RETURN

THE CITY MAP OF ANCIENT CARNUNTUM – COMBINING ARCHAEOLOGICAL PROSPECTION, PHOTOGRAMMETRY AND GIS

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ABSTRACT

The city map of ancient Carnuntum is a joint project of the Institute for Prehistory of the University of Vienna and IDEA (Interdisciplinary Research Intstitute for Archaeology, University of Vienna).
Aerial photographs of the last 50 years are used to create a highly detailled map of the archaeological features of Carnuntum, the ancient Roman capital of Pannonia. Using analytical and digital photogrammetry, a 3D model of the landscape was measured and the archaeological features of a large area were mapped with high accuracy. These data are combined with geophysical surveys and excavation results using a GIS-system. The result is a city map of ancient Carnuntum, showing the road system, the single houses, graveyards, public places etc. which consequently will be used by the local archaeologists.

KURZFASSUNG

Die Erstellung eines Stadtplanes von Carnuntum, der römischen Provinzhauptstadt Pannoniens, ist ein Gemeinschaftsprojekt des Instituts für Ur- und Frühgeschichte der Universität Wien und IDEA (Interdisziplinäres Einrichtung für Archäologie, Universität Wien). Die Basisdaten für die Herstellung einer detaillierten und maßstäblich genauen Karte der archäologischen Landschaft von Carnuntum bilden Luftbilder aus den letzten 50 Jahren. Aus diesen Luftbildern wurde mittels analytischer Photogrammetrie ein digitales Geländemodell erstellt. Dieses diente als Grundlage für Orthophotos, die unter Zuhilfenahme von digitalen photogrammetrischen Methoden berechnet wurden. In der Folge wurden die archäologischen Befunde des gesamten Raumes kartiert. Diese Daten können mit den Ergebnissen der geophysikalischen Prospektion und archäologischer Grabungen unter Verwendung eines GIS kombiniert werden. Resultat ist ein Stadtplan des antiken Carnuntum, der das Straßensystem, einzelne Gebäude, öffentliche Plätze, Friedhöfe, etc. enthält und eine Basis für die Planung weiterer archöologischer Arbeiten darstellt.

1. INTRODUCTION

The archaeological landscape of Carnuntum is located 45 km east of Vienna, close to the Slovakian border. The area is characterised by the river Danube cutting through the foothills of the Carpathian mountains in the east and its gravel-terraces forming a flat to slightly hilly terrain (Fig. 1).

As the Roman capital of the province Pannonia, Carnuntum was an important town during the first four centuries of the first millenium AD. Today, the archaeological remains are spread over an area of approximately 300 hectares within the modern communities of Bad Deutsch Altenburg and Petronell (Fig. 2).

During the 19th century Carnuntum was called the "Pompeji at the doors of Vienna" due to the good preservation of the Roman ruins. In the meantime, the situation has changed drastically. Both aerial photography and geophysical data show that the archaeological heritage has suffered severe damage through the local agricultural policy of the last few decades. Many fields have been deep ploughed resulting in a large-scale destruction of the antique features. A large stone quarry already destroyed the Pfaffenberg with the Roman sanctuary on top of this former hill. The economic and housing development of the modern villages, which are located in the archaeological zone, poses another threat

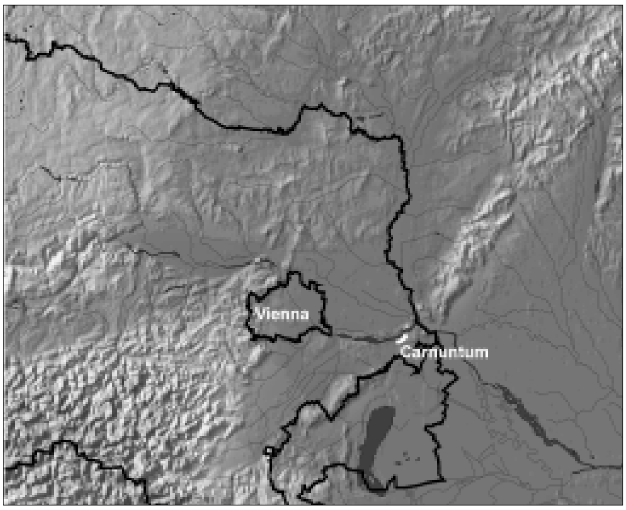

Figure 1: *Relief map of the eastern part of Austria.*

on the cultural heritage. At the same time, erosion due to agriculture takes away centimeter by centimeter of the archaeological layers. This constant destruction of Roman Carnuntum cannot be prevented fully. Therefore, cultural resource managment 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 antique remains can be recorded before they are completely vanished. As a first step, we decided in 1997 to create a city map of ancient Carnuntum. Aerial photographs of the last 50 years are currently used to create a highly detailled map of the archaeological features of Carnuntum. The preparation of this map is a joint project between the Institute for Prehistory of the University of Vienna and IDEA (Interdisciplinary Research Intstitute for Archaeology, University of Vienna).

2. AVAILABLE DATA

The first aerial photographs made over the area of Carnuntum date back to the 1930s. At that time, E. Swoboda, a former member of the flying corps during the World War I, used his contacts to the military to get aerial photographs from this area. One of these pictures, made on the 28th of April 1939, shows the Roman military camp (Fig. 3). Both the enclosure walls and the system of the inner buildings can be seen clearly.

Today the aerial archive of the Institute for Prehistory, Vienna, has several hundred photographs of the area of Carnuntum. Both vertical and oblique photographs are used (see also M. Doneus 1996, 124). The vertical films were produced by the Austrian Air Force at Langenlebarn. Due to a contract between the Ministery of Science and the Ministery of Defense, the Institute for Prehiostory has permission to use all of the photographs produced in Langenlebarn for

Figure 2: *Aerial photograph from May 1968 showing part of the area of Carnuntum. 1: military camp, 2: amphitheatre I, 3: canabae, 4: auxiliary camp, 5: excavated area of the civil city (photograph: Fliegerhorst Langenlebarn).*

Figure 3: *Oblique photograph from the 28th of April 1939 showing the Roman military camp. The enclosure walls and the system of the inner buildings can be seen clearly.*

scientific purposes. Therefore, we have several vertical coverages of Carnuntum from various years and seasons giving a very good overview of the archaeology in the whole area. The photographs are exposed both on black and white and infrared falsecolor material. The exposures are realized using a Zeiss RMK. The scales range from 1: 8.000 to 1: 15.000.

Figure 4: *Oblique photograph from the 15th of June 1998. The field in front of the military amphitheatre I is full of cropmarked archaeological features. The main road, interrupted by several drains, is leading towards the amphitheatre. On both sides smaller roads branch off in right angles. Between the roads several buildings can be discerned.*

Another important data source besides vertical photographs are oblique photographs. These are made by ourselves using high winged airplanes (Cessna 150 or 172) and calibrated medium format cameras (Hasselblad) with black and white as well as color slide films. Hence, the best time for the flights can be chosen, that is when the crops reveal the archaeological structures with fine detail. During the flight the crop-marked archaeological features are photographed from the most suitable angle of view. This results in high quality documents which consequently make important contributions to the interpretation (Fig. 4).

A third category of data come from a former project. Already 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 our efforts. Unfortunately, this project was not continued. However, the resulting orthophotographs are still available. They show parts of the Canabae and the military camp and are also incorporated into the ongoing project.

Besides the aerial photographs, different kinds of maps are available. Most important are the cadastral maps of the modern villages Petronell and Bad Deutsch Altenburg with scales of 1:2.000 and 1:1.000, the geological and the pedological map.

Maps from excavations can be considered a fourth category of data. More than a hundred years of excavation resulted in numerous maps of excavated features. Among these, the Roman military camp, both amphitheatres, the forum, the thermal bath, and parts of the civil city are most useful (see also Jobst 1983).

3. MAPPING STRATEGY

Due to the different data sources, we decided to use both analytical and digital photogrammetry for obtaining both a digital terrain model and the rectification of the aerial photographs. Interpretation would be done using the orthophotographs in a geographical information system, where also a combination with other data sources, such as geophysical prospection results, excavation maps, or older orthophotographs would consequently be realized.

The procedure to obtain the combined map of ancient Carnuntum can be divided into 5 steps:

1. Orientation of vertical photographs used for the digital terrain model.
2. Measuring a digital terrain model and digitising the cadastral map.
3. Rectification of vertical and oblique photographs.
4. Interpretation of orthophotographs.
5. Combination of the results with other data.

4. REALIZATION

The project started in autumn 1997. Since there is no financial support from outside, the work can be done only sporadically. So far, each of the 5 steps has been realised to a different degree. The first two points are almost finished. The other steps are fulfilled at a degree of around 10 %.

4.1 Orientation of vertical photographs

The first step of the project was to obtain a digital terrain model to be later used for the rectification of the aerial photographs. To be able to also rectify oblique photographs within a sufficient error tolerance, the DTM would have to be a fairly accurate representation of Carnuntum´s topography. Therefore, instead of purchasing the terrain data, we decided to measure them ourselves.

From the former mapping project mentioned above a block of 46 vertical photographs covering the whole area with an overlap of 60% was available. The block was manufactured 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. Additionally, the whole block was already oriented via aerotriangulation, done by the Institute for Photogrammetry and Remote Sensing of the Technical University of Vienna.

For the measurements a total of 45 vertical aerial stereopairs were analysed. The stereomodels were set up on our analytical plotter DSR 14 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 the tachymeter TC1010 (Leica). Around 10 control points were used on the average which enabled a transforming of the model into the ordnance survey coordinate system.

4.2 Digital catastre and digital terrain model

A total of 60 land register maps covering an area of 4250 hectares of todays villages Petronell and Bad Deutsch Altenburg were digitized and georeferenced using a CAD program. To allow a flexible presentation, lots, buildings, ancient ruins, roads, vegetation, cadastral borders, coordinates, and annotation were placed on different layers.

Although a digital photogrammetrical station (Softplotter™ on a Silicon Graphics O2 workstation) was available, we decided to measure the digital terrain model “manually” using the analytical plotter DSR14. The reason was that we wanted to obtain the DTM at ground level, whereas the automated extraction using digital correlation techniques would measure the DTM on top of crops, trees and houses.

In that way 3D-points of a surface covering approximately 2434 hectars (also the surrounding topography of Carnuntum was considered) were recorded using a 30 m grid. Additionally, 3D-contour lines were extracted. Approximately 127.000 points were measured.

4.3 Rectification of vertical and oblique photographs

The digital terrain model is a basic requirement for the rectification procedure which is also done digitally. The images are scanned with a pixelsize of 15 microns (black and white negatives) or 30 microns (infrared falsecolor). The scanning is done on a PS1 scanner provided by *the Bundesamt für Eich- und Vermessungswesen* and the Technical University of Vienna. The oblique slides with a format of 6 by 6 cm are scanned using our Polaroid SprintScan 45 with a resolution of 2000 DPI or 12 microns. The data are stored on tapes or burnt on CD-Roms.

Control point information is obtained either from field measurments using a total station 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 procedure is done digitally using the software Softplotter™ on a Silicon Graphics O2 workstation with 256MB RAM. Depending on the used camera, scale, quality of the distribution, and measurement of the ground control, the accuracy lies between 0,25 and 0,75 meters.

Finally, using the outer orientation values and the digital terrain model, each image is rectified. The DTM was measured at ground level. However, the archaeological features are usually visible in the crops, that is somewhat higher than the ground. Therefore, depending on the obliquity of the photograph´s viewing direction, the resulting orthophotograph would have an error in the viewing direction. To exclude this error, an adequate value is added to the terrain data depending on the height of the photographed crops. The resulting orthophotographs usually have a pixelsize of 0.2 meter. They are stored either as a tagged image file (.TIF) with a corresponding world file (.TFW) for further use in geographic information systems or in the ERDAS Imagine® file format (.IMG).

4.4 Interpretation of orthophotographs

The interpretation is done using the geographic information system ERDAS Imagine® which is fully integrated into the digital photogrammetric system Softplotter™. The file format of the orthophotographs can be directly read by the GIS.

Buried archaeological features usually have different chemical and physical properties from the surrounding undisturbed soil. Therefore, former pits, ditches, or walls etc. provide changed growing conditions for plants resulting in a contrasting growing height and/or color of the crops. These differences show up more or less clearly (Doneus 1994).

Using image enhancment techniques, the orthophotographs are treated with contrast stretch, Wallis filter, or crispening (Scollar, Weidner, Huang 1984; Scollar 1990). This makes the archaeological features better visible. However, only filters which change the values of pixels are used. Filters, like sharpening, that change also the geometric position of pixels, are avoided.

All of the georeferenced orthophotographs and their filtered variations are then compiled in a layer stack of the viewer. The two uppermost layers can be flickered, i.e. quickly switched on and off. This is a very good means to quickly estimate the geometrical correctness of both images. Landscape changes are also identified easily using this tool.

The interpretation is done image by image on screen in separate layers using different colors and attributes for different features. Using a vertical or horizontal swipe line, only portions of the top and bottom image can be viewed. This is very useful, if one wants to look “behind” the interpretation drawing to see whether or not the features drawn from one orthophoto are also visible in other images.

In that way, all available orthophotos are interpreted one by one. Since every image shows the area in different conditions and consequently in different detail, the composite interpretation drawing is gaining more and more archaeological meaning.

4.5 Combination of the results with geophysical prospection and excavation maps

The magnetic scanning system developed and used in Austria by Archeo Prospections® is mounted on two completely unmagnetic wooden wheelbarrows. The main wheelbarrow carries the two caesium sensors which are fixed in a Plexiglas tube for gradiometer array measuring the difference between the total and the local magnetic field. The resulting magnetogram is a digital image which is georeferenced. The achievable accuracy lies at about 10 cm as could be verified by excavations (Neubauer, Melichar, Eder-Hinterleitner 1996).

The combination of the orthophoto and vectorized data as well as the combination of the orthophoto and geomagnetic results is again done using GIS. To be able to overlay orthophotos, geomagnetic images and vectors, they have to be set up in a uniform coordinate system, a prerequisite that is already fulfilled with our data.

The orthophoto is overlaid with all the other information such as the land register, isolines, vectorized aerial or geophysical interpretations, and other images, for example magnetograms. The interpretation drawings can be checked again and modified directly with the combined image in the background.

The aerial overview facilitates the estimation of the geophysical details. On the other hand, the detailed geophysical images are a very important source during the aerial archaeological interpretation. They give additional information that help to retrieve the maximum information of the photograph (Doneus, Neubauer 1998).

Figure 5: Map of the interpretation. 1: Canabae, 2: military camp, 3: forum, 4: main road with graves and tombs, 5: auxiliary camp, 6: complex of buildings and civil amphitheatre II, 7: graveyard, 8: civil city of Carnuntum, 9: city wall and two parallel ditches.

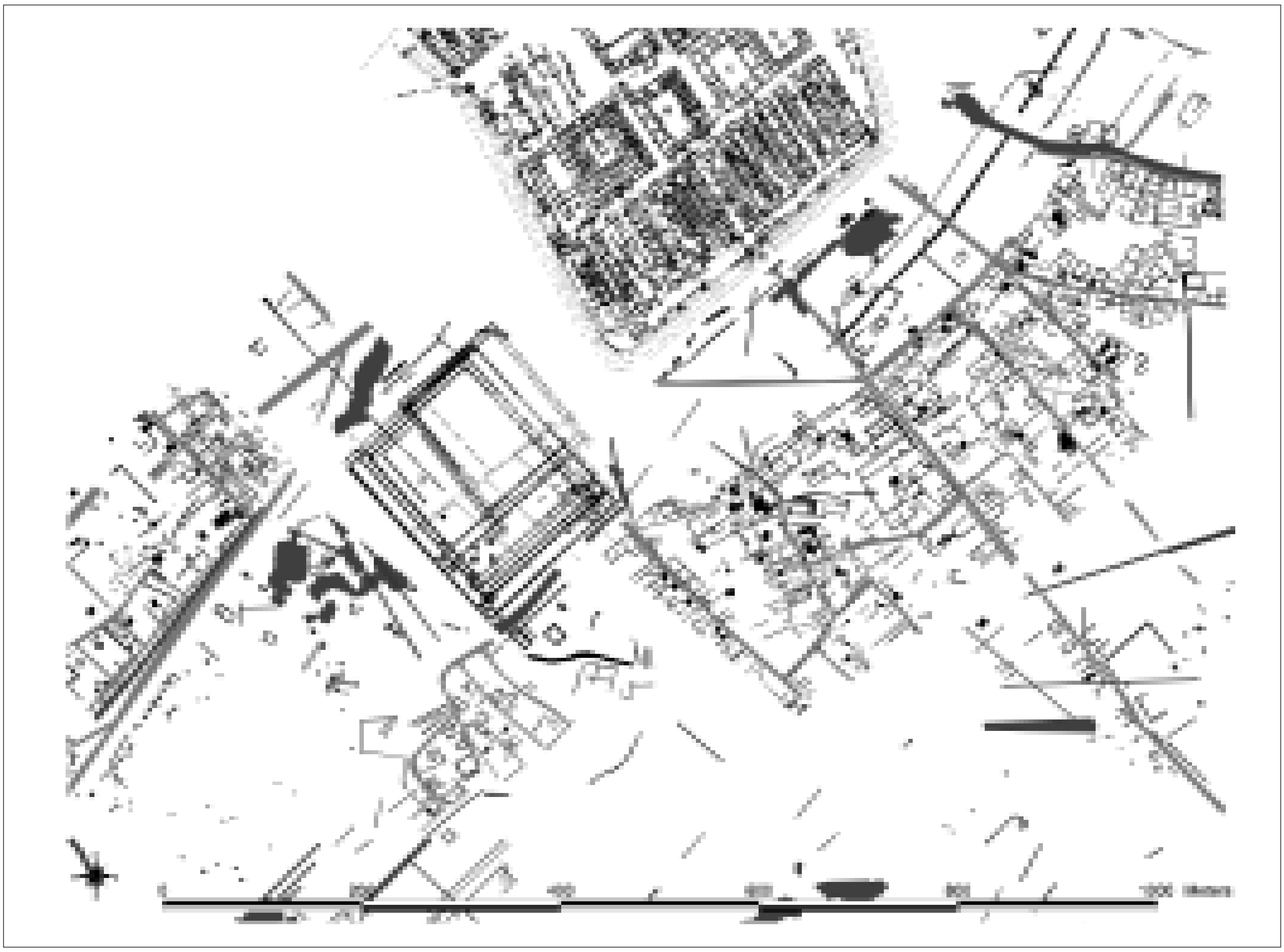

Figure 6: Zoomed view of the interpreted area around the military camp. Gray = roads, darkgray = ditches/pits, black = walls.

The excavation results – mainly the military camp, the forum, the two amphitheaters, and parts of the civil city – were scanned from publications, imported into the GIS, and georeferenced. If the maps had no coordinates, control information was taken from the digital cadastre or measured from the aerial photographs.

5. RESULT

So far, aerial photographs showing archaeological features in an area of 270 hectares have been mapped. Although only about 10 percent of the available photographs are rectified and interpreted, the composite map shows already a considerable degree of detail (Fig. 5 - 7). In the Canabae (1) around the military camp (2) the whole road network – partly with side drains – could be reconstructed. Between the roads, more than a hundred buildings can be identified. West of the camp parts of the forum (3) are visible. The main road leading to the west is accompanied by several graves and tombs (4). Further west the ditches of the auxiliary camp (5), where the cavalry was situated, could be mapped. The camp is already partly destroyed by the expansion of the village Petronell. The second area, west of this village, shows a complex of buildings (6) belonging to the civil amphitheatre and a large graveyard (7), which is partly intersecting and therefore not contemporary. North lies the civil city of Carnuntum (8), which is protected by a city wall and two parallel ditches (9). Again, the road network is visible.

It is not our intention to give a full description of the mapped features which would be beyond the scope of this article. However, already this very crude description gives an impression of the great variety of structures and the high degree of detail possible. Even more details can be seen in the results of the geophysical prospection which are already partially published (Neubauer 1997).

6. CONCLUSION

We will concentrate our work in the near future on the integration of the remaining aerial photographs and the combination of the results with geophysical prospection. Additionally, we will continue flying over Austria´s largest archaeological landscape. Even after 50 years of aerial photography, new features are still to be found which will make the puzzle more and more complete.

It is hoped that after more than a hundred years of

Figure 7: Zoomed view of the interpreted area around the civil amphitheatre II.

archaeological investigations in Carnuntum, which resulted in a patchwork of excavations, we can bring together all the available information and produce the first comprehensive map of the ancient city.

7. ACKNOWLEDGEMENTS

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8. REFERENCES

Doneus M. 1994: Luftbildarchäologie am Institut für Ur- und Frühgeschichte in Wien, Archäologie Österreichs, 5/1, 1994, 76 - 87.

Doneus M. 1996: Photogrammetrical Applications to Aerial Archaeology at the Institute for Prehistory of the University of Vienna, Austria, International Archives of Photogrammetry and Remote Sensing, Vol. XXXI, Part B5, Commission V, Vienna 1996, 124 - 129.

Doneus M., Neubauer W. 1998: 2D Combination of Prospection Data. Archaeological Prospection 5, 1998, 29-56.

Jobst W. 1983: Provinzhauptstadt Carnuntum. Österreichs größte archäologische Landschaft. Wiener Verlag, Himberg 1983.

Neubauer W., Melichar P., Eder-Hinterleitner A. 1996: Collection, visualization and simulation of magnetic prospection data, Interfacing the Past. Computer Applications and Quantitative Methods in Archaeology. CAA95, Analecta Praehistorica Leidensia no. 28, H. Kamermans and K. Fennema (editors), Leiden 1996: 121-129.

Neubauer, W. 1997: Resistivity and magnetics of the Roman town Carnuntum, Austria: an example of combined interpretation of prospection data. Archaeological Prospection 4, 1997, 179-189.

Scollar I., Weidner B., Huang T. 1984: Image Enhancement Using the Median and the Interquartile Distance. Computer Vision, Graphics and Image Processing 25, 1984, 236-251.

Scollar I. 1990: Numerical treatment of archaeological air photos: a non-mathematical introduction. Studies in modern archaeology, 3, 1990, 201- 256.