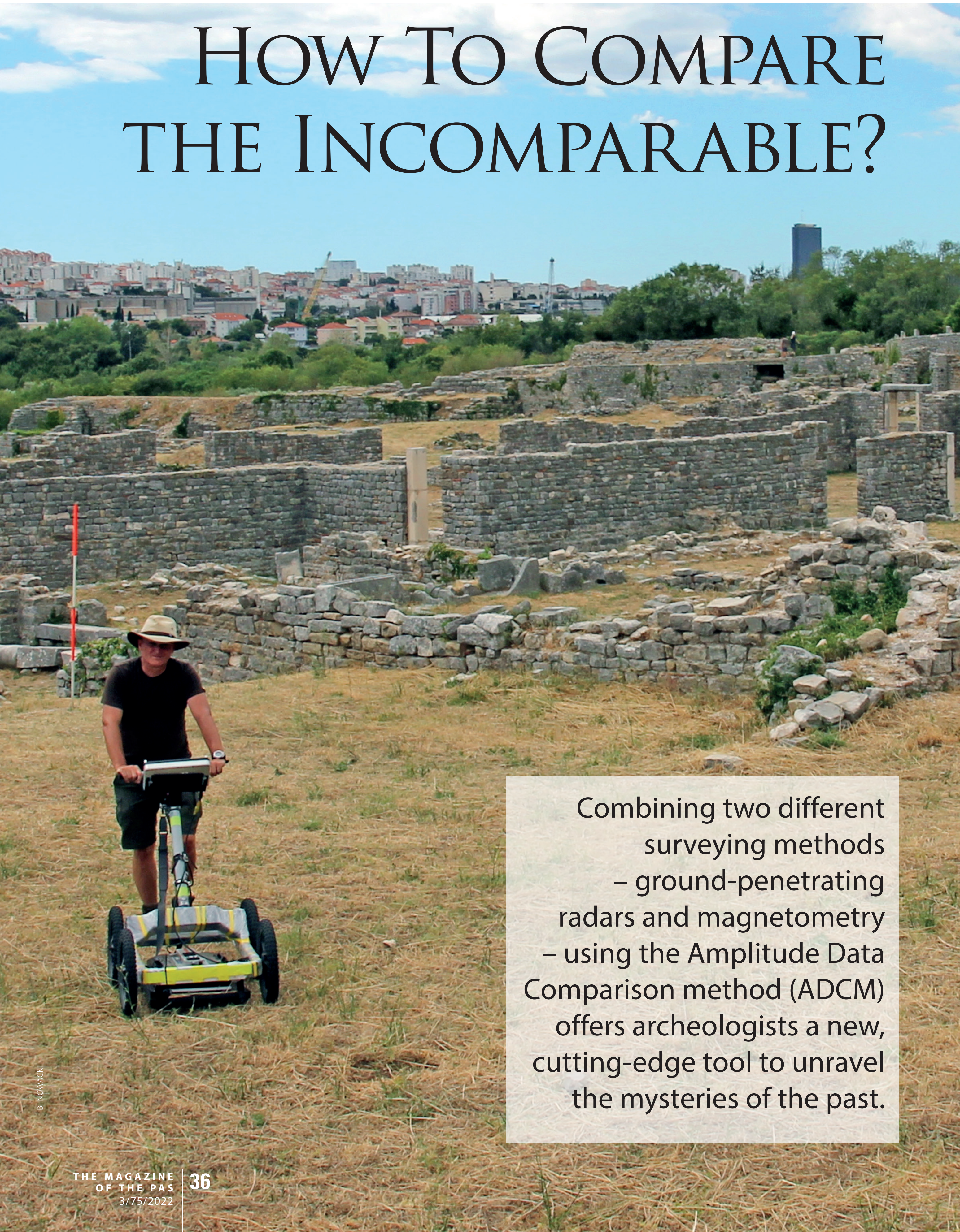
 DOI: 10.24425/academiaPAS.2022.143993

How To Compare the Incomparable?



B. NOWACKI

Combining two different surveying methods – ground-penetrating radars and magnetometry – using the Amplitude Data Comparison method (ADCM) offers archeologists a new, cutting-edge tool to unravel the mysteries of the past.

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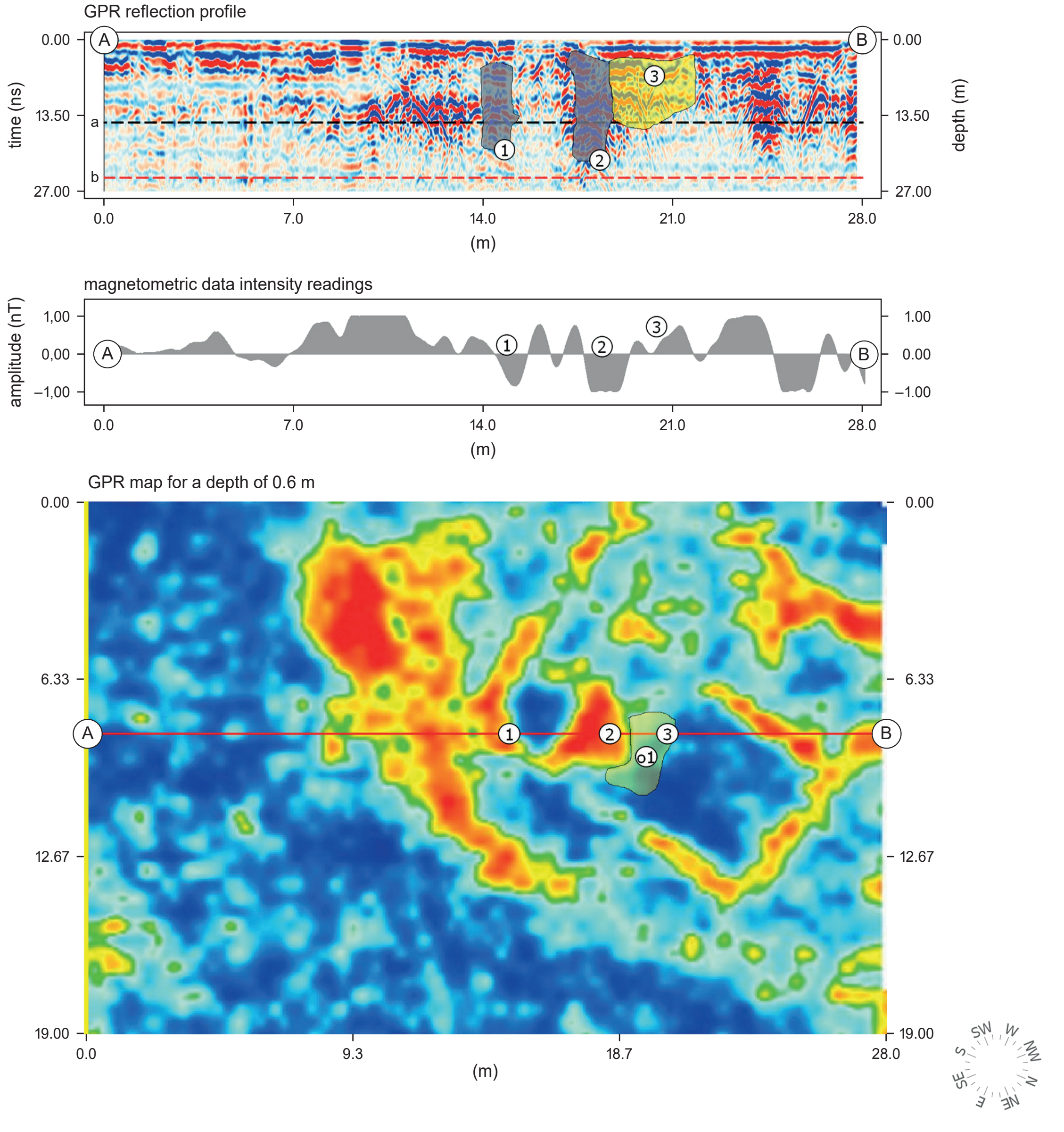
Geophysical methods have been successfully used in non-invasive archaeological prospecting for many years. Among these methods, two play a leading role: magnetometry and ground-penetrating radar (GPR). Each has its own advantages and limitations, being based on completely different physical phenomena. A GPR device sends high- and ultra-high-frequency electromagnetic waves into the ground through its transmitting antenna. When an electromagnetic wave encounters a boundary between two geological layers that differ significantly in terms of their physical and electrical properties, reflections are produced and then recorded by the receiving antenna. The greater the contrast between the physical properties of the layers, the stronger the reflections produced by the boundary between them. Such conditions are met, for example, by sands that border clayey sediments. The radargrams (reflection profiles) obtained as a result of GPR surveying are vertical cross-sections of variations in electrical parameters of the ground that map the amplitude of the recorded signal. Collecting parallel scans makes it possible to interpolate GPR signal amplitude values to obtain horizontal sections, called GPR maps or, more properly, “time slices.”

Unfortunately, GPR also has certain serious limitations. In fieldwork, low-resistivity sediments (ones that easily conduct electric current) are the most important factor that impacts negatively on the results of GPR surveying. Examples include alluvial soils and clay sediments, which form a screen nearly impermeable to electromagnetic waves, thus significantly reducing the depth range of the GPR system. Ground-penetrating radar is especially useful in detecting all types of voids in the ground, especially when they are at least partially filled with air. At the boundary between the ground and the ceiling of the void, significant increase is observable in the velocity of the electromagnetic wave, which results in the appearance of a distinctive anomaly in the GPR image (a diffraction hyperbola or reflection surfaces). For reasons related to its specific characteristics, however, GPR is not useful in searching for embankments, moats, or, for example, relics of prehistoric wooden settlements – this is due to the poor contrast between the fill material of such archeological features (which is usually organic) and the surrounding ground (which is also often full of organic matter), as well as insufficient resolution.

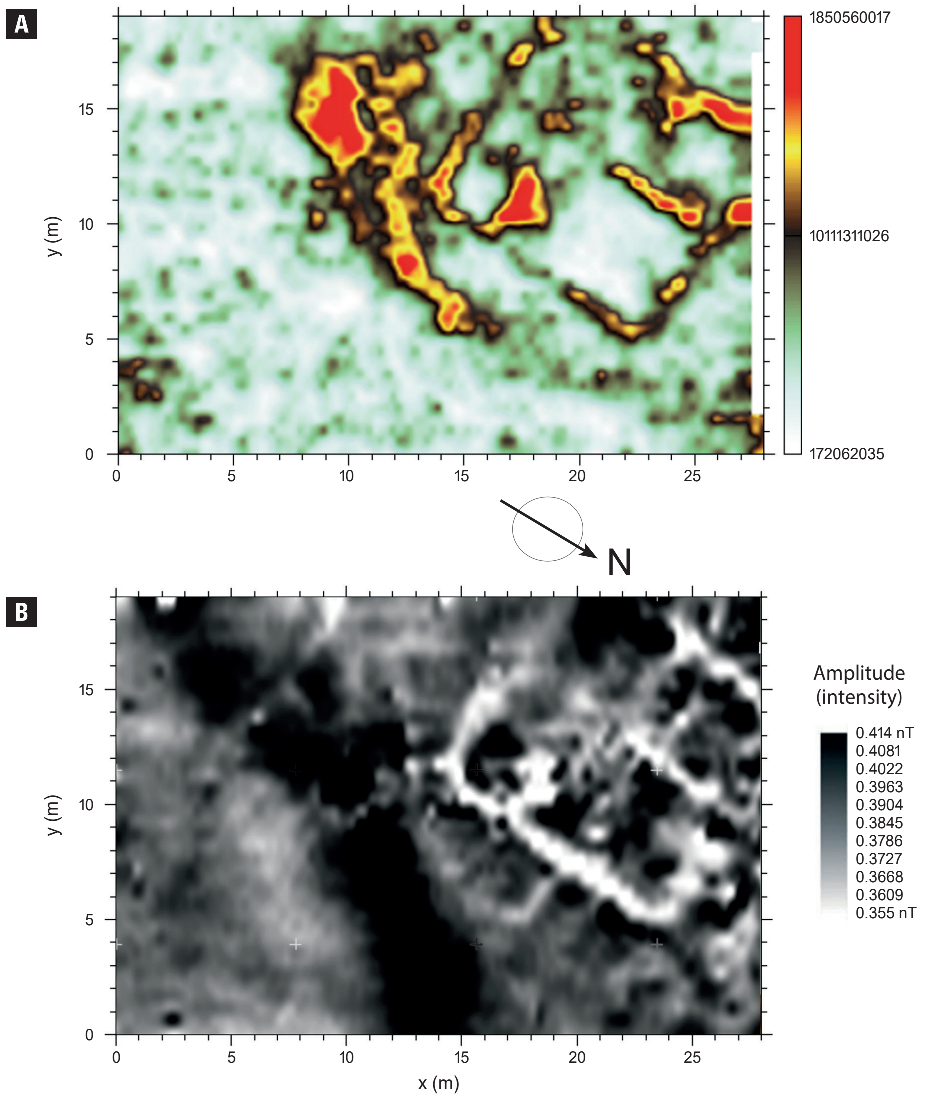
Although the principles by which GPR operates are relatively simple, the methodology for conducting surveys and processing data is extremely complicated, due to the highly complex nature of electromagnetic wave reflection. For these reasons, GPR is the most demanding of the existing non-invasive archaeological prospecting methods. Operators of GPR devices need to have not only vast experience, but above all a thorough knowledge of geology and sedimentology, not to mention a basic grasp of geophysics – without this, it is impossible to correctly interpret the obtained images.

Magnetic field

Unlike GPR, magnetometry makes use of a different physical phenomenon – it is based on measuring the intensity of the Earth's magnetic field. Approximately 90% of the Earth's total magnetic field is generated



Results of ADCM analysis using software currently under development – ADCMI (Amplitude Data Comparison Method – Integrator). This sample analysis concerns a Roman building discovered on the island of Rab in Croatia. The upper image shows a selected GPR profile. Below, there is a magnetic amplitude record along the same survey line. The bottom image shows a GPR map for a depth of 0.6 m with the designation of selected structures and the location of the profile being analyzed



Comparison of GPR and gradiometer surveys:
A. GPR map for a depth of 0.6 m showing relics of a Roman building on the Croatian island of Rab.
B. Map of the distribution of the intensity (amplitude) of the Earth's magnetic field for the same area. GPR scanning revealed walls and burned material a hearth

and defined as the main or normal field (it comes from the Earth's interior, which is in fact a giant magnet). Geomagnetic surveying in archaeology is aimed at detecting anomalies, which we use to determine the difference between the locally measured value of the Earth's magnetic field and the value of the normal field (the average value of the magnetic field in a given area). In fieldwork, the intensity of the geomagnetic field is measured using magnetometers (which measure the total value of the Earth's magnetic field) or gradiometers (which measure selected field vector components). Underground objects that have magnetic properties cause disturbances in the Earth's magnetic field, creating local anomalies. Maps of the distribution of the intensity of the magnetic field in a given area created as a result of such surveys reveal deviations from the average value – decreases and increases in the amplitude, measured in nanoteslas (nT). These anomalies are mainly generated by concentrations of ferromagnetic minerals and objects, such as metals, burned material, destruction layers or objects filled with organic matter (some bacteria also produce ferromagnetic particles).

This overview already indicates that geomagnetic surveying is excellently useful in archaeology, in searching for all traces of human presence – in the form of hearths, ancient moats, postholes, storage pits, concentrations of pottery, and so on. The unquestioned advantages of this method include, first of all, the speed of measurements and the relatively easy processing of field data. Correct interpretation of the results is a different issue – here, the operator's experience plays the most important role. Despite its undoubted advantages, this method is not suitable for identifying the vertical archaeological sequence of buried objects or structures, which may have different ages. Geomagnetic profiling only allows us to obtain a map of the archaeological site in the form of deviation map of absolute value of the magnetic field, so there is no third dimension – depth. Another limitation is posed by the small depth range, which in practice does not exceed 1.5–2 meters.

A. Survey of an archaeological site using a GPR system with a 450 MHz antenna, Croatia.
B. Survey of an archaeological site using a fluxgate gradiometer, Croatia

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Two methods combined

The above comparison shows that both GPR and geomagnetic surveying each have not only important advantages, but also major limitations. Despite being based on completely different physical phenomena, the two methods complement each other perfectly in terms of the information they provide to archaeologists. In other words, what is seen by a GPR often remains invisible in geomagnetic surveys, and vice versa. The only question that remains is how to directly compare the results of the measurements obtained using devices that differ so greatly from each other.

The results of geophysical and magnetometry scanning were compared for the first time in a survey of one of the Roman sites in Croatia. The GPR reflection profiles (radargrams) were compared with the corresponding magnetic amplitude records (in nanoteslas – nT) obtained through geomagnetic prospecting performed at the same site and in the same survey area. The method was officially named ADCM – the Amplitude Data Comparison Method.

What is ADCM based on? As we have mentioned, GPR and magnetometry provide very different data, which at first glance are not directly comparable. However, it is possible to juxtapose individual GPR reflection profiles (radargrams) against their corresponding magnetic amplitude records (magnetic signature). This provides us with information about the nature of archaeological structures preserved underground (especially regarding the material of which they are made). In another words, ADCM allows for not only a spatial (3D) analysis of buried archaeological features based on GPR images, but also the identification of their material structure, based on magnetic signature readings.

Let us illustrate the use of ADCM with three simple examples. GPR radargrams usually show reflections reflected from lithological boundaries or buried features. This means, for example, that we know that at a given site there is a depression at a specific depth, but we cannot tell what it is filled in with. But if compare the GPR image being analyzed with magnetic amplitude records obtained along the same survey line and, for example, find a specific increase in the magnetic field intensity amplitude in the same place, we can conclude that this depression is filled in with organic matter. This allows us to say with a high degree of likelihood that the revealed anomaly is a storage pit. Let us now assume that a GPR scan at a different site revealed walls that form the outline of an ancient building. Unfortunately, GPR images alone only allow us to conclude that these structures form walls. But if we compare the GPR profiles with magnetic amplitude records, which will show a clear decrease in the magnetic amplitude value at the location of the walls, it will be clear to us that the structures were built of non-magnetic material, in this case limestone or sandstone (neither type of rock shows magnetic properties). Finally, let us imagine that we have located an unidentified structure with an oval outline on GPR profiles and plans. GPR images alone will not allow us to saying anything about this feature. However, if we compare this specific location with magnetic field intensity records and they turn out to correspond to a very high value of the magnetic amplitude, we will be almost certain that the anomaly being analyzed is a stove or a hearth.

We could list many more examples here. The more ADCM analyses we perform within a given survey site, the more we will know about the underground structures at that site. ADCM allows us to determine what material was used to make the structures underground without disturbing the soil, or without excavations that would destroy the archaeological heritage. This is without doubt the greatest advantage offered by ADCM, which is one of the harbingers the transformations that archaeology is bound to undergo in the near future. A new era of "archaeology without a shovel" is truly upon us. ■

Further reading:

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