



First conclusions about results of GPR investigations in the Church of the Assumption of the Blessed Virgin Mary in Kłodzko, Poland

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Abstract. The article presents results of a ground penetrating radar (GPR) investigation carried out in the Church of the Assumption of the Blessed Virgin Mary in Kłodzko, Poland, dating from the 14th to 16th centuries. Due to the 20th century wars, the current state of knowledge about the history of the church is still poor. Under the floor of the Catholic temple, unknown structures might exist. To verify the presence of underground structures such as crypts and tombs, a GPR survey was carried out in chapels and aisles with 500 and 800 MHz GPR shielded antennas. Numerous anomalies were detected. It was concluded that those under the chapels were caused by the presence of crypts beneath the floor.

1 Introduction

Significant progress in archaeology was possible thanks to the advancement of the ground penetrating radar (GPR) technology and methodology. GPR is widely used in several scientific fields, such as geology and environmental and civil engineering. In archeology, GPR offers a good image of what could lie underground, e.g. caves, tombs and buried objects. The concept of the GPR is well known. An electromagnetic pulse is directed to the ground. Heterogeneities cause reflections that are detected by a receiver (Annan and Cosway, 1992).

The GPR investigation presented in this paper took place in the Church of the Assumption of the Blessed Virgin Mary in Kłodzko. It is a town in the southwestern part of Poland. The first information about a sacral building in this region comes from the 12th century. The current Catholic temple was constructed between the 14th and the 16th centuries. Its founder was Ernest of Pardubitz, the first Archbishop of Prague. In the beginning, it was a Joannite property, but soon after fell under Jesuit management. Nowadays the church is administered by the Society of Jesus (www.klodzko.pl; Religious monuments, 2017).

The mortuary chambers situated on the territory of the church are as follows: the remains of Ernest of Pardubitz; the Dead People's Chapel, which is immediately adjacent to the north and contains the remains of Count Montani of Oldřichovice (a surveyed site); the Main Altar (1727–1729); the Altar of the Assumption of the Blessed Virgin Mary (1725); the Chapel of St. Jacob (also a surveyed site) (www.klodzko.pl; Religious monuments, 2017); and Parafia Rzymskokatolicka (WNMP, 2017).

The main sources of information were the sketches of the church presented in Figs. 1 and 2 and a few websites. The current state of knowledge about the temple underground is still poor. The aim of the presented work is to verify the presence of structures under the church floor.

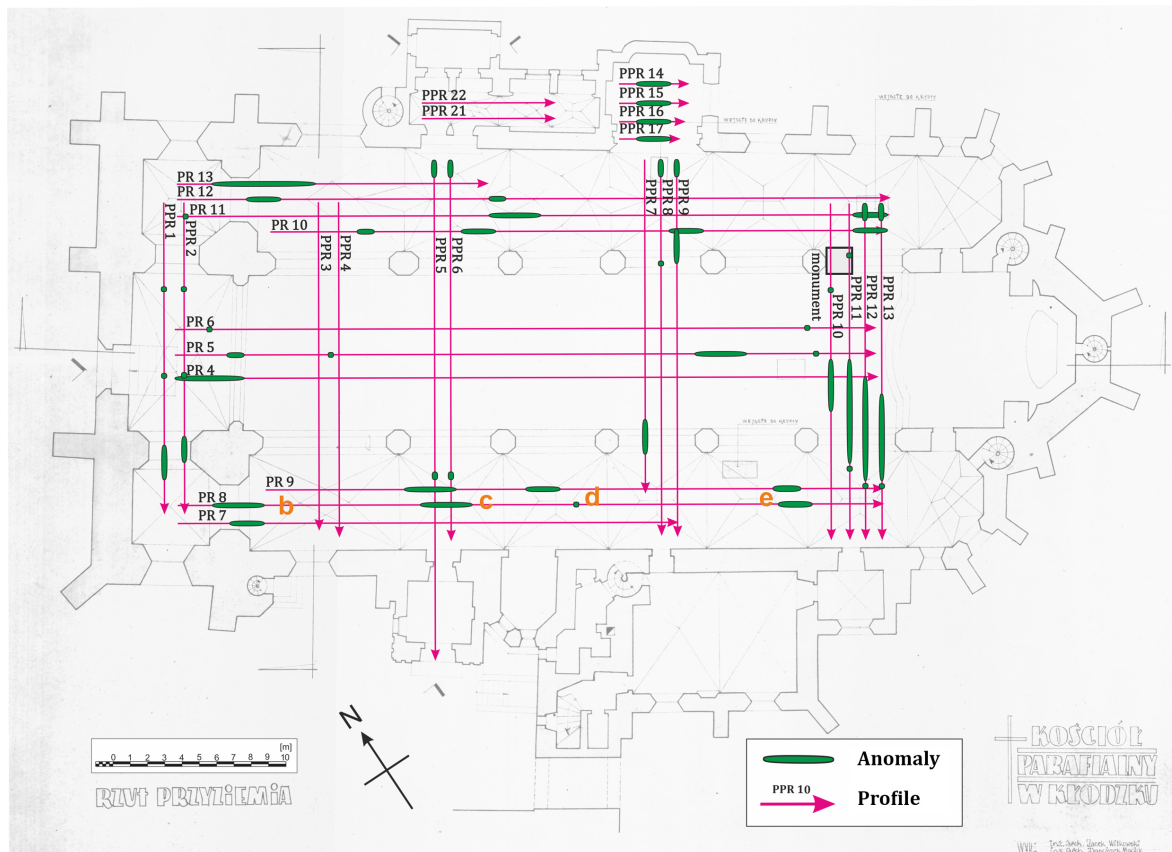


Figure 1. The ground floor plan of the church with the profiles (red) and anomalies (green) set by a 500 MHz antenna. The visualisation was created by the Department of Geophysics, AGH University of Science and Technology.

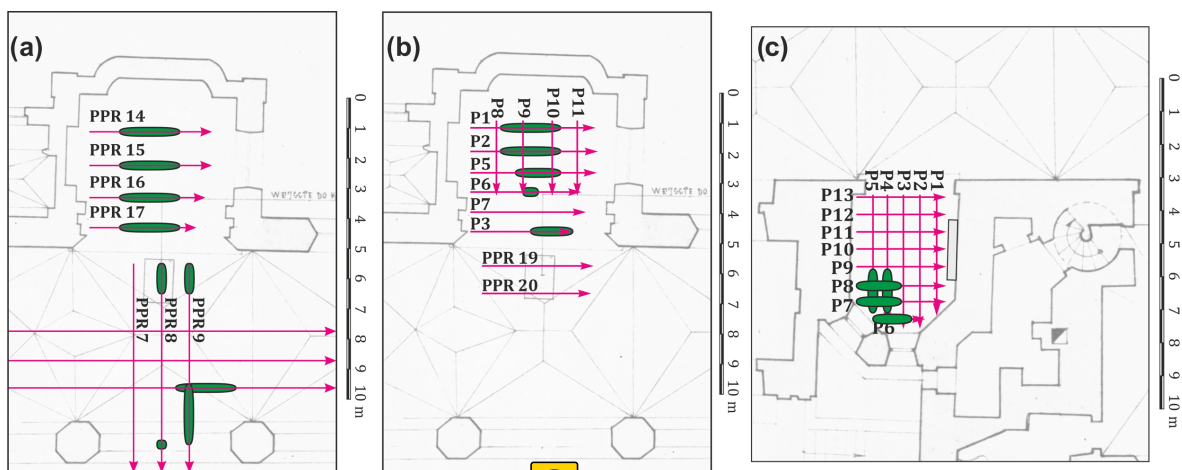


Figure 2. (a) The ground floor plan of the Dead People's Chapel with the profiles set by a 500 MHz antenna (PPR 14, PPR 15, PPR 16, PPR 17). (b) The ground floor plan of the Dead People's Chapel with the profiles set by an 800 MHz antenna (P1, P2, P3, P5, P6, P7, P8, P9, P10, P11). (c) The ground floor plan of the Chapel of St. Jacob with the profiles set by an 800 MHz antenna (P1–P5 and P6–P13). The visualisation was created by the Department of Geophysics, AGH University of Science and Technology.

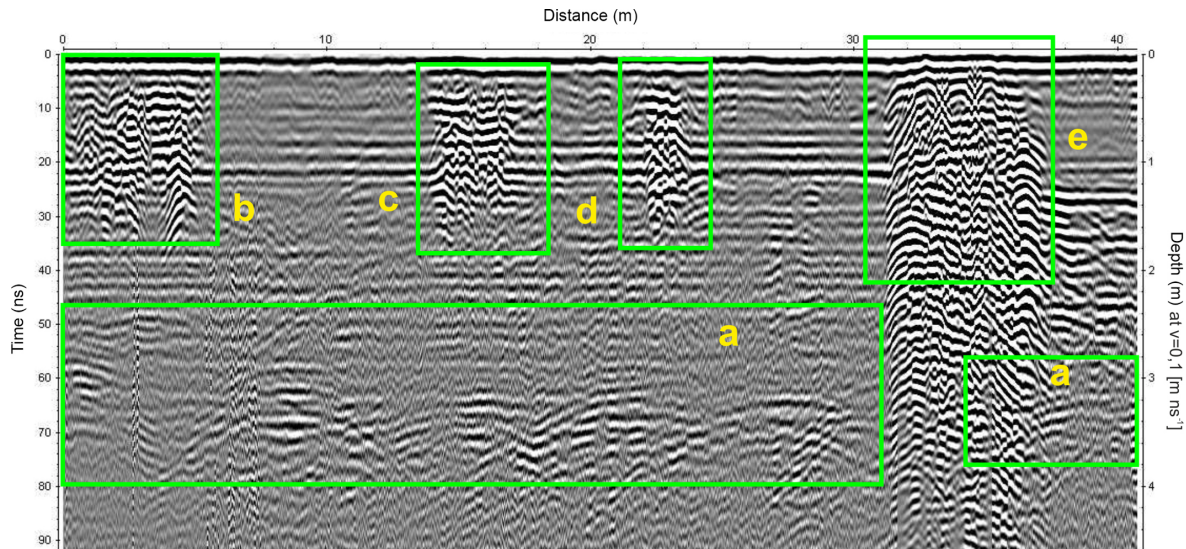


Figure 3. Profile PR 8 and antenna 500 MHz.

2 Acquisition and processing

The surveys were conducted in aisles and chapels. The radargrams were recorded with a GPR ProEx, produced by MALÅ Geoscience, equipped with 500 and 800 MHz shielded antennas. The velocity for the surrounding medium was established as 0.1 m ns^{-1} (based on similar investigations by Panisova et al., 2016, and a similar processing approach by Persico, 2014, pp. 13–16). The localisation of the profiles in aisles is shown in Fig. 1 (profiles from 500 MHz antenna), in the Dead People’s Chapel in Fig. 2a and b (profiles recorded with a 500 MHz (a) and an 800 MHz (b) antenna). Figure 2c shows the profiles from the Chapel of St. Jacob recorded with an 800 MHz antenna. The floors of the chapels were covered by regular grids of profiles with 1 m spacing. The following survey parameters were assumed: for the 800 MHz antenna, the step of measurements was 0.02 m and the time increment was 0.12 ns; for the 500 MHz antenna, the step of measurements was 0.04 m and the time increment was 0.2 ns. Anomalies which were detected on the radargrams are shown with the green ovals on the ground floor plans (Figs. 1, 2). The processing sequence for the recorded radargrams includes routine steps (Karczewski et al., 2011).

3 Analysis and interpretation

3.1 Aisles

Several clear hyperbolic anomalies were recorded along the aisles at a time of 50–80 ns (2.5–4 m) with both the 500 MHz antenna and the 800 MHz antenna. The shape of the upper part of the reflectors at a time of 50–80 ns (2.5–4 m) along the aisles resembles the curve of a 15 m radius circle (in the case of the velocity in the medium of 0.1 m ns^{-1}), according to the

evaluation of the angle between the branches of the hyperbolic anomalies (e.g. PR 8 in Fig. 3, anomaly “a”). The shallow anomalies (2–20 ns) along the PR 8 profile (at the distances 2–5, 14–18 and 22–24 m) are marked in Figs. 1 and 3 (anomalies “b, c, d”). These anomalies were probably caused by the foundations of the pillars (Daniels, 2004, p. 356). The shallow anomalies and strong reflections at a distance of 32–36 m are connected with elements of the central heating system under the floor (Figs. 1 and 3, anomaly “e”). According to the comparison of the data obtained along and across the aisles and the information about the setting of the former church (www.klodzko.pl; Religious monuments, 2017), it can be concluded that the reflections from 50 to 80 ns might have been caused by the presence of the remains of the foundations of a previous sacral building. Despite the fact that the antennas were shielded, these anomalies might also be interpreted as reflections from the ceiling of the church (the vaults of the naves) (Daniels, 2004, pp. 335–336) because when we set the velocity at 0.25 to 0.30 m ns^{-1} (the velocity of electromagnetic wave in air) and the radius 0, the shape of the synthetic hyperbola also resembles the shapes of the anomalies at a depth of 50–80 ns (2.5–4 m) on the profiles from the aisles.

3.2 Dead People’s Chapel

The radargrams registered with the 500 MHz antenna show a hyperbolic anomaly at 6 ns (corresponding to a depth of 0.3 m). The anomaly is clearly visible on the radargram from the PPR 14 profile (Fig. 4a and b, anomaly “f”). There is also another reflection visible at 26–32 ns (1.2–1.6 m) (anomaly “g”). The radargram from the 800 MHz antenna also reveals a clear anomaly at 50 ns (2.5 m), which is hardly visible in the data from the 500 MHz antenna (anomaly “h”). Figure 4c

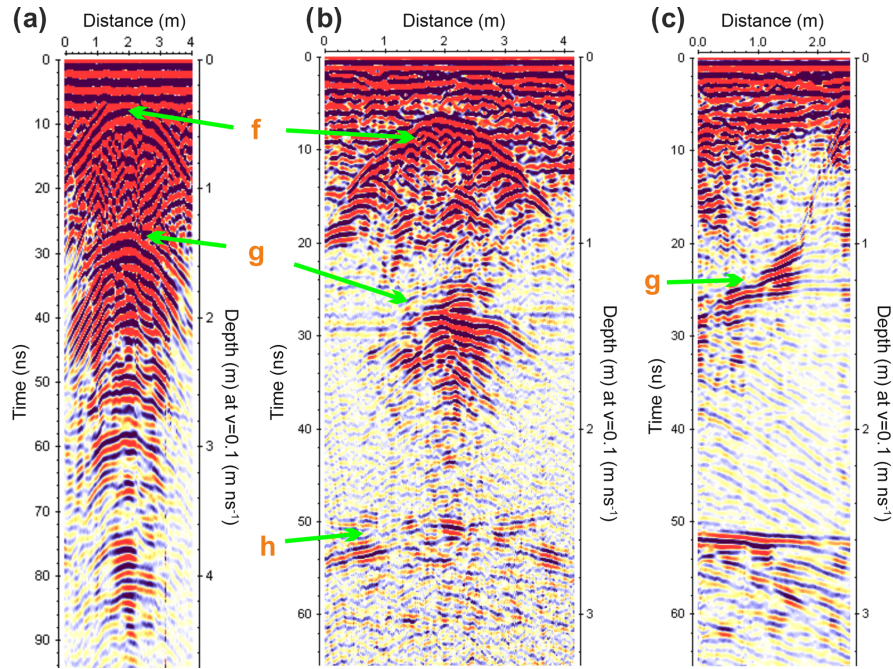


Figure 4. (a) Profile PPR 14 and 500 MHz antenna. (b) Profile P1 and 800 MHz antenna. (c) Profile P9 (perpendicular to profile P1) and 800 MHz antenna.

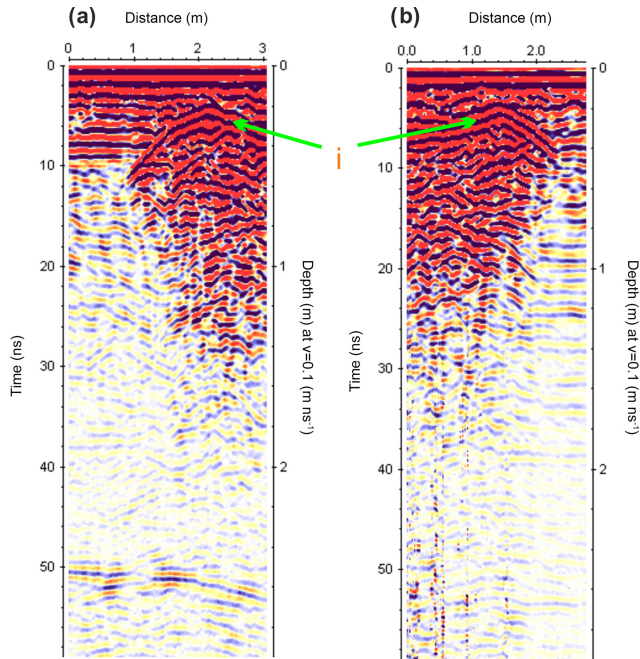


Figure 5. (a) Profile P5 and 800 MHz antenna. (b) Profile P8 and 800 MHz antenna.

shows the radargram obtained along the P9 profile, which is perpendicular to the P1 (Fig. 4b). The deepest reflection at time 50 ns is still visible. The reflection at 26 ns continues

from the beginning to the end of the profile with changing depth.

The hyperbolic anomaly at 6 ns is interpreted as a reflection from the ceiling (vault) of the crypt. It is the most probable interpretation of this anomaly. Crypts and tombs are common in medieval Catholic temples. In this church, there are various crypts which are marked on the ground floor plan, e.g. the crypt under the PPR 19, the PPR 20 profiles on Fig. 2b (probably Count Montani's crypt). However, the recorded crypt is considered to be new because there is no sign of it on the church sketches (Fig. 2a, b). The localisation of the anomaly suggests that the entrance to the crypt may be under the altar. Underneath the anomaly “f”, there is another reflection visible at time 26 ns (anomaly “g”). Its shape may be classified by velocity pull-up (Conyers, 2012, pp. 171–175) and can be interpreted as a coffin in the crypt or the crypt floor. Velocity pull-up is a phenomenon which appears on a radargram when an electromagnetic wave meets a high-velocity medium surrounded by a low-velocity one. Reflections from the velocity boundary at the bottom of the anomaly are pulled up. However, this explanation implies quite a large size of the crypt (even 3 m in height). For this reason, it is probable that this reflection comes from another underground object located under the crypt. It should also be taken into account that indicated reflections may be an effect of multiple reflections. In that case, the height of the crypt should be counted from the top to the bottom of the reflection at 6 ns (anomaly “f”). The shape of the reflection at 26 ns also suggests that it might be connected with the already known

crypt, which is justified because in Fig. 4c it appears at different times. The deepest anomaly at 50 ns could be defined as reflections from the ceiling of the chapel. Another possible interpretation is that these might be the remains of the previous church.

Probable dimensions of the discovered crypt are 3 m in width and 1.8–2.1 m in height. The velocity of the electromagnetic wave in the crypt (0.3 m ns^{-1}) is three times higher than the velocity in the ground, so the apparent height of the crypt projected on the radargram (Fig. 4a, b) is different (0.6–0.7 m) because the value 0.1 m ns^{-1} was applied as the average velocity for the radargram. Therefore, it was assumed that the crypt is filled with air.

3.3 Chapel of St. Jacob

A hyperbolic anomaly at 4 ns (0.2 m) is visible on the radargrams from this chapel (Fig. 5a and b, anomaly “i”). The difference between similar anomalies (at 6 ns from the Dead People’s Chapel) is that directly under the main reflection there are much smaller disturbances. Like in the Dead People’s Chapel, connections at 50 ns are visible.

The main hyperbolic reflection at a time of 4 ns is interpreted as the vault of a crypt (Fig. 5a, b). The changes in the shape of the anomaly are associated with the direction of the profiles. The vault can be described as a barrel or pointed barrel vault (Imposa and Grassi, 2015; Barilaro et al., 2007). In that case, on the profiles crossing perpendicularly to its stretch a hyperbolic anomaly was detected (Fig. 5a). The radargrams collected parallel to the stretch of the vault showed flat reflections (Fig. 5b) because the shape of the crypt ceiling was lateral under them.

The probable size of the crypt is 2 m in width. The crypt is also a newly discovered underground object. Because of the shape and location of the anomaly, the expected entrance to the tomb is outside the chapel.

It should be mentioned that our results were compared with similar surveys that had been conducted in the Church of St. George (Panisova et al., 2016). The researchers evaluated the same velocity for the underground medium as we did: 0.1 m ns^{-1} . They detected the reflection corresponding to the upper part of the crypts at 10 ns (our 4–6 ns) and 20–24 ns (possibly our 26 ns) to the lower part.

4 Conclusions

As a result of the investigation carried out in the church in Kłodzko, two previously unknown crypts were discovered just beneath chapels floors. Their location and size were estimated. The position of the crypt in the Chapel of St. Jacob suggests that its entrance may be outside the church. The complexity of the radargram image from the Dead People’s Chapel gives rationale to the hypothesis that there are po-

tential connections between newly discovered crypt and already known one.

The majority of the radargrams recorded along the profiles in the aisles and chapels include hyperbolic anomalies at a time of 50–80 ns (2.5–4 m). They are probably the effect of electromagnetic wave diffraction. In that case, two explanations are proposed. The first one is that their origin is probably connected with the remains of the previous church; the other one is that these are diffraction points on the ceiling of the Catholic temple.

This research might be helpful for future investigations, especially archeological excavations and restoration works.

Results of the survey proved that a better vertical resolution could be obtained with an 800 MHz antenna than with a 500 MHz antenna.

Data availability. TS3

Competing interests. The authors declare that they have no conflict of interest. TS4

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References





- Annan, A. P. and Cosway, S. W.: Ground Penetrating Radar Survey Design, Symposium on the Application of Geophysics to Engineering and Environmental Problems 1992, 329–351, 1992.
- Barilaro, D., Branca, C., Gresta, S., Imposa, S., Leone, A., and Majolino, D.: Case study. Ground penetrating radar (G.P.R.) surveys applied to the research of crypts in San Sebastiano’s church in Catania (Sicily), *J. Cult. Herit.*, 8, 73–76, <https://doi.org/10.1016/j.culher.2006.10.003>, 2007.
- Chernov, A., Cogoni, M., Dziubacki, D., and Bădescu, A.: Processing and interpretation of GPR data collected in the Church of the Assumption of the Blessed Virgin Mary in Kłodzko, Poland,

- Geophys. Res. Abstr., EGU2017-18298, EGU General Assembly, Vienna, Austria, 23–28 April 2017. **TS5**
- Conyers, B. L.: Interpreting Ground-penetrating Radar for Archaeology, 1st Edn., Routledge, New York, 2012.
- 5 Daniels, D. J.: Ground Penetrating Radar, 2nd Edn., Vol. 1, The Institution of Electrical Engineers, London, 2004.
- Karczewski, J., Ortyl, Ł., and Pasterniak, M.: Zarys metody georadarowej, 2nd Edn., Wydawnictwo AGH, Cracow, 2011.
- Imposa, S. and Grassi, S.: Georadar survey inside the Santa Maria Maggiore church of Ispica (Sicily-Italy), Environ. Earth. Sci., 73, <https://doi.org/10.1007/s12665-014-3542-9>, 2015. **TS6**
- 10 Panisova, J., Murín, I., Pašteka, R., Haličková, J., Brunčák, P., Pohánka, V., Papčo, J., and Milo, P.: Geophysical fingerprints of shallow cultural structures from microgravity and GPR measurements in the Church of St. George, Svätý Jur, Slovakia, J. Appl. Geophys., 127, 102–111, <https://doi.org/10.1016/j.jappgeo.2016.02.009>, 2016.
- Parafia Rzymskokatolicka Wniebowzięcia Najświętszej Maryi Panny: Klodzko.jezuici.pl, available at: <http://www.klodzko.jezuici.pl/historia.html>, last access: 1 May 2017. 20
- Persico, R.: Introduction to ground penetrating radar, John Wiley & Sons, Inc., Hoboken, New Jersey, 13–16, 2014.
- www.klodzko.pl – Religious monuments: Klodzko.pl, available at: <http://www.klodzko.pl/en/for--tourists/monuments--of--klodzko/173--the--church>, last access: 3 May 2017. 25

Remarks from the language copy-editor

- CE1** What is Joannit? I have not found this term anywhere. Please check if this is the correct translation. 
- CE2** Please check; this seems to be the correct term for the order of the Jesuits. 

Remarks from the typesetter

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