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Georadar measurements for
Statens Vegvesen in
Vågå kommune

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Title:
Georadar measurements for Statens Vegvesen in Vågå kommune

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Summary:
In October 2015, the NGU conducted Georadar measurements in two locations in Vågå municipality, Oppland county. The survey is funded by the Norwegian Public Roads Administration (Statens vegvesen) and its purpose is to test the method's efficiency in supplementing the construction of new roads. More specifically, our main goal is to discover the maximum thickness of sediments and delineate the depth at which bedrock lies.

All measurements have been handled by Georgios Tassis from NGU and Tore Thomassen from Statens vegvesen. Two Georadar systems have been employed for this purpose: Pulse EKKO PRO by Sensors & Software for the profile running along the road north of Vågåmo and RTA by Malå for all the rest. All measurements were resumed during a single sunny day in October 13th 2015.

This report presents the measurement scheme (method, execution and processing) along with all the processed radargrams which resulted from the measured profiles. Each profile is accompanied by commenting on the results while the profiles themselves are presented in 1:1 scale (depth scale equal to distance scale) in three Appendices.

The results of this survey portray the benefit of Georadar application in surveying sediment thickness or depth to bedrock in connection to road construction. The use of unshielded antennas where maximum depth penetration is required was not optimal for this survey due to the fact that cultural noise levels were high. Effects coming from power lines and housing in the region have been identified and after discarding them, the GPR implementation has detected layers which are in their majority in good agreement with the existing drilling information in Vågåmo. No drilling information is available though in Rudilykkja and all interpretation is based on the detected reflectors alone which can be misleading due to the fact that the layers that we have picked might not represent the bedrock surface. Our results indicate a maximum depth to bedrock equal to at least 10 meters for both areas.

The depth to bedrock maps presented in this report should be thought of as trends of bedrock undulations and not accurate depths since accurate velocity values do not exist and the wavelength of the GPR signal for the 50 MHz antenna is quite broad (more than 1 m locally) and therefore respective errors are expected when picking surfaces on such radargrams. Some positioning problems due to the fact that the Malå RTA system had to be used to survey difficult terrain, should also be taken into consideration when these bedrock trend maps are examined.

Keywords:	Geophysics	Georadar
Bedrock	Sediment thickness	Road construction
		Scientific report

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1. INTRODUCTION

In October 2015, the Geological Survey of Norway (NGU) conducted Georadar measurements in two locations in Vågå municipality, Oppland County. The survey is funded by the Norwegian Public Roads Administration (Statens vegvesen) and its purpose is to test the method's efficiency in supplementing the construction of new roads. More specifically, our main goal is to discover the maximum thickness of sediments and delineate the depth at which bedrock lies.

All measurements have been handled by Georgios Tassis from NGU and Tore Thomassen at Statens vegvesen. Two Georadar systems have been employed for this purpose: Pulse EKKO PRO by Sensors & Software for the profile running along the road north of Vågåmo and RTA by Malå for all the rest. All measurements were resumed during a single sunny day in October 13th 2015.

The first area of interest is north of the town of Vågåmo, where a new road and pedestrian walkway is going to be constructed near the already existing road. In this area, a variety of profiles have been conducted with a total length of ~3.8 km (**figure 1**). The second area is located east of Vågåmo at Rudilykkja where a single profile has been conducted along highway 15 and 30 m uphill within local farmland (**figure 2**). The total distance covered with Georadar measurements for this study is ~4.15 km distributed in 16 profiles of various lengths.

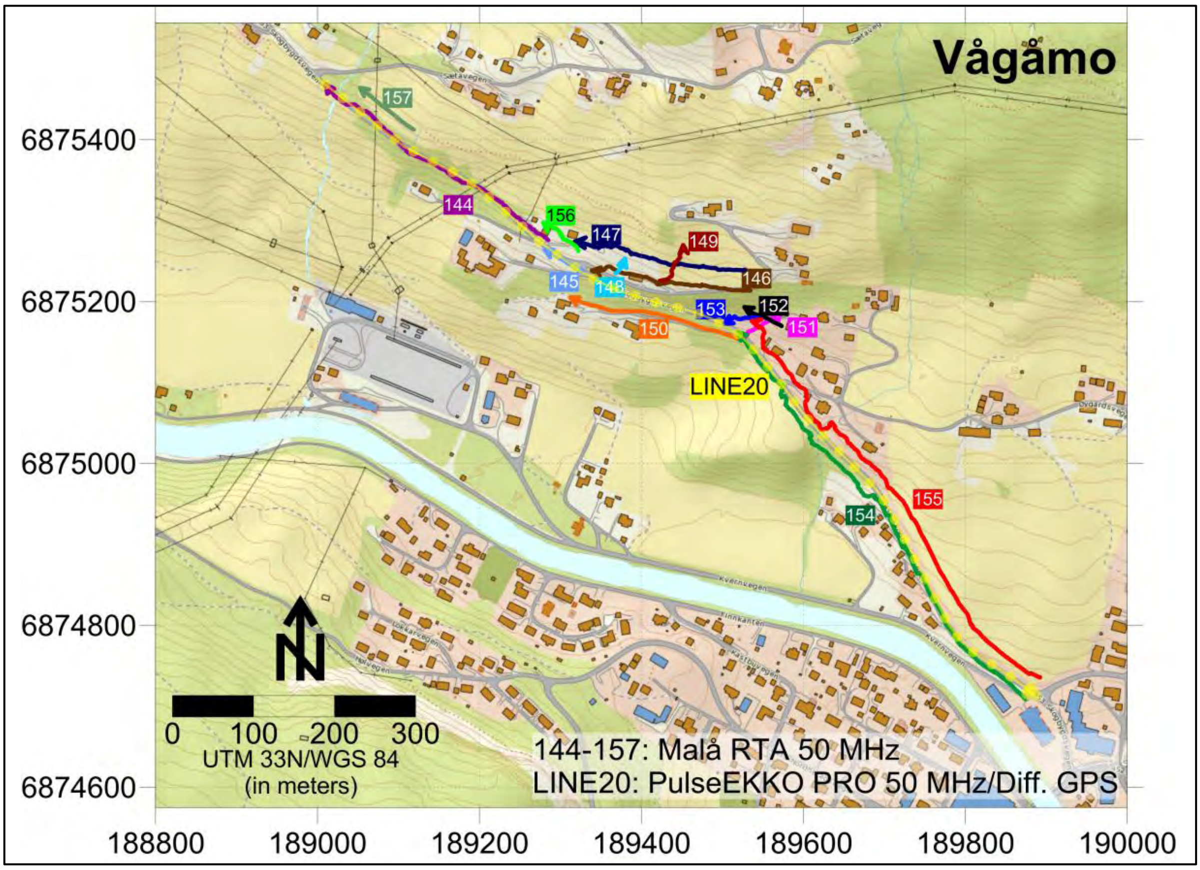

Figure 1: Geographical distribution of the Georadar profiles conducted north of Vågåmo.

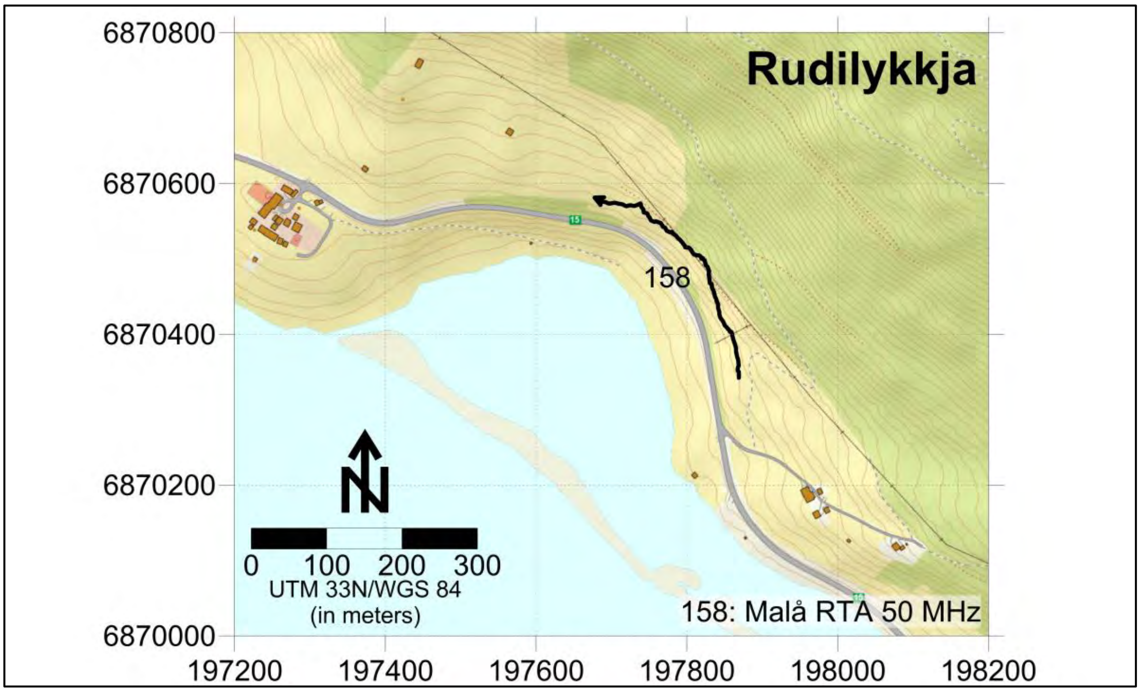

Figure 2: Georadar profile conducted east of Vågåmo at Rudilykkja.

This report will focus on presenting the results obtained via processing of the GPR profiling. Additional information such as drilling depth to bedrock measurements provided to us by Statens vegvesen has also been employed to facilitate the extraction of conclusions.

2. METHOD DESCRIPTION, MEASUREMENTS AND PROCESSING

2.1 Method description

The Ground Penetrating Radar (GPR) or Georadar is an electromagnetic method which can be used to survey the layering and structure of the subsurface. The method is based on the recording of reflected electromagnetic wave pulses from interfaces in the ground. The electromagnetic wave is inserted into the ground with the use of a specially designed antenna which functions as a transmitter. Part of its energy is reflected on boundaries which represent a change in the ground's dielectric properties and returns to the surface. The rest of the energy continues downwards and can be reflected on other subsurfaces it comes across. On the surface, the reflected signal can be registered with the use of a receiver antenna and subsequently sent to a control unit for enhancement and digitization. In this recording with proper processing we may define the two-way travel time until each detected reflector and with the knowledge of the wave's velocity in the ground, we can convert these travel times into accurate depths.

2.2 Data acquisition

Acquisition parameters are shown in **table I**.

Profil #	GPR System	Frequency (MHz)	Time window (ns)	Sampling frequency (MHz)	No. of stacks
144	Malå RTA	50	2101.84	506.22	1
145	Malå RTA	50	2101.84	506.22	1
146	Malå RTA	50	2101.84	506.22	1
147	Malå RTA	50	2101.84	506.22	1
148	Malå RTA	50	2101.84	506.22	1
149	Malå RTA	50	2101.84	506.22	1
150	Malå RTA	50	2101.84	506.22	1
151	Malå RTA	50	2101.84	506.22	1
152	Malå RTA	50	2101.84	506.22	1
153	Malå RTA	50	2101.84	506.22	1
154	Malå RTA	50	2101.84	506.22	1
155	Malå RTA	50	2101.84	506.22	1
156	Malå RTA	50	2101.84	506.22	1
157	Malå RTA	50	2101.84	506.22	1
158	Malå RTA	50	2101.84	506.22	1
LINE20	PulseEKKO PRO	50	2000	626	4

Table 1: Sampling characteristics of each profile.

As already mentioned, two GPR systems have been employed in this survey whose performance has already been found to be quite similar (Tassis et al., 2015; Tassis & Rønning, 2015). Most profiles have been carried out with Malå's RTA (Rough Terrain Antenna) system using a 50 MHz antenna. This system offers the possibility of performing Georadar measurements in rough terrains and forested areas due to its flexible antenna setting which resembles a snake. However, when utilizing this Georadar we are presented with positioning problems since the instrument's GPS is not mounted where the actual measurements take place namely between the transmitter and receiver antennas but on the surveyor who carries the storing and display unit. When 50 MHz is the antenna frequency employed, this discrepancy is ~7 m i.e. each trace is being registered 7 meters behind its assigned GPS reading (**figure 3**). This error is corrected for in the processing. However, this can lead to errors when profiles change direction and it is expected that the RTA measurement positioning will be suffering in accuracy. The problem will be addressed again later in this study with notes which will be added to each interpreted image originating from the Malå GPR.

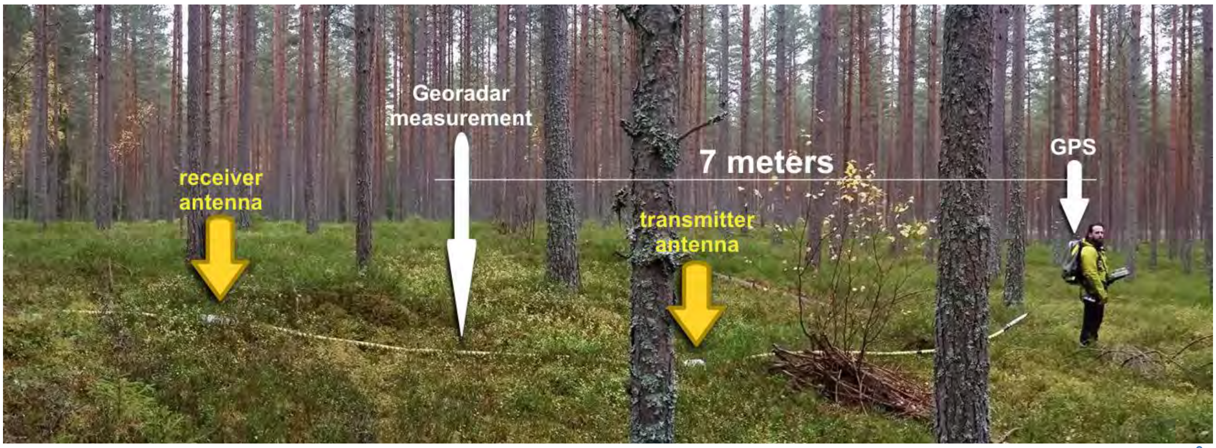

Figure 3: Explanation scheme for the 7 meter discrepancy in measurement positioning for Malå RTA Georadar (50 MHz antenna frequency).

As can be seen in **figure 1**, all profiles north of Vågåmo are done in populated areas and in the vicinity of the already existing road. This allowed us to perform a measurement with PulseEKKO PRO by Sensors & Software running on the asphalt and along the road using a 50 MHz antenna as well. This particular system using this particular frequency is bulky and cumbersome and cannot be used in rough terrains but it is reliable and produces high quality data. Furthermore, our technicians at the NGU have upgraded the instrument by adding an external GPS on the cart between transmitter and receiver. This allows us to register traces with their true GPS positioning as opposed to the RTA instrument. For this particular project we have further enhanced the GPS accuracy by using a differential GPS system instead of the normal standalone system we normally use. For this purpose, a base station was established on a nearby fixed geodetic point (**figure 4**).


Figure 4: Differential GPS base station above Vågåmo.

This point has been chosen out of a list of such points in Norway due to its proximity to our area of interest. In order for our moving station GPS positions to be corrected, radio communication must be established between moving and base station. Therefore, the distance between them should be within the instrument's radio range which in our case is 5 km. Indeed, all profile points measured are less than 1 km away from the base station we have chosen. **Table 2** shows all information regarding this particular point.

Feature	Value
Point number	E29T0255
Point name	OP51 SKYTTARPALLEN
UTM 32N Northing	6860088.501 (in meters)
UTM 32N Easting	504514.496 (in meters)
Elevation nn2000	484.531 m
Elevation nn1954	484.456
Ellipsoid height	529.139
Point type	S (fixed)
Ground	BEDROCK

Table 2: Information about the fixed geodetic point used as base station for our differential GPS.

The measurements acquired with the differential GPS are accurate and also include topography. Unfortunately, the other GPS unit employed by the Malå RTA system is not accurate neither in positioning nor in topography. For this purpose, all recordings had to go through refining and in some case repositioning according to already marked points by Statens vegvesen. Points representing wrong readings (singular or sets of points) have been removed from our profiles and replaced by interpolation values along the assumed course of the profile. After refining the X and Y coordinates for each profile, topography was obtained by sampling the Norwegian Digital Terrain Model (DTM, 10 m resolution) for the aforementioned coordinates. Topography was then smoothed with a low pass filter to avoid abrupt changes due to limited resolution. Our profiles contain traces which are recorded every 0.5 m and therefore the point resolution in every radargram is higher than the available DTM. All the extra blank GPS positioning has been filled with minimum curvature interpolation. Topography is shown with each profile in a separate plot at the respective Appendices.

All profiles in both Vågå localities have been measured with the use of the 50 MHz antenna. This antenna frequency has been employed in order to reach the maximum depth penetration since it is the lowest frequency antennas the NGU possesses. A very important parameter when performing GPR measurements is the Time Window i.e. the total registration time. A higher Time Window allows the Georadar to record data from deeper reflectors therefore, we have set a value of 2000 ns (nanoseconds). However, the actual survey depth is controlled by the electric conductivity of the ground and in our case does not allow the signal to penetrate deeper than 400 ns as can be seen in the Average Trace Amplitude (ATA) plot in **figure 5**. The ATA plot is a useful pre-processing tool which allows us to discern the time that the signal decays back to noise levels. Essentially, this indicates the maximum penetration depth for any given area.

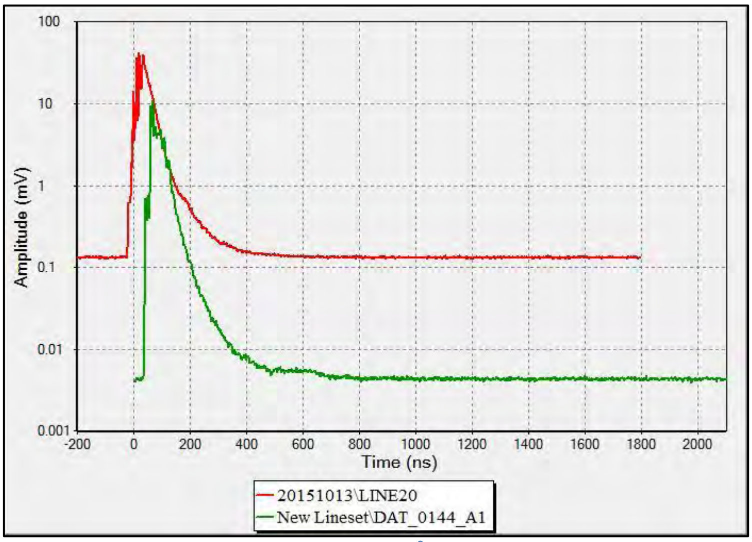

Figure 5: Average Trace Amplitude plot for Malå RTA (green) and PulseEKKO PRO (red) Georadars.

No Common Mid Point (CMP) measurement has been performed in order to calculate the ground velocity. However, the presence of fully formed hyperbolas in some of the upper layers of our profiles have presented reflections which after proper fitting have yielded a velocity of around 0.1 m/ns. This velocity is in good agreement with the soil formations present in the region (mainly moraine and fluvial sediments) and means that the maximum penetration achieved is ~20 meters.

2.3 Data processing

All profiles were processed with the use of two software programs: a) EKKO_project V1 R3 (Sensors & Software 2013) for Pulse EKKO PRO data (Line20), which is the designated software for processing S&S data and b) RadExplorer 1.42 (DECO Geophysical 2005, Bouriak, S. et al 2008) from Malå Geoscience for all Malå RTA profiles (lines 144-158). The processing modules utilized for each program are described in the following section.

The only profile processed in EKKO project was line 20 (**figure 1**). For this purpose we have compiled a procedure flow which contains the following routines: dewowing, background average subtraction, AGC gain control type and ultimately conversion to depth. **Table III** displays the purposefulness of each routine.

Routine	Effect on data
Dewow	Removes unwanted low frequency "wow"
Background Average Subtraction	Removes average signal from all traces
Automatic Gain Control (AGC)	Equalizes all signals in each trace regardless of depth
Conversion to depth	Converts nanoseconds to meters on the Z axis

Table 3: Processing routines employed in EKKO_project (LINE20).

All other profiles have been processed in RadExplorer using the following routines: DC removal, time-zero adjustment, background removal, AGC amplitude correction, bandpass filtering, and finally conversion to depth. **Table 4** explains the effect of implementing these routines.

Routine	Effect on data
DC Removal	Removes the constant component of the signal
Time zero adjustment	Sets the time where first break occurs
Background removal	Subtracts the mean trace
Automatic Gain Control (AGC)	Equalizes amplitude along the traces
Bandpass filtering	Increases signal/noise ratio
Conversion to depth	Converts nanoseconds to meters on the Z axis

Table 4: Processing routines employed in RadExplorer (lines 144-158).

Background removal is the most sensitive processing tool used in GPR data processing and its purpose is to remove the strong flat signal present in the first nanoseconds of each radargram (direct pulses in the air and in the griund). Strong surface waves are an issue that has already been tackled by Tassis et al. (2015) and Tassis & Rønning (2015) when Malå RTA is being utilized. However, bedrock could also be locally flat in each profile meaning that the aforementioned wave is not the only flat reflector that will be appearing in the data. A strong background removal filter (short length) would of course remove the surface wave but it would also scramble all other flat reflectors detected throughout the profile. Essentially the application of such a filter would result in the distortion of flat reflectors or even the complete removal of such horizontal layers. In this sense, only weak background removal has been employed (long length i.e. equal to the entire length of each profile) in order to isolate the surface wave and leave all other horizontal reflectors uninfluenced.

2.4 Data presentation

All profiles are presented without the incorporation of topography for two main reasons. First due to the fact that artificial effects cannot be identified in the ground when profiles are displayed along with topography. Second, because it becomes impractical to present the results coherently. In this sense, we have not exaggerated our profiles in depth vs. horizontal position. This analogy has been kept constant and equal to 1:1 i.e. depth scale is equal to distance scale. Drillings which coincide or lie relatively close to the survey lines are marked in each profile to help interpretation. Again, it should be noted that matching drillings and trace positions within Malå profiles is dubious due to the inaccuracy of the GPS system attached to the Georadar. This is not the case with the Sensors & Software georadar but still not all boreholes coincide with the path of LINE20. On the other hand, all drillings presented in the results have reached bedrock.

Distance is shown in every profile on the top (every 20 meters) and in more detail at the surface of each profile. Interpreted reflectors are shown in yellow lines within the profiles. These interpretations are not continuous throughout the length of the radargrams due to the fact that in some areas it is neither possible nor safe to pick any surface.

3. RESULTS

3.1 PulseEKKO PRO profile in Vågåmo: LINE20

The processed image for LINE20 is shown in **Appendix -01**.

Since the profile is over 1200 m long and the displayed depth is just 25 m, **LINE20** is presented in four parts to keep the 1:1 analogy scale in both axes. The profile is running along an asphalt road in a moderately inhabited area north of the town of Vågåmo. The presence of power lines, several houses, fences as well as excavated bedrock along the road (which includes vertical stone walls), plagues our data with a number of prominent artificial effects i.e. false anomalies. We will try to pinpoint these false anomalies in the result description but generally, large hyperbolic anomalies are due to large targets above the ground and do not represent any ground features. Such anomalies can be seen at 90, 240 and 315 meters. Inclining straight lines are also not natural features and may represent not fully developed hyperbolas from targets above the ground. Examples of such features can be seen at 620, 630 and 670 meters. Another type of artificial effect refers to continuous reflections that are repeated and extend to depth like the ones at 315 and 960 meters.

A clear reflector is followed quite nicely on the first 150 meters by a smoothly deepening reflector which coincides with a 4.9 m drilling found at 5 meters horizontal distance. The same reflector appears to be coming up at around 38 meters where a 3.0 m drilling is present before deepening again until 57 meters distance. Then, the soil layer becomes thinner and thinner until 150 meters where a fully formed hyperbolic feature is found which is repeated in depth (ringing effect). This hyperbola has yielded the 0.1 m/ns velocity used in all our calculations and represents a ground structure. Another similar structure can be seen at around 190 meters where bedrock seems to be at a relatively shallow depth.

At 190 meters distance, a strong reflector appears to be gaining in depth again until around 350 meters where a drilling has found bedrock at 1.3 m depth. Between 440 and 560 meters, a series of parallel reflectors can be seen inclining towards the northwest to a relatively big depth. A neighboring drilling indicates that sediment depth is noteworthy in this part of the profile, since the aforementioned borehole has found bedrock at 9.0 m depth. This way that these reflectors are built up could be indicative of a succession of deltaic sediments. Another interesting feature that could support this claim is the straight reflector running through these layers with an opposite inclination and could be assigned to the ground water table. However, the direction of the inclination of the whole system and the supposed GWT does not justify such a claim. At 560 meters this series of reflectors reaches its minimum depth but another set of layers reappears soon after at 580 meters distance where a drill hole has yielded a sediment thickness equal to 4.5 m. This reflector is retaining a depth that is lower than the aforementioned value for several tens of meters until the horizontal distance becomes 645 meters.

At this point another series of moderately deep reflectors occurs along a rather long segment of the profile until around 800 meters, validated by a set of drillings performed in this area (8.0 m at 708 meters, 4.0 m at 733 meters, 3.9 m at 798 meters). However, we should discard the lower prominent reflectors (below 10 m depth) at the area between 730 and 755 meters as artificial effects. After 800 meters distance the image becomes difficult to interpret with several deeper horizons appearing and a number of not fully formulated hyperbolas plaguing the radargram. One could follow two reflectors, one shallow at around 2 m depth and a deeper one at around 8 m depth but no drilling data exist in the area to validate which one is the safest option.

The area after 860 meters and until the end of the profile presents a big variety of reflectors in depth which are not in good agreement with the existing drillings. Artificial effects are in abundance in this region probably due to the denser housing along the road. In any case, the borehole data indicate that whichever reflector is to be chosen, it shouldn't exceed 2 m in depth.

3.2 Malå RTA profiles in Vågåmo: 144-157

Due to the difficulty of applying the PulseEKKO PRO Georadar in vegetated areas or slopes of uneven terrain and small room for maneuvering, we have performed several profiles using the Malå RTA system and following the guidelines given by Statens vegvesen as best as possible. Most of the profiles presented below run parallel to LINE20 to offer a pseudo three dimensional outline of the sediments. It should be noted that some of the planned profiles were impossible to perform due to housing, fencing and steep topography while in other cases parts of profiles are coinciding with LINE20. Regardless of this, all radargrams are presented in the exact same way as before without having to split them due to the fact that none of them is longer than 600 meters.

Profiles 144 to 153 are presented in **Appendix-02**.

Profile 144 is 330 meters long and lies in the northern part of the survey area. The profile starts off with a big variety of reflectors which are probably artificial effects probably induced by the neighboring houses. At about 52 meters of horizontal distance a somewhat clear reflector is formulated, matching the 4.7 m bedrock depth borehole measurement. This reflector is becoming shallower but its undulations remain obvious enough for the following meters. During its course it goes over three underground features which represent unknown underground structures, first at 155, second at 195 and third at 225 meters (center of the hyperbola). Past that point, the strong reflectors reappears along with other deeper ones. However, drillings indicate that we should look for the bedrock-sediment limit in the uppermost part since it is expected to be less than 3.0 m below the ground surface.

Profile 145 is a short profile (115 meters long) which lies before profile 144. It displays several reflectors until a 5.0 m depth but generally we can assume that sediment thickness along this profile is not larger than 3.0-3.5 m (3.4 m drilling present in the profile). However, no clear top bedrock reflector appears.

As opposed to profiles 144 and 145, **profile 146** runs about 30 m north of LINE 20 (**figure 1**). It is around 195 meters long and its purpose is to check the sediment thickness 30 meters uphill from where the new road will be constructed. Lots of reflectors can be seen in this profile from its very beginning but bedrock should be found below 5.0 of depth. The only drilling coinciding with this profile is unfortunately on top of a big artificial effect which is due to a big house (at about 120 meters distance). Due to that, no clear information about bedrock can be acquired here.

Profile 147 is another 30 m from profile 146 up the hillside. Several clear reflectors are undulating in the top part of the profile, presenting a larger depth for the first 120 meters of distance and a shallower one for the remaining 100 meters. A drilling situated at the latter part of the profile (northwestern half) is in a really good agreement with a reflected layer which is found at 3.4 m depth. An interesting feature is two deep but clear reflectors which are crisscrossing at about 127 meters distance. These reflectors are not perfect lines therefore aren't artificial effects and represent some interesting underground feature which cannot be interpreted without any further information.

Profile 148 is connecting profiles 146 and 147 at their northern edge and is spreading for about 45 meters directly uphill. Several reflectors are shown which appear to be gaining in depth as we move upwards topographically. A neighboring borehole indicates a bedrock depth of 3.4 m, which could refer to a layer appearing somewhat deeper in our profile. The linear reflectors in the beginning of the profile could be artificial effects though.

Profile 149 on the other hand is connecting profiles 146 and 147 at their southern edge. It is just over 60 meters long and also climbs a slope. Sediment thickness is starting from about 3.3 m according to a neighboring drilling, but reflectors indicate that it does not increase much more throughout the profile with bedrock appearing to lie at a more or less constant depth.

Profile 150 is situated 30 m south from LINE20, surveying the downhill part of the area below the scheduled road route (**figure 1**, **Appendix-02**). Within this 220 meter long profile and according to the drilling already carried out along this line (9 m at 95 meters distance), sediments of relatively significant thickness are contained. This is validated by the variety of deep reflectors found within the first 140 meters of the profile. After this point the same reflectors seem to become shallower among some false anomalies and this pattern is kept until the end of the profile. A borehole at 148 meters distance indicates that bedrock was found after 3.0 m of drilling while our data indicate a slightly larger depth. However, as already mentioned, this particular part of the profile is plagued by artificial effects and features could be masked.

Profiles 151, 152 and 153 are three short profiles which are surveying a small subarea in the mid segment of the region and are intersecting one another. Their positioning can be seen in **figure 1** and the attached map at **Appendix-02**. Profile 151 indicates a limited sediment thickness throughout its 62 meters of length. Profile 152 presents a somewhat larger number of reflectors at its first 18 meters but the remaining part plus the entire profile 153, continue displaying a limited bedrock depth. It should also be noted that both 151 and 152 profiles show the same artificial effect in the form of a straight line inclining towards the west.

Appendix-03 displays the processed radargrams for profiles 154 to 157.

Profile 154 runs almost parallel to the southern half of LINE20 and almost coincides with it. As already described for LINE20, this is a moderately inhabited area with several houses along the road which cause strong artificial effects to our data. The first 280 meters of the profile are full with these false anomalies appearing as consecutive straight lines inclining towards the southeast. According to the drillings done for this part of the profile, bedrock is quite shallow and does not exceed 2.0 m. However, an assessment concerning the first half of the profile is ambiguous at best. Nevertheless, as soon as we are clear of the housing at about 270 meters distance, a shallow strong reflector appears and runs smoothly until about 410 meters. A single borehole present within this stretch at 318 meters is in quite good agreement with this particular reflector, since it met bedrock at 2.0 m depth where this layer is detected. After 440 meters of distance where a strong artificial effect is located, reflectors are deepening again until the end of the profile. This deepening is followed up quite nicely in our data with a reflector which is in very good agreement with the already existing drilling data (4.0 m at 485 meters, 8.0 m at 518 meters and 4.8 m at 555 meters). Some false anomalies near the end of the profile do not obstruct the interpretation.

The longest profile measured with Malå RTA Georadar during this field trip to Vågå municipality is **profile 155**. Its total length is almost 600 meters and it is situated 30 m uphill from profile 154. Two thirds of the profile lie in unobstructed farmland while its last third maneuvers around a sparsely inhabited area north of the existing road. The radargram starts off with a relatively shallow reflector which gradually deepens for the first 70 meters of the profile. This is not particularly followed up by the existing drilling which demonstrates shallower depth to bedrock at 65 meters (2.7 m) than in the beginning of the profile (3.3 m). However, reflectors can be assigned to these depths in both locations and followed up to link these borehole measurements. Sediment depth seems to continue at a similar depth scale for the following 75 meter segment, which also contains an artificial effect at 110 meters of horizontal distance. A drill hole at 130 meters has met bedrock at 4.7 m depth and from this point onwards, the detected layers appear to increase in number and depth until 230 meters. Drillings once again indicate shallower bedrock depths with 3.0 and 2.7 m at 175 and 225 meters distance respectively. After this point, reflectors shrink back to shallow depths and continue to stay at the uppermost levels of the radargram (1.8 m at 270 meters, 1.6 m at 315 meters) borehole depths: until at about 380 meters when the profile enters the inhabited area and the first artificial effect is found. Despite of this, a strong reflector appears to survive within the false anomaly at a depth which is in good agreement with a drilling at this point showing bedrock at 2.1 m below. This particular reflector stays at about this depth for the following 100 meters with a small exception at 425 meters where the detected layer makes a small dent just after the 1.4 m bedrock measurement at 422 meters. According to the last drilling in the profile (7.2 meters at 485 meters), sediments are increasing in depth and this is followed up by the larger number of deeper reflectors appearing in the last part of profile 155. However, this part is again plagued by artificial effects which scramble the processed image and make interpretation difficult regardless of the obvious general increase in reflectors.

Profile 156 is a short profile (around 65 meters long) which covers a housed area at the mid part of the survey region. Reflectors and a neighboring drilling (1.6 m) indicate that bedrock is shallow here. However, more than half of the profile is infested with false anomalies and repeated reflections therefore no safe conclusion can be reached.

The last profile north of Vågåmo is **profile 157**. It is located in the northernmost part of the survey area and runs parallel to profiles 144 and LINE20 about 30 meters north of the existing road. Its total length is around 80 meters and shows a quite strong reflector running through the profile at a depth of around 4 to 5 m. An artificial effect covering a large portion of the profile shields our image but some reflectors can still be located in the radargram.

3.3 Malå RTA profile in Rudilykkja: 158

Rudilykkja is a small farmland area about 15 kilometers east of Vågåmo. **Profile 158** follows the course of a smooth round turn of highway 15, at a constant distance of 30 meters from the road. Half of the 340 meters of the profile's length are performed in farmland and the other half in a forested area of the region. Results are shown in the bottom part of **Appendix-03**. Unfortunately, no drilling data are available for this region therefore all assessments are based solely on the processed Georadar image. Reflectors appear to be relatively shallow in the beginning of the profile with some increased depth between 40 and 60 meters of horizontal depth. Another clustering of reflectors can be seen between 90 and 120 meters where information from about 15 m depth is collected. From this point, reflectors become deeper and deeper and continue to remain so until the end of the profile. Some artificial effects around 220 meters could mask real information but the image becomes rather clear past that point with several layers undulating until a depth of 15 m. It should also be noted that reflectors within the first 5 m of depth appear to be thinner and more detailed than the ones in depth, especially after 240 meters of horizontal distance. This could indicate a difference in soil composition.

3.4 Summary of results

Interpretation results are shown in **figures 6, 7** and **8**. The picked depth to bedrock estimations have been gridded and plotted against the area map. It should be noted that results for Malå RTA in Vågåmo have been gridded separately from the results from PulseEKKO PRO for the same area. This was done due to the fact that PulseEKKO PRO data do not suffer from positioning problems and their coordinates are accurate as opposed to the Malå RTA data. Regardless, the results for both systems are coherent enough with both maps presenting a larger sediment thickness in the middle of the surveyed area and smaller depth to bedrock on the edges. In Rudilykkja bedrock appears to be deepening towards the northwest but we should keep in mind that we don't have drillings to support this claim apart from the GPR radargrams.

The profiles at Vågåmo are shown in **figures 6** (Malå RTA lines) and **7** (PulseEKKO PRO line) while the profile in Rudilykkja is shown in **figure 8**. In Vågåmo bedrock appears to be deeper in the middle part of the survey area, a claim supported by picked depths for both systems (**figures 6** and **7**). In Rudilykkja the results present a sediment thickness which is increasing from east to west (**figure 8**). It should be noted that the resulting grids are more trustworthy in the vicinity of picks (black dots in **figures 6, 7** and **8**) than farther away from them.

4. DISCUSSION

4.1 Technical discussion

As already explained Malå RTA data suffer in positioning accuracy for two reasons: a) low quality of compatible GPS system and b) due to the 7 meter offset between measurement and GPS point registration (see **figure 3**). In order to compensate for these problems, positioning has been manually refined by getting rid of all the obviously wrong points and all picks where moved 7 meters back against the direction of the profile to match their true position. Still, inaccuracy is at least as high as the GPS specified one (3-4 meters).

In addition, drilling has taken place before the GPR profiling and that is not recommended. In fact, NGU proposes that in the future, such surveys should be done the other way around: GPR profiling should lead investigations and then drilling should occur in positions picked by the presence and/or depth of reflectors. Otherwise, accurate matching of drilling positions within GPR profiles can prove a very difficult task impaired by further inaccuracy.

In this study, one antenna frequency (50 MHz) have been employed with the use of two GPR systems. Due to unavailability of time, profiles were produced without any prior frequency testing. The use of a 50 MHz antenna (Malå RTA) proved to be problematic in two ways. First, the resolution of the produced reflections was lower than required for such shallow sediment layers. Reflectors identified in the respective radargrams presented a high wavelength which in cases exceeded 1 m of width. This subsequently reduced the efficiency but most importantly the accuracy of the interpretation procedure.

The 50 MHz antenna proved to be extremely sensitive to the effect of power lines in the vicinity of the profiles but also to the presence of housing in the area. False anomalies have appeared in the radargrams like wide hyperbolas and linear features at a depth proportionate to the profile distance from the power lines and the respective houses. Such strong noise is impossible to remove and could cause misinterpretations especially when non experts are viewing such results. Overall, if prior testing had been done, a 100 MHz antenna would have been chosen over the 50 MHz, sacrificing unneeded depth penetration for resolution since sediment thickness in both regions is small.

4.2 Geological discussion

Interpretation was connected to the available drilling data with drillings down to bedrock being used except the case of Rudilykkja where no boreholes are available. Wherever a measured bedrock depth matched a reflector, this reflector was picked throughout its length and thus an estimation of the sediment thickness was extracted. Other strong reflectors have also been picked in the absence of borehole measurements to supplement the final sediment depth estimation grid but in the lack of such additional drilling information, any assessment is risky due to the fact that said reflectors may not necessarily represent bedrock.

The results are as accurate as the velocity calculation in the region. In our processing we have used a velocity equal to 0.1 m/ns which was chosen accordingly to the geological formations present in the region and is partly calculated as hyperbola fitting where this was possible (one hyperbola). Essentially this velocity transforms 100 ns of signal penetration into 5 meters of depth. However, velocity can change within the area and cause uncertainty problems. Detailed velocity mapping for each profile would be time consuming and would eradicate the method's advantage of fast implementation. Therefore, in order to maintain this high production rate in GPR profiling, we have assumed that the velocity of 0.1 m/ns is constant for all the profiles throughout their length and depth. This assumption inserts an uncertainty factor to the interpretation since GPR wave velocity is not constant in any given area, even if a single sediment formation is dominant in every profile. For example, the same 100 ns of penetration could correspond to 5.5 meters of depth for a velocity of 0.11 m/ns but also 4.75 meters of depth for a velocity of 0.095 m/ns. Such changes in velocity within the same formation can be induced by the presence of water i.e. drier areas will allow waves to travel faster than wet ones. Conclusively, the interpretation results are prone to velocity variations due to the presence of water in the same formation or the variety of different formations encased in each profile.

The survey area has proven to be quite challenging for the use of GPR. Penetration depths were small although low frequency antennas were employed (50 MHz), reflectors were not continuous and therefore not easy to follow in radargrams, various surface targets created a big number of artificial effects which masked possible reflectors obstructing interpretation and the errors in GPS positioning for the Malå RTA system and the mismatch between drillings and profile routes rendered the whole interpretation procedure problematic. However, useful information was extracted from the all the profiles and sediment thickness estimation maps were created.

In the present survey, it is impossible to identify the bedrock reflection without any information from drillings or bedrock exposures. On the other hand, georadar can give a continuous image of interfaces mapped in drillholes and in this way these two methods supplement each other.

5. CONCLUSIONS

The results of this survey portray the benefit of Georadar application in surveying sediment thickness or depth to bedrock in connection to road construction.

The use of unshielded antennas where maximum depth penetration is required was not optimal for this survey due to the fact that cultural noise levels were high. Targets above the ground have induced signals into our data which mask reflectors and obstruct interpretation. These effects have been identified to the extent that it was possible and after discarding them, the GPR implementation has detected layers which are in their majority in good agreement with the existing drilling information in the region.

The penetration depth is small due to the conductivity of the top layer but so is the expected sediment thickness in the region. Our interpretation results indicate a maximum depth of at least 10 meters for the both the area north of Vågåmo and the

Rudilykkja area. Be that as it may, the sediment-bedrock limit was not clearly detected with the application of GPR for reasons varying from large signal wavelengths that increase uncertainty to geological restrictions that didn't offer enough penetration. All depth to bedrock maps presented in this report are consistent with the GPR methodology and theory however, degrading factors present in this study should always be taken under consideration when utilizing these results. We suggest that these maps should be treated as trend maps indicating the overall bedrock morphology than quantitative depth to bedrock measurements.

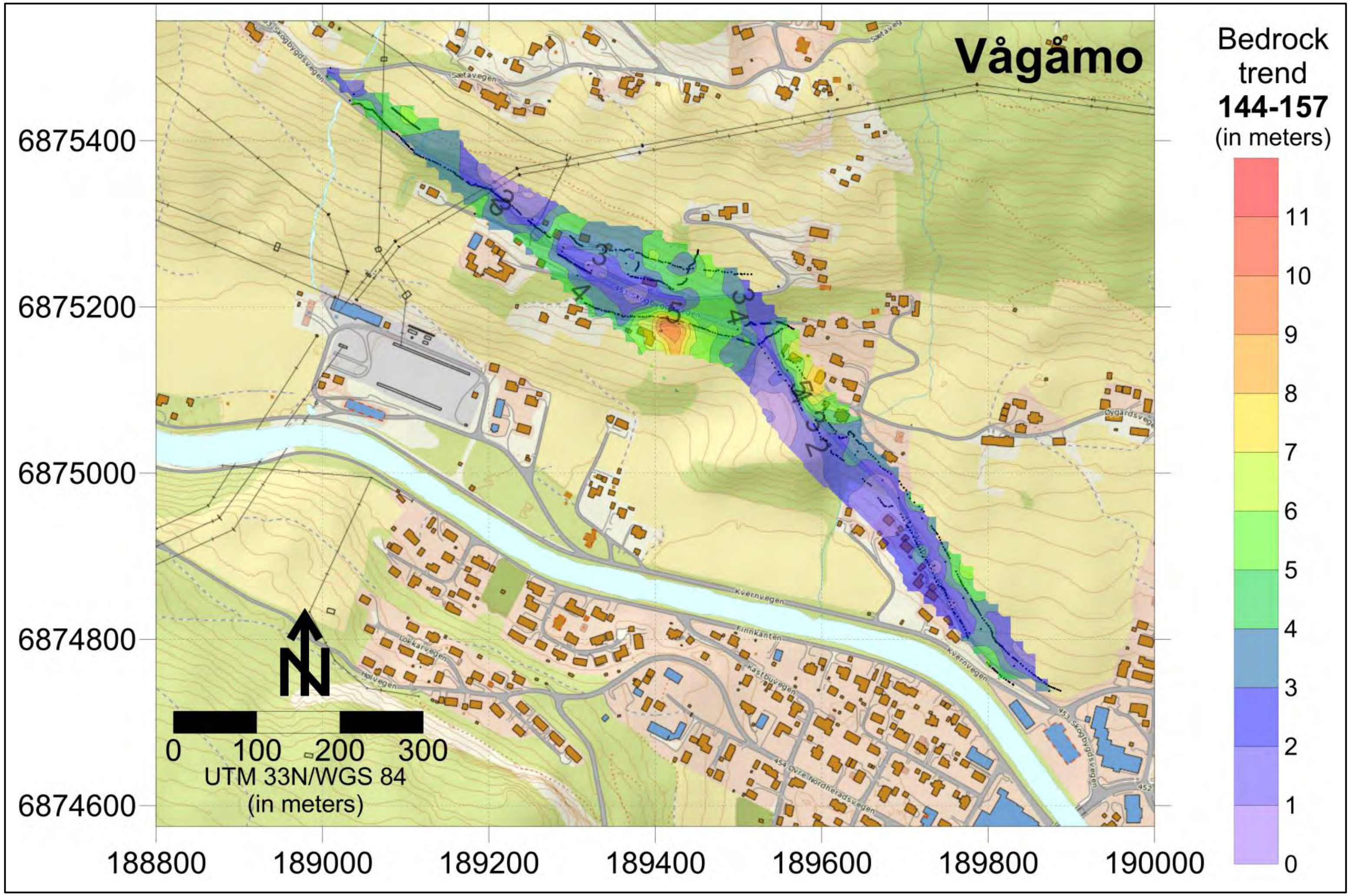

Figure 6: Trend map of bedrock morphology in Vågåmo (Malå RTA 50MHz profiles).

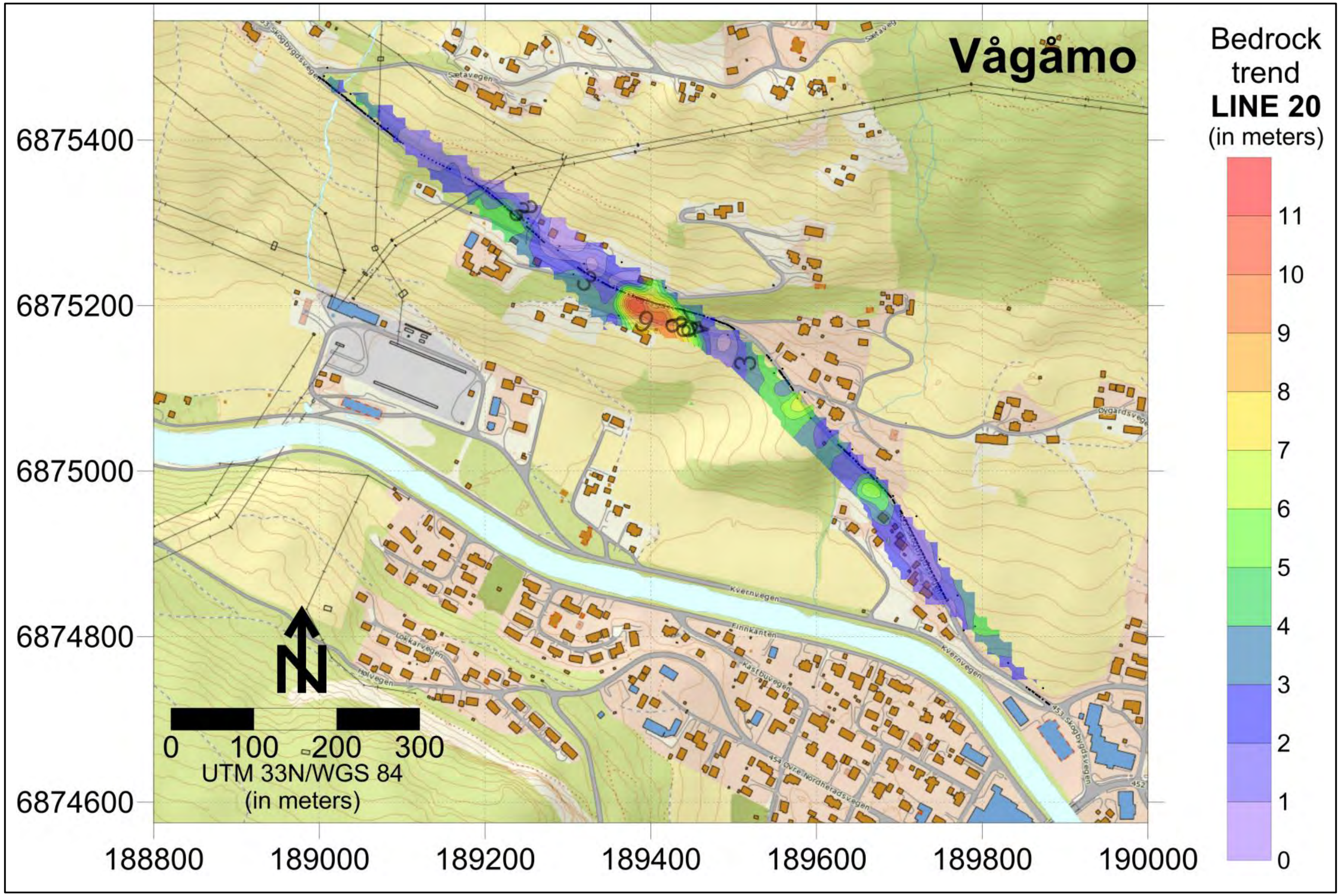

Figure 7: Trend map of bedrock morphology in Vågåmo (PulseEKKO PRO 50MHz profile).

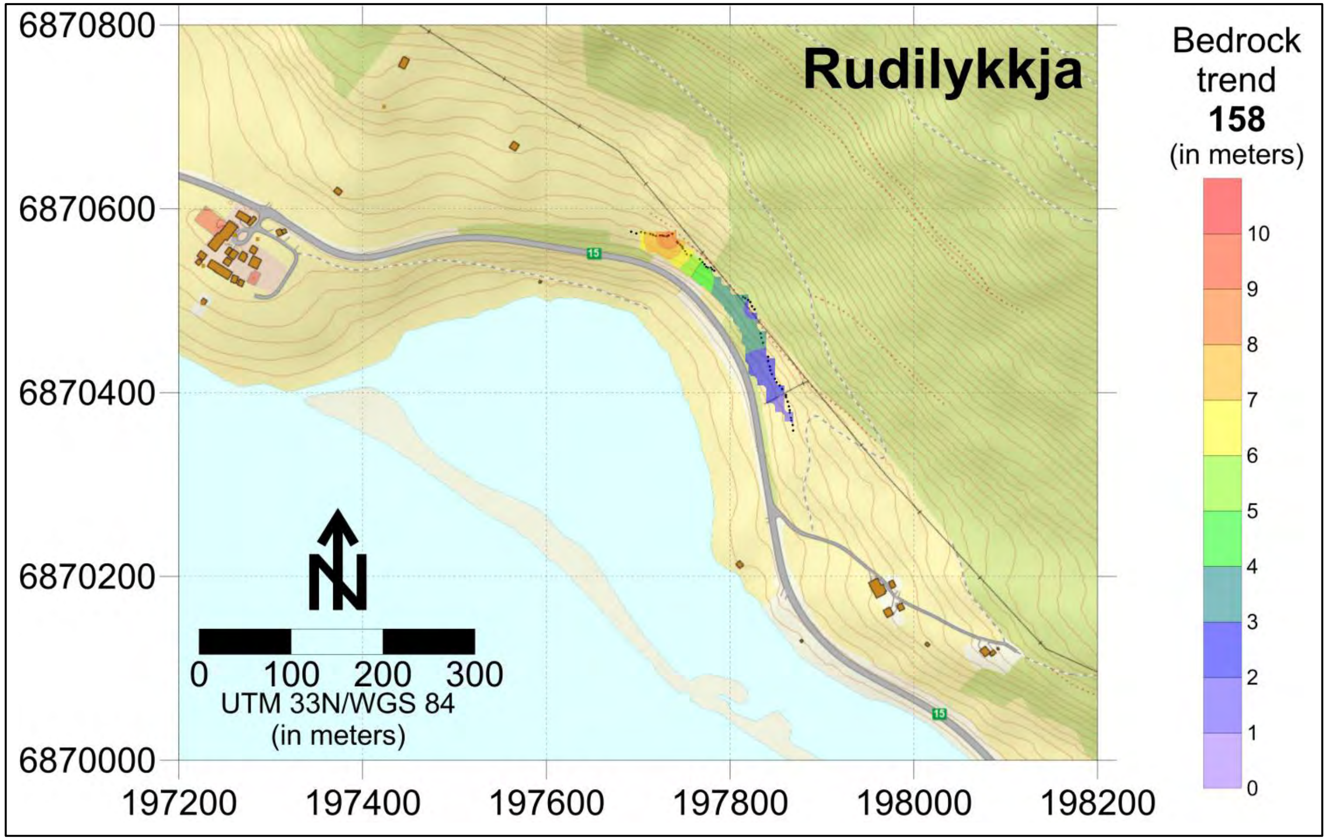

Figure 8: Trend map of bedrock morphology in Rudilykkja (Malå RTA 50MHz profile

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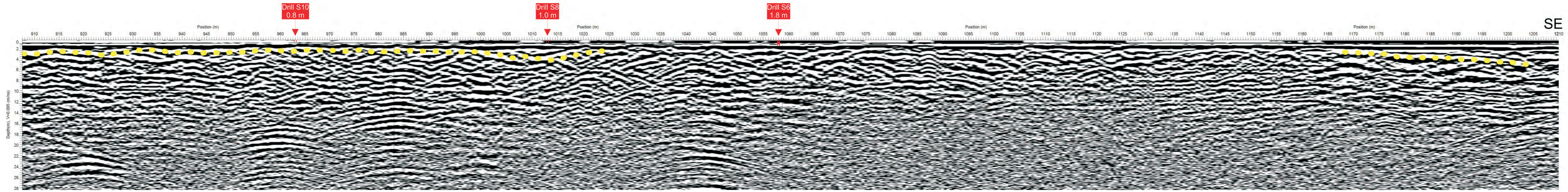

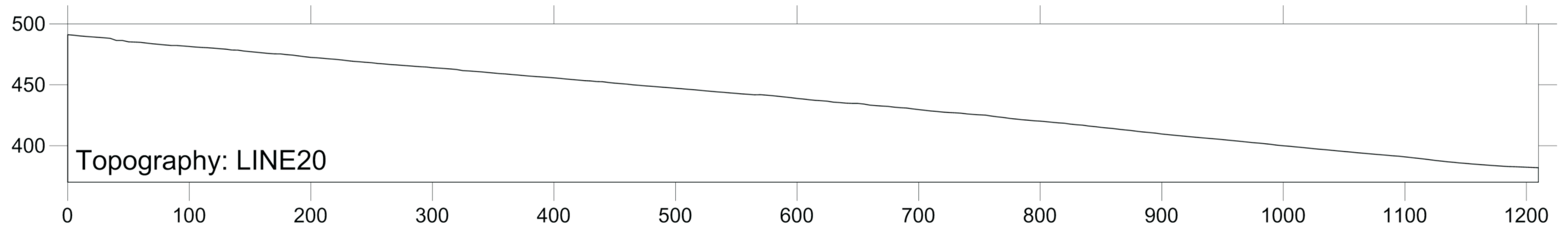

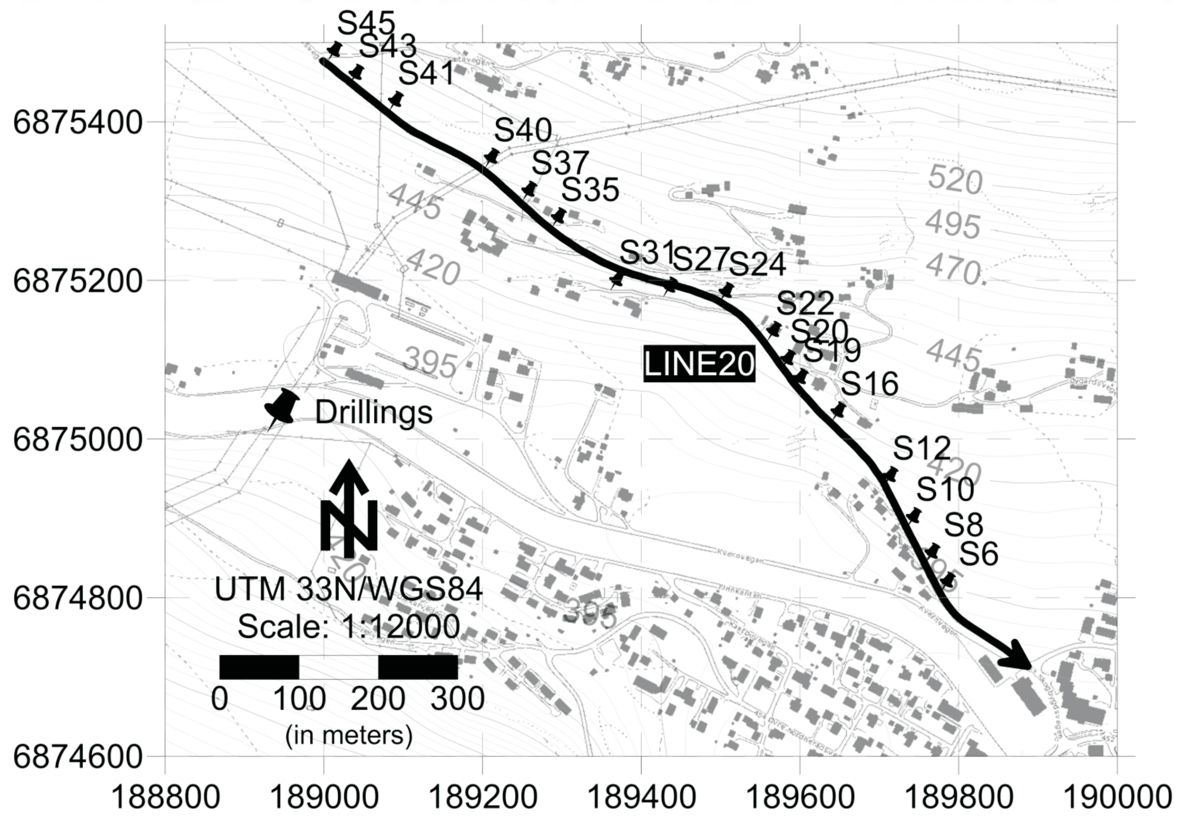

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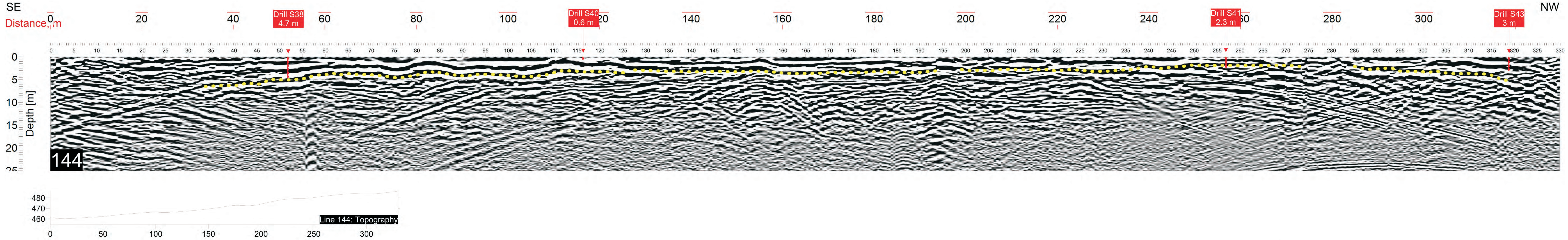
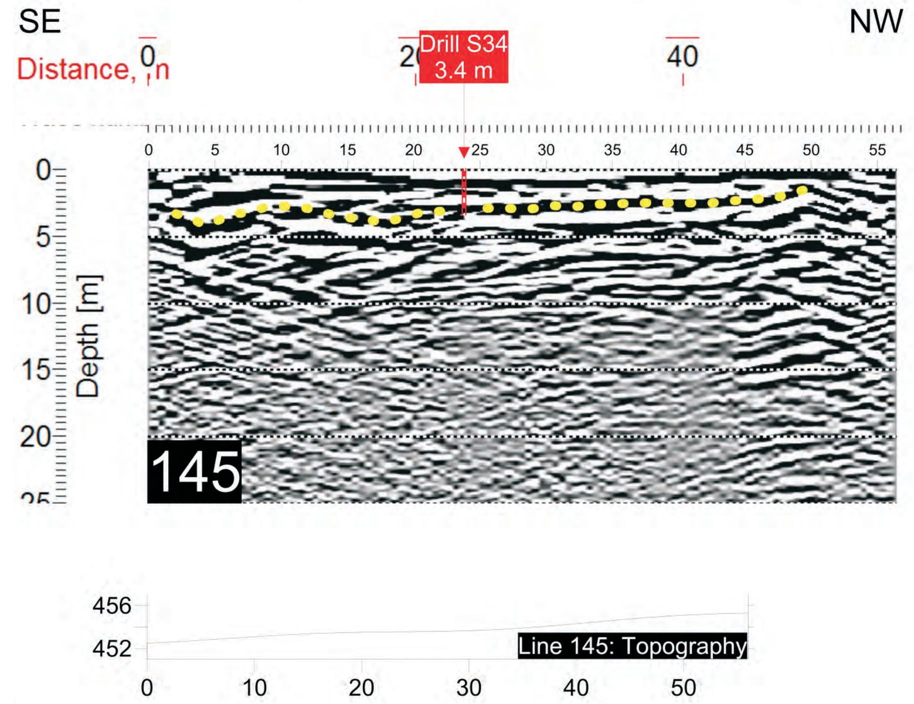
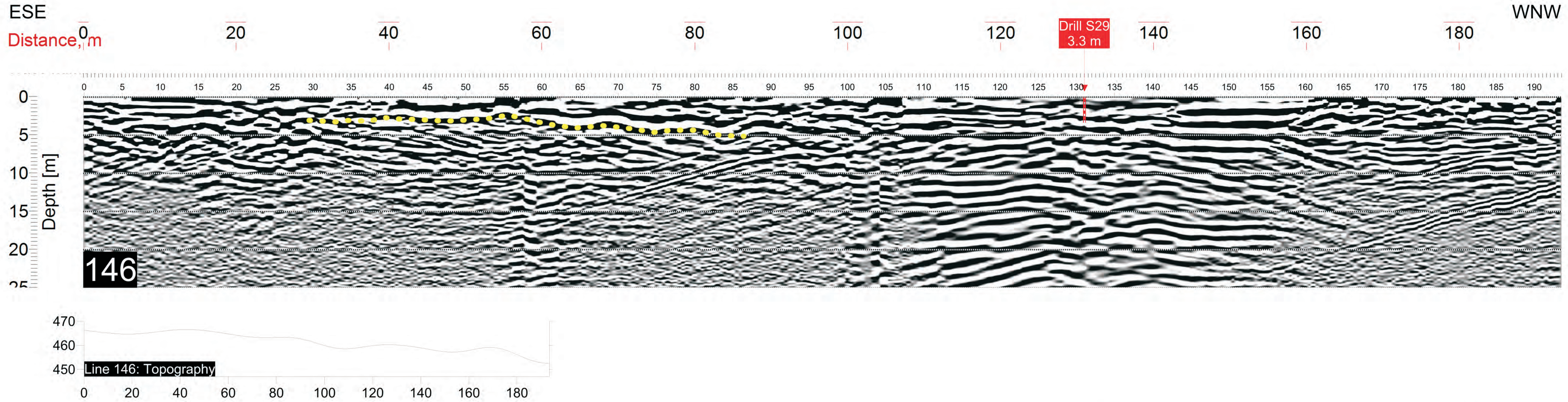
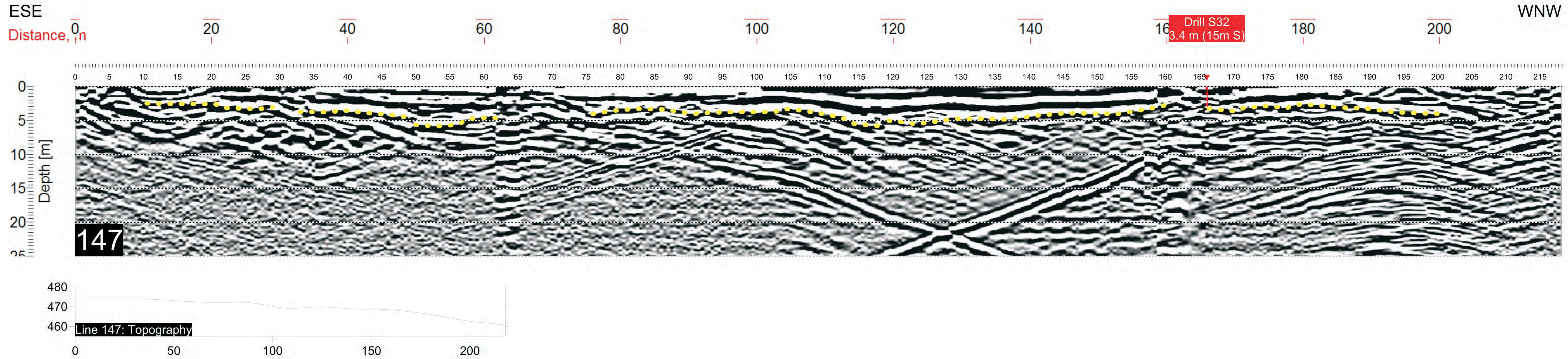
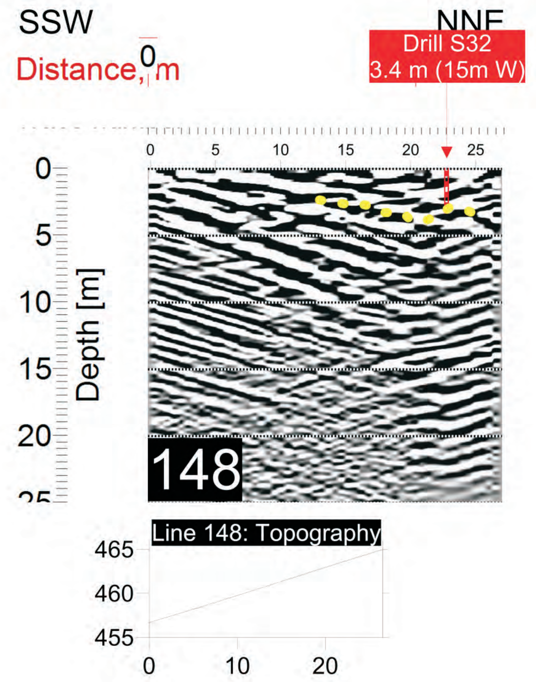
NORGES GEOLOGISKE UNDERSØKELSE TRONDHEIM	TEGNING NR 2015.061-01	KARTBLAD NR 1618 I	

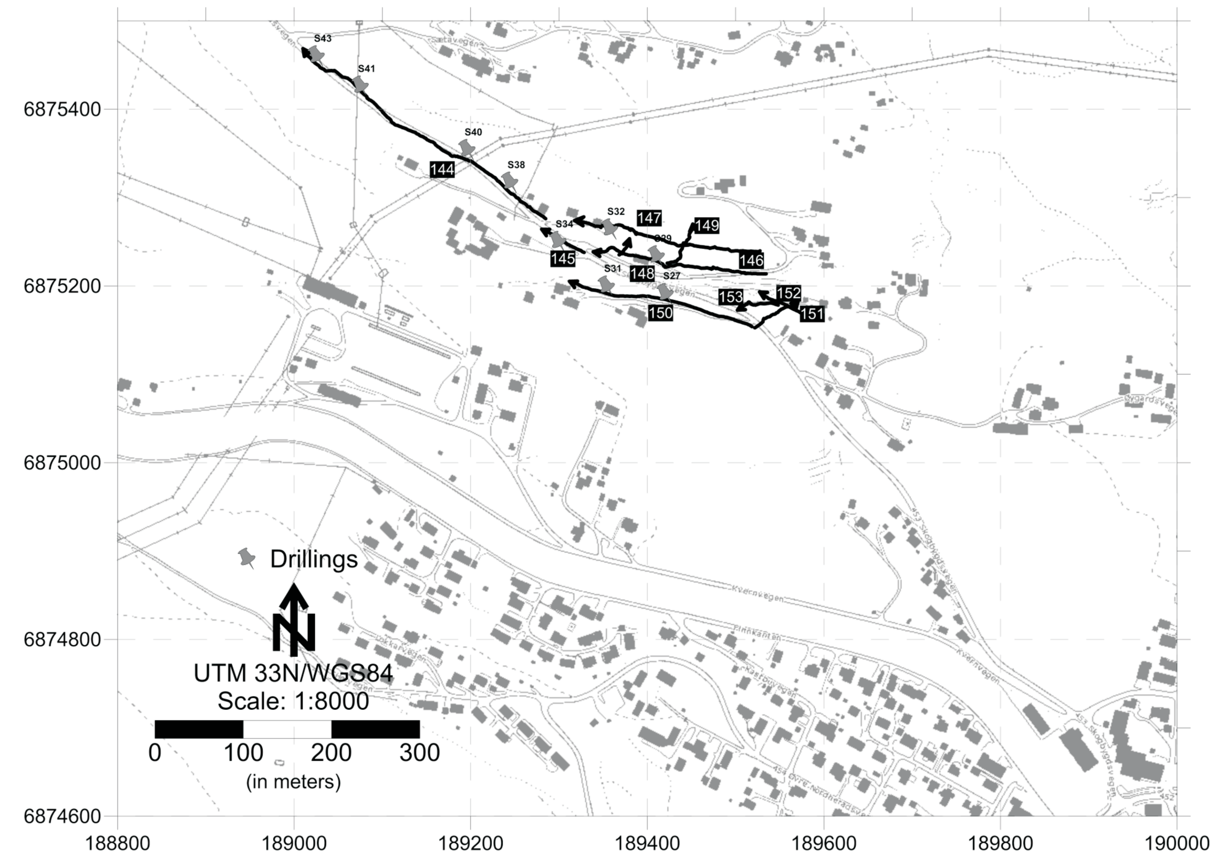


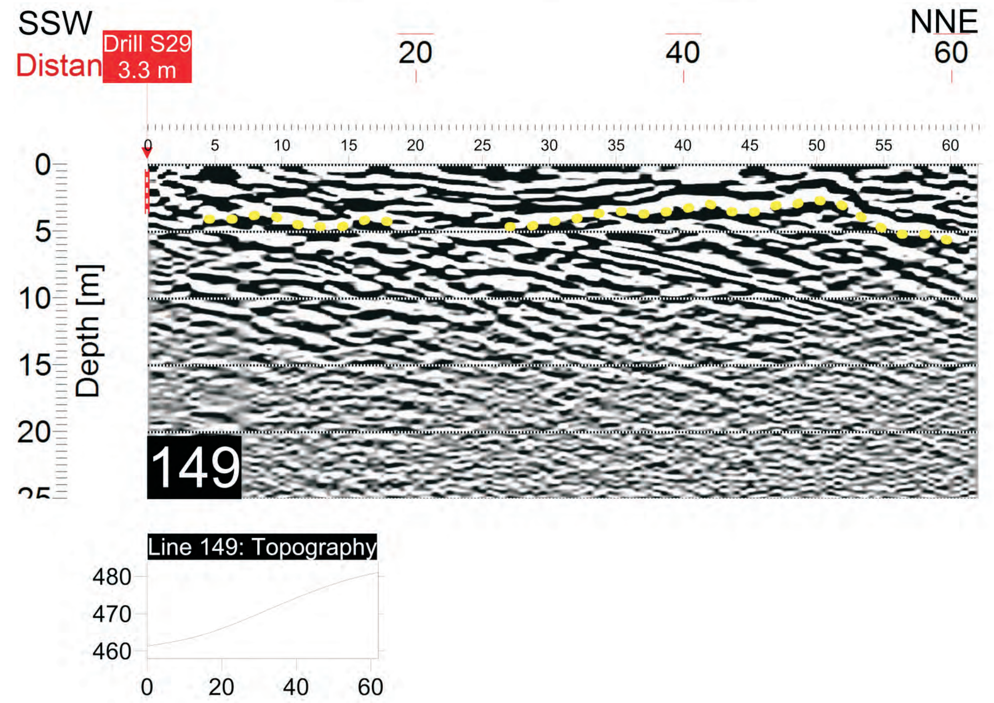


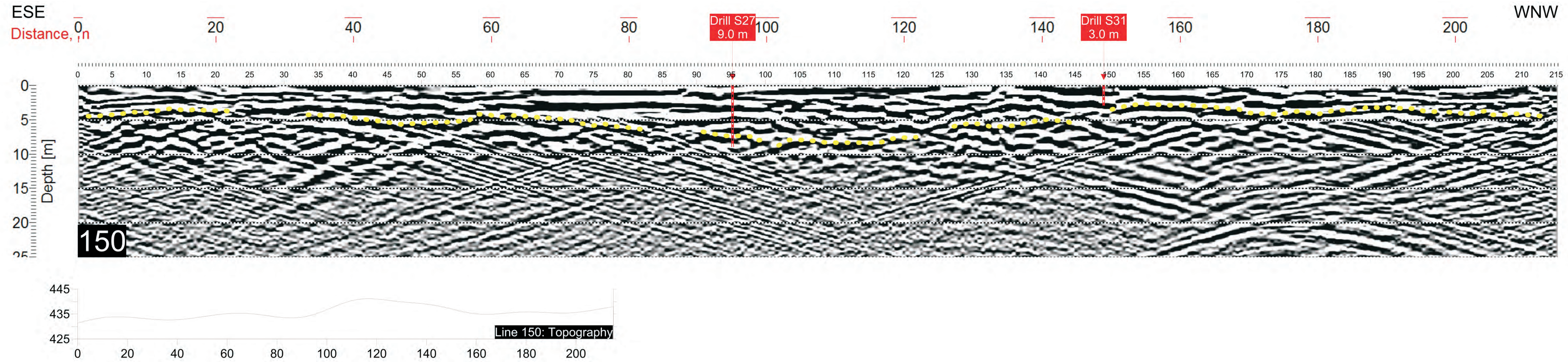


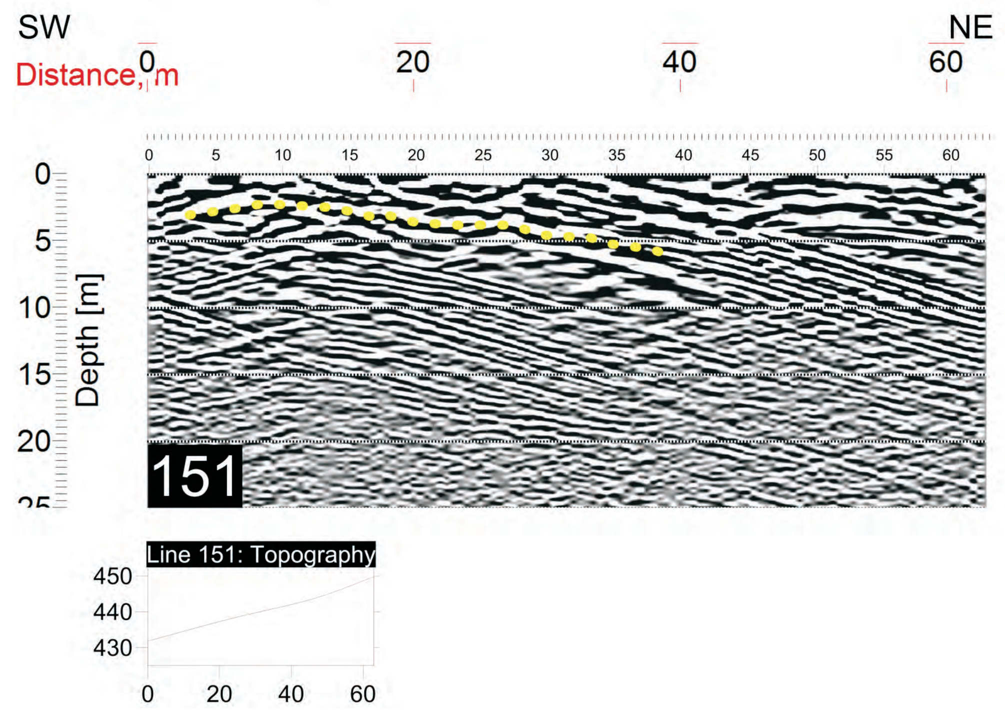


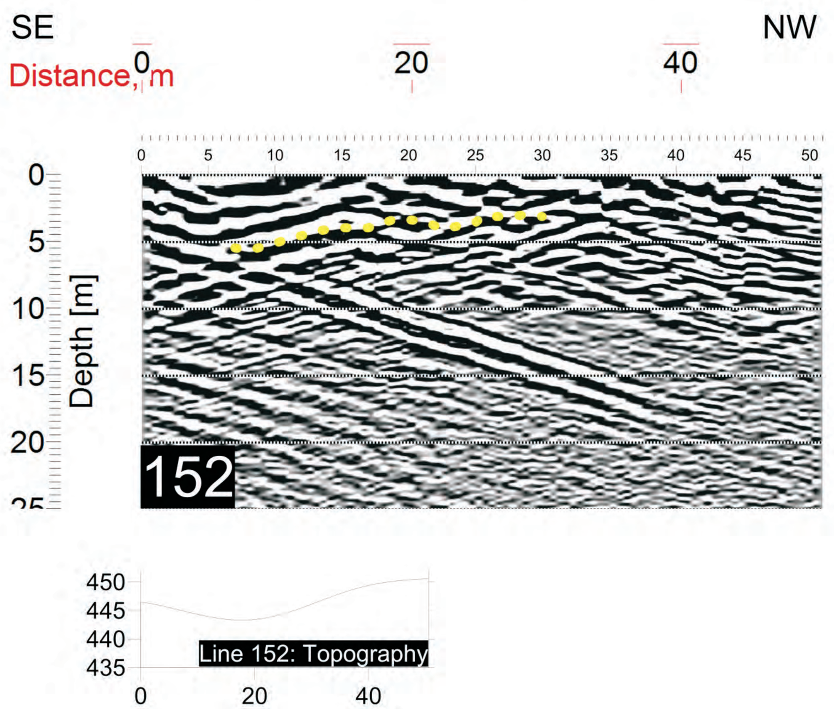


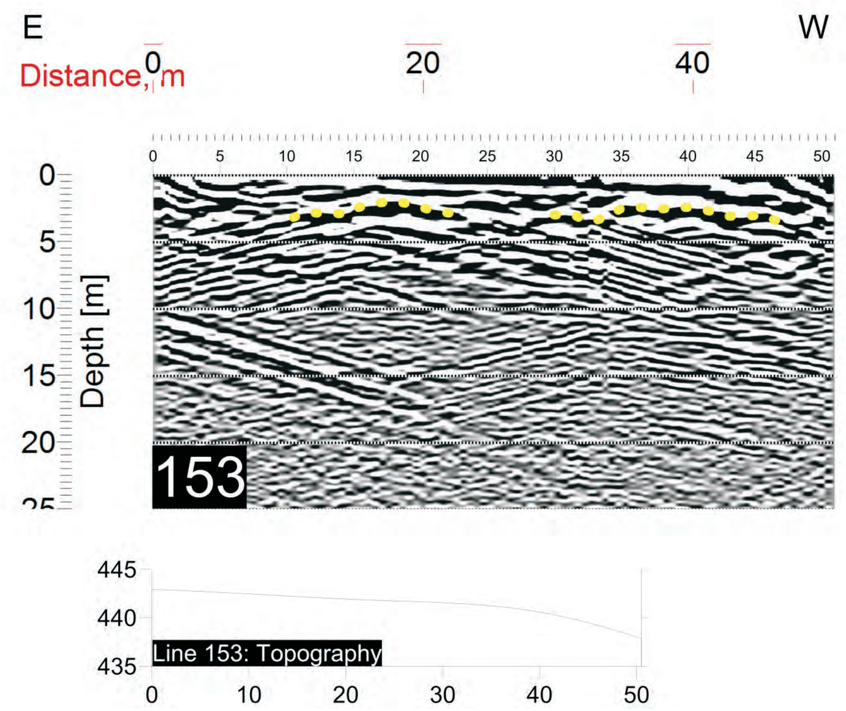












STATENS VEGVESEN
GEORADAR LINES 144-153 (MALÅ RTA - 50 MHz)

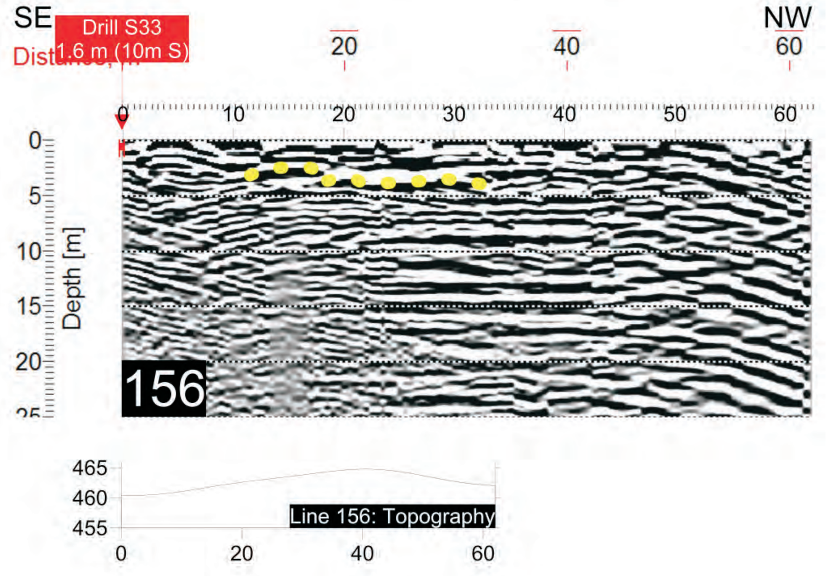
VÅGÅMO

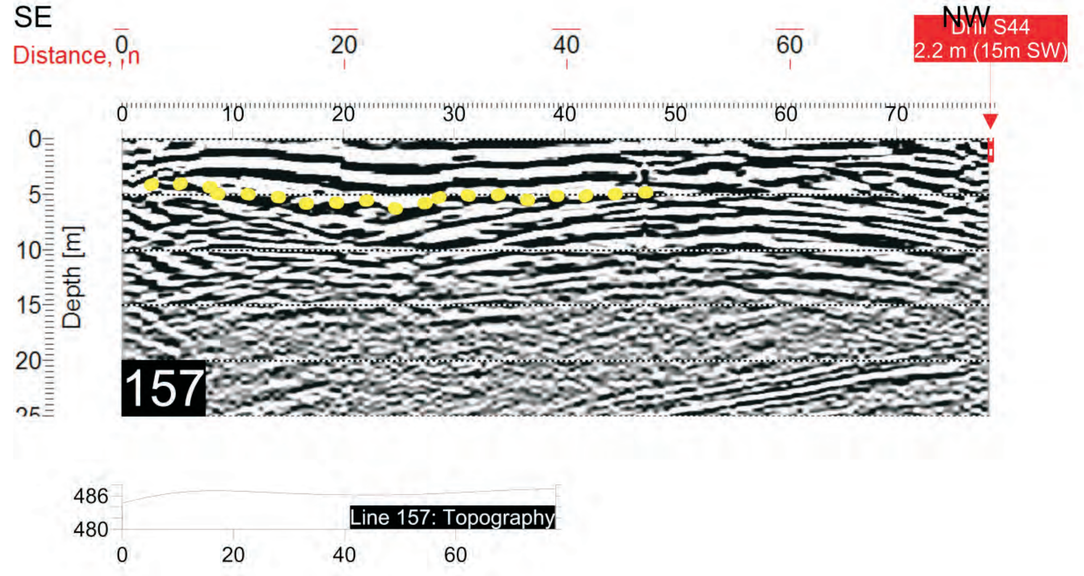
VÅGÅ KOMMUNE, OPPLAND

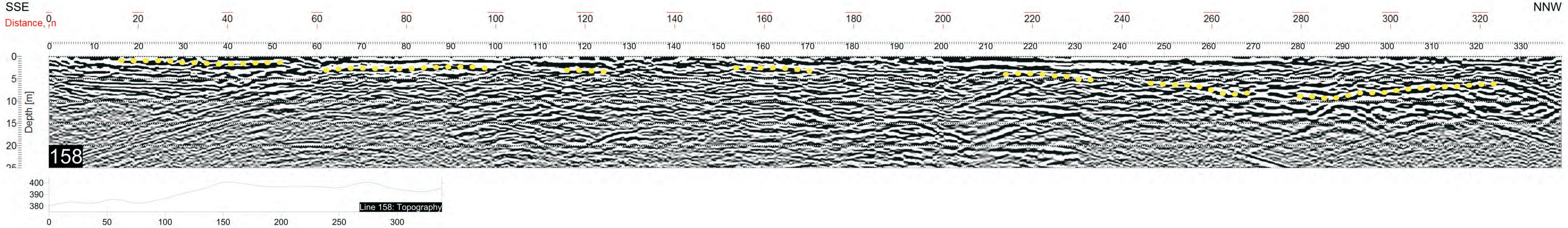
MÅLESTOKK		
1:8000 (MAP)	MÅLT GT	OCT 2015
	TEGN GT	DEC 2015
	TRAC	
	KFR KONF.	

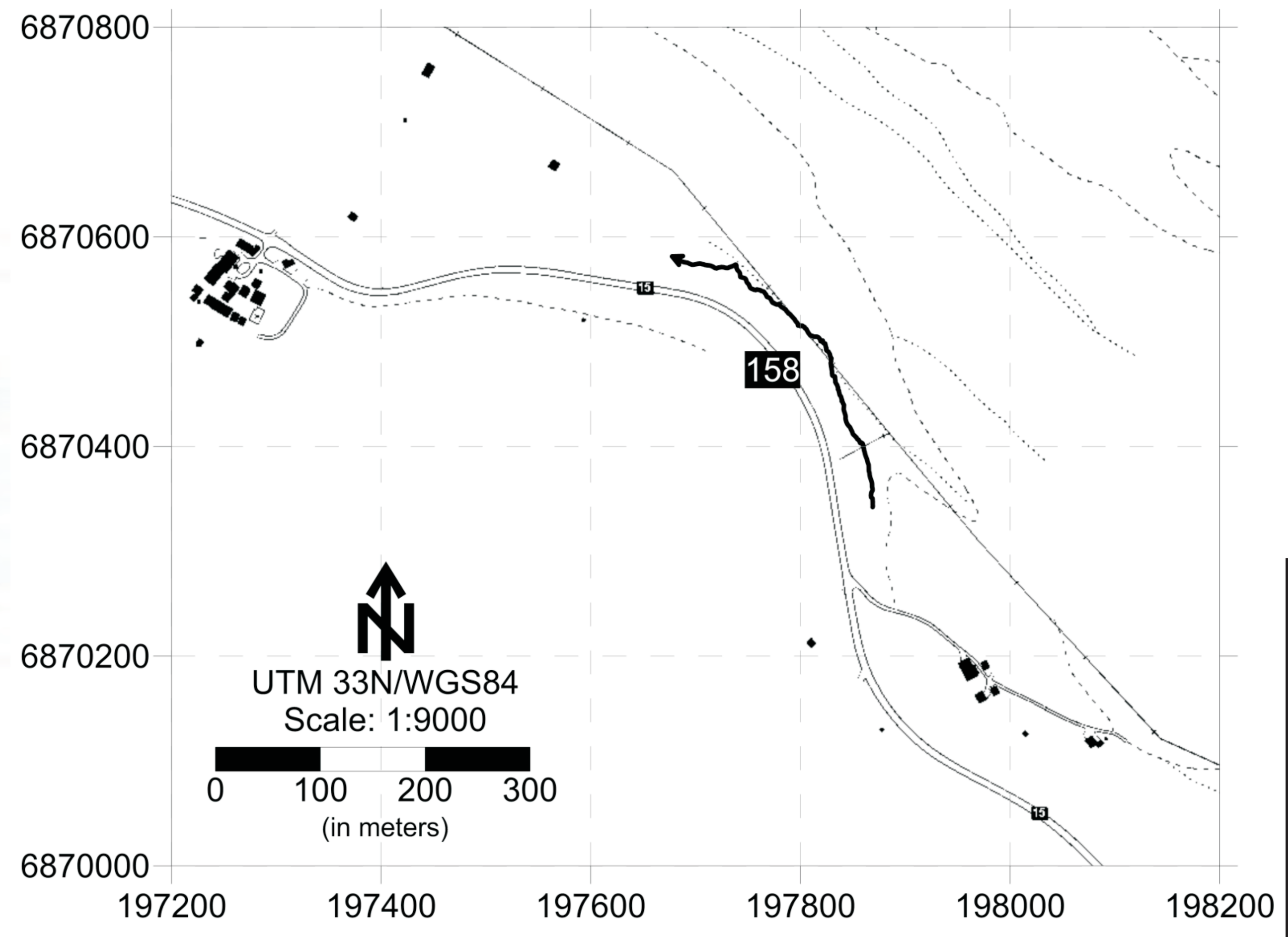
NORGES GEOLOGISKE UNDERSØKELSE
TRONDHEIM

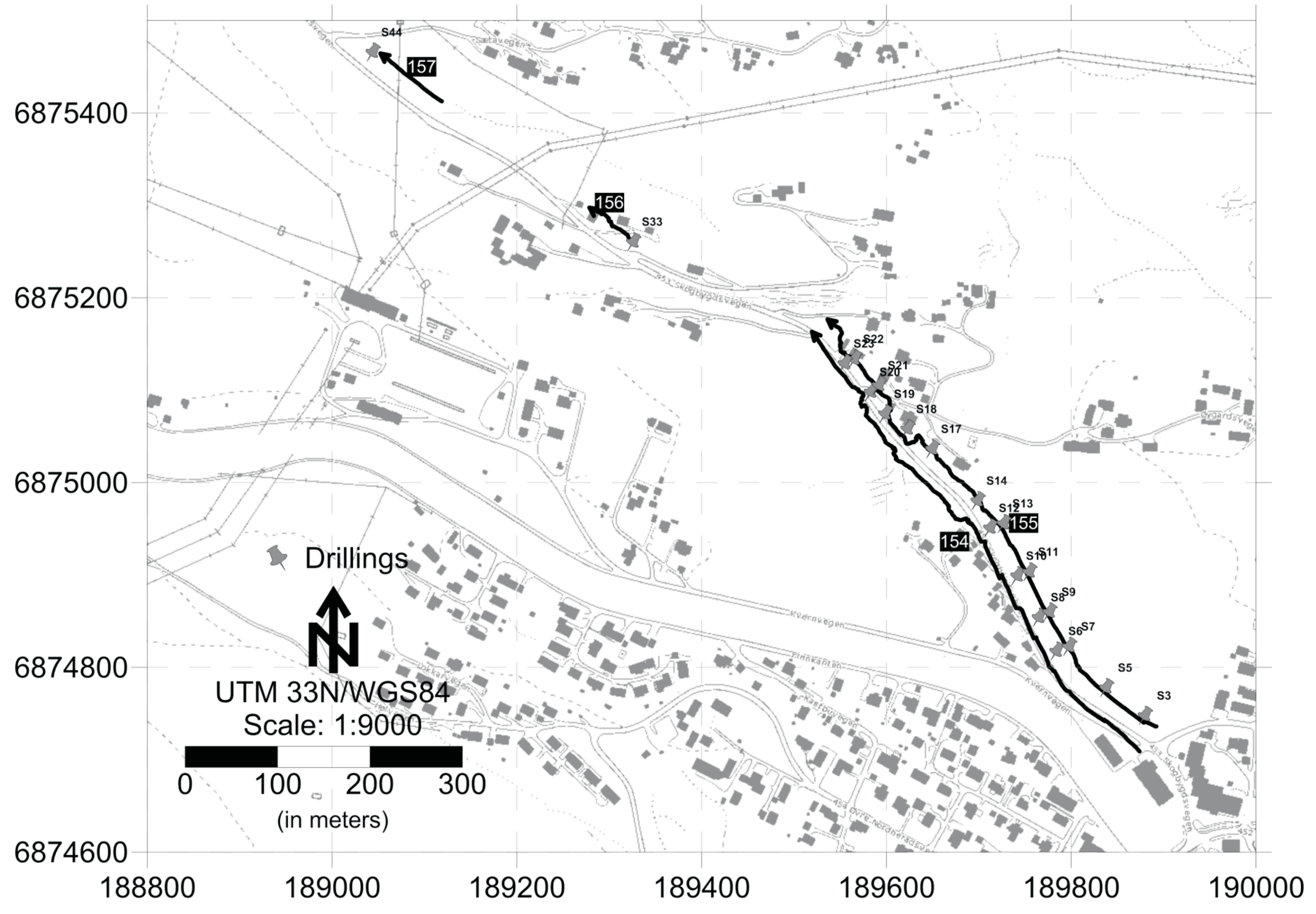
TEGNING NR	KARTBLAD NR
2015.061-02	1618 I











STATENS VEGVESEN GEORADAR LINES 154-158 (MALÅ RTA - 50 MHz) **VÅGÅMO/RUDILYKKJA** VÅGÅ KOMMUNE, OPPLAND	MÅLESTOKK 1:9000 (MAPS)	MÅLT GT TEGN GT TRAC KFR KONF	OCT 2015 DEC 2015
NORGES GEOLOGISKE UNDERSØKELSE TRONDHEIM	TEGNING NR 2015.061-03	KARTBLAD NR 1618 I	

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