3D S-wave High-Resolution Seismic Survey

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Summary

Nyírád Deákipuszta area in the western edge of the Bakony-mountains was one of the bauxite mining areas in Hungary. Underground mining activity also included very strong groundwater deepening. After closing the mining activities and rising back the groundwater level many of the mined blocks collapsed and closed surface movements. These surface movements can be still dangerous, therefore reliable and detailed geotechnical data are required for planning. High-resolution seismic survey can provide very important information and data for the required geotechnical planning and calculation. 2D P-and S-wave seismic survey measured over a previous mining block with ongoing surface movements provided very reliable survey results for planning of surface infrastructure. In addition a 3D S-wave seismic survey was carried out over the most important area for future constructions. Seismic mapping of the topmost layers could be completed very effectively using Lightning electronic vibroseis source and STRYDE receivers for S-wave recording. Preliminary results of the 3D seismic measurement shows detailed tectonic and sedimentary information, but no additional subsurface deformation due to the historical mining activity.

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Introduction

Mining of bauxite in the Nyírád-Deákipuszta area, in the western edge of the Bakony-mountains started early 70s. Before starting the underground mining an intensive drilling program was completed in the area between 1955 and 1970, providing geological information and finding the underground bauxite lenses. On average 4.5-5 wells were drilled in each hectare (100x100 m area). These wells were 60-90 m deep, depending on the surface elevation and the subsurface geology. Figure 1 shows the location of these exploration wells with black dots marking the ones that found no bauxite, while red dots marking the bauxite discoveries. These bauxite layers were varying in depth and in thickness, typically found 45-80 m deep below the surface. Thickness of the bauxite lenses are mapped from the drilling data and is shown in the left map of Figure 1.
Digital Elevation Model recorded by Envirosense Hungary in 2020 not only indicates 190-205 masl elevation, but clearly shows surface deformation, depression and surface fractures over the subsurface mined bauxite layers. Figure 1 right map marks with pink outline the horizontal extension of the subsurface mines and with light blue the safety area above the collapsing mine areas. Figure 2. Shows two aerial photos of the same area, one recorded in 1988, during the mining activity, the other one GoogleEarth image recorded in 2022 more than 20 years after the mining activity stopped. Surface vegetation showed variation already in 1988, however at that time elevation differences were not significant yet, agricultural activity was not limited. By now the surface subduction above the mining blocks is typically 0.5 – 1meter and these parts are protected. Key point of our geophysical survey was to image the subsurface variations with a high-resolution seismic survey across and in the vicinity of the collapsed area. Measuring across the mined area (Nyírád-1_2023 2D seismic profile) P- and S-wave seismic image and velocity field was recorded, while Nyírád-2_2023 2D profile was running parallel with a valley, but not crossing previously mined areas.

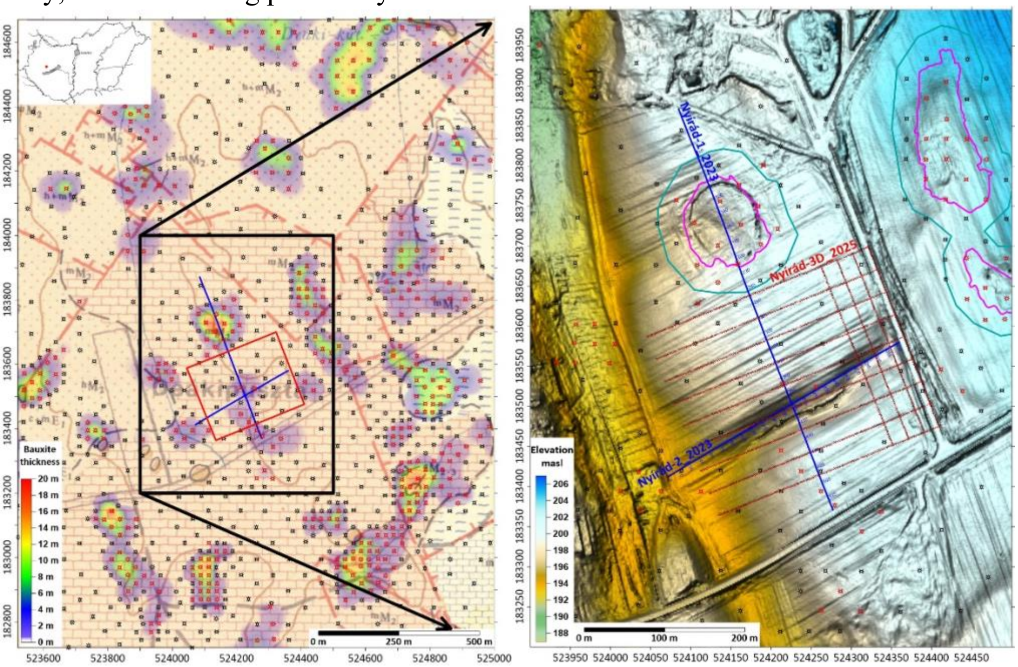

Figure 1 *Nyírád survey area shown in the geological map of the surrounding area (detail of 1:20000 "Sáska" map shown on the left) and digital terrain map (DTM) recorded by Envirosense Hungary in 2020 shown in the right map. Black rectangle in the left map indicates elevation area shown in right map and areas in Figure 2.*

The 3D S-wave seismic survey measured in 2025 mapped the vicinity of the mined area, focusing on the underground tunnel system running between the mined areas. 3D survey area also covers an unmined section with less than 4 m bauxite layer thickness mapped by the exploration wells.

It is also important to mention, that groundwater layer was significantly changed during mining. Schmieder & Szilágyi, 1988 (in Hungarian) documented more than 100 m regional deepening of underground water level during the mining years. The lowering of the ground water level stopped after mining and by 2016 rising water level reached and filled all the mining areas (Smaragd GSH 2017, in Hungarian). Increasing water level reaching the old mining blocks modified the physical properties, very likely increased vertical movements of the layers above the bauxite mining blocks. P and S wave seismic velocity will indicate on one hand the existence of water layer, on the other hand changes of physical properties above the old mining blocks.

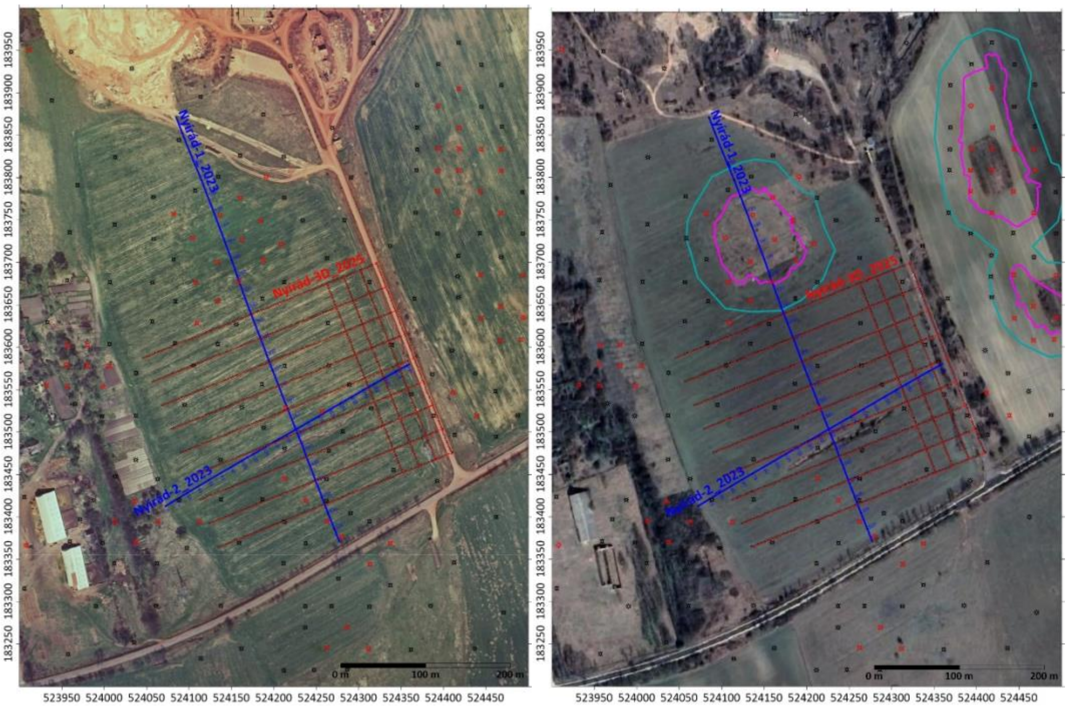

Figure 2 *Nyírád survey area shown in 1988 aerial photo (left) and 2022 GoogleEarth image (right). In the GoogleEarth image pink lines mark the horizontal limits of the bauxite mining, while light blue lines indicate the currently available safety limits on the surface.*

Applied Seismic Surveys

In 2023 2D P- and S-wave seismic profiles were measured along two, almost perpendicular profiles. Nyírád-1_2023 profile was 536 m long with NNW-SSE and 4 m receiver and source point spacing. Northern part of the profile was above the mining block indicated by surface subduction. Nyírád-2_2023 was 333 m long with WSW-ENE direction and 3 m receiver and source spacing. Nyírád-2_2023 was running parallel to a small valley, crossing sections where old wells indicate a few meters of bauxite layer, but no mining was applied in this subarea.

Seismic sources:

In 2023 both for P- and S-wave seismic source the Lightning eVibe electronic vibroseis source developed by Seismic Mechatronics (https://seismic-mechatronics.com/) was used. Sweep length of 20 seconds with 8-120 Hz linear upload frequency was applied. In 2023 both the P-wave and S-wave 2D seismic lines were recorded during daytime. Unfortunately the survey are is close to the Nyírád-Sümeg road, which is generating acoustic noise by the cars and especially the trucks and busses driving in each directions. Data processing showed the noise generated by the traffic, therefore the 3D S-wave seismic survey in 2025 was recorded during the nights. This caused a significant improvement in the data quality.

In 2025 the Lightning eVibe vibroseis source and an S-wave hammer developed by Geomega was combined. Figure 3. shows both seismic sources. The vibroseis source was applied using the same 20 seconds an 8-120 Hz linear sweep as in 2023. The S-wave hammer was generating two shots at each source point. Comparison of the seismic source results will be presented, but in summary we can clearly state the better data quality and higher S/N ratio of the vibroseis source.

Figure 3 *S-wave seismic sources used for the 3D seismic survey were combination of hammer (left image) and Lightning eVibe manufactured by Seismic Mechatronics (right image)*

Seismic recorders:
In 2023 2D seismic survey recording was completed using 3Components GS-30CT 10 Hz geophones and Unite-1 digitizing system. A geophone location is visible just behind the vibroseis in Figure 3.
In 2025 during the 3D S-wave seismic survey using the STRYDE system was a major step forward. 1210 geophone locations used 2420 STRYDE components placed in the ground as shown in Figure 4. Two teams using two 4x4 pickup cars could deploy the 2420 channels in two days, which was a very ensured an effective work. All STRYDES were active only during the nights and the vibroseis shooting started the night following the second deployment day, when the complete recording system was ready. Luckily in this survey area there was no danger of either animals or locals causing problem to the recording system, therefore none of the 2420 STRYDE applied was damaged or stolen.

Figure 4 *2C S-wave recording with STRYDE system placed in two horizontal directions in the ground*

Seismic results:
During the 2023 2D seismic survey both P- and S-wave measurements showed very strong velocity variation and seismic reflection imaging along the northern part of Nyírád-1/2023 line. Figure 5. shows top 50 meters of the calculated S-wave velocity field and the depth converted S-wave seismic reflection profile. Mining area and part of the protection area identifies the subsurface movements above the bauxite mine. It is also clear, that the valley crossed by the seismic profile between 400-420 meters has tectonic evidence in the topmost imaged layers, but neither P-, no S-wave velocity reduction is observed below the valley.
2023 2D seismic survey has shown, that for the topmost, shallow layer imaging S-wave seismic is preferred to P-wave. Based on these results S-wave 3D survey was selected for the 2025 survey of that area, which was important for planning and geotechnical information. Key question was to ensure that neither the not mined bauxite layer, nor the subsurface tunnels connecting the mined areas can cause surface problem in the future.

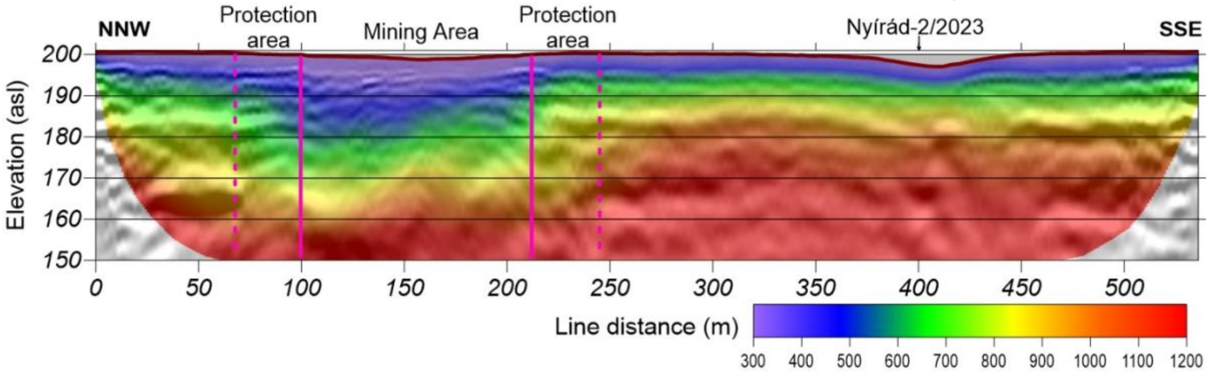

Figure 5 *Nyírád-1/2023 2D S-wave seismic profile clearly showing the collapsed seismic layers and the significantly reduced S-wave velocity above the old bauxite mine area. S-wave velocity range was typically between 300 and 1200 m/s as shown by the colour scale.*

Figure 6. shows two perpendicular S-wave profiles selected from the 3D dataset. Several subsurface tectonic and sedimentary elements can be identified, including deepening in the middle part of Line-07, around 150 m. This is a bauxite filled depression which was discovered by the early drilling activity, as visible in Figure 1, however due to the limited layer thickness no underground mining was developed in this area. Another important result of the 3D S-wave imaging is that the underground tunnels were not causing any S-wave velocity anomaly, indicating that none of them were collapsed and reduced the physical strength up to the surface.

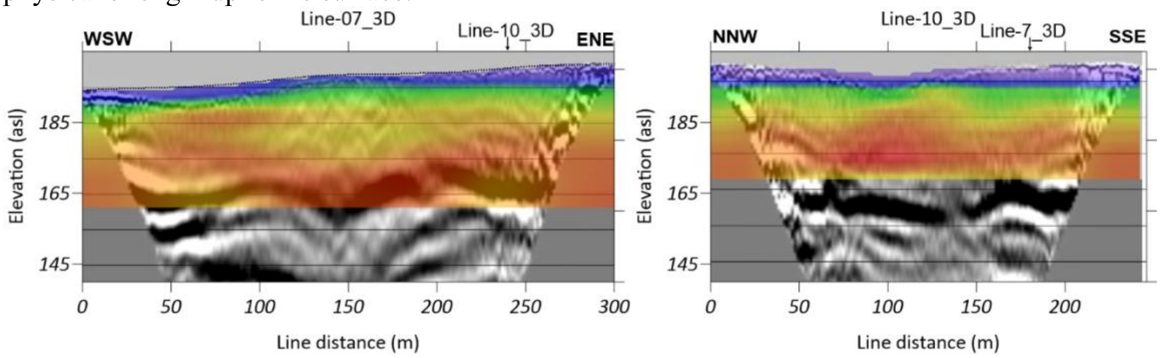

Figure 6 *Two lines selected from the 3D S-wave seismic data. Line07 and Line-10 are perpendicular crossing each other. S-wave velocity scale is identical with the scale shone in Figure 5.*

Conclusions

Geophysical measurements have been completed first in 2D P- and S-wave mode, later with 3D S-wave imaging of the near surface layers. Seismic imaging of the top layers and the near surface velocity field was giving detailed information about the collapsed mining areas and showed no near surface influence of the underground tunnel system of the mining. 3D S-wave imaging with night recording using an electronic vibroseis source and STRYDE recording system was optimal for this subsurface imaging.

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