NGU REPORT 2020.039

Quaternary mapping at Orkdal, Orkland municipality with the use of Georadar measurements, 2016 – 2019

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NORGES GEOLOGISKE UNDERSØKELSE
- NGU -

REPORT

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Report no.: 2020.039	**ISSN: 0800-3416 (print)** **ISSN: 2387-3515 (online)**	**Grading:** Open

Title:
Quaternary mapping at Orkdal, Orkland municipality with the use of Georadar measurements, 2016 – 2019

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County: Trøndelag	**Commune:** Orkland
Map-sheet name (M=1:250.000) Trondheim	**Map-sheet no. and -name (M=1:50.000)** 1521-I Orkanger, 1521-IV Snillfjord
Deposit name and grid-reference:	**Number of pages:** 43 **Price (NOK):** 195 **Map enclosures: -**

Fieldwork carried out: 11/2016 – 11/2019	**Date of report:** 08.2021	**Project no.:** 368000	**Person responsible:** Marco Brönner

Summary:

Between November 2016 and November 2019, NGU carried out Georadar measurements in several localities in Orkland municipality in connection with mapping of Quaternary sediments. Specifically, GPR lines were measured at the wider Gjølme area (2016 - 2017), along the entire Skjenaldelva river valley (2017 – 2019) and the area around and east of Orkdal church in Fannrem (2018 - 2019). The measurements include a total of 64 individual profiles with a total length of 13.5 km. By reason of ensuring high resolution along with satisfying penetration, the main frequency used was 100 MHz. Both in-house systems available at the NGU were used according to terrain conditions i.e., PulseEKKO PRO was mostly used along roads and flat fields free of vegetation while Malå RTA was employed at more uneven/challenging terrains.

The purpose of the Georadar measurements was to provide subterrestrial information on the Orkdal sediments which would aid the project of updating the old Quaternary maps from the 1970s, resolve complex geology in selected localities and supplement a master's thesis focused on the Skjenalddalen tributary valley. This report describes all stages of the GPR survey (method, implementation, processing) and presents maps and figures for all measured radargrams. To better present the results of this 4-year survey, the total area has been divided in four distinct subareas, namely Gjølme, Skenalddalen north-east, Skjenalddalen south-west and Fannrem. For each area, a brief description of the results is given along with a general Quaternary geological interpretation.

The measurements were performed over deposits of variable composition and origin, namely marine and fluvial or glaciofluvial sediments. In that sense, results vary from minimal penetration where clay is dominant to clean horizontal or dipping reflectors where fine deposits like sand or gravel prevail. In most cases, the use of 100 MHz GPR frequency yielded adequate resolution while the maximum penetration depth achieved was approximately 25 meters. The resulting radargrams revealed contacts between sediments of different composition and grain size, the hidden geometry of deposit layers, traces from old shoreline landslides in quick clay areas etc. Lastly, GPR profiles constitute a constant source of information for Skjenalddalen and Orkdal, and can be revisited to supplement future surveys in the wider area.
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Keywords: Geophysics	Georadar	Quaternary Geology
Sediments	Mapping	Valley Fill
		Scientific Report

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1. INTRODUCTION

The GPR measurements reported here were carried out in association to a mapping project in the northern part of Orkdalen addressing the valley's Quaternary geology. The area is already covered by an old Quaternary map from 1977 (Reite 1977, 1983). However. more detailed mapping was done to provide a more accurate and up to date map based on fieldwork, modern LiDAR data and other additional information (Hansen & Gislefoss, 2019; Hansen & Gislefoss, in prep). The geophysical investigations were done to get a better understanding of selected areas displaying a relatively complex geology. For example, some of the measurements have helped to reveal traces from old shoreline landslides in areas where quick clay has also locally been detected (Hansen et al. 2019). Some extra GPR measurements were carried out in the nearby Skjenalddalen tributary valley as a basis for a master study (Berntsen-Hagelund, in prep). A more detailed description of the Quaternary geology provided by the new map of Northern Orkdalen is given by Hansen & Gislefoss (in prep).

GPR was promoted as the main geophysical method to survey the Quaternary deposits in Orkdal due to the known low electrical conductivity ground conditions in Norway which allows deep signal penetration in favorable formations. The combined results presented in this report refer to data collected during a 4-year period, from 2016 to 2019. The first survey in Gjølme took place during a snowy day in November 2016 using the PulseEKKO PRO cart with 100 MHz antennas (Sensors & Software, 2005). In October 2017 and July 2018, additional profiles in Gjølme were conducted along with the largest part of the Skjenalddalen valley and Fannrem surveys in snow-free conditions, using the Malå RTA (Snake) system in addition to the cart (100 MHz frequency). However, due to the inability of completing a few planned profiles in Skjenalddalen (animals, equipment problems) and the fact that the quality of the data collected with the cart in Fannrem was below standards due to strong ambient noise, we returned to both areas in November 2019 and concluded the survey.

2. METHOD

Ground Penetrating Radar (GPR) or Georadar as is also commonly mentioned, is an electromagnetic geophysical technique which can be used to investigate stratification in the underground. It uses electromagnetic fields to probe lossy dielectric materials to detect structures and changes in material properties within the materials (Davis & Annan,1989). With GPR, the electromagnetic fields propagate as essentially nondispersive waves. The signal emitted travels through the material, is scattered and/or reflected by changes in impedance, giving rise to events which appear similar to the emitted signal (Butler, 2005). These reflected signals are registered at the surface and utilized to reconstruct interfaces in the ground. This is achieved by the compilation images where 1D electromagnetic "soundings" are positioned consecutively to create a uniform 2D image (radargram – **figure 2.1**).

In lossy dielectric materials, electromagnetic fields can only penetrate to a limited depth before being absorbed. Hence, exploration depth is always a variable. However, the frequency range where GPR functions is between 1 and 1000 MHz, and the choice of frequency also controls the projected depth of an investigation. In lower frequencies, the pulses are easily dispersed while at higher frequencies the signal absorption becomes too strong and the penetration depth extremely limited. GPR studies are therefore planned with a frequency choice that compromises penetration depth (lower frequencies) with desired signal resolution (higher frequencies) in relation to the survey goals.

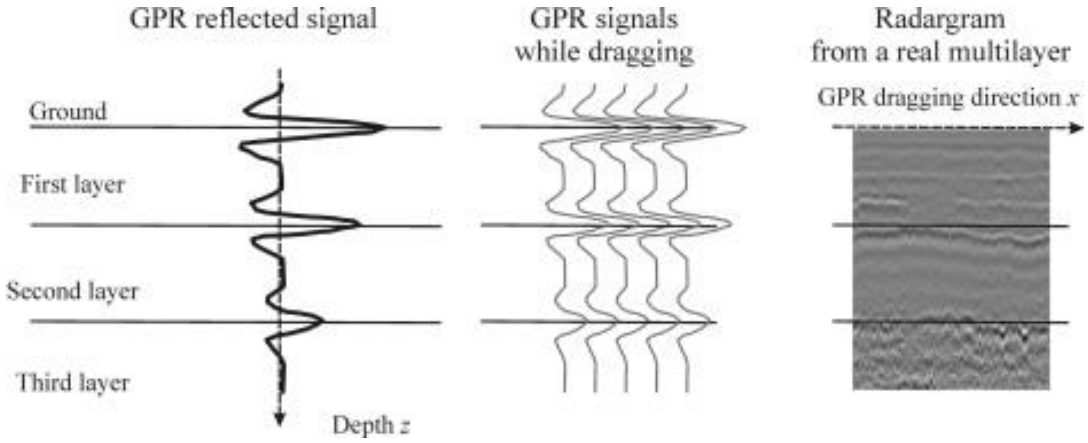


Figure 2 1: *From a single GPR signal to a radargram (Benedetto A. & Benedetto F., 2014).*

3. DATA / PROCESSING

64 profiles that correspond to a total of roughly 13,5 km of data, were measured at Orkdal. Based on the need to balance data resolution with penetration depth, the 100 MHz antenna frequency was picked for utilization. This frequency offers a projected penetration of a few tens of meters and a detail level of about 0.5 m, so that information about the internal sediment structure can be revealed to a satisfactory extent. Both systems available to the NGU, namely PulseEKKO PRO by Sensors & Software and Malå RTA (Snake) by Guideline GEO were employed at Orkdal, depending on the terrain. Ideally, the former is a better choice than the latter in terms of signal quality (Tassis & Rønning., 2015) but its perpendicular broadside antenna configuration (antennas parallel and dragged perpendicularly) makes it deployable only on flat and open surfaces. In uneven or vegetated areas where the cart is impossible to operate, the Snake system is used due to its parallel endfire antenna configuration (antennas in a row and dragged in-line) to provide data of slightly inferior quality. Trace spacing was set equal to 0.25 meters, time window equal to a maximum of 30 meters depth coverage on a default 0.1 m/ns velocity and triggering was prompted either by the cart odometer for PulseEKKO PRO of by the hip-chain of the Snake system. Positioning along lines was registered using a Garmin GPSMAP 60Cx handheld GPS and then tied to the GPR data.

Due to the large extent of this 4-year survey reported here and for more comprehensive presentation, the general Orkdal area has been divided into four subareas: Gjølme (18 profiles - 2782 meters), Skjenalddalen north-east (25 profiles - 6018 meters), Skjenalddalen south-west (13 profiles – 2629 meters) and Fanrem (8 profiles – 2025 meters). **Figure 3.1** presents the location of the profiles measured in Gjølme and the entire Skjenald river valley (Skjenalddalen) plotted on the Quaternary map available for the area today while **figure 3.2** shows the same for Fannrem which is found a bit farther to the south from Orkanger. Profiles are shown in simple red lines to depict their relation of the GPR survey to the Quaternary geology of the study area.

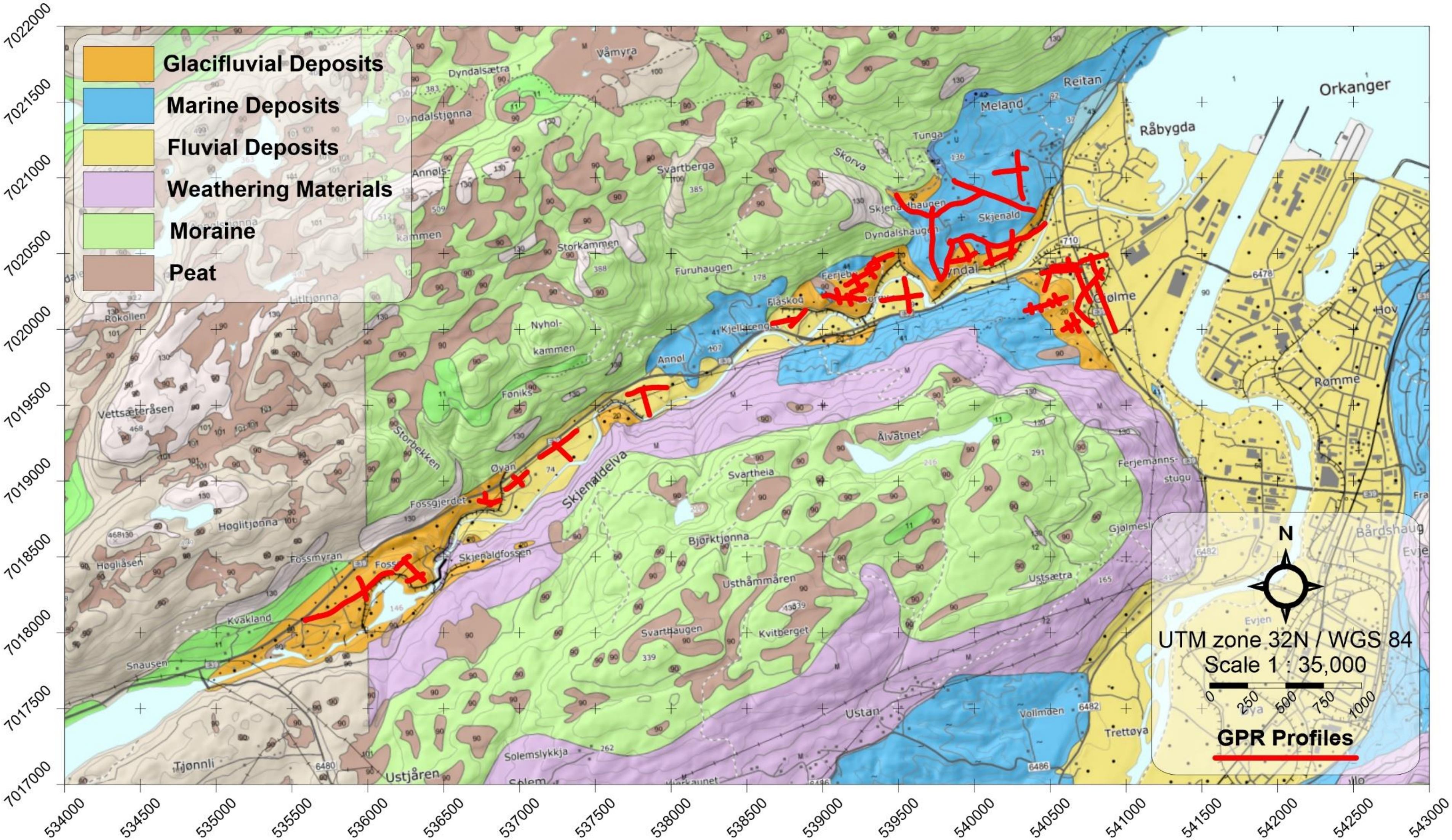


Figure 3.1: *Positioning for Georadar profiles collected in Gjølme and Skjenalddalen (red) plotted on Quaternary geology map (Reite, 1977; Reite, 1980).*

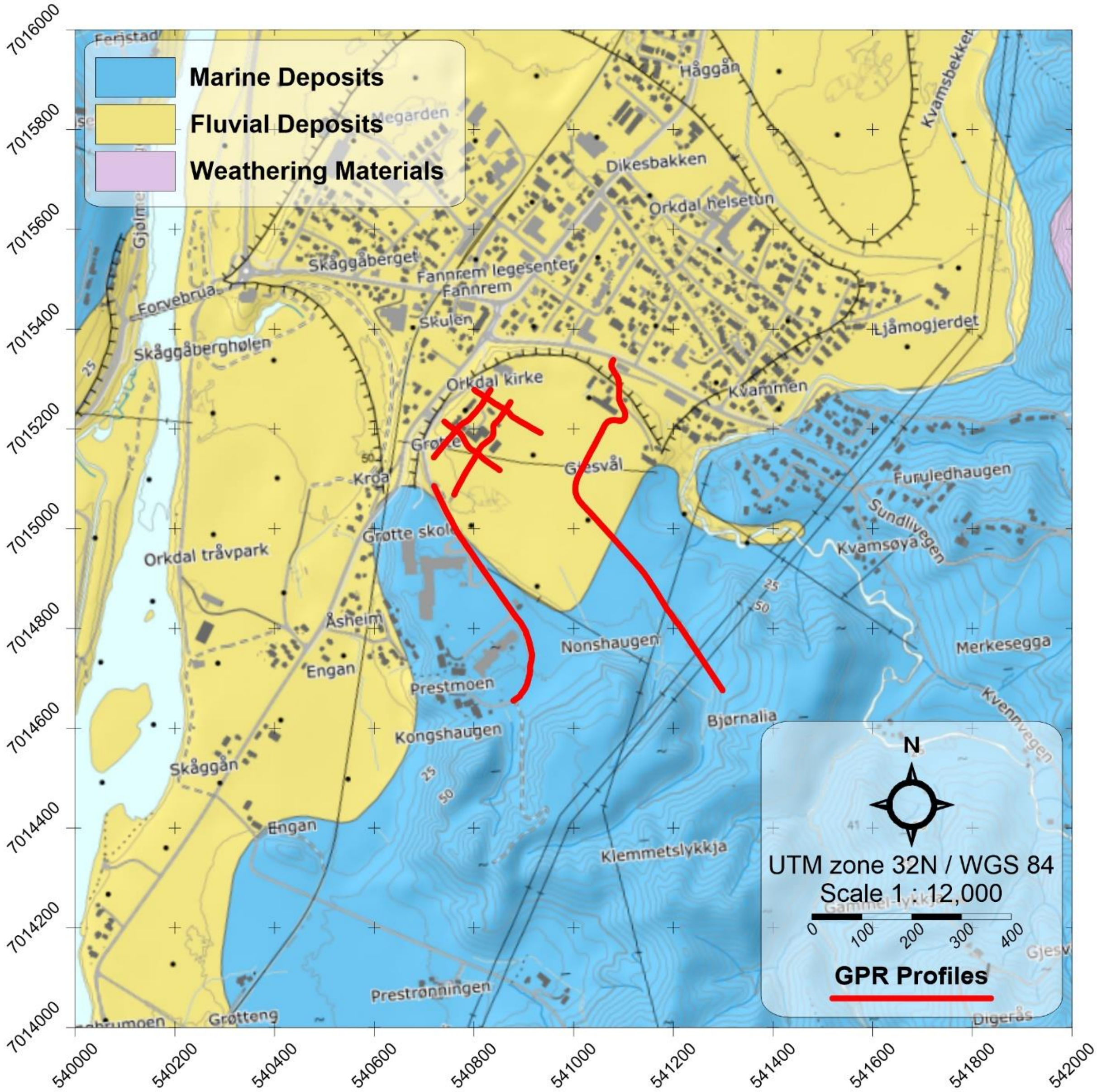


__Figure 3.2:__ Positioning for Georadar profiles collected in Fannrem (red) plotted on Quaternary geology map (Reite, 1977).

As seen, most of the conducted lines are extending on either fluvial or glaciofluvial deposits while a few of them can be found on marine sediments, especially in the north-eastern tip of Skenalddalen. In theory, the attenuation of the electromagnetic GPR signal in high dielectric permittivity materials such as sand or gravel is slow and thus maximal skin depth (depth at which the transmitted wave loses one third of its original amplitude) is allowed. In other words, maximal penetration according to frequency is expected in the yellow/orange areas in **figures 3.1** and **3.2**. On the other hand, highly conductive formations such as clay, attenuate the signal much faster and thus minimal penetration is expected in areas shown in blue respectively. On that note, profiles in Gjølme and Fanrem that cross over from either fluvial or glaciofluvial to marine sediments, should highlight how increased conductivity affects signal attenuation.

Preparation of GPR data required position refining and elevation sampling from available Digital Terrain Models (DTM). In the case of Orkdal, positioning was logged with a handheld GPS which has a 3-meter error margin. However, the availability of high resolution orthophotos helped regulate positioning with help from landmarks such as field limits, roads, buildings etc. After optimal positioning was assigned to every trace, detailed elevation was sampled from the Mapping Authority's Orkdal DTM (0.5 m resolution – Kartverket, 2016). All data were therefore processed and are subsequently presented with relatively accurate topography.

All collected data were processed with software package EKKO_Project v.5 regardless of which system was employed. Therefore, it was required for all Snake system data (rd3 file format) to be converted into EKKO_Project compatible files (dt1 format) and that was accomplished with ReflexW v.9.1 software. As a result of the big number of measured profiles, the two fundamentally dissimilar systems used and the different years and ground conditions that these data were collected, processing is not uniform but rather optimized per individual profile. Hence, **table I** presents a summarized description of the modules used with rounded-up information. Lastly, it should be noted that the velocity picked for depth conversion is the default one (0.1 m/ns) due to lack of CMP (Common Mid-Point) measurement.

Processing module	***Value / Description***
Edit First Break	*4 -40 ns (only Snake data)*
Bandpass Filter	*Fc1 0 % / Fp1 20 % / Fp2 100 % / Fc2 120 %*
Depth Conversion	*Velocity 0.1 m/ns*
Dewow	*Window Width (Pulse Widths): 1.33*
Background Subtraction	*Filter Width: 20 m (rectangular)*
SEC2 Gain (PulseEKKO PRO)	*Attenuation 0.7 - 2.5 dB/m, Start Gain 0.5 – 1.0, Maximum Gain 40 - 80*
SEC2 Gain (Malå RTA)	*Attenuation 0.3 – 10.0 dB/m, Start Gain 1.4 – 8.0, Maximum Gain 80 - 300*

Table I: *Processing modules employed in EKKO_Project v5.*

4. RESULTS

In this section, all processed radargrams will be presented, commented upon, and given a brief geological interpretation, categorized per subarea that the general Orkdal area was divided in i.e., Gjølme, Skjenalddalen north-east, Skjenalddalen south-west and Fannrem. Furthermore, since the total number of profiles is still large, each of the aforementioned subareas will also be split in parts according to profile relevance to one another for more comprehensive presentation.

4.1 Gjølme Results

The profiles in Gjølme were conducted within a period of 2 years (2016 – 2017). In total, 18 profiles were measured, adding up to 2782 meters of data (**figure 4.1**). The first fieldtrip took place in November 2016 under heavy snowfall and PulseEKKO PRO system was utilized (cart). As seen in **figure 4.1**, profiles were positioned both along local roads and fields, with the latter being measured on some decimeters of snow. All orange and red profiles were measured on that expedition with the valuable help of NGU colleague Lina Gislefoss, namely profiles GJ-01 to 11, GJ-13, GJ-14, GJ-16 and GJ-18. The remaining profiles shown in light orange and brown, namely GJ-12,-15 and-17, were measured on a second visit to the area in October 2017, on snow-free conditions using Malå RTA (Snake) system.

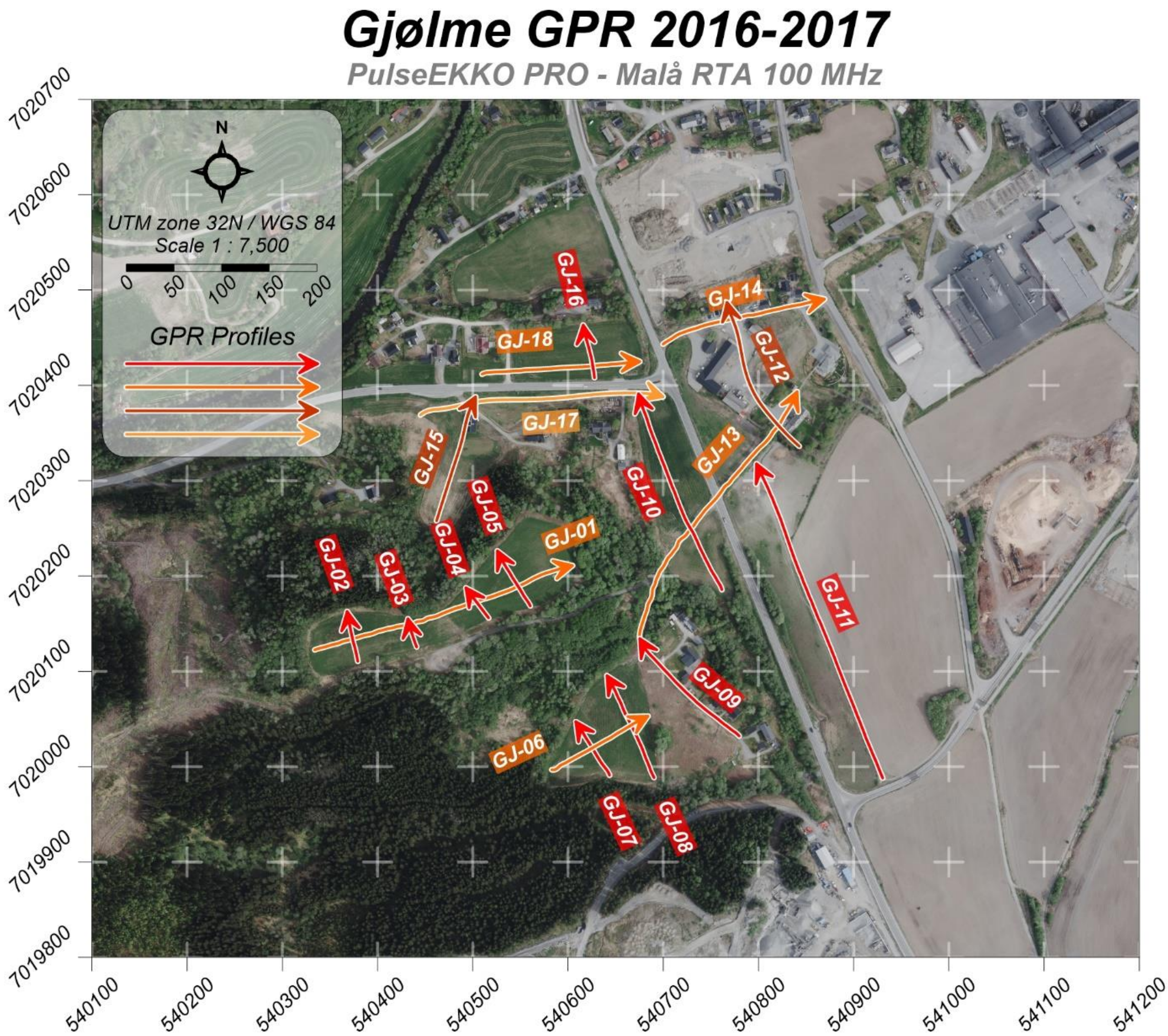
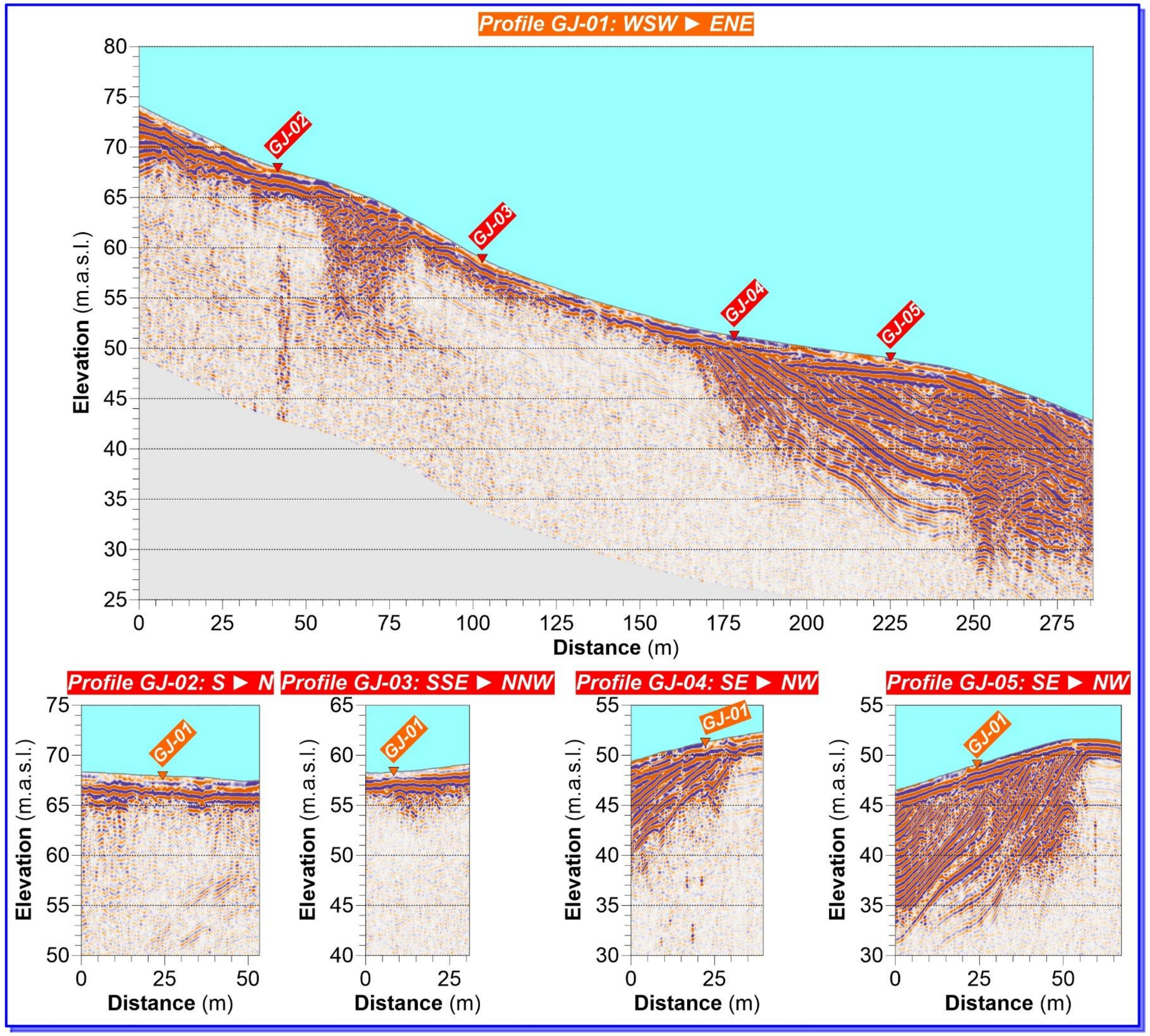
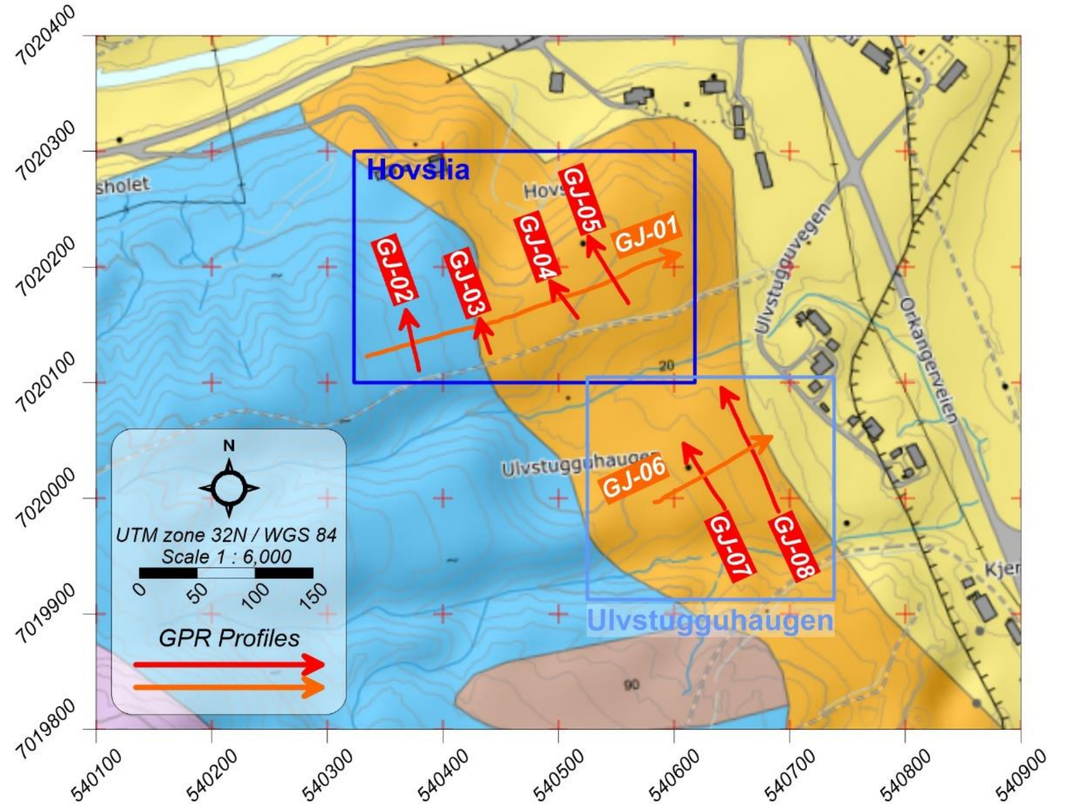


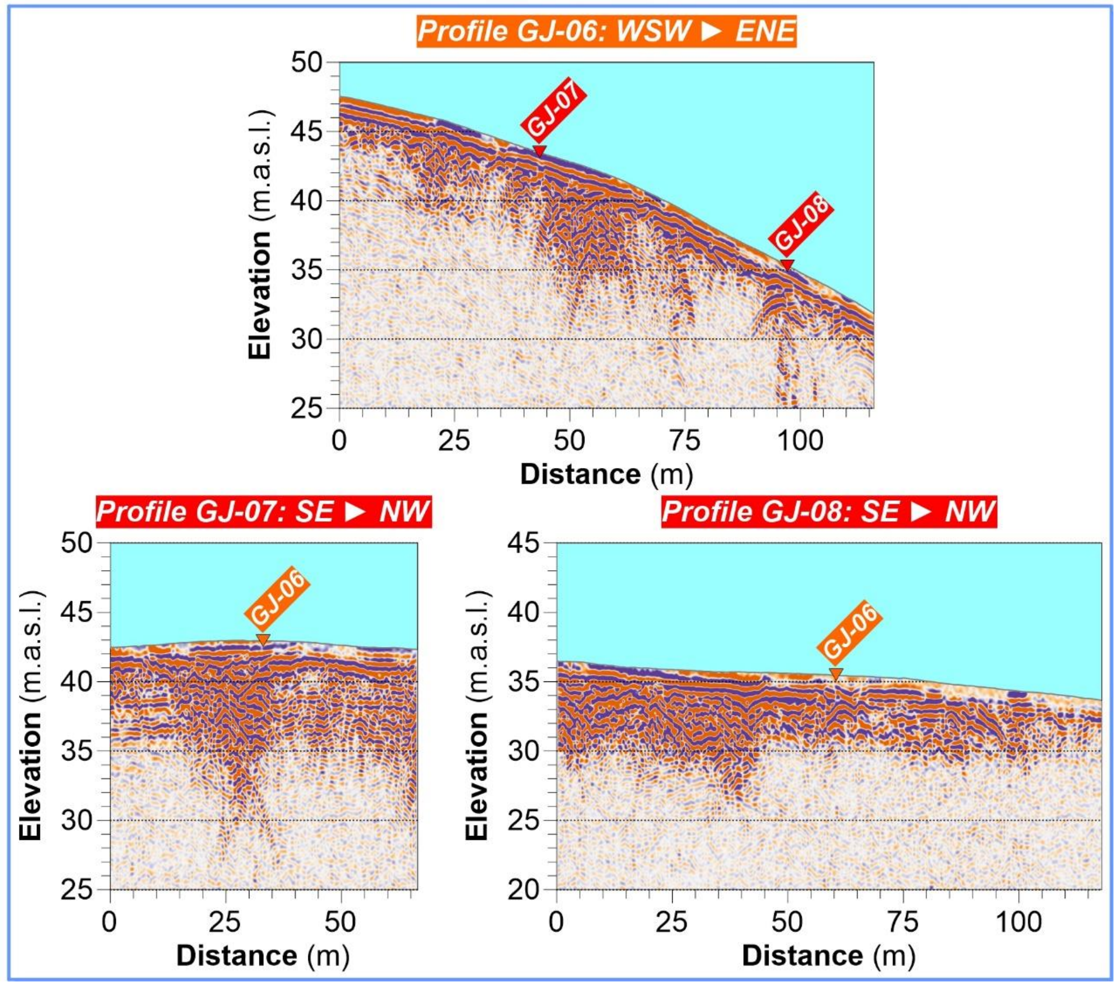
__Figure 4.1:__ Positioning for Georadar profiles collected in Gjølme in 2016 (orange & red) and 2017 (light orange and brown - orthophoto: Orkdal-Meldal-Frøya; Norge i bilder. 2018).

4.1.1 <u>Hovslia / Ulvstugguhaugen</u>

Figure 4.1.1 presents the results for the south-west part of Gjølme study area which includes profiles GJ-01 to GJ-08, all measured in snow-covered fields with PulseEKKO PRO – 100 MHz antennas (perpendicular broadside). Profiles GJ-01 to GJ-05 cover Hovslia and are framed by the blue rectangle while profiles GJ-06 to GJ-08 are located at Ulvstugguhaugen and are framed by the cyan box. The map at the top right corner of **figure 4.1.1** shows the positioning of the profiles in relation to the existing Quaternary map (1521-I Orkanger map sheet after Reite, 1977).







GPR information

Instrument:	Sensors & Software PulseEKKO PRO	**Processing Routines:**	Dewow SEC2 Gain Type Bandpass/Lowpass Filter
Antenna Frequency:	100 MHz - Perpendicular Broadside	**Depth Conversion:**	Velocity 0.100 m/s (Default)
Processing Software:	EKKO_project v.5	**LiDAR Topografi:**	NDH Orkdal 2016 - 0.50m Vertical Exaggeration 3

Figure 4.1.1: *Radargrams for profiles measured at Hovslia (blue frame) and Ulvstugguhaugen (cyan frame) in Gjølme subarea, and map showing positioning of the profiles in relation to the existing Quaternary map (Reite, 1977).*

The Hovslia profiles present a fine example of the influence electrically conductive formations such as marine deposits have on the GPR signal. According to the 1977 Quaternary geology map, profile GJ-01 starts off at marine sediments and then crosses over to glaciofluvial formations at about one third of its length. Profiles GJ-02 to GJ-05 intersect profile GJ-01 at four different positions, with profile GJ-03 appearing to be exactly at the limit between marine and glaciofluvial deposits. However, the GPR results indicate that the shift in formations happens a bit farther down the slope, at about 175 meters and roughly where profile GJ-04 is found. Measurements inside the marine deposits are characterized by minimal penetration (max. 5 meters) and such clayish materials are found on more than half of profile GJ-01, the entirety of profiles GJ-02 and 03 and at the south end of profiles GJ-04 and 05. Respectively, as soon as clay shifts to possible sand or gravel, the GPR signal is transformed into initially eastwards dipping reflectors for profile GJ-01 which seem to flatten out towards the east and north-dipping for perpendicular profiles GJ-04 and GJ-05. Essentially, it may be extracted that foresets found here are dipping towards the north-east. The penetration follows the dipping sandy layers and is maximally 20 meters. However, it is unsafe to conclude whether this is the maximum thickness of these sediments or the point where the electromagnetic signal is fully spent. Another interesting feature of profile GJ-01 can be found between 25 and 50 meters of distance, where penetration is locally doubled in relation to the neighbouring clays, at a location where the old Quaternary map marks the transition from marine to glaciofluvial sediments. However, the true limit is revealed to be more to the east, whereas localized packages of sand/gravel (~20 meters in horizontal dimension) may still be found within clay.

In Ulvstugguhaugen, profiles GJ-06 to 08 appear to be entirely on glaciofluvial sediments however, GPR measurements present neither the penetration nor the layering observed in the east of Hovslia. In most cases penetration is minimal (5 meters) indicating the strong presence of clay, while limited localities of 10-meter penetration can be found on all three of these profiles, namely where GJ-06 and 07 cross but also between 30 and 50 meters in profile GJ-08. These areas can again represent glaciofluvial packages within marine deposits, but the Georadar-results obtained in this area show that either the glaciofluvial cover is quite thin (5-10 meters) or clay is the dominant formation here and not sand or gravel like is shown in the old Quaternary map in **figure 4.1.1**.

4.1.2 Orkangerveien / Gjølme center

This set of results shown in **figure 4.1.2** focuses on the eastern half of Gjølme where profiles GJ-09 to 11 and GJ-13 to 14 were measured with PulseEKKO PRO while profile GJ-12 was collected with Malå RTA (Snake). GPR frequency used was 100 MHz with perpendicular broadside antenna configuration for the former and parallel endfire for the latter. Results are again subdivided into two areas, namely Orkangerveien in the south framed by the blue line and Gjølme center in the north marked by the cyan one. Recurrently, the existing Quaternary map is shown in support of the GPR measurements.

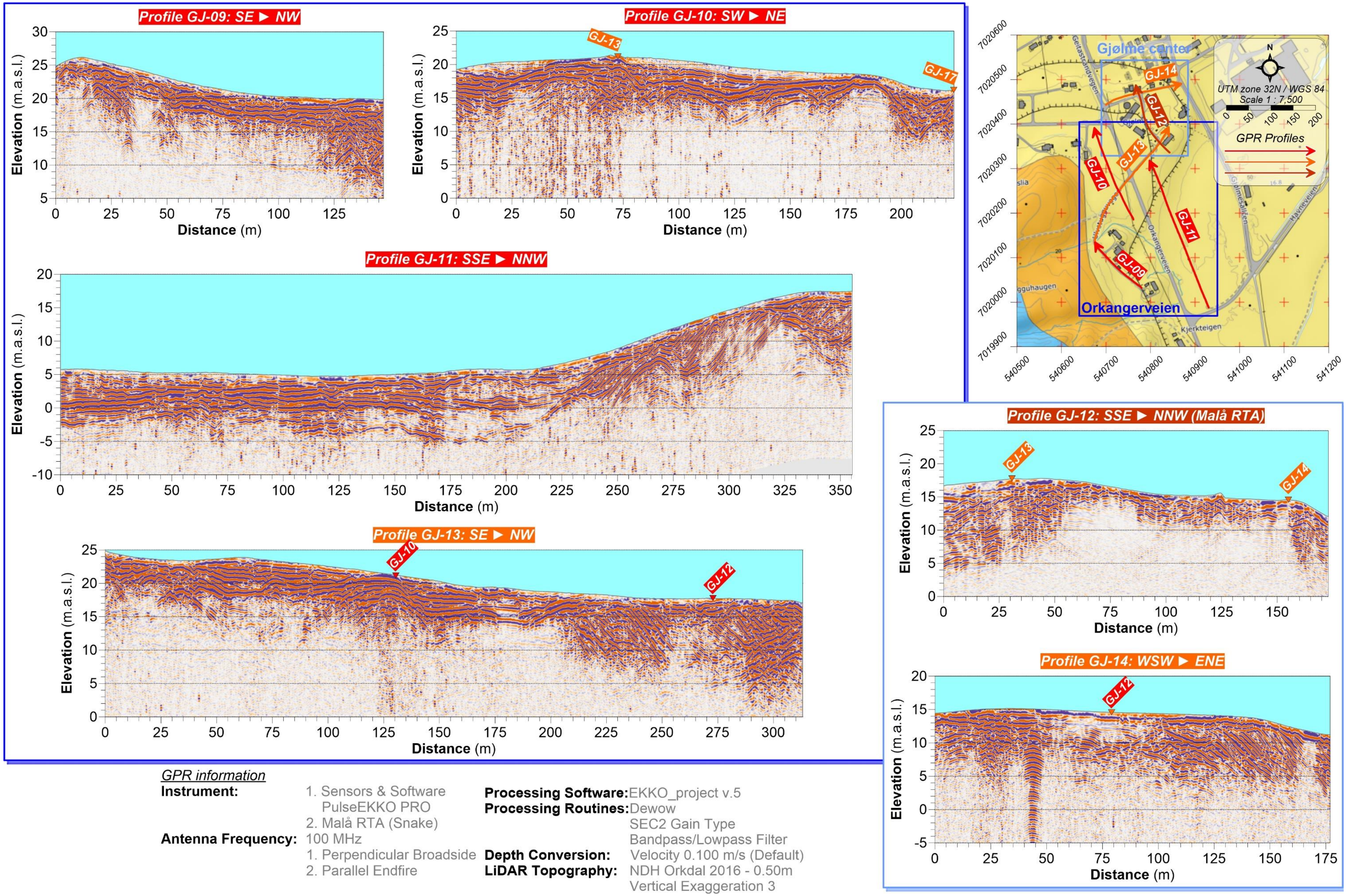


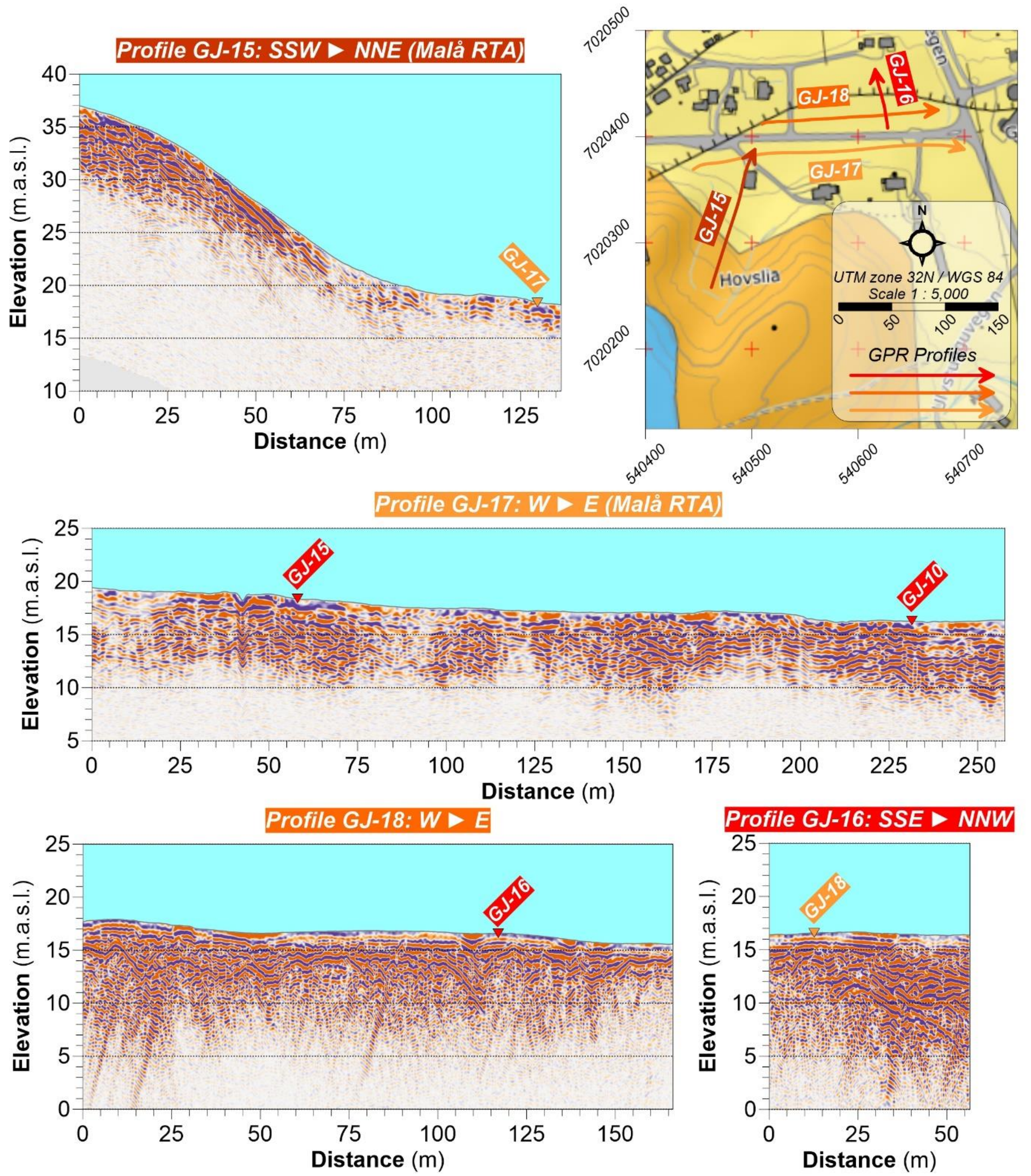
Figure 4.1.2: *Radargrams for profiles measured at Orkangerveien (blue frame) and Gjølme center (cyan frame) in Gjølme subarea, and map showing positioning of the profiles in relation to the existing Quaternary map (Reite, 1977).*

As seen in **figure 4.1.2**, all profiles presented here are well within fluvial sediments according to the existing Quaternary map. The profiles alongside Orkangerveien (GJ-09 to 11) and the one crossing the main road obliquely (GJ-13), are characterized by mostly clear horizontal reflectors of maximally 10 meters of penetration to the south of the blue rectangle area, while the northward rise in elevation from 5 to 15-20 meters above sea level is accompanied by a shift towards more undulating layers. This is more emphasized in profiles GJ-10 and GJ-11 (second half), but also in the middle part of profile GJ-13. The fact that achieved penetration does not exceed 10 meters while measuring over fluvial sediments, indicates that the possible thickness of this formation is similar to what is seen in the radargrams. Regardless, areas of sudden increase in penetration can still be found in almost all profiles, especially at the end of profile GJ-09 and at two different spots along the second half of profile GJ-13. Penetration depth in these areas jumps from about 7-8 meters to over 15 meters, while no specific structuring can be extracted due to the crisscrossing outlook of the detected reflectors which may be due to crossing foresets in a direction perpendicular to their dipping orientation. The only exception for Orkangerveien can be seen for the sand/gravel package between 200 and 250 meters in profile GJ-13, where a south-east dipping pattern may be observed.

In Gjølme center which is framed by the cyan rectangle in **figure 4.1.2**, radargrams for profiles GJ-12 and GJ-14 describe two different regimes. Profile GJ-12 starts of at the same area where profile GJ-13 ends where a localized package of possible sand/gravel is yielding a 15-meter penetration depth. However, while going through houses and farms, penetration drops rapidly to less than 5 meters which is indicative for clay. Profile GJ-14 on the other hand, shows a more stable penetration rate of about 7 to 10 meters, which is characterized by horizontal reflectors on its western half and eastward dipping reflectors on its eastern half. It should be noted that since profiles GJ-12 and GJ-14 were measured with Snake and PulseEKKO PRO system respectively, the data quality in GJ-14 is superior. This can be seen at the cross point between these two profiles where the cart enables resolving more reflectors around 5 meters from the surface, while the Snake system's signal is completely spent after 2 meters of penetration.

4.1.3 Skjenaldsveien

The last part of the Gjølme area is named after the main road E39 that enters Skenald valley (Skjenalddalen) and it contains four profiles in total. Profiles GJ-15 and 17 south of the road were measured with the Snake system while profiles GJ-16 and GJ-18 north of the road were conducted with the PulseEKKO PRO cart. The existing Quaternary map suggests that all profiles were collected over formations favourable to GPR method, particularly fluvial deposits except for the first one-third of profile GJ-15 which covers glaciofluvial sediments. All profiles presented here were measured on either snow-covered (GJ-16 and 18) or snow-free (GJ-15 and 17) fields.



<u>*GPR information*</u>

Instrument: 1. Sensors & Software PulseEKKO PRO
2. Malå RTA (Snake)

Antenna Frequency: 100 MHz
1. Perpendicular Broadside
2. Parallel Endfire

Processing Software: EKKO_project v.5

Processing Routines: Dewow
SEC2 Gain Type
Bandpass/Lowpass Filter

Depth Conversion: Velocity 0.100 m/s (Default)

LiDAR Topografi: NDH Orkdal 2016 - 0.50m
Vertical Exaggeration 3

Figure 4.1.3: *Radargrams for profiles measured at Skjenaldsveien in Gjølme subarea, and map showing positioning of the profiles in relation to the existing Quaternary map (Reite, 1977).*

After a quick glance at **figure 4.1.3**, one can immediately note that these data have not yielded results that justify being measured over favourable formations, except for profile GJ-16. Profile GJ-15 measured with use of the Snake, starts off with a minimal penetration of 5 meters and inconclusive geometry for its reflectors at the top of the slope towards Hovslia, but then the signal decays to almost no penetration at all at the level of the road. Neighbouring profile GJ-17 which is collected with use of the cart south of Skjenaldsveien and parallel to the road, does not reveal data of much better quality than the profile described above. It does yield stronger reflectors that appear to be sub-horizontal, but they are often discontinued by areas of no penetration which could be due to the presence of clay.

North of the road, profile GJ-18 is more continuous in signal than profile GJ-17, but the depth penetration and appearance of reflectors are still inconclusive. In addition, the profile is plagued by ambient noise with inflicts linear features throughout the length of the radargram. The noise can be associated with powerlines and neighbouring structures such as farmhouses and auxiliary facilities over and inside the field where measuring took place. The only profile that returns results that could be attributed to fluvial deposits is profile GJ-16 which in its small length and noisy content unveils reflectors slightly dipping towards the north and a depth penetration of around 15 meters. In general, GPR-profiling here points towards a thin cover of fluvial sediments if not strong presence of clayish materials that consume the electromagnetic signal fast and inhibit further penetration.

4.2 Skjenalddalen North-East Results

As the name implies, this subarea refers to the north-eastern part of Skjenald river valley. This part of the Orkdal survey consists of 25 profiles - namely SkNE-01 to 25 - amounting to 6 km of data whose position is shown in **figure 4.2**. All profiles were collected using Malå RTA (Snake) system with the standard parallel endfire antenna configuration of 100 MHz frequency. Even though the majority of profiles was planned and subsequently measured in fields, those that were originally planned on roads were not obtained with the cart due to equipment problems. Profiles SkNE-11 to 25 were carried out in October 2017 while profiles SkNE-01 to 10 in July 2018 due to the presence of animals in the fields that forbade the completion of the survey in 2017. Ground conditions on the first fieldtrip were wet from rain prior to measuring and generally drier in comparison during the second one.

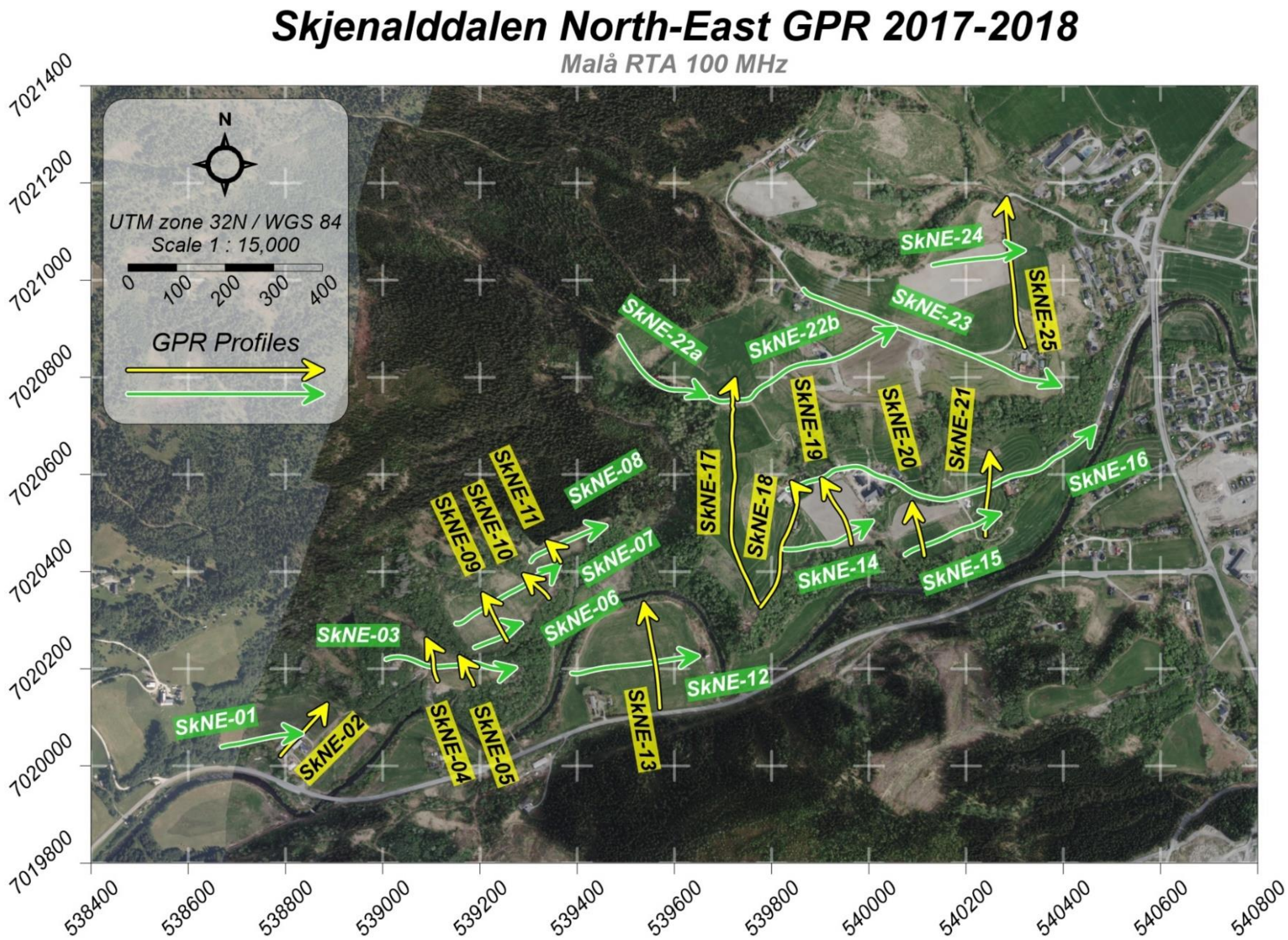


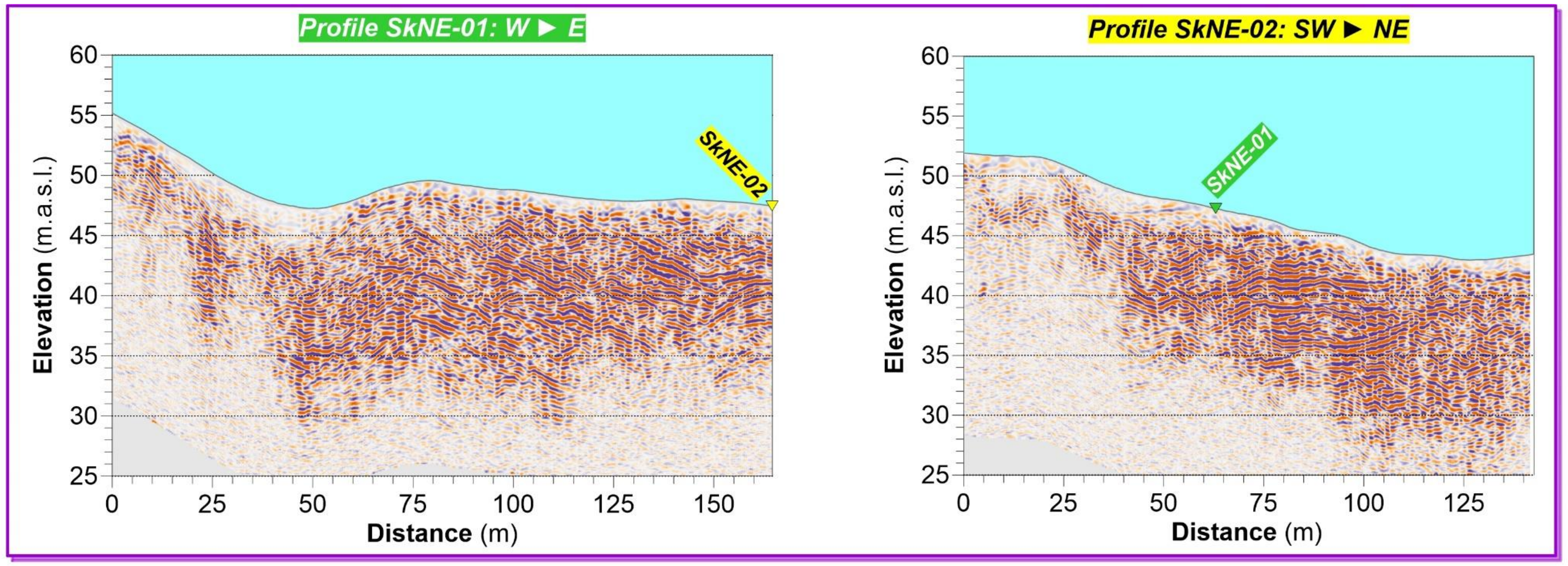
Figure 4.2: *Positioning for Georadar profiles collected in Skjenalddalen North-East in 2017 and 2018 (Orthophoto: Orkdal-Meldal-Frøya; Norge i bilder. 2018).*

4.2.1 Kjellarenget / Kjerringhaugen

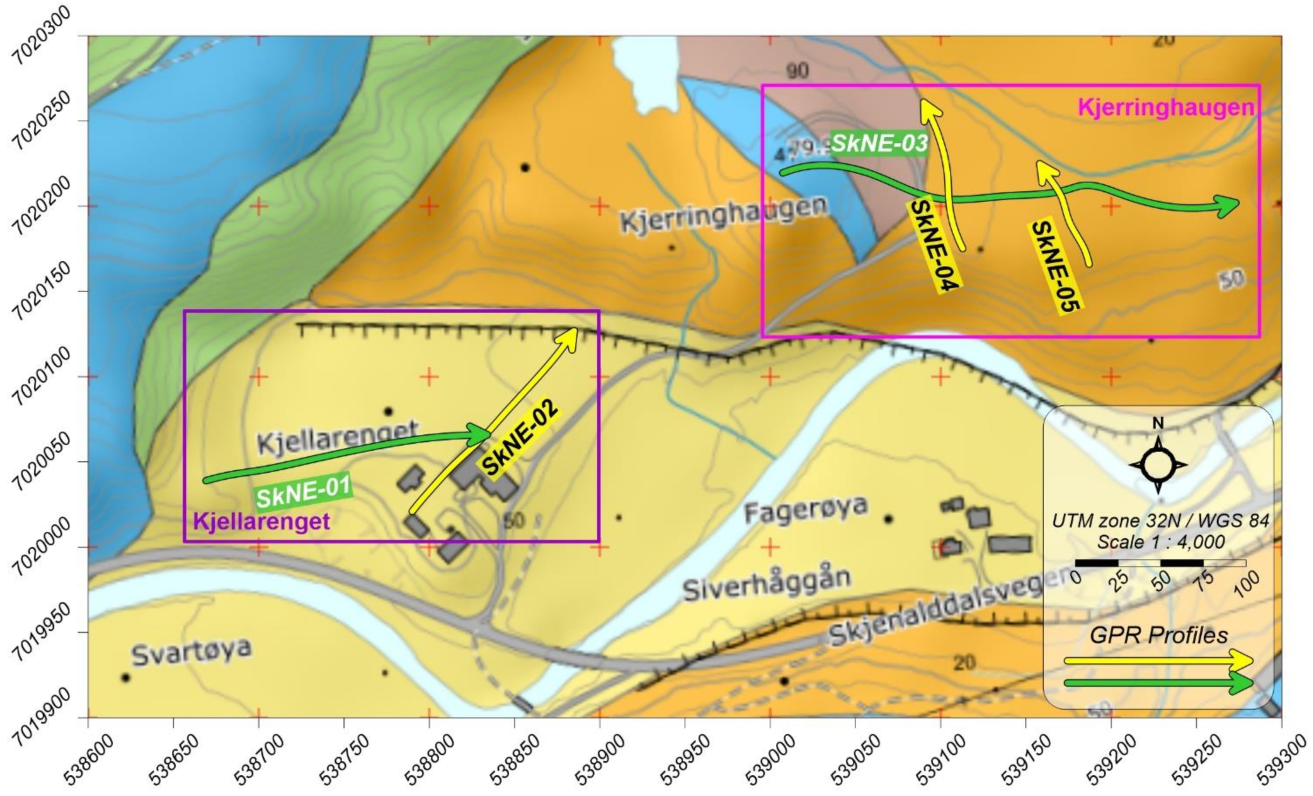
Figure 4.2.1 presents the resulting radargrams for profiles SkNE-01 to 05 which were measured at the southwestern corner of the Skjenalddalen North-East subarea in Orkdal. The positioning of these lines is also presented in relation to the existing Quaternary map for the region in order to help predict the performance of GPR method for each profile. In this sense, profiles SkNE-01 and 02 lie entirely within fluvial sediments and the same applies for profiles SkNE-04 and 05 but for glaciofluvial sediments instead, therefore these profiles are projected to yield good data. On the other hand, if profile SkNE-03 is divided in four parts, the first one is placed over marine deposits before continuing over to peat and glaciofluvial sediments and therefore it is not expected to allow good signal at least in its beginning.

In Kjellarenget, the GPR-results predominantly validate the Quaternary mapping by presenting a penetration depth which is locally over 20 meters with that being especially noticeable at the east / northeast part of the area marked with the purple rectangle on the map in **figure 4.2.1**. Specifically, profile SkNE-01 displays reflectors at various depths that are mainly eastward dipping with intertwined secondary reflectors that dip towards the opposite direction (westward), while the respective reflectors in line SkNE-02 are more horizontal but slowly shifting towards dipping southwest near the end of the profile. Also considering the crisscrossing reflectors in profile SkNE-02, it can be assumed that the measurements at Kjellarenget reveal south-east dipping layers. However, it should not go unnoticed that both profiles are characterized by minimal penetration in their beginning. If the Quaternary geology of the area is also considered, the beginning of profile SkNE-01 is not very far away from marine deposits and therefore it can be assumed that the underlying influence of clay beneath the fluvial cover is still strong even after the contact. The same does not apply to profile SkNE-02 and so we can assume that clay can still be found quite close to the surface for that part of the profile with the weakest signal.

Kjerringhaugen can be seen in **figure 4.2.1** highlighted by a magenta rectangle which encloses profiles SkNE-03 to 05. Firstly, the most interesting profile here is SkNE-03 which according to the Quaternary geology map, surveys three different sediment types i.e., marine deposits, peat and glaciofluvial deposits. As expected, marine sediments consume the electromagnetic signal very fast and therefore penetration is only 5 meters during the starting 35 meters. The following part of SkNE-03 presents a strong increase in penetration, delineating short intertwining reflectors down to almost 15 meters of depth and mapping peat quite extensively. Upon entering the glaciofluvial sediment region though, the processed image for profile SkNE-03 is not as good as expected and penetration is minimal. Structurally, there is an almost continuous reflector that starts around the intersection with profile SkNE-04 and dips eastwards until flattening out near the end of the profile. Above this reflector, several others can be observed with possible localized mini-foresets at the intersection with SkNE-05, but penetration only goes as deep as 10 meters below which suggests presence of clay. Secondly, profiles SkNE-04 and 05 display similar behaviour: 15-meter penetration in the south gradually diminishing to 5 meters in the north. Especially for profile SkNE-04, the northern half of the data could easily be interpreted for clay. Lastly, the ambient noise contaminating results in Kjerringhaugen is due to electric fences that were still in operation despite the animals being absent.



GPR information
Instrument: Malå RTA (Snake)
Antenna Frequency: 100 MHz
Parallel Endfire
Processing Software: EKKO_project v.5
Processing Routines: Dewow
SEC2 Gain Type
Bandpass/Lowpass Filter
Depth Conversion: Velocity 0.100 m/s (Default)
LiDAR Topography: NDH Orkdal 2016 - 0.50m
Vertical Exaggeration 3



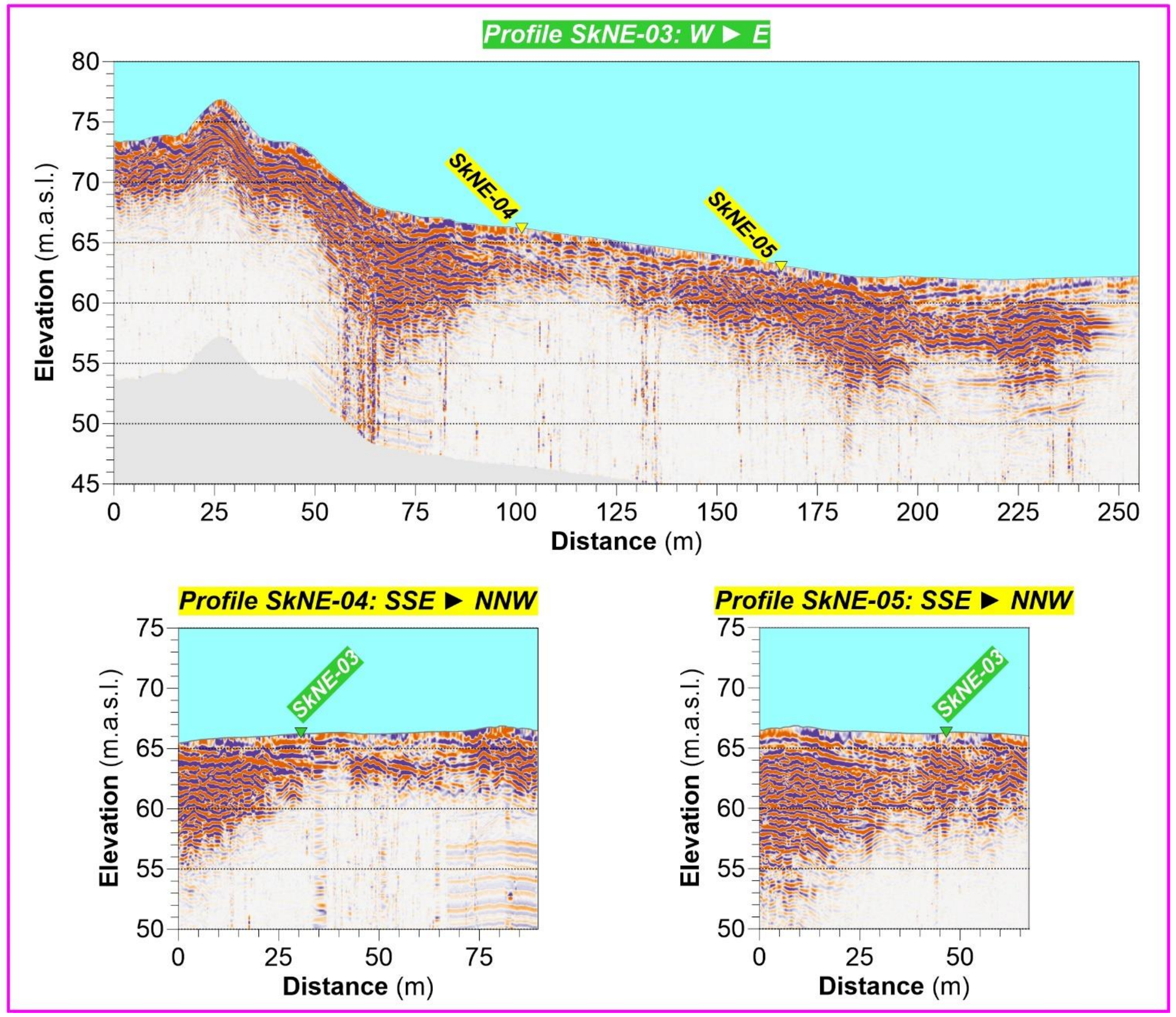


Figure 4.2.1: *Radargrams for profiles measured at Kjellarenget and Kjerringhaugen in Skjenalddalen North-East subarea, and map showing positioning of the profiles in relation to the existing Quaternary map (Reite, 1977).*

4.2.2 Ferjebu / Storøya

Figure 4.2.2 demonstrates radargrams for profiles SkNE-06 to 13, divided into two groups namely Ferjebu (SkNE-06 to 11) shown in the magenta box and Storøya (SkNE-12 and 13) outlined by the purple one. The map accompanying the results for these two areas, shows the sediments on which these profiles were measured. Principally all Ferjebu profiles were conducted on top of glaciofluvial deposits while both Storøya lines were measured over fluvial sediments. It is therefore expected that GPR would be the ideal method for investigating these areas.

Examining penetration achieved at Ferjebu, all profiles show good results with a generally uniform depth coverage of ideally 20 meters but no less than 12-13 in any case which is representative for sand/gravel. Nevertheless, profiles SkNE-07 and -08 which are neighbouring marine deposits only a few meters to the north, display discontinuities in signal strength which could either be caused by increased humidity in the ground or localized appearance of clay. Qualitatively, a big variety of reflectors can be found in these results varying from horizontal to dipping and from undulating to intertwining. Reviewing the profiles aligned after the SW-NE direction, SkNE-06 is characterized by sub-parallel but also locally undulating strong reflectors, SkNE-07 features a quite prominent horizontal reflector at 62 meters elevation above sea level which runs the first half of the radargram before being overpowered by packages of southwest dipping layers on its other half while SkNE-08 starts off with weaker similarly dipping layers before shifting to horizontal layers of unclear structure again. The profiles which are perpendicular to the aforementioned, are also challenging to interpret with SkNE-09 which is the westernmost being dominated by crisscross reflectors with a small hint for northwest dipping, SkNE-10 in the middle mainly revealing flat reflectors while the easternmost line SkNE-11 clearly showing a southeast dipping pattern. Altogether, Ferjebu is indeed dominated by glaciofluvial deposits, but no clear structural information can be extracted from the GPR data.

The results at Storøya constitute limited penetration in relation to the previously described results at Ferjebu. Both profiles SkNE-12 and 13 display a uniform stoppage of penetration below the elevation of 20 meters above sea level. However, the more uneven topography across profile SkNE-12 causes penetration to vary in depth from 5 to 15 meters whereas for profile SkNE-13 which is flatter, a more constant coverage of 7-8 meters depth is achieved. The reflectors detected in both profiles are sub-horizontal without any special characteristics except for the northern end of profile SkNE-13 where the strong reflector group bends downwards to create a basin of very weak signal that could be associated with water saturation near the Skjenald riverbed. In conclusion, even though no clear reflector was mapped by the GPR for the water table, the stoppage of penetration can be linked to water saturation.

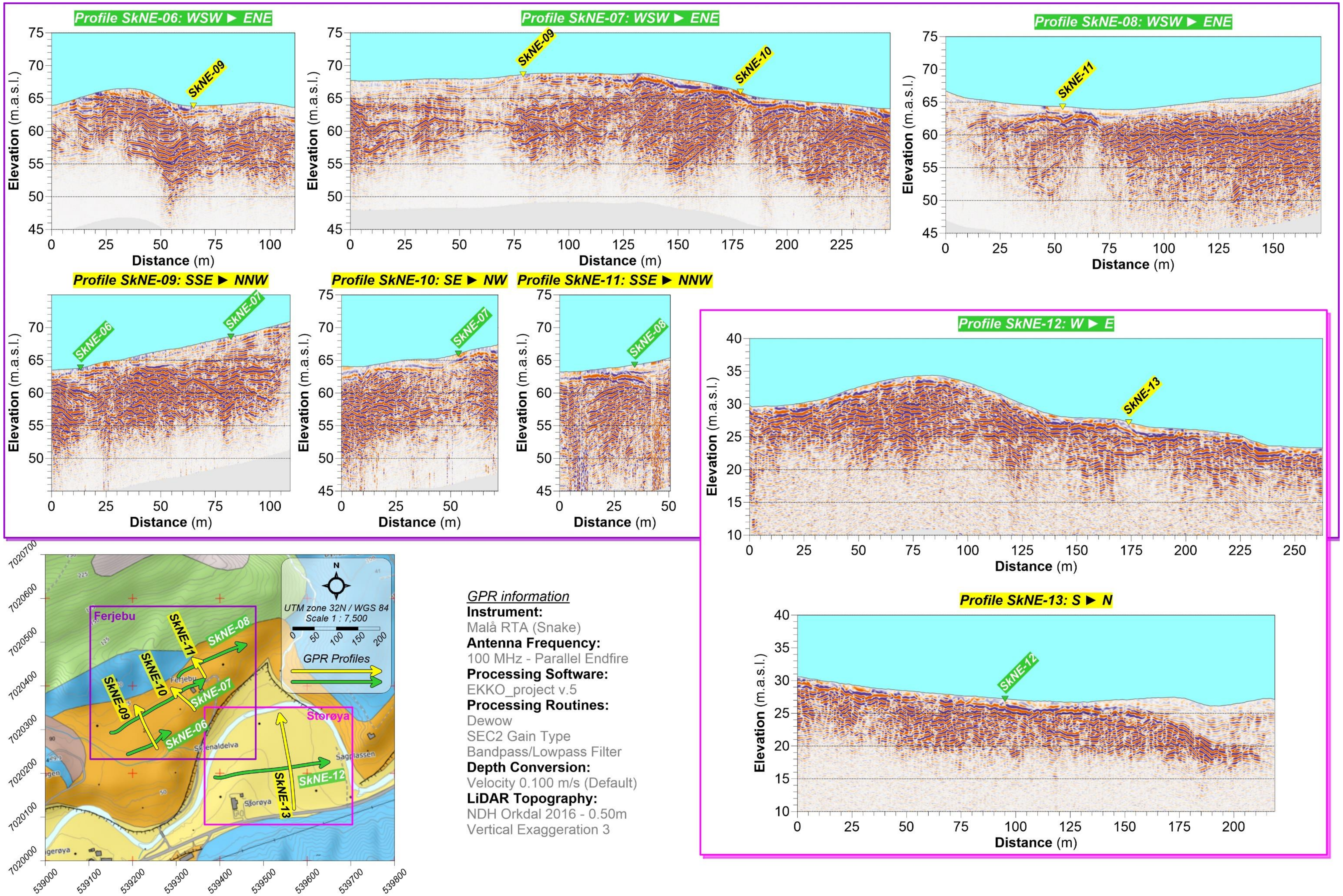


Figure 4.2.2: *Radargrams for profiles measured at Ferjebu and Storøya in Skjenalddalen North-East subarea, and map showing positioning of the profiles in relation to the existing Quaternary map (Reite, 1977).*

4.2.3 Dyndal / Skjenaldhaugen

The third part of the Skjenalddalen North-East subarea is found a bit farther to the east and is again divided into two segments as seen in **figure 4.2.3**, namely Dyndal which is highlighted by the purple rectangle and contains profiles SkNE-17 and 18 and Skjenaldhaugen framed by a magenta box and containing profile SkNE-22. Profiles in both segments investigate marine deposits for the most part i.e., formations unpromising to GPR investigations except for a small fraction at the fringes of the area covered where Quaternary mapping shows appearances of glaciofluvial deposits.

Starting off with Dyndal which is enclosed by the purple rectangle shown in **figure 4.2.3**, it may be observed that for profile SkNE-17 running south to north, minimal penetration is achieved aside from the first 50 meters distance where a cluster of sub-horizontal / crisscrossing reflectors is registered down to 15 meters. This verifies the presence of marine deposits at the greater part of the profile but also that of glaciofluvial sediments on the first few meters, like the Quaternary map denotes. Profile SkNE-18 on the other hand presents a similar signal distribution to profile SkNE-17 with strong reflectors at the beginning and the overall loss of penetration farther into the marine sediments. However, even though Quaternary mapping suggests that one third of profile SkNE-18 should be within the glaciofluvial deposits, the GPR-data reveal strong reflectors that are registered continuously for almost half the length of the profile. After that point, penetration is lost aside from a single horizontal reflector at 57 m.a.s.l. and a localized package of strong signal after 215 meters distance. Another interesting feature in profile SkNE-18 has to do with signal in the beginning of the line being distributed similarly to what has been observed at the end of profile SkNE-13 at Storøya (**figure 4.2.2**). Again, there is a 5-meter-thick top layer in which no reflectors were registered by GPR, lying over a 10-meter-thick group of sub-horizontal reflectors typical for sand or gravel. This top layer can once again be thought of as water-saturated sediments in connection with the river found a few tens of meters away. Finally, ambient noise in the form of two linear reflectors forming the letter X are due to the farm found in the area.

In Skjenaldhaugen which is framed by the magenta rectangle in **figure 4.2.3**, profile SkNE-22 starts off on top of glaciofluvial deposits which are represented in the radargram with many short intertwining reflectors that locally reach 10 meters in depth and extend for a total of 150 meters distance. However, the contact with the neighbouring marine sediments in the existing Quaternary map lies at 75 meters distance and even though reflectors stop being detected at this point, another package of strong reflectors reappears locally from 100 to 170 meters distance, possibly representing an unmapped pocket of sand and/or gravel within the clay. After that point, GPR measurements clearly survey pure marine deposits, as easily deduced by the signature signal distribution for clays characterized by minimal penetration (2-3 meters maximum).

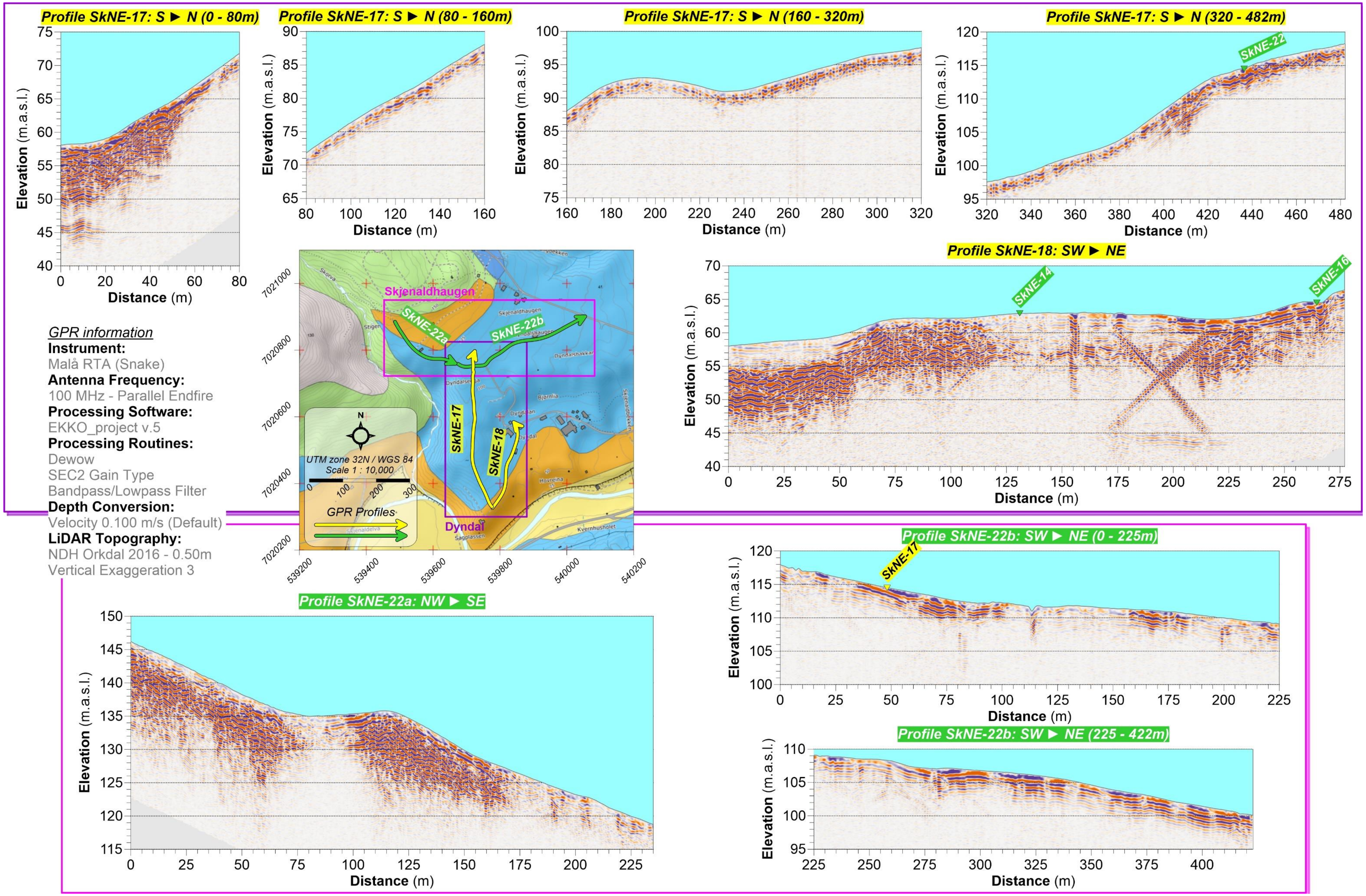


Figure 4.2.3: *Radargrams for profiles measured at Dyndal and Skjenaldhaugen in Skjenalddalen North-East subarea, and map showing positioning of the profiles in relation to the existing Quaternary map (Reite, 1977).*

4.2.4 Dyndalsvegen / Hovreina-Skjenaldbekken

The fourth set of results presented for Skjenalddalen North-East is shown in **figure 4.2.4** split in two parts: Dyndalsvegen (purple rectangle) including profile SkNE-16 that was named after the main road that the profile was measured on and Hovreina-Skjenaldbekken (magenta rectangle) which includes profiles SkNE-14, 15 and 19 to 21, all performed in local farm fields. The Quaternary map also included in **figure 4.2.4** suggests that, when it comes to sediments, profile SkNE-16 is shared between marine and glaciofluvial/fluvial, profiles SkNE-14 and 15 are almost entirely on glaciofluvial, and profiles SkNE-19 to 21 are mostly on glaciofluvial but also cross over to marine near their end.

In the case of the Dyndalsvegen profile entitled SkNE-16 (presented in **figure 4.2.4** split in four parts due to large topography changes along its course with the correct sequence of sub-radargrams pointed out with red arrows) and up to 350 meters of distance where the contact between marine and glaciofluvial sediments should be met, the signal shows insufficient penetration (roughly 5 meters) but not as small as would be expected of clay. In addition to that, an area of over double the achieved penetration so far (12-13 meters) found between 75 and 150 meters distance indicates that not only conductive formations are surveyed on the first half of profile SkNE-16. After about 370 meters distance, penetration stays increased steadily and varying in response according to either glaciofluvial or fluvial deposits. The former yields a penetration of locally up to 15 meters while the latter does not exceed 10 meters. Reflectors appear to be horizontal and locally intertwining, but without any distinct structural characteristics.

The last part of profile SkNE-16 can be directly compared with profiles SkNE-14 and 15 in Hovreina-Skjenaldbekken due to their identical direction and the fact that they survey formations favourable to GPR (glaciofluvial deposits). Concerning signal penetration, the radargrams for SkNE-14 and 15 in **figure 4.2.4** display similar results with depth coverage being maximally 10-12 meters. Qualitatively though, the detected reflectors convey more information that with profile SkNE-16. Particularly, profile SkNE-14, after the brief clay hint in the starting 25 meters of the profile in accordance with the Quaternary map, shows a uniform depth coverage with more distinct horizontal structuring and a clear undulating reflector at 50 meters distance. It also reveals a top layer with no reflectors detected, which is delimited by 52 meters of elevation and could be due to water-saturation. In contrast, profile SkNE-15 does not contain such a top layer, but instead identifies reflectors with a southwest dipping tendency but also more laterally discontinuous signal strength.

Finally, the remaining lines at Hovreina-Skjenaldbekken i.e., profiles SkNE-19 to 21, are all generally directed from south to north and have a similar outlook. Namely, their largest part is characterized by strong reflectors, sub-parallel and locally crisscrossing distribution and maximum depth penetration of 10 meters which gradually gives place to responses more characteristic to marine deposits. This shifting point varies in distance per profile according to how soon or late each line crosses over the contact between glaciofluvial and marine sediments, but in general is in good agreement with what the existing Quaternary map shows. Generally, the quality of the GPR signal in this area is mediocre, although parts of it being covered by dielectrically favourable formations such as sand and/or gravel.

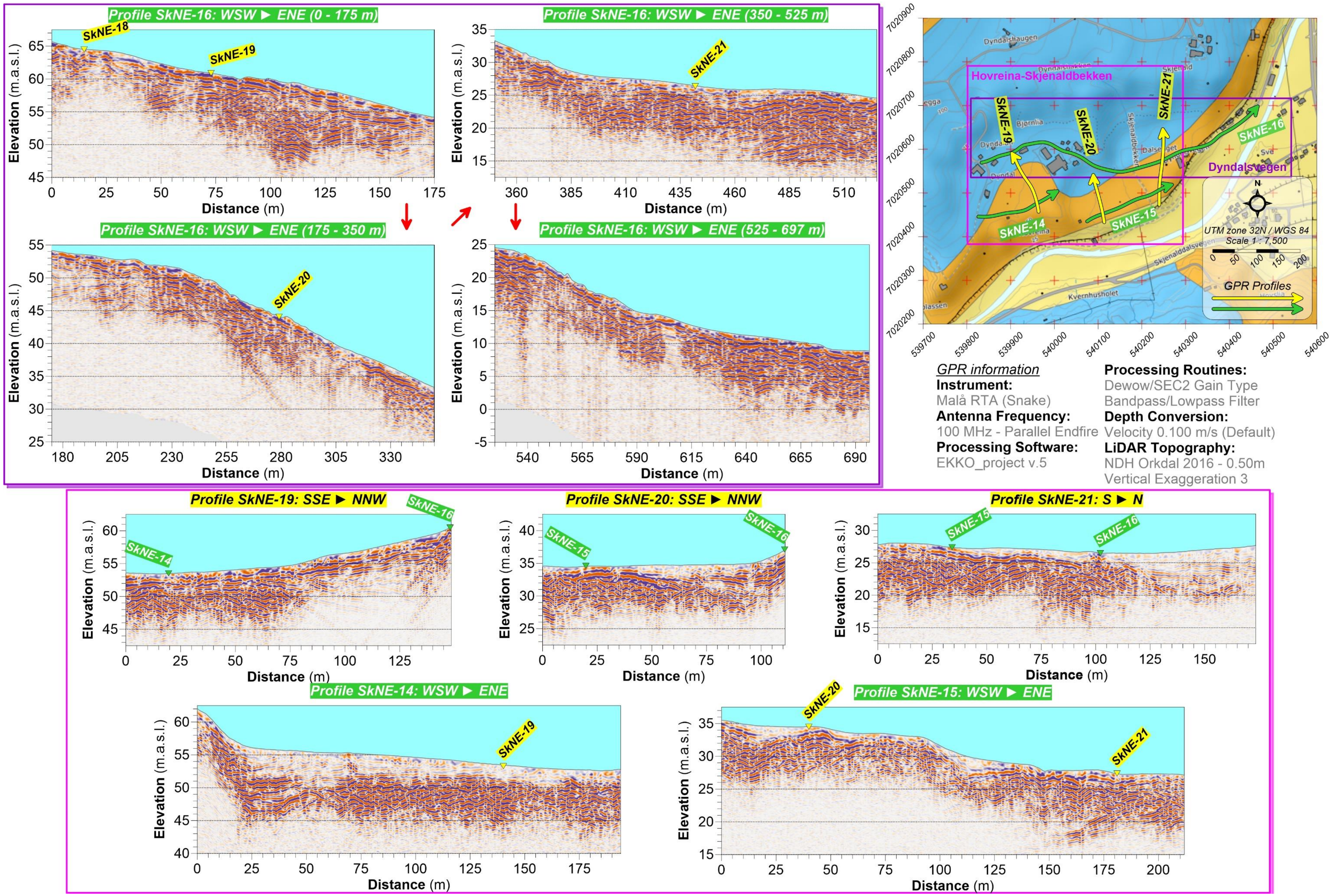


Figure 4.2.4: *Radargrams for profiles measured at Dyndalsvegen and Hovreina-Skjenaldbekken in Skjenalddalen North-East subarea, and map showing positioning of the profiles in relation to the existing Quaternary map (Reite, 1977).*

4.2.5 Skjenaldhaugen / Trettungan

The GPR results from the northeastern part of Skjenald river valley are concluded with Skjenaldhaugen and Trettungan localities marked by a purple and magenta rectangle respectively. **Figure 4.2.5** shows the resulting radargrams for profiles SkNE-23 to -25, which regardless of locality are positioned on top of marine sediments as shown in the Quaternary map included in the figure. Profile SkNE-23 is the only profile in Skjenaldhaugen and is dealt between a local road and a field while profiles SkNE-24 and -25 that make up Trettungan, follow a field and a road respectively. It is safe to assume that if the Quaternary map is accurate, GPR measurements here will be of little to no use for this part of the valley.

Profile SkNE-23 representing the Skjenaldhaugen locality is presented in **figure 4.2.5** split in four parts, since the axis exaggeration used (Y axis is 3 times X axis) along with the large elevation difference between start and finish would make it impractical to present with enough detail in printed format. That being said, not much detail is found in the beginning of this radargram, with depth penetration being just 3-4 meters for the first 350 meters. However, depth coverage increases at this point and becomes about 7-8 meters for the remainder of its length. It is therefore safe to assume that the first part of the profile is clay whereas the rest could potentially be clay-bearing sand or gravel that would allow a slight increase in penetration but still not great. From a structural standpoint, reflectors in the south-eastern part of SkNE-23 appear to be either flat or crisscrossing that would point towards sand and/or gravel from what was seen in the previous section.

Regarding Trettungan, profile SkNE-24 presents a shorter but also similar version of SkNE-23 seen in the previous paragraph. This means that the trend of minimal penetration switching to slightly higher farther to the east is again noted here with similar qualitative and quantitative characteristics. Furthermore, profile SkNE-25 which starts off in the general area where SkNE-24 ends, appears to yield 10 meters of penetration at an almost stable rate all the way north to where it crosses profile SkNE-23 as the map in **figure 4.2.5** displays. North of there, signal becomes indicative of clay but until that point, the presence of sand and/or gravel is very probable. It is therefore assumed that the eastern part of this area is less conductive but whether the glaciofluvial/marine contract farther to the east should be moved to fit the GPR results, is up for investigation.

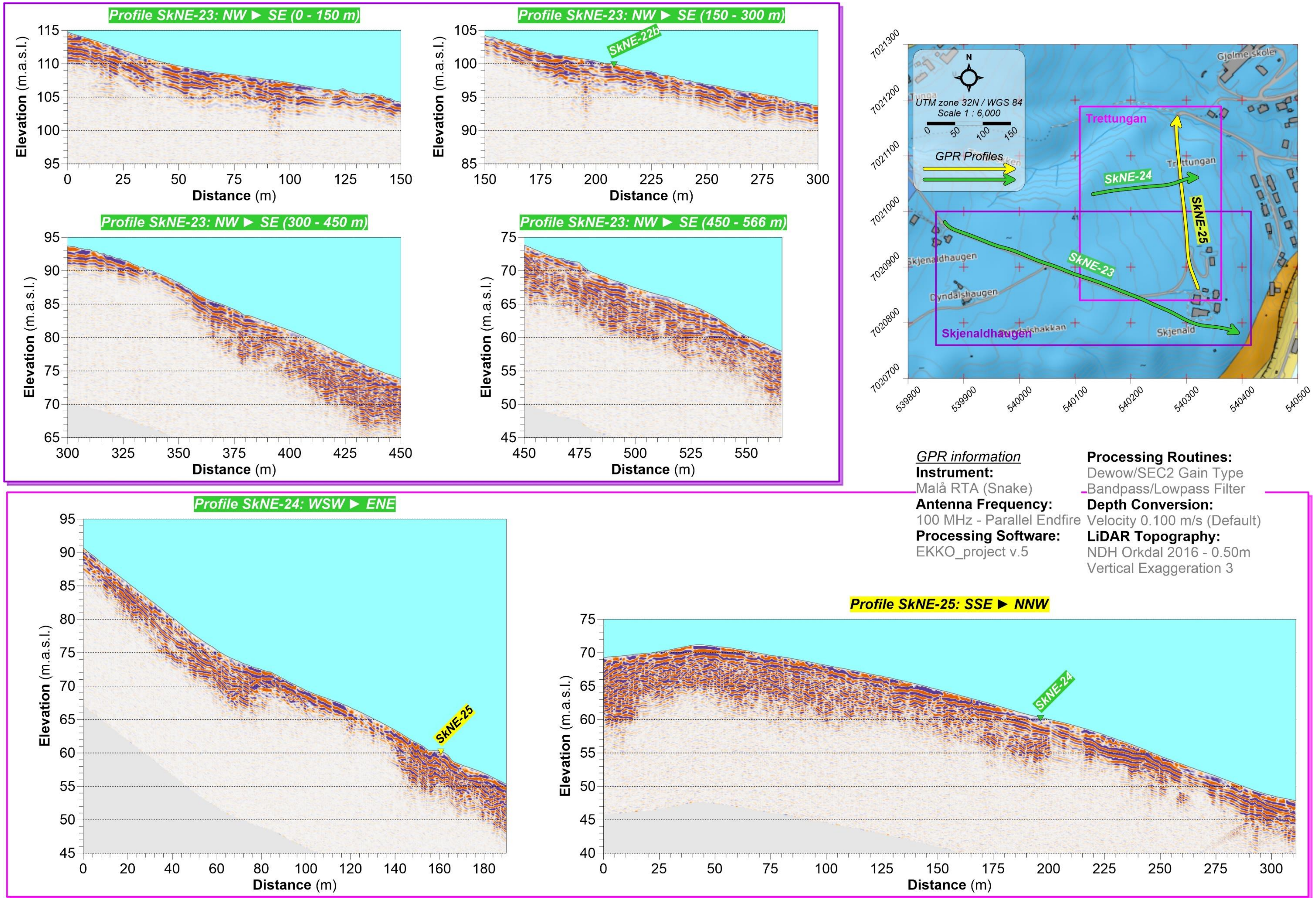


Figure 4.2.5: Radargrams for profiles measured at Skjenaldhaugen and Trettungan in Skjenalddalen North-East subarea, and map showing positioning of the profiles in relation to the existing Quaternary map (Reite, 1977).

4.3 Skjenalddalen South-West Results

This subarea covers the southwestern part of Skjenald river valley towards Vollavika and Gangåsvatnet lake. 13 profiles named SkSW-01 to 13 have been conducted for this part of the Orkdal survey with total length equal to 2.6 km. **Figure 4.3** displays the distribution of the measured lines along the valley. Again, all profiles were collected using the 100 MHz frequency antenna for Malå RTA (Snake) as in the north-eastern part of the valley. All profiles were carried out in October 2017 with the Snake system regardless of terrain due to the already mentioned equipment problems with PulseEKKO PRO. As in the other half of the Skjenald river valley, ground conditions were wet from preceding rain.

4.3.1 Fossflatvegen / Fossen

Figure 4.3.1 presents the resulting radargrams for profiles SkSW-01 to 05 which were measured at the southwestern tip of Skjenalddalen South-West subarea in Orkdal. These lines are plotted over the existing Quaternary map for the region and lie entirely within glaciofluvial sediments. Results presented in this report so far, show that GPR performs well over such formations as long as these sediments remain continuous in depth. Profile SkSW-01 is the only one extended over a gravel road however, PulseEKKO PRO system was not possible to be employed there due to technical difficulties. All other profiles were measured within either flat or ploughed farmland, without the latter affecting GPR-performance.

In Fossflatvegen, profile SkSW-01 – which is split in three parts for better presentation – starts off with fragmented signal strength that allows a 15-meter penetration and reveals horizontal layering. However, the continuation of the profile towards the northeast returns a properly strong signal whose penetration is over 20 meters and locally even 25 meters. As seen in **figure 4.3.1**, the middle part of SkSW-01 (225 to 400 meters distance) is still dominated by horizontal reflectors, but near its end, northeast-dipping layers appear below a package of horizontal reflectors that are roughly five meters thick. Profile SkSW-02 on the other hand crossing SkSW-01 right before the middle part ends, displays a similar result to the third part of SkSW-01 described above i.e., a package of horizontal reflectors down to 155 meters above sea level and then hints of dipping towards the north which leads to a combined interpretation of generally northeast dipping layers for this area.

Farther to the northeast in Fossen, processed radargrams for profiles SkSW-03 and -04 show similar results, namely layers clearly dipping towards the northeast below flat reflectors down to 155 meters of elevation. Profile SkSW-05 on the other hand, displays a more complex reflector regime. As seen in **figure 4.3.1** there is a strong reflector starting at 155 m.a.s.l. like in the other profiles, which deepens soon at a rate which is higher than the topographic depression above it, before flattening out again 10 meters deeper, at 145 m.a.s.l.). At about 95 meters and above this layer can be found the only reflectors dipping towards the southeast, which makes understanding of layer geometry in the area difficult to comprehend. Regardless, the penetration is again steadily over 15 meters and locally even 25 meters, which is in good agreement with the glaciofluvial sediments shown in the Quaternary map (Reite, 1980).

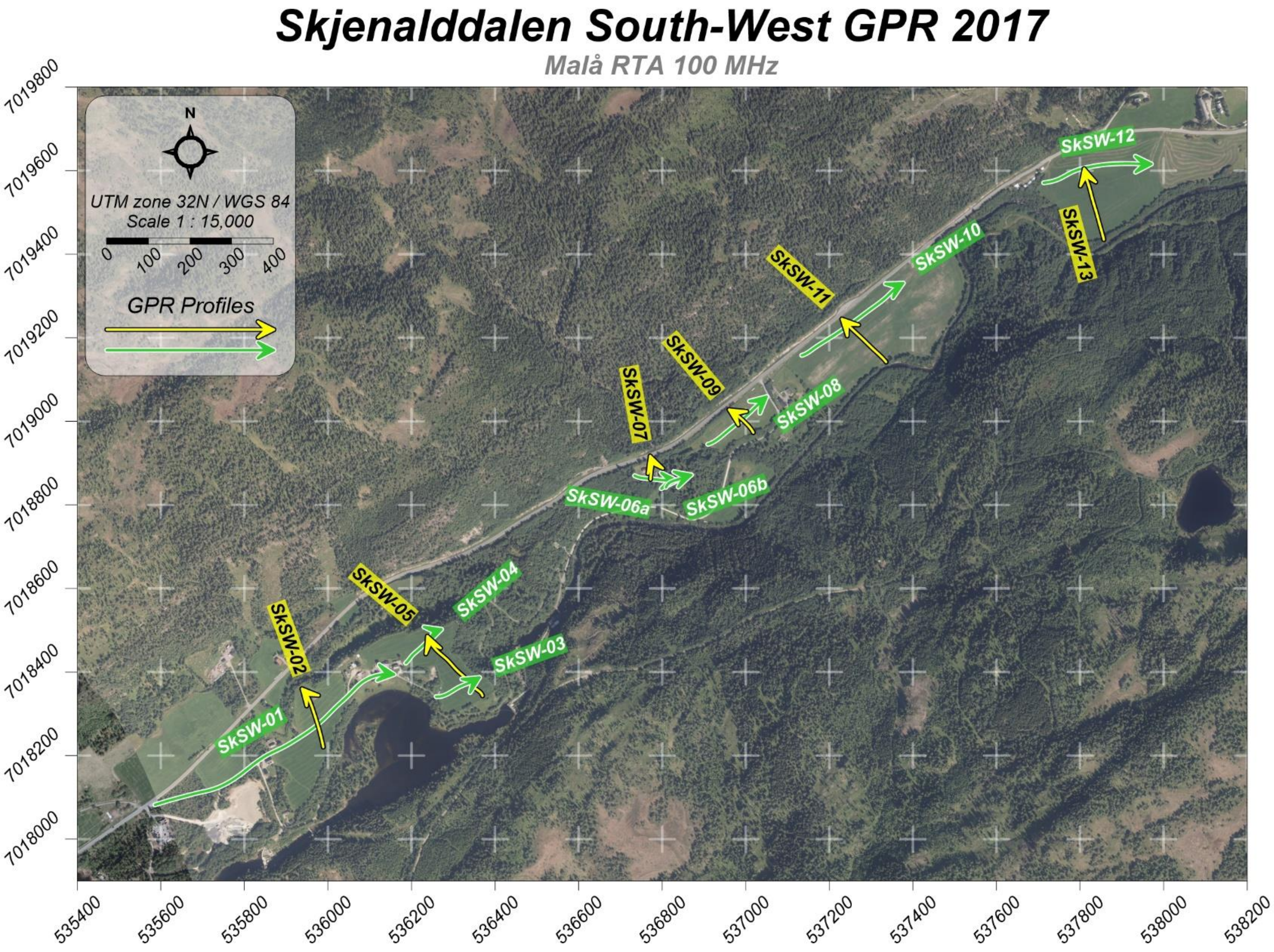


Figure 4.3: *Positioning for Georadar profiles collected in Skjenalddalen South-West in 2017 (Orthophoto: Orkdal-Meldal-Frøya; Norge i bilder. 2018).*

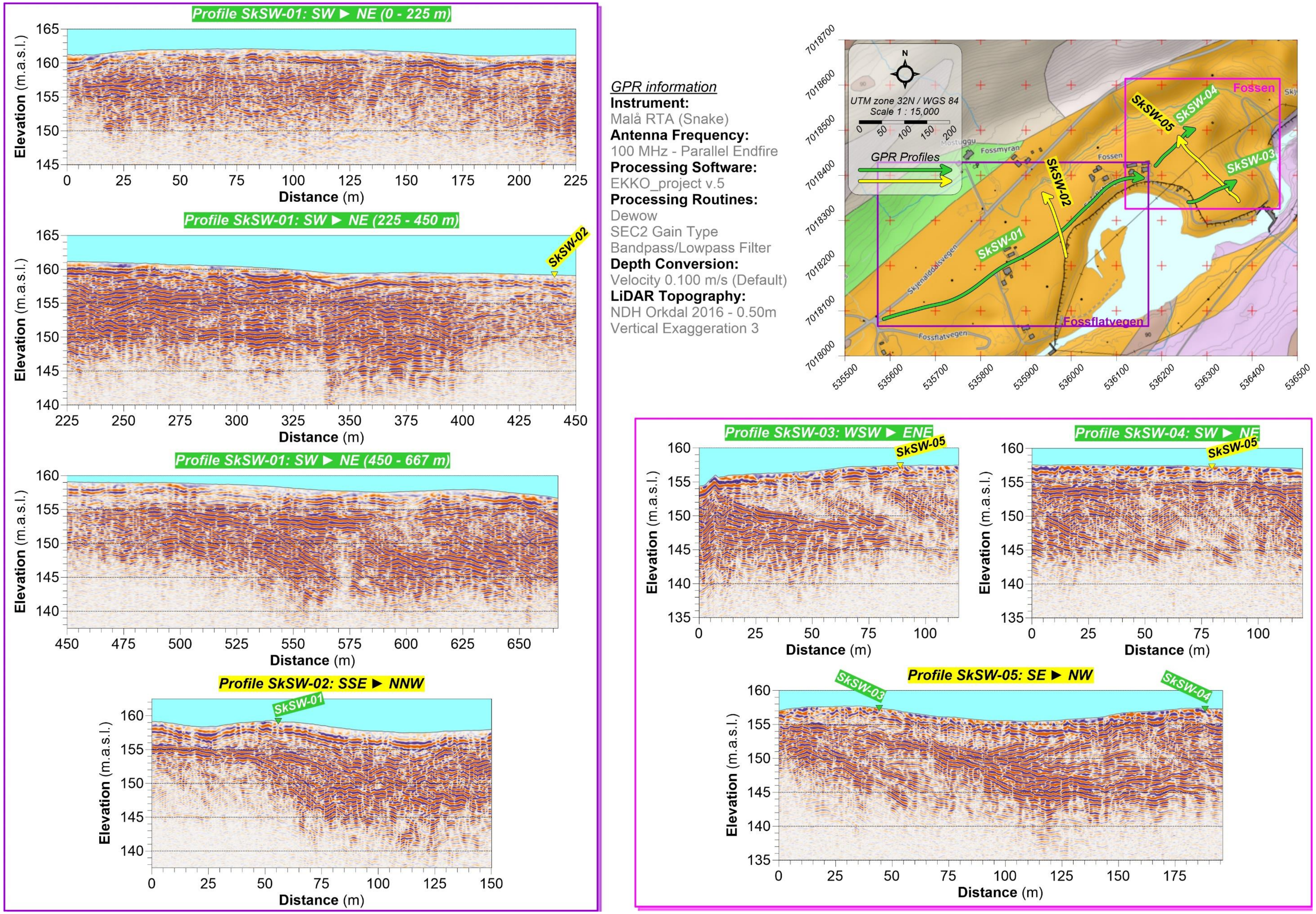


Figure 4.3.1: Radargrams for profiles measured at Fossflatvegen and Fossen in Skjenalddalen South-West subarea, and map showing positioning of the profiles in relation to the existing Quaternary map (Reite, 1977; Reite, 1980).

4.3.2 Øyan

Figure 4.3.2 demonstrates the processed radargrams for Øyan which is found a few hundred meters to the northwest of the previous locality. All data were gathered on flat farm fields with the help of the Malå RTA system and the 100 MHz antenna. According to the Quaternary map shown in the top right corner of the figure, profiles were either measured on top of glaciofluvial (SkSW-06 and -07) or fluvial (SkSW-08 and -09) sediments, promising good penetration, and overall data quality.

However, the results obtained from the measurements in Øyan exhibit worse conditions for GPR in the ground than expected. Profiles SkSW-06 (both a and b) and -07 that are measured over glaciofluvial sediments, present a decent penetration depth equal to slightly over ten meters with generally horizontal reflectors except for a few localities where layers are crisscrossing and moderate overall signal strength. Neither direction reveals dipping layers, but profile SkSE-07 achieves limited penetration in its second half which implies hindering conditions in the ground for electromagnetic waves towards the contact with moraine to the north.

Data quality for profiles SkSW-08 and -09 is even worse as seen at the bottom of **figure 4.3.2**, even though measurements were conducted over theoretically favourable formations (fluvial sediments). Profile SkSW-09 which is parallel to SkSW-07, verifies the loss of signal strength and penetration towards the north while at the same time reveals a depression in the layering detected. Profile SkSW-08 on the other hand presents a completely different regime, with low signal penetration (five meters) interrupted by small patches of crisscrossing reflectors of increased penetration (ten meters) every few meters, if we overlook the first 50 meters of distance where almost no penetration is achieved. Generally, Øyan appears to be covered by a thin layer of either glaciofluvial or fluvial sediments, before giving place to less favourable formations for GPR measurements (clay and/or water saturated layers).

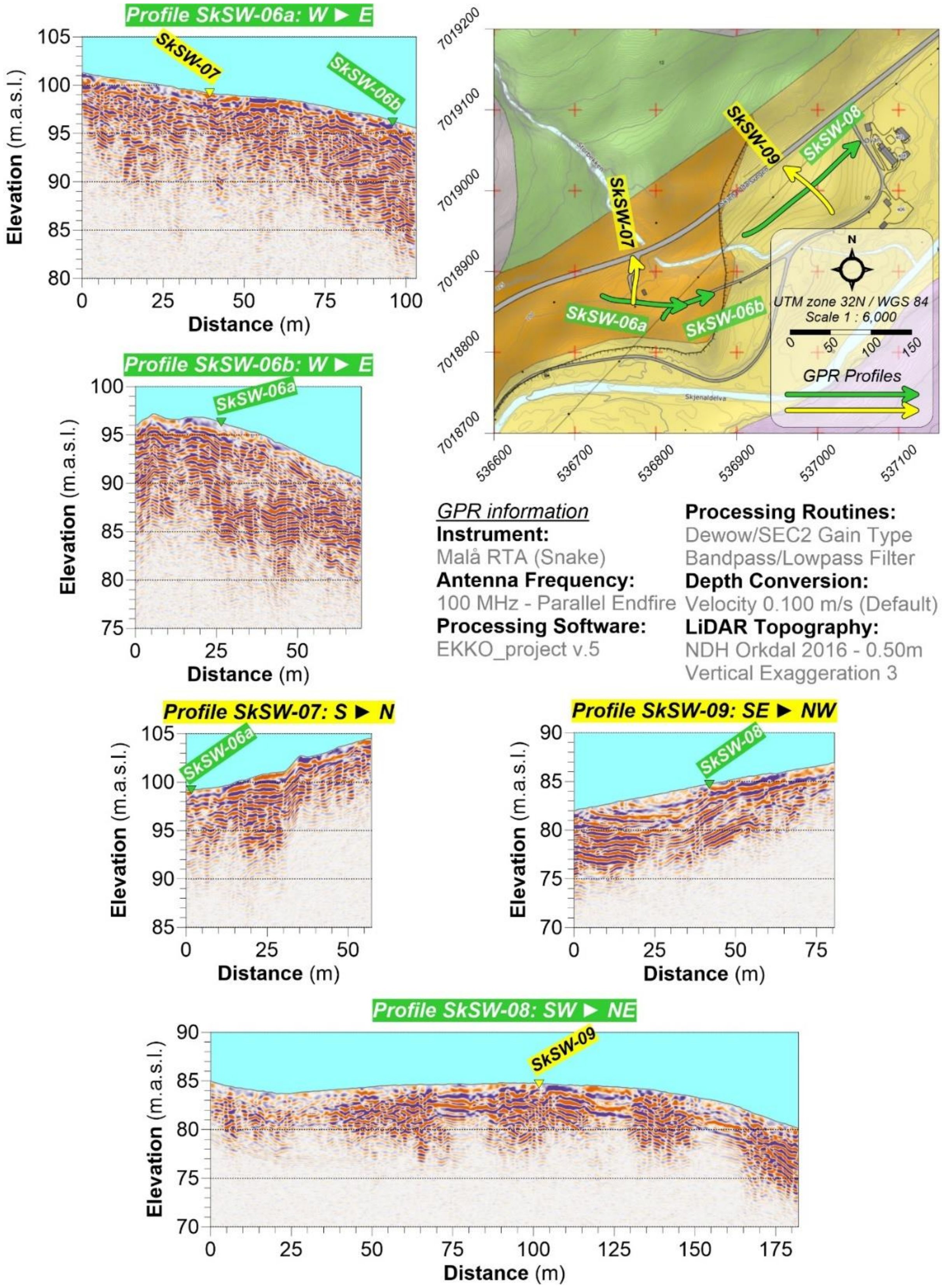


Figure 4.3.2: *Radargrams for profiles measured at Øyan in Skjenalddalen South-West subarea, and map showing positioning of the profiles in relation to the existing Quaternary map (Reite, 1977).*

4.3.3 Annølsøya / Kvernøya

The last localities in subarea Skjenalddalen South-West are called Annølsøya and Kvernøya and have been surveyed by profiles SkSW-10/11 and SkSW-12/13 respectively. All data presented in **figure 4.3.3** were collected over farm fields of fluvial deposits with Malå's Snake system, 100 MHz antenna frequency and parameters identical to what has been used throughout the survey.

The results in **figure 4.3.3** verify less favourable dielectric conditions than expected with signal that is overall inconsistent both in penetration and strength. At Annølsøya, profiles SkSW-10 and -11 present signal penetration that is maximally 15 meters and many crisscrossing reflectors with hints of layers dipping southwest for the former and more horizontal-like reflectors for the latter profile. Penetration depth is not uniform for neither of these profiles, revealing packages of stronger reflectors that are not necessarily interrupted, but occasionally become much weaker in a lateral sense.

The above-described lateral variation in signal strength is more pronounced in profile SkSW-12 at Kvernøya which also contains the clearest reflectors found in any of the four profiles measured in this locality, with eastward dipping layers superficially which become flatter in depth between 50 and 160 meters distance. Penetration for this patch is maximally 15 meters but outside of it, signal is very weak to almost non-existent even though most reflectors are generally uninterrupted. Profile SkSW-13 on the other hand, is more comparable to profiles SkSW-10 and -11, with lots of crisscrossing reflectors and unremarkable penetration (max ten meters). It is then assumed that water saturation plays a big role in what is seen with GPR measurements.

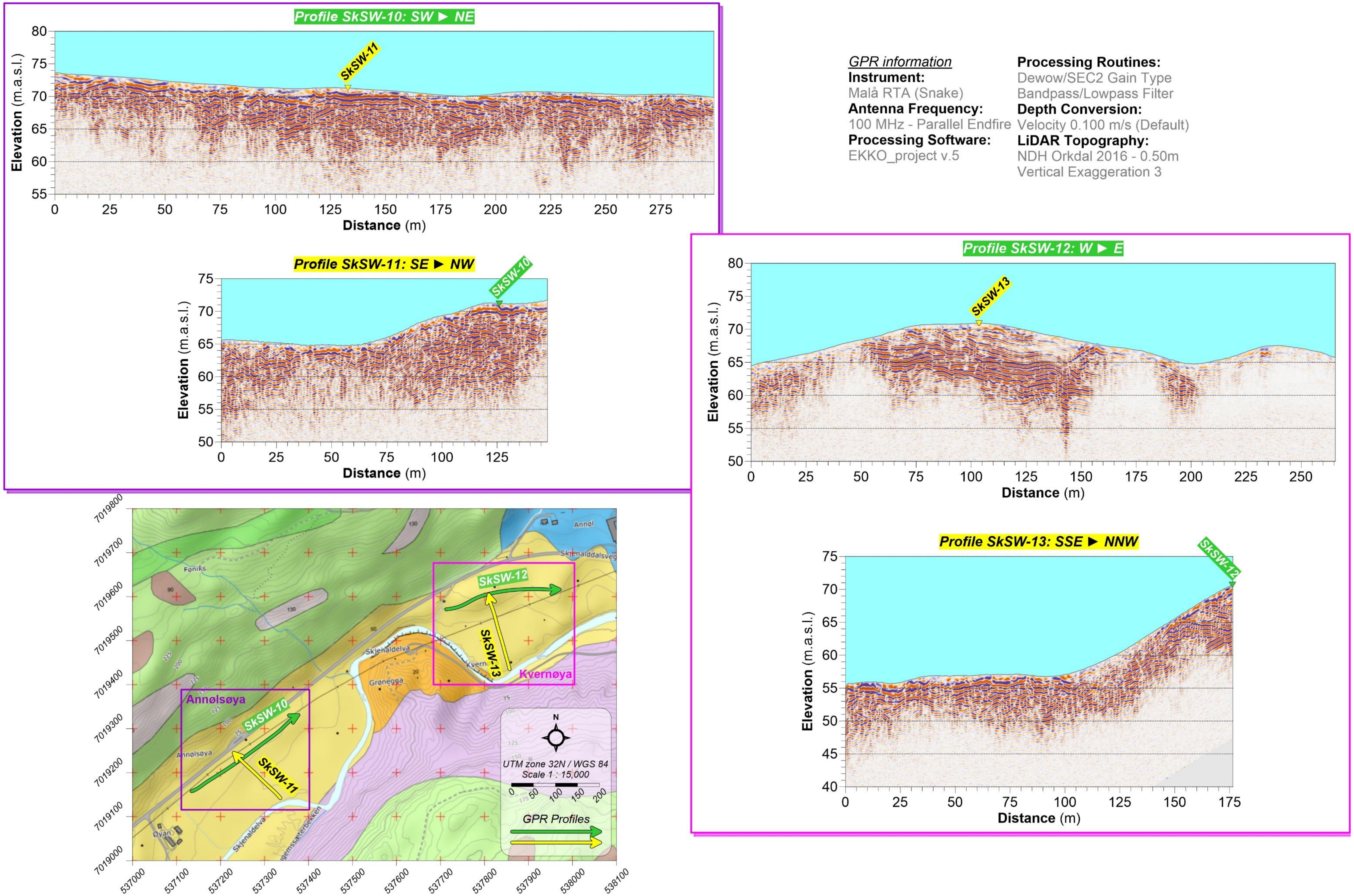


Figure 4.3.3: *Radargrams for profiles measured at Annølsøya and Kvernøya in Skjenalddalen South-West subarea, and map showing positioning of the profiles in relation to the existing Quaternary map (Reite, 1977).*

4.4 Fannrem Results

The Fannrem subarea is not part of the Skjenald river valley but belongs to the neighbouring Orkdal valley which extends southwards from Orkanger town. This survey was almost entirely conducted twice, due to equipment problems during the first visit in the area in July 2018. After repeating almost all measurements in November 2019, eight profiles were produced as seen in **figure 4.4**. Seven of them (FA-01 to -07) were collected with PulseEKKO PRO along roads or smooth farmland, while profile FA-08 was conducted with Malå RTA due to limited accessibility for the cart in this locality. The frequency employed was again 100 MHz for both systems, generating a total coverage of slightly over 2 km of data.

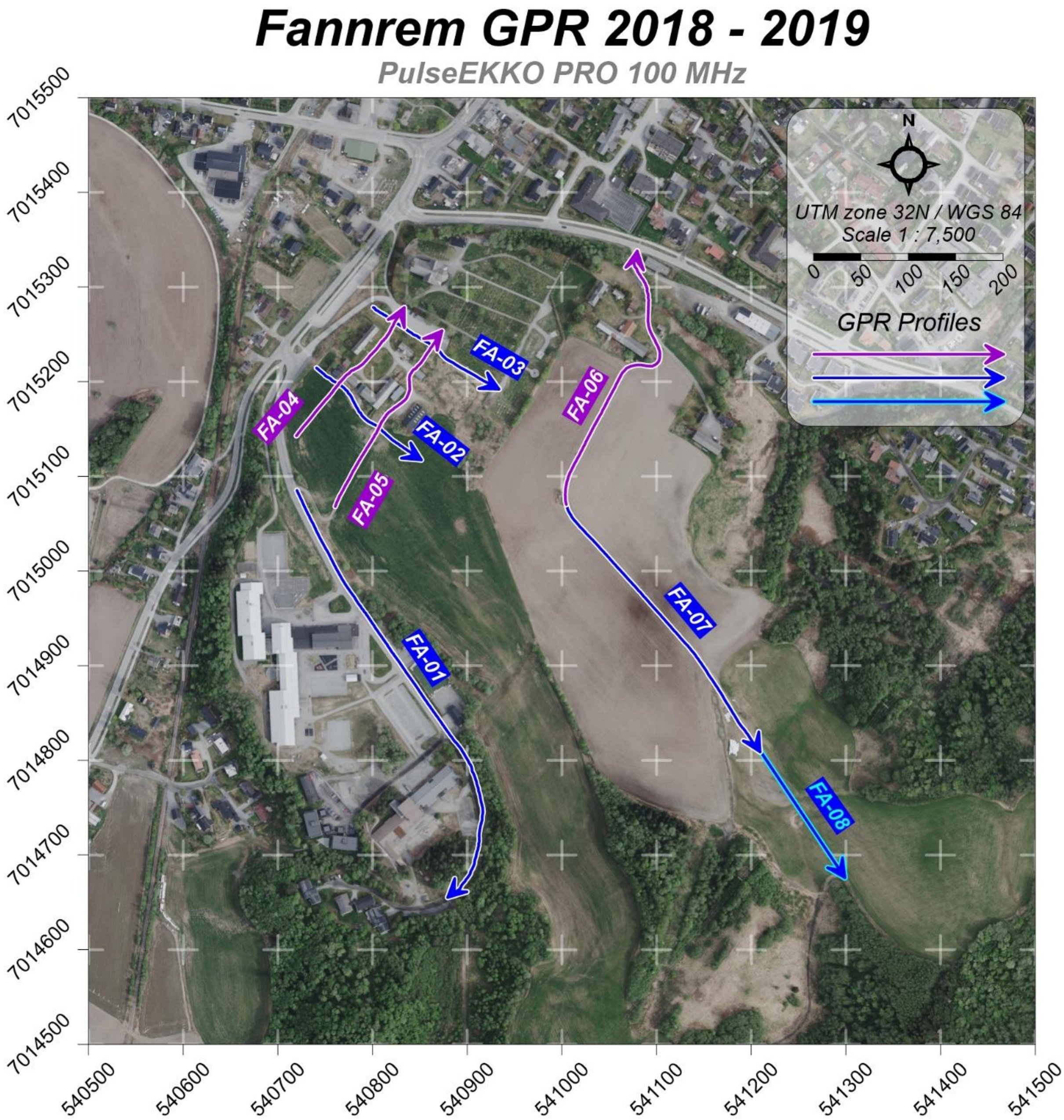


Figure 4.4: *Positioning for Georadar profiles collected in Fannrem in 2018 - 2019 (Orthophoto: Orkdal-Meldal-Frøya; Norge i bilder. 2018).*

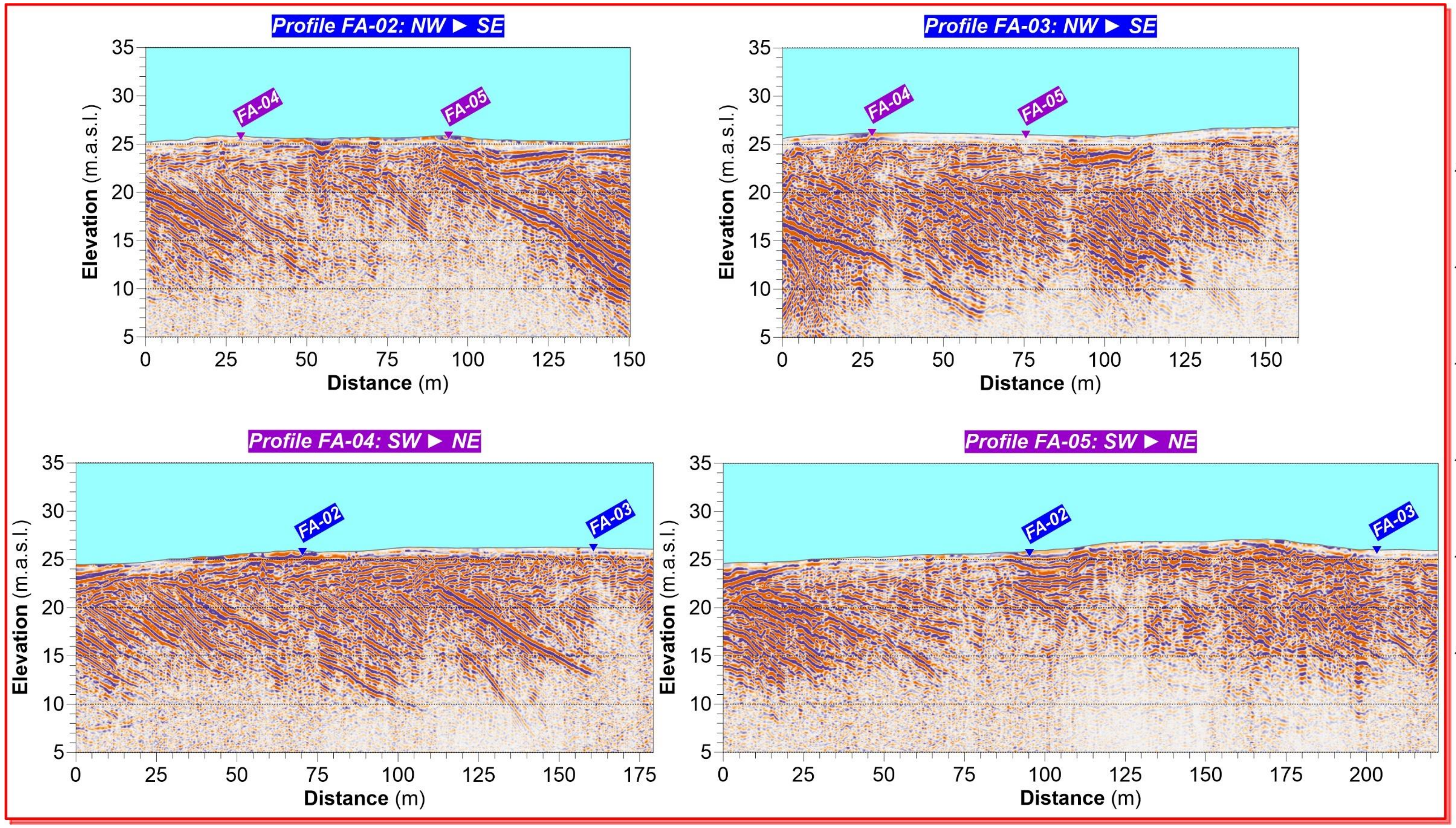
4.4.1 Orkdal church / Gjesvål

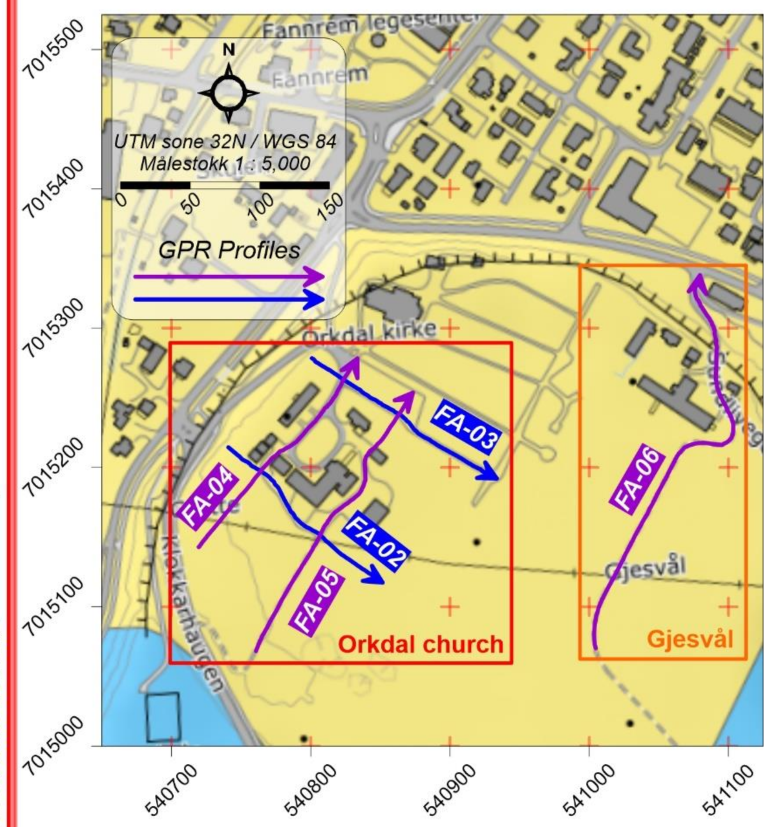
The first set of data from Fannrem is divided in two localities for better result presentation. The first one is found just south of Orkdal church and consists of four profiles i.e., FA-02 to FA-05 while the other is located more to the east in relation to the church and consists of one profile i.e., FA-06. Positioning for all profiles and processed radargrams are shown in **figure 4.4.1** along with the current Quaternary map for the area which shows all profiles measured over fluvial deposits.

The area south of the church marked by the red rectangle and named Orkdal church, is covered in detail by two pairs of parallel profiles placed perpendicular to each other and thus forming a local grid. In this way, the full geometry of possible detected reflectors can be more thoroughly surveyed. The large farmhouse and auxiliary structures in the area did not generate any ambient noise and therefore, the resulting radargrams shown in **figure 4.4.1** include a big variety of clear dipping layers for profiles in both directions. For profiles FA-02 and -03, layers dip towards the southeast whereas for perpendicular profiles FA-04 and -05, dipping is directed towards the northeast. In addition, profiles FA-02, -03 and -04 contain the highest frequency of dipping reflectors whereas for profile FA-05, the signal outlook becomes more complex after the first 100 meters distance which implies that the dipping direction is more purely southeastward in that area. Generally, it is safe to assume that since almost all profiles reveal dipping layers, the main dipping direction is eastward with a small shift toward the southeast on the east end of the Orkdal church locality.

Looking at the geometry of detected layers in more detail, it is easy to notice that in the Orkdal church locality there are two specific horizons that are more pronounced in signal strength when compared to the ones next to them. These two reflectors are better displayed in profiles FA-02 and -04, whereas profiles FA-03 and FA-05 are only able to detect one of them due to positioning. Therefore, these two high impedance contrasts found with GPR are located in the western portion of the area, closer to the main road. In that same area, all profiles involved, map a 4-meter overburden of horizontal reflectors before the dipping layers start appearing beneath it. It is also useful to note that this layer shows a mild dip which is opposite to what happens below it i.e., lightly slopes towards the west. Lastly, achieved penetration is close to 20 meters for most measured profiles which is in good agreement with the Quaternary map and shows that fluvial sediments here are at least 20 meters thick.

In Gjesvål, profile FA-06 shown in the bottom of **figure 4.4.1** shows a similar but also degraded image of what is seen in Orkdal church locality. Even though the signal is mostly discontinuous in strength, GPR still detects hints of northward dipping reflectors down to 15-20 meters, overlain by a mildly southward dipping top layer, similarly to what is seen in profiles FA-04 and -05 that share the same direction as FA-06. After 100 meters distance, penetration is diminished to five meters and no dipping reflectors appear in depth whereas after 200 meters distance at the edge of the terrace, the top layer stops being clearly delineated, and the signal becomes more scrambled. The last 100 meters of profile FA-06 display a dielectric regime that has also been encountered in Skjenalddalen, with shallow crisscrossing reflectors interrupted by a patch of unstructured layers with increased penetration. In any case, the reason why GPR signal is hindered over fluvial sediments in these areas is unclear.





GPR information
Instrument: Sensors & Software PulseEKKO PRO
Antenna Frequency: 100 MHz Perpendicular Broadside
Processing Software: EKKO_project v.5
Processing Routines: Dewow
SEC2 Gain Type
Bandpass/Lowpass Filter
Depth Conversion: Velocity 0.100 m/s (Default)
LiDAR Topography: NDH Orkdal 2016 - 0.50m
Vertical Exaggeration 3

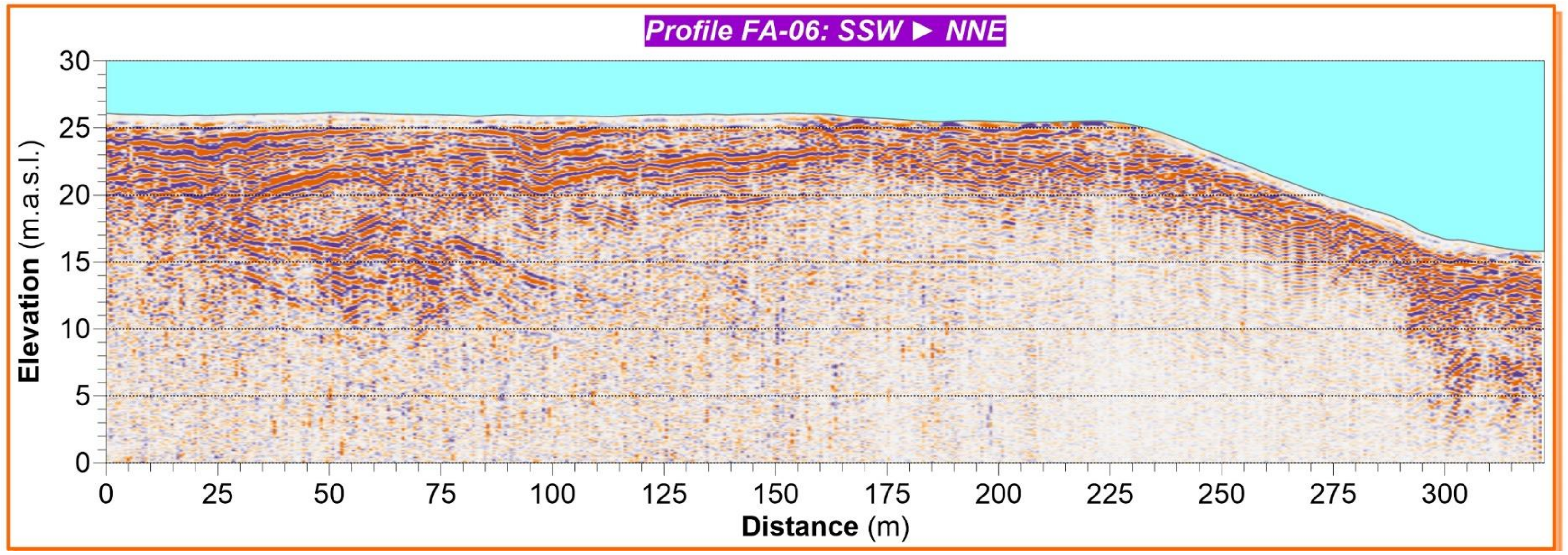


Figure 4.4.1: *Radargrams for profiles measured at Orkdal church and Gjesvål in Fannrem subarea, and map showing positioning of the profiles in relation to the existing Quaternary map (Reite, 1977).*

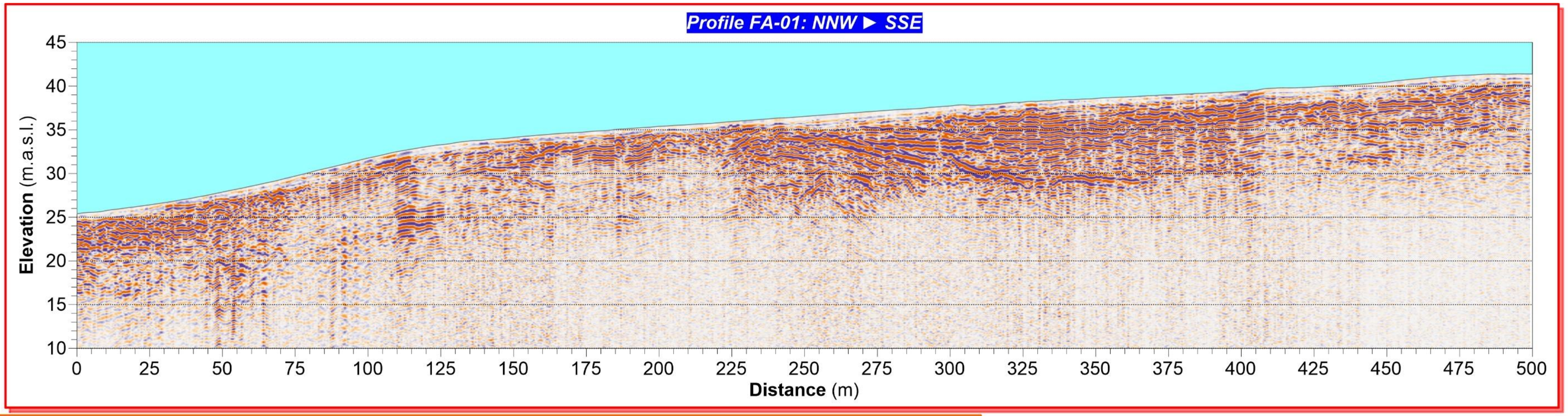
4.4.2 Prestmoen / Nonshaugen

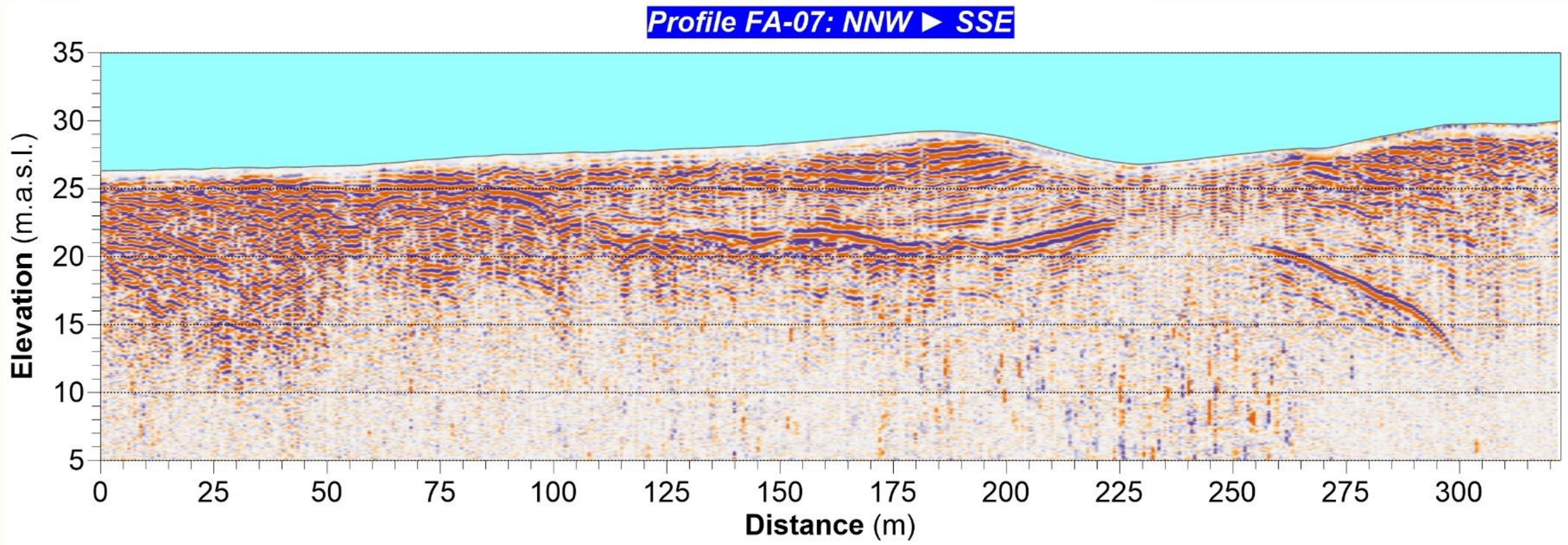
The last set of data for both Fannrem and the entire Orkdal survey are shown in **figure 4.4.2**. Prestmoen locality contains profile FA-01 and Nonshaugen profiles FA-07 and -08. According to the Quaternary map also included in the figure, profiles FA-01 and -07 cross over from fluvial to marine deposits, with the former in an acute angle and the latter almost perpendicularly. Profile FA-08 being the continuation of FA-07 with the use of Snake system over a farm field, lies entirely within marine deposits. Lastly, concerning data collection, profile FA-01 was conducted with the cart over an asphalt road that turned into gravel near its end while FA-07 was measured with the cart but entirely on a gravel farm road this time.

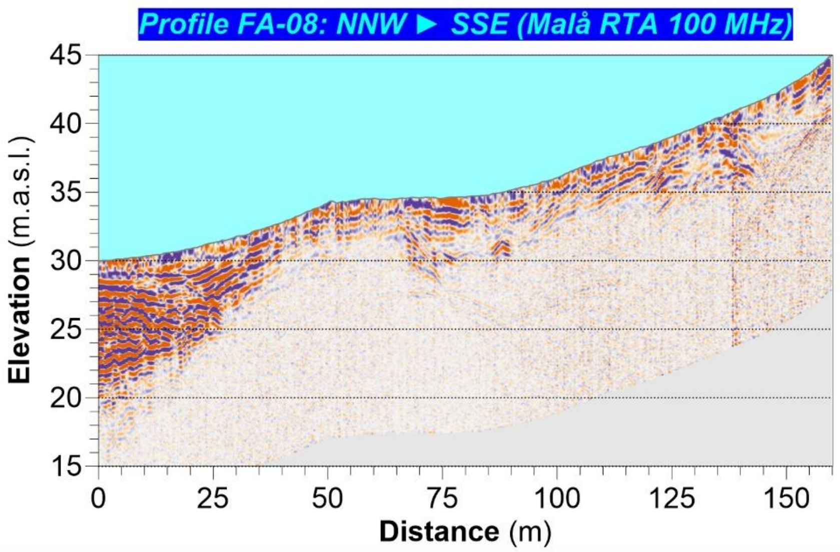
Profile FA-01 measured at the Prestmoen locality, follows almost perfectly the fluvial and marine deposit contact as seen in the map of **figure 4.4.2**, and this special condition is also reflected in the resulting radargram. The GPR signal is disconnected and patchy up to 225 meters distance, with penetration changing from acceptable in the first 75 meters (about 12-13 m) to very shallow with local reflector concentration like the one at 115 meters distance. After that point, there is a systematic change in the dielectric regime that is described by a prominent reflector that starts off at 250 meters distance, dipping towards the southeast until flattening out at roughly 30 meters above sea level and ten meters below the surface. Combined with the increase in ground elevation, this lineament creates a basin that is filled with many strong horizontal reflectors, unindicative of marine deposits both in outlook and penetration. However, at 400 meters distance the profile turns to the southwest and this change in direction towards the middle of the mapped marine deposits, is represented by gradual loss of penetration again even though horizontal layering is still noticeable although weaker in signal strength.

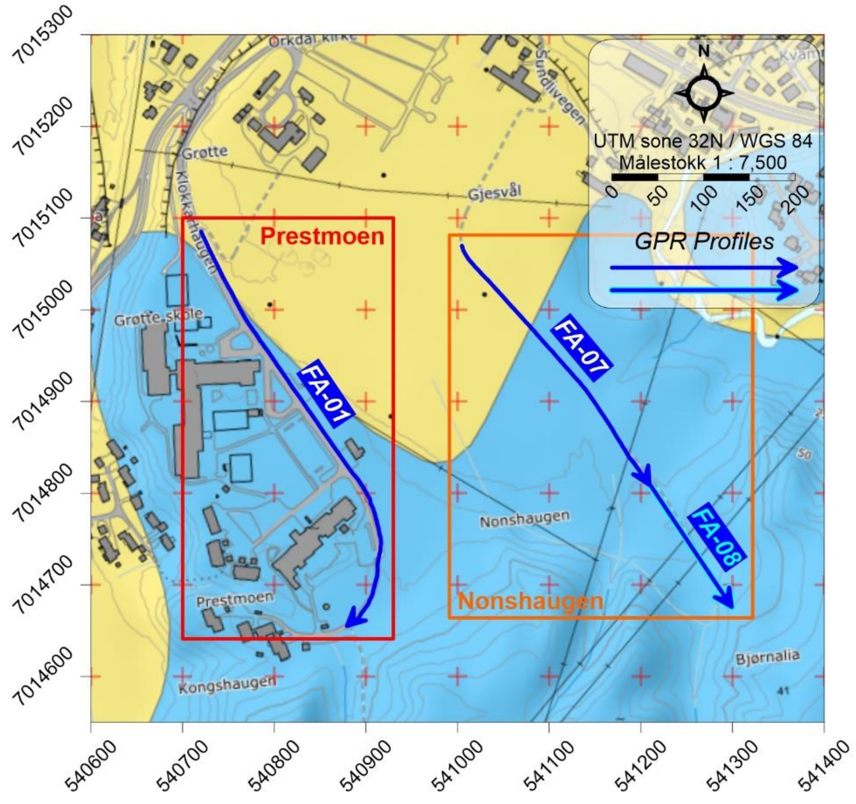
According to the Quaternary map in **figure 4.4.2**, the first 120 meters of profile FA-07 at Nonshaugen are measured over fluvial sediments and this is verified by the GPR data with penetration down to 17-18 meters in the beginning, gradually decreasing towards the fluvial/marine contact. Reflectors in the beginning are mostly crisscrossing or sub-horizontal but signal strength is good which validates the fluvial deposits mapped in that area. Past that mark, a similar underground setting to what was seen in the second half of profile FA-01 is revealed. Specifically, a basin is formed by a prominent reflector infilled with horizontal layering imaged by fully formulated flat reflectors. The prominent reflector that represents the bottom of this basin, is again flattening out but this time appears to be in lower elevation than in Prestmoen which is 20 meters above sea level. Between 225 and 250 meters distance, all signal is lot that could be due to the power lines in the area, but right after that part of the profile, the prominent reflector mentioned above reappears taking a sharp dip to the southeast. Horizontal layering is still visible, but loss of penetration doesn’t allow following this structure in depth. Regardless, it is still a strong indication that the formation surveyed in this area are not marine deposits.

On the other hand, the only profile in this locality that contains typical GPR signal in clays, is profile FA-08. The first 25 meters of this profile contain the last remnants of the basin seen in profile FA-07 with strong sub-horizontal reflectors, but the rest of the profile is only characterized by minimal penetration and no revealed reflectors, which is typical for conductive ground.









<u>*GPR information*</u>

Instrument: 1. Sensors & Software PulseEKKO PRO; 2. Malå RTA (Snake)

Antenna Frequency: 100 MHz; 1. Perpendicular Broadside; 2. Parallel Endfire

Processing Software: EKKO_project v.5

Processing Routines: Dewow; SEC2 Gain Type; Bandpass/Lowpass Filter

Depth Conversion: Velocity 0.100 m/s (Default)

LiDAR Topography: NDH Orkdal 2016 - 0.50m; Vertical Exaggeration 3

Figure 4.4.2: *Radargrams for profiles measured at Prestmoen and Nonshaugen in Fanrem subarea, and map showing positioning of the profiles in relation to the existing Quaternary map (Reite, 1977).*

5. CONCLUSIONS

This report sums up the results for a GPR-database acquired over a four-year period and several fieldtrips to compile and therefore is quite extensive both in volume and information content. However, implementation of Georadar has a high productivity ratio when conditions are favourable, producing lots of data over short time, with moderate effort compared to other geophysical methods. The total of 13.5 kilometres of radargrams collected in Orkdal, constitutes a rich source of information that not only aids in the revision of the NGU Quaternary maps, but can also supplement future surveys in the area.

All profiles were planned and conducted over three types of deposits which constitute two opposing dielectric regimes i.e., favourable for fluvial or glaciofluvial and unfavourable for marine. Considering that, results have either verified or doubted the existing Quaternary mapping based on GPR-signal quality, reflector structure and depth penetration. Moreover, contacts between the above-described dielectric regimes were better resolved by the fundamentally different GPR-signal obtained in such areas. Marine deposits in Orkdal were easily identifiable by the lack of signal penetration whereas fluvial and glaciofluvial sediments allowed information to be extracted from depths between 10 and 25 meters below the surface. Results vary from inconsistently dotted or crisscrossing reflectors to clear layering, dipping or otherwise.

In conclusion, GPR measurements in Orkdal have shown that the difference in quality between PulseEKKO PRO and Malå RTA collected data can be noticeable. Therefore, it is advisable that the road network and smooth unvegetated terrain in each area must be fully exploited in planning, for obtaining the best quality data with the PulseEKKO PRO system. However, Malå RTA can still supplement every survey with good enough data in areas where the cart cannot be operated. In addition, manmade structures such as buildings or powerlines can always be a source for ambient noise especially for the highly sensitive cart setting whereas the Snake system's unrefined signal is generally unimpeded by such interference. Lastly, GPR-measurements in Orkdal have proven once more that the dielectric properties of the ground are still the decisive factor for any Georadar survey's success. In Orkdal, measurements over fluvial deposits have resulted in unforeseen bad quality signal while some marine sediment covered localities have been proven more friendly to the propagation of electromagnetic waves than expected.

6. REFERENCES

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