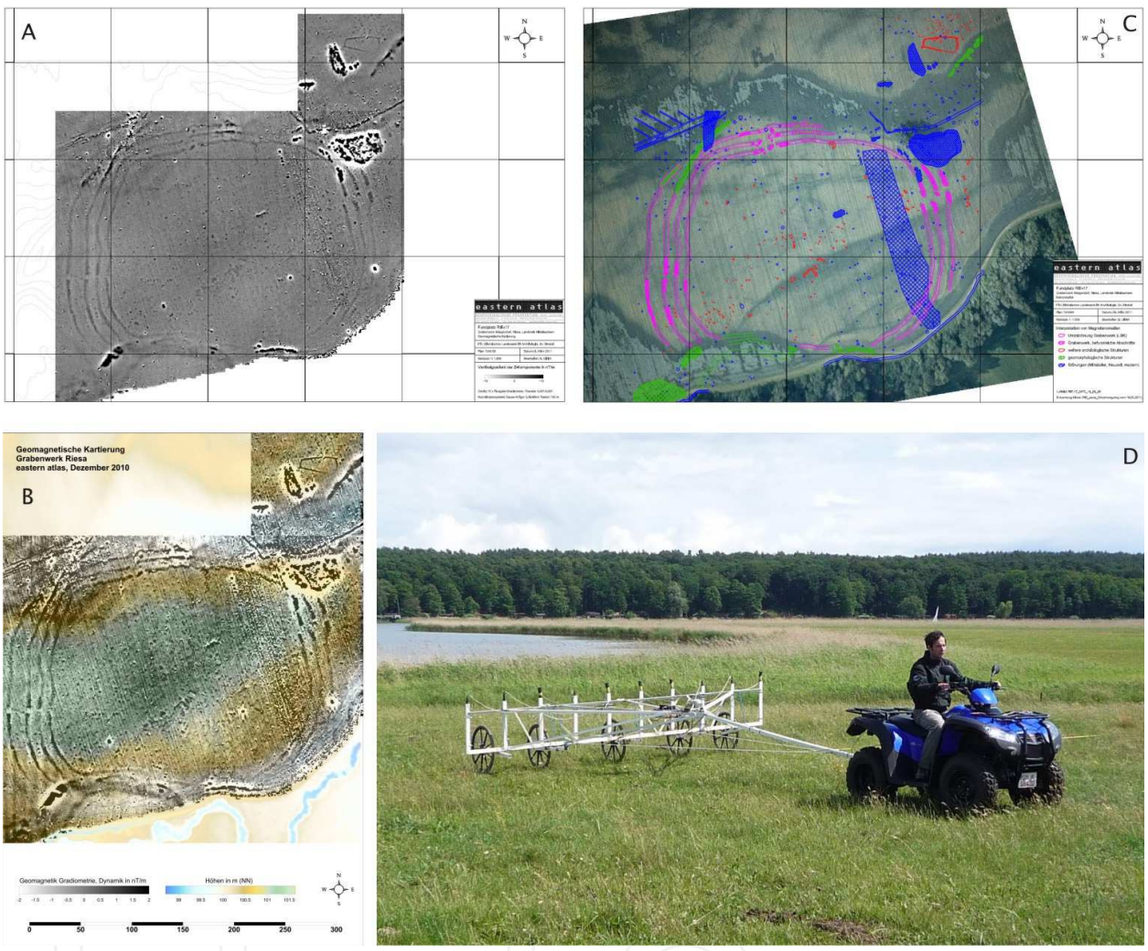


Fig. 13. A. Magnetic Plot. B. Combined Magnetic-altimetric plot. C. Interpretation dyagram overimposed to an aerial view of the site. D. Eastern Atlas, 10 probe fluxgate system.

Magnetic mapping is the most common geophysical method in the investigation of archaeological sites. Magnetic prospection is especially suitable for the prospection of large settlement areas and archaeological landscapes when wheeled arrays of gradiometers are applied. During the last decade the development of these arrays have focused on the application of fluxgate gradiometers. The economic advantages of fluxgate magnetometers is that they can be assembled to large arrays (D) with comparatively low costs in contrast to the costly Caesium (Cs) or SQUID magnetometers. Most important precondition for the successful application of fluxgate arrays in archaeological research is a high-quality data logging exploiting the dynamic range and the maximal resolution of the probes to a maximum extend. Using a high-resolution broadband data logger with high sampling rates (up to 1000 Hz) the measuring accuracy of fluxgate sensors can be fully utilized.

The example shows the magnetic data of an Neolithic circular ditch system near Riesa (Saxony, Germany). The data was registered using a light-weight wheeled fluxgate gradiometer array consisting of 10 individual probes and the newly developed 24-bit digitizer LEA D2. For positioning both a GPS system and a survey wheel (odometer) were used. The total area was 11 hectares, and the time needed for the data collection only one day (in December 2010)

The magnetic data show the course of the four ditches as positive anomalies due to their fillings consisting of material enriched with organic components and hence with higher magnetization. In the northern part some modern perturbances overlay the Neolithic structures, but in the uppermost part of the area another smaller Neolithic ditch structure is visible. In the southern part the ditch system is partly eroded by a meandering stream.

10.2 Silchester Roman town (United Kingdom)

By Neil Linford (English Heritage)

Data for this case study were collected over the abandoned Roman town of Calleva Atrebatum, close to the village of Silchester, Hampshire, UK. An area of over 5ha was covered at a sample density of 0.075m x 0.075m using a 3D-radar GeoScope GPR system, together with a vehicle towed V1821 array antenna. The GeoScope is a stepped-frequency, continuous wave (SFCW) radar system recording the amplitude and phase over a wide bandwidth of user defined frequencies and dwell times for each sample location. Measurements were made over a bandwidth between 50 and 1250MHz in 2MHz steps with a dwell time of 2.5µs at each frequency. Positional control was provided by a real time kinetic differential GPS antenna mounted on the GPR array. The amplitude time slice between 15.6–16.8ns (approximately 0.78–0.84m) shows details of the basilica-forum complex at the heart of the Roman town, surrounded by a grid pattern of internal streets with numerous ancillary building remains. The survey was conducted by the Geophysics Team of English Heritage in collaboration with colleagues from the University of Reading, further details of the survey and subsequent data processing can be found in Linford *et al.* (2010) and Sala and Linford (in press) respectively.

10.3 Puig Ciutat Roman Republican Site (Oristà, Barcelona)

By Sala, Garcia & Tamba

The archaeological site of Puig Ciutat is placed in central Catalonia, in an elevation surrounded by a meander of Gavarresa River. Since his casual discovering in 1982, there only have been carried a survey in 2005 by Roger Sala and Maria Lafuente, covering the Field C1, using a fluxgate magnetic gradiometer (Geoscan Research FM-256) and a 20X20m GPR survey. The results of this first survey revealed an entire occupation of the explored area and evidences of several burned areas, including a singular building placed in the center of the field.

In 2010 the team of SOT Archaeological Prospection and the archaeologists Àngels Pujol and Carles Padrós started the Puig Ciutat Exploration Project, witch aims to establish a first approach to the site and his environs, and at the same time, to explore new work methodologies, combining archaeology and geophysics.

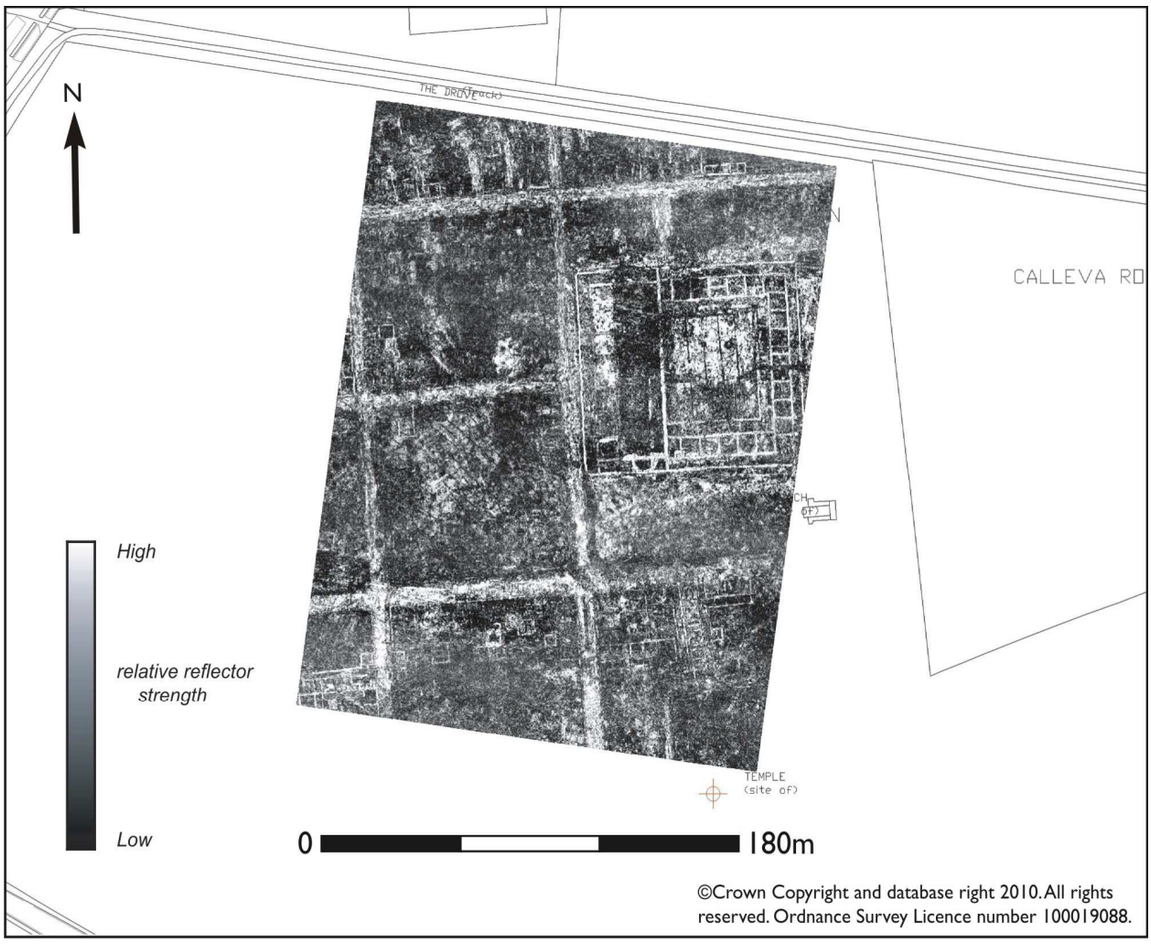


Fig. 14. The 3D radar systema applied to Archaeology in the Silchester Roman Town. Amplitude map of approximately 0.78–0.84m depth, showing the plant of the forum.

The 2010 and 2011 seasons have been divided in geophysical survey campaigns (June 2010, May 2011) and excavation campaigns (July 2010, July 2011) in witch archaeologists have took part of geophysical surveys and geophysicists have took part in the excavations. Although the field works have just started, the preliminary results of first surveys and excavations revealed an interesting archaeological site. The excavation of four specific areas previously explored with magnetometry and GPR showed a roman settlement that suffered a firing destruction. The analysis of excavation works dated preliminarily the destruction between 70 and 30 B.C.

The results of magnetic surveys in the fields C1 and C2 are shown in the figure 15, B. In both cases, delimitated high-contrast areas are detected, witch are interpreted as fired buildings. The GPR surveys carried in the same fields the time slices (figure 15C) reveal a complex building distribution.

Using the interpretation diagrams (figure15D) four excavation trenches have been placed (figure 15E), revealing building areas with evidences of fire destruction, including roman military weaponry and importation italic pottery.

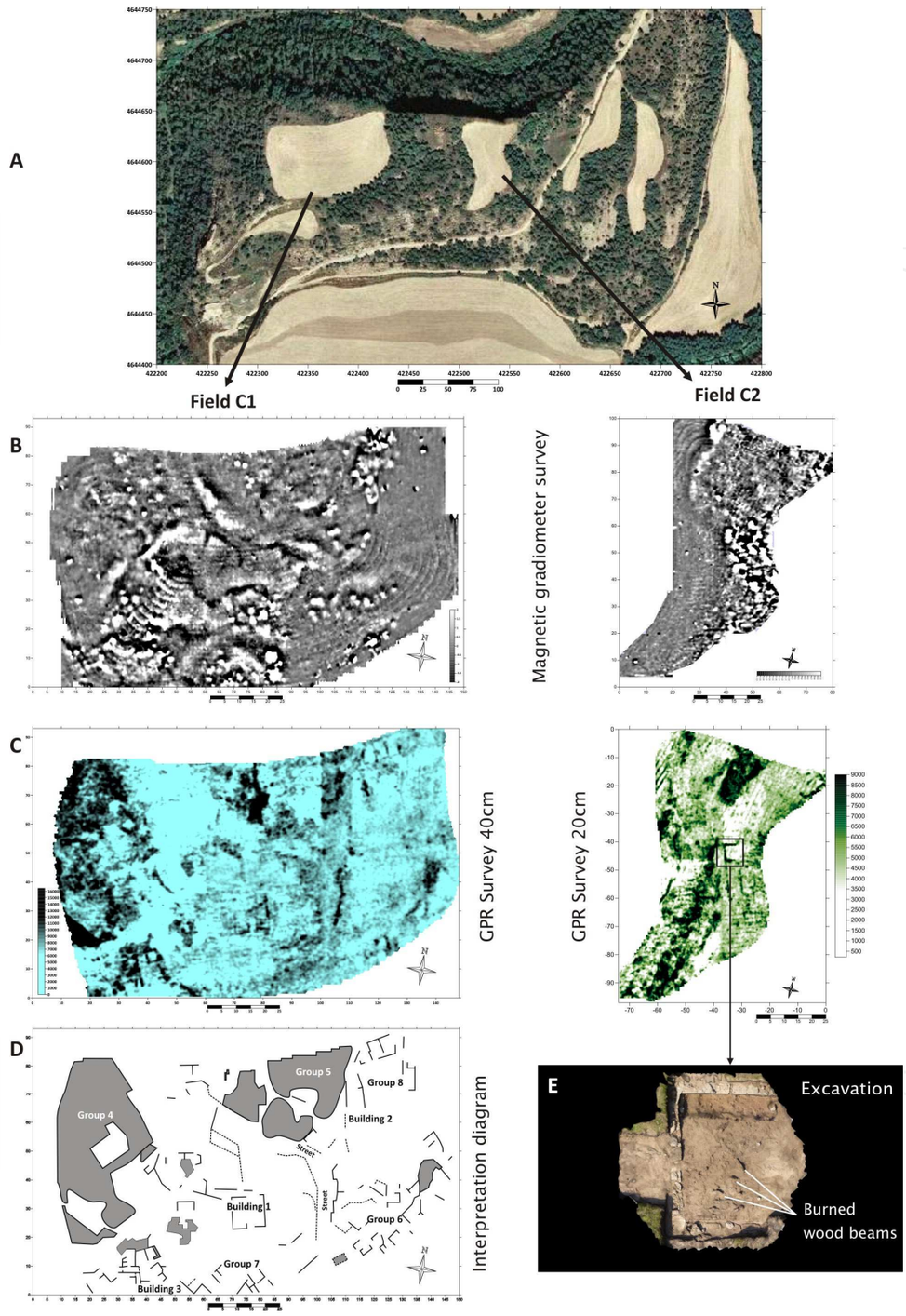


Fig. 15. Puig Ciutat Exploration Project 2010-2011.
A. Aerial view of the site (ca. 5ha). B. Grayscale plots of the magnetic surveys using a Bartingron G-601 Fluxgate gradiometer. C. GPR survey plots of the same fields using a IDS HI-Mod system with dual antennae of 200 and 600MHz. D. Interpretation diagrama of field C1 based in GPR data. E. Photogramteric plant of a building located in the field C2 in the GPR survey during the excavation.

10.4 La Dou Neolithic-Late Bronze Site (La Vall d'en Bas, Girona)

By Sala, Garcia & Tamba

Placed in the south face of Pyrenees, the Garrotxa region consists in a group of valleys and plains around an inactive volcanic area. The investigations carried by Dr. Maria Saña (UAB)

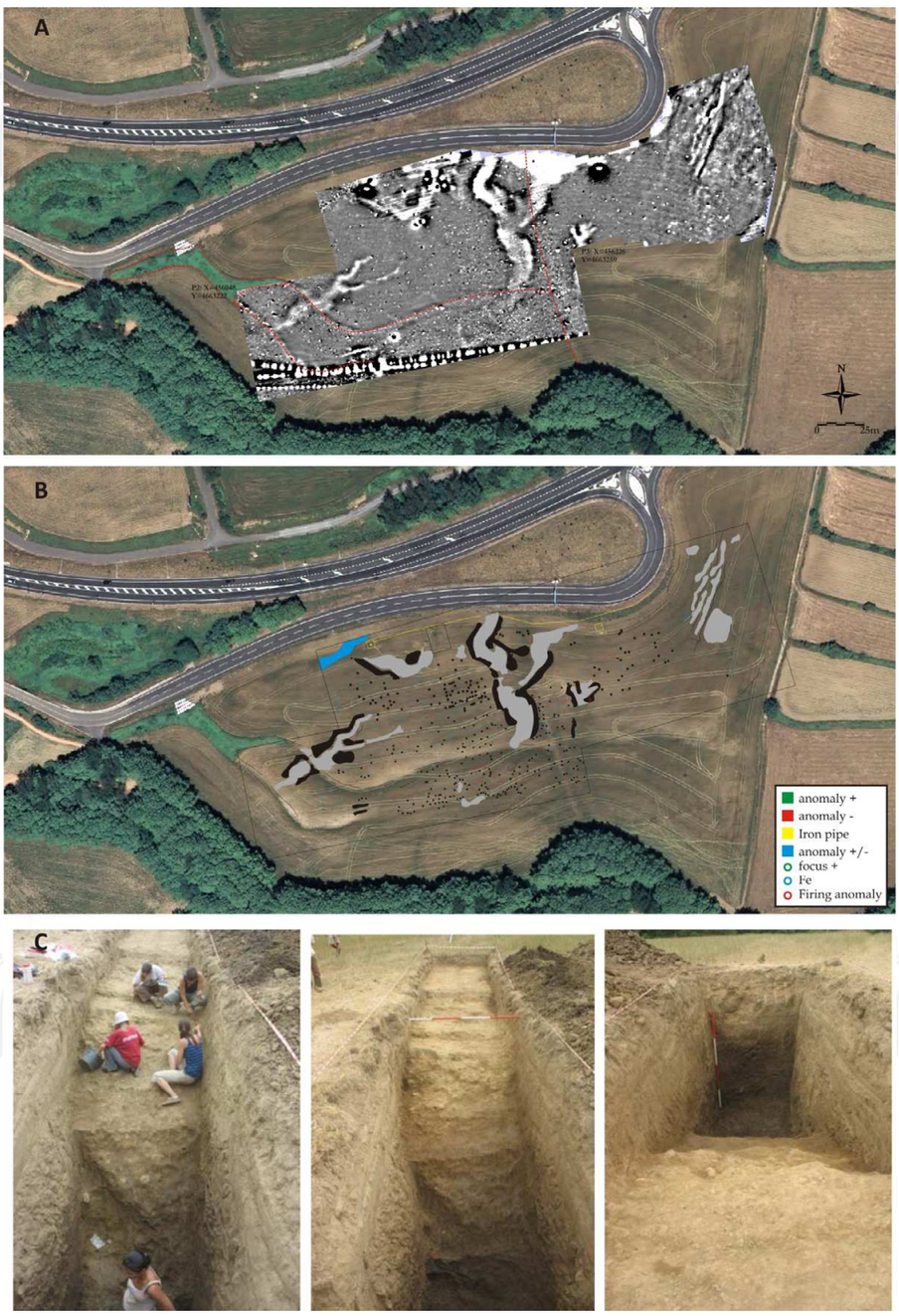


Fig. 16. Archaeological site of La Dou. A. Aerial view of explored area with over imposed magnetogram. Old field divisions are marked in red, thanks to the previous documentation. B. Interpretation diagram. C. Images of the excavation of a trench crossing the ditch.

centered from the Neolithic to the Bronze Age of this region, discovered a group of neolithic firing pits in a rescue excavation in La Dou (St. Esteve d'En Bas).

In 2009 the team of Dr. Maria Saña contacted the SOT team to carry a geophysical survey, witch aims to map a possible settlement related with the known firing pit areas. The survey used a fluxgate magnetic gradiometer (Bartington G-601) to explore a 2,48ha area. The results shown in the figure 16B show multiple groups of magnetic anomalies placed in the access of the valley. The most important group has been interpreted as a possible ditch with a quadrangular geometry. The excavation trenches carried in 2010 by the Dr. Saña team, discovered the remains of a Bronze Age ditch, also locating remains of a fired palisade in the bottom of the excavation (figure 16C).

Other interesting groups of magnetic anomalies are located in the survey, such as a group of focus positive anomalies interpreted as post-hole concentrations or other high-contrast bipolar anomalies interpreted as other firing pits.

10.5 IDS STREAM-X multi antenna GPR system test in Empúries Roman City (L'Escala, Girona)

By Sala, Garcia & Tamba and Alexandre Novo

The archaeological site of Empúries (L'Escala, Girona) is one of the most important sites of Catalonia for the Helenistic and Roman periods. It includes a Greek settlement (palaiapolis) and a Roman city dated from IIth BC to IIth century AC.

In February of 2010, collaboration between SOT Archaeological Prospection and the SOING-GeoAsiter companies allowed to carry a test survey of the IDS STREAM-X, 200MHz GPR multi antenna system in the Roman city area. The local archaeological research team designed a ca. 2Ha survey area in the south west corner of the city perimeter in order to compare the results with the hypothetical insulae divisions extracted from the excavated areas (figure 17A).

The IDS STREAM-X system is one of the most advanced array antennae system based in the Fast-Wave IDS control unit technology. The specific array used in the survey uses a stack of 15 200MHz antennae separated 12.5cm. The entire system was mounted in a frame pulled by a quad, locating readings with a GPS system (17B).

The data obtained were processed in order to obtain plain views of the results using the time-slice technique. The figures 17C and 17D show sequences of time slices of the two explored areas and an interpretation diagram. The time slice plots show how the high data density allows obtaining sharp images of buried buildings and urban divisions. The clearness of the results provide an easy understanding document that archaeologists could use intuitively and to interpret it.

10.6 GPR survey in the basilica of Santa Maria (Castelló d'Empúries, Girona)

By Sala, Garcia & Tamba

The Basilica of Santa Maria d'Empúries is one of the most important monuments of the village. Builded in the XIIIth and XIVth centuries as a witness of the economic and political

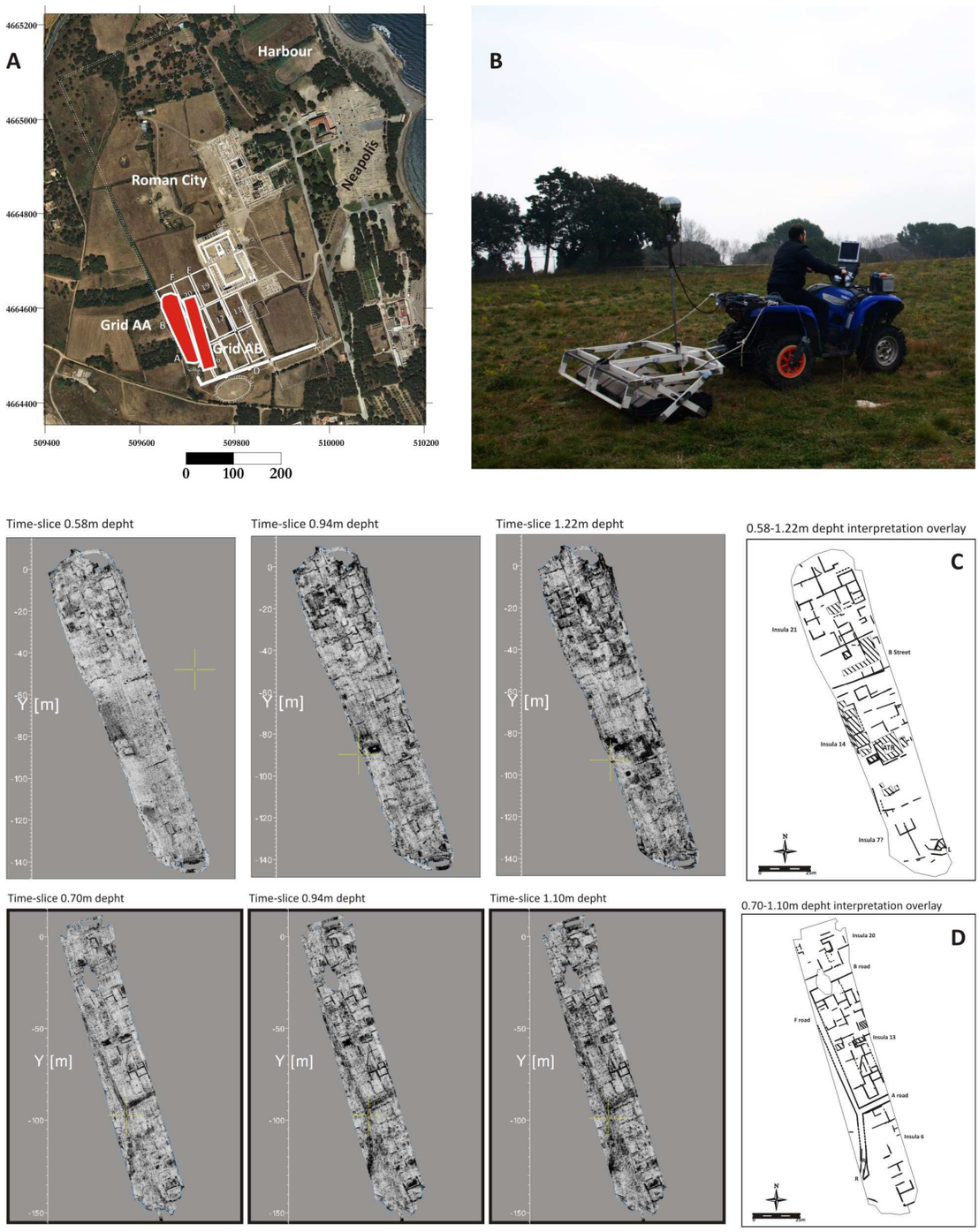


Fig. 17. A. Aerial view of the Empúries archaeological area with the suvey area remarked in red. B Geophysicist Alexandre Novo collecting data with the STREAM X system. C. Grid AA time slices and an interpretation diagram D. Grid AB and an interpretation diagram.

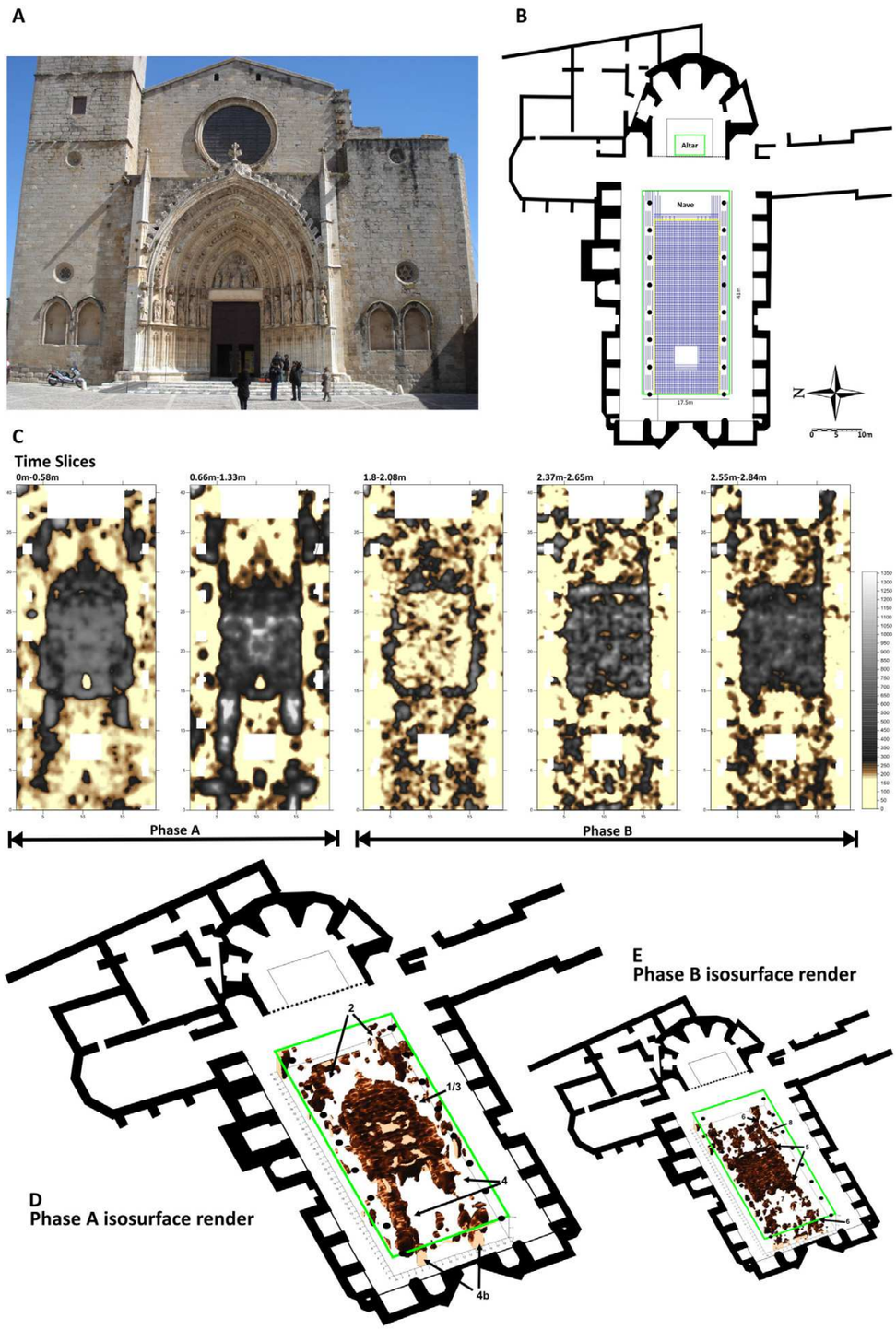


Fig. 18. GPR survey at the Basílica of Santa Maria, Castelló d'Empúries. A. Image of the façade of the Basilica. B. Plant of the building, with a plot of explored area. C. Time-slice sequence indicating the two interpreted phases. D and E. 3D isosurface renders of the two phases in the context of the church's plant.

influence of the Empúries County, it's one of the points of investigation the archaeologist Dra. Anna Maria Puig. After years of investigation, Dra. Puig collected documental and archaeological documentation that explored the evolution of medieval churches of Empúries County from early medieval period (Ss. VIII-XI).

In 2007, with the support of Castelló d'Empúries Town Hall, there was planned a GPR survey to explore evidences of previous buildings buried under the gothic-stile Basilica.

The survey was done applying an area survey in the central nave of the church, using a GSSI SIR-3000 system with a 270MHz antenna. As shown in the figure 18B, the survey strategy consisted in cover the central nave with perpendicular GPR profiles with 40cm spacing, covering an area of 41X17.5m.

The collected data was processed using the time-slice technique, generating horizontal cuts to obtain plain views of detected features. The plots shown in the figure 18C allowed describe two phases under the basilica's pavement. A first layer called Phase A (0.3-1.7m depth), is interpreted as the remains of a previous building of smaller dimensions, but with at least a central nave placed in the same axis of the actual building.

A second layer, or Phase B was defined in deeper time-slices (from 1.7m depth) as an underlying rectangular feature, that could be interpreted as a structural or basement part of Phase A building, or as the remains of a earlier building.

11. Conclusion

This chapter aimed to expose the basic knowledge of archaeological geophysics as a first approach for archeologists. The measured magnitudes used in these techniques and the way to represent them are not away from the daily work of an archaeologist. Indeed, when our eyes allows us to differentiate each strata in an excavation, we are using a kind of geophysical survey, measuring the different reflection of light and mapping it in our mind.

After decades of investigation and application, Archaeological Geophysics are intensively used in both investigation and rescue Archaeology in some European and American countries. But unfortunately, not all archaeologists feel familiar with these methods, since they are not yet in all the archaeological careers as a didactic content. Obviously this should change, because otherwise, future archaeologists could loose the opportunity to use a powerful tool and to optimize his resources.

In the other hand, the evolution of geophysical sensors has enhanced their capabilities in precision, resolution and speed. As seen, the use of GPR antennae arrays or multi sensor systems opens a new perspective for archaeologists, increasing the potential range and resolution of their studies, allowing a much more effective work. But all this technification should not make forget that the objective, after all, is Archaeology.

Indeed, all the techniques and methods exposed have evident applications in archaeological works (exploration, delimitation, detailed description), but there's a new and long way to expand their use in combination with other non-destructive techniques and in the study of the correlation between magnitudes of different existing survey methods.

12. Acknowledgments

We would like to thank the contributions of Mr. Cornelius Meyer at Eastern Atlas and Dr. Paul Lindford at English Heritage. Dr. Alexandre Novo and Gianfranco Morelli also supported this chapter with their work in Empúries and his advice and patience.

The short cases studies and examples presented are the product of scientific collaborations with archaeologists Dra. Maria Saña (La Dou), Anna Maria Puig (Basílica of Castelló d'Empúries), Jordi Principal (Molí d'Espígol), Joaquim Tremoleda (Empúries) and the archaeological section of Aranzadi Society of Sciences.

Finnally, we want to thank the teaching and advice of Dr. Dean Goodman, Dr. Armin Schmidt and the important task of all members of ISAP society, witch is an example of how a scientific collective could be connected and cooperate as a knowledge web.

13. References

Aspinall, A., Gaffney, Ch., Schmidt, A. *Magnetometry for Archaeologists* (2008) ISBN-10: 978-0-7591-1106-6 Altamira Press. Plymouth

Clark, A. (1990) *Seeing Beneath the Soil. Prospecting Methods in Archaeology*. ISBN 0-415-21440-8. B.T. Batsford Ltd.

Conyers, L., Goodman, D. (1997) *Ground-Penetrating Radar: An Introduction for Archaeologists.* ISBN-10: 0761989277. Altamira Press. Plymouth

D. Goodman, Y. Nishimura, and J.D. Rogers, *Time Slices in Archaeological Prospection*. Archaeological Prospection, vol. 2, 1995, pp. 85-89. Willey and Sons

García, E. et alii *Resultats Preliminars de la Primera Campanya d'Excavació al Jaciment Arqueològic de Puig Ciutat (Oristà, Osona)* (2010). Ausa XXIV, pp. 685-714. Patronat d'Estudi Osonencs

Harris, E. (1979) *Principles of Archaeological Stratigraphy*. ISBN 0123266513. Academic Press. London & New York.

Kvamme, K. *Integrating Multidimensional Geophysical Data.* (2006). Archaeological Prospection, 13, pp57-72. Willey and Sons.

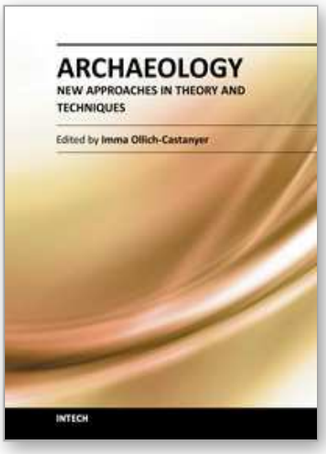
Linford, N., Linford, P., Martin, L. and Payne, A. (2010). *Stepped-frequency GPR survey with a multi-element array antenna: Results from field application on archaeological sites. Archaeological Prospection* 17 (3):187-198.

Novo, A., Sala, R., Morelli, G., Leckebusch, G., Tremoleda, J. *Full wave-field recording: STREAM-X at Empúries Site* (2011) ISBN 978-605-396-155-0. 9th International Conference on Archaeological Prospection. Extended Abstracts Archaeological Prospection. Istanbul.

Sala, J. and Linford, N. (in press). *Processing stepped frequency continuous wave GPR systems to obtain maximum value from archaeological data sets. Near Surface Geophysics* 10.

Sala, Roger; Lafuente, Maria. *Visualising the Ibero-Roman site of Puig-Ciutat (Catalonia, Spain) from magnetic variation maps and GPR time-slices.* 7th International Conference on Archaeological Prospection. «Archaeological Prospectioin». *Archaeologického ústavu slovenskej akadémie vied, Studijné Zvesti* [Nitra, Eslovàquia] (2007), p. 234-238.

Witten, A. (2006) *Handbook Of Geophysics In Archaeology*. ISBN-10: 1904768601. Equinox Publishing



Archaeology, New Approaches in Theory and Techniques

Edited by Dr. Imma Ollich-Castanyer

ISBN 978-953-51-0590-9

Hard cover, 292 pages

Publisher InTech

Published online 09, May, 2012

Published in print edition May, 2012

The contents of this book show the implementation of new methodologies applied to archaeological sites. Chapters have been grouped in four sections: New Approaches About Archaeological Theory and Methodology; The Use of Geophysics on Archaeological Fieldwork; New Applied Techniques - Improving Material Culture and Experimentation; and Sharing Knowledge - Some Proposals Concerning Heritage and Education. Many different research projects, many different scientists and authors from different countries, many different historical times and periods, but only one objective: working together to increase our knowledge of ancient populations through archaeological work. The proposal of this book is to diffuse new methods and techniques developed by scientists to be used in archaeological works. That is the reason why we have thought that a publication on line is the best way of using new technology for sharing knowledge everywhere. Discovering, sharing knowledge, asking questions about our remote past and origins, are in the basis of humanity, and also are in the basis of archaeology as a science.

How to reference

In order to correctly reference this scholarly work, feel free to copy and paste the following:

Roger Sala, Ekhine Garcia and Robert Tamba (2012). Archaeological Geophysics - From Basics to New Perspectives, Archaeology, New Approaches in Theory and Techniques, Dr. Imma Ollich-Castanyer (Ed.), ISBN: 978-953-51-0590-9, InTech, Available from: http://www.intechopen.com/books/archaeology-new-approaches-in-theory-and-techniques/archaeological-geophysics-from-basics-to-new-perspectives

INTECH
open science | open minds

InTech Europe
University Campus STeP Ri
Slavka Krautzeka 83/A
51000 Rijeka, Croatia
Phone: +385 (51) 770 447
Fax: +385 (51) 686 166
www.intechopen.com

InTech China
Unit 405, Office Block, Hotel Equatorial Shanghai
No.65, Yan An Road (West), Shanghai, 200040, China
中国上海市延安西路65号上海国际贵都大饭店办公楼405单元
Phone: +86-21-62489820
Fax: +86-21-62489821