NGU REPORT 2024.026

Application of Ground-Penetrating Radar for Mapping of Quaternary deposits in the Alta Region, Finnmark County

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Geological Survey of Norway
P.O. Box 6315 Torgarden
NO-7491 Trondheim, Norway
Tel. +47 73 90 40 00

Report no.: 2024.026
ISSN: 0800-3416 (print)
ISSN: 2387-3515 (digital)
Grading: Open

Title: Application of Ground-Penetrating Radar for Mapping of Quaternary deposits in the Alta Region, Finnmark County
Authors: Georgios Tassis, Louise Hansen
Client: NGU
County: Finnmark
Municipality: Alta

Map-sheet name (M=1:250.000): Alta
Map-sheet name (M=1:50.000): 1834 II
Deposit name and grid-reference: 816050/7779100 (UTM zone 33 N)
Numbers of pages: 60
Price (NOK): 319,-

Map enclosures: None
Fieldwork carried out: 15–23.08.2020
Date of report: 21.11.2024
Project no.: 383500
Person responsible: Marco Brönner
Keywords: Georadar, GPR, Quaternary Geology, Sediments, Mapping

Summary:
The Ground Penetrating Radar (GPR) survey in the Alta area of Finnmark County, Norway, supported by NGU and NVE, aimed to update outdated Quaternary geological maps and better understand subsurface geology. Conducted in August 2020, the survey covered 14 locations, utilizing PulseEKKO Pro and Malå RTA systems to analyse depositional environments and sedimentary structures. The GPR methods revealed variations in reflectivity, attenuation, and layering. Northern areas, such as Altahøyden and Tverrelva valley, showed moderate to shallow penetration due to fine-grained, water-rich sediments, but still provided insights into subsurface transitions. Southern areas, composed of coarser, permeable sediments, allowed deeper penetration, revealing clearer stratigraphy and geological features, such as dipping layers and basin-like structures. A separate GPR profile at Kråkneset, site of a major June 2020 quick clay landslide, identified horizontal layers with a coarse-grained top overlying fine, attenuative sediments, aligning with observed geohazard conditions. Noise from nearby infrastructure posed challenges, particularly in areas like Energiveien and Altahøyden, but selective analysis still uncovered valuable geological details. Overall, the survey enhanced understanding of the region’s complex geology, surveying fluvial, deltaic, and marine processes, and providing updated data for geohazard assessment and landscape interpretation.

Table of Contents

PREFACE

This report presents the findings of a comprehensive ground-penetrating radar (GPR) survey conducted to enhance our understanding of the subsurface geology in the Alta region. The study was undertaken to refine existing Quaternary geological maps and provide critical insights into sedimentary structures, depositional environments, and potential geohazards.

The GPR methodology, employing advanced systems and tools, enabled the identification of variations in reflectivity, attenuation, and stratification across diverse terrains. From shallow, fine-grained sediments in the northern areas to deeper, coarser-grained deposits in the south, the survey highlighted the dynamic nature of subsurface geology. Notably, a profile recorded near the site of a recent quick clay landslide offered valuable information on the geohazard conditions in this region. Despite challenges such as ambient noise and interference from infrastructure, key geological features were discerned through careful analysis.

This report serves as a record of the methodologies applied, the data collected, and the interpretations derived, contributing to a deeper understanding of the Alta region’s complex geological framework.

1. INTRODUCTION

The Ground Penetrating Radar (GPR) surveys reported here were conducted as part of a larger project aimed at producing a 1:20,000 scale Quaternary geological maps along the Altaelva and Tverrelva rivers near Alta in Finnmark County.

Quaternary geological maps show the distribution of genetic deposit types in the Norwegian landscape alongside with information on landforms and detailed observations. The maps are produced by the Geological survey of Norway (NGU) that present them digitally to the public via www.ngu.no. Maps at an appropriate scale (more detailed than N50) provide a basis for landslide susceptibility and hazard assessments as well as serving other purposes in society that concern the landscape and deposits. The selection of the Alta area for mapping was done by NGU and the project was financially supported by NVE. At the time of the GPR survey, the available Quaternary geological map for Alta N50 was from 1979 (Follestad, 1976), lacking coverage of some important areas below the marine limit. In addition, the old map does not show any geohazard related information and was thus prone to an update. Mapping of Quaternary deposits is based on several types of data including high resolution digital elevation models from LiDAR, orthophotos and fieldwork. Additional GPR data provide valuable information on sedimentary structures that help the interpretation of the landscape and its long-term development.

GPR is suitable as a method in areas with low electrical conductivity, which enables deep signal penetration under suitable conditions. Penetration of the GPR signal is low in conductive material such as marine clay. This report presents data collected over 10 days in August 2020, using two GPR systems from NGU. Most data were collected from the area that was mapped near Alta. Alongside the planned survey, a GPR profile was also recorded in an area northwest of Alta town, shortly after a quick clay landslide (Hansen, Dagestad, Tassis, & Eilertsen, 2020). The landslide happened in June 2020 at Kråknes, involving approximately 900,000 cubic meters of material that disappeared into the fjord. Although no injuries were reported, the landslide destroyed eight buildings. The PulseEKKO Pro system was deployed on flat, open terrain (such as roads and clearings) with cart-mounted antennas, while the Malå RTA (Snake) system was used in uneven, forested areas. The survey utilized 100 MHz antennas, providing a suitable balance between resolution and depth penetration for the surveyed landforms. The purpose of this report is to document the GPR data that were collected in the Alta area including details on the applied methods.

2. METHOD DESCRIPTION

Ground Penetrating Radar (GPR), also referred to as Georadar, is an electromagnetic geophysical technique designed to investigate subsurface stratification. It works by transmitting electromagnetic waves into the ground, which then interact with the materials they encounter. These waves propagate through lossy dielectric materials, meaning materials that exhibit energy loss due to absorption and scattering, and they detect changes in material properties or structures (Davis & Annan, 1986).

The transmitted electromagnetic waves move through the subsurface as essentially nondispersive waves, maintaining their shape without significant spreading over distance. When the waves encounter changes in material impedance – such as differences in composition, density, or moisture – they are reflected or scattered. These reflections produce signals that resemble the initial transmitted wave (Butler, 2005). These reflected signals are received at the surface, where they are recorded and processed to reconstruct underground interfaces and structures.

This is accomplished by positioning a series of 1D electromagnetic "soundings" side by side to generate a continuous 2D image, commonly referred to as a radargram (Figure 2.1). The radargram visualizes the subsurface layers, structures, or objects by displaying reflected wave events, enabling geophysicists to interpret material changes and subsurface features.

In lossy dielectric materials, the penetration of electromagnetic waves is limited due to energy absorption, which results in penetration depth becoming a variable that depends on several factors. One of the key determinants is the frequency of the electromagnetic waves used in the GPR system. GPR operates within a frequency range of 1 to 1000 MHz, and the choice of frequency has a direct impact on both the depth of exploration and the resolution of the subsurface features being imaged.

At lower frequencies, the pulses can penetrate deeper into the ground, but the signals tend to disperse more, leading to lower resolution. Conversely, at higher frequencies, the resolution of the signal is improved, allowing for finer details in the resulting radargram. However, the drawback of using higher frequencies is that the signal absorption by the material becomes stronger, reducing the depth of penetration significantly.

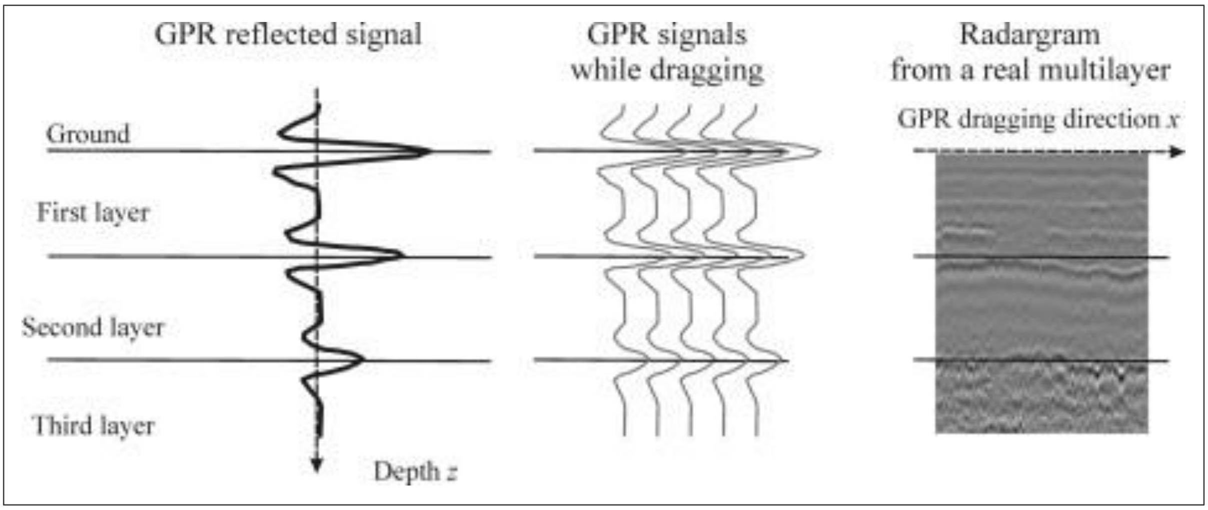


Figure 2.1: From a single GPR trace to a full radargram (Benedetto & Benedetto, 2014).

Therefore, when planning GPR studies, a balance between penetration depth and signal resolution must be achieved by selecting an appropriate frequency based on the goals of the survey. Lower frequencies are selected for deeper exploration, whereas higher frequencies are chosen when higher resolution is needed for imaging shallower subsurface structures. This compromise is essential to maximize the effectiveness of GPR in various geological or environmental conditions.

3. DATA ACQUISITION & PROCESSING

A total of 59 GPR profiles were recorded across 14 locations south of Alta, covering approximately 27.6 kilometres. Of these, 43 profiles, spanning nearly 21.8 kilometres, were collected using the PulseEKKO Pro system by Sensors & Software. The remaining 16 profiles, covering 5.8 kilometres, were acquired with the Malå RTA (Snake) system by Guideline GEO. As shown in Figure 3.1, the PulseEKKO Pro system operates in a perpendicular broadside configuration, where the transmitter and receiver antennas are mounted parallel to each other and pushed perpendicularly on a cart. From an electromagnetic field perspective, this setup provides enhanced signal quality but requires clear, unobstructed terrain due to its bulk.

In contrast, the Snake system (Figure 3.2) utilizes a parallel endfire configuration, with the transmitter and receiver antennas positioned in a row, 2.2 meters apart. This setup enhances manoeuvrability in forested or challenging terrain, though it slightly reduces signal quality compared to the conventional perpendicular broadside configuration. However, in field conditions where terrain limitations make the perpendicular setup impractical, the parallel endfire configuration provides a feasible alternative, as the minor signal quality reduction does not significantly impact geological interpretation (Tassis & Rønning, 2015).

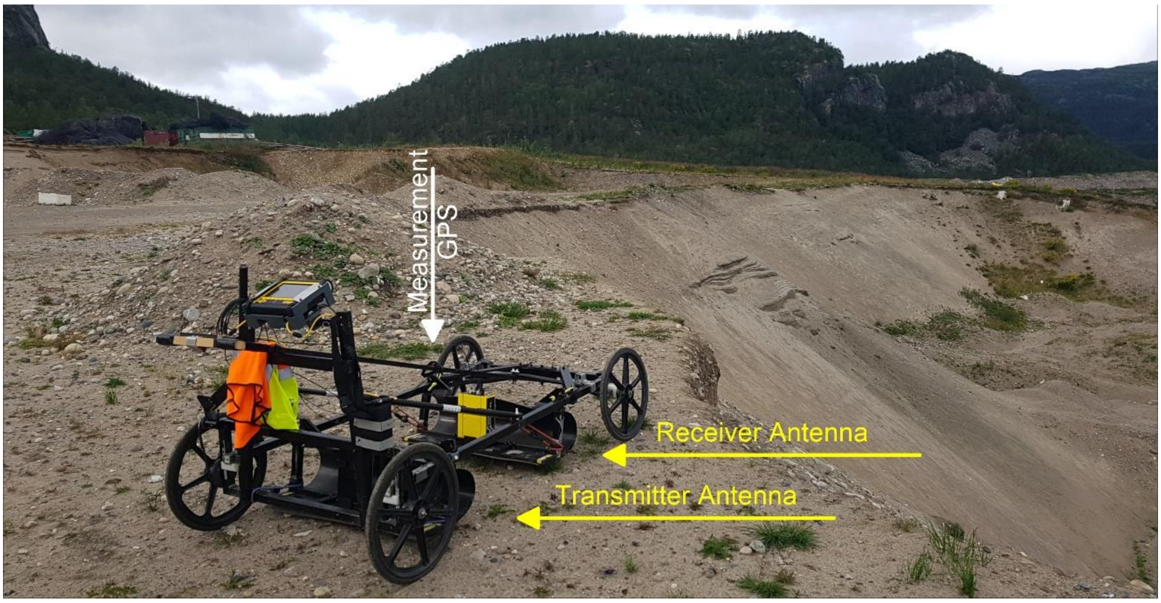


Figure 3.1: PulseEKKO Pro cart system deployed in the field in Alta with necessary clarifications. Central frequency employed: 100 MHz.

For the survey at Alta, a central frequency of 100 MHz was selected for both systems to balance resolution and depth penetration. Traces were recorded at 25-centimeter intervals to provide detailed imaging of subsurface features across the survey area. The maximum time window was adjusted based on the system: 1000 nanoseconds for the PulseEKKO Pro and 750 nanoseconds for the Snake system, resulting in estimated depth coverages of approximately 50 meters and 37.5 meters, respectively, assuming a standard wave velocity of 0.1 m/ns.

The two systems use different rotor-based methods to control data acquisition. In the PulseEKKO Pro system, a device attached to the back-left wheel registers rotations, triggering data capture once enough rotations equate to 25 centimetres of travel. The Snake system, on the other hand, employs a hip-chain device, which unrolls a cotton thread that activates a rotor, triggering measurements at consistent intervals regardless of the operator's walking speed. Positioning along survey lines for both systems was recorded using a Garmin GPSMAP 60Cx handheld GPS, with later corrections applied to align GPR trace positions for the Snake system (see Figure 3.2). For the PulseEKKO Pro system, positioning is recorded precisely, as the GPS is mounted directly over the measurement point (see Figure 3.1). The GPS data is then refined and synchronized with the GPR traces to ensure accurate spatial correlation between the GPR data and the survey area.

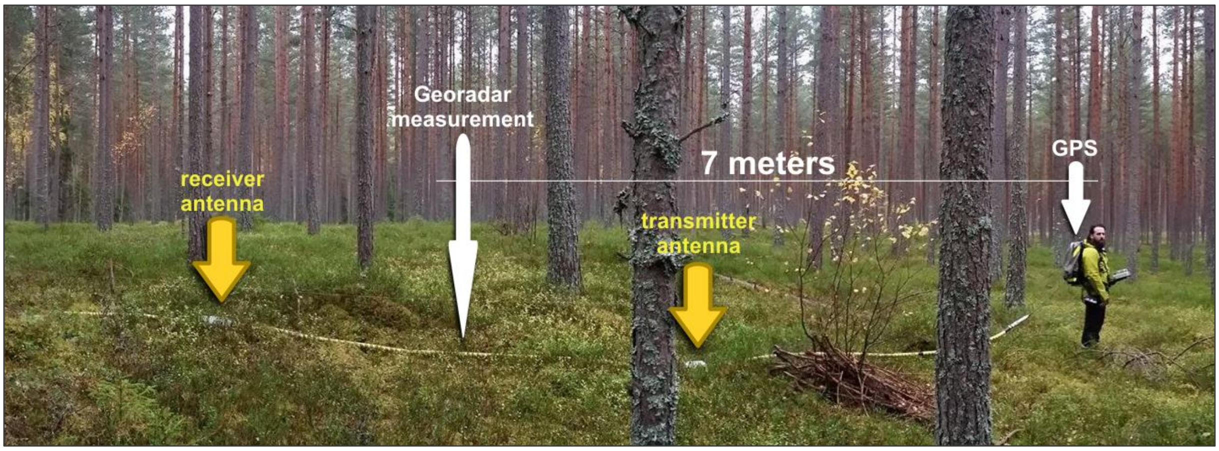


Figure 3.2: Malå Rough Terrain Antenna (RTA) or Snake system deployed in the field with necessary clarifications. Central frequency employed: 100 MHz.

Feil! Fant ikke referansekilden. illustrates the locations of GPR profiles within the broader Alta area, highlighting the deposit types surveyed, that are primarily of fluvial, glacifluvial, and marine deposits according to the existing Quaternary maps of the area (Follestad, 1976; Olsen, Reite, Riiber, & Sørensen, 1996). Fluvial and glacifluvial sediments are generally considered as favourable for GPR surveys, exhibiting low attenuation and higher velocities, depending on the composition, moisture content, and compactness of the deposits. Specifically, sand-dominated deposits, commonly found in Norway, tend to exhibit higher velocities due to their lower water content compared to fine-grained silts and clays, which can retain more moisture and thus reduce EM wave speed. In fluvial sediments dominated by sand and gravel, EM wave propagation velocities range from 0.09 to 0.15 m/ns. Conversely, glacifluvial sediments typically allow for relatively high GPR velocities due to their coarser, often well-sorted texture, which generally ranges from 0.10 to 0.16 m/ns (Jol & Bristow, 2003; Annan, 2005).

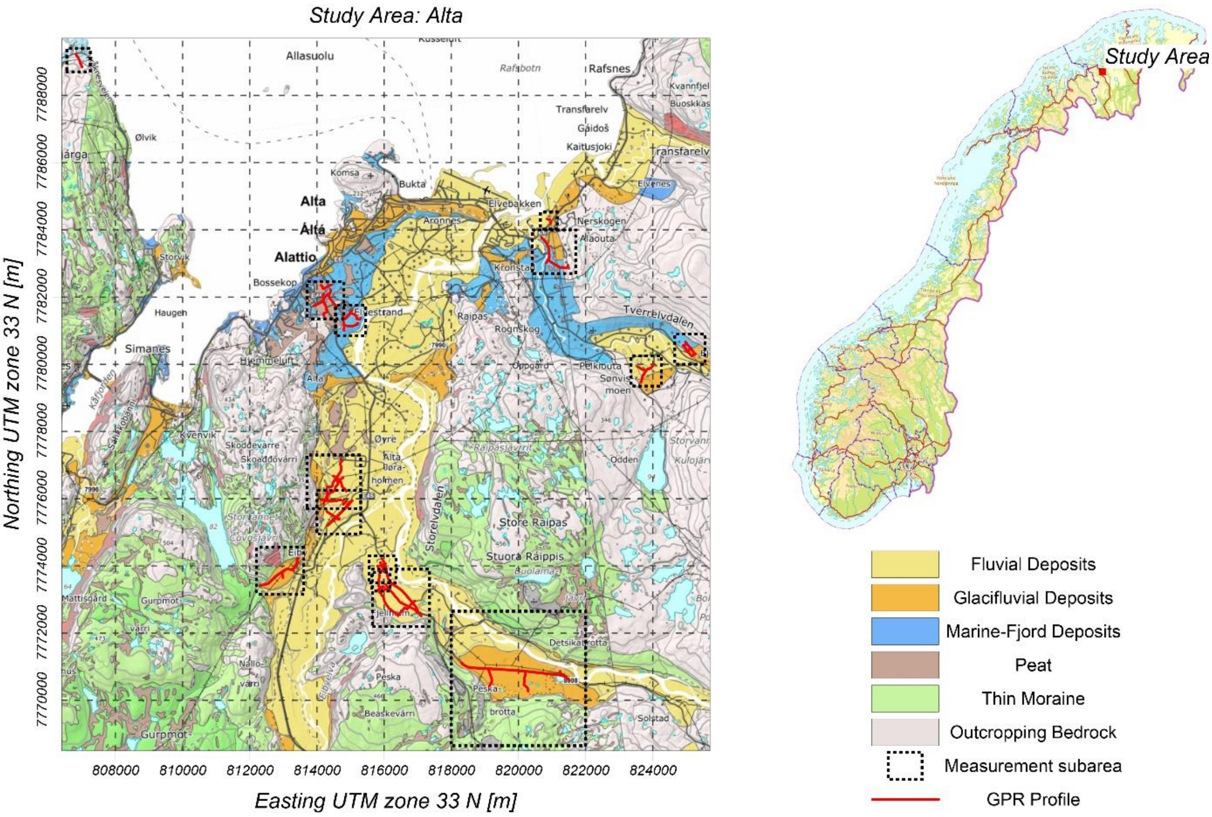


Figure 3.3: Location of the survey area and the GPR profiles measured in Alta and Kråkneset (upper left corner), placed on the old Quaternary geology maps of the region (Follestad, 1976; Olsen, Reite, Riiber, & Sørensen, 1996).

As shown in Figure 3.3, the majority of profiles measured in Alta are situated over deposits where favourable conditions for GPR surveys are expected according to old Quaternary maps of the area. It should be kept in mind, however, that the old maps are coarse and do not follow modern standards. Some profiles either cross into or entirely overlay marine sediments. Marine sediments, which encompass a range of materials from fine silts to coarse gravels, typically produce GPR velocities at the lower end of the spectrum and are generally not favourable for GPR surveys where a good penetration is expected (Cowan & Powell, 1991). When clay is dominant, signal absorption and scattering can lead to complete signal penetration failure. Nevertheless, such significant changes in signal can effectively delineate the boundaries between coarser and finer-grained sediments (Tassis, 2021).

In the Alta survey, Common Mid-Point (CMP) measurements were not necessary. The velocity in each profile was determined by fitting hyperbolas, due to the presence of a significant number of such features in our data. This approach enabled accurate depth conversion, which was subsequently transformed into true elevation.

The preparation of the GPR data involved refining positioning to correct for erroneous points, followed by elevation sampling from available Digital Terrain Models (DTM). In Alta, positioning was recorded using a handheld GPS with a 4-meter error margin. Considering this uncertainty, real-world X-Y coordinates (UTM zone 33 north) were assigned to each trace, complemented by elevation Z values sampled from the Mapping Authority's NDH Alta 5pkt (Terratec, Laserskanning For Nasjonal Detaljert Høydemodell: NDH Alta 5pkt, 2017) and 2pkt (Terratec, 2018) DTMs. While all data were processed and presented with realistic topographical features, it is important to note that they are not entirely accurate.

All collected data were processed using the software package EKKO_Project v.5 (Sensors & Software, 2018). Initially, data from the Snake system, which were in the rd3 file format, required conversion to the dt1 format to ensure compatibility with the EKKO_Project software package. This conversion was handled by ReflexW v.9.1 software (Sandmeier, 2023). Processing was tailored to each individual profile but remained relatively consistent across the different sites due to similar ground conditions. Table 1 **Feil! Fant ikke referansekilden.**provides a summarized description of the processing modules used in EKKO_Project v5, offering rounded-up information about each module applied. Overall, the data processing approach was uniform across the surveyed localities around Alta.

Table 1: Processing modules employed in EKKO_Project v5.

Processing module	***Value / Description***
Edit First Break	*19 -21 ns*
Bandpass Filter	*Fc1 0 % / Fp1 20 % / Fp2 100 % / Fc2 120 %*
Spatial Median Filter	*Filter Width: 4 pts / Mean: 1 pts*
Migration / Depth conversion	*FK migration: 0.085 – 0.122 m/ns*
Dewow	*Window Width (Pulse Widths): 1.33*
Background Subtraction	*Filter Width: 10 – 20 m (rectangular)*
SEC2 Gain (PulseEKKO Pro)	*Attenuation 0.4 – 1.3 dB/m, Start Gain 0.32 – 1.25, Maximum Gain 100 - 800*
SEC2 Gain (Malå RTA)	*Attenuation 0.58 – 1.9 dB/m, Start Gain 1.5 – 2.7, Maximum Gain 350 - 800*

4. RESULTS AND INTERPRETATIONS

This section presents and interprets all processed radargrams, organized by subareas within the broader Alta region, which includes 14 locations: Kråkneset, Tverrelvdalen South, Tverrelva East, Tverrelvdalen Sagafossen, Tverrelva Outlet, Sierra, Peskamoen, Stengselsmoen, Sandsvingen, Røstmoen, Skillemoveien, Energiveien, Thomasbakken, and Altahøyden. Results are presented in the following sequence and format:

a. Maps displaying positioning
b. Average Trace Amplitude (ATA) plots depicting penetration depth, and
c. Processed radargrams, with their Z-axis (elevation) exaggerated by a factor of two to enhance the visibility of recorded reflections and stratigraphic details.

An **Average Trace Amplitude (ATA) plot** represents the average signal amplitude (in microvolts) for selected GPR profiles, providing key insights into signal attenuation throughout a survey area. By illustrating how radar reflection strength diminishes over time, ATA plots identify the depth at which the radar signal becomes indistinguishable from background noise i.e., the level of the signal registered before the transmission of the first EM pulse at time zero. This attenuation depth can be estimated using a known or assumed electromagnetic wave velocity. Rapid attenuation, indicated by sharper attenuation curves, is associated with materials of high conductivity, such as wet or clay-rich soils, which absorb and scatter the radar signal. In contrast, longer attenuation times and milder curve slopes signify low-conductivity materials like dry sands, rocks, or resistive soils, allowing deeper signal penetration. By identifying the point at which reflections cease to provide reliable data, ATA plots are essential for understanding the depth range and limitations of GPR surveys.

4.1 Kråkneset (KR-1)

The Kråkneset area is located in the far northwest corner of the Alta study area (Figure 3.3) and is not directly related to the primary mapping objective of the rest of the survey. The single profile KR-01 was measured behind the backscarp of a quick clay landslide that happened in June 2020, the effects of which are visible in the orthophoto of the map in Figure 4.1.1. This image depicts the road disrupted by the landslide scar, with the phenomenon continuing northwest of the profile's endpoint. The application of the data for the landslide study is presented in NGU report 2020.029 (Hansen, Dagestad, Tassis, & Eilertsen, 2020).

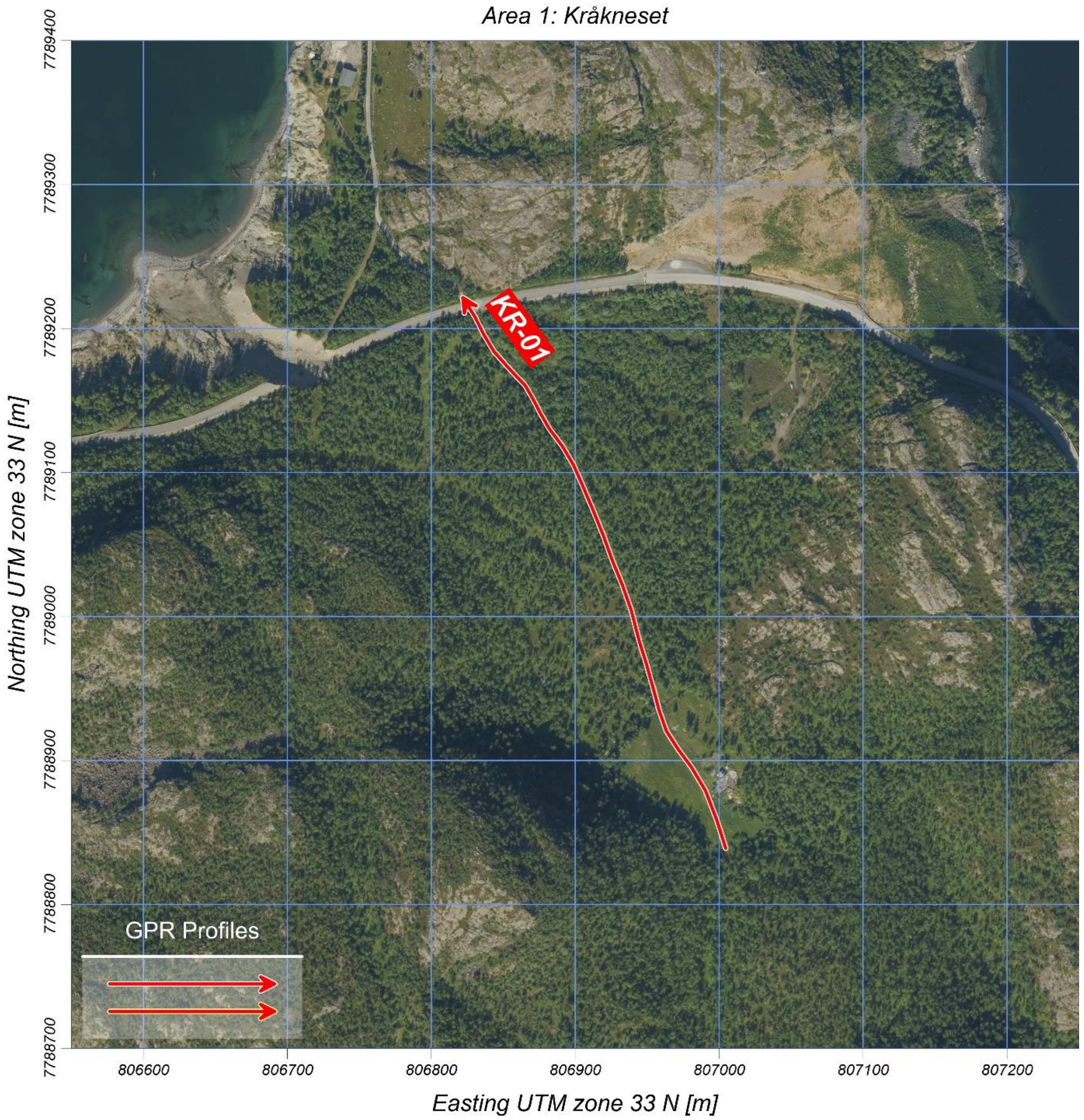


Figure 4.1.1: Positioning of Georadar profile KR-01 collected at Kråkneset. The scarp of the quick clay landslide, that happened along the shoreline in June 2020 and took part of the road, is visible in the upper left corner. Orthophoto: Vest Finnmark (Field-Group, 2023).

The Average Trace Amplitude (ATA) analysis for the Kråkneset GPR profile indicates that the signal is fully attenuated after approximately 350 nanoseconds, as shown in Figure 4.1.2. With the velocity for this profile calculated via hyperbola fitting to be 0.105 m/ns, this attenuation time corresponds to a maximum penetration depth of about 18.3 meters, suggesting that the subsurface conditions in this area are moderately favourable for signal propagation.

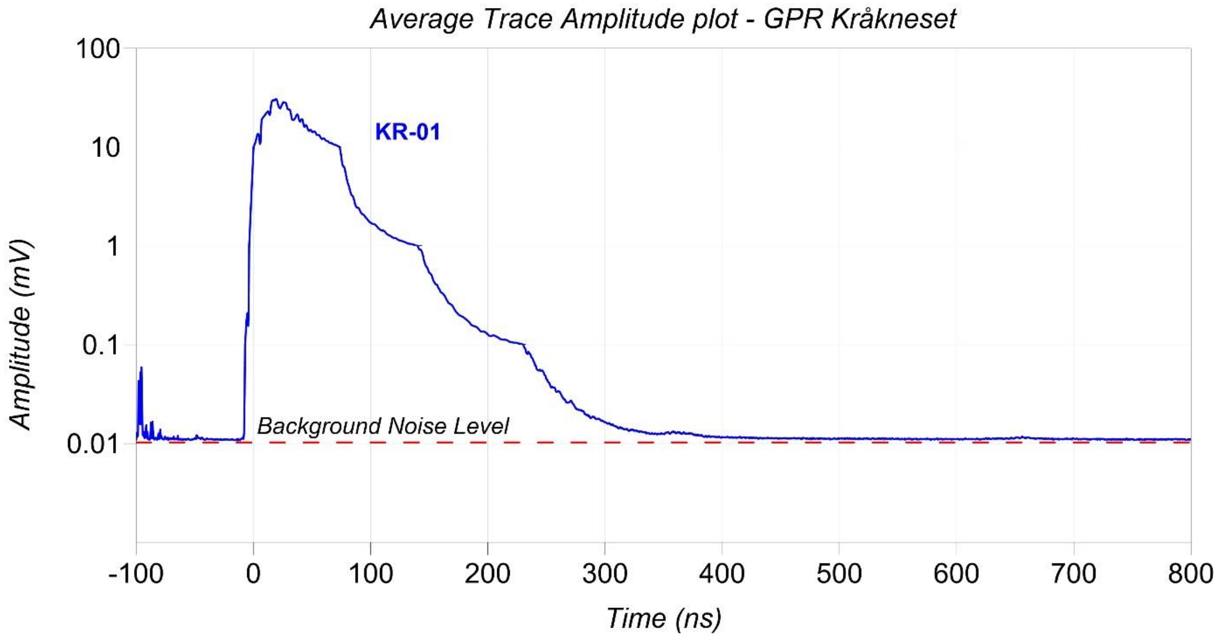


Figure 4.1.2: GPR signal Average Trace Amplitude (ATA) for Kråkneset subarea displaying the penetration depth achieved.

The processing results for **profile KR-01**, shown in Figure 4.1.3, reveal a distinct reflection that divides the profile into two zones: an upper part with several reflectors and a lower part where the signal is strongly attenuated. A sub-horizontal reflector appears at approximately 42 meters above sea level (m.a.s.l.) at the beginning of the profile, with a mild upward dip framing a series of inclined reflections within the topographic rise starting at around 120 meters. Although these reflections are somewhat indistinct, the profile shows indications of foresets and the deposits are considered as coarse-grained. Below the top layer – where the profile's strongest reflections are observed, extending no more than 8-10 meters thick – GPR waves are significantly attenuated, possibly suggesting the presence of more water-saturated, fine-grained materials.

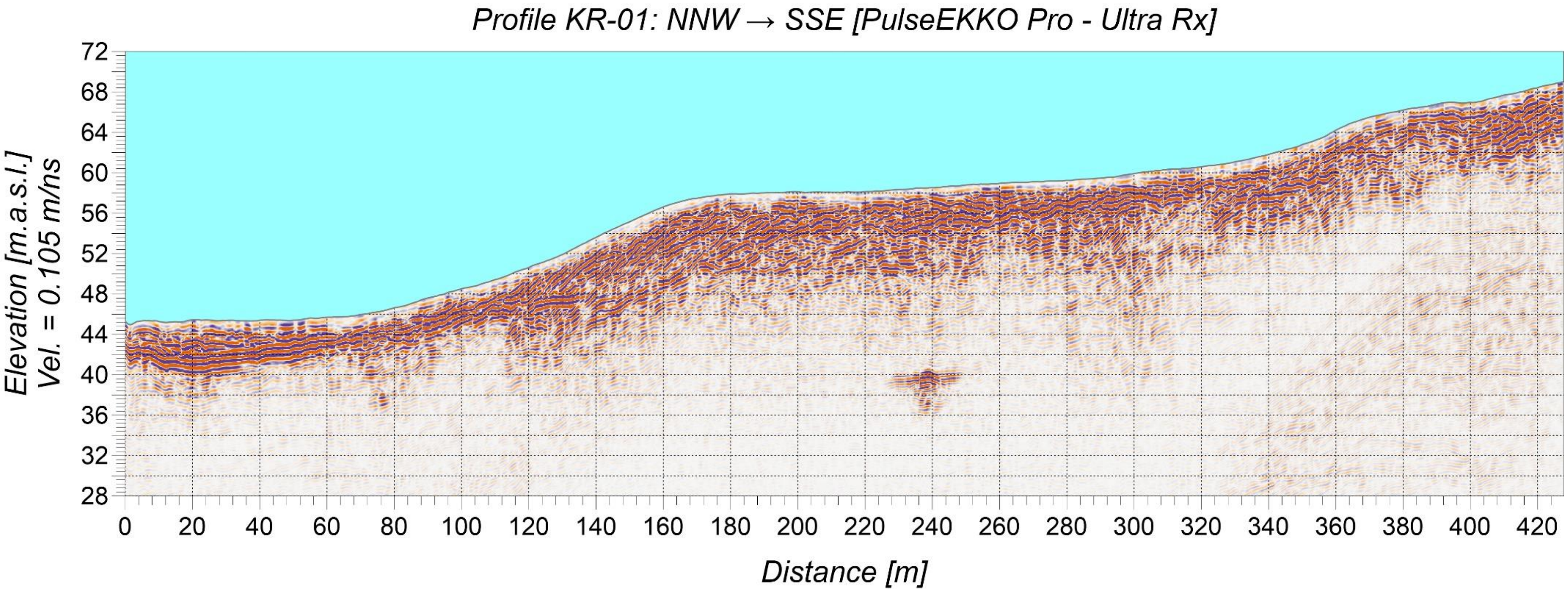


Figure 4.1.3: Processed radargram for profile KR-01 at Kråkneset.

4.2 Tverrelvdalen South (AL-1, AL-2)

The Tverrelvdalen South subarea, situated at the eastern end of the study region and south of the Tverrelva River, is a sparsely populated area characterized by farms, houses, and agricultural land use. Two profiles were measured here along two perpendicular roads using the PulseEKKO Pro system mounted on a cart, as shown in Figure 4.2.1. The combined length of these profiles is just under 1 kilometre. Although profiling in this area should generally be low in noise, the presence of several electrified fences introduced artifacts that extend in depth in both profiles. Each profile also crosses a bridge, which is evident in the topography along the profiles and is further marked in our data by the ringing effect caused by the gaps beneath the bridges at 185 and 68 metres, respectively.

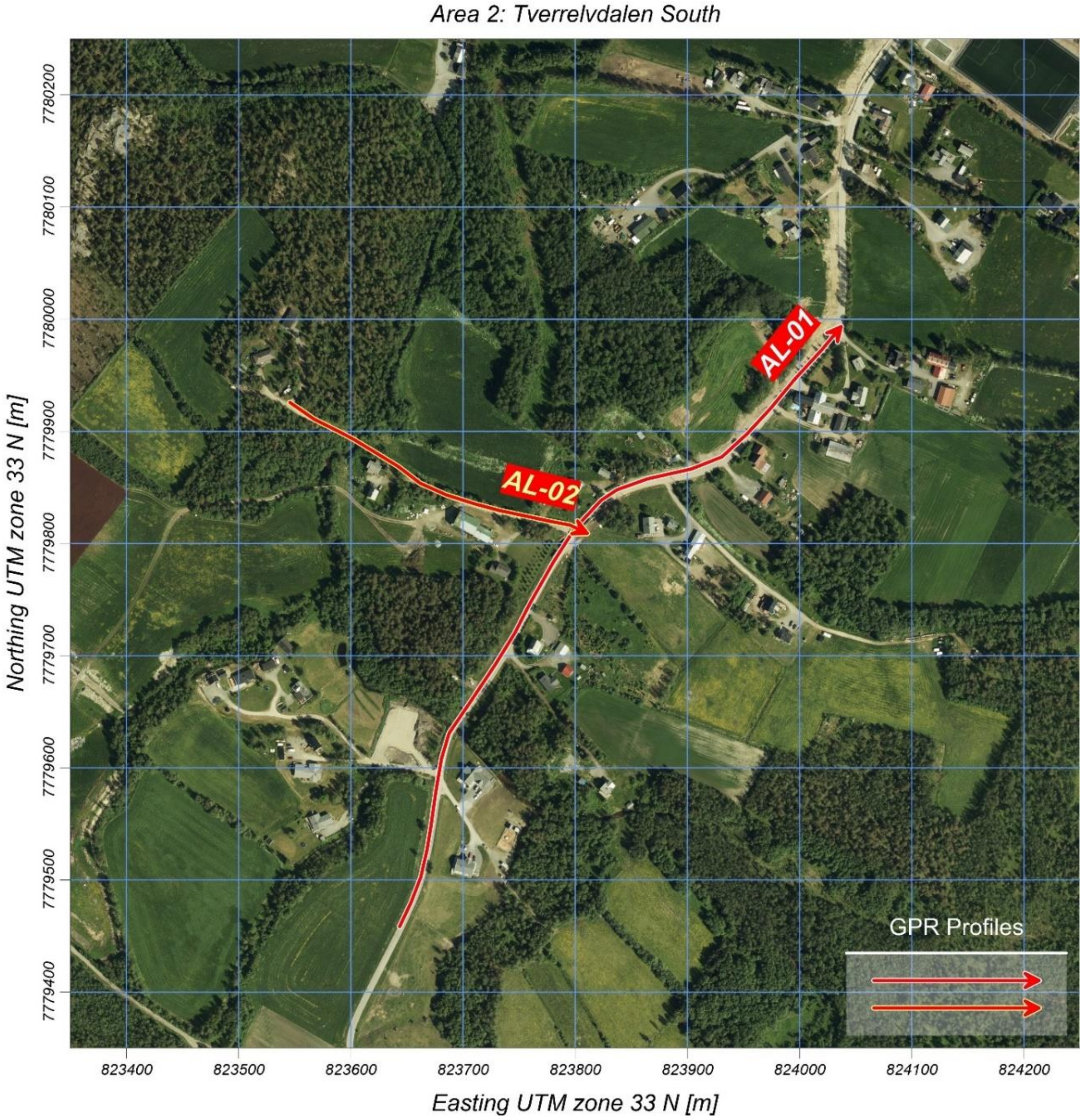


Figure 4.2.1: Positioning of Georadar profiles AL-01 and AL-02 collected at Tverrelvdalen South area. Orthophoto: Vest Finnmark (Field-Group, 2023).

As in Kråkneset, the hyperbola-based velocity estimation is 0.105 m/ns, with complete signal attenuation occurring at around 350 nanoseconds as seen in Figure 4.2.2. This would suggest that reflectors were registered down to nearly 19 meters at Tverrelvdalen South. However, this is an effect attributed to ambient noise caused by the electrified fences rather than a true penetration depth, which is in fact much smaller.

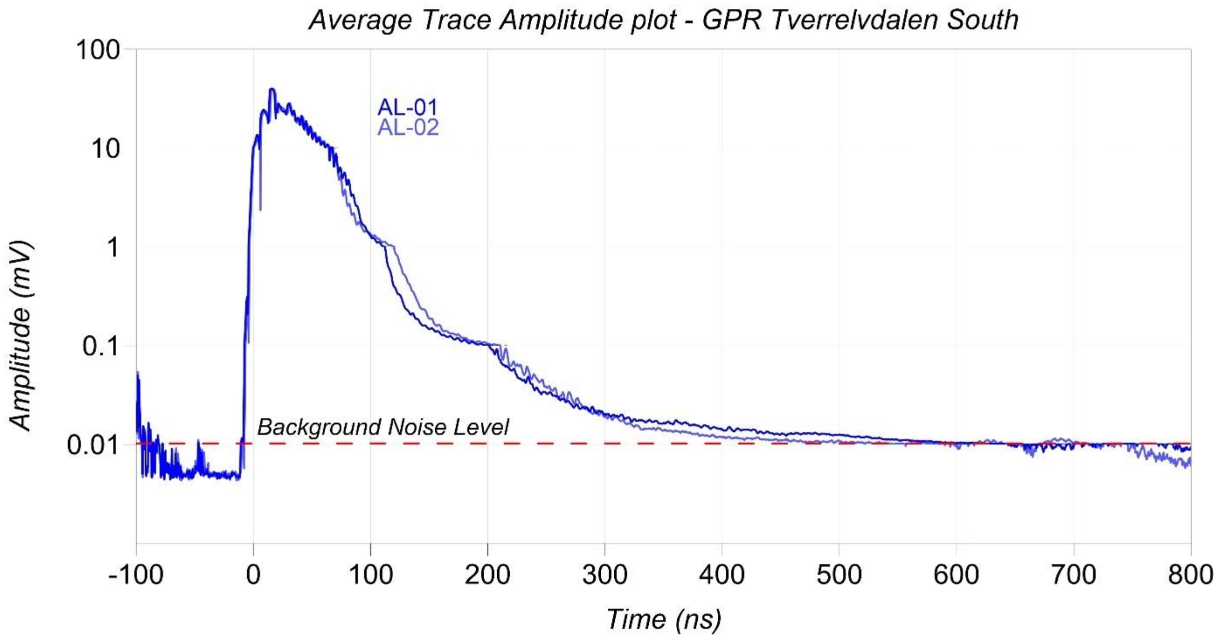
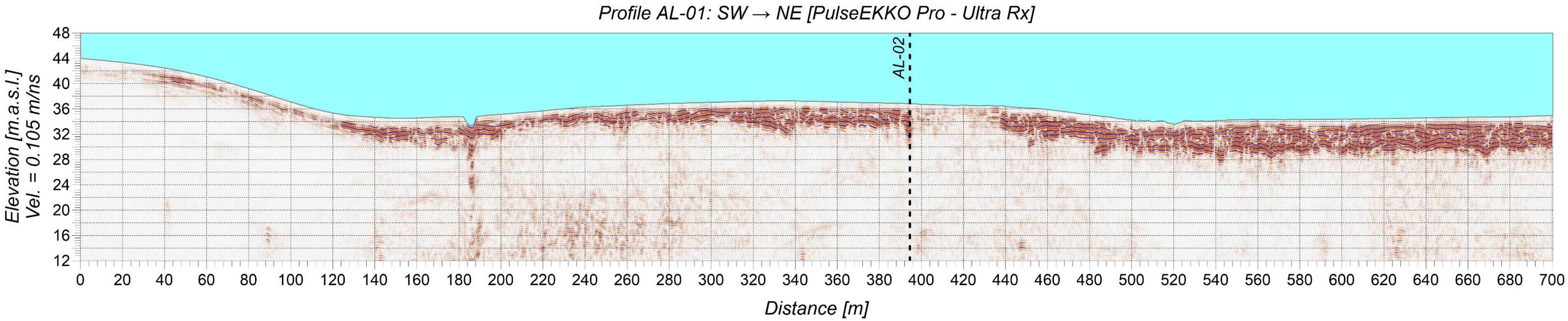


Figure 4.2.2: GPR signal Average Trace Amplitude (ATA) for Tverrelvdalen South subarea displaying the penetration depth achieved.

Figure 4.2.3 displays the processed results for **profiles AL-01** and **AL-02**, effectively illustrating the actual penetration depth achieved in this area. Both profiles are characterized by very shallow reflections, which appear almost negligible at the southern end of profile AL-01 and the western end of profile AL-02. Moving northward and eastward along both profiles, the penetration depth increases to nearly 6 meters, with reflections indicating sub-horizontal layering which is indicative of coarse-grained sediments such as sand. However, no further penetration is observed beyond this depth. This could be either due more fine-grained materials such as clay, or possibly unfractured bedrock that does not contain any stratification mappable by GPR.



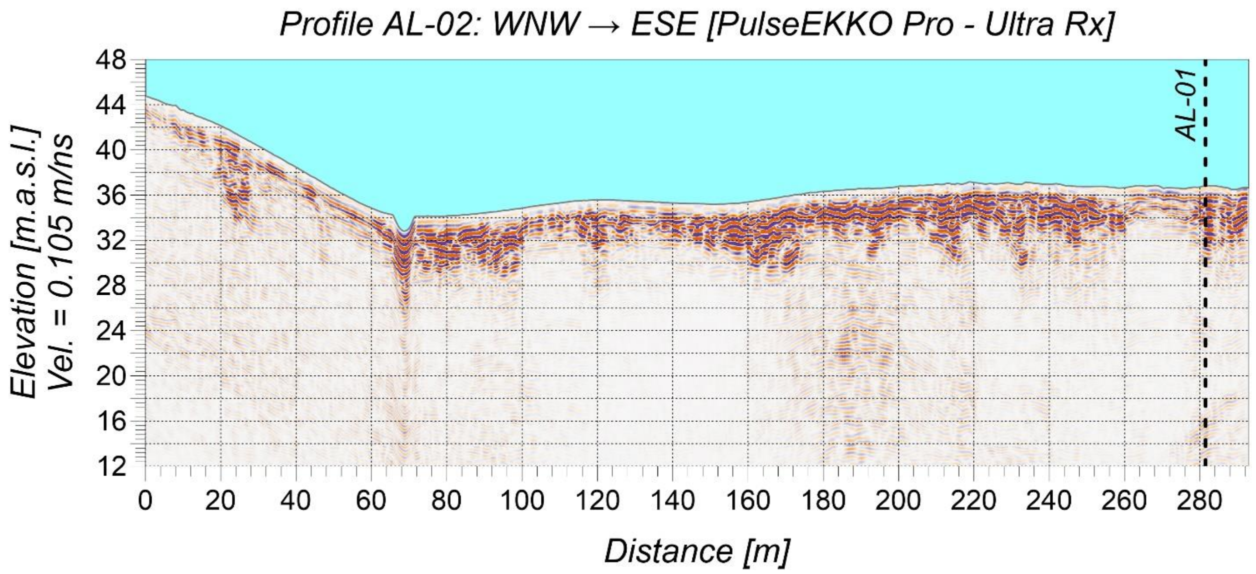


Figure 4.2.3: Processed radargrams for profiles AL-01 and AL-02.

4.3 Tverrelva East (AL-3)

The third surveyed area, Tverrelva East, is located approximately 1 kilometre northeast of the previous area, on the northern bank of the river. As shown in Figure 4.3.1, all profiles were measured over agricultural land. Profile AL-03 was recorded along a small auxiliary road through the fields using the PulseEKKO Pro cart, while all other profiles were measured directly over the fields with the Malå RTA (Snake) system. The total profiling length collected here was 1.27 kilometres, with 1.1 kilometres recorded using the Snake system.

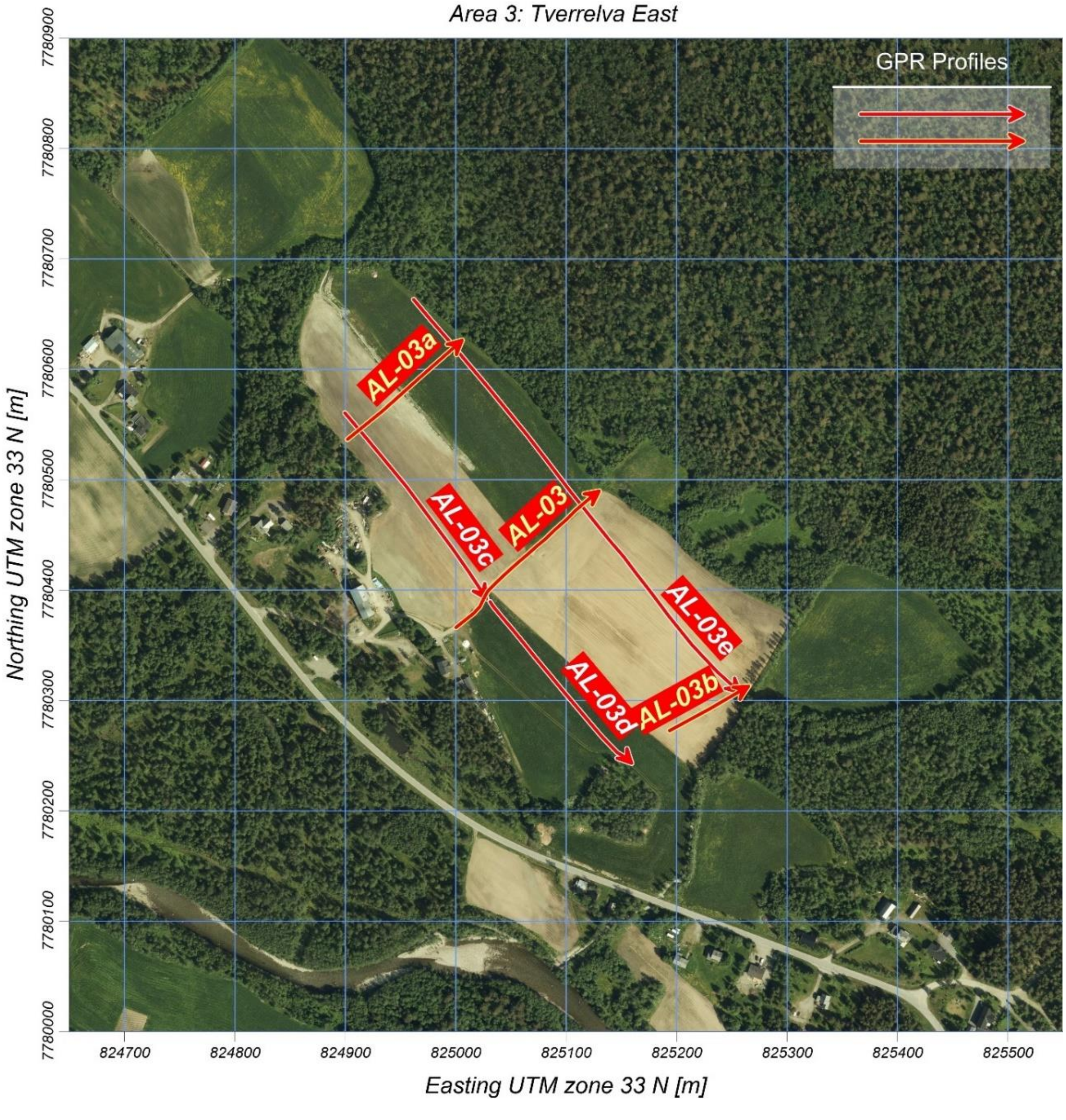


Figure 4.3.1: Positioning of Georadar profiles AL-03 and AL-03a to e collected at Tverrelva East area. Orthophoto: Vest Finnmark (Field-Group, 2023).

Figure 4.3.2 presents the ATA plots for each system separately, reflecting the inherent differences in signal quality. Profile AL-03, measured using the perpendicular broadside antenna configuration, showed slower signal attenuation, reaching noise level at 250 nanoseconds. In contrast, the parallel endfire data attenuated to noise level after 150 nanoseconds. Given a calculated velocity of 0.095 m/ns, the maximum depths reached are approximately 12 meters for the cart system and 7 meters for the Snake system, indicating possible clay presence in this region.

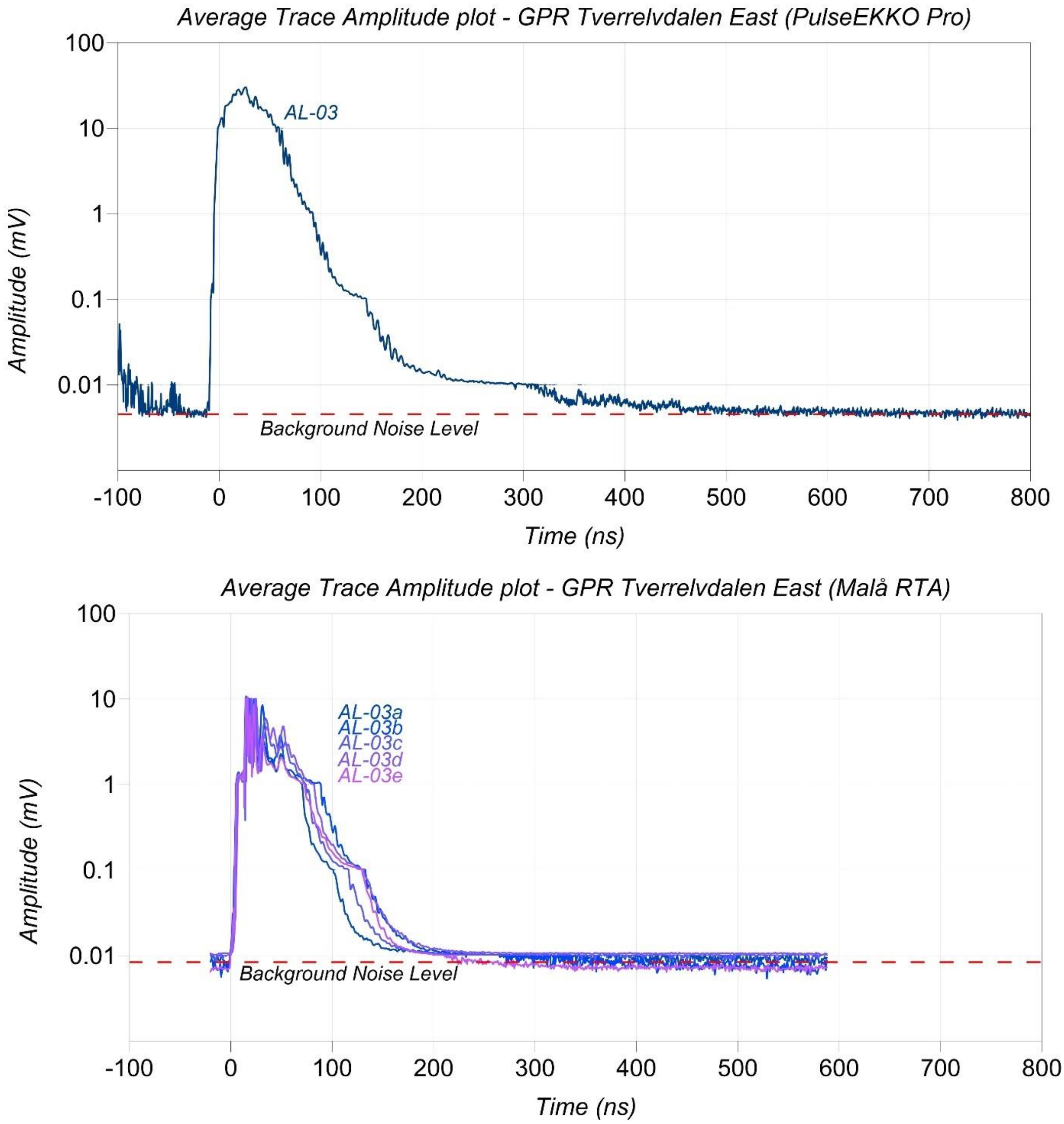


Figure 4.3.2: GPR signal Average Trace Amplitude (ATA) for Tverrelvdalen East subarea displaying the penetration depth achieved for PulseEKKO Pro (top) and Malå RTA (bottom) systems.

As anticipated, the processed radargrams for all profiles measured at Tverrelvdalen East, shown in Figure 4.3.3, display only shallow reflectors, with most profiles registering reflections no deeper than 4 meters from the surface. The primary notable feature in this region appears in **profiles AL-03c** and **AL-03e**, where a prominent horizontal reflection at 39 meters above sea level (m.a.s.l.) remains level despite a slight upward slope in the terrain. In particular, at the southeastern end of profile AL-03e, this reflection is overlain by a series of intertwining reflections spanning an almost 7-meter-thick region, which aligns with the maximum penetration depth expected for the Snake system. Regardless of this locality, the Tverrelvdalen East region appears to be predominantly composed of superficially coarse-grained sediments, underlain by clay-bearing layers.

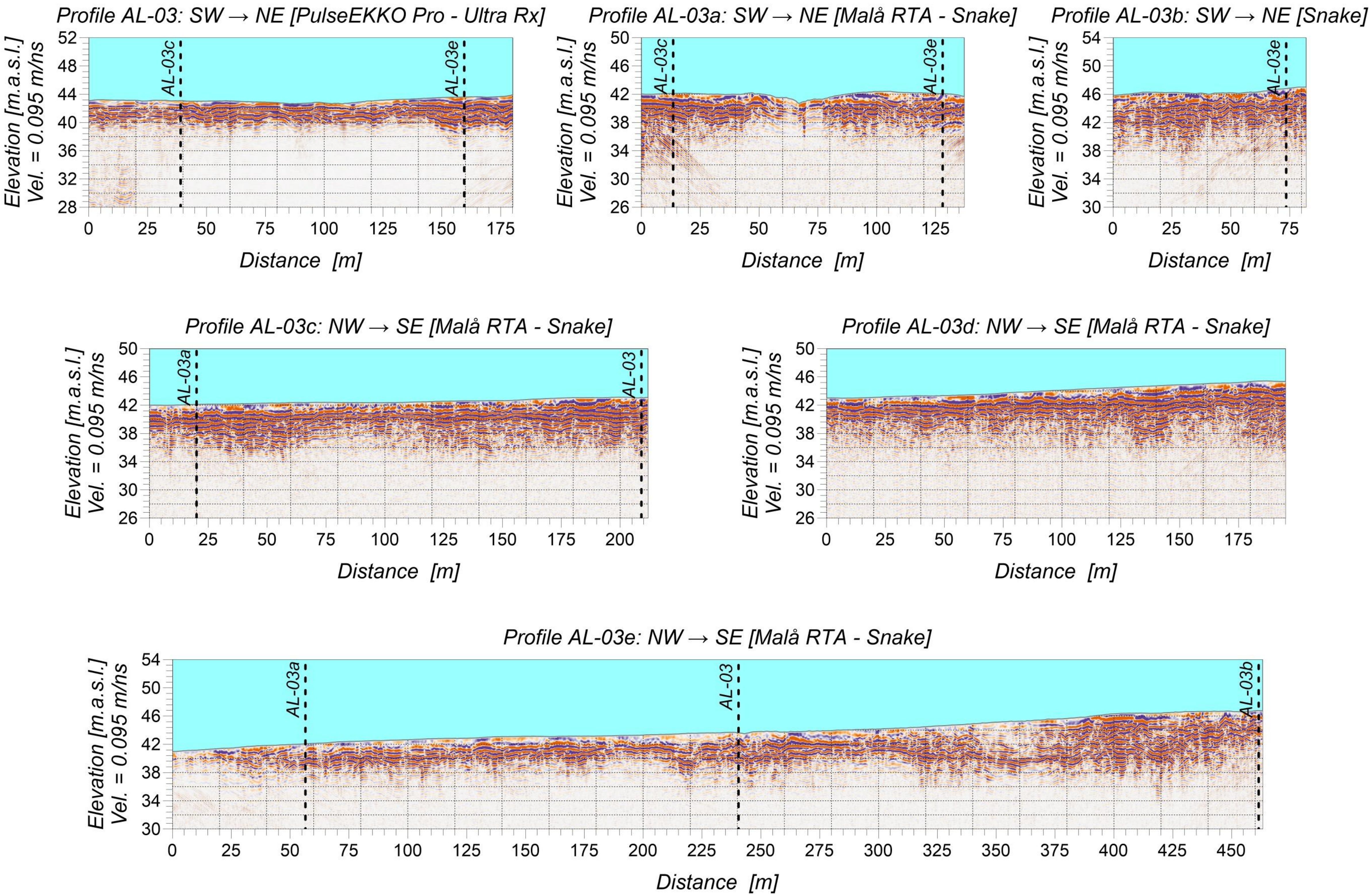


Figure 4.3.3: Processed radargrams for profiles AL-03 (PulseEKKO Pro) and AL-03a to e (Malå RTA).

4.4 Tverrelvdalen Sagafossen (AL-05)

The Tverrelvdalen Sagafossen area is located 4.5 kilometres northwest of Tverrelvdalen East. Two profiles, AL-05 and AL-05a, were measured here using the PulseEKKO Pro system, covering a total length of just over 1.6 kilometres along two roads near a relatively more densely populated area, though mostly situated outside it. The positioning of these profiles is shown in Figure 4.4.1, which highlights areas with potential ambient noise from nearby housing or other artificial structures.

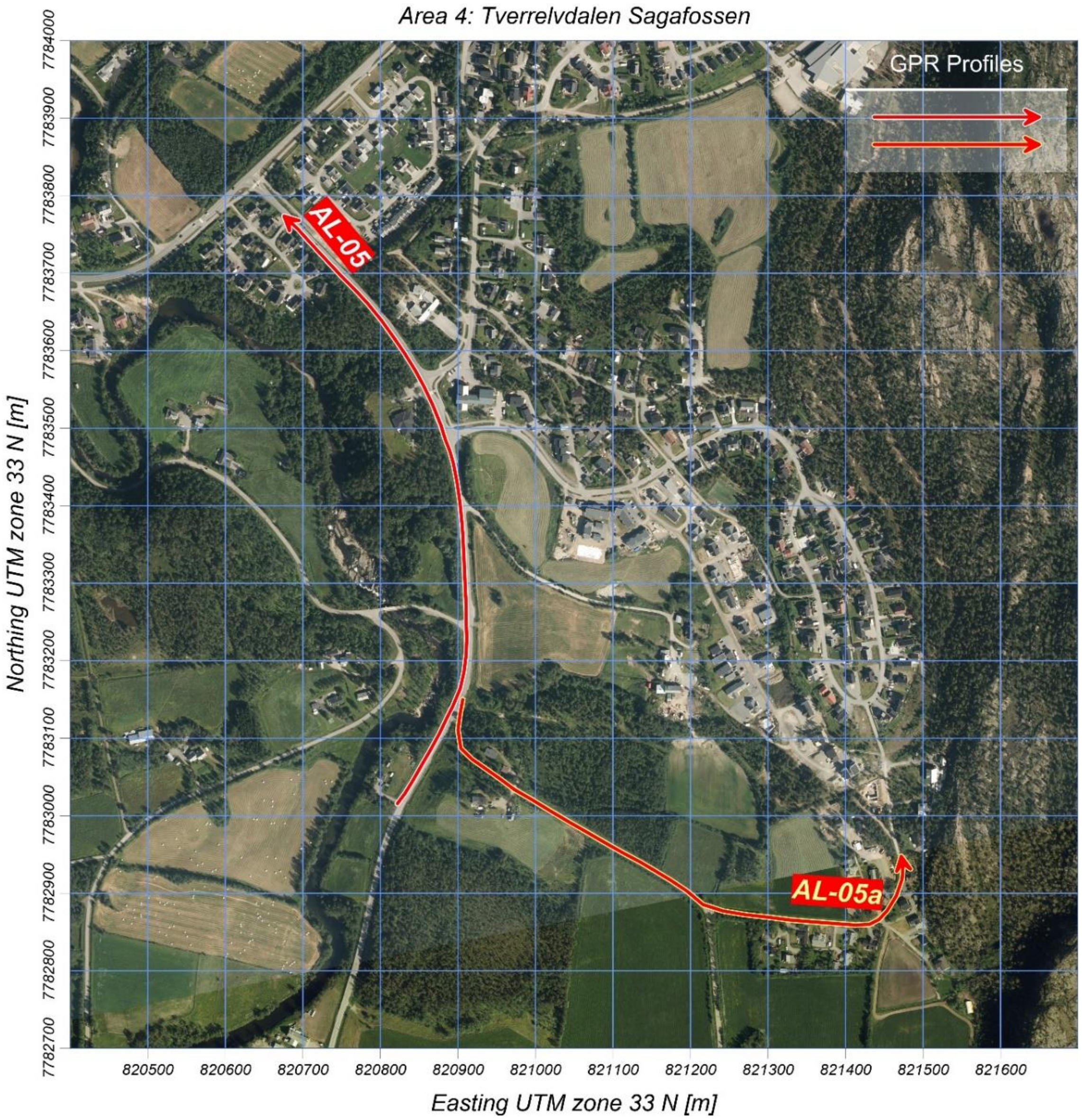


Figure 4.4.1: Positioning of Georadar profiles AL-05 and AL-05a collected at Tverrelvdalen Sagafossen area. Orthophoto: Vest Finnmark (Field-Group, 2023).

Figure 4.4.2 presents the ATA plot for both profiles measured in this area, revealing a consistent signal attenuation that reaches noise level after 400 nanoseconds. This indicates that, with a velocity of 0.105 m/ns calculated via hyperbola fitting, reflections were collected at a maximum depth of 21 meters for both profiles.

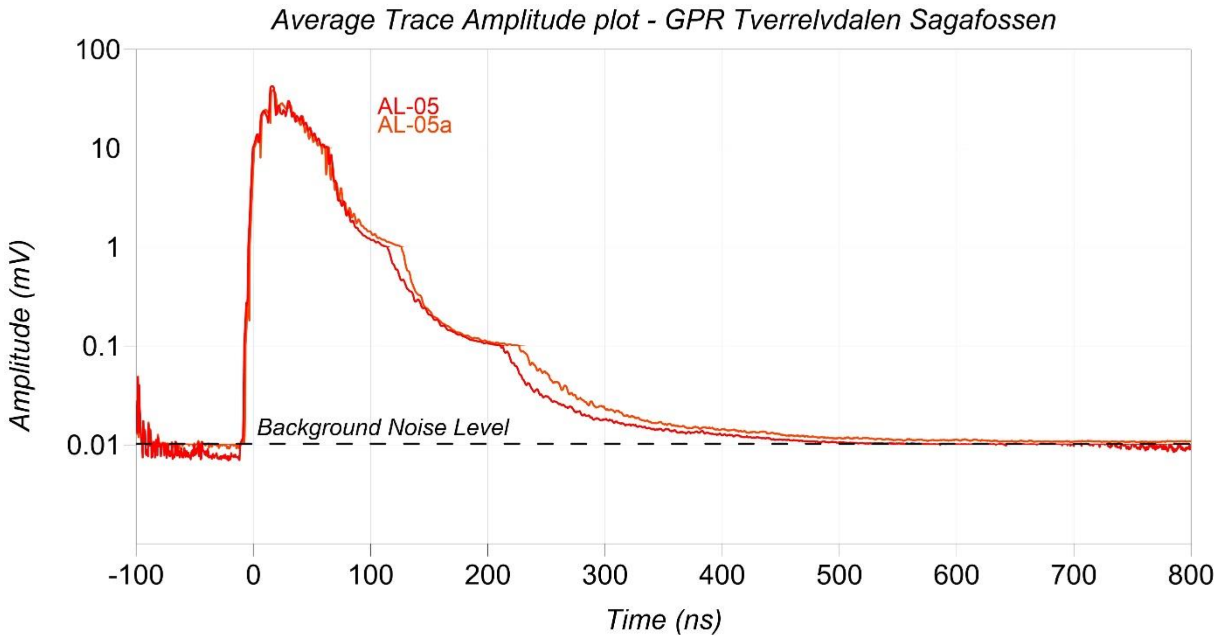


Figure 4.4.2: GPR signal Average Trace Amplitude (ATA) for Tverrelvdalen Sagafossen subarea displaying the penetration depth achieved.

The processed radargrams for **profiles AL-05** and **AL-05a**, shown in Figure 4.4.3, indicate that the observations made in the ATA plot are not representative of the entire profile lengths. Instead, they reflect local maxima in penetration resulting from more favourable permittivity conditions. Notably, these areas occur between 260 and 280 meters and 530 and 570 meters for profile AL-05, as well as from 690 meters to the end of profile AL-05a. These regions likely consist of more coarse-grained materials that facilitate deeper GPR signal penetration before becoming fully attenuated. This contrast is prominently displayed in our results, highlighting the differences between these areas and their neighbouring zones with minimal penetration possibly reflecting the presence of clay.

Another intriguing feature revealed by the GPR profiles in the Tverrelvdalen Sagafossen area is a prominent reflection that generally follows the topography along the profiles, albeit with some deviations. The two locations where this reflection diverges from the surface reveal interesting structures. The first instance occurs at the end of profile AL-05 at 730 metres, where the reflection dips more steeply than the overlying topography, undulating briefly before flattening out until the end of the profile. In contrast, profile AL-05a shows this reflector remaining flat between 280 and 460 meters, disregarding a mild rise in the topography. It then sharply inclines uphill to meet the slope and remains superficially correlated to it farther along the line. This creates a small basin, filled with materials that lack clear layering, but are favourable for the propagation of electromagnetic waves such as unlayered sand.

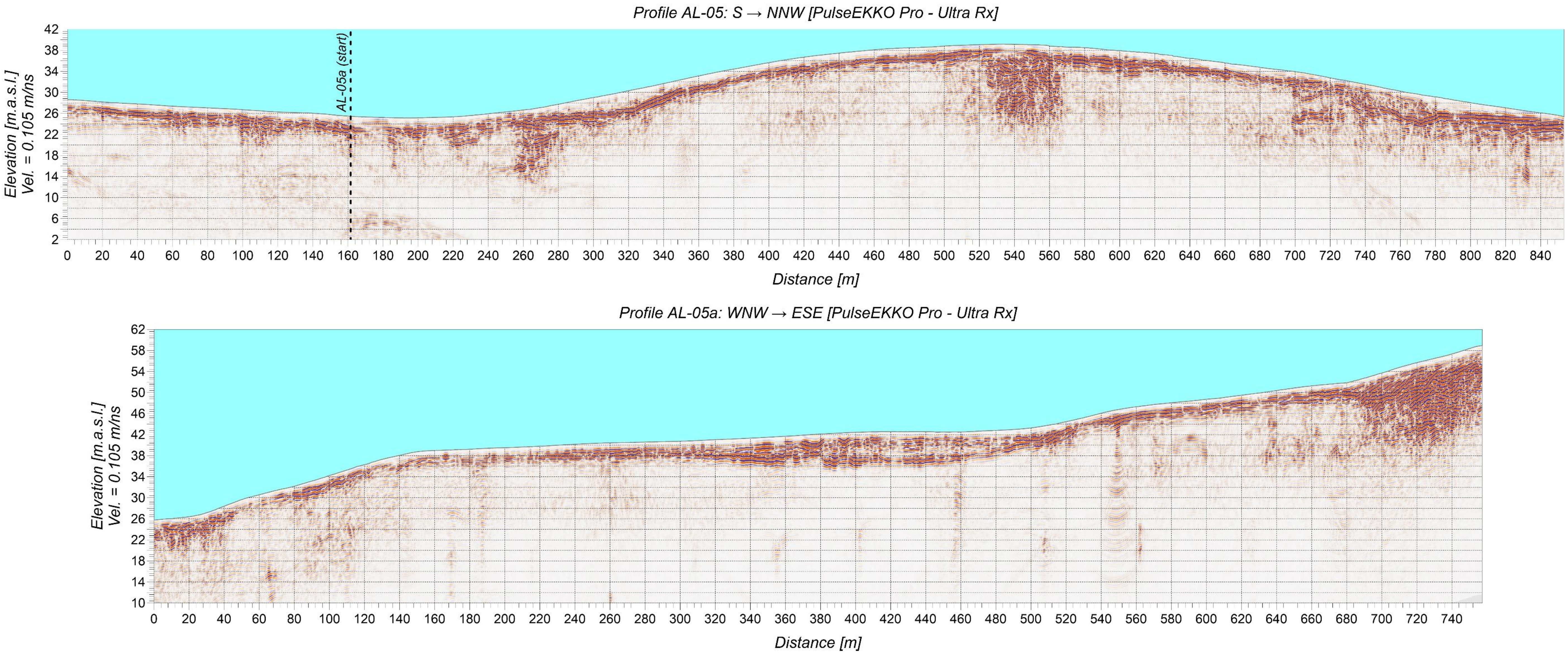


Figure 4.4.3: Processed radargrams for profiles AL-05 and AL-05a.

4.5 Tverrelva Outlet (AL-06)

The Tverrelva Outlet area is located just north of Sagafossen, close to where the Tverrelva river meets the ocean, as the name suggests. As shown in Figure 4.5.1, a single GPR profile was measured in this area along a gravel road using the PulseEKKO Pro system mounted on a cart.

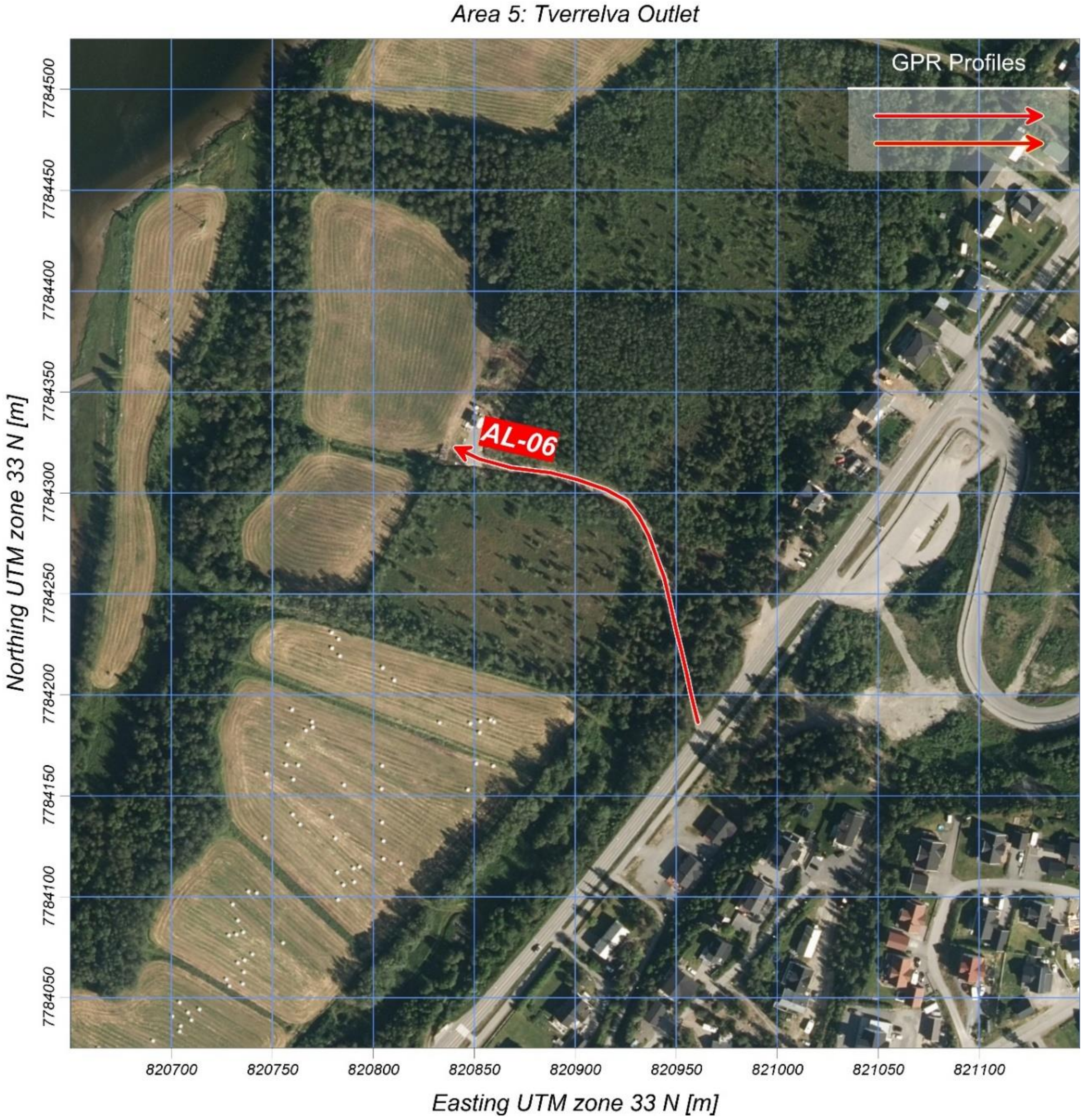


Figure 4.5.1: Positioning of Georadar profile AL-06 collected at Tverrelva Outlet area. Orthophoto: Vest Finnmark (Field-Group, 2023).

The ATA plot for profile AL-06, shown in Figure 4.5.2, indicates that the electromagnetic (EM) wave is completely attenuated after approximately 400 nanoseconds. The calculated velocity in this area is 0.095 m/ns, which implies that no reflections can be registered below a depth of 19 meters.

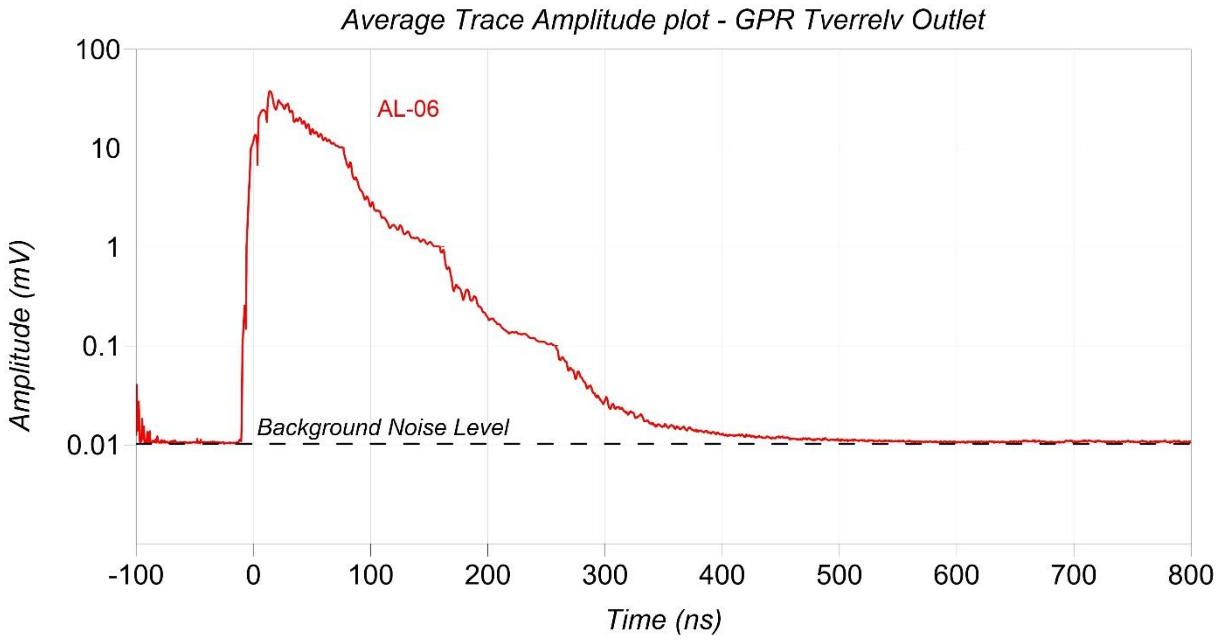


Figure 4.5.2: GPR signal Average Trace Amplitude (ATA) for Tverrelva Outlet subarea displaying the penetration depth achieved.

Figure 4.5.3, displaying the processed radargram for **profile AL-06**, reveals another instance of inhomogeneous depth penetration along this profile. Overall, penetration depth varies from shallow at the beginning of the profile to almost negligible near its end, except for a localized concentration of possibly coarse-grained sediments at the base of a relatively sharp elevation drop between the 60- and 100-meter mark. This concentration largely influences the appearance of the ATA plot but does not generally indicate a favourable permittivity environment across the area surveyed by profile AL-06, aside from this specific section.

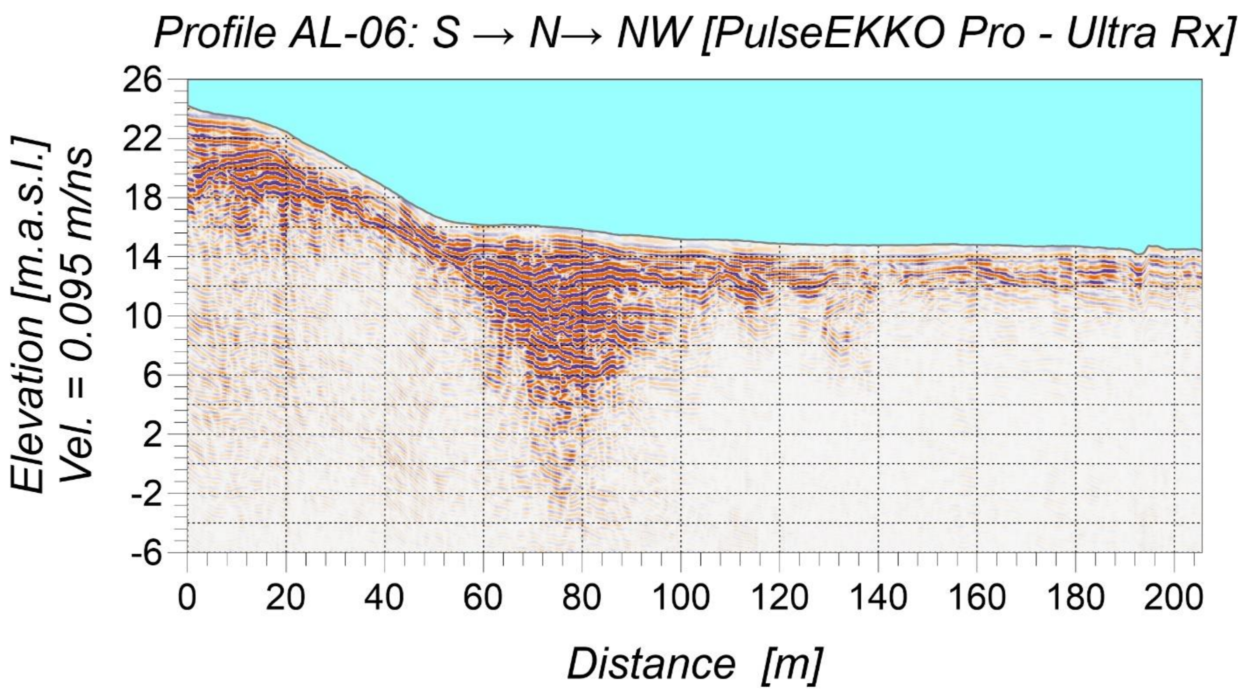


Figure 4.5.3: Processed radargram for profile AL-06.

4.6 Sierra (AL-07, AL-08, AL-09, AL-10)

The next area presented in this report is Sierra, located at the far southern end of the Alta survey area. It is the largest subarea and includes a primary 3.3-kilometer profile, designated AL-07, which extends along an asphalt road. Additional profiles, AL-08 through AL-10, were measured perpendicular to AL-07 along gravel roads at varying lengths. The total profile coverage in this area amounts to approximately 4.58 kilometres, all collected using the PulseEKKO Pro system. This system was chosen because the cart setup is easily manoeuvrable over roads, enabling superior data quality compared to the Snake system. The positioning of all profiles measured in the Sierra area is displayed on the map in Figure 4.6.1.

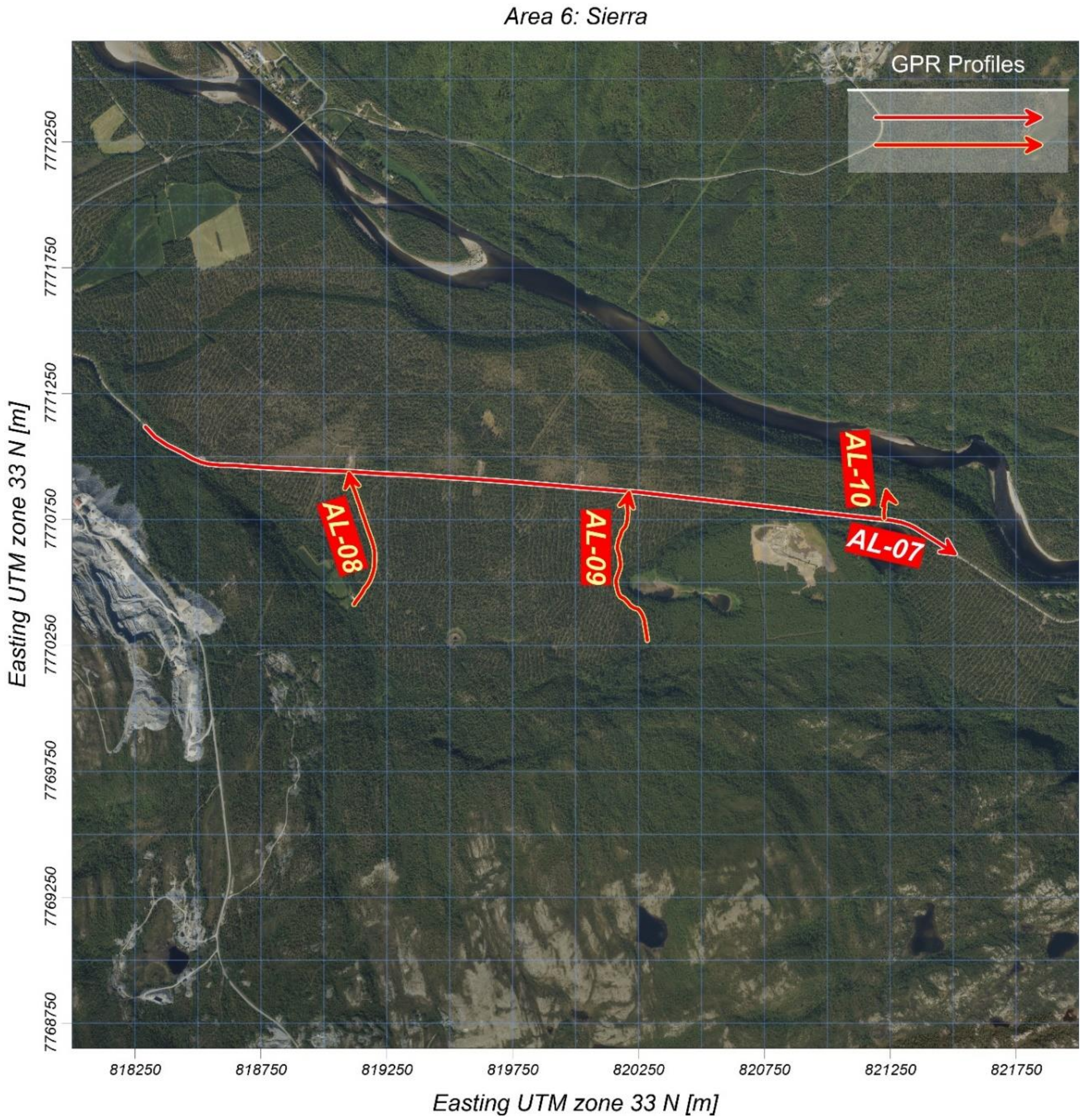


Figure 4.6.1: Positioning of Georadar profiles AL-07, AL-08, AL-09 and AL-10 collected at Sierra area. Orthophoto: Vest Finnmark (Field-Group, 2023).

Figure 4.6.2 displays the ATA plot for all profiles collected in the Sierra area, revealing a range of attenuation rates across the datasets. Despite this variability, all profiles show signal attenuation converging to background noise levels after around 550 nanoseconds. With a calculated velocity of 0.12 m/ns, this corresponds to a significant penetration depth of approximately 33 meters in this area. Such depth suggests locally favourable permittivity conditions, likely due to the presence of coarse-grained sediments with minimal water content, which supports effective GPR signal propagation.

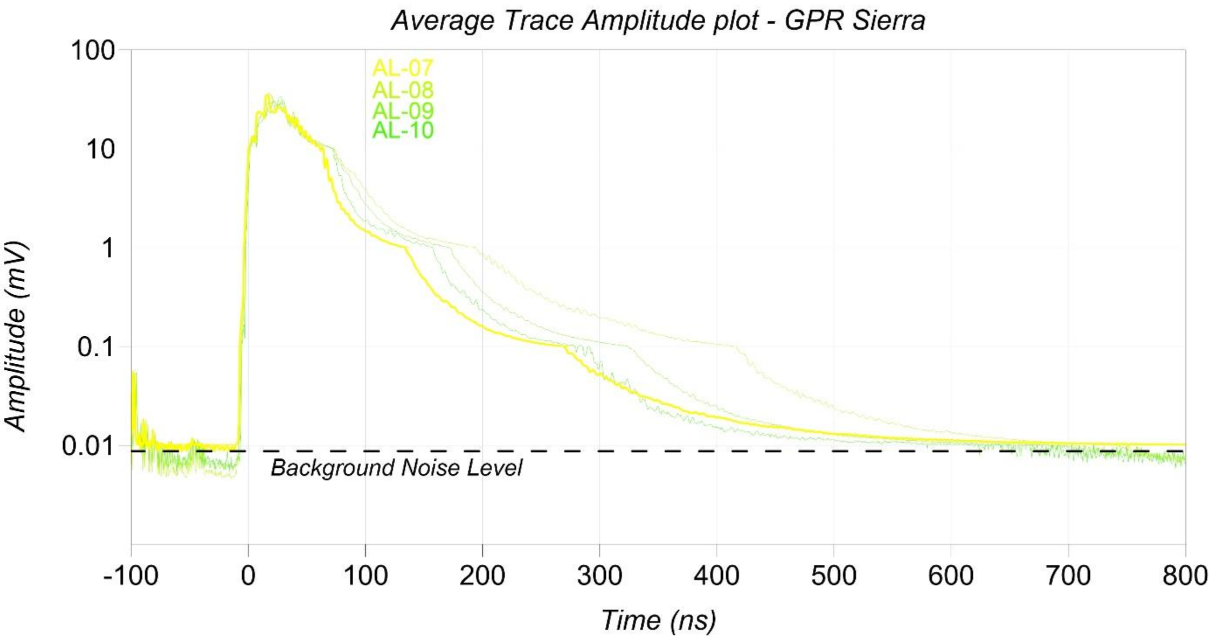


Figure 4.6.2: GPR signal Average Trace Amplitude (ATA) for Sierra subarea displaying the penetration depth achieved.

Figure 4.6.3 presents the processed radargrams for the Sierra area, with **profile AL-07** divided into three segments due to its extensive length of over 3 kilometres. In the first 150 metres of the first segment, several prominent reflections are visible, underlain by a sharply northwest-dipping reflector, reaching depths of approximately 15 meters. Around the 175-meter mark, this reflector begins to flatten, and by 400 meters, distinct foreset layers emerge, notable for locally reaching thicknesses of at least 25 meters.

These foresets, which consistently dip westward, are characterized by zones of variable reflectivity. Between 600 and 800 meters, clusters of high reflectivity suggest regions dominated by coarse-grained material, while weaker reflections observed from 840 to 950 meters may imply increased water content, likely influencing signal quality and attenuating EM waves more than surrounding areas.

In the second segment of profile AL-07, the radargram reveals a less favourable reflectivity regime compared to the first segment. The foreset structures that were prominent earlier are no longer distinctly visible. Instead, this part of the profile is characterized by a reflective top layer, with a thickness of up to 6 meters, containing mildly undulating reflections. Below this reflective layer, the radargram shows predominantly weak reflections, suggesting an environment with higher water retention. This increased moisture (possible silt) appears to be impacting the GPR signal’s strength and clarity, leading to more subdued reflections.

The third and final segment of AL-07 continues this trend, with a similar reflective top layer and areas dominated by weak reflections beneath it. However, some foreset structures become visible intermittently, although they appear less distinct than in the first segment. These localized foresets are not as clearly defined or continuous, which further supports the likelihood of varying sedimentary conditions and water content affecting signal penetration and reflectivity across the length of profile AL-07.

The radargrams for the profiles perpendicular to AL-09 shown in Figure 4.6.3, confirm the previous findings of a reflective top layer around 6 meters thick, underlain by layers of weak reflections extending down to approximately 25 meters. Across **profiles AL-08**, **AL-09**, and **AL-10**, there is generally no evidence of foreset structures perpendicular to the orientation of these profiles, with one exception: in the initial 100 meters of profile AL-08, strong continuous reflectors are observed with depth. These reflectors may suggest layering which dips southwest, though this is not definitively clear.

Beyond this segment, the weak reflections in profiles AL-08, AL-09, and AL-10 are largely sub-horizontal and often intersect with one another. This crisscrossing pattern likely reflects varying subsurface conditions, such as changes in moisture or sediment composition, which disrupt the continuity of reflections and further obscure any potential stratification or indications of foresets.

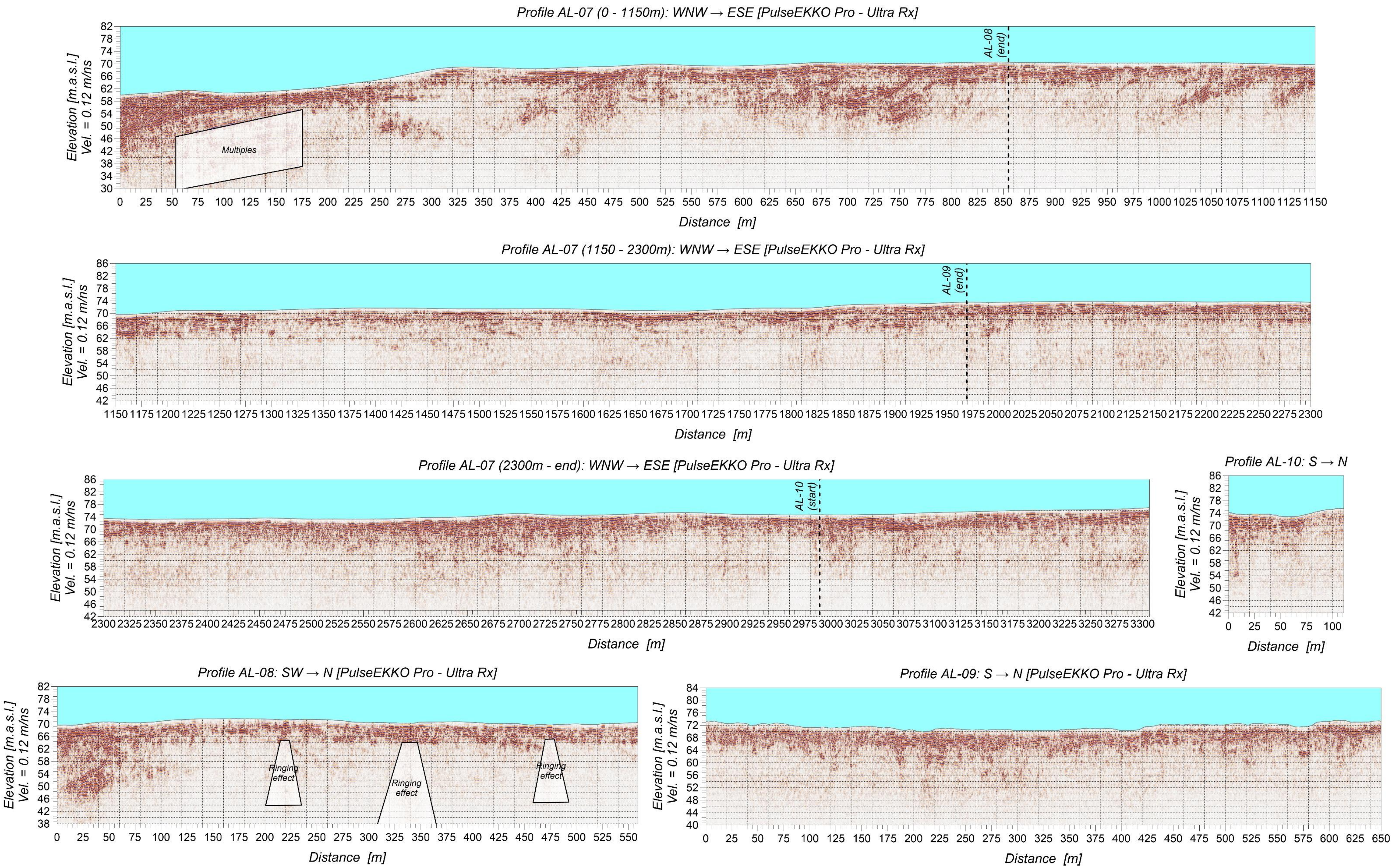


Figure 4.6.3: Processed radargrams for profiles AL-07, AL-08, AL-09 and AL-10.

4.7 Peskamoen (AL-11, AL-12, AL-13, AL-14)

The Peskamoen subarea, located approximately 4 kilometres northwest of Sierra along the southern bank of the Gammelbollo River, comprises GPR profiles totalling over 5 kilometres. As depicted in Figure 4.7.1, the surveyed terrain includes mostly man-restored woodlands with distinct tree rows, facilitating straightforward navigation with the Malå RTA system. The Snake system was employed for the majority of profiles – approximately 3.7 kilometres – owing to its suitability for manoeuvring through the obstructed forested terrain. The exception is profile AL-11, which was measured with the PulseEKKO Pro cart along an asphalt road that bisects the area, offering a smoother surface and ensuring high-quality data acquisition along the profile.

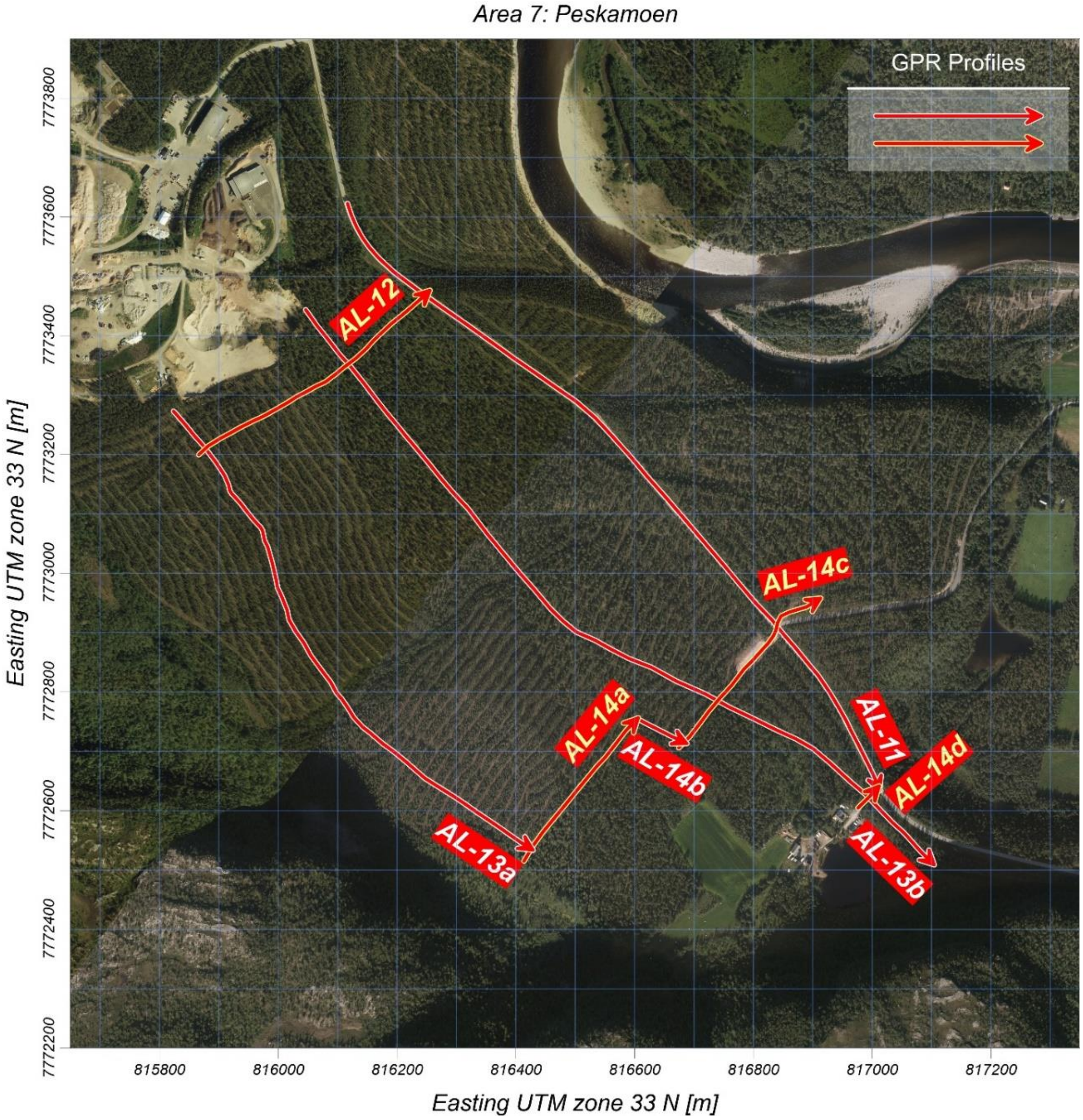


Figure 4.7.1: Positioning of Georadar profiles AL-11, AL-12, AL-13(a and b) and AL-14 (a to d) collected at Peskamoen area. Orthophoto: Vest Finnmark (Field-Group, 2023).

The ATA plot for the Peskamoen GPR profiles, displayed in Figure 4.7.2, separates data according to the measurement system used: Malå RTA and PulseEKKO Pro. Signal attenuation reaches background noise levels after approximately 450 nanoseconds for profiles collected with the Malå RTA system and after about 500 nanoseconds for PulseEKKO Pro profiles. Hyperbola fitting in profile AL-11 produced an estimated velocity of 0.092 m/ns, translating to maximum investigation depths of around 20. meters for the Malå RTA data and up to 23 meters for PulseEKKO Pro data.

For the Snake-collected profiles, the ATA plot reveals varying attenuation rates across different localities. Nevertheless, signal attenuation consistently reduces to background noise by around 450 nanoseconds, suggesting that conditions across the surveyed terrain in Peskamoen generally support similar depth penetration for profiles collected with the Snake system.

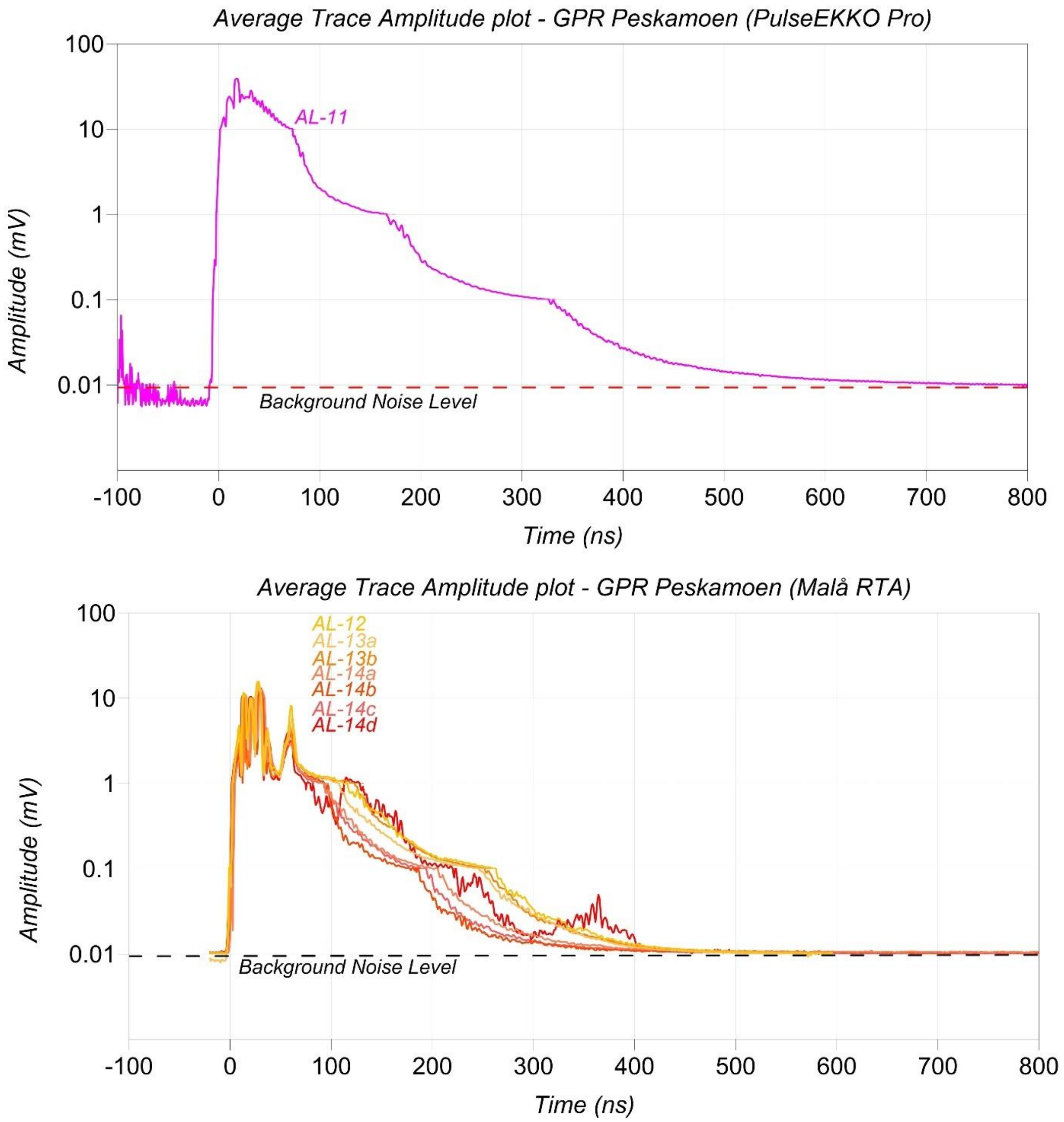


Figure 4.7.2: GPR signal Average Trace Amplitude (ATA) for Peskamoen subarea displaying the penetration depth achieved for PulseEKKO Pro (top) and Malå RTA (bottom) systems.

Figure 4.7.3 presents the processed radargrams for Peskamoen, where the complexity of subsurface structures is evident across all results. Specifically, **profile AL-11** which was collected with the PulseEKKO Pro system (shown at the top), reveals intricate layering beneath the surface. At its first 120 meters, two distinct reflection clusters are apparent: one at approximately 8 meters depth, dipping northwest at a steeper angle than the surface topography, and a more superficial reflector that aligns more closely with the topography. Near the 140-meter mark, this superficial reflector shifts direction, dipping south-eastward beneath the otherwise flat terrain.

In the processed radargrams for Peskamoen's Snake system profiles, the layering geometry is also distinctly complex. **Profile AL-12** begins with an 18-meter-thick stratified section, featuring a prominent reflector that rises from 44 to 56 meters above sea level over a 240-meter stretch. Between the 140- and 240-meter marks, several short foreset structures emerge, adding to the dynamic layering pattern. This stratified section is interrupted by a sharp surface drop, and at the base of this descent, a 20-meter-thick package of unlayered material appears, spanning approximately 50 meters in width.

Beyond this point and up to the next significant topographic descent at 400 meters, the profile exhibits robust reflectivity with signs of sub-horizontal layering and occasional southwest-dipping foresets. In the final 80 meters of AL-12, the layering pattern mirrors the first 240 meters. This section is marked by southwest-dipping, linear reflectors, suggesting a recurring depositional structure.

Profiles AL-13a and **AL-13b**, positioned sub-parallel to profile AL-11 (see Figure 4.7.1), exhibit a comparable reflectivity regime. Both profiles initiate over an area of varied dipping reflections that are consistently strong regardless of depth, before transitioning into an area overlain by a thinner reflective top layer beneath which lies a thicker, low-reflectivity package lacking distinct stratification. Moreover, in profile AL-13b, as with AL-11, there is a notable section of distinct south-eastward dipping reflections at the end of the line. This feature frames the aforementioned low-reflectivity zone in the middle of the profile, creating two opposing slopes that could represent structural or depositional changes at the boundaries before the 630 and after the 1150-meter mark. These antithetical slopes, mirroring the layering patterns found in profiles AL-11 and AL-13b, suggest underlying structural continuity across these profiles. It should be noted that profile AL-13a does not capture this feature, due to its shorter length compared to AL-11 and AL-13b.

Focusing on the first 600 meters of profile AL-13a reveals a distinctive reflectivity pattern. This segment showcases a nearly 20-meter-thick sediment package that is defined by a prominent sub-horizontal reflector situated at 42 meters above sea level. Notably, this reflector begins to rise in elevation after the 300-meter mark, converging with the major topographic change at 600 meters distance and 58 meters above sea level elevation.

This upward trend in the reflector can be correlated with similar features observed in profile AL-12, suggesting a consistent westward dip in the sediment package until the 520-meter-mark. However, within this segment, several reflectors exhibit a pronounced south-eastward dipping pattern, which stands out significantly and indicates a complex internal structure.

In contrast, the initial 600 metres third of profile AL-13b displays a more fragmented reflectivity pattern. Here, the reflections appear disconnected and exhibit only mild undulations, lacking the clarity and definition found in AL-13a. This difference in reflectivity may suggest variations in sediment characteristics between the two profiles, pointing to a more inhomogeneous sediment structure in AL-13b compared to the more clear and distinct layering observed in AL-13a.

The final segment of profile AL-13b reveals two nearly linear features that dip towards the southeast at varying angles. The more superficial of these features appears to flatten out after a few tens of meters, effectively framing a higher reflectivity top layer above it. This top layer exhibits significantly greater reflectivity compared to the underlying materials, indicating a marked difference in permittivity characteristics between the two layers. Additionally, this section is characterized by an array of other linear features that contribute to the overall complexity of the sedimentary structure in the area. These variations suggest the presence of significant permittivity differences along a northwest-southeast axis, which may reflect diverse sedimentary processes or variations in material composition.

Profiles AL-14a to **AL-14c** primarily serve to connect the longer Peskamoen profiles, and they largely traverse the above-described areas with a reflective top layer underlain by weak, unlayered reflections. Consequently, these profiles don’t add substantial new information to the interpretations established from adjacent profiles. There are some lateral shifts in reflectivity throughout, but the most notable change occurs near the end of AL-14c, where a transition from weak to strong reflectivity is observed down to the 20-meter depth mark. This shift could indicate a boundary between different sedimentary units or a change in material composition, such as an increase in coarse-grained materials.

Profile AL-14d, positioned perpendicularly to the terminal segments of AL-11 and AL-13b, captures both of the southeast-dipping reflectors identified in those profiles but depicts them as horizontal. Although the length of AL-14d is limited, this horizontal appearance could suggest that the contacts represented by these reflectors are relatively flat over shorter distances or that profiling is intersecting these dipping surfaces in an almost perfect perpendicular direction.

In summary, the GPR profiles at Peskamoen reveal a complex sedimentary structure characterized by distinct layering and variable reflectivity. The profiles show an upper reflective top layer, often underlain by a thicker sequence of weaker, unlayered reflections, suggesting finer-grained, possibly water-retentive materials. Notable features include clusters of dipping reflectors, with orientations that vary both laterally and vertically, indicating possible foresets or other sloped depositional surfaces. Profiles near each other occasionally capture the same reflectors at different orientations, implying localized shifts in stratigraphy that suggest complex structures in this area.

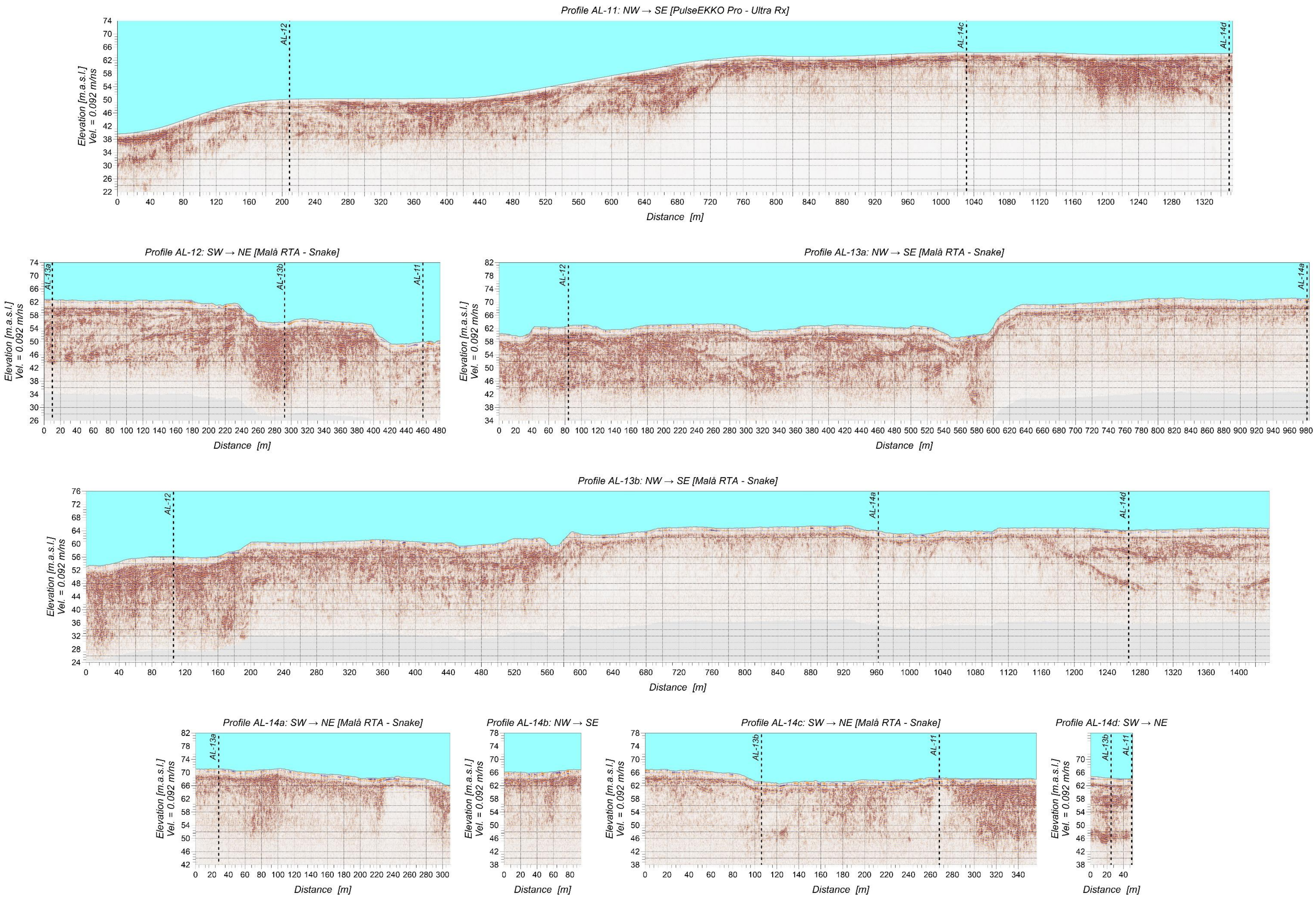


Figure 4.7.3: Processed radargrams for profiles AL-11, AL-12, AL-13 (a and b) and AL-14 (a to d).

4.8 Stengselsmoen (AL-15, AL-16, AL-17, AL-18)

The Stengselsmoen survey area, which encompasses the sand and gravel open pit along with the adjacent recycling centre in the Peskamoen map's northwest corner (see Figure 4.7.1), was explored through four GPR profiles totalling slightly over 660 meters in length. These profiles, collected using the PulseEKKO Pro system on the site's flat terrain, included profile AL-15, which followed a gravel road through the pit, and profiles AL-16, AL-17, and AL-18, which focused on the sand and gravel terrace in the south as seen in Figure 4.8.1. It should be noted that the photograph in Figure 3.1 was taken at Stengselsmoen providing an overview from the surveyed southernmost terrace, illustrating the layout and context of the surveyed landscape to the northwest.

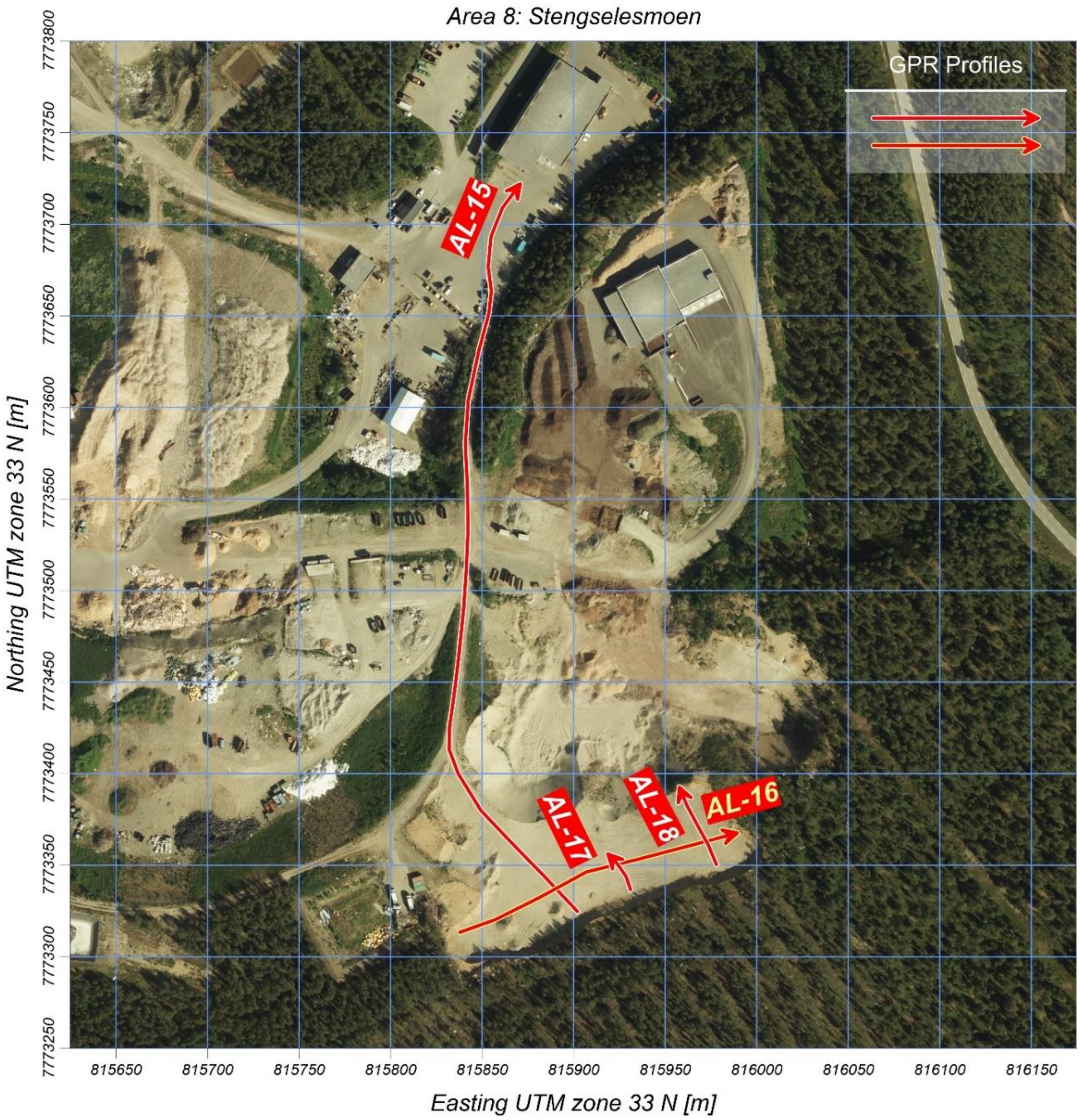


Figure 4.8.1: Positioning of Georadar profiles AL-15, AL-16, AL-17 and AL-18 collected at Stengselsmoen area. Orthophoto: Vest Finnmark (Field-Group, 2023).

The coarse-grained sediment composition at Stengselsmoen is favourable for GPR penetration, as confirmed by the ATA plot in Figure 4.8.2. In this area, signal attenuation occurs after approximately 550 nanoseconds, enabling reflections to be captured at depths of up to 25.2 meters. This depth capacity is based on a calculated EM wave velocity of 0.092 m/ns, which is consistent with the anticipated increased penetration within the coarse-grained deposits.

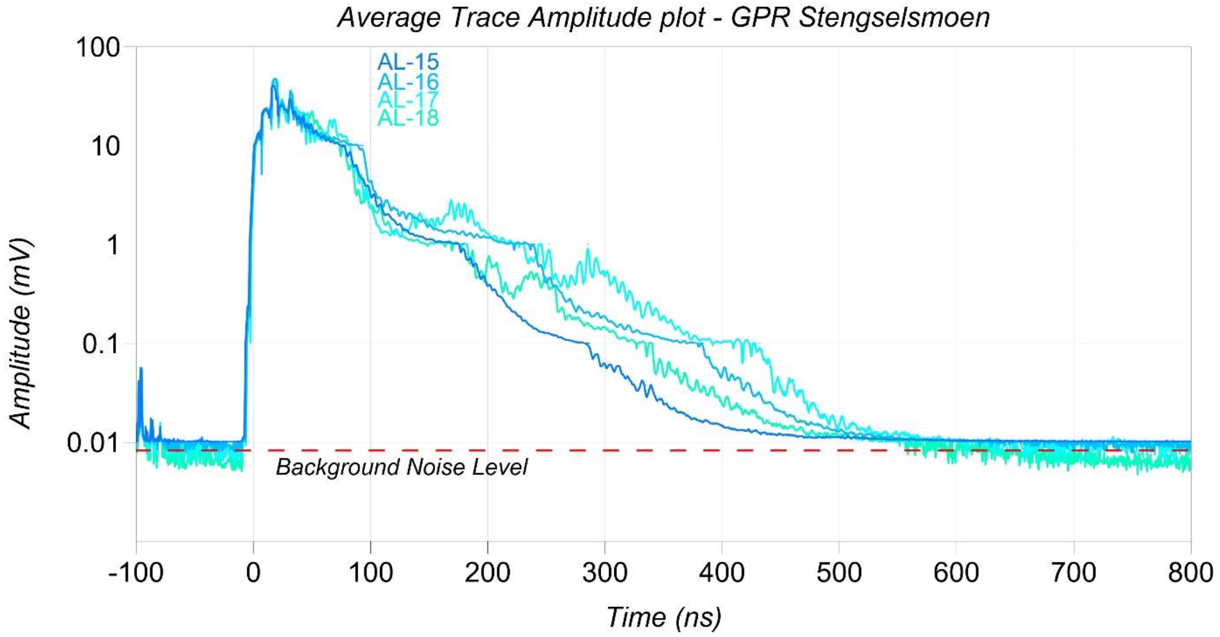


Figure 4.8.2: GPR signal Average Trace Amplitude (ATA) for Stengselsmoen subarea displaying the penetration depth achieved.

The processed radargrams in Figure 4.8.3 for Stengselsmoen reveal strong reflectivity and notable reflection patterns across the profiles. **Profile AL-15**, covering the terrace area, identifies sand and gravel layers extending at least 20 meters deep, with reflectors showing a smooth south-eastward dip. However, from 120 to 260 meters, as the profile descends from the terrace along a gravel road, penetration decreases sharply, due to possible increase in water content in the ground. The final segment of AL-15 (after the 250 metres), which passes through the recycling centre, experiences significant ambient noise, but still captures reflections down to about 10 meters. This part of the profile shows gently undulating layers, highlighting the sedimentary structure in the lower area of Stengselsmoen.

In **profile AL-16**, positioned on the terrace, GPR results indicate a nearly 25-meter-thick section of strong reflectivity, with layers dipping south-westward. Near the surface, possible foresets are observed alongside various dipping reflections, segmented by zones of low or no reflectivity. A prominent reflector begins at 43 meters above sea level at the start of the profile and slopes upward, intersecting the profile until it meets the surface at 55 meters above sea level. These findings suggest a southern dip of layers, aligning with observations from the initial segment of profile AL-15. Below this main reflection, especially in the profile's latter half, reflectors become increasingly chaotic and fragmented, displaying lateral shifts and vertical disruptions.

The remaining profiles that are aligned perpendicular to profile AL-16, successfully map the vertical differences in reflectivity that were already marked. More specifically, both profiles capture the dipping reflections mapped in profile AL-16, but also validate the chaotic outlook of reflections beneath 48 and 44 meters above sea level for profiles AL-17 and AL-18 respectively.

The remaining profiles, **AL-17** and **AL-18**, which run perpendicular to profile AL-16, effectively illustrate the vertical variations in reflectivity previously identified. Both profiles confirm the presence of the dipping reflections observed in AL-16, while also validating the disordered appearance of reflections found beneath elevations of 48 and 44 meters above sea level, respectively. This alignment emphasizes the complex nature of the sedimentary layers beneath the more coherent surface reflections at Stengselsmoen.

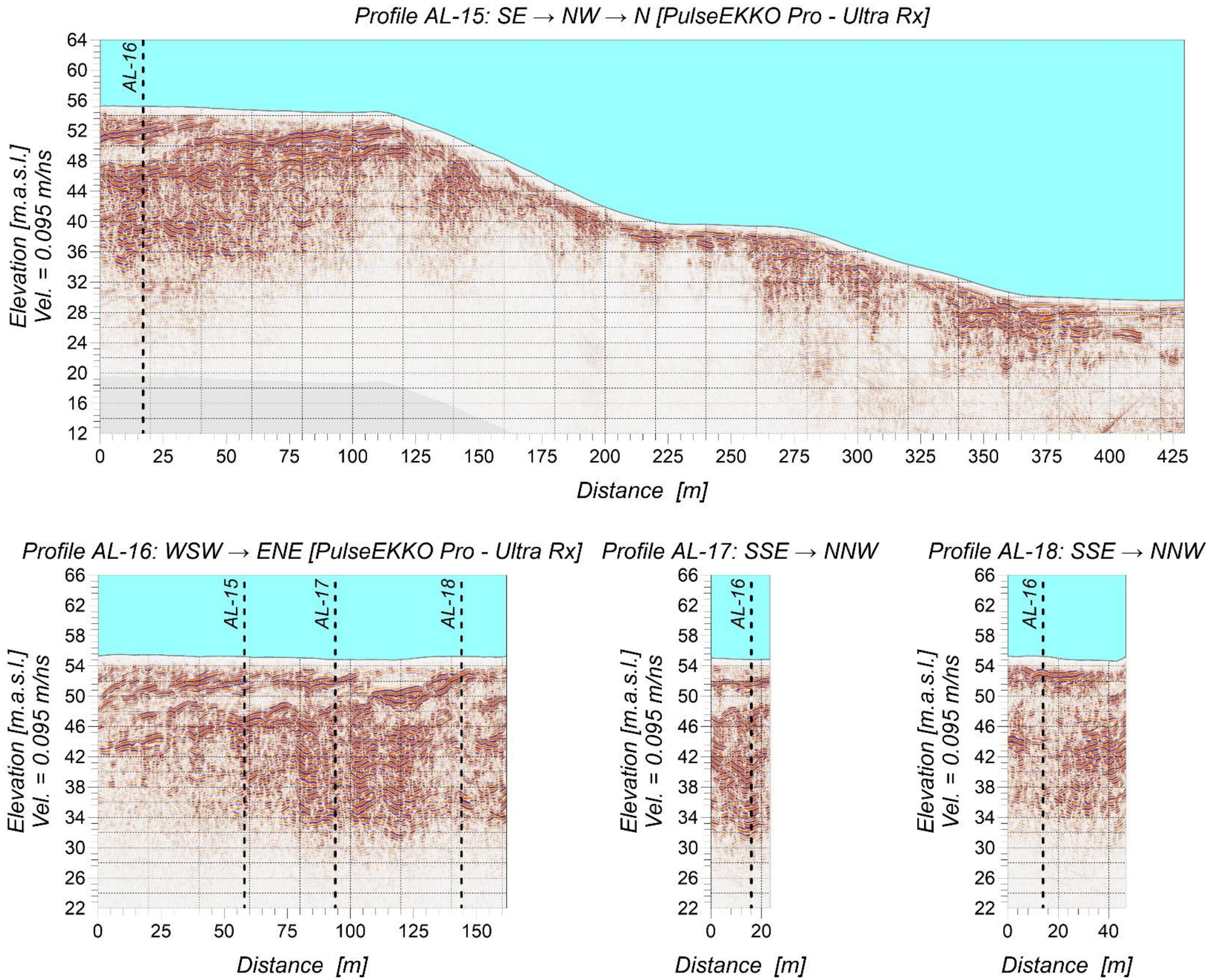


Figure 4.8.3: Processed radargrams for profiles AL-15, AL-16, AL-17 and AL-18.

4.9 Sandsvingen (AL-19, AL-20, AL-21, AL-22)

The Sandsvingen area, as depicted in Figure 4.9.1, is situated just north of the Peskamoen and Stengselsmoen regions, extending along the continuation of the asphalt road and adjacent to the recycling centre. In this area, four GPR profiles were measured: two profiles (AL-19 and AL-20) were collected using the PulseEKKO Pro system along the roads, while the other two profiles (AL-21 and AL-22) were conducted within the forest using the Malå RTA system. In total, approximately 1.44 kilometers of GPR data were gathered at Sandsvingen, with about 0.88 kilometers collected using the cart system and the remaining 0.56 kilometers obtained with the Snake system.

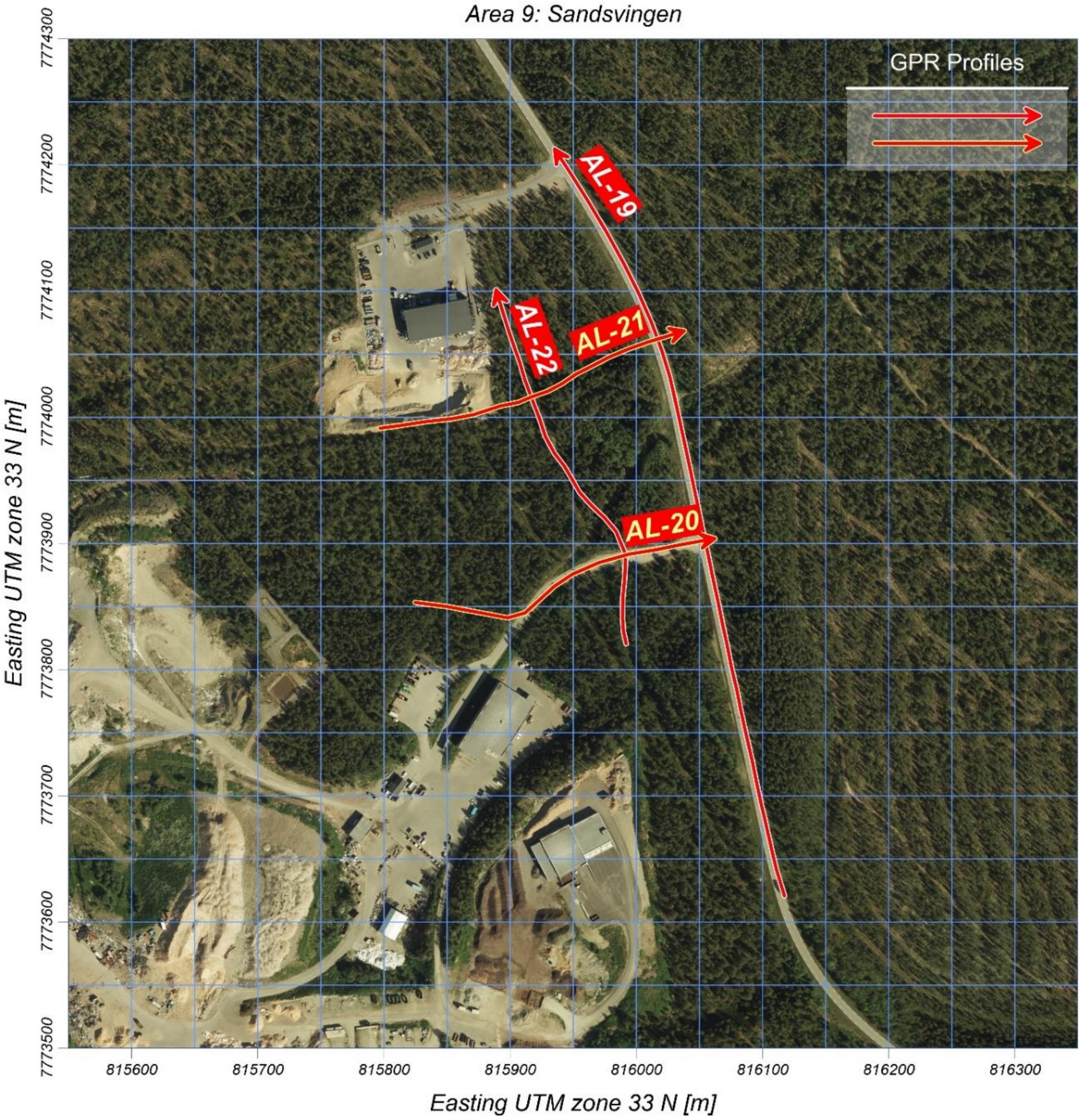


Figure 4.9.1: Positioning of Georadar profiles AL-19, AL-20, AL-21 and AL-22 collected at Sandsvingen area. Orthophoto: Vest Finnmark (Field-Group, 2023).

The ATA plot analysis for Sandsvingen, presented in Figure 4.9.2, combined with a calculated velocity of 0.085 m/ns, highlights a notable difference in signal attenuation between the two GPR systems used. For the PulseEKKO Pro system, the signal decays to background noise levels at around 600 nanoseconds, allowing reflections to be recorded down to a depth of approximately 25.5 meters. In contrast, the Malå RTA system experiences faster signal attenuation, reaching noise levels at around 400 nanoseconds, resulting in a reduced penetration depth of roughly 17 meters. This discrepancy suggests that the Malå RTA system may be more affected by subsurface conditions that limit signal depth in this area.

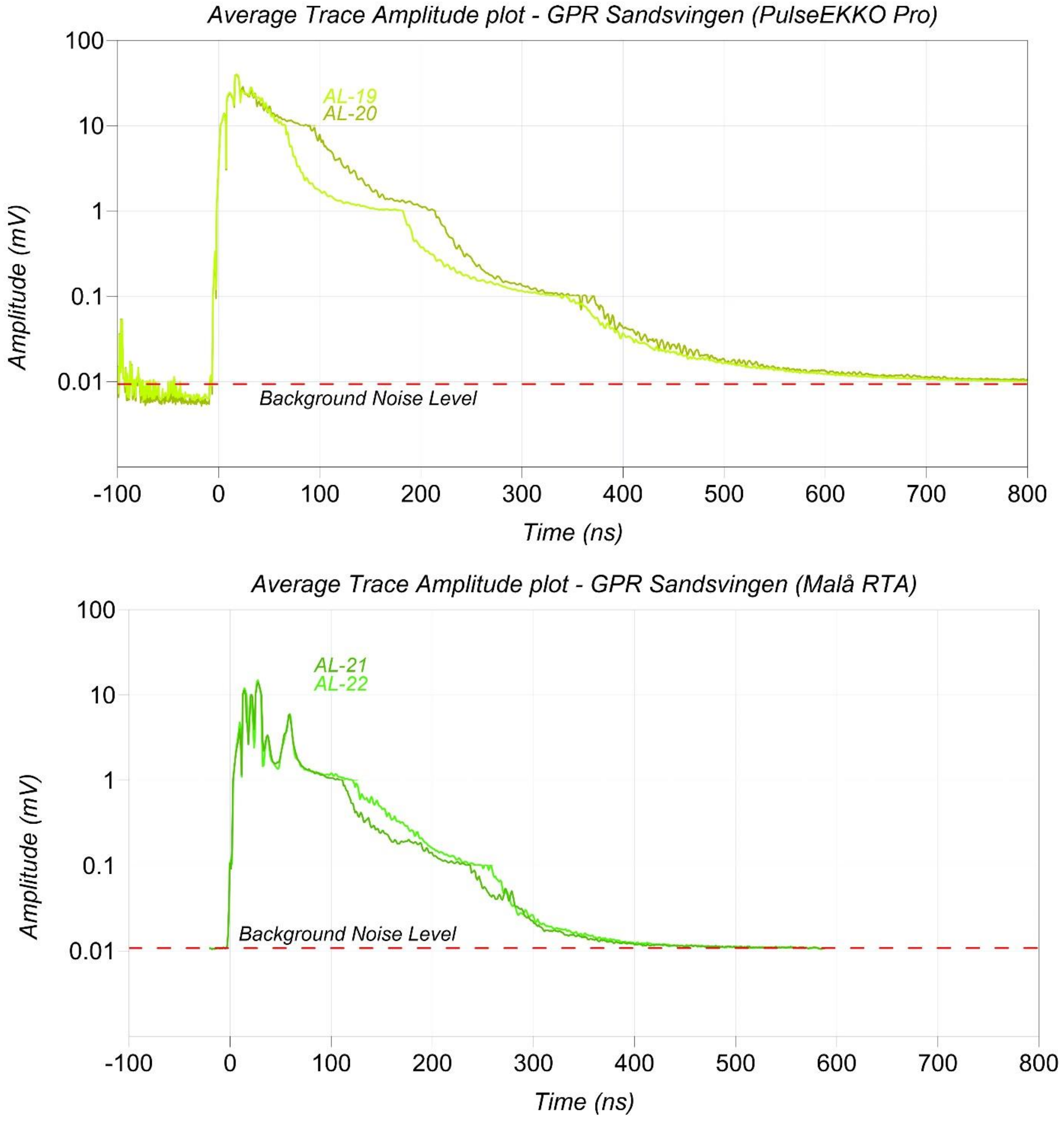


Figure 4.9.2: GPR signal Average Trace Amplitude (ATA) for Sandsvingen subarea displaying the penetration depth achieved for PulseEKKO Pro (top) and Malå RTA (bottom) systems.

In **profile AL-19** from Sandsvingen (shown in Figure 4.9.3), well-defined layers dip consistently northwards, creating foreset-like structures. The weak signal between these foresets accentuates the distinctiveness of the layered structures, highlighting this type of sedimentary pattern. These layers extend down to approximately 22 meters above sea level for the first 450 meters of the profile, below which a flat, reflective "barrier" interrupts the signal, resulting in a disconnected and patchy appearance. Around the 450-meter mark, this sub-horizontal “barrier” comes to an abrupt stop, while a dipping reflector starting at the surface at the same position appears continuing below this level, down to around 14 meters above sea level at 560 meters. This reflector frames an area at the north-western end of line AL-19 with favourable conditions for GPR signal quality, as strong reflections are consistently observed down to nearly 20 meters from the surface.

Profile AL-20, unlike AL-19, presents sub-horizontal, mildly undulating reflections that are largely discontinuous up to the 180-meter mark. Beyond this, signal quality decreases, in correlation with the rising terrain. Only a few thin, superficial reflections dipping southwest could potentially be interpreted as foresets, but these lack significant clarity, thickness and depth. Overall, the profile is limited to resolving structures within the upper 8–9 meters, suggesting more restrictive conditions for signal penetration compared to AL-19.

Moving forward with the Snake system-collected data, **profile AL-21**, running parallel to AL-20, initially shows sub-horizontal, mildly undulating, and discontinuous reflections similar to those in AL-20, contained within an approximately 10-meter-thick layer lacking clear stratification. Beyond the initial 100 meters, AL-21's reflections shift, aligning more closely with those in AL-19. Here, distinct dipping reflections with an eastward dip emerge, underlain by a flat reflector at about 22 meters above sea level. Given that foresets in profile AL-19 were dipping northwards, a collective north-eastward dip for foresets within the northern part of the Sandsvingen region can be interpreted.

Lastly, **profile AL-22**, which runs parallel to AL-19, captures a similar permittivity regime despite the dramatic topographic changes in the forest, which are smoothed out along the asphalt road. As shown in Figure 4.9.3, the flat reflection at 22 meters above sea level also observed in AL-19 remains consistent throughout the length of the profile, creating a “barrier” above which the strongest reflectivity is mapped. Beyond this, the profile is marked by patches of strong, unlayered reflectivity and areas exhibiting eastward-dipping reflections, particularly in the second half of the profile. The results from AL-22 further confirm a difference in permittivity conditions between the northeastern part of the area and the rest of the surveyed region, highlighting variations in subsurface characteristics across the landscape.

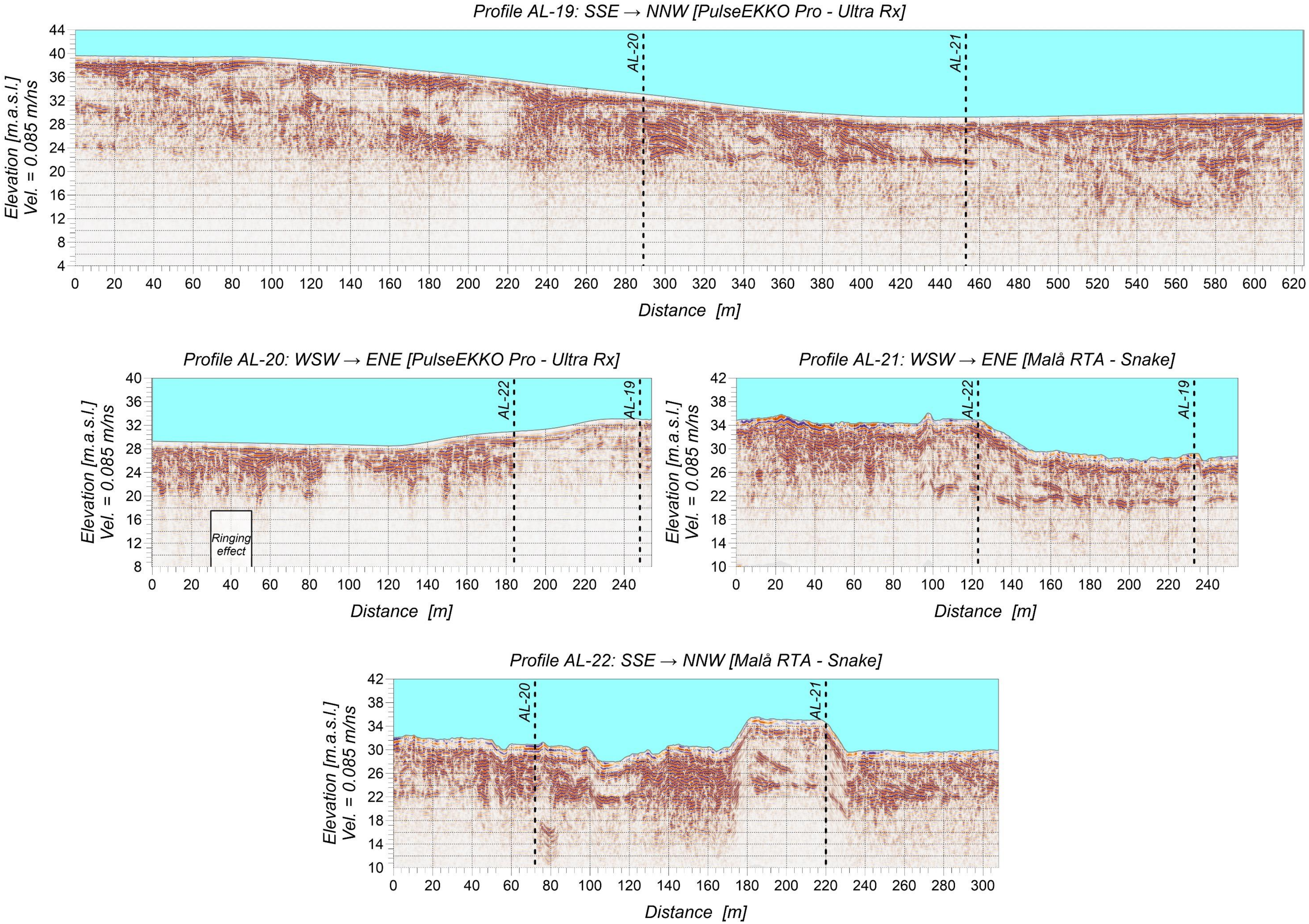


Figure 4.9.3:Processed radargrams for profiles AL-19, AL-20, AL-21 and AL-22.

4.10 Røstmoen (AL-24, AL-25, AL-26)

Approximately 3 kilometers southwest of the combined Peskamoen, Stengselsmoen, and Sandsvingen areas lies the next surveyed subarea, Røstmoen. As shown in Figure 4.10.1, Røstmoen consists mainly of farmland surrounded by forest and a few housing structures. In this area, nearly 1.8 kilometres of GPR data were collected, predominantly along roads and some flat fields. The PulseEKKO Pro system was the exclusive system used in this region, taking advantage of its superior signal quality due to its broadside antenna configuration.

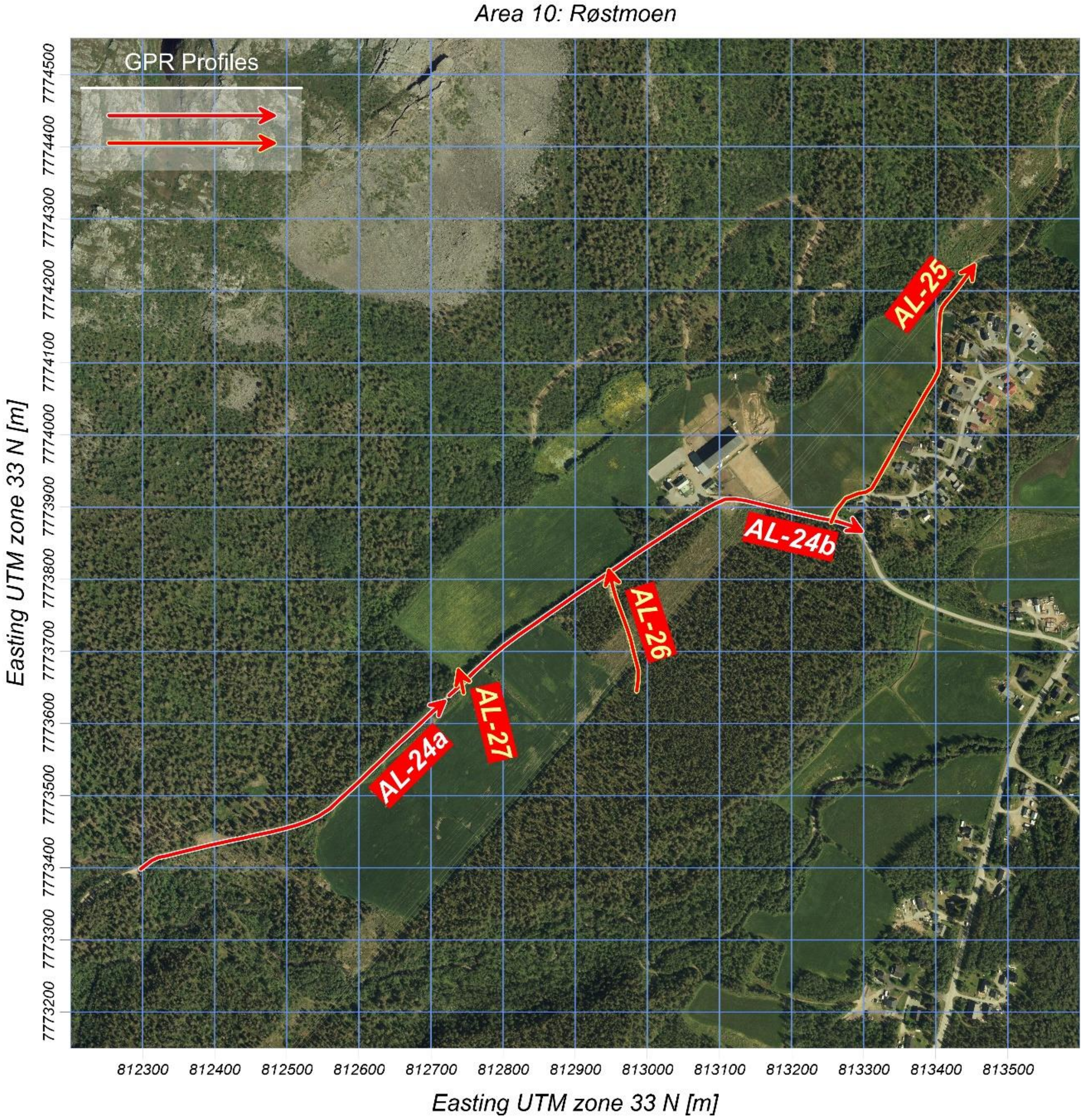


Figure 4.10.1: Positioning of Georadar profiles AL-24 (a and b), AL-25, AL-26 and AL-27 collected at Røstmoen area. Orthophoto: Vest Finnmark (Field-Group, 2023).

In the Røstmoen subarea, the signal attenuation slope observed across all GPR profiles is consistent, suggesting uniform permittivity conditions throughout the region. Hyperbola fitting analysis has determined that the propagation velocity of electromagnetic (EM) waves in this area is 0.122 m/ns, which is typical for relatively dry coarse-grained materials. Based on the signal attenuation occurring at 600 nanoseconds, the maximum penetration depth in this subarea is calculated to be approximately 36.6 meters.

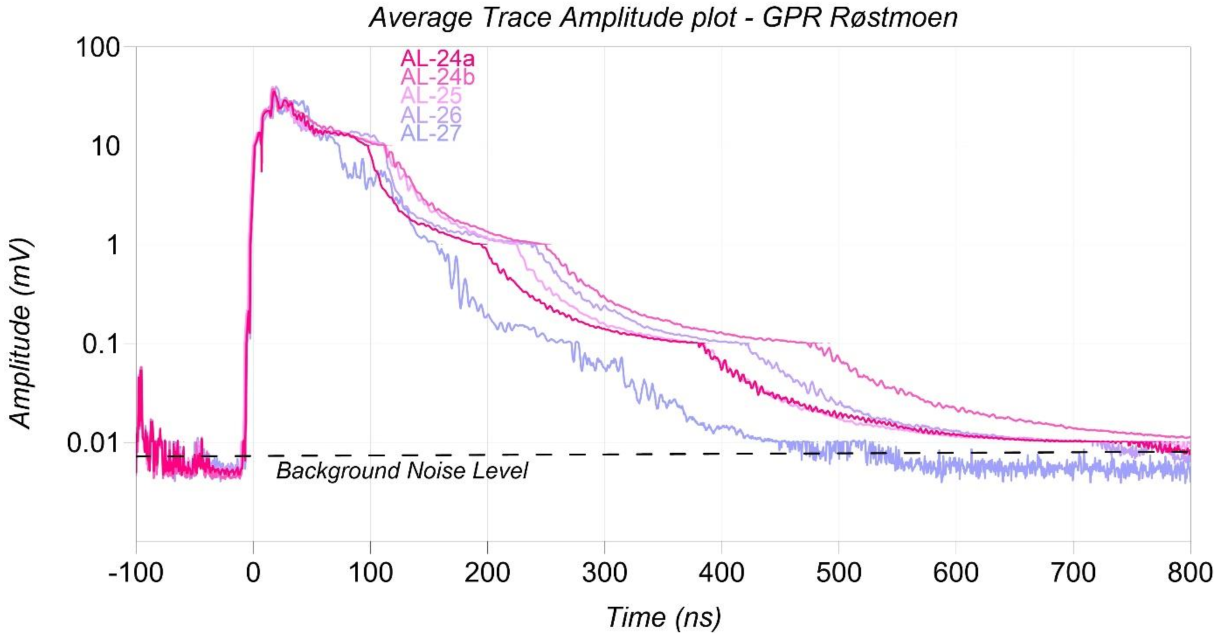


Figure 4.10.2: GPR signal Average Trace Amplitude (ATA) for Røstmoen subarea displaying the penetration depth achieved.

The radargrams for Røstmoen, as shown in Figure 4.10.3, confirm the favourable permittivity conditions that allow for strong signal penetration and well-defined reflections throughout the profiles. In **profile AL-24a**, depth penetration reaches over 30 meters, where several northeast-dipping reflections are visible. These reflections remain identifiable even as they weaken below 52 meters above sea level. Towards the profile's end, where the topography flattens, potential foresets appear occurring beneath a sequence of horizontal reflections. This horizontal reflective layer thickens gradually, from around 6 meters near the 380-meter mark to almost 10 meters at the profile's end.

Profile AL-24b, extending northward from AL-24a along the same road, continues the reflective patterns observed at the end of AL-24a. A well-defined horizontal reflector is consistently observed at around 58 meters above sea level, under which foreset structures persist, though they display a weakened signal indicative of materials with likely higher water content that dampen reflectivity. This sediment layer appears to be at least 30 meters thick. Toward the end of AL-24b, where the elevation decreases, the dipping reflections become more prominent, and the previously well-defined horizontal layer appears blurred.

Profile AL-25, intersecting AL-24b at its midpoint and oriented perpendicularly, reveals complex subsurface conditions with variable reflection orientations. Initially, reflections indicate foresets dipping northwest, although this pattern is inconsistent. In the middle of the profile, reflections flatten, and towards the end, the dip reverses to a southwest orientation. Unfortunately, ambient noise from nearby power lines has impacted the profile’s clarity, masking the deeper, weaker reflections similar to the ones seen in the AL-24 profiles.

A similar pattern emerges in **profile AL-26**, which intersects AL-24b perpendicularly near its end and continues northward along one of the area’s side-roads. In this radargram, a flat layer is observed at 58 meters above sea level, underlain by weak reflectivity as already seen in other profiles farther to the south. As in AL-26, dipping reflections within this low signal amplitude part of the profile, appear to be dipping in both directions, creating a basin-like structure in the middle of the line. Lastly, another interesting feature can be observed at 34 meters above sea level, where a flat reflector up to the 120-meter mark, suddenly acquires a south-eastward dip and retains it until the end of the profile.

In contrast, **profile AL-27** is relatively short and therefore not able to capture the more complex structures seen in the other, longer profiles. However, it should be noted that it is characterized by sharp sub-horizontal reflections throughout its depth, particularly within the most superficial 8-10 meters.

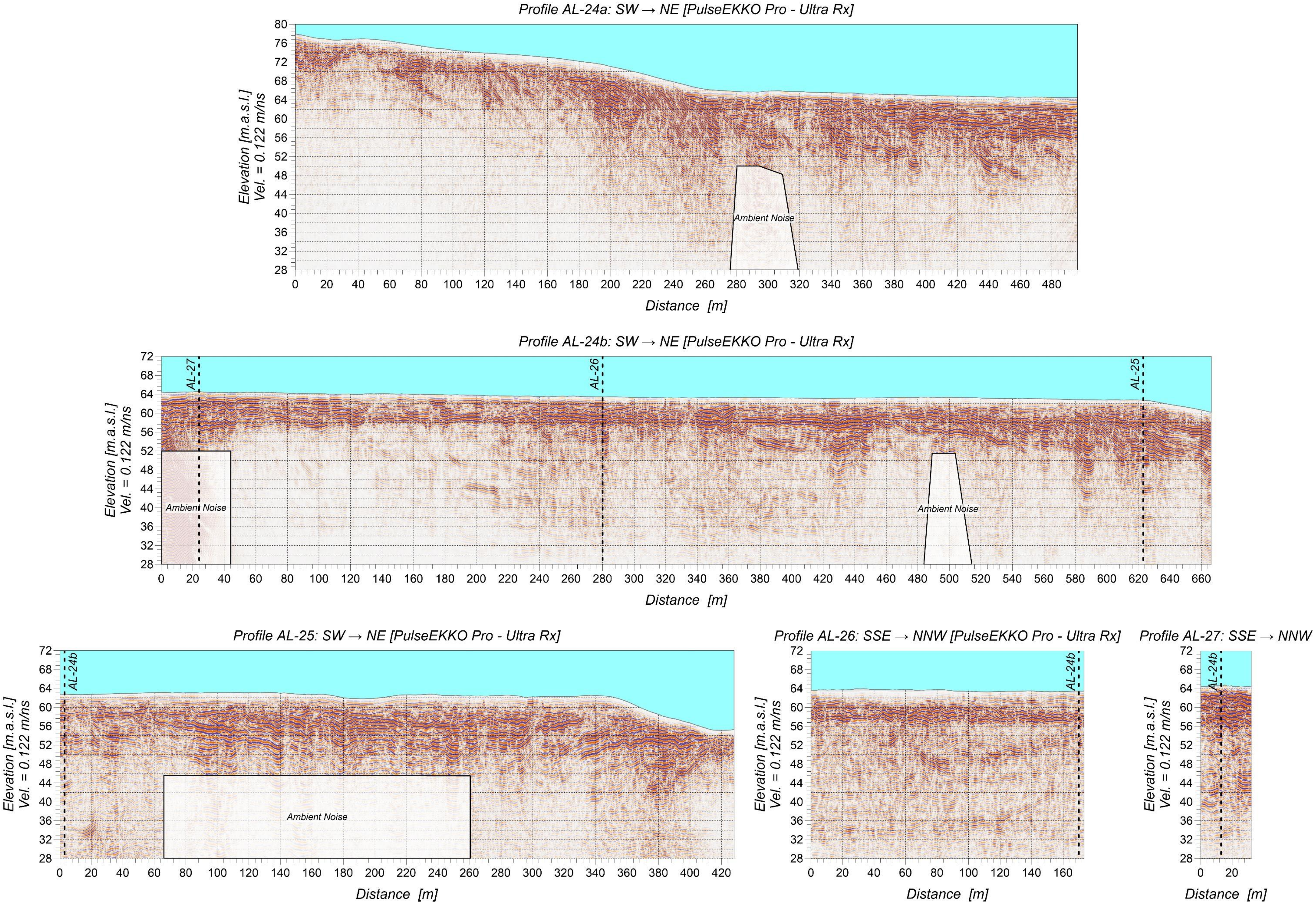


Figure 4.10.3: Processed radargrams for profiles AL-24 (a and b), AL-25, AL-26 and AL-27.

4.11 Skillemoveien (AL-28, AL-29, AL-30)

Located approximately 2.5 kilometres north of Røstmoen, the Skillemoveien area was surveyed with a combination of GPR systems across both roadways and sandy paths. Three of the four profiles utilized the PulseEKKO Pro system, while the fourth, AL-30a, was measured with the Malå RTA system. Altogether, around 1.5 kilometres of GPR data were gathered in this predominantly forested region, which also contains a few residences on its western side as depicted in the map of Figure 4.11.1. The profile collected with the Snake system, totalling about 200 meters, contributes to the overall dataset, offering information from the forested part of the survey area where the cart system could not be deployed.

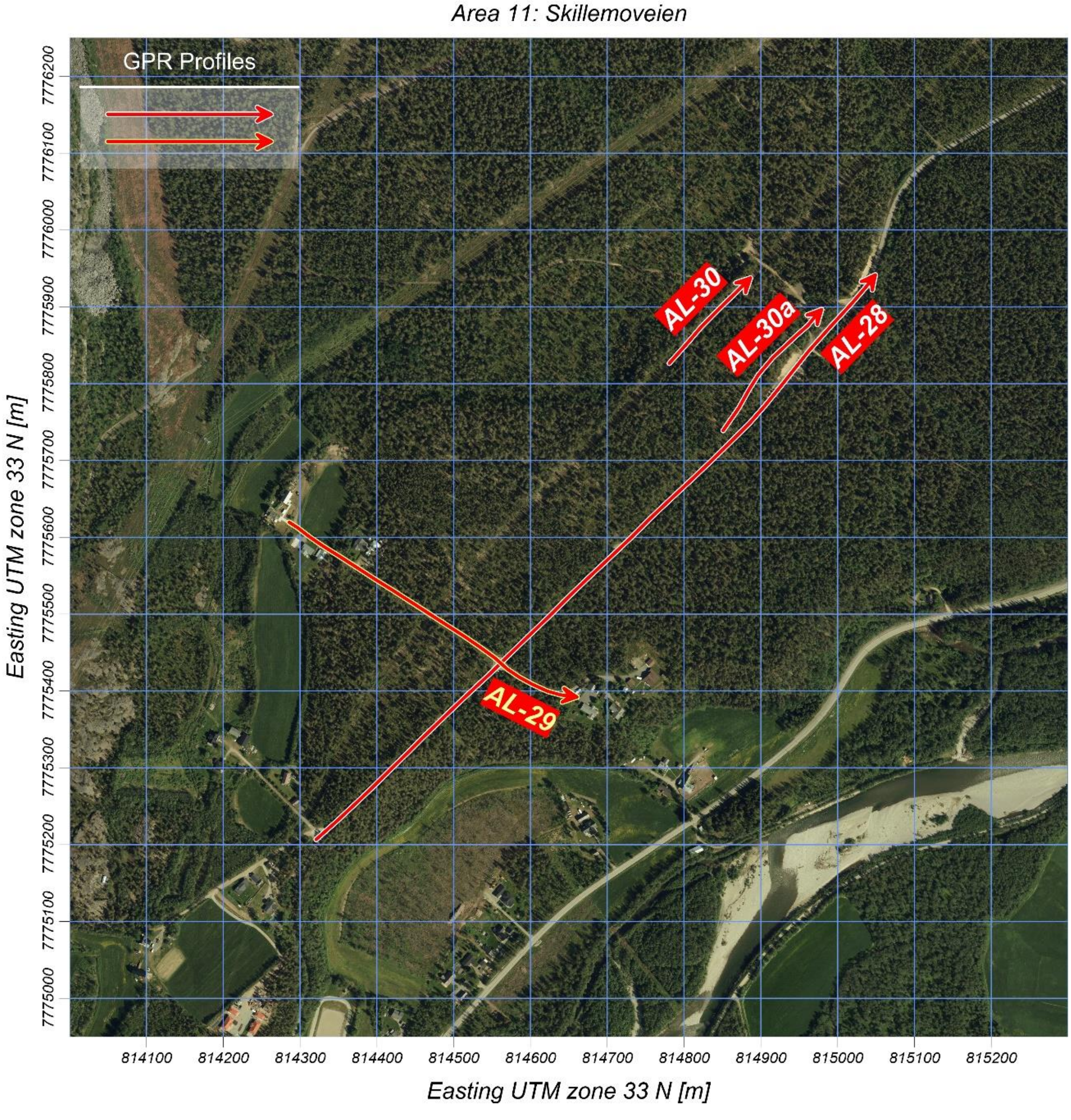
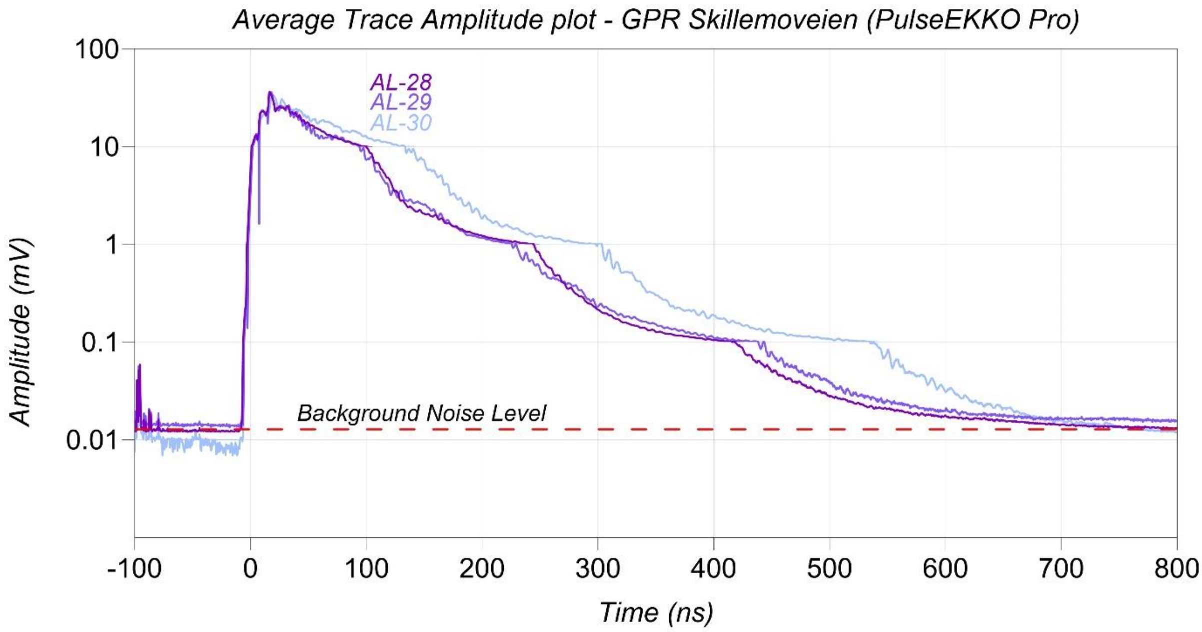


Figure 4.11.1: Positioning of Georadar profiles AL-28, AL-29, AL-30 and AL-30a collected at Skillemoveien area. Orthophoto: Vest Finnmark (Field-Group, 2023).

Figure 4.11.2 presents the ATA plots for the Skillemoveien area profiles, revealing favourable permittivity conditions indicated by the gradual signal attenuation. For the profiles collected with the cart system, background noise levels are reached after 650 nanoseconds, yielding a depth coverage of 32.5 meters, based on the calculated wave velocity of 0.1 m/ns. In contrast, the Snake system profile shows more rapid attenuation, reaching background noise levels at 450 nanoseconds, which limits the effective depth coverage to 22.5 meters.



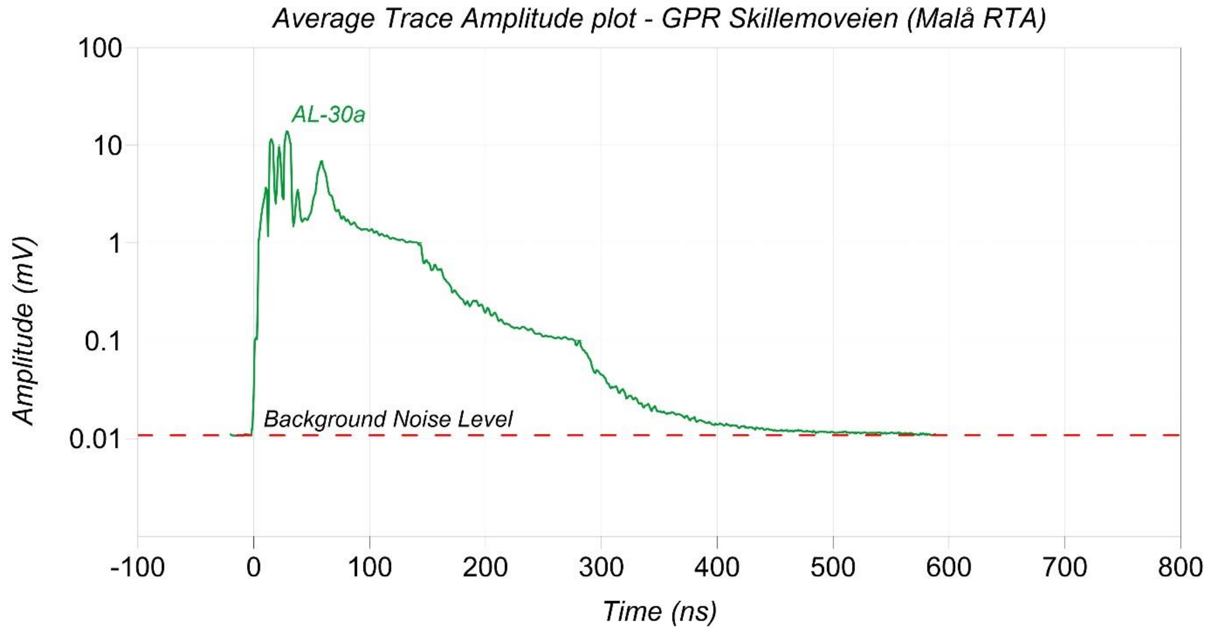


Figure 4.11.2: GPR signal Average Trace Amplitude (ATA) for Skillemoveien subarea displaying the penetration depth achieved for PulseEKKO Pro (top) and Malå RTA (bottom) systems.

Examining **profile AL-28** in Figure 4.11.3 reveals several noteworthy linear features, with various undulating reflections within the first 20 meters of depth. In the initial 300 meters of the profile, mildly south westward-dipping reflections stand out, marked by distinct zones lacking reflectivity around them. At the 300-meter mark, a prominent reflector begins, dipping almost continuously over the next 500 meters, descending from 55 to 40 meters above sea level. Above this reflection, foreset-like layers are visible, dipping towards the southwest. These layers are interrupted by a prominent vertical feature at 760 metres, after which the reflections become increasingly patchy and discontinuous for the remainder of the profile.

Running perpendicular to AL-28, **profile AL-29** reveals similar reflection patterns but with a more pronounced horizontal alignment in its strongest reflections starting at the 100-meter mark and continuing to the profile’s end. Prior to this, a dense cluster of reflections appears, displaying basin-like structures and potentially northwest-dipping layers. Beyond the 100-meter mark and below the

50-meters above sea level elevation, reflectors appear dipping toward the southeast, suggesting a complex deposit.

Profile AL-30, the final cart-measured line at Skillemoveien, runs parallel to the last 150 meters of both AL-28 and AL-30a profiles, the latter of which will be discussed next. This profile displays predominantly mildly undulating reflections, with a top layer approximately 15 meters thick and only minimal signs of southwest-dipping layers, which are nonetheless consistent with observations from the latter half of AL-28. Beneath the top layer, the reflectors become notably weaker, exhibiting a sub-horizontal, interwoven pattern.

The final profile, **AL-30a**, collected with the Snake system, shows strong reflections along its length with distinct, northeast-dipping layers until a marked elevation drop at around 130 meters. These dipping layers align with observations in profiles AL-28 and AL-30, as AL-30a runs parallel to both and is positioned closer to AL-28. Beyond this drop, the reflections become more sub-horizontal, showing a pattern of flat reflectors rather than continuous layering. This transition suggests a change in subsurface structure, with flatter, less stratified material dominating the lower portion of the profile.

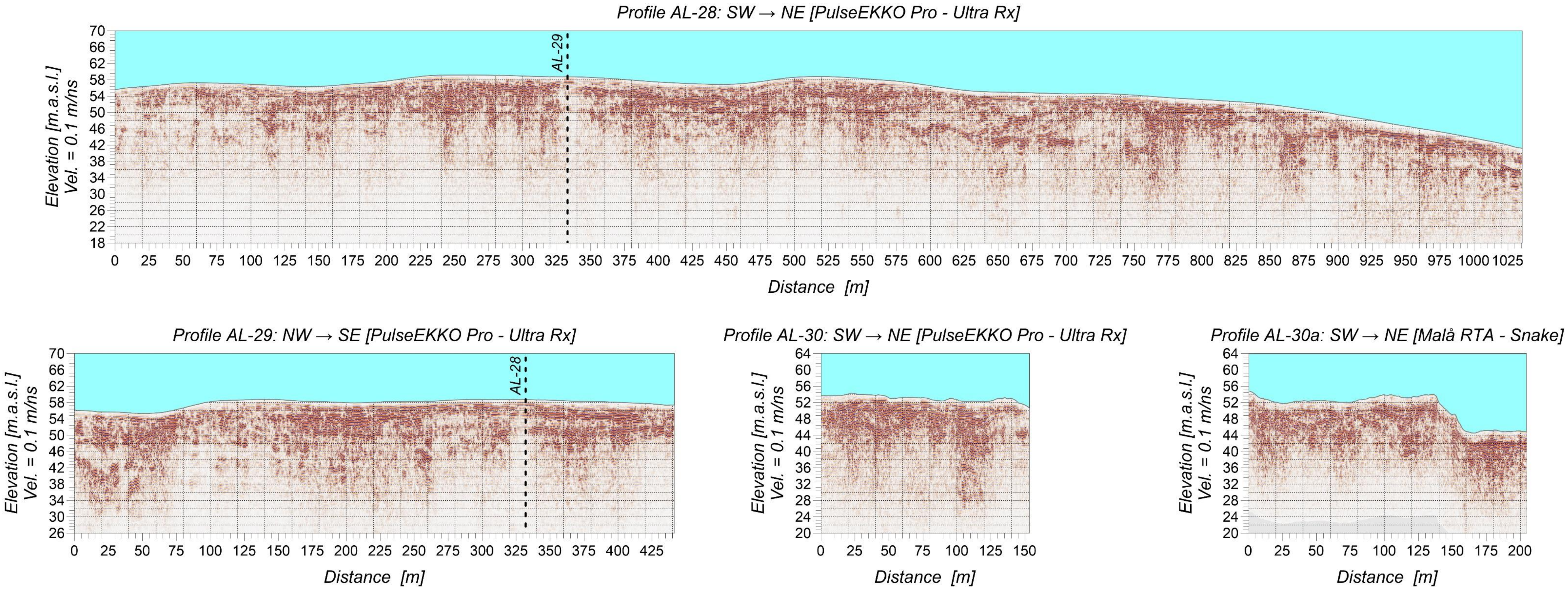


Figure 4.11.3: Processed radargrams for profiles AL-28, AL-29, AL-30 and AL-30a.

4.12 Energiveien (AL-31/32, AL-33, AL-34, AL-35, AL-36)

The Energiveien area, located just north of Skillemoveien and south of Alta town, represents the final survey area in the valley system. As illustrated in Figure 4.12.1, six profiles were collected across roads and forest paths, with profiling being affected by significant ambient noise from the various powerlines and related energy installations in the area. Both the PulseEKKO Pro and Snake systems were deployed, selected based on specific terrain requirements. Altogether, over 3.8 kilometres of data were collected in an irregular grid, with the PulseEKKO Pro system handling the majority of the survey work. The only profile captured with the Snake system, AL-35a, spans approximately 225 meters.

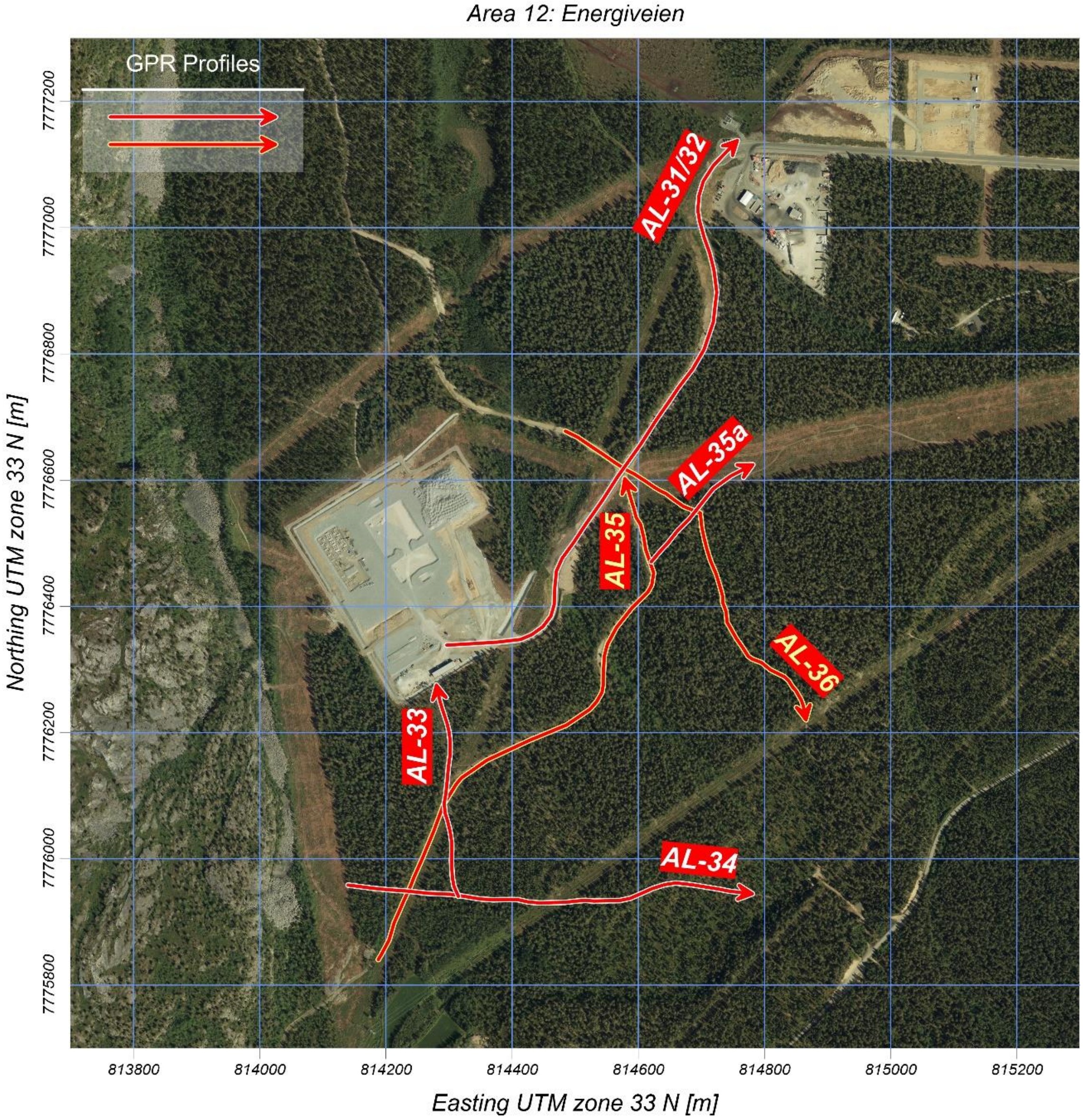
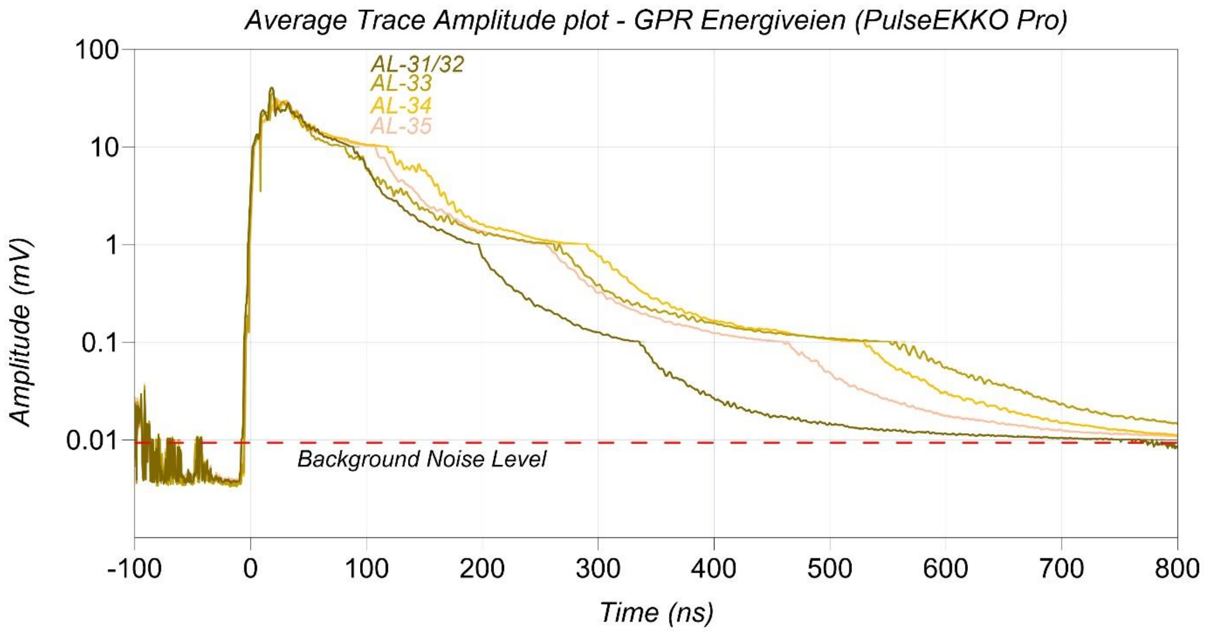


Figure 4.12.1: Positioning of Georadar profiles AL-31/32, AL-33, AL-34, AL-35, AL-35a and AL-36 collected at Energiveien area. Orthophoto: Vest Finnmark (Field-Group, 2023).

The ATA plots for the cart-based PulseEKKO Pro system data in the Energiveien area, shown in the top section of Figure 4.12.2, indicate that the signal reaches background noise levels after roughly 600 nanoseconds. This sustained signal duration highlights favourable conditions for GPR measurements in this location. In contrast, the single profile measured with the Snake system, with its ATA plot at the bottom of the figure, exhibits faster attenuation, converging with background noise around 500 nanoseconds – a discrepancy less pronounced than observed in other areas.

Using a calculated EM wave velocity of 0.015 m/ns, the PulseEKKO Pro data translates to a depth penetration of approximately 31.5 meters, while the Malå RTA system achieved just over 26 meters.



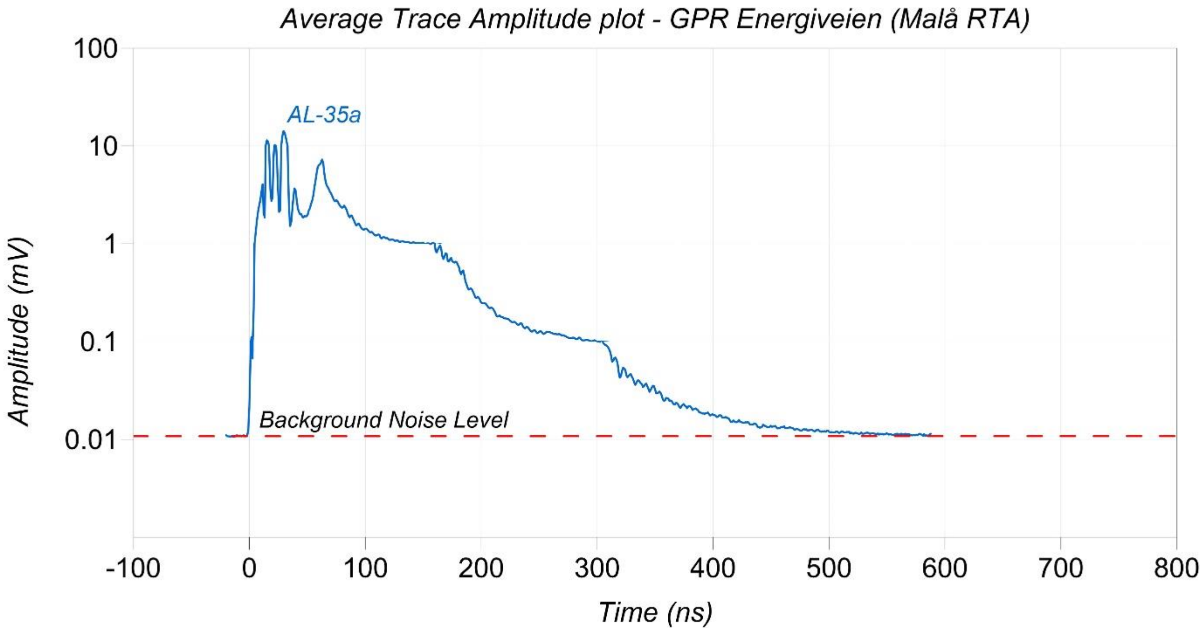


Figure 4.12.2: GPR signal Average Trace Amplitude (ATA) for Energiveien subarea displaying the penetration depth achieved for PulseEKKO Pro (top) and Malå RTA (bottom) systems.

The processed radargram for **profile AL-31/32**, displayed along the other radargrams in Figure 4.12.3, reflects considerable noise interference due to its alignment along a powerline and its proximity to large energy installations at both ends. Despite applying filtering to reduce these artifacts, the lower portion of the profile remains unreliable and has been blanked out. This is also the case with many of the other profiles, which also have some of their parts blanked to avoid misinterpretations.

In the first 300 meters, signal penetration is limited, capturing only shallow reflections that follow surface topography. At the 300-meter mark, however, a prominent reflector deviates from the surface's flattening and descends steadily until about 450 meters, before ascending again near 600 meters and reconnecting with the surface around the 700-meter mark. This basin-like structure displays strong, discontinuous reflections between 300 and 500 meters, framed by non-reflective zones. The profile concludes in a similar manner to its start, characterized by superficial reflections with some lateral variations in signal strength.

Profile AL-33 runs in a north-south direction just south of the beginning of profile AL-31/32. It is characterized by strong, flat-appearing reflections that span nearly 30 meters in thickness. These flat reflections are interrupted by a series of south-dipping layers within the topmost 10-metres, which could potentially represent foresets. The profile is located along a forest path, and as such, it is largely unaffected by noise, making the data relatively clean and reliable for interpretation.

In contrast to profile AL-33, **profile AL-34** which runs perpendicular to it, intersects two powerlines, which introduces significant noise into the data. Despite this interference, the reflections detected throughout the length and depth of the profile remain quite strong. In the first 300 meters, the reflection pattern is similar to that of AL-33, with horizontal discontinuous reflectors intersected by westward-dipping layers, which can - jointly to profile AL-33 - be interpreted as possible south-westward-dipping foresets. Beyond the 450-meter mark, as the elevation drops, the signal becomes much stronger. In this segment of the profile, a 5-meter-thick top layer appears to be underlain by a series of prominent continuous reflections for another 5 metres in depth.

Profile AL-35, oriented similarly to AL-31/32 but positioned slightly farther south, yields rather inconclusive results. In its first half, the profile displays a dense concentration of thick horizontal reflections between 60 and 340 meters, with some south-eastward-dipping layers closer to the surface, specifically above 50 meters above sea level in elevation. Moving to the second half of the profile, a noticeable topographic depression between 650 and 750 meters is underlain by another large concentration of strong, deep sub-horizontal reflections, extending nearly 30 meters in thickness. This pattern persists toward the end of the profile, with another intriguing feature: a small low-reflectivity zone sandwiched between two sets of stronger reflectors.

The only profile obtained with the Snake system, **AL-35a**, is located near the end of profile AL-35. It captures the same low reflectivity zone framed by strong reflectors both above and below. However, in the second half of the profile, the reflectivity becomes patchy and discontinuous, with a thickness of approximately 20 meters. This is attributed to the faster attenuation of the GPR signal with the Malå RTA system, which results in limited depth penetration in relation to data collected with the cart system in the same area.

The final profile measured at Energiveien, **AL-36**, is dominated by horizontal reflections throughout its length. Lateral variations in signal are notable, with the first two-thirds of the profile showing a 5-meter-thick top layer of strong horizontal reflections, underlain by areas of low reflectivity interspersed with brief instances of stronger signal. Between 300 and 450 meters, a large vertical feature is captured, displaying crisscrossing reflections that extend to nearly 30 meters in depth. The last 200 meters of the profile exhibit a low reflectivity regime, with only a few exceptions of either horizontal or north-eastward dipping reflections.

Despite the strong ambient noise at Energiveien, the GPR data has successfully provided valuable insights into the subsurface deposition. The profiles reveal consistent horizontal layering in the uppermost sections, with interruptions indicating more complex geological features below. These findings suggest that, even under challenging conditions, the GPR was able to effectively capture the deposition patterns and variations in the subsurface.

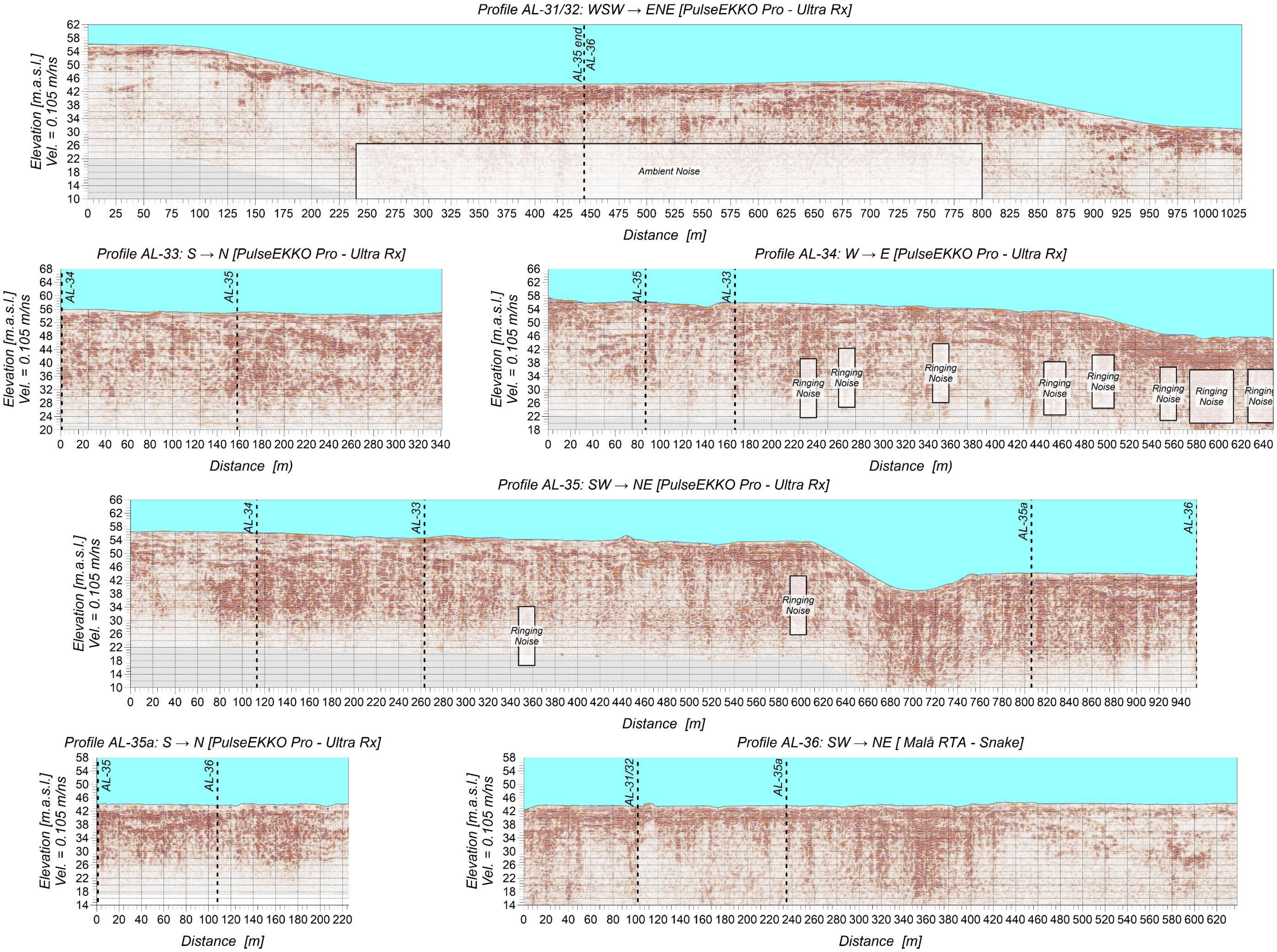


Figure 4.12.3: Processed radargrams for profiles AL-31/32, AL-33, AL-34, AL-35, AL-35a and AL-36.

4.13 Thomasbakken (AL-37, AL-38, AL-39, AL-40)

Thomasbakken is one of the final two areas in this survey, located at the southern edge of Alta town, close to densely populated neighbourhoods. As shown in the map in Figure 4.13.1, the GPR profiling in this subarea traverses a mix of suburban streets and farm areas, which suggests a higher likelihood of ambient noise in the data. Four primary profiles and two auxiliary short lines were collected using the PulseEKKO Pro system, covering a total of nearly 1.8 kilometres.

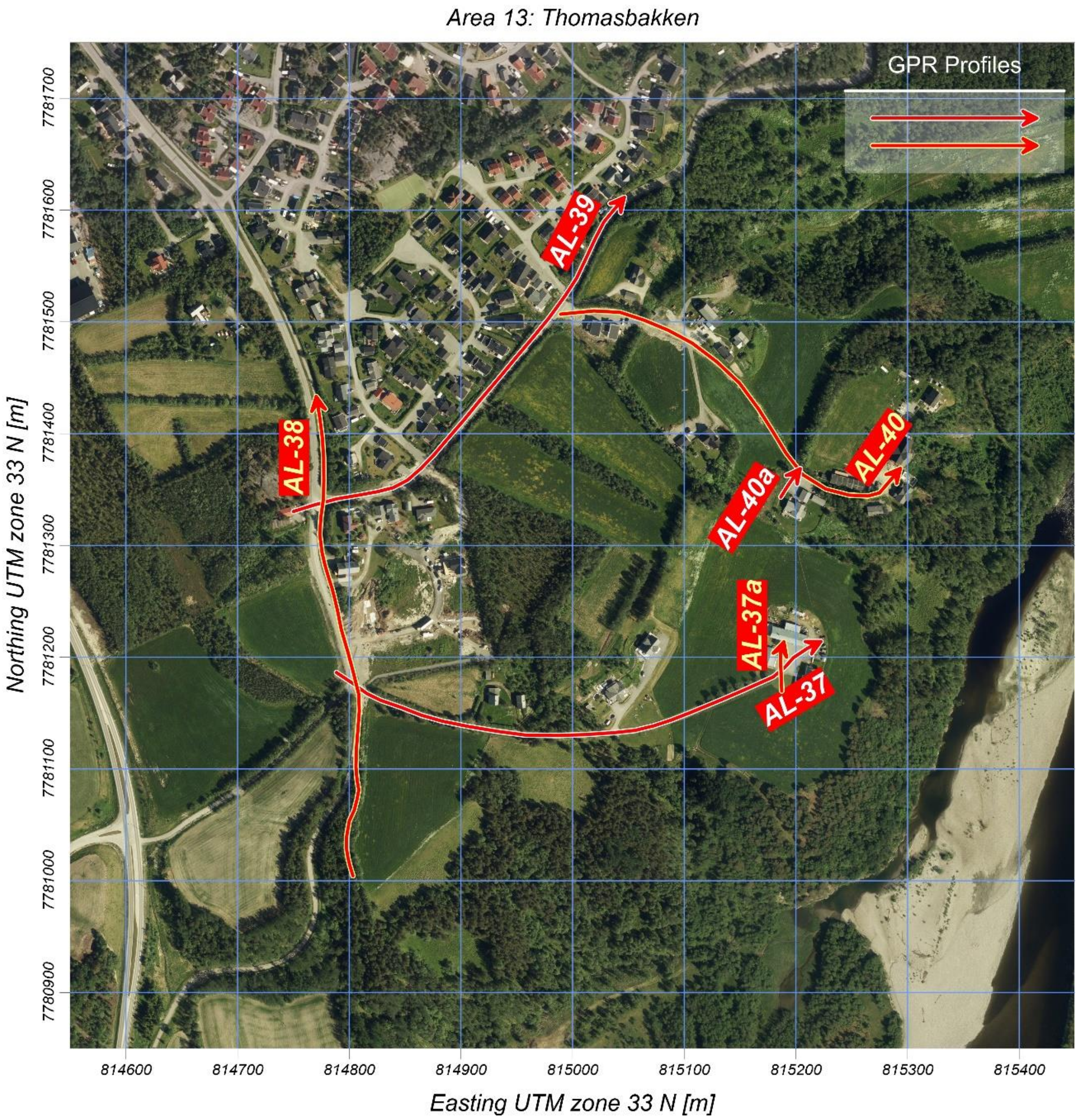


Figure 4.13.1: Positioning of Georadar profiles AL-37, AL-37a, AL-38, AL-39, AL-40 and AL-40a collected at Thomasbakken area. Orthophoto: Vest Finnmark (Field-Group, 2023).

Figure 4.13.2 presents the ATA plot for the GPR profiles measured at Thomasbakken, revealing relatively steep attenuation curves. All profiles reach background noise levels after approximately 350 nanoseconds, which corresponds to a depth coverage of about 17.5 meters, assuming a velocity of 0.1 m/ns derived from hyperbolic reflections in the data.

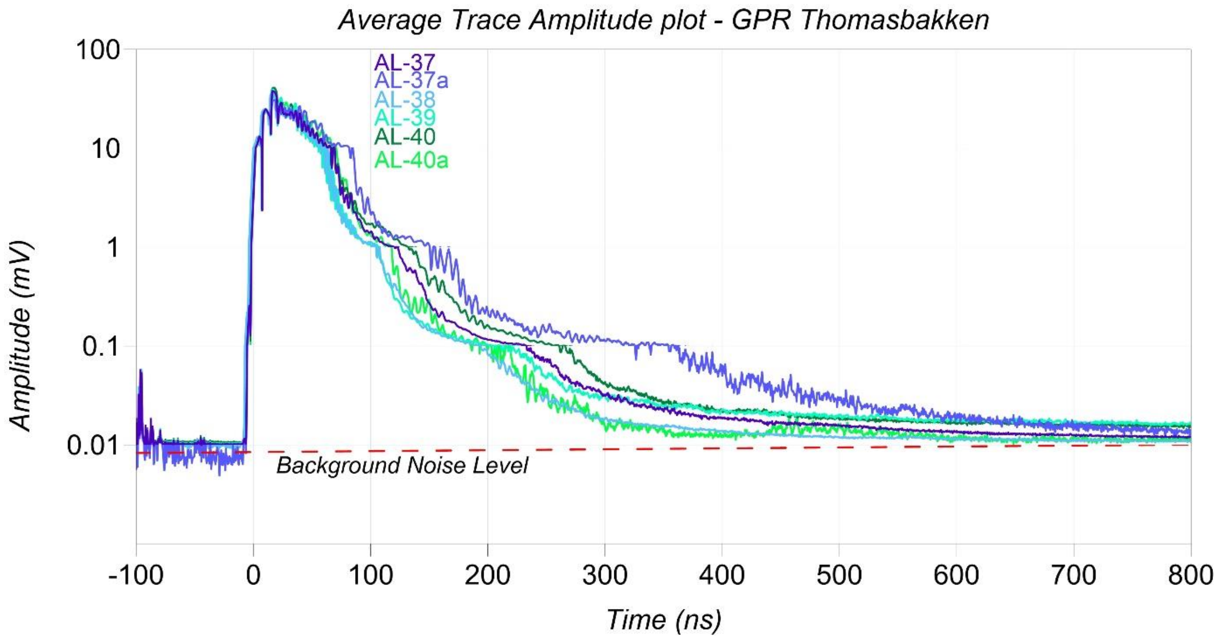


Figure 4.13.2: GPR signal Average Trace Amplitude (ATA) for Thomasbakken subarea displaying the penetration depth achieved.

The less favourable conditions for GPR surveys at Thomasbakken are reflected in the results shown in Figure 4.13.3. Most profiles exhibit only shallow penetration (a few meters), with a few notable exceptions. These include three specific areas: the end of profile AL-37 (confirmed by the short auxiliary profile AL-37a), the intersection of profiles AL-38 and AL-39, and the end of profile AL-40, beyond the point where the auxiliary line AL-40a was measured. Overall, Thomasbakken appears to be dominated by water-saturated fine-grained materials based on these results.

In the first area of interest – the last 160 meters of **profile AL-37** – the previously attenuated signal strengthens noticeably around the 300-meter mark. This transition reveals a 4-meter-thick layer of horizontal reflections near the surface, underlain by westward-dipping reflections extending to approximately 15 meters depth. Additionally, profile AL-37a offers a complementary view of this configuration, also showing a highly reflective top layer above a southward-dipping reflector.

In the second half of **profile AL-38**, a northward-dipping reflection becomes evident at the 340-meter mark, remaining nearly continuous over the next 80 meters. This reflection descends from approximately 55 to 49 meters above sea level throughout this section. At the intersection with **profile AL-39**, this dipping reflection is only at its start, and thus the only feature that profile AL-39 is able to capture, is the strongly reflective top layer. For the next 100 meters, the pattern persists, but thereafter, the signal attenuates almost immediately upon surface penetration.

Lastly, the final 100 meters of **profile AL-40** reveal a structure resembling that seen in profile AL-37, featuring a thin, strongly reflective top layer underlain by a series of north-eastward-dipping reflectors. This reflective layer extends to at least 15 meters in thickness, with additional, weaker reflections visible at greater depths. Notably, profile AL-40a intersects profile AL-40 just before this feature begins, covering an area outside of this reflective section.

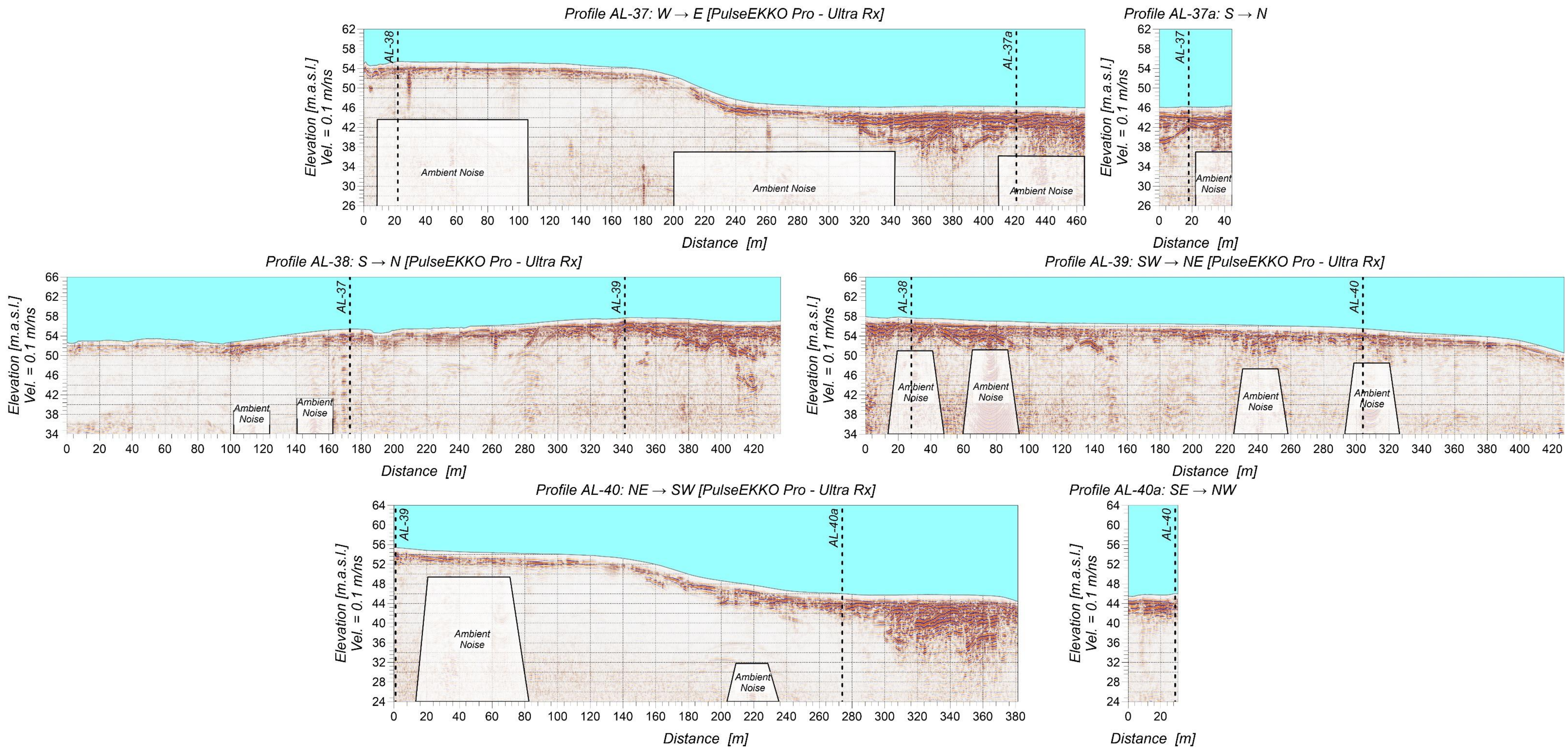


Figure 4.13.3: Processed radargrams for profiles AL-37, AL-37a, AL-38, AL-39, AL-40 and AL-40a.

4.14 Altahøyden (AL-41, AL-42, AL-43, AL-44, AL-45)

Northeast of the Thomasbakken area and situated closer to the urban centre of Alta town lies Altahøyden. This area includes five GPR profiles conducted amidst residential and other buildings, which are known to introduce ambient noise into GPR measurements. All profiles in this subarea were measured using the PulseEKKO Pro system mounted on a cart, resulting in nearly 2.4 kilometers of data. The positioning of these profiles in relation to the housing in the area is presented in Figure 4.14.1.

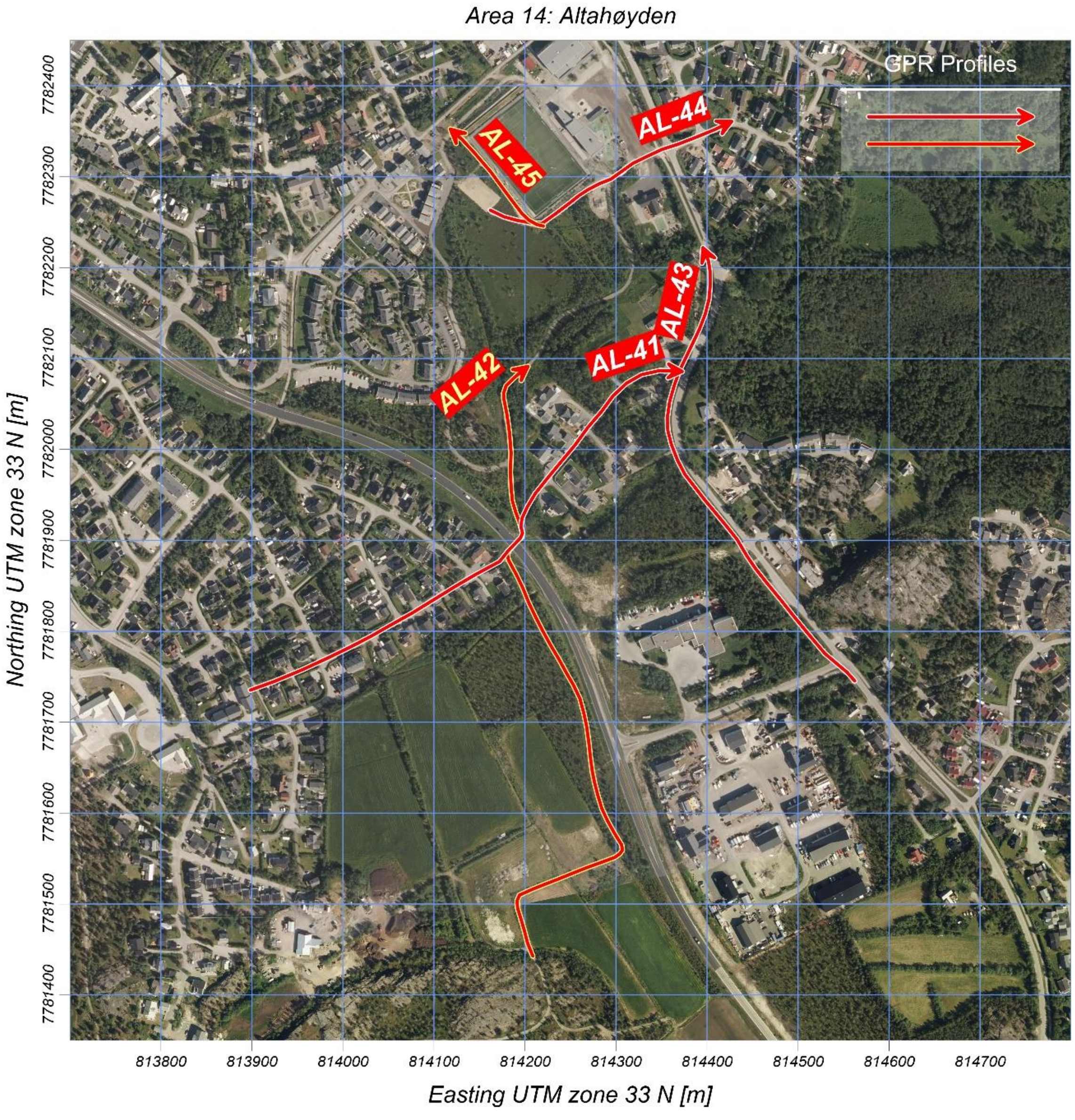


Figure 4.14.1: Positioning of Georadar profiles AL-41, AL-42, AL-43, AL-44 and AL-45 collected at Altahøyden area. Orthophoto: Vest Finnmark (Field-Group, 2023).

As in Thomasbakken, the ATA plots for the profiles measured at Altahøyden presented in Figure 4.14.2 show a similar signal attenuation time, i.e., 350 nanoseconds. The calculated velocity for this area is 0.11 m/ns, which is slightly higher than that in Thomasbakken. This results in a slightly increased penetration depth, approximately 19 meters.

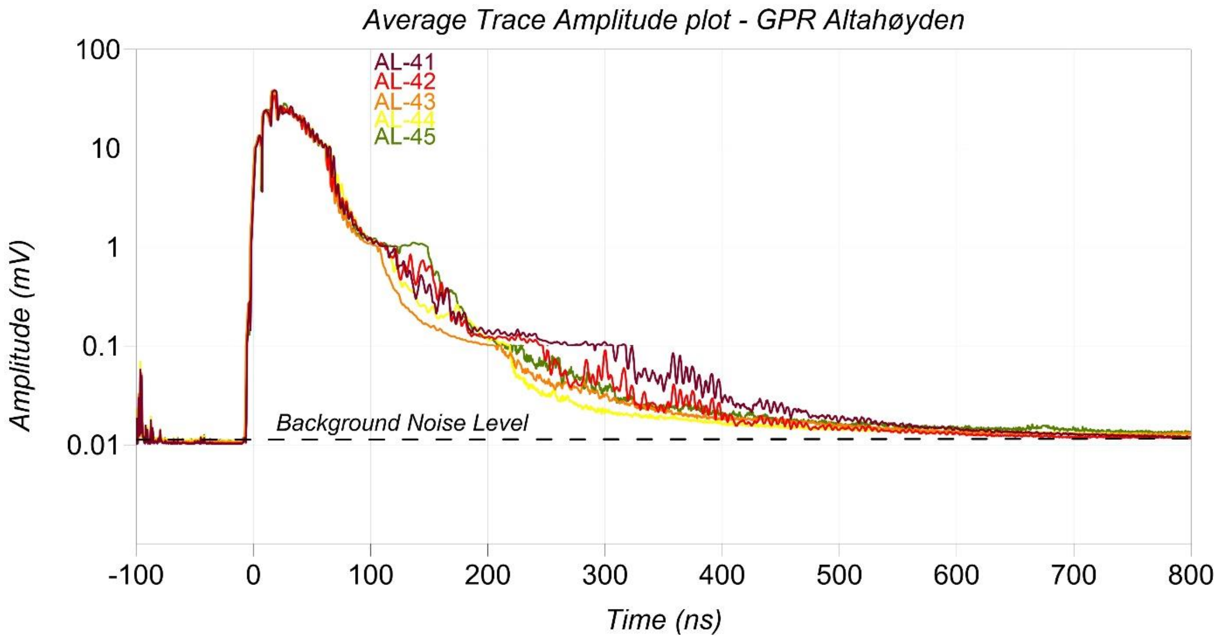


Figure 4.14.2: GPR signal Average Trace Amplitude (ATA) for Altahøyden subarea displaying the penetration depth achieved.

The radargrams from Altahøyden, as shown in Figure 4.14.3, reveal a generally challenging environment for GPR measurements, with limited penetration and weak signal due to poor permittivity conditions. Most profiles only display a shallow superficial reflection layer, lacking any substantial features at greater depths. Additionally, noise interference from nearby artificial structures is significant; for instance, profiles AL-41 and AL-42 show blanked sections due to crossing through a pedestrian tunnel under the highway, while profile AL-43 displays prominent thin vertical noise artefacts likely due to underground piping or wiring.

Despite the challenges, certain valuable features are visible within some GPR profiles at Altahøyden. Besides **profile AL-41** that does not capture any interesting features, **profile AL-42** captures initial signs of northward-dipping layers around the 40-meter mark, although these reflections weaken beyond approximately 10 meters depth. Between 160 and 360 meters, a more defined top layer emerges, with weak reflections beneath it that hint at additional northward-dipping layers. Notably, after a topographic descent beginning around the 500-meter point, rich reflections persist nearly to the profile's end. Here, a set of reflections is observed dipping northward at a slightly steeper rate than the surface, forming a basin-like structure that deepens to about 7 meters below the surface. While the basin itself appears largely non-reflective, its base is well-defined.

Profile AL-43 contains little information about underlaying sediments besides its first 60 meters, with traces of a flat lying reflection at around 36 meters above sea level. However, a bit farther to the north at a lower elevation, both **AL-44** and **AL-45** profiles consistently pick up a flat reflection at approximately 20 meters above sea level. Given the positioning of these measurements, this flat lying reflection represents a geological boundary located to the west of the small area surveyed by these two profiles. Moreover, the final 100 meters in profile AL-44 show an 8-meter-thick area of high reflectivity of westward dipping, but at a very gentle angle.

In profile AL-43, only limited sedimentary information is captured, with a faint, flat reflection around 36 meters above sea level between 100 and 160 meters. In contrast, profiles AL-44 and AL-45, positioned to the north of Alltahøyden area at lower elevations, consistently detect a flat reflection at about 20 meters above sea level, suggesting a geological contact to the west of this surveyed section. Additionally, the last 100 meters of profile AL-44 reveal a high-reflectivity zone, approximately 8 meters thick, with traces of westward-dipping layers at a gentle angle.

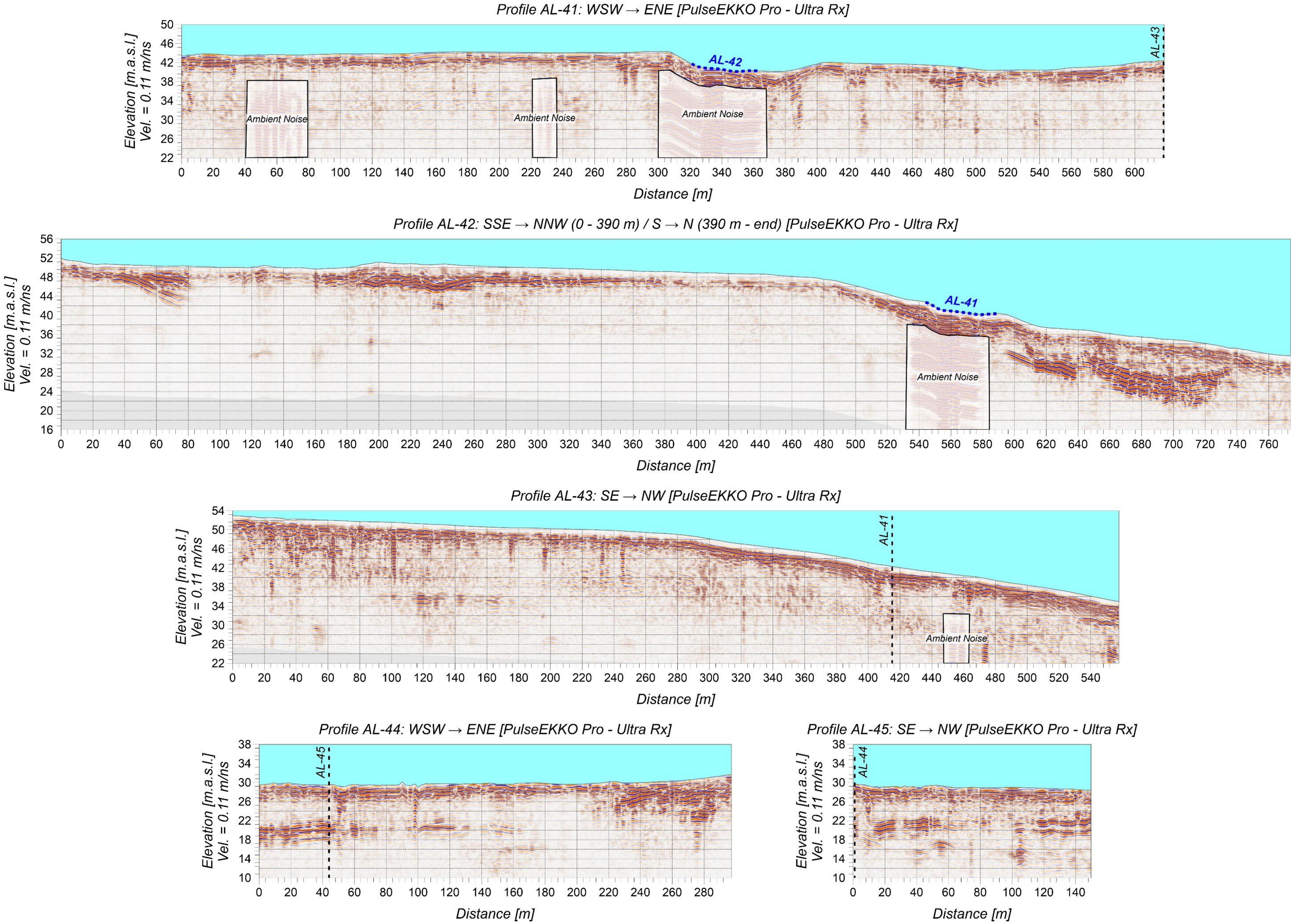


Figure 4.14.3: Processed radargrams for profiles AL-41, AL-42, AL-43, AL-44 and AL-45.

5. CONCLUSIONS

The extensive GPR survey conducted across multiple subareas south of Alta, reveals notable patterns in subsurface structure and depositional environments. The combined data gathered using PulseEKKO Pro and Malå RTA systems have enabled a detailed view of variations in reflectivity, attenuation, and structural layering across 14 distinct locations, each characterized by various geophysical signatures. Key interpretations are based on the continuity of reflections, the presence of dipping layers, and the varying penetration depths achieved with each system, all of which aids in understanding depositional trends and geological boundaries within this region.

The GPR survey at **Kråkneset** revealed well-defined horizontal and gently dipping layers, with a strong reflective top layer above a distinct non-reflective base, likely representing clay or other fine-grained, high-attenuation materials. This structure suggests a coarse-grained layer overlaying finer sediment. In the wider Alta area, GPR survey results reveal significant variation in permittivity conditions related to sediment composition. The survey area divides effectively into two parts: the northern areas near Alta town and the southern areas extending farther out.

In the northern areas, including **Altahøyden, Thomasbakken**, and all profiles measured in the wider **Tverrelva** river valley, GPR achieved mostly moderate to shallow penetration depths, suggesting fine-grained sediments with higher water content, which likely hastens signal attenuation. Despite these conditions, interesting subsurface features emerged, in the form of sharp transitions in reflectivity. This highlights that, even in areas with less ideal permittivity, GPR can still yield useful data, capturing localized reflectivity contrasts and providing valuable geological insights.

Conversely, almost all **southern areas** displayed more favourable permittivity, allowing for deeper penetration and clearer imaging of subsurface layers. These regions generally consist of coarser-grained sediments, aligning with higher permeability and lower water retention, which enhances signal transmission and depth. Here, GPR data were instrumental in identifying sedimentary layering and stratigraphic features, including dipping layers and basin-like structures, offering a more comprehensive view of the subsurface.

Ambient noise levels had a significant impact on GPR data in certain areas, with artificial structures such as housing, power lines, energy installations, and underground wiring and piping causing interference. These disturbances manifest as artefacts on the radargrams, affecting the clarity of the recorded data which complicate the identification of true geological features. In some cases, filtering out these noise signals proved impossible.

Despite these challenges, valuable geological information could still be extracted, particularly when noise sources were properly identified and marked. In areas like **Energiveien, Altahøyden**, and **Thomasbakken**, where noise from nearby infrastructure was prevalent, the GPR survey still managed to capture important subsurface features. By focusing on reflections that were not influenced by the artificial disturbances, it was possible to interpret key geological structures, such as sedimentary layers and possible faults, even in noisy environments.

In conclusion, the GPR survey presented in this report explored diverse deposits across the Alta region, revealing complex subsurface geology through GPR profiling. It captured a range of features, from foreset-dominated layers in **Sierra** to the intricate stratigraphy in Skillemoveien and clay-rich sediments in **Tverrelva** valley, indicating fluvial, deltaic, and possibly marine processes. Despite challenges from ambient noise in areas like **Energiveien, Altahøyden,** and **Thomasbakken**, valuable data on subsurface reflectivity and stratification was still obtained.

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GEOLOGICAL
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NORWAY
- NGU -

Geological Survey of Norway
PO Box 6315, Sluppen
N-7491 Trondheim, Norway

Visitor address
Leiv Eirikssons vei 39
7040 Trondheim

Tel (+ 47) 73 90 40 00
E-mail ngu@ngu.no
Web www.ngu.no/en-gb/