

ABSTRACT

Over 100,000 individuals were killed in Ponar Forest, Lithuania from 1941-1944. Eighty Jewish prisoners forced to burn the bodies of the victims were held in the forest for roughly a year. In an attempt to escape, they dug a 30-meter tunnel over the course of 70 days. Eleven people were able to survive the escape and tell the tragic story. The objective of the research is to locate the proposed tunnel and bring scientific validation to the survivors' stories using ground penetrating radar (GPR) survey. GPR is a noninvasive geophysical technique to image the subsurface using high frequency electromagnetic (EM) pulses. The pulses are sent into the ground from a transmitting antenna and are then reflected to the surface and received by a second antenna. Based on survivor testimonies and prior research conducted at the site, a 10x20 meter grid was laid out for investigation. Data was collected along 40 parallel lines spaced 0.25 meters apart at a frequency of 225 MHz using a pulseEKKO 1000 GPR system. Results of the processed data showed irregular subsurface stratigraphy located 3-4 meters beneath the surface. The interpreted anomalies are determined to be the tunnel based on the location and dimensions.

INTRODUCTION

The use of ground penetrating radar (GPR) for archaeological investigation has been a growing field throughout the scientific community (Conyers 2016). The noninvasive geophysical technique allows for the subsurface to be visualized in both 2 and 3-dimensional perspectives without destruction of the study area. GPR was used to investigate the subsurface stratigraphy in Ponar Forest located 10 km southwest of the Lithuanian capital of Vilnius (Figure 1a). Ponar Forest is located in a post-glacial fluvial environment and is mapped as an area of loamy sand, which is highly suited for GPR investigation due to ease in signal penetration (Smith and Jol 1995).

Prior to World War II (WWII), Ponar Forest was used for recreation by families living in Vilnius and the surrounding areas. However, when the Soviets took military control of Vilnius during the early stages of WWII the forest was converted to a military base and numerous large pits were built for fuel and ammunition storage (Figure 1b).

However, when the German Nazis gained control over the capital they used the pits as an execution and burial site of their prisoners. From 1941 to 1944, an estimated 100,000 people were shot and killed in the Ponar Forest (Bubnys 2013). The massacre that occurred here is thought by some to be the beginning of the Nazi's "Final Solution" (R. Freund personal communication, July, 2016). As the Nazis began to lose WWII, they brought in a group of 80 men and women from nearby concentration camps were brought in to exhume and dispose of the bodies by burning them. This group was known as the Burning Brigade (Bubnys 2013). Housed in one of the empty pits (referred to as Pit 6) the Brigade knew they too would be killed once the work was finished (Figure 2). To escape their impending death, the Brigade, which included an engineer and electrician, planned to escape by digging a tunnel from inside Pit 6 to the forest using their hands along with materials found on the bodies of victims. Completion of the 30-meter-long tunnel took roughly 76 days and began inside Pit 6 and into a low point in the forest (Figure 3). On April 15th, 1944 the Brigade made their escape. Only 12 managed to escape while 11 survived the war. The purpose of the project was to scientifically validate the location of the escape tunnel and the survivors' story through the use of GPR investigation.



Figure 1: (a) The location of the study was Vilnius Lithuania. (b) The location of the study relative to the capital, Ponar Forest was converted to a Soviet army base with multiple pits for storage were created. (GoogleEarth 2017)



Figure 2: The temporary home for the Brigade, Pit 6, as viewed today within the Ponar Memorial Museum. Centered in the pit is a replica of the machine they used to transport bodies (Erickson 2016)



Figure 3: Image taken from the Ponar Memorial Museum of the hypothesized design of Pit 6, the Brigade's barrack and the escape tunnel (Jol 2016)

Prior to GPR investigation, electrical resistivity tomography (ERT) surveys were conducted by P. Bauman and A. McAllister near Pit 6 in search of the tunnel. The location was determined with the help of K. Bensimon, expert in tunnel construction. ERT is a geophysical technique that uses electrical resistivity measurements to image the subsurface.

The results of the study showed high resistance southwest of Pit 6 and gave researchers a specific area to further study (Figure 4 and 5). Based on the results, it was likely the tunnel was located here due to the linear path from the entrance within Pit 6 and the locations of the area with high resistance (Figure 6).



Figure 4: Aerial imagery of showing the high resistance locations from ERT results (7, 5, and 6). Dashed line indicates the hypothetical path of the tunnel (WorleyParsons 2016)

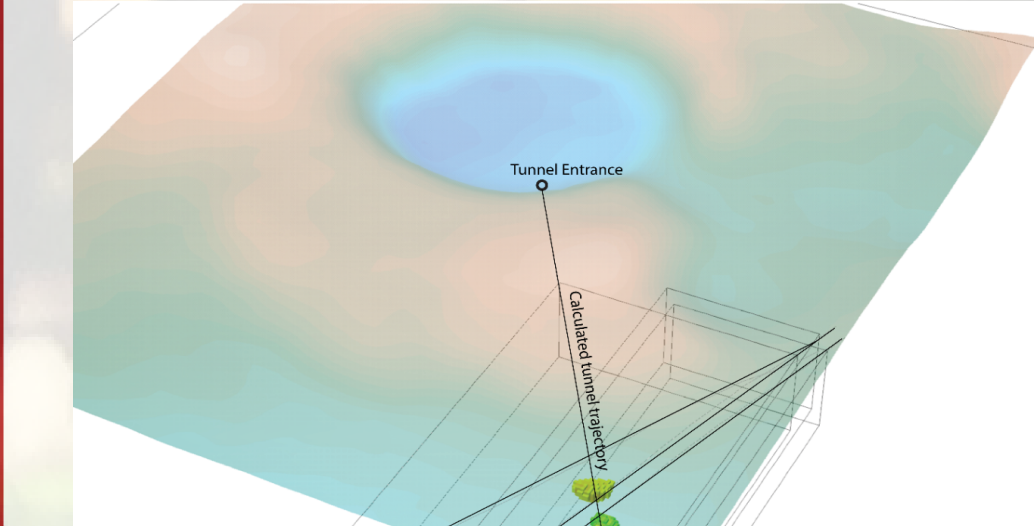


Figure 5: Results from the ERT survey. The high resistance areas have the dimensions of 2 by 2 meters (WorleyParsons 2016)

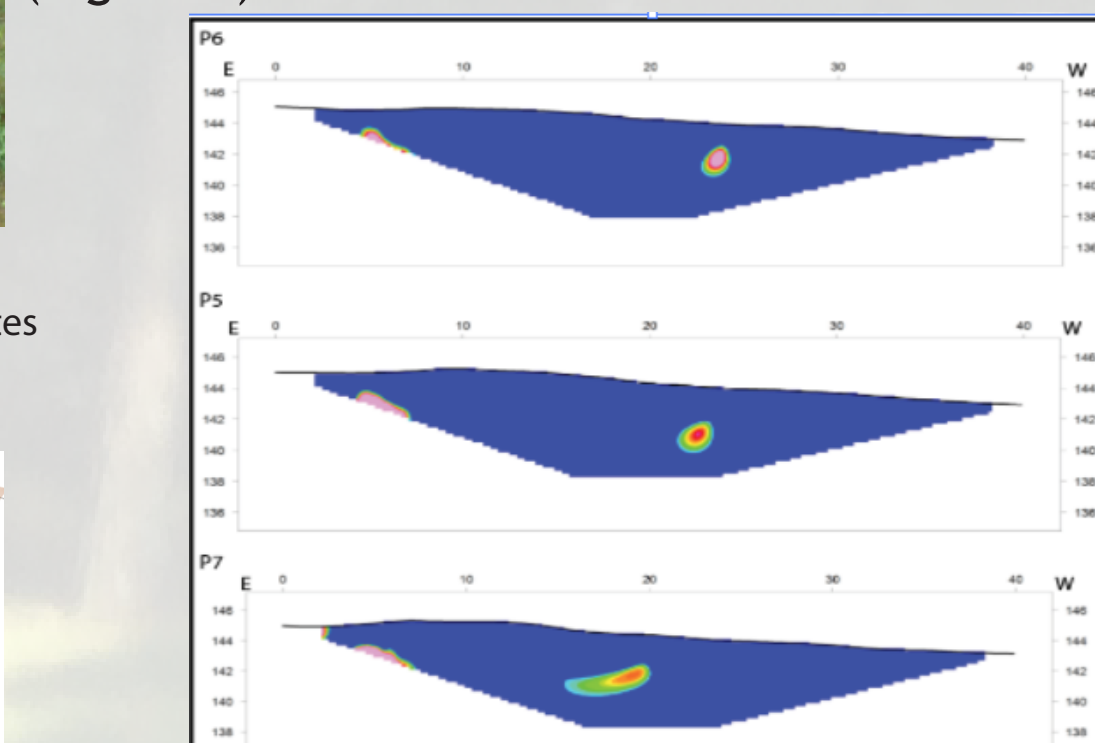


Figure 6: ERT results from survey 7, 5, and 6 appear in a linear path from the entrance of the tunnel and into the forest (WorleyParsons 2016)

GROUND PENETRATING RADAR

GPR is a noninvasive process used to image the subsurface with high frequency electromagnetic (EM) energy. Using two antennae, an EM pulse is sent into the ground from a transmitting antenna where the pulse travels through the subsurface until contacting a material of differing dielectric properties and is then reflected back to the surface and collected by the receiving antenna (Jol & Bristow 2003) (Figure 7). The frequency of the pulses are chosen based on desired signal depth and resolution, a concept known as the range-resolution trade-off (Davis and Annan 1989).

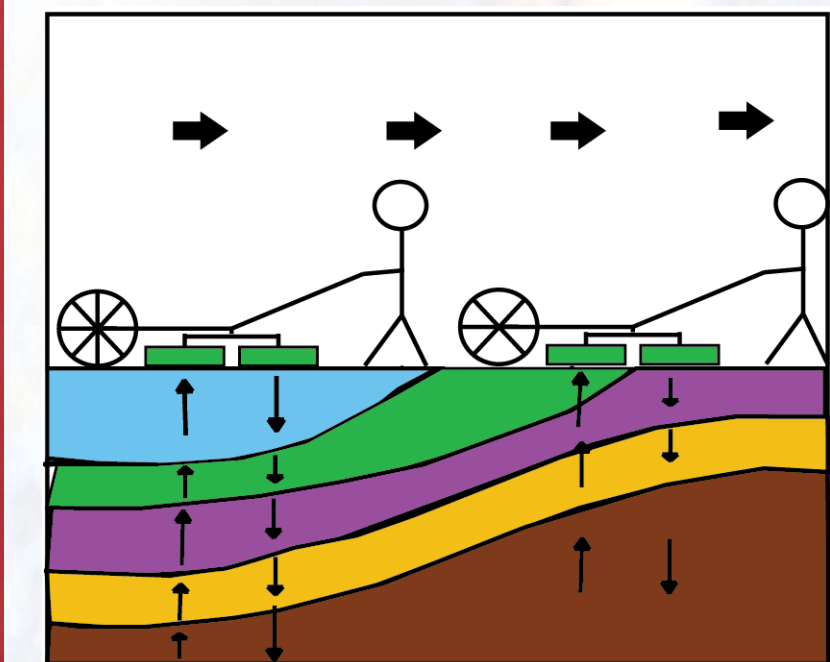


Figure 7: GPR theory diagram. EM pulse emitted from one antenna and returned to second antenna upon reaching differing features (Theory: Jol and Bristow 2003; Diagram: Seamans 2016)



Figure 8: Sensors and Software pulseEKKO1000 consisting of A) Transmitting antenna, B) Receiving antenna, C) wheel with odometer, and D) Computer that records data in real-time (Erickson 2016)

METHODS

DATA COLLECTION

The location of the survey grid was based on the survivors' testimonies as well as previously collected ERT data (Figure 9). The 10 by 20 m grid was laid out using survey tapes so that detailed notes on surface features could be collected (Figure 10). The grid consisted of 40 lines spaced 0.25 m apart with a step size of 0.05 m. The pulseEKKO 1000 (Figure 8) was used with an antenna frequency of 225 MHz was used which allows for roughly 10 m based on the near surface velocity of 0.13m/ns. The velocity was calculated after the collection of a common midpoint (CMP) survey (Figure 11). Topography of the grid was also collected using a Topcon Laser Leveler to provide necessary surface adjustment of the GPR transects collected.

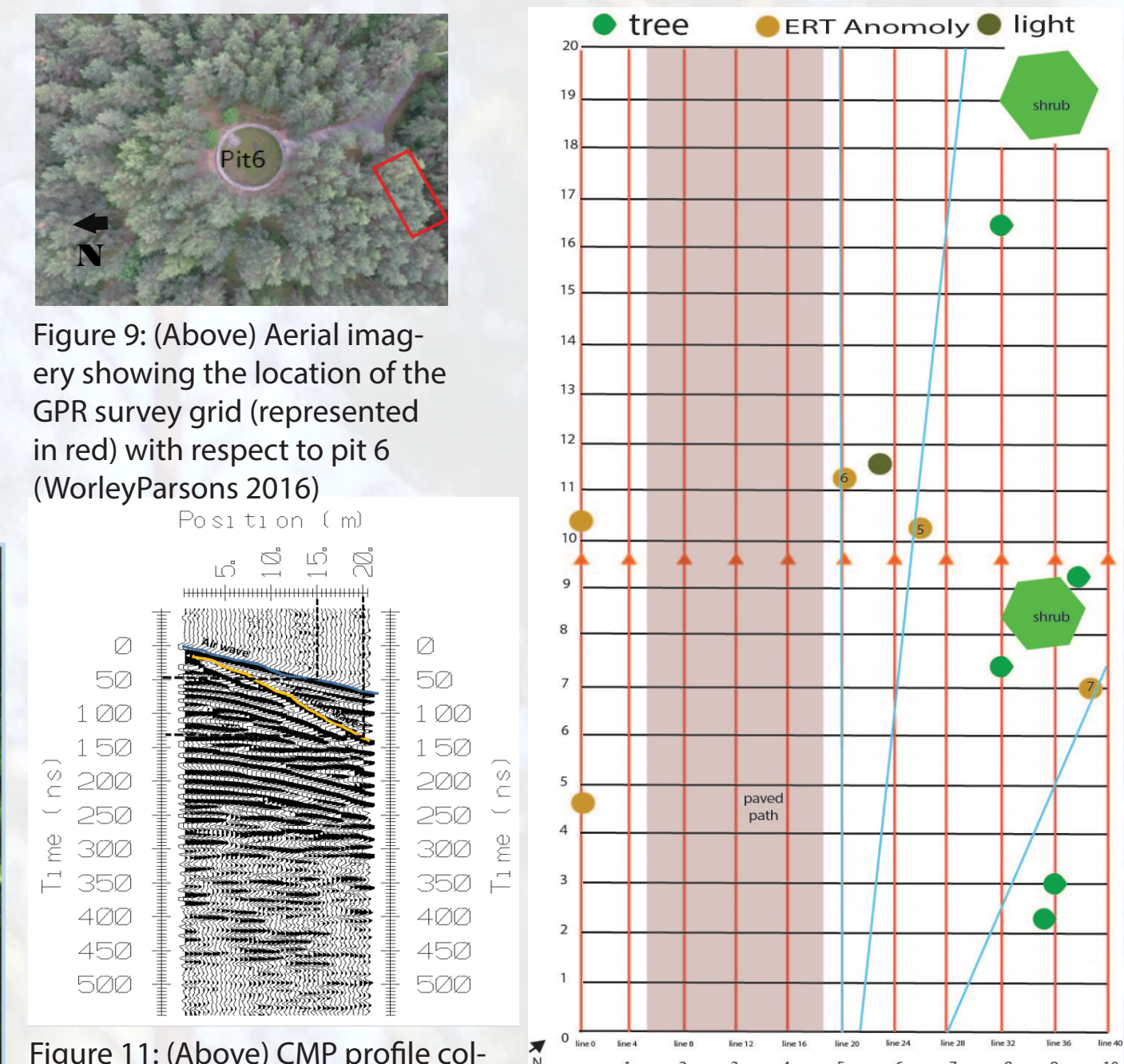


Figure 9: (Above) Aerial imagery showing the location of the GPR survey grid (represented in red) with respect to pit 6 (WorleyParsons 2016)

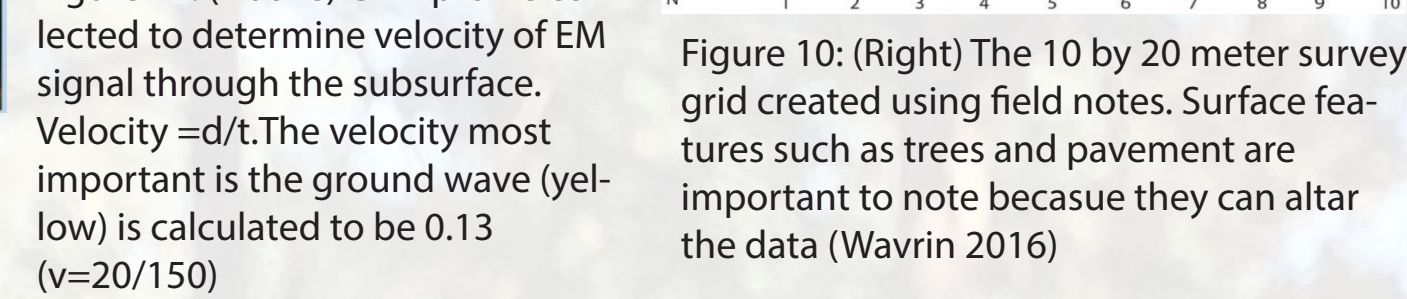


Figure 10: (Right) The 10 by 20 meter survey grid created using field notes. Surface features such as trees and pavement are important to note because they can alter the data (Wavrinn 2016)

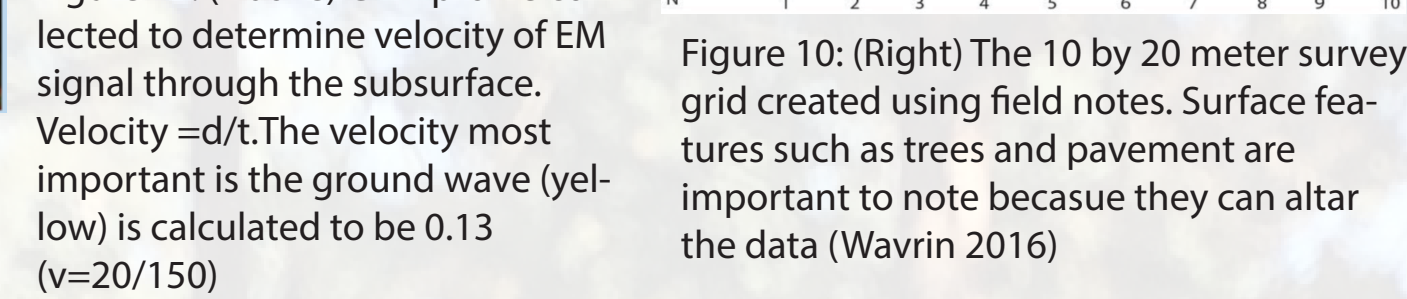


Figure 11: (Above) CMP profile collected to determine velocity of EM signal through the subsurface. Velocity = d/t. The velocity most important is the ground wave (yellow) is calculated to be 0.13 (v=20/150)

DATA PROCESSING

Following GPR data collection, the raw data was processed with several programs including: EKKO Project, GPF Edit, and Voxler.

- EKKO Project:
 - +Processing of individual transects
 - Filter Application
 - Horizontal spatial filter
 - Dewow- remove "noise from the data"
 - Vertical Temporal Filter
 - Gain Application
 - Automatic gain control (AGC)- continuously adapts to stratigraphic horizon (Conyers 2016)
 - Topography attachment
 - +Analysis of transects
 - Line view and slice view
- GPF Edit:
 - +Lines oriented in the correct direction
 - +Length adjustment of transects to create a uniform appearance
 - +Single grid file created
- Voxler:
 - +3D rendering software
 - Further interpretation
 - Visual communication of the results

RESULTS

2D PROFILES

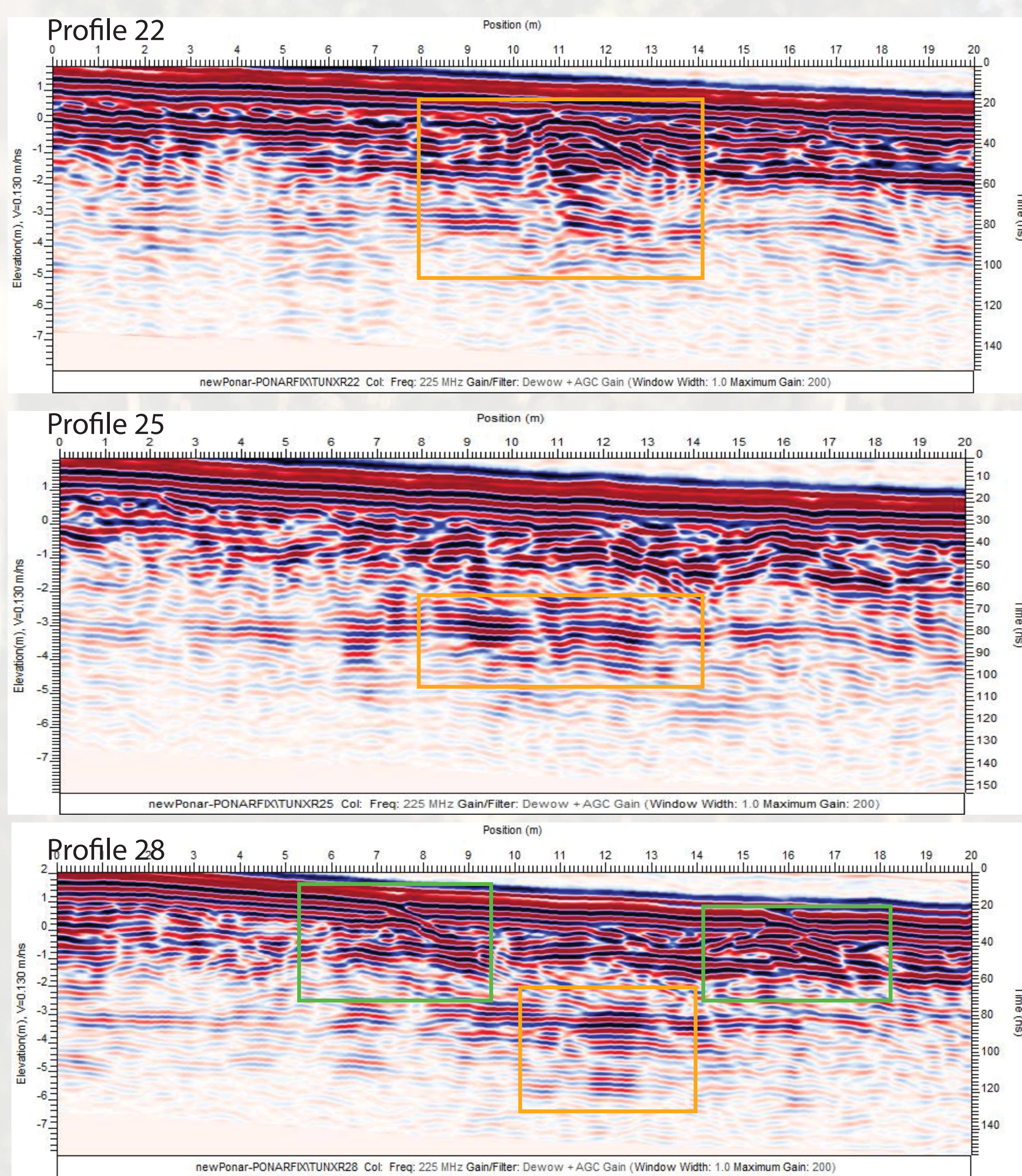


Figure 13: Profile of GPR line 25. The highlighted anomaly is located 3-4 meters beneath the surface.

Figure 14: Profile of GPR line 28. Various anomalies (green and orange) are highlighted.

Figure 12: Profile of GPR line 22. A slight hyperbolic anomaly is shown at the 11 meter mark and begins roughly 1 meter beneath the surface.

The various processing procedures formally described allowed for the transect profiles to be viewed, analyzed and interpreted. The various profiles have had a color ramp applied to them for visualization purposes. Though 40 lines made up the grid, only a selection of transects are interpreted.

Profile 22: The profile shows a large hyperbolic anomaly roughly 4 meters in length (shown in the area within the orange box) (Figure 12). The feature is located from 1-3 meters in depth. Based on the location of the anomaly (refer to figure 10) the anomaly is interpreted as a void in the stratigraphy which results in more reflections.

Profile 25: The profile shows a strong subparallel reflection pattern located 3-4 meters beneath the surface (Figure 13). The strong reflection is located where the ERT data indicates a large void. As it is more prominent than others at that depth it is interpreted that the area has differing sediment characteristics, likely higher moisture content. Interpreted as a collapsed tunnel segment.

Profile 28: The profile shows two near surface unconformities (green) located 1 meter beneath the surface (Figure 14). The small hyperbolic anomalies are located near trees. The roots of the trees are likely the cause of the hyperbolic pattern noted. The strong subparallel reflection is also seen (orange).

The 2D slice views are images taken from EKKO project. Each slice depicts 10 cm in depth of the entire 10 by 20 meter grid. The images have a level 4 AGC gain to enhance the reflection strength. This allows for the various patterns to be seen with ease. Areas of blue indicate low reflection while red is the highest. Figures 15 and 16 are within 1 meter in depth. The areas highlighted in red are located along the edge and beneath the paved sidewalk which is the likely cause of the high reflections. Figures 17-20 are 3 meters or more in depth. The areas clearly seen are interpreted to be sections of the collapsed tunnel.

2D SLICE VIEW

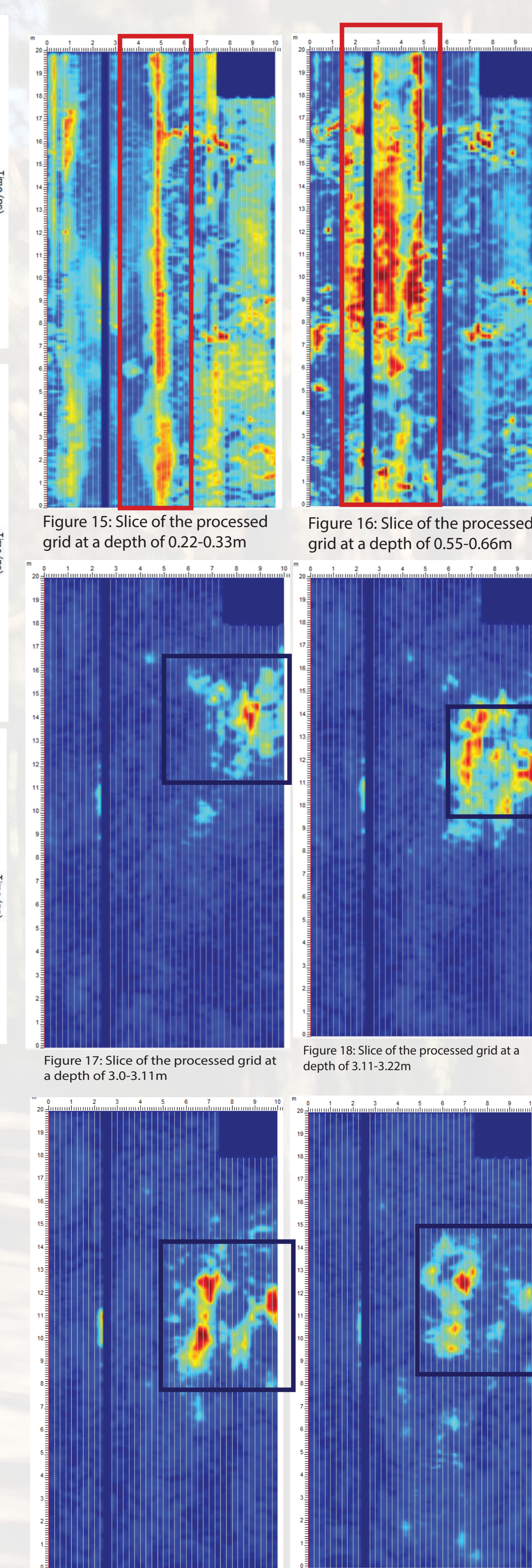


Figure 15: Slice of the processed grid at a depth of 0.22-0.33m

Figure 16: Slice of the processed grid at a depth of 0.55-0.66m

Figure 17: Slice of the processed grid at a depth of 3.0-3.11m

Figure 18: Slice of the processed grid at a depth of 3.11-3.22m

Figure 19: Slice of the processed grid at a depth of 3.22-3.33m

Figure 20: Slice of the processed grid at a depth of 3.77-3.88m

RESULTS 3D IMAGES

The following images are the results from the processed lines and grid after being imported into Voxler, a 3D rendering software. Areas with warm colors indicate high levels of reflections. There are several of these visible in the 3D results. The interpretations and descriptions of the various anomalies suggest a variety of surface interferences during the collection process along with subsurface anomalies located 3-4 meters in depth. Table 1 has both descriptions and interpretations of the anomalies.

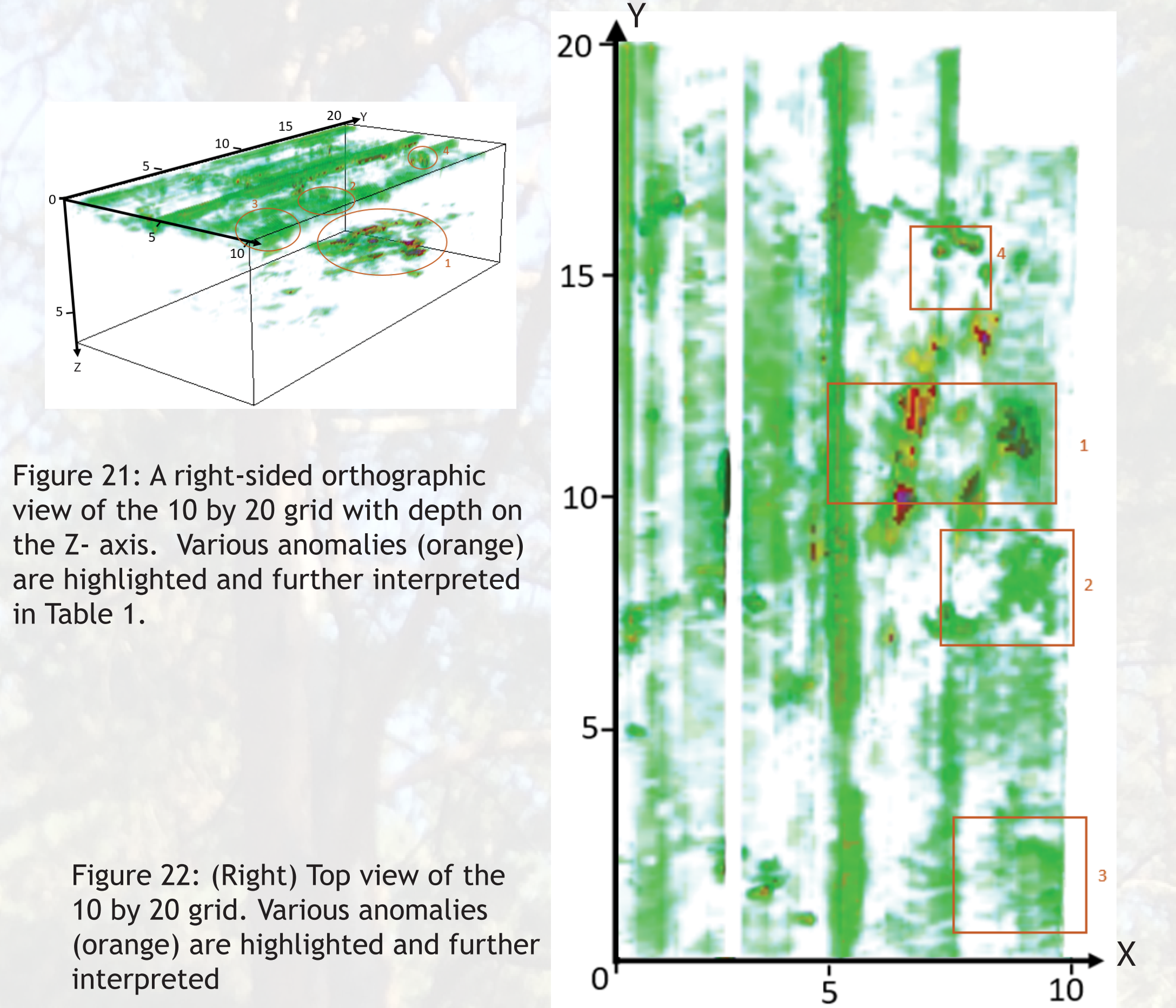


Figure 21: A right-sided orthographic view of the 10 by 20 grid with depth on the Z-axis. Various anomalies (orange) are highlighted and further interpreted in Table 1.

Figure 22: (Right) Top view of the 10 by 20 grid. Various anomalies (orange) are highlighted and further interpreted

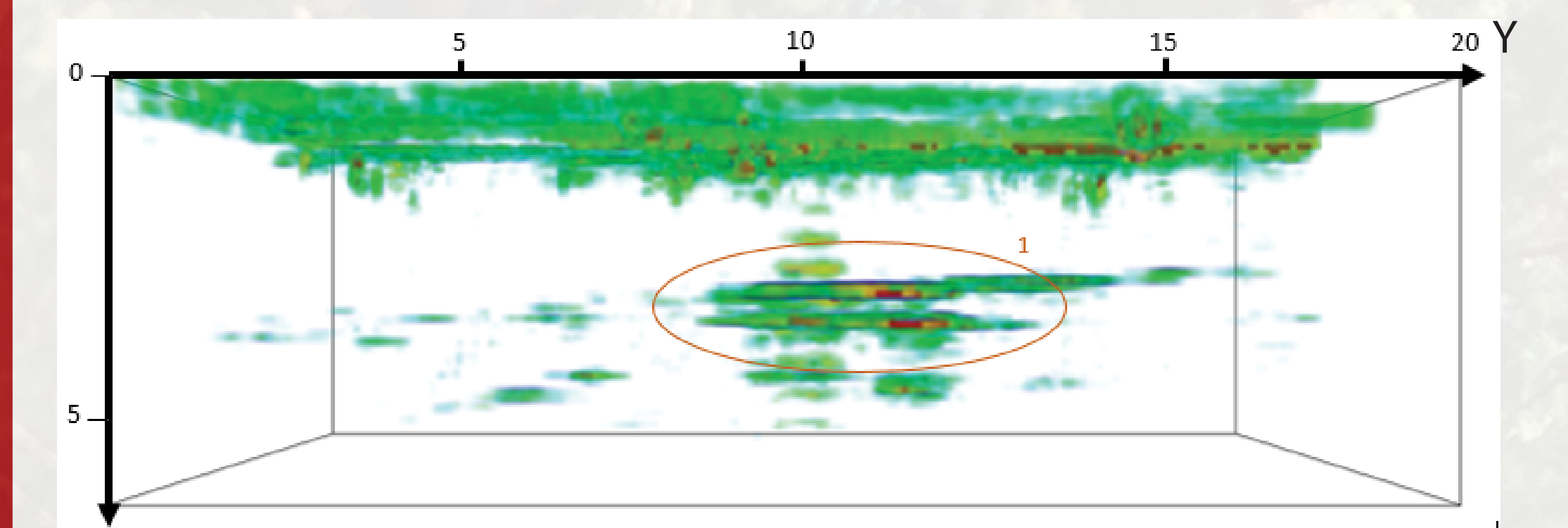


Figure 23: Right-sided 3D image of the grid showing the length (Y) and depth (Z). The results and interpretations of the depicted anomaly can be seen in Table 1.

Anomaly	Depth Z (m)	Description	Interpretation
1	3-4	Subsurface anomalies located at x=7, y= 12 and x=10, y=11 spaced 2m apart in a linear fashion; roughly 3x1 m each	Based on the location, ERT data, and dimensions the anomaly is interpreted as a portion of the escape tunnel
2	0-0.5	Surface anomaly 2x3m located at x=9, y=8	Location suggests the anomaly is near 2 trees which likely caused the high reflection
3	0-0.5	Surface anomaly 2x3m located at x=10, y= 2	No surface features present though this location was atop a hill with small brush and vegetation likely causing high reflection
4	0-0.5	Surface anomaly located at x=7, y= 16	Location suggests the anomaly is a large tree which likely caused the high reflection

CONCLUSION

GPR investigation at Ponar Forest located in Vilnius, Lithuania provided researchers with subsurface images roughly 6 meters in depth. The area, consisting of dry sands, was an ideal location for GPR investigation. The objective of the study was to work on an interdisciplinary team to find the remains of an escape tunnel hand dug by 80 prisoners in 1944. Prior to the results of the study, the tunnel had no scientific evidence to its existence but only the stories for the 11 survivors. The results from both the GPR and ERT investigation compliment each other showing subsurface anomalies roughly 3- 4 meters beneath the surface and located in the same area southwest of the grid. As the dimensions of these features are also the same (1x1m) it is inferred that these are segments of the collapsed escape tunnel.

Ponar Forest is the scene of a massacre, a brave escape, and today a memorial for the 100,000 individuals who lost their lives. The museum on the grounds is meant to inform the public of the tragedy and contains details of the escape. The results from the research is planning to be used to add to the memorial and museum at the location of the tunnel.

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