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Using Ground Penetrating Radar (GPR) for detecting a crypt beneath a paved church floor

Uporaba georadarja (GPR) za zaznavo kripte pod tlakovanimi tlemi cerkve

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Abstract

After the discovery of an archive document regarding an underground crypt beneath the floors of the Church of St. Margaret (Sv. Marjeta) in Dol pri Ljubljani, Slovenia, further research was carried out to confirm its presence. An area filled with construction waste was discovered during a recent small-scale renovation of the church floor. This finding suggested the potential underground chamber may have been partly filled in during one of the previous restorations. A non-invasive GPR study was carried out along eight profiles inside the church to prove the existence of an underground crypt. Results show the presence of an air-filled chamber, confirmed later by a hole drilled in the floor. Additional findings in the church archive and pictures taken by a camera, lowered through a drilled hole, revealed three previously unknown caskets in the crypt. According to the archives, two of them belong to Baron Wolf Daniel Erberg and his wife who died in 1783 and 1774, respectively.

Izvleček

Po odkritju uradnega dokumenta o obstoju podzemne kripte pod tlemi cerkve Sv. Marjete v Dolu pri Ljubljani v Sloveniji so bile za njeno potrditev izvedene nadaljnje raziskave. Med nedavno manjšo prenovo tal v cerkvi so odkrili območje, zapolnjeno z gradbenimi odpadki. Ta ugotovitev nakazuje, da je bil morebiten podzemni prostor verjetno zasut med eno od prejšnjih obnov. Da bi zagotovili več dokazov o obstoju kripte na neinvaziven način, so bile v notranjosti cerkve izvedene georadarske meritve v osmih profilih. Rezultati kažejo na obstoj kripte, napolnjene z zrakom, kar je bilo kasneje potrjeno z izvrtano luknjo v tleh. Novi dokumenti, najdeni v arhivu in posnetki kamere, spuščene skozi luknjo v tleh, so razkrili tri prej neznane krste v kripti. Glede na arhivske podatke, dve od njih pripadata baronu Wolfu Danielu Erbergu ter njegovi ženi, ki sta umrla v letih 1783 in 1774.

Introduction

The Church Sv. Marjeta (St. Margaret), located in Dol pri Ljubljani, Slovenia, was first mentioned in 1262 (Grebenc, 2012) and again in 1427, as a Gothic building. Under the leadership of architect Mihael Perski, the church underwent extensive reconstruction in 1753 (Grebenc, 2012). Since then, there has been no major reconstructions apart from the re-paving of the church floor in 1886.

We (priest Alojzij Grebenc serving at this church), have been researching the history of the church for many years and also written two books on the subject (Grebenc, 2012, 2013). While searching through the church archives, we came across a document issued in 1836 by the diocese to the Erberg Barons, a local noble family. The document was a permit for building an underground crypt on the church premises, however all further

correspondence between the Erberg family and the diocese has been lost in the destruction of the rectory in 1944.

During a recent small-scale renovation, one of the floor stones beneath the wooden benches (pews), was removed (black line in Fig. 1). This revealed an area filled with construction waste material, suggesting that an underground chamber could have existed in the past and has been partly filled in at the time of the last paving of the church floor in 1886. In the search for more evidence of an underground chamber, a Ground Penetrating Radar (GPR) study was carried out. By using this non-invasive geophysical method, we wanted to determine whether such an underground chamber does exist beneath the church floor, and if so, is there any part of it left that has not been filled-in with waste material.

The GPR study was conducted inside the church where there was enough space for the profiles to be recorded. This method has been successfully applied in studies researching known underground chambers/crypts (e.g. Leucci et al., 2021) as well as previously unknown underground chambers (e.g. Barilaro et al., 2007). GPR has been widely used in numerous surveys to date for researching both natural air-filled subsurface voids (Lago et al., 2022; Lan et al., 2022; Zajc et al., 2015) and manmade subsurface air-filled structures (Mendoza et al., 2023; Obrocki et al., 2019).

Methodology

Location of GPR Profiles

The GPR profiles were recorded inside the church, along the stone paved floor in all the areas where the internal layout permitted the passing of a GPR cart in a straight line (Fig. 1). Longitudinal profiles were recorded along the aisle between pews about 1 m apart and on each side of the pews. A transverse profile (P4) was recorded in front of the pews, parallel to the steps leading to the altar (Fig. 1). At the time of the measurements, an electrical cable was laid out diagonally along the aisle. The location where profiles P1-P3 crossed the cable was marked during recording.

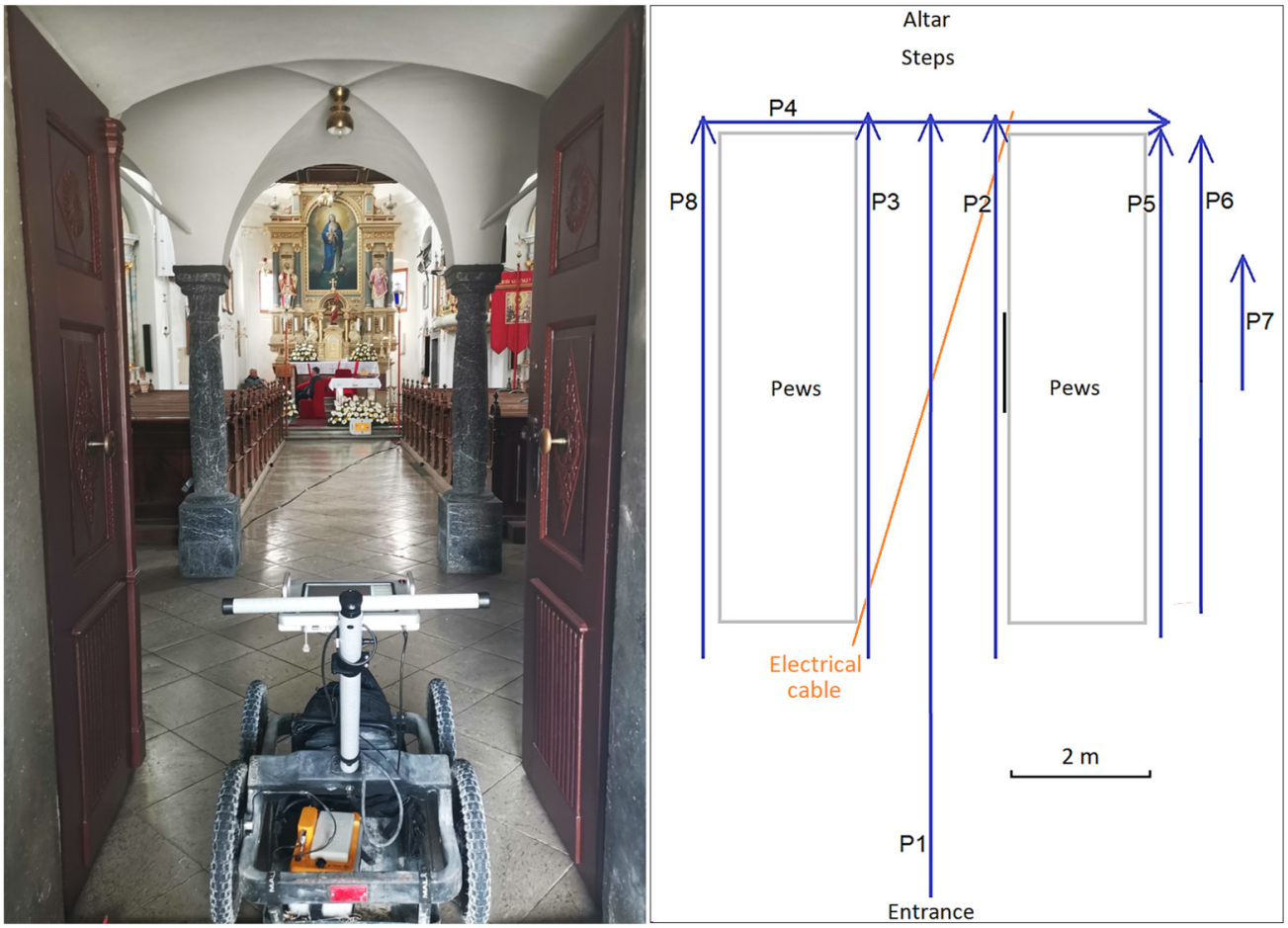


Fig. 1. Left – GPR measurements with GPR cart inside the church; right – GPR profiles (blue lines), electrical cable (orange line), location of removed floor stone (black line).

Equipment Used

For the recording of the profiles, a MALÅ ProEx control unit and antennas mounted on a cart (Fig. 1) with two different frequencies, 500 MHz and 800 MHz were used. This ensured a sufficient depth penetration through the church floor and enabled a comparison of results with different resolutions.

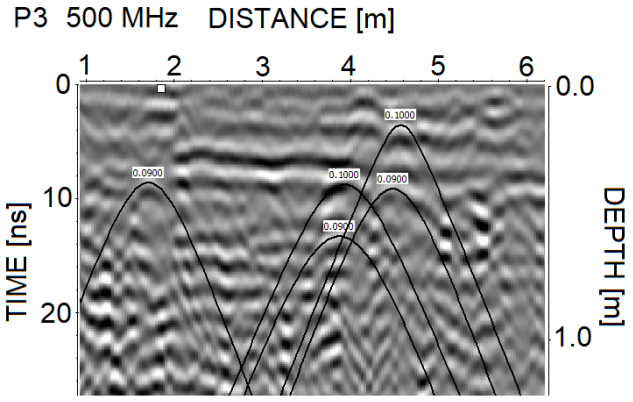


Fig. 2. Examples of different signal velocities, determined with hyperbola fitting.

Data Processing

The GPR profiles were processed using ReflexW, v. 8.5 by Sandmeier Software. The procedures and parameters of the processing flow are shown in Table 1. Due to the presence of different types of sediments, as well as fills of construction waste beneath the church floor, the subsurface is extremely heterogeneous. When the signal passes through the different types of materials, its velocity changes and therefore varies significantly with depth. The velocity also changes laterally as the profiles are recorded over different mediums, e.g. waste material, sediments and air-filled chambers. Figure 2 shows an example of different signal velocities within the profile P3, determined with the hyperbola fitting procedure. Consequently, an average signal velocity of 0.09 m/ns was used for the time-to-depth conversion across all GPR profiles. High velocity variation along the profiles was also the reason that data migration could not be successfully applied. As the purpose of the study was to find a potential air-filled chamber and no exact depths needed to be extracted from the GPR data, a rough estimation of the signal velocity was sufficient for determining the depth scale.

Results

By comparing profiles recorded with the 500 and 800 MHz antennas, it is evident that the same features can be identified in both. An example of the comparison is shown for profile P2 (Fig. 3), which was recorded along the church aisle in the direction from the entrance to the steps in front of the altar. A continuous linear boundary (yellow line) indicates the thickness of the church paved floor at the depth of approx. 30 to 40 cm. Chaotic reflections and anomalies indicate the presence of subsurface voids, which represent underground air-filled chambers (red frames). Such patterns in GPR profiles are caused by multiple signals that reflect off walls and other objects inside the air-filled voids. When the diameters of the voids are significantly larger than the GPR frequency wavelength, they produce irregular reverberation patterns (Kofman et al., 2006; Luo & Lai, 2020) or so-called chaotic reflections (Thitimakorn et al., 2016). These areas appear closer to the church entrance and are not present at the location of the previously removed floor stone (black line in Fig. 3), which revealed the area filled in with construction waste. Here, the penetration depth is hindered due to a higher signal attenuation and signal scattering (green frames), caused by the presence of heterogeneous materials. A strong anomaly can also be seen at the point of crossing an electrical cable on the floor of the church (blue frames). By analysing the 500 MHz parallel longitudinal GPR profiles that show the presence of chaotic reflections, it is evident that these appear in the same area of the church (red areas in Fig. 4) and therefore indicate the location of the air-filled underground chamber.

Processing steps	Parameter	
	500 MHz	800 MHz
DC Shift	60 – 68 ns	30 – 36 ns
Time-zero correction	- 5.5 ns	- 3.3 ns
Background removal	Whole line	Whole line
Gain	Energy decay	Energy decay
Bandpass filtering	240/350/600/850 (MHz)	350/550/1000/1300 (MHz)
Time-depth conversion (hyperbola fitting)	0.09 m/ns	0.09 m/ns

Table 1. GPR data processing steps applied.

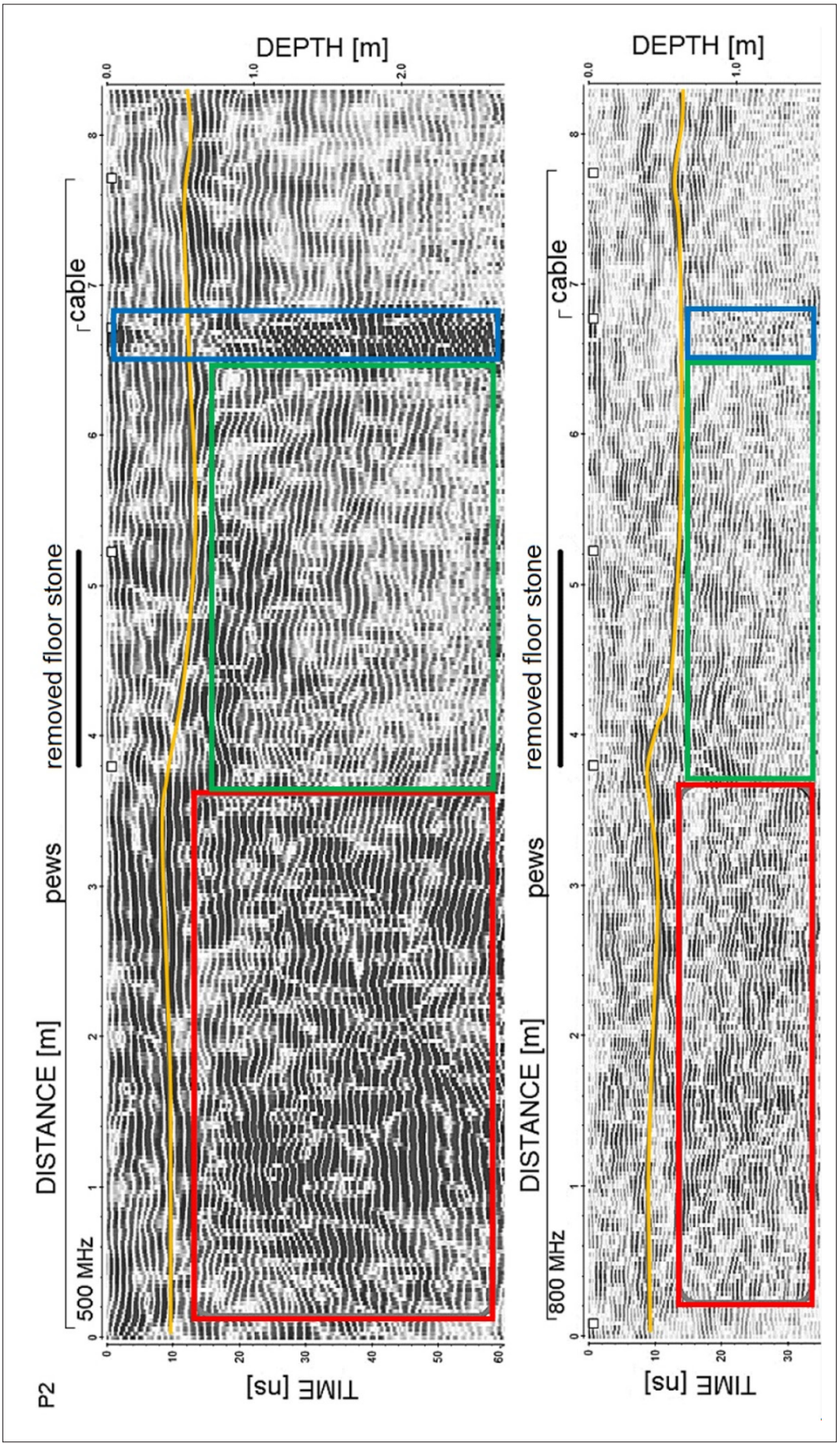


Fig. 3. Comparison of 500 MHz (top) and 800 MHz (bottom) radargrams for P2 profile with marked floor boundary (yellow line), area with chaotic reflections (red frames), area of high signal attenuation (green frames) and effects from crossing an electric cable (blue frames). See Fig. 1 for the location of the profile.

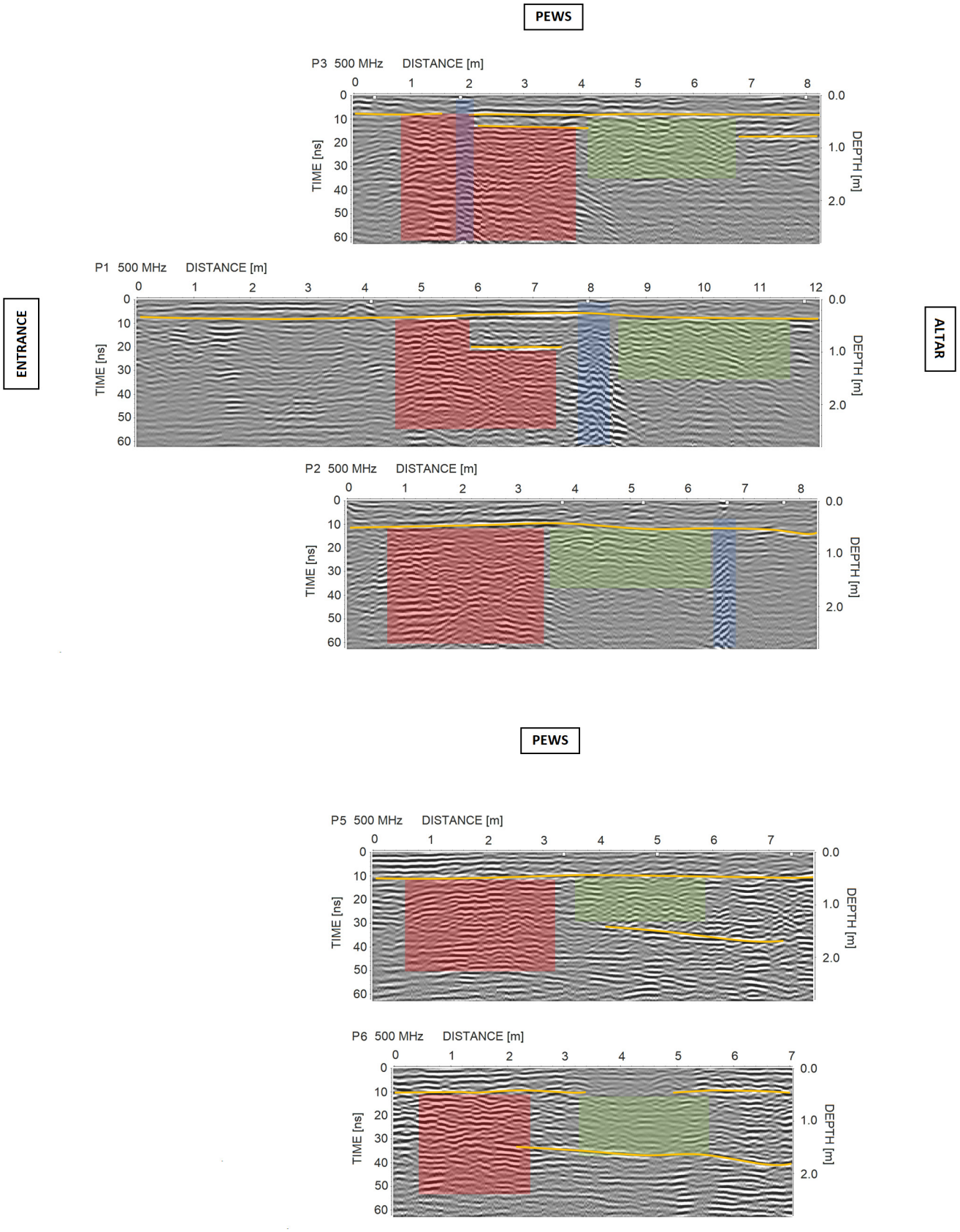


Fig. 4. Longitudinal 500 MHz GPR profiles P1 to P3, P5 and P6, showing the location of chaotic reflections (red area), high signal attenuation (green area), effect from crossing an electric cable (blue area) and linear reflections (yellow lines). See Fig. 1 for location of GPR profiles.

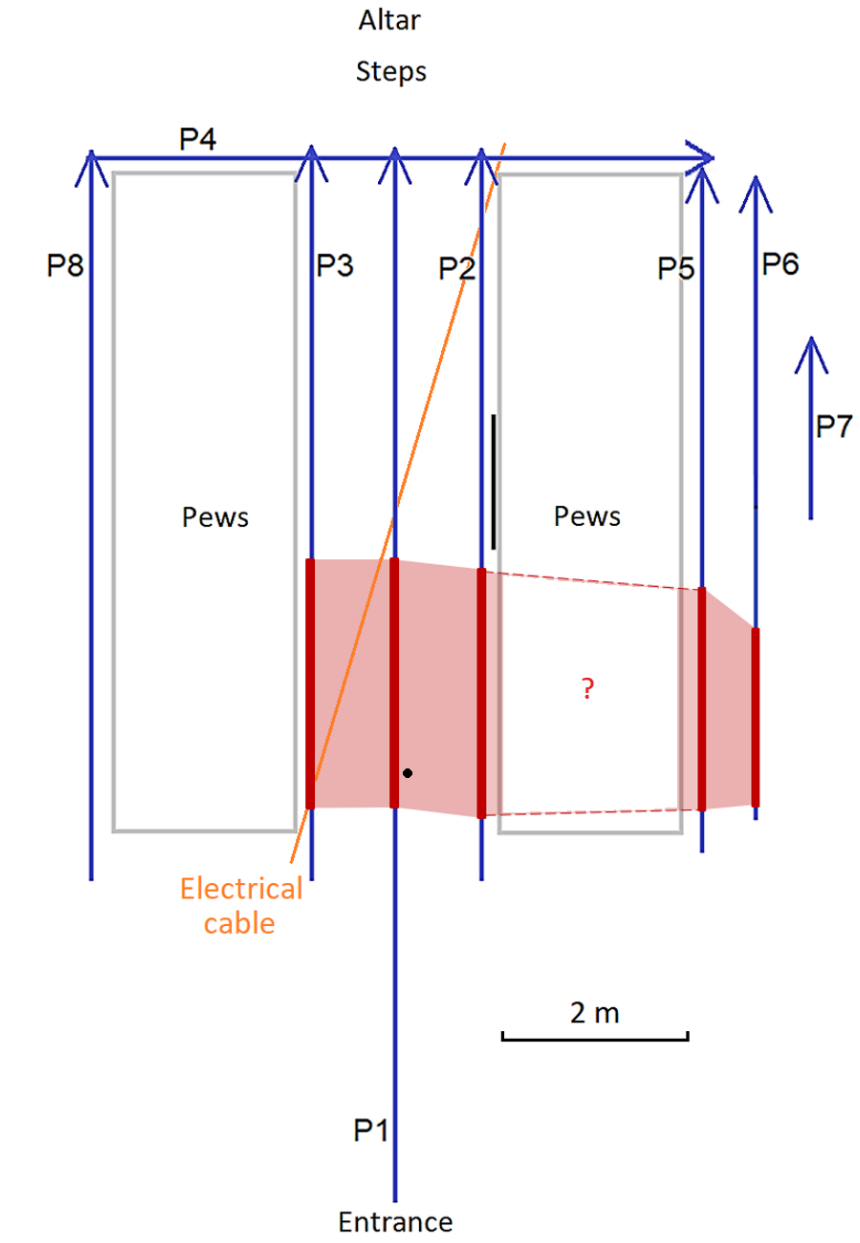
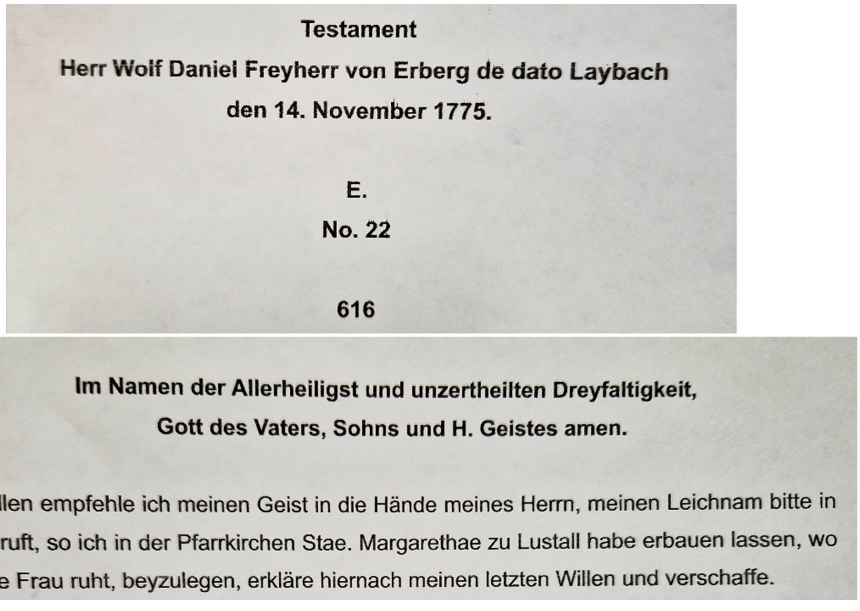


Fig. 5. Plan sketch based on GPR results from Fig. 3, depicting the area of underground air-filled chamber (red polygon) and location of drilled hole (black circle).



Testament

Herr Wolf Daniel Freyherr von Erberg de dato Laybach

den 14. November 1775.

E.

No. 22

616

Im Namen der Allerheiligst und unzertheilten Dreyfaltigkeit,

Gott des Vaters, Sohns und H. Geistes amen.

Vor allen empfehle ich meinen Geist in die Hände meines Herrn, meinen Leichnam bitte in die Gruft, so ich in der Pfarrkirchen Stae. Margarethae zu Lustall habe erbauen lassen, wo meine Frau ruht, beyzulegen, erkläre hiernach meinen letzten Willen und verschaffe.

Fig. 6. Last will and testament of Baron Wolf Daniel Erberg, where he states he wishes to be buried next to his late wife in the crypt of the St. Margaret church in Dol pri Ljubljani (Lustall) (from the Archives of the Republic of Slovenia).

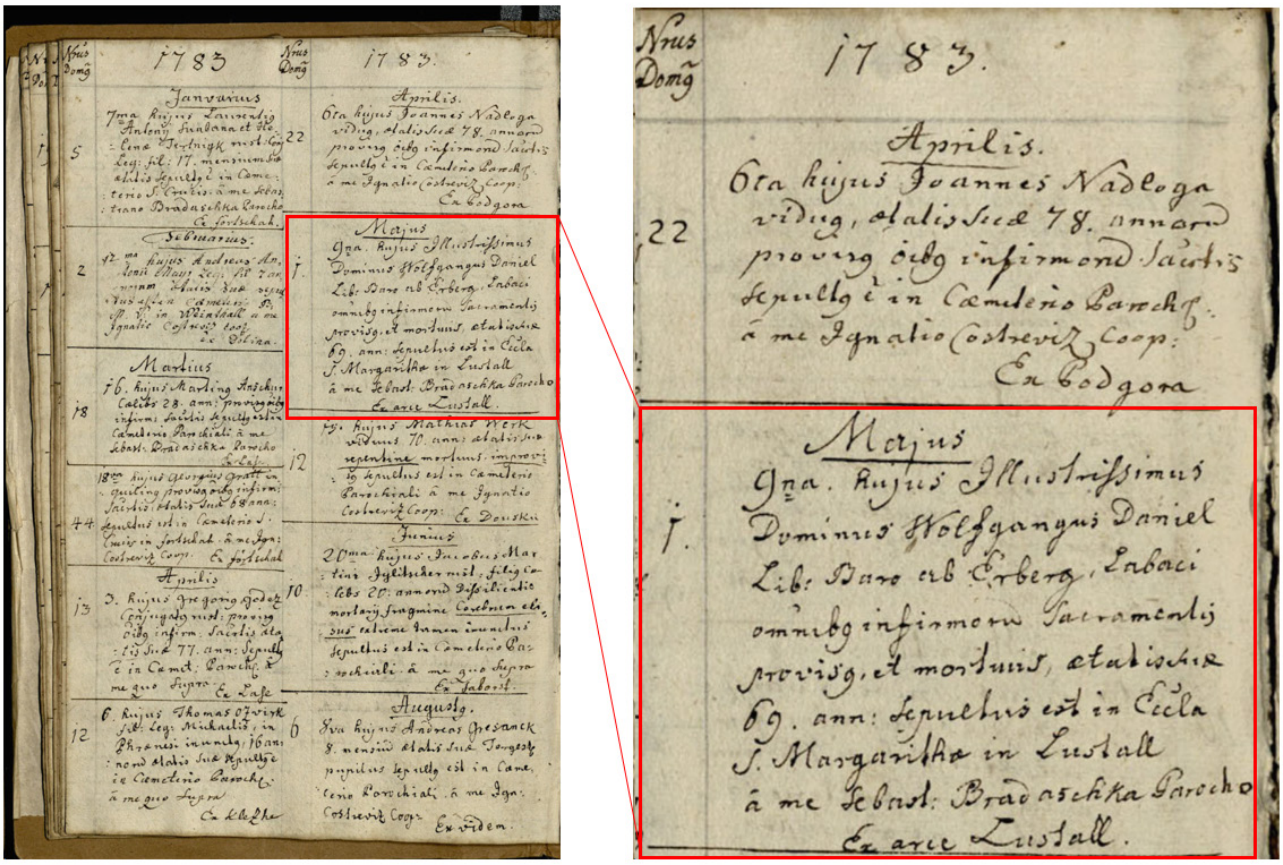


Fig. 7. Entry in the death records of the Church of St. Margaret in Dol pri Ljubljani, where it states that Baron Wolf Daniel Erberg has died aged 69 and is buried in the church crypt (NŠAL, 2023).

Discussion

Based on the GPR results, the plan sketch in Figure 5 was created. It shows the areas of chaotic reflections seen on individual GPR profiles linked into a connected area (red polygon). This area represents the part of the subsurface chamber not filled in with construction waste material. Similar chaotic reflections have been linked to the presence of subsurface voids in other GPR studies (e.g. Thitimakorn et al., 2016). Due to the low number of profiles and lack of data below the pews it is not possible to exactly determine the spatial extent of the crypt using these GPR results. We can only provide a rough estimation of its spatial occurrence. For a more detailed analysis, pews would need to be removed and a dense 3D GPR survey would need to be performed. For the purpose of verifying the existence of the crypt, we found the recorded eight profiles were sufficient.

These GPR results were presented at an international conference (Zajc, 2023) and prompted a more thorough investigation of the church register of burials as well as the archdiocesan archive. Two more documents mentioning the church crypt were found. The first was a last will and testament from the Baron Wolf Daniel Erberg from 1775 (Fig. 6), written in German, where he states that he wishes to be buried alongside his late wife in the crypt of the Church of St. Margaret in Lustall (German name for Dol pri Ljubljani). Since his wife died in 1774, a year before this last will was written, it provides proof that the crypt does exists somewhere on the church premises and at least one person was buried in it.

The second written record found after the GPR survey was completed, was the entry in the church death records (Fig. 7), where it states that in May of 1783, Baron Wolf Daniel Erberg has died aged 69 and is buried in the crypt of the Church of St. Margaret in Dol pri Ljubljani (entry written by priest Sebastian Bradaška). This provided even more evidence on the existence of the crypt and encouraged to continue with the investigation. First, a small hole was drilled into the church floor in the area where the GPR results show signs of an underground chamber. The telescopic inspection camera lowered into the hole revealed an underground air-filled room with an arched ceiling, thus confirming GPR results. However, the low resolution of the camera and insufficient lighting made it impossible to determine the size of the room or to define any other objects inside. Therefore, in

Fig. 8. Still photographs taken from the recordings of the crypt with an arched ceiling. Left – three partially uncovered caskets; right – inscription on one of the caskets (author: J. Igličar).

November 2023, a larger hole of approx. 10 cm in diameter was drilled in the same area (black circle in Fig. 5) and a light source was lowered into the chamber to investigate its contents with a higher resolution camera. The video recordings showed a room about 3 × 4 m in size and about 2 m deep, located beneath the church aisle, containing three wooden caskets. The caskets are partially uncovered, revealing the body remains underneath the wooden lids (Fig. 8). There are also inscriptions written on the sides of the caskets, however, due to the poor resolution of the images, they are not fully readable. Based on the existing records, it is assumed that the crypt was built by the Baron Erberg family during the last extensive reconstruction of the church in 1753 and the entry was most likely filled up by construction waste material during the last renovation of the church floor in 1886. Currently, it is not yet known who the remains in the third casket belong to.

Conclusion

The GPR results provided proof of the existence of an underground crypt, mentioned in the archives of the Church of Sv. Marjeta (St. Margaret) in Dol pri Ljubljani. Moreover, by carrying out the GPR study, we were able to precisely locate the crypt. Based on the GPR results, further investigation of the church archives prompted an underground camera inspection, which confirmed its presence in this exact area. This confirmation is of great cultural and historical importance, therefore further investigations will be carried out in the future.

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