Results of GPR survey of AGH University of Science and Technology test site (Cracow neighborhood).

October 02, 2017

Two GPR sets were used for the survey.
First GPR set: low-frequency GPR "Loza-N" [1].

Technical characteristics:

1. Frequency band : 1-50 MHz;
2. Antennas type – half-wavelength resistively-loaded dipoles (Wu-King antennas);
3. Antenna frequency/length: $f_c = 25\,\mathrm{MHz}\ \ (6\,\mathrm{m})$;
4. Transmitter applies to the antenna 15 kV pulses;
5. Repetition rate: 150 Hz;
6. Pulse duration: 5-10 ns;
7. Standard Loza-N receiver;
8. Time window: 512, **1024**, 2048 or 4096 ns;
9. Dynamic range: 120 dB;
10. Discretization step: 1, 2, 4 or 8 ns;
11. Measurement rate: about 1 shot a second, depending on time window.

[1]. JSC VNIISMI, Russian Federation, www.geo-radar.ru/.

Fig.1 . GPR survey path **PL-01**

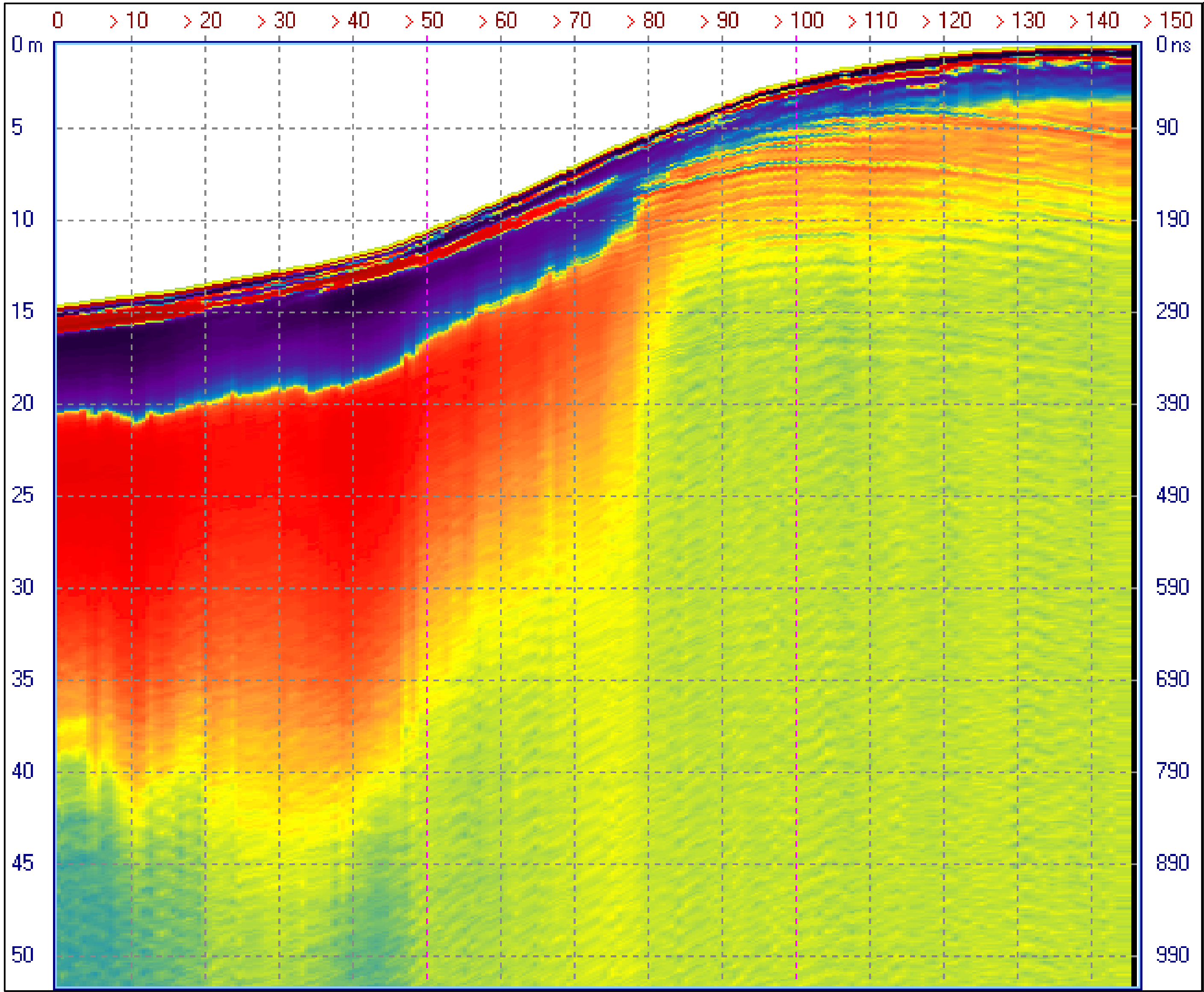


Рис. 2. PL-01 radargram, raw data.

GPR data analysis

The results are represented in the form of B-scans composed from A-scans, with uniform steps. Each shot forms a vertical column, one pixel wide. The information is contained in the amplitude and sign of the received signal, registered with 2 ns time interval (for 1024 ns time window). Each A-scan contains 512 values of the signal amplitude and phase.

The amplitude values are displayed in the radargram in a color palette. By convention, maximum “positive” amplitudes are depicted with red colors, and maximum “negative” amplitudes are shown as dark blue colors. Minimal amplitudes are depicted with yellow color, the intermediate values are represented in the chosen color scale. Variations of the false colors allow one to visually perceive all the dynamic range of the amplitudes and phases of the probing signal.

A real geophysical sense have only the boundaries of the different color zones and the order of color changes.

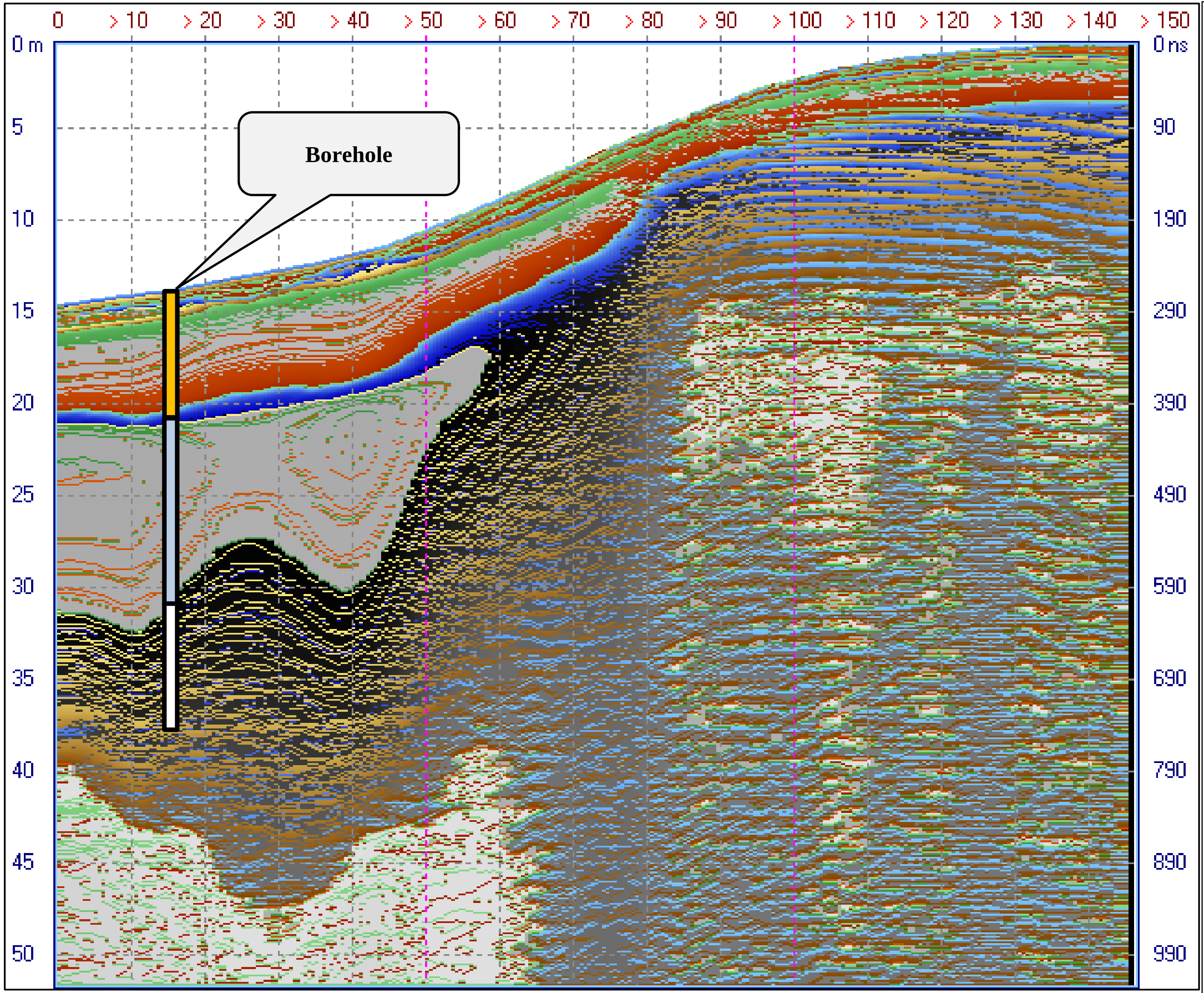
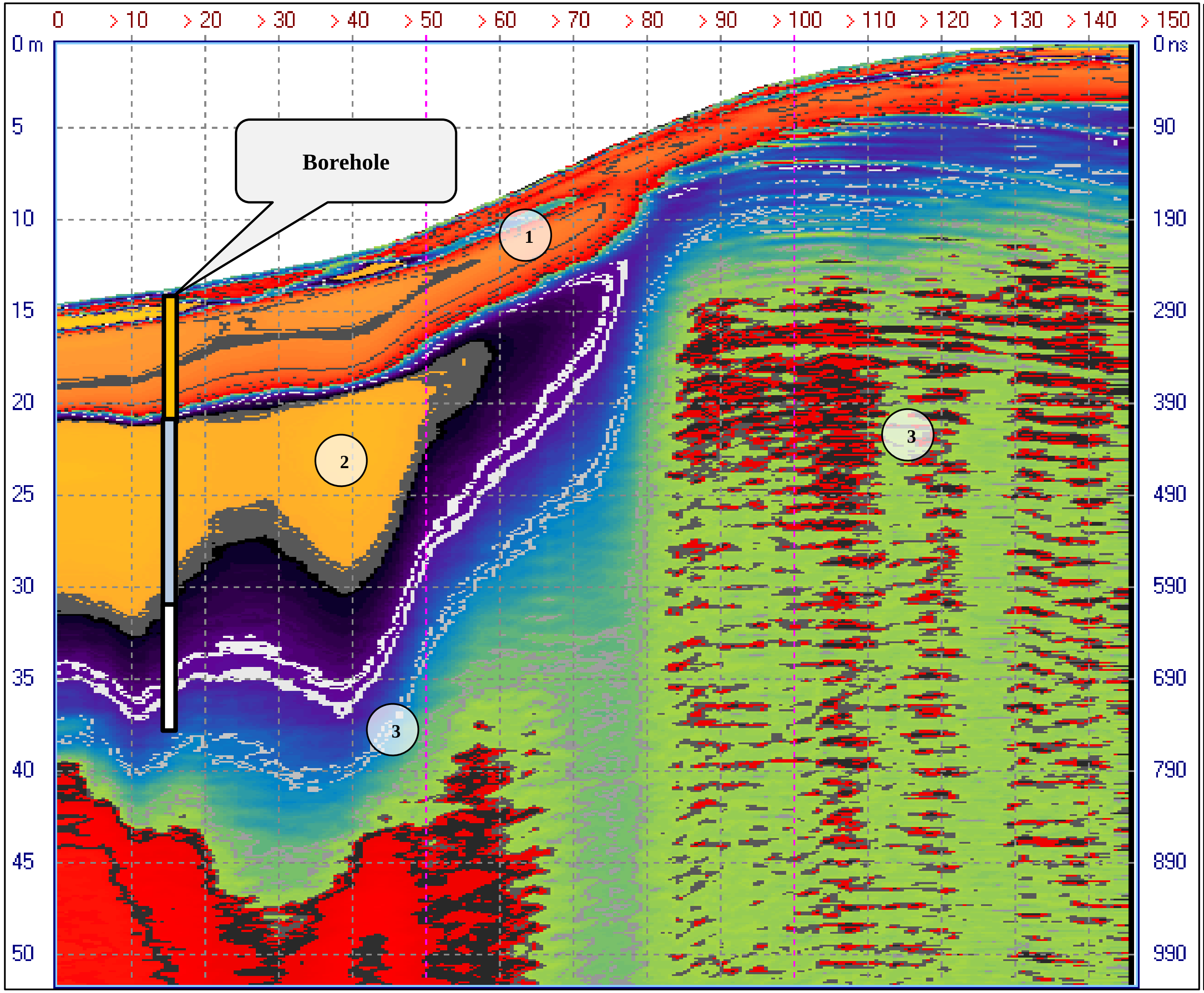


Fig.3. B-scan along **PL-01** path, "No 1" processing

The combination of different color and hue areas in the radargram represents the spatial distribution of subsurface permittivity and conductivity gradients that determine the amplitude and sign of the probing pulse reflection coefficient. The peculiarities of EM wave interaction with horizontal and inclined interfaces of the subsurface medium may result in an extremely complicated color pattern. Its quantitative interpretation presents a fundamental mathematical problem, still not completely solved – see [2]. However, for an experienced geophysicist, the radar cross-section (B-scan) gives a reliable visual information on the geological object under inspection.

A raw GPR B-scan (without any processing) along **PL-01** path is shown in Fig.2 in a 256-bit color scale with positive "red" and negative "blue" amplitude values. Figure 3 presents one of the prossesing schemes implemented in "Krot" software. This procedure ("No1") consists in low- and high-frequency filtering and plotting the time derivative of the received signal waveform. Such a presentation form allows one to detect the levels of sharp variations of the received signal and significantly simplifies the geological interpretation. For convenice, the relief, obtained from GPS data, is taken in account in the plots.

[2]. A. Berkut, et al. Deep penetration radar: hardware, results, interpretation. IWAGRR 2017, Edinbourgh, UK.



Legend for Figs. 3 and 4:

- sands
- silts, clay
- limestone

A synoptic geological column has been drawn from the borehole data (Fig. 5). The lithological structure of the area neighboring **PL-01** path is characterized by the following geological horizons:

- Horizon (1) - from the earth surface to the depths of 7-8 m in the left part of the profile and 3-5 m in its right part - is represented by **sands of different composition.**
- Horizon (2) – depths 7-15 m in the left part of the scan, represented mainly by clayish grounds, clay in the bottom. This layer lenses out along the survey path and disappears beyond 75th meter of the profile.
- Horizon (3) – depths 15-20 m in the left part of the scan and 3-5 m in its right part, is represented by limestone of different degree of metamorphism.

The selected geological horizons probably are underlain by limestone rock formation.

Fig.4. B-scan along **PL-01** path, “No 2” processing mode

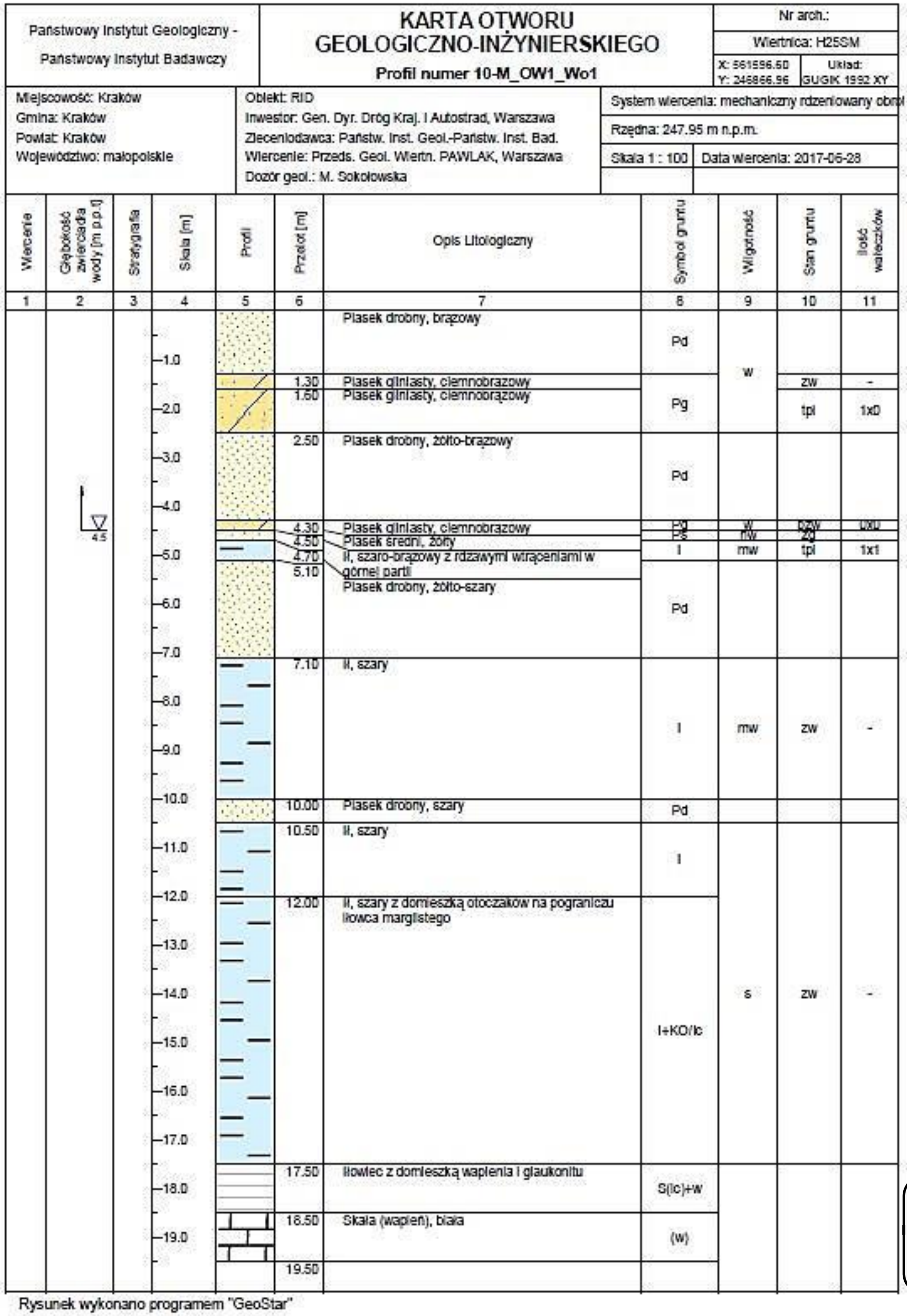


Figure 4. depicts the same GPR cross-section in 'No2' processing mode: low- and high-frequency filtration plus "amplitude segregation" procedure. This algorithm consists in replacing smoothly varying colors of the B-scan with sharply changing contrast steps, which gives a positive visual effect of perceiving small gradients of the subsurface medium.

The vertical time axis in the presented radargrams has been recalculated in a depth scale at a rate 4.6-4.8 cm/ns radar velocity. Such an approximation is enough for a rough representation of the underlying geological structure. For a more accurate estimate of the medium dielectric permittivity, additional borehole measurements or mathematical radar data inversion are necessary [2].

Fig. 5. Lithological section from borehole data

Fig. 6. GPR data collection with "**ROTEG**" GPR

Second GPR set - digital receiver “**ROTEG**” [3]; 15 kV transmitter and 25 MHz antennas were taken from “**Loza-N**” GPR set.

Technical characteristics:

1. «ROTEG» digital receiver;
2. Frequency band: 0.1-500 MHz;
3. Sampling frequency: 3.6 GHz;
4. Measurement rate: up to 1000 1/s;
5. Operation modes: odometer, timer, manual, GPS navigation;
6. Time window - 12 000 ns;
7. Dynamic range: 120 dB;
8. Data registration via WiFi;
9. GPS positioning accuracy: 1-2 m;
10. Barometric height measurement accuracy ± 10 cm.

[3] RT GPR, Czech Republic, www.rtgpr.com

Fig. 7. “ROTEG” GPR receiver mounted on a flexible dipole antenna

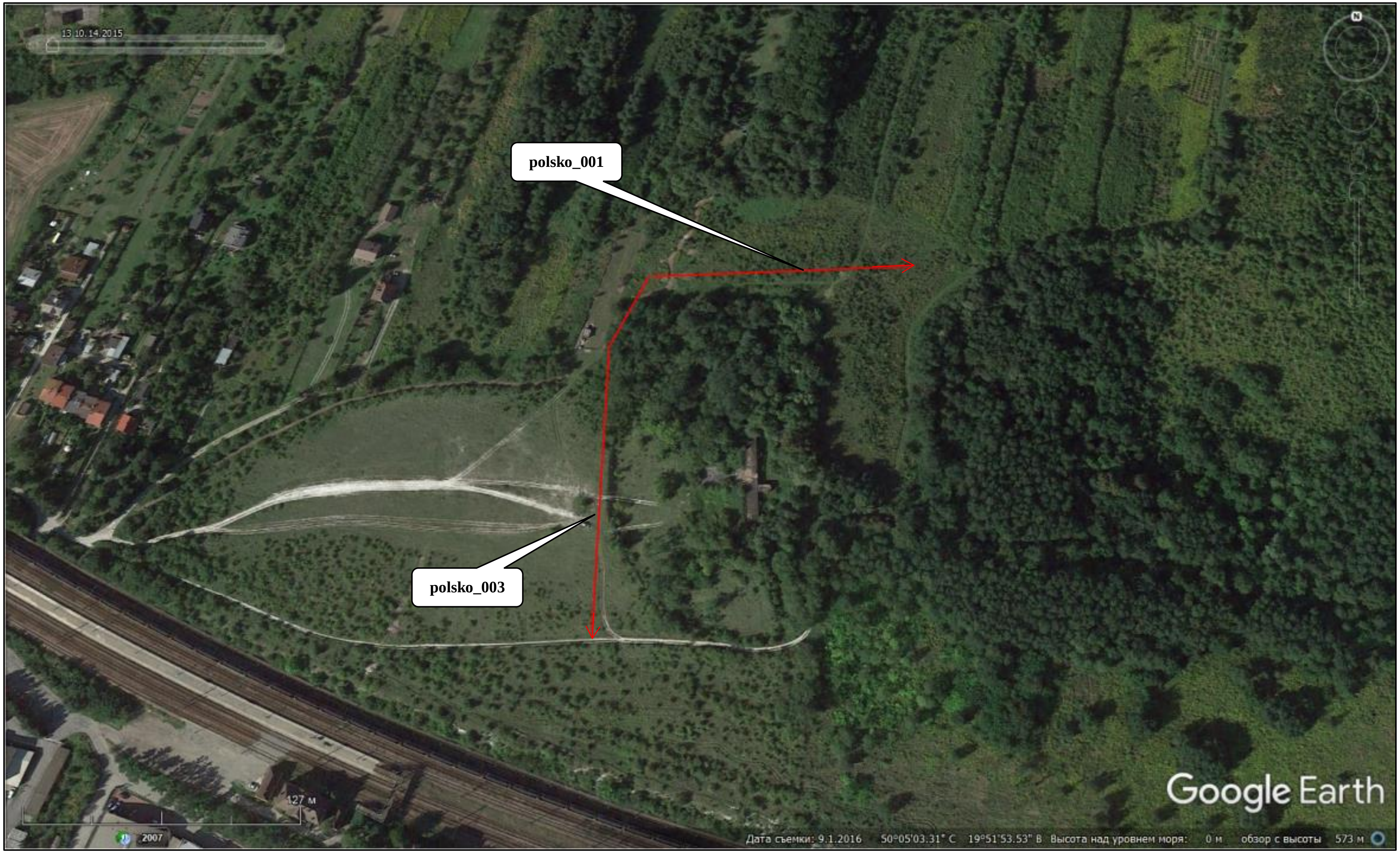


Fig. 8. GPR paths map: «**polsko_001 – 003**»

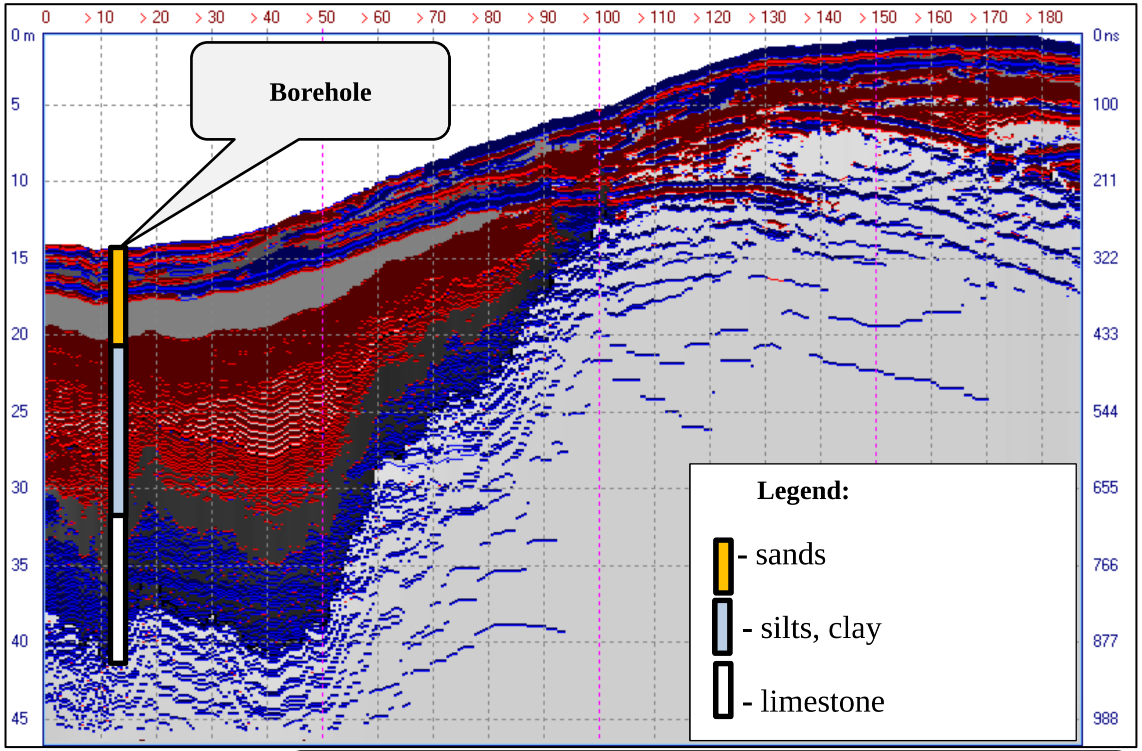


Fig. 9. GPR B-scan along **polsko_001** path (ROTEG GPR), "No 3" processing

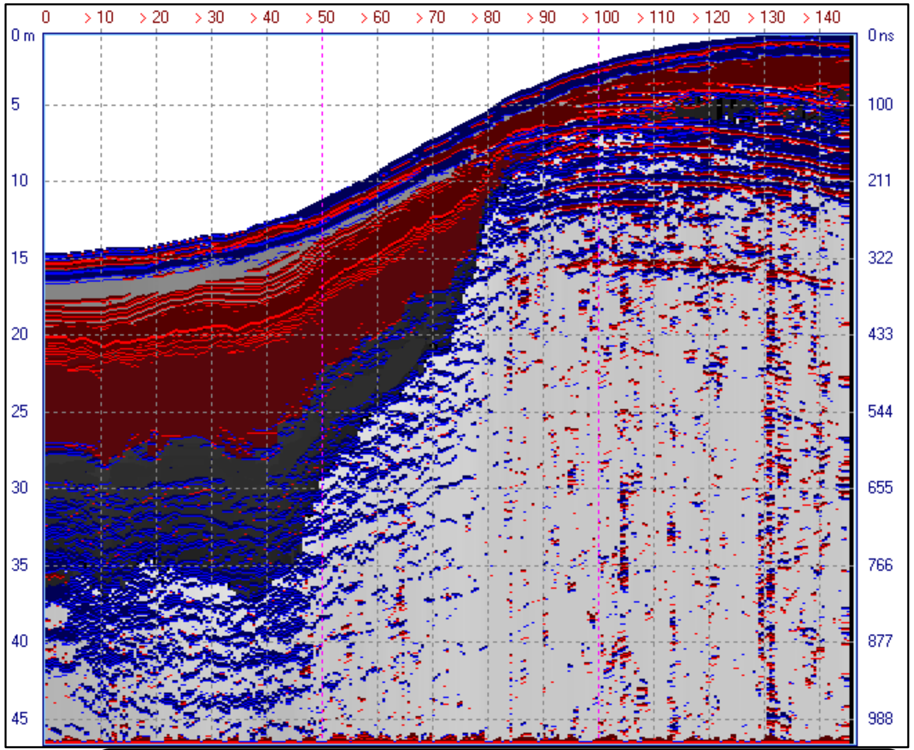


Fig. 10. GPR B-scan along **PL-01** path ("Loza-N" GPR), "No 3" processing

In order to compare the results of subsurface probing with "ROTEG" and "Loza-N" GPR (**polsko_001** and **PL-01**, respectively) in Figs. 9-10 the corresponding B-scans are shown. Another processing algorithm ("No 3") has been used: low- and high-frequency filtration plus "max and min amplitude segregation" procedure. The resulting radargram is composed from local positive (red) and negative (blue) amplitude maxima. This presentation emphasizes the smallest variations of the return signal, being the indication of minimal lithology changes.

One can notice that two absolutely different registration modes yield practically identical results. In "**ROTEG**" receiver, it is direct digitization with a high-rate, wide dynamic range ADC. In "**Loza-N**", the received signal waveform is derived from repeated amplitude measurements with gradually changing threshold in a wide dynamic range. In "Loza-N" GPR, 150 transmitter shots are necessary in order to reconstruct the radar return pulse waveform. For the "**ROTEG**" receiver, one transmitter pulse is enough to obtain the full signal waveform, which substantially accelerates the measurement process – see Fig. 6.

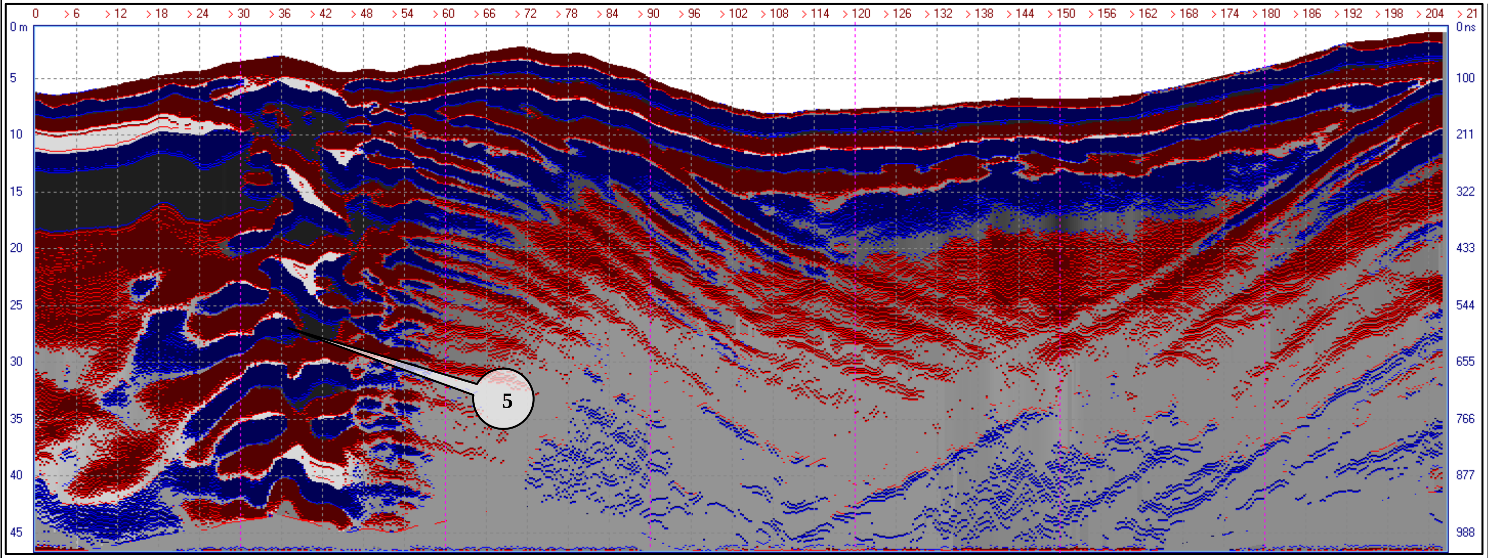


Fig. 11. GPR B-scan along **polsko_003** path (ROTEG GPR), “No 3” processing

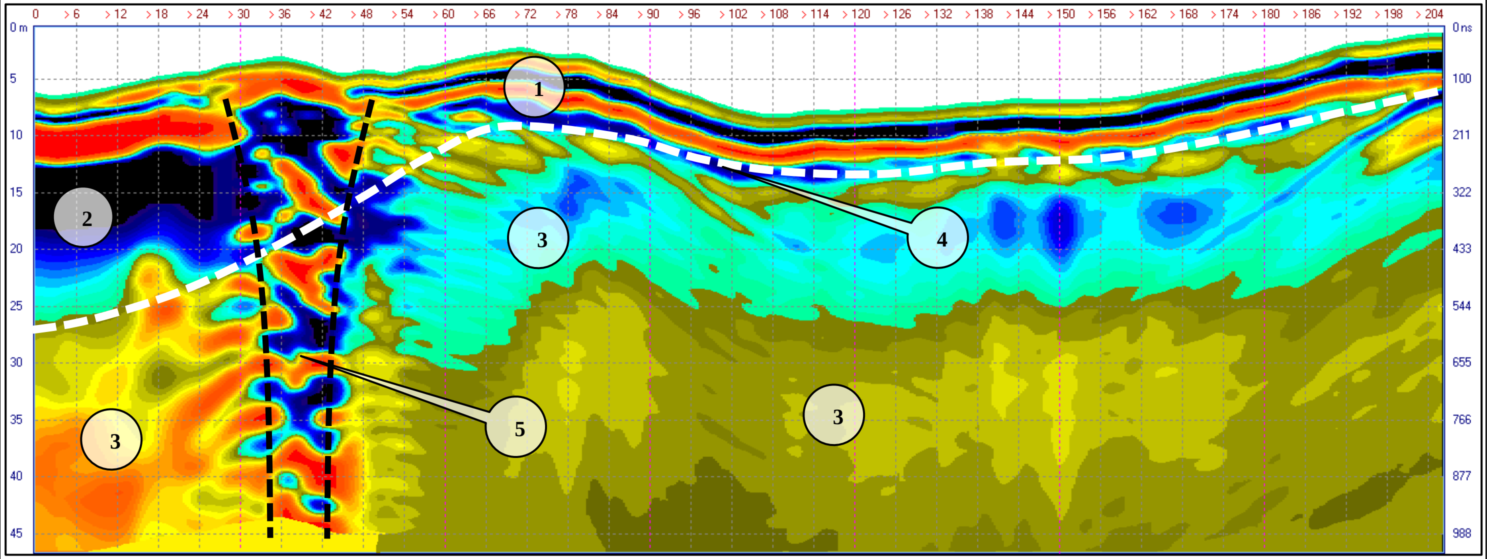


Fig. 12. GPR B-scan along **polsko_003** path (ROTEG GPR), “No 4” processing

Another GPR cross-section has been obtained at the AGH test site - **polsko_003** in N-S direction – see Fig. 8. This B-scan has been recorded with “**ROTEG”** receiver, from “**Loza-N**” 15 kV transmitter with 25 MHz antennas.

In Figs. 11-12, the results of the measurement post-processing are depicted in two presentation modes:

-“No 3” algorithm: low- and high-frequency filtration plus “max and min amplitude segregation” procedure;

-“No 4” algorithm: low-frequency filtration and gradual color amplitude scale.

The lithology of this survey path is represented by the following geological horizons:

- Horizon (1) - from the earth surface to the depths of 6-8 m in the left part of the profile and 3-5 m in the right part - sands of different composition.
- Horizon (2) – depths 8-15 m in the left part of the scan: silty grounds, clay in the bottom. This layer lenses out along the survey path and disappears beyond 50th meter of the profile.
- Horizon (3) – depths 15-20 m in the left part of the scan and 3-5 m in its right part, is represented by limestone of different degree of metamorphism.

The white dash line in Fig. 12 marks approximately the interface between the horizons (**1-2**) (sands and silts) and horizon (3) – limestone.
At the 30-48 m part of the **polsko_003** B-scan a complicated pattern can be seen. Two causes of forming such a structure:

- Aerial interference from the metallic net fence nearby the survey path;
- Footprint of a suffusion funnel – developing karst structure.

The latter version is supported by the fact that his anomaly was observed at a short survey piece, although the whole first 50-m part of the way went along the fence. For a confident interpretation, additional measurements are to be done.

All the presented results have been obtained by post-processing using **"Krot"** software, developed specially for **"Loza"** GPR series [1]. The results registered with "**ROTEG"** receiver were translated to the "Krot" format with "**Spirio"** software.

Conclusion: GPR field measurements were performed at the AGH test site. The obtained results are presented in a wide spectrum of post-processing modes, which gives a possibility to estimate the possibilities and specifics of deep GPR probing of the wet grounds with high signal attenuation.

In a supplement, the primary GPR probing data, converted to the "Reflex" software format, are given.

Supplement

1. **PL-01** B-scan (**"Loza-N"**) in "Reflex" format - **PL01____.DAT**.
2. **polsko_001** B-scan ("**ROTEG"**) in "Reflex" format **- polsko_001.DAT.**
3. **polsko_003** B-scan ("**ROTEG"**) in "Reflex" format **- polsko_003.DAT.**

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