Integrated geophysical archaeological prospection resulting in the discovery of the school of gladiators in the Roman town of Carnuntum in Austria

Wolfgang Neubauer[1], Sirri Seren[2], Alois Hinterleitner[1,2], Michael Doneus[1], Klaus Löcker[1,2], Immo Trinks[1], Erich Nau[1], Michael Pregesbauer[1,3], Matthias Kucera[(*)1], Geert Verhoeven[1], Timothy Saey[4], Philippe De Smedt[4] and Marc Van Meirvenne[4]

[1] *Ludwig Boltzmann Institute for Archaeological Prospection and Virtual Archaeology, Austria.*
[2] *Archeo Prospections®, Central Institute for Meteorology and Geodynamics, Vienna, Austria.*
[3] *Airborne Technologies GmbH, Austria.*
[4] *Department of Soil Management, Ghent University, Belgium.*

Summary

In the Roman town of *Carnuntum* 40 km south-east of Vienna (Austria) the unique discovery of a school of gladiators was made using a multi-disciplinary approach based on high-resolution near-surface geophysical prospection. The outstandingly well preserved architecture was revealed through non-invasive mapping using latest highly efficient multichannel ground penetrating radar systems. Foundations of a building complex including a circular training arena surrounded by wooden stands, the gladiator's living quarters, practice fields and an associated cemetery were mapped in unprecedented detail. In this paper, state-of-the-art near-surface geophysical prospection involving large-scale data acquisition, precise real-time positioning, and efficient data processing followed by detailed geophysical and archaeological interpretation is presented.

Introduction

The Roman town of *Carnuntum* (Petronell-Carnuntum, Austria), located 40 km south-east of Vienna on the southern bank of the Danube river, was home to some 50,000 to 80,000 inhabitants and consisted of both a Roman legionary camp with associated civilian settlement and a civil town. As vibrant capital of the Roman province Pannonia, *Carnuntum* was an important town during the first four centuries AD. For more than 15 years, this hidden archaeological landscape is within the focus of a large-scale archaeological survey employing and developing the latest non-invasive remote sensing and geophysical near-surface prospection methods and technologies (Neubauer et al., 2012; Doneus & Neubauer, 2005; Doneus et al. 2001).
Repeated aerial photography flights over *Carnuntum* revealed traces of Roman buildings in a field west of the Roman road connecting the amphitheater with the civil town (Figure 1).

Geophysical prospection approach

In 2000 a magnetometer prospection survey using a manually operated five sensor PICODAS MEP750 Cesium magnetometer, was carried out in a field neighboring the civil amphitheater of Carnuntum, which had been excavated earlier and still is visible as an upstanding monument in the landscape. The magnetic prospection data sampled with a spatial resolution of 12.5 x 50cm revealed traces of the foundation walls of a trapezoidal building complex, as well as associated infrastructure such as a canal belonging to the town's water supply system (Figure 2).

Figure 1: In the foreground the ruins of the western amphitheater of Carnuntum can be seen. In the large neighboring field the remains of the school of gladiators were discovered.

A subsequently in 2000 conducted ground penetrating radar (GPR) survey using a Sensors & Software pulseEkko Pro 900 MHz antenna manually towed in a sledge with 5cm inline GPR trace spacing and 50cm cross line spacing resulted in GPR depth-slices (depth-converted using a constant velocity of 10cm/ns) showing a large trapezoidal building complex as well as additional circular structures in the buildings courtyard (Figure 3). Due to this particular layout, similarities with known structures from the Roman Empire and the vicinity of this building to the amphitheater of Carnuntum this find was interpreted as a school for gladiators.

Recent technological and methodological developments in regard to increased efficiency of near-surface magnetometer and GPR prospection surveys using

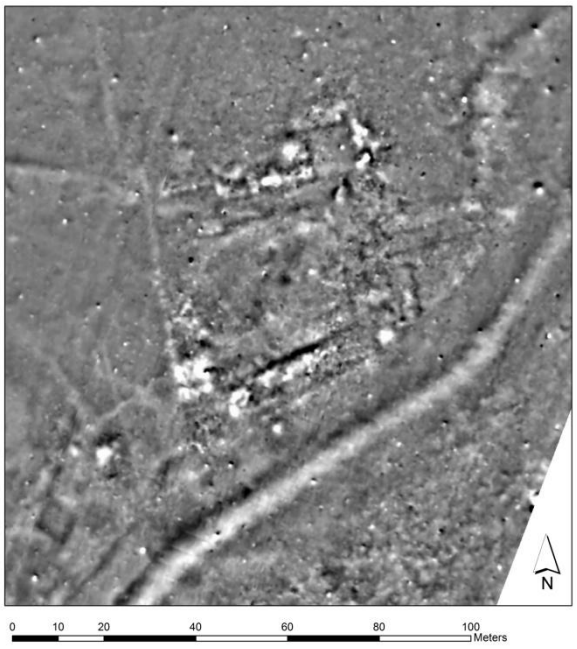

Figure 2: Cesium magnetometer prospection result across the school of gladiators conducted in 2000. The 254 grey-scale values are linearly distributed between white (representing data with -10nT) and black (+10nT).

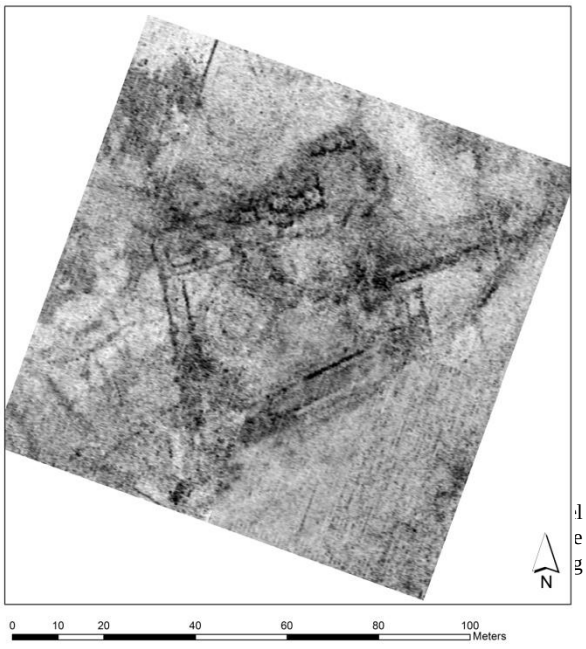

Figure 3: Figure 3: GPR depth-slice (70-80 cm depth) of the single channel survey conducted in 2000. Within the courtyard a circular structure can be seen (∅ 19 m). This has been interpreted as the training arena of the gladiators.

motorized systems have resulted in the possibility to cover areas up to 15 hectares per day with multi-sensor magnetometer arrays (25cm horizontal sensor spacing) and two hectares per day with high-resolution multichannel GPR systems. The MALÅ Imaging Radar Array (MIRA) with 400 MHz antennae includes 16 channels with 8cm channel spacing and possibilities for 4 or 8cm inline GPR trace spacing using a trace stacking factor of 4 and operation speeds of 12-15km/hrs. Using a robotic total-station or Real-time Kinematic GPS with centimeter accuracy at data rates of 5Hz or more, and smart navigation solutions, the acquisition of 3D archaeological prospection data volumes has become possible, imaging underground structures in unprecedented resolution (Trinks et al. 2010).

In spring 2011 an international team of archaeologists, geophysicists, soil scientists and IT experts from the Ludwig Boltzmann Institute for Archaeological Prospection and Virtual Archaeology and its international partners conducted a high-definition GPR survey of the school of gladiators using a MIRA system in a motorized configuration (Figure 4).

The measured GPR data were processed into depth-slice images using special software developed in close collaboration with ZAMG *Archeo Prospections*®.

Subsequently, the GPR results have been complemented with magnetometer data acquired using a novel motorized 10-sensor Foerster fluxgate gradiometer array.

In collaboration with the Department of Soil Management of Ghent University, high-resolution electromagnetic induction (EMI) data were acquired in autumn using a novel four-coil DualEM-21S sensor (DualEM, Ontario, Canada). After processing the data with in-house developed algorithms, the EMI data provided complementary information about the magnetic susceptibility and electrical conductivity of soil volumes with different depth extent, linking magnetometer and GPR data and permitting a site analysis based on underlying geology, hydrology, geomorphology and pedology. The integration of the individual survey methods in combination with a detailed digital terrain model obtained through airborne laser scanning explains the school's layout, its topographic location and the associated drainage and water supply system (Figure 5).

Archaeological Interpretation

The detailed geophysical and archaeological interpretation of the data resulted in maps showing the intact remains of a complete Roman school of gladiators (Latin *ludus*). The

ludus is located outside the gates of Carnuntum's civil town, west of the ruins of the 2nd century AD amphitheater, which according to a contemporary inscription had been the fourth largest in the Roman Empire. The self-contained training and living quarters of the *ludus* cover approximately 2,800 m² located within a walled area of about 11,000 m² (Figure 6).

Figure 4: The MALÅ Imaging Radar Array (MIRA) with 16 x 400MHz channels spaced at 8cm. The RTK-GPS receiver is situated centrally above the GPR antenna box. The system is hydraulically mounted in front of a small tractor. System control and data recording was conducted through software on a ruggedized laptop in front of the operator.

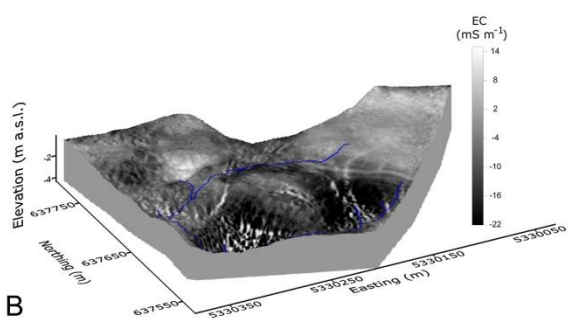

Figure 5: A 3D visualization of the top (0-0.5m) electrical conductivity (EC) draped over the modeled gravel surface of the *ludus* area. This information was extracted from the EMI measurements using EC-depth slicing. On top of the EC-plot, calculated flow-lines were plotted.

A single, easily controlled entrance to the complex can be seen on its eastern side, facing the amphitheater. To the north and within the walled compound an extended open *campus* adjoins the school, which most likely held further practice areas and wild animal enclosures. Inside the school's courtyard a separate circular training arena with 19m diameter was surrounded by wooden spectator stands founded on stone basements. In the center of this arena, clear evidence of the *palus* was recorded, a wooden pole used to exercise blows with the sword and body slams with the shield (Futrell, 2006).The importance of this pole can also be deduced from the names given to the best gladiators: *primus palus* (Futrell, 2006, Mejer, 2007).

Around the closed courtyard a building complex including a 100 m² heated training hall, an extensive bathing complex and an assembly hall has been identified. Additionally, the small cells of the gladiator's and an administrative wing and housing for the school's owner (*lanista*) (Bomgardner, 2000, Meijer, 2007) can clearly be discerned in the prospection data. The barracks of the school were most likely two to three stories high as indicated by typical stairway corridors. Aside from foundation walls of these buildings, the in unprecedented resolution collected geophysical prospection data revealed a mayor part of the public water and drainage network, hypocaust floor-heating systems, paths and gateways. In the immediate vicinity of the school of gladiators, distinctly separated from other burial fields of *Carnuntum*, the separate cemetery of the gladiators was discovered.

Conclusions

Given its state of preservation, dimensions and type of architecture, the discovered *ludus* is considered to be internationally unique. Although it is estimated that over one hundred *ludi* must have been built throughout Roman history (Meijer, 2007), most of them have been destroyed or covered over. The only known existing building comparable to the find made in *Carnuntum* is the partly excavated *Ludus Magnus* near the Coliseum in Rome (Colini, 1962). Unlike the new discovery, the *Ludus Magnus* is only partly accessible today and fewer details have been prareserved.

This unique archaeological find exemplifies the tremendous amount of highly-detailed information that can be gathered by following the latest multidisciplinary, entirely non-invasive, and hence archaeologically sustainable, non-destructive, prospection approach. Large-scale high-resolution GPR, magnetometer and EMI measurements are proven to be well suited for the investigation and safeguard of buried cultural heritage.

Acknowledgements

The Ludwig Boltzmann Institute for Archaeological Prospection and Virtual Archaeology is a research institute of the Ludwig Boltzmann Gesellschaft (www.lbg.ac.at) and was founded in 2010. The institute carries out its research activities together with several international partner organizations and aims to create a network of archaeological scientists supporting interdisciplinary research programmes for the development of large scale, efficient, non-invasive technologies for the discovery, documentation, visualization and interpretation of Europe's archaeological heritage. The lead partners of the institute based in Vienna, are the University of Vienna (A), the Vienna University of Technology (A), the Austrian Central Institute for Meteorology and Geodynamics (A), the Province of Lower Austria (A), Airborne Technologies (A), the Roman-Germanic Central Museum in Mainz (D), the Swedish Central National Heritage Board (S), IBM VISTA at the University of Birmingham (GB) and the Norwegian Institute for Cultural Heritage Research (N).

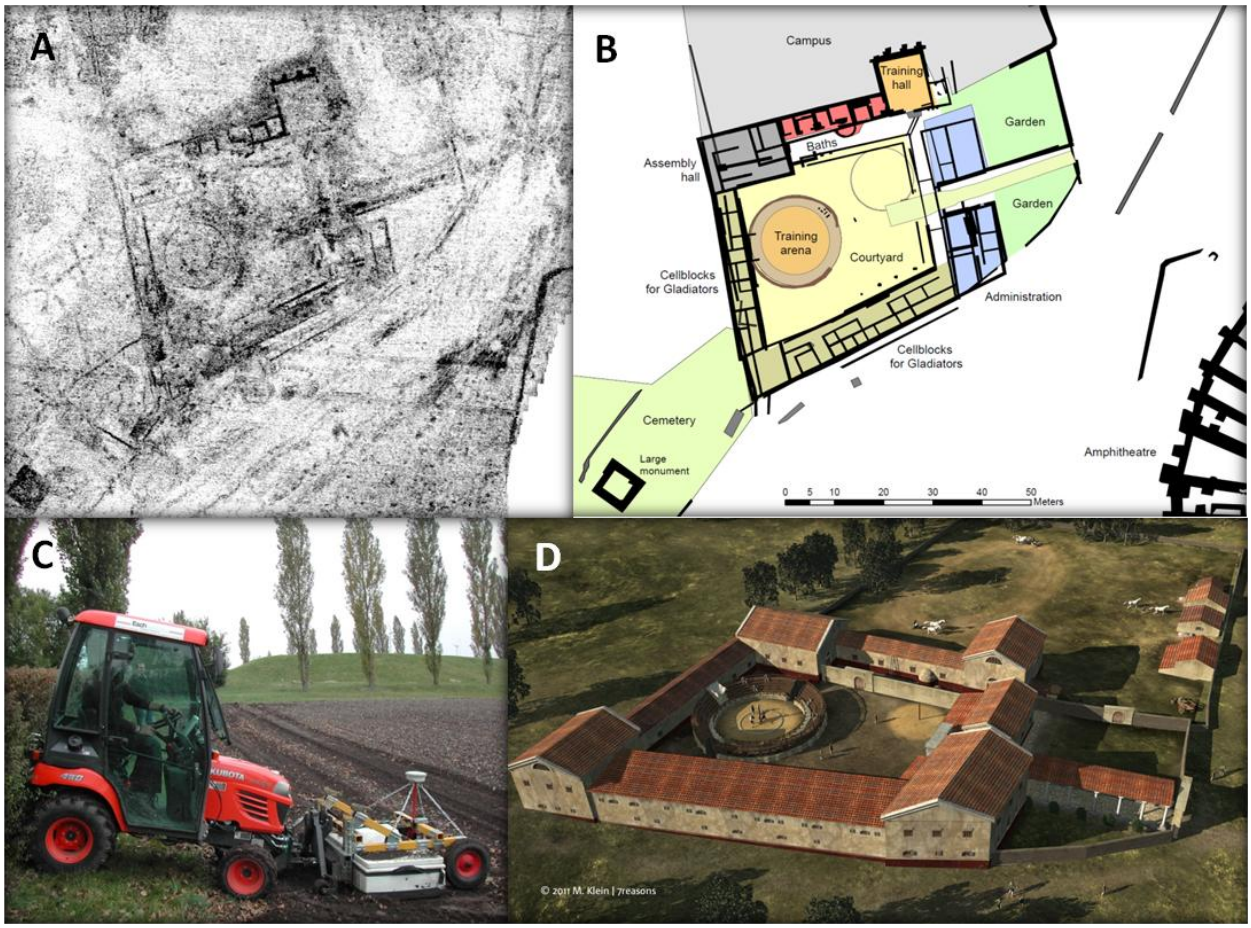

Figure 6 A: high-definition GPR depth-slice (80cm below surface) showing the foundations of the *ludus*. B: Archaeological interpretation of all prospection data. C: MIRA system in front of the amphitheater. D: Virtual reconstruction of the *ludus* at Carnuntum.