Experiences from microgravity and GPR surveys for subsurface cavities detection – case studies from SW- and central Slovakia

Roman Pašteka [1*], Dennis Wilken [2], Tina Wunderlich [2], Erik Andrássy [1], Ema Nogová [1,3], Dominika Godová [1,3], Lenka Ondrášová [1,3], Jozef Bódi [1,3]

1 Department of Engineering Geology, Hydrogeology and Applied Geophysics, Comenius University in Bratislava, Slovakia
2 Institute of Geosciences, Kiel University, Kiel, Germany
3 Earth Science Institute of the Slovak Academy of Sciences, Bratislava, Slovakia
* Corresponding author: E-mail: roman.pasteka@uniba.sk

Abstract
Combination of microgravity and GPR method constrains each other and help to detect subsurface cavities in a very effective way. Several examples are presented, some of the data-set were acquired during common summer schools between Kiel University and Comenius University in Bratislava.

Keywords
cavity detection; georadar; joint interpretation; microgravity

Introduction

In archaeological prospection, for the detection of subsurface cavities mainly geoelectrical and electromagnetic methods have been and are commonly used. Among them, especially the GPR method (ground penetrating radar) can very well recognize subsurface cavities due to their intensive differences in geoelectrical properties to the subsurface (e.g. Leucci 2006). Beside geoelectrical methods, microgravimetry represents a very important tool for the detection of cavities – due to their intensive density contrast with surrounding soils and rocks (e.g. Pašteka et al. 2020). Very effective is a joint use of these two methods, as it has been shown in many studies (e.g. Pánisová et al. 2013; Pašteka et al. 2019). Here we present results from several surveys, performed in medieval churches in SW- and central Slovakia. Some of them were acquired during common summer geophysical schools, organized by Christian-Albrechts University in Kiel and Comenius University in Bratislava – as an example we can bring forward the Erasmus IP project INCA (International Course on Archaeogeophysics; Rabbel et al. 2010).

Methods

In this contribution we present mainly results, acquired by means of GPR instrument GSSI with 400 MHz antenna and gravimeter Scintrex CG-5. Distance between GPR lines was 0.3 m, gravity points were acquired in nets of 1 x 1 m. GPR data were processed by standard way, where mainly gain control, removal of multiples and filtration played important roles. Microgravity data were processed in a form of incomplete Bouguer anomalies, where the so-called building corrections (removal of the gravity effect of the building masses) are very important (e.g. Pašteka et al. 2020). Results from both methods (GPR and microgravimetry) were interpreted together in a joint qualitative and quantitative interpretation. In the following section we shortly describe selected aspects from achieved results during acquiring both used methods in several churches from Slovakia.

Results

In the frame of the geophysical summer school INCA and also other local projects, several churches in SW- and cen-

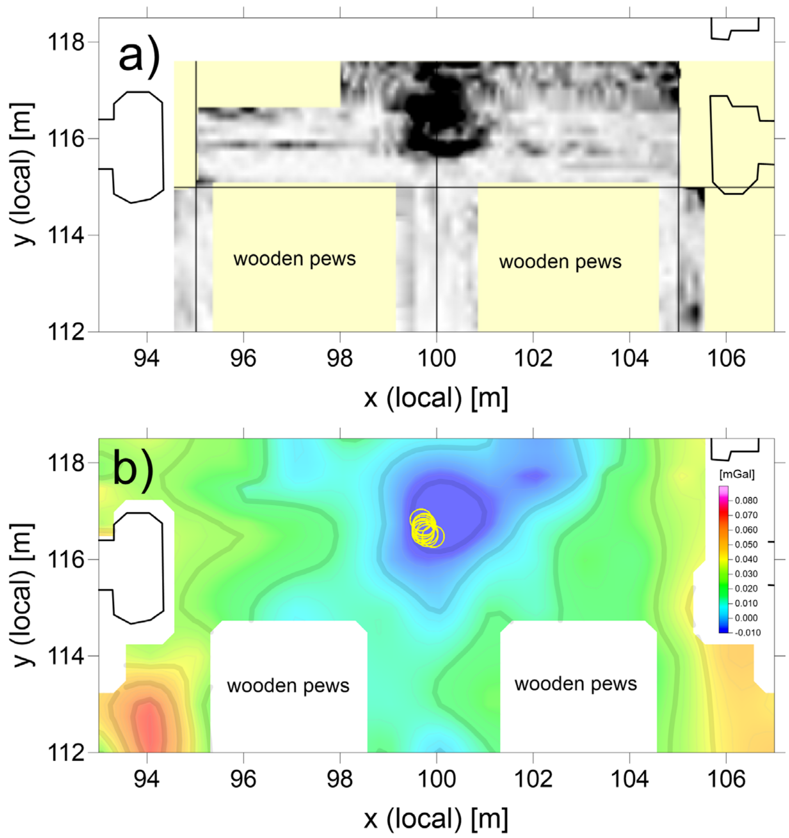

Fig. 1: Results from archaeogeophysical survey in the St. Catherine's church in Banská Štiavnica. a) horizontal GPR slice for the depth 1.0 m, b) incomplete Bouguer anomaly for the correction density 2.0 g*cm^{-3}, together with the results of the 3D Euler deconvolution (yellow circles).

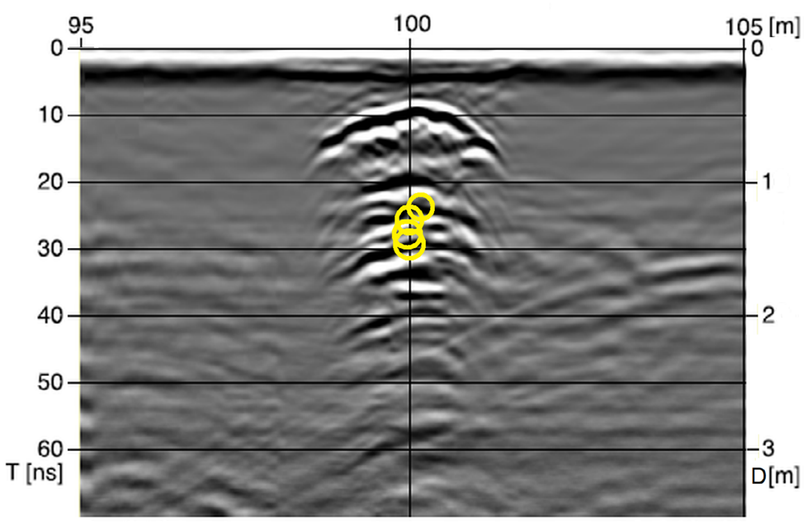

Fig. 2: Vertical GPR slice, crossing the central part of the detected anomaly in Fig. 1. Positions of the 3D Euler deconvolution depth solutions (structural index = 2) are displayed as yellow circles.

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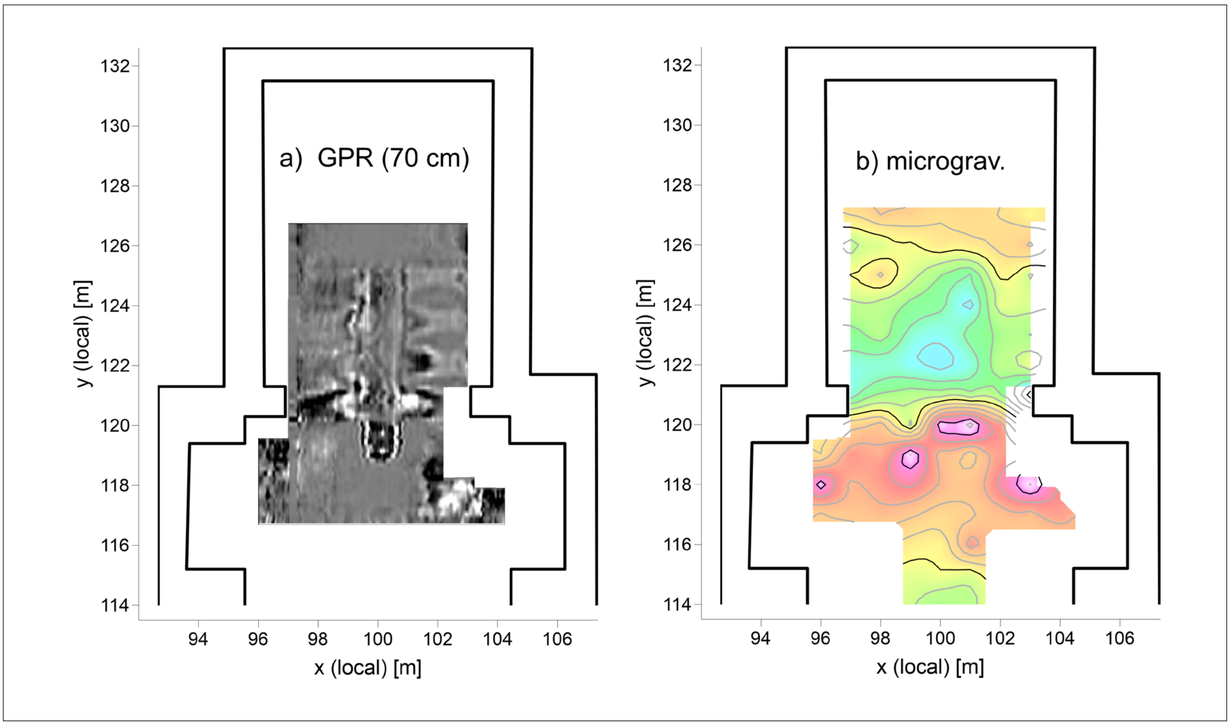

Fig. 3: Results from archaeogeophysical survey in the St. Joseph's church in Beckov. a) horizontal GPR slice for the depth 0.7 m, b) incomplete Bouguer anomaly for the correction density 2.0 g*cm^{-3}.

tral Slovakia were explored by means of GPR and micogravity methods. In the interior of St. Catherine's church in Banská Štiavnica (central Slovakia) the major part of the aisle (beside the places with large wooden pews) and a part of the presbytery was covered by GPR and microgravity measurements. In the transition area between aisle and presbytery (Fig. 1), both methods detected an important cavity, with high probability a crypt. In the horizontal reflection amplitude section from the GPR method it is characterized by a dominant symmetric anomaly in the centre of the figure (Fig. 1a). The map of incomplete Bouguer anomalies shows a little more complex character (Fig. 1b) – beside the central anomaly over the cavity of interest, there are is also a small low on the right-hand edge of the main negative anomaly. This aspect is not well explained until today, probably it is connected with a density weak part below the floor in the church. Estimation of the depth extent of the detected cavity was performed from both methods. Depth of the upper edge (approx. 0.35 m) can be very well recognized from vertical GPR sections (Fig. 2), but the bottom edge estimation is strongly influenced by the existence of multiple reflection in the interior of the cavity and can be hardly determined from the GPR results. For this estimation we have used the quantitative interpretation of microgravity data – 3D Euler deconvolution method (Reid et al. 1990) has estimated the depth of the centre of cavity in approx. 1.3 m (Fig. 2) and 3D density modelling has confirmed the depth extent of the cavity from approx. 0.35 m to 2 m below the floor of the church (in the case of an air-filled cavity).

Very similar results were acquired in the St. Martin's church in Bratislava and Joseph's church in Beckov (SW-Slovakia). In St. Martin's church a system of several crypts with irregular organisation was confirmed and one unknown cavity was interpreted (in the SE corner of the presbytery – not shown as a figure here). In the St. Joseph's church the GPR method has found a central crypt in the presbytery (in a form of so-called columbarium – Fig. 3a), which was the first case in Slovakia that the small spaces for coffins could be recognized in horizontal GPR sections (Pašteka et al. 2019). Microgravimetry method could confirmed only the total effect of this crypt (Fig. 3b; not the separated coffin spaces in the columbarium - these objects were too small). No one from these three sites were explored by means of archaeological survey yet (shallow drillings with video-inspection). We are looking forward to obtain the feet-back from this kind of verification in the future.

Conclusion

In this contribution we show results from case studies from various churches in SW- and central Slovakia. Combination of microgravimetric and GPR can be very effective in the detection and study of subsurface cavities such as crypts: these are manifested in horizontal GPR sections as intensive reflectors and in incomplete Bouguer anomaly maps as dominant minima. In the majority of cases, central positions of anomalies from both methods are laterally identical. From the GPR vertical sections it is possible to estimated very well the upper depth limit of detected cavities and from quantitative interpretation of microgravity data (by means of density modelling and Euler deconvolution) we can determine the centres and vertical extents of interpreted cavities. In this study, we present also a case with the limitations of microgravity method: in the St. Joseph's church in Beckov the GPR method has found a central crypt in the presbytery (in a form of so- called columbarium) and microgravimetry could confirmed only the total effect of this crypt (not the separated coffin spaces in the columbarium - these objects were too small).

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