13.1 Combined representation of part of the civil town
Based on an orthophotograph, along with excavation
evidence for insulae and the monumental baths, plus
magnetic survey, resistivity mapping, GPR imaging and
aerial photo interpretation.
INTRODUCTION

The last decade has seen a considerable development in aerial archaeology and geophysical prospection. The main progress in aerial archaeology - apart from the political events and the associated start of active aerial survey in the countries of eastern Europe - has been in techniques for the rectification and mapping of air photographs. Today, digitised images can be rectified using sophisticated photogrammetrical techniques (DONEUS 2001) or specialist programmes (HAIGH 1998; SCOLLAR 1998). They then become readily available for on-screen interpretation. Geophysical prospection has also undergone major developments through the introduction of ever more sensitive sensors and of special devices for rapid high-resolution measurement in the field. Computers have made it possible to handle the huge mass of data that can be gathered within a single hour of magnetic prospection or within mere minutes of scanning by ground penetrating radar (GPR).

However, it seems that the development of interpretation techniques has not kept pace with the speed with which data can now be collected. Consequently, geophysicists tend to present their data as prospection “results” while aerial archaeologists have a tendency to talk about “cropmarks” rather than archaeological features. Refinement in the interpretation of prospection data depends on the development of interpretation tools and on a high degree of archaeological feedback.

As one of the most important “new” tools, GIS has found its way into archaeological prospection almost four decades after its first invention. GIS has found its way into archaeological prospection almost four decades after its first invention. GIS opens up the possibility of combining the various prospection data and results, which can then be re-evaluated and re-interpreted to give a more holistic view of a site or landscape. It also opens a vast array of new possibilities for interpretation, beyond the current practice of prospection archaeologists.

THE SITE OF CARNUNTUM

The archaeological landscape of Carnuntum is located 45 km east of Vienna, close to the Slovakian border where the Danube cuts through the foothills of the Carpathian mountains in the east, its gravel-terraces forming a flat to slightly hilly terrain. The subsoil is formed by river terraces covered by a chernozem. Carnuntum, the Roman capital of the province of Pannonia, was an important town during the first four centuries AD. The archaeological remains cover an area of approximately 1900 hectares within the modern communities of Bad Deutsch Altenburg and Petronell (Fig. 13.2).

In Austria, archaeological prospection is concentrated at the University of Vienna. Aerial archaeologists and geophysicists sit side by side in the Vienna Prospection Archive, enabling a close relationship between aerial archaeology and geophysical prospection. In recent years parts of our scientific investigations have been concentrated on the combination of different prospection techniques, this becoming a standard procedure in our daily working routine (DONEUS, NEUBAUER 1998).

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Many fields have been subjected to deep-ploughing, often financed by looters and treasure hunters, and there has been large-scale destruction of the ancient structures. A stone quarry has destroyed the mountain of the Pfaffenberg, along with the Roman sanctuary on its peak. The economic and housing development of the modern villages, located within the archaeological zone, poses another threat to the cultural heritage. At the same time agricultural erosion slices away centimetre after centimetre of the archaeological layers. This constant destruction cannot be fully prevented, so cultural resource management will have to concentrate on preserving the most important parts. In order to support preservation an appropriate prospection strategy had to be established so that the archaeological remains can be recorded before they completely vanish. Therefore, in 1997 the decision was taken to create a map of the ancient city, based on aerial photographs, as a first step in a systematic prospection of the archaeological landscape of Carnuntum. Aerial photographs from the past fifty years are now being used to create a highly detailed map of the archaeological features. The preparation of this map is an ongoing internal joint project between the Institute for Prehistory of the University of Vienna and the Vienna Institute for Archaeological Science (VIAS).

In addition a case study funded by the Austrian Ministry of Science and Traffic was launched to develop a standardised combination of geophysical archaeological prospection methods (aerial archaeology, magnetics, resistivity mapping and GPR) so as to create a highly detailed interpretation model of particular archaeological monuments. As a study area for this part of the project a large building complex was selected in the civil town of Carnuntum. This had been detected some time before through resistivity mapping and could be interpreted as the town’s forum, sought for over a hundred years (Fig. 13.1, just left of centre). The ongoing conduct of the research project is funded by the Austrian Ministry of Science and the Department for Cultural Affairs of the County of Lower Austria. The project also encompasses the standardisation of GPR surveys for archaeological applications, with targeted surveys of the forum (Neubauer et alii 2002), parts of the civil town and the surroundings of the ceremonial arch known as the “Heidentor”.

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AERIAL RECONNAISSANCE

The first aerial photographs taken over the area of Carnuntum date back to the 1930s when E. Swoboda, a former member of the flying corps during the World War I, used his contacts in the military to obtain aerial photographs of the area. Today the project's aerial archive contains several hundred photographs, both vertical and oblique, of the Carnuntum area (Doneus 1996). Vertical photographs have been taken by the Austrian Air Force, operating out of Langenlebarn. The collection includes vertical coverage of Carnuntum from various years and seasons, providing an excellent overview of the area's archaeology. The photographs include both black-and-white and infrared false-colour material, taken with a Zeiss RMK. The scales range from 1:8,000 to 1:15,000. Oblique air photographs are taken by ourselves, using high-wing aircraft (Cessna 150 or 172) and calibrated medium-format cameras (Hasselblad) with black-and-white as well as colour slide films.

A third category of data comes from an earlier project. Two decades ago, between 1978 and 1984, a project was set up to rectify aerial photographs from the area of Carnuntum. The idea was to create a city map at the scale of 1:2,000. It was a joint project between the Austrian Archaeological Institute and the Institute for Photogrammetry and Remote Sensing of the Technical University of Vienna and can be seen as a predecessor of the present project. Unfortunately, this work was not continued, but the resulting orthophotographs, covering parts of the canabae and the military camp, are still available and will be incorporated into our own work.

In addition to the aerial photographs various kinds of maps are available. Most important are the cadastral maps of the modern villages of Petronell and Bad Deutsch-Altenburg, at scales of 1:2,000 and 1:1,000, along with geological and pedological maps and plans from the last hundred years of archaeological excavation, the most useful being those of the Roman military camp, the two amphitheatres, the grand baths and parts of the civil town (Jorst 1983). Because of the differing data sources it was decided to use analytical and digital photogrammetry methods both to create a digital terrain model and to rectify the aerial photographs. The interpretation is carried out within a GIS, in which the orthophotographs can be combined with other data sources such as geophysical prospecting results, excavation maps and older orthophotographs.

AIR PHOTO RECTIFICATION

The first step is to obtain a DTM for later use in the rectification of the aerial photographs. So as to allow rectification of oblique as well as vertical air photographs within an acceptable error tolerance the DTM has to be a fairly accurate representation of Carnuntum's topography. From the former mapping project there was available a block of forty-six vertical photographs, covering the whole area. The block was created in 1976 at a scale of approximately 1:5000 by the Bundesamt für Eich- und Vermessungswesen, on behalf of the Institute for Photogrammetry and Remote Sensing of the Technical University of Vienna. The orientation work, by aerotriangulation, was also carried out by the Institute. The stereomodels were set up on the project's analytical plotter using the initial values of the aerotriangulation. The average model accuracy is approximately 0.30 m in plan and 0.25 m in height. Additionally, several other vertical stereopairs were oriented. In this case, ground control was obtained by field measurements using a tachymeter. A DTM was created from the vertical stereopairs, covering more than 2,000 hectares through 127,000 measured points.

For digital rectification of the air photographs the images are scanned at a high resolution (12-15 µm pixel-size). Control-point information is obtained either from field measurements using total station survey or from the oriented stereopairs. The orientation of the aerial photographs is either calculated using space resection (for single images) or a bundle adjustment. This is done digitally using Softplotter™ and ERDAS Imagine Orthobase. Depending on the camera used, the scale and the distribution and the quality of the ground control points, the resulting accuracy lies between 0.25 and 0.75 m. Each image is rectified using the outer orientation values and the digital terrain model. The resulting georeferenced orthophotographs usually have a pixel-size of 0.2 m and are ready to be used in any GIS.

GEOPHYSICAL PROSPECTION

The first geophysical surveys in Carnuntum were undertaken in 1990 in response to building activities and expansion of the modern settlements. All of the early surveys, done by Archeo Prospections, had to solve distinct problems on a small scale. During the late summer of 1996 a first large scale prospection campaign in the civil town was carried out during a two-week-long student training exercise on resistivity surveying, mapping an area of 5 hectares. The survey was located 280 m west of the excavated insulae and 80 m south of the grand baths in the “Tiergarten” of Traun castle. These investigations, in a hitherto unexplored part of the town centre, resulted in the detection of the forum. This was the stimulus for specific research projects and further
large-scale surveys in the area of the civil town, covering up to the time of writing about 100 hectares. The work was carried out by Archeo Prospections and the Central Institute for Meteorology and Geodynamics, in cooperation with the Vienna Institute for Archaeological Science (VIAS).

Magnetic, resistivity and GPR surveys are the most successful geophysical prospection techniques for archaeological purposes. Resistivity mapping using RM15 and GPR is far more time-consuming than large-scale high-resolution magnetic surveying using multisensor caesium gradiometers. These instruments are therefore normally applied only in detailed target areas. Magnetic prospection is the preferred method on extensive urban and suburban areas, complemented by targeted resistivity and/or GPR surveys to enhance the information, particularly in respect of features characterised by stony deposits. Magnetometry, carried out in a standard grid of 0.125×0.5 m, recovers such things as ditches, pits, ovens, brickwork and wooden palisades very clearly and is able to cover more than 3 hectares per day under good field conditions. But the stone walls of Roman buildings are usually only resolved in moderate detail, often being obscured by large anomalies, representing deposits of brick and tile inside and around the buildings. Additional survey by resistivity or GPR can highlight walls, floors or other stony features. For prospection of the inner structure of a Roman town large-scale resistivity or GPR surveying may be of primary use. But a combination with magnetics adds important information on such things as pits, ditches, wooden structures, robber-trenches and walls of bricks or tiles from the roofs.

In 1996 resistivity data combined with information gained from aerial photography gave an insight into an area of about 5 hectares of the Roman town. In the resistogram of the investigated building complex the symmetrical layout of the forum stands out clearly against the surrounding built-up district with its complicated street pattern. The resistivity measurements have been complemented by a magnetic survey. The combination of the two types of data and their archaeological interpretation resulted in a first interpretation model (NEUBAUER, EDER-HINTERLEITNER 1997), used as primary input for the present case study. The aim of the subsequent GPR survey was to gain higher spatial resolution and depth-related information to help in the creation of a three-dimensional interpretation model.

GPR is an advanced method of prospection, with high potential in archaeological applications. The adaptation of a commercially available PulseEKKO 1000 GPR device for archaeological applications and the determination of adequate measuring parameters were achieved through test measurements. The experience showed that the measuring distances used in previous studies are not appropriate for
the examination of complex archaeological questions. Line spacing – as for other methods used in archaeological prospection – must not be greater than 0.5 m and conventional visualisations of single vertical sections are difficult to read and understand. Therefore only a small part of the information inherent in the measured data has been used so far for interpretation. Archaeological interpretation is thus made difficult or even impossible. The negative feedback from archaeologists, based mainly on the lack of relevant interpretation, has hindered the application of this potentially most informative and non-destructive method of prospection. In order to use GPR in archaeological interpretation processes a standardised method of data representation and visualisation had to be developed, following the established procedures of geomagnetic and resistivity mapping. Tests on commercial software showed no convincing results, so adequate software had to be developed, producing time- or depth- slices as digital images in horizontal plane or any vertical direction by computing a three-dimensional data block of the GPR amplitude distribution (Fig. 13.3). Animation of such image sequences makes mental recognition of archaeological structures by the interpreter easier. Digital image sequences found via selection of relevant horizontal depth-slices are now georeferenced and integrated into the GIS for subsequent detailed, depth-correlated, archaeological interpretation.

ARCHAEOLOGICAL INTERPRETATION

Archaeological interpretation is carried out using GIS. To allow the orthophotos, geophysical images and vectors to be overlain on one another they have to be set up in a uniform coordinate system, a prerequisite that is already fulfilled in the project’s data. The interpretation drawings derived from GPR-data, in combination with the available resistivity and magnetic data as well as information from aerial photography, lead to a detailed archaeological interpretation model. Two-dimensional interpretation maps and three-dimensional interpretation models can be derived from this basis. The orthophotos from aerial archaeology are enhanced using digital image-processing techniques such as contrast enhancement, Wallis-filter, and crispening to make the archaeological features more clearly visible. All of the georeferenced orthophotos and their filtered versions are then compiled in the GIS viewer. The interpretation is done image by image on-screen in separate layers, using different colours and attributes for different kinds of features. Since every image shows the area in different conditions and consequently in different detail, the composite interpretation drawing acts as a summary of the information visible on all of the available photographs.

Aerial photographs showing archaeological features in an area of 270 hectares have been mapped. Although only about 10 percent of the available photos have been rectified and interpreted the composite map already shows a considerable degree of detail. In the canabae around the military camp it has proved possible to reconstruct the whole of the road network, parts of it displaying side-drains. Between the roads more than a hundred buildings can be identified. West of the camp parts of the forum are visible. The main road to the west is lined by graves and tombs (Fig. 13.4). Further west the ditches of the auxiliary camp, where the cavalry was situated, have also been mapped. The camp has already been partly destroyed by the expanding village of Petronell. The second area, west of the village, shows a complex of buildings belonging to civil amphitheatre II, along with a large graveyard, the two partly intersecting one another and therefore clearly not contemporary. The civil town of Carnuntum, protected by its massive wall and two parallel ditches, is currently used for pasture and archaeological features can only be seen from the air in very dry summers. In most of the photographs only the road network is visible (Fig. 13.5).

Greater detail can be seen in the results of the geophysical prospection. A large building complex was explored in this case study. It has a symmetrical layout covering an area of over 3000 m², with a wall thickness of up to 1.5 m. It forms the southern end of the forum of Carnuntum. The northern part of the building complex could be reached from the lower open square of the forum by a monumental staircase. The complex includes three large halls, each with a floor area of about 150 m² and one of them with an apsis. The corresponding room to the east is equipped with a hypocaust, showing that it was heated and probably served as the curia, the meeting hall of the city council. The central hall shows a pedestal or platform in front of the rear wall. In the southern part small rooms, some constructed with cellars, are flanked by corridors. These were reached by two staircases and a porticus from a triangular open space to the south. The halls lining the forum, each with a porticus, presumably housed shops, with cellars below. Beneath the floor level of the building two channels or drains were traced, leading to the river Danube. Information was also been documented on the depth of the foundations, the filling layers and the plastering, as well as the height of the remaining walls, the positions of wall-debris and the depth reached by the modern plough (Fig. 13.6).

A full description of the mapped features would be inappropriate here (but see Neubauer, Eder-Hin-
13.4 Aerial archaeological interpretation
The area around the legionary camp.

CONCLUSIONS AND FUTURE PROSPECTS

This case study can be regarded as a prime example of combined archaeological-geophysical prospection. The available aerial photographs are complemented by extensive non-destructive magnetic, electric and electromagnetic measurements. The resulting images can be combined with supplementary information. Thus quick and economical insights can be gained into the archaeological monuments by digital image combination. Combined interpretation of data with a reading distance of 0.5 m or less, along with digital orthophotos at a similar resolution, provide an accurate basis for conservation and development planning and represent an economical means of documenting the archaeological monuments. The choice of specially adapted measuring devices and measuring parameters can make this information even more precise through the addition of GPR data, providing depth-information. The developed interpretation techniques allow the incorporation of GPR data into the standardised GIS-based interpretation process used for other types of archaeological prospection data. Based on GPR and other available geophysical data a detailed three-dimensional interpretation model of individual archaeological monuments can be derived. Experience from methods of evaluation and interpretation developed during this case study gives the opportunity to plan a specific strategy for the wide-scale prospection of Carnuntum. There is clearly an urgent need for this from the scientific point of view, and for development planning. Such prospection could make an enormous contribution to the formulation of cost-effective conservation strategies through combined and focused action for this largest of archaeological zones in Austria. Further work will concentrate on integration of the remaining aerial photographs and combination of the results with geophysical prospection. It is planned to apply geophysical prospection methods to the survey of 550 hectares of the urban and suburban central area of Carnuntum. Flying and air photography will continue over this most magnificent of Austria’s archaeological landscapes. Even after fifty years of aerial survey new features are still to be found, both in the centre and in the surrounding area, each adding a new piece to the puzzle. After more than a hundred years of archaeological investigation involving a patchwork of excavations, we can now hope to summarise all the available information so as to produce the first comprehensive map of the ancient city of Carnuntum.
13.5 Aerial archaeological interpretation
The area of the civil town of Carnuntum.

13.6 Three-dimensional interpretation of the GPR data for the forum