Scientific Report for NERC GEF Loan 878

Mounds and flats: revealing the prehistoric and historic landscape of the Cetina Valley, Croatia

by Armin Schmidt

Abstract

Ground Penetrating Radar surveys were undertaken at Diocletian's Palace in the World Heritage Site of Split and in the Cetina Valley, Croatia. Using 100, 200 & 500MHz antennas, data were collected as 3D data cubes and along individual transects. The data cubes provided new archaeological insights into the building history of Diocletian's Palace and clearer imaging and depth information of features than would have resulted from magnetometer surveys alone. High- and low frequency antennas detected different features (archaeological remains *vs.* palaeochannels) and numerical data combination would not have significantly improved the results.

Background

This project is part of a larger archaeological mission entitled '*Scanning and geophysical survey at the World Heritage Site of Split and in the Cetina Valley*', which is being undertaken by Prof Vince Gaffney, University of Birmingham in collaboration with Dr Chris Gaffney, University of Bradford and Dr Armin Schmidt, GeodataWIZ. It builds on work that started in 2002. The first field season of the project (24 June - 3 July 2009) comprised of a 3D scanning survey in Diocletian's Palace in Split, around the Mausoleum, and at the 9th century church of Sveti Spas. In addition, fluxgate gradiometer surveys, using a cart-mounted Foerster Ferex system, were undertaken at Sveti Spas, Citluk (Roman Aequum) and around the late antique church at Otok.

This GEF loan formed a sub-project to the overall mission with separate and specific objectives. Using data from the main mission as contextual information, GPR surveys were undertaken with the GEF's PulseEKKO Pro 1000 around the Mausoleum of Diocletian and in the lower town of Split, at Citluk and at Otok. The location of these sites is shown in Figure 1.

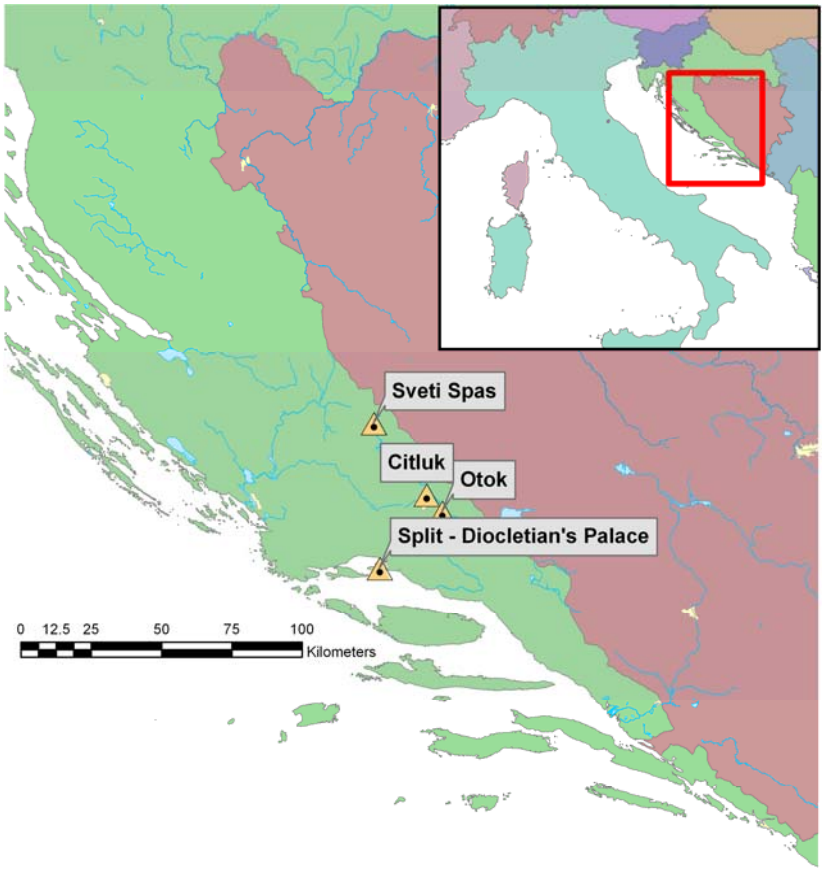


Figure 1: Location of Sites

The objectives of this project were defined as:

- Investigate evidence at Diocletian's Palace of earlier building phases.
- Investigate underlying geological formations that may have influenced the design of Diocletian's Palace.
- Investigate the potential for non-invasive geophysical techniques at a variety of archaeological sites within the Cetina Valley.
- Produce plans of the subsurface remains at these sites.
- Combine GPR data collected with antennas of different frequencies to achieve a combination of depth penetration and spatial (depth) resolution.

The plans submitted prior to this field season were augmented by archaeological objectives, partly in response to advice from local Croatian archaeological collaborators and partly due to the malfunctioning of equipment (see below) that necessitated changes to the project.

Survey procedure

During surveys with the PulseEKKO Pro 1000 it became apparent that the system did not record trigger pulses correctly when operating in continuous mode, as required for high-frequency surveys (e.g. 500MHz). While still on fieldwork, GEF was made aware of this and communication with the manufacturer (Sensors&Software) revealed that this was due to a firmware error (whether this has now been corrected is unknown to the author). As a result of this malfunctioning, the data collection was considerably slower than anticipated and software had to be written to rectify the corrupted data. In addition, the field conditions encountered on site, and worsened by heavy rain, necessitated that data collection with the relatively bulky 100 & 200MHz antennas was undertaken in stepped mode (i.e. stopping every 0.1m to collect a new trace) and therefore proved to be much slower than planned. Consequently, the overall survey work undertaken during this field season had to be restricted. It was therefore decided to collect all 3D data cubes with the 500MHz antenna and complement it in one area (Diocletian's Palace, Peristyle S) with 100 and 200MHz data cubes. For additional comparisons all antennas (100, 200 & 500MHz) were used on selected long transects at Otok (Areas 3 & 4).

All 500MHz 3D data cubes were collected along lines 0.5m apart, continuously acquiring data always in the same direction (i.e. not zig-zag). Markers were placed with the manual trigger every metre, using a tape as a guide. This resulted in a trace separation of approximately 0.01 to 0.03m that was later rubberbanded to 0.1m. The 100 & 200MHz data cubes were collected on lines 1m apart in stepped mode (0.25m for 100MHz and 0.1m for 200MHz). The areas surveyed in this way were:

- Diocletian's Palace, Peristyle S (Area 1): 23m×7m (100 & 200 MHz), 23m×10m (500MHz)
- Diocletian's Palace, Peristyle N (Area 2): 9m×10m
- Diocletian's Palace, Crypt (Area 3): 6m×11m
- Diocletian's Palace, North of Church (Area 5): 45m×7m
- Citluk, Area 1: 46m×7.5m
- Citluk, Area 2: 75m×14m
- Citluk, Area 3: 57m×14m
- Citluk, Area 4: 20m×20m
- Otok, Area 1: 20m×5m
- Otok, Area 2: 15m×10m

Transect data were collected in continuous mode for the 500MHz antenna with markers every 1m and in stepped mode for the 100 & 200MHz antennas:

- Split, lower town, two transects along Cardo towards Northern (Golden) Gate (Area 4): 90m @ 0.1m (500MHz)
- Split, lower town, two transects east of Cardo (Area 6): 60m @ 0.1m (500MHz)
- Split, lower town, two transects west of Cardo (Area 7): 60m @ 0.1m (500MHz)
- Otok, Area 3: 100m @ 0.25m (100MHz), 0.1m (200M & 500MHz)
- Otok, Area 4: 100m @ 0.25m (100MHz), 0.1m (200M & 500MHz)

Figure 2: Location of data cubes/timeslices and transects for Diocletian's Palace and the lower town of Split.

Data quality

The processed data are of good to very good quality, as can be seen from the timeslices presented in Figures 3 and 4. In particular the data from Citluk (Fig. 4) show the extremely accurate positioning of the antennas during survey, resulting in very sharp images of the walls of buried Roman buildings.

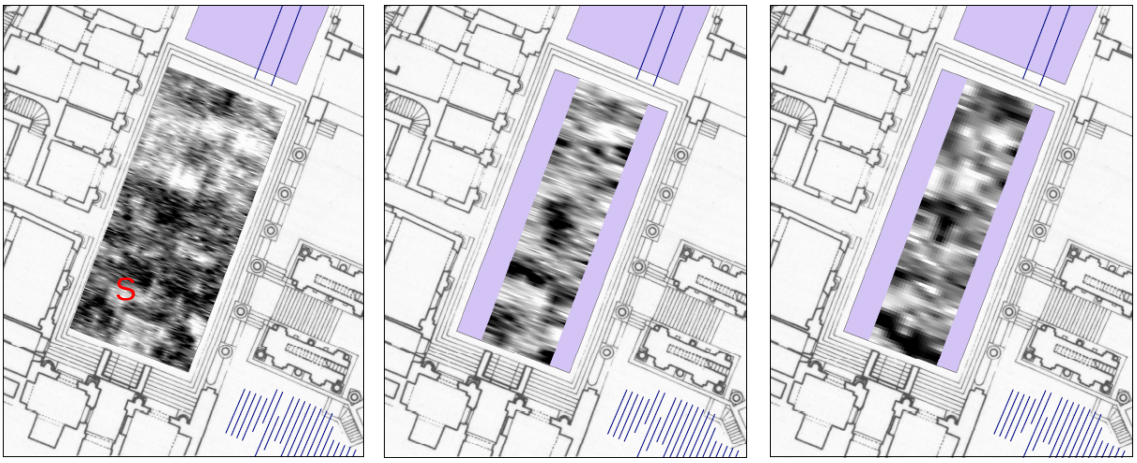


Figure 3: Timeslice data from the Lower Peristyle of Diocletian's Palace. Left: 500MHz ca. 0.9m depth; Middle: 200MHz ca. 0.7m depth; Right: 100MHz c. 0.4m depth.

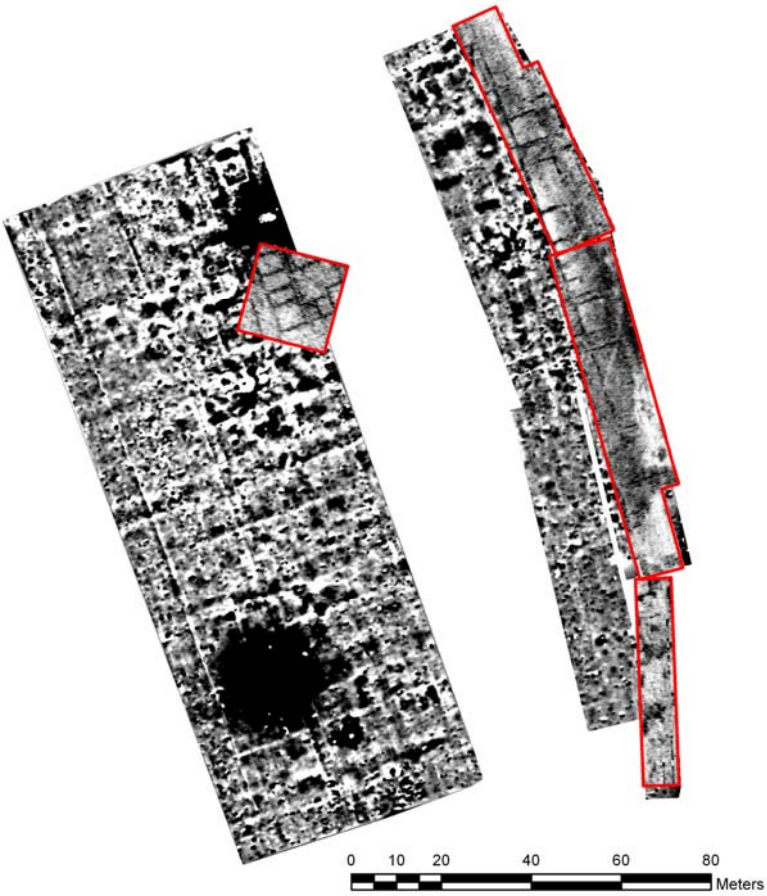
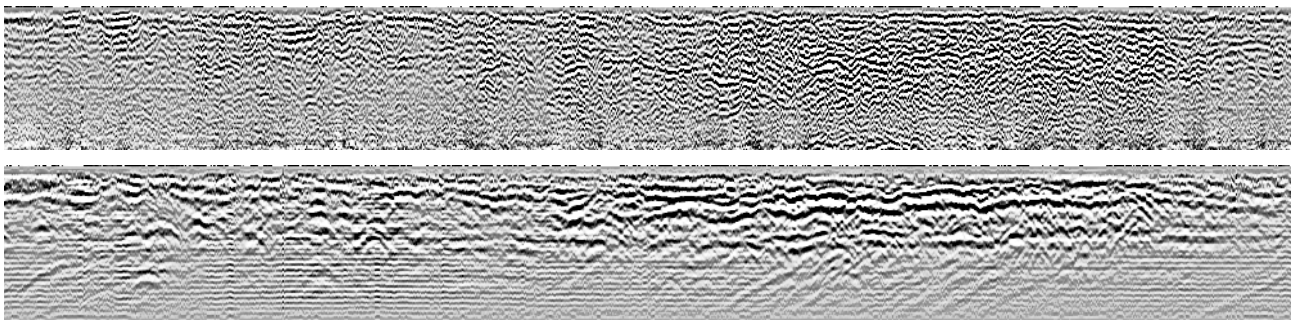


Figure 4: Selection of timeslices from Citluk, overlaid onto magnetometer survey data.



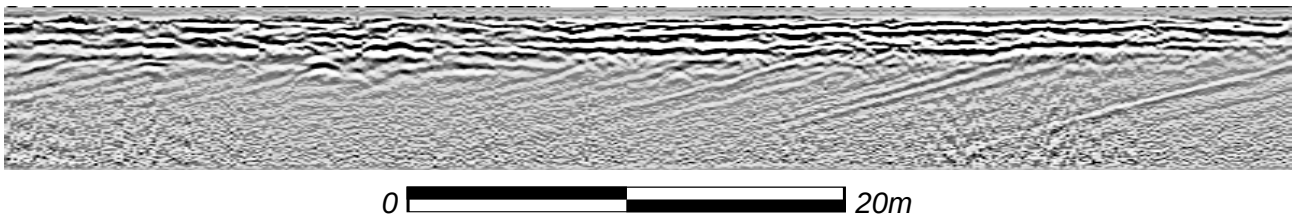


Figure 5: Otok, Area 3. Top: 500MHz, 40ns; Middle: 200MHz, 100ns; Bottom: 100MHz, 200ns.

Processing and modelling

While 100 & 200MHz data were acquired in stepped mode, 500MHz data had to be rubberbanded to a sampling interval of 0.1m, using markers that were placed every 1m, after correction of erroneous markers that were randomly inserted by the faulty firmware (see above). Data were then bandpass filtered (using a trapezoidal ramped frequency gate) and time-constant defects removed by subtracting an average trace from each radargram. Migration tests resulted in velocity values of approximately 0.08m/ns for all sites, which is surprising given the expected difference between urban and rural setting. This is probably due to the generally very wet conditions before and during the surveys. This velocity was used for migration of the data which were subsequently compiled into time slices of 0.1m thickness by levelling all lines.

Interpretation to date

The time slices of the Peristyle in Diocletian's Palace (Fig. 3) show that the stairs that now enter onto the Peristyle at its far-south end were originally situated further north (see red 'S' in Figure 3 Left), nearly opposite to the entrance to the Mausoleum. This discovery demonstrates that the initial architectural design was mainly influenced by the symbolic importance of ascending from the dark cellars onto the Peristyle and standing directly opposite to the Mausoleum's entrance, whereas in a later remodelling the architectural integrity of the Peristyle as an open space became more important and therefore the stairs were moved backwards (and became much steeper). The 100 & 200MHz data cubes add little to this archaeological analysis, partly due to the lower spatial resolution of their wavelets. They do show, however, indications of possible geological changes at the deeper levels. Local geological data are currently being sourced by the Croatian collaborators and will be compared to these lower frequency data.

The comparison of data collected with three different frequencies along two transects in Otok (e.g. Fig. 5) shows that the low-frequency data (mainly 100MHz) are linked to the formation of gravel islands with slanting interfaces (long wavelength and deep penetration), whereas only the high-frequency data (500MHz) show spatial variation at sufficient spatial resolution to make them useful for possible archaeological interpretations.

Preliminary findings, conclusions and recommendations

The timeslices created from the 500MHz data cubes were of great help to reveal new insights (e.g. older design of stairs in Diocletian's Palace; Fig. 3) or to provide clearer images and depth information of features that were detected by magnetometer surveys (e.g. Citluk, Area 4, westernmost 20m×20m block, where magnetometer data are 'swamped' by a strong ferrous anomaly; see Fig. 4). Depth penetration and spatial resolution of the lower-frequency data were of considerably less value for the archaeological analysis. In hindsight, a closer line spacing of the lower frequency data cubes (100 & 200MHz) might have allowed a better comparison with the shallow data from the 500MHz antenna.

The project showed that where data are collected separately with antennas of different frequencies, the added value may be limited. This was especially clear at Otok, where the different datasets recorded different features (palaeochannels with 100MHz, anthropogenic soil disturbance with 500MHz). For such separate surveys it appears to be best to choose survey parameters individually for each frequency, adjusted to the features to be investigated, and then to analyse the data separately. Little is gained from numerically combining the datasets. Only if data from different frequency antennas can be collected simultaneously, which is not easily achieved with the equipment from the GEF, is a joint analysis a feasible option.

Publications

V. Gaffney, C. Gaffney, H. Goodchild, A. Schmidt, G. Sears, T. Sparrow and M. Lobb (2009) Scanning and geophysical survey at the World Heritage Site of Split and in the Cetina Valley. Preliminary report to the Croatian Authorities.

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