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Comparison between Sensors & Software and Malå GPR equipment based on test measurements at Eikesdalen, Nesset municipality, Norway

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REPORT

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Title:
Comparison between Sensors & Software and Malå GPR equipment based on test measurements at Eikesdalen, Nesset municipality, Norway

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County: Møre og Romsdal		**Commune:** Nesset	
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Summary:

In June 23rd 2015, NGU conducted a set of GPR test measurements in Eikesdal, Møre og Romsdal county. The aim for these measurements was to compare performance of the NGU georadar systems. A single profile was measured four times i.e. with two different GPR systems (PulseEKKO PRO and Malå RTA) and two different antennas (50 and 100 MHz) per system. All profiles were measured using similar time window (~2000 ns) and sampling frequency (~10x antenna frequency) settings albeit with different antenna configurations: PulseEKKO uses perpendicular broadside antenna configuration as opposed to Malå RTA which utilizes parallel endfire by default. The 800-meter long profile was measured on a country road alongside Aura river and displays a delta succession with topsets, foresets and bottomsets. The pronounced foresets are inclined towards the Eikesdalsvatnet lake to the north.

The aim of this test is to compare the performance of both systems and antennas in the same environment, under the same conditions and using the same settings. The test was conducted in the most coherent fashion possible. The resulting data have been compared according to the antenna frequency used and therefore, the data have been divided into two sets: one set for 50 MHz and one for 100 MHz antenna. The comparison took place in terms of overall performance, signal quality, resolution and penetration depth. All data have been processed with simple but identical routines in EKKO_project and have been imaged by using the same illustration settings. The choice of software has been done on the basis of unique comparative and qualitative tools offered such as the Average Trace Amplitude (ATA) plot which is the best suited tool when comparing such datasets.

In summary we may conclude that 50 MHz antenna results are equally good for both systems while for 100 MHz antenna usage, PulseEKKO PRO performs better in terms of depth penetration. With the Malå 50 MHz system, the initial direct wave signals last longer and hide near surface reflections from groundwater table. PulseEKKO PRO also offers the possibility of performing CMP measurements which is a feature not available with Malå GPR due to the built-in transmitter/receiver configuration employed. Therefore, when the terrain is favorable, PulseEKKO PRO usage is recommended especially for 100 MHz antenna surveying.

Keywords: Geophysics	Electromagnetic measurement	Ground Penetrating Radar
Test measurement	Sensors & Software	Malå Geoscience
	Delta structures	Scientific report

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1. INTRODUCTION

Since 1992, NGU has used Ground Penetration Radar (GPR) systems produced by Sensor & Software in Canada (Pulse EKKO IV, Pulse EKKO 100 and EKKO Pro). In the spring of 2015 NGU purchased a new system produced by Malå Geoscince with Rough Terrain Antennas (RTA). Earlier tests of these systems have documented better performance on the Sensors & Software system (Tassis et al. 2015). To compare the performance of the new GPR system, a new test was performed in Eikesdalen, Nesset municipality, Møre og Romsdal county, on June 23rd 2015.

A single profile has been measured with two different GPR systems (PulseEKKO PRO and Malå RTA) and two different antenna frequencies (50 and 100 MHz) per system resulting in four radargrams. All profiles were 800 meters long and have been measured along a country road next to Aura river. This particular line has been measured in the past with the use of the two aforementioned systems and a 50 MHz antenna, but the NGU had no control over the instrument settings and the processing modules applied. In addition the resulting images were not clear enough and that rendered any comparison between them problematic (**figure 1**).

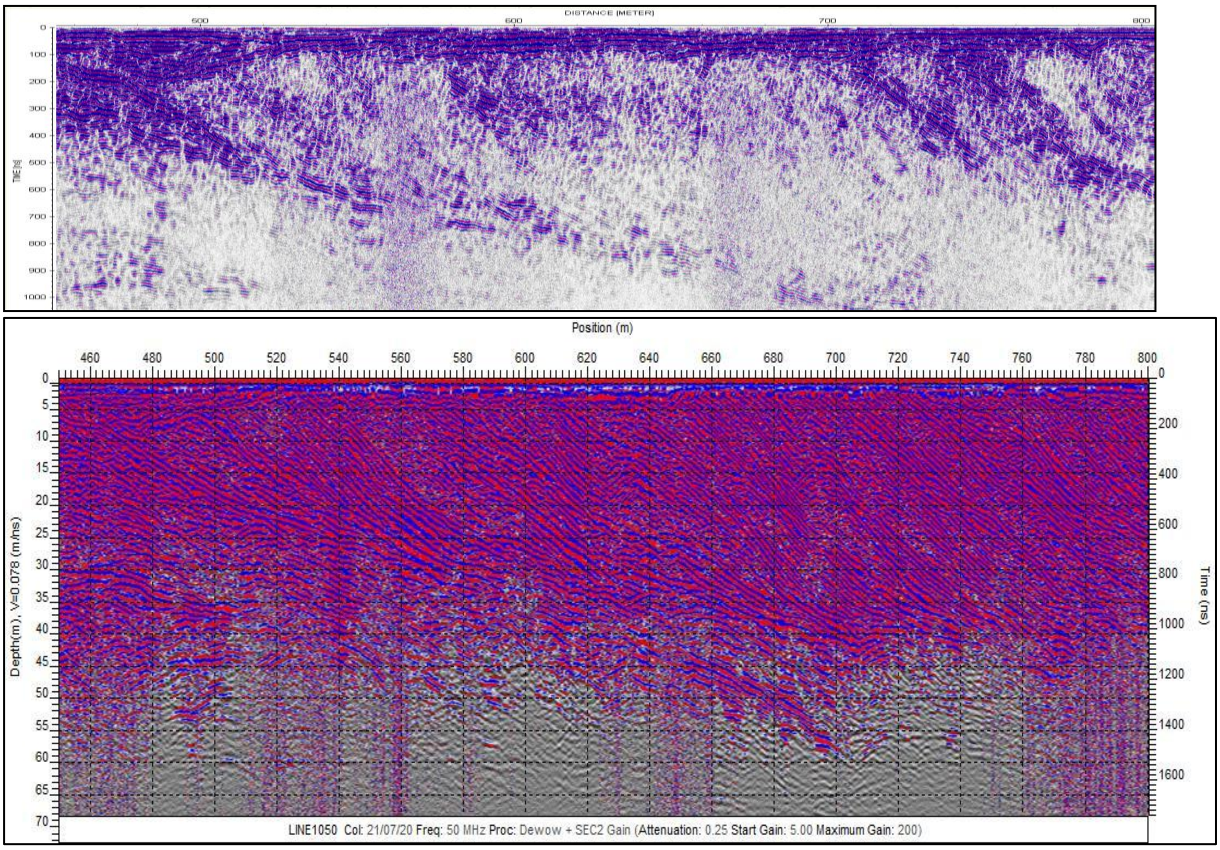

Figure 1*: Single profile measured with Malå RTA (top) and PulseEKKO (bottom) Georadars and 50 MHz antenna in Eikesdalen. Each manufacturer has developed their own software for data processing and the GPR data were processed and presented in each of these designated programs. PulseEKKO results seem more detailed and with a larger penetration depth.*

Regardless of this, multible inclined reflectors had been revealed and the succession is interpreted as delta deposits to the north. Therefore, this line was a suitable environment for comparison purposes if replicated under full control by the NGU. In this sense, profiles were measured using similar if not identical settings for each frequency employed in order to produce coherent results. However, the default antenna configuration used by each system was not possible to alter. Consequently, PulseEKKO profiles were measured with perpendicular broadside as opposed to Malå RTA profiles which were surveyed with parallel endfire antenna configuration.

All measurements were performed on a single cloudy but rainless day within a span of a few hours on June 23rd, 2015. Hence, moisture conditions in the ground remained constant as opposed to the previous survey where measurements were done in different days under the influence of different weather and ground humidity conditions. Ensuring that the only discrepancy between the newly measured profiles would be the antenna configuration, the resulting data were subjected to identical processing modules in EKKO_project software. Malå data were converted into readable format with the use of Reflex-Win version 7.2.3 program (Sandmaier 2010). The choice of software has been done on the basis of unique comparative and qualitative tools offered such as the Average Trace Amplitude (ATA) plot which is the best suited tool when comparing such datasets. Subsequently, the discrepancies in depth penetration and resolution seen in **figure 1** can now be safely verified or discredited.

The same line measured in this survey, was also measured with the Pulse EKKO IV system back in 1995 (Lauritsen 1995).

In this report, data are presented to enhance the performance of the two systems. If someone is interested in a better geological presentation, please contact one of the authors.

2. LOCATION AND GEOLOGICAL SETTING

As already mentioned, the profile has been carried out following a local dirt road next to the Aura river bed (**figure 2**). It extends from 149252 m Easting and 6945349 m Northing until 148968 m Easting and 6946020 m Northing. Its total length is just over 800 meters (max. 820 m).

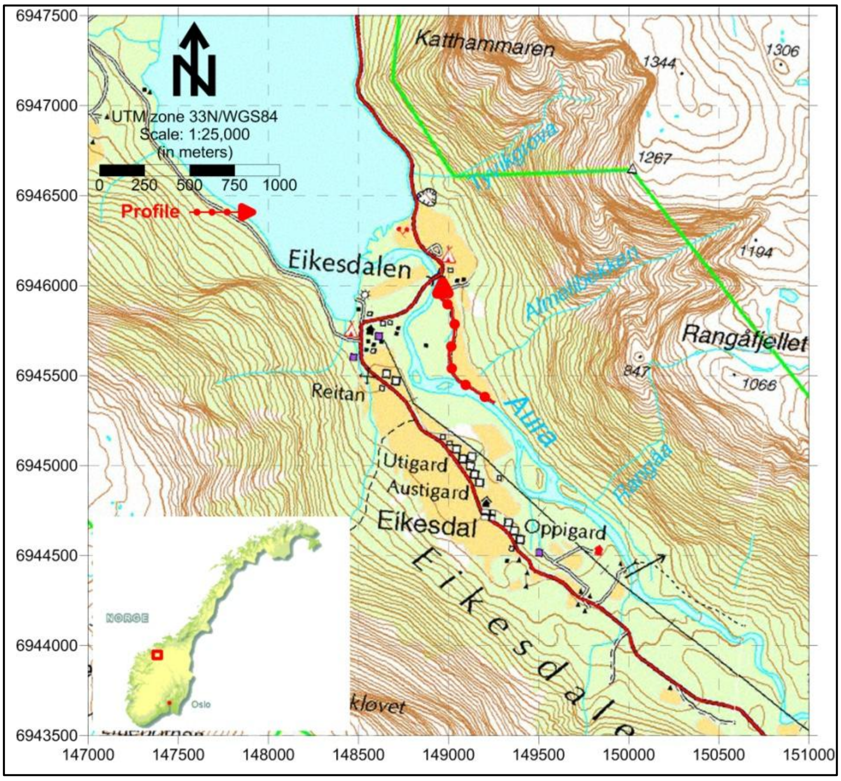

Figure 2: *Study area at Eikesdalen. The transect where testing has been carried out is shown with the dotted red line.*

The survey has taken place on a fluvial plain along Aura river (figures 2 and 3). The georadar profiles are dominated by clear, inclined reflections representing delta foresets and the entire deposit is interpreted as a delta succession constructed during progradation of a delta into Eikesdalsvatnet (**figure 1)**. The slopes along the valley are dominated by various gravitational deposits and exposed bedrock consist of dioritic to granitic gneiss (ref, see Quaternary map in **figure 3**).

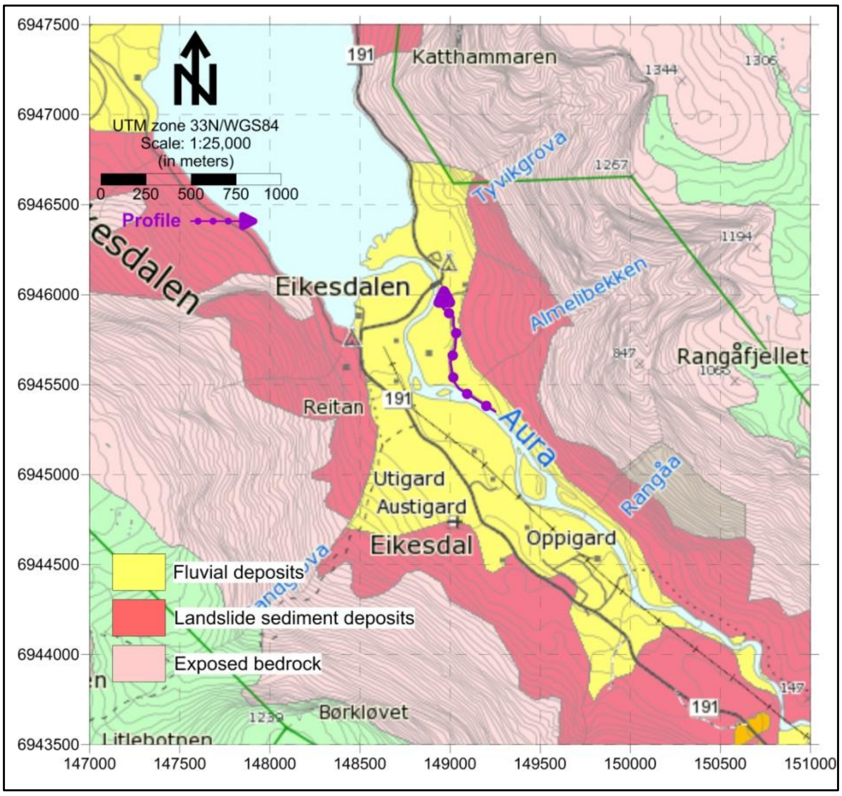

Figure 3: *General Quaternary map from the study area at Eikesdalen. The transect where testing has been carried out is shown with the dotted purple line (From: www.ngu.no).*

3. GEORADAR SYSTEMS, FREQUENCIES AND ANTENNA CONFIGURATIONS

3.1 Profile measurements

Recently, the NGU has acquired a Malå RTA (Rough Terrain Antenna) GPR system which has been added to already existing PulseEKKO PRO system by Sensors & Software. Having access to both systems, NGU georadar specialists Jan Steinar Rønning and Georgios Tassis were able to plan and perform the test survey in Eikesdalen with full control of the input parameters and settings and therefore produce comparable results for each antenna frequency used. The RTA system, which is also referred to as Snake system, due to the shape and maneuverability of its antennas, uses the parallel endfire configuration where transmitter and receiver are placed in line, while PulseEKKO PRO uses the perpendicular broadside configuration where transmitter and receiver antennas are placed parallel to each other. However, as already shown by Tassis et al. (2015), the choice between utilizing any of these two configurations has little impact on the quality of the resulting data. Hence, same frequency radargrams can be considered as directly comparable regardless of the different antenna configuration.

The Eikesdalen profile has been measured with the use of a 50 and a 100 MHz antenna for both systems using similar time window (~2000 ns) and sampling frequency (~10x antenna frequency) settings (**table I**). The sampling interval has been calculated by dividing the time window to the number of samples per trace. The sampling frequency f_S was found by inverting the sampling interval, and after halving it, we obtained the Nyquist frequency f_N (=f_S/2). In order to avoid aliasing in our data, the Nyquist frequency should be well above the central antenna frequency. As can be seen in **table I**, Nyquist frequency is at least five times the utilized antenna frequency guaranteeing optimal resolution.

Equipment	Antenna Frequency (MHz)	Sampling interval Δt (ns)	Sampling frequency f_s (MHz)	Nyquist frequency f_N (MHz)	Time Window (ns)
S&S PB	50	1.60	626	313	2000
Malå PE	50	1.97	506	253	2102
S&S PB	100	0.80	1250	625	1800
Malå PE	100	0.95	1051	526	1925

Table I: Sampling characteristics of each profile repetition (PB= Perpendicular Broadside, PE= Parallel Endfire).

3.2 CMP Measurements for velocity calculations

The study area being dominated by inclined deltaic sediments, is not particularly suitable for performing a successful Common Mid Point measurement. Such a measurement requires horizontal layering therefore, we had to seek a locality close to the center of the valley where the probability of such a setting is higher. The most suitable place for a CMP measurement was chosen to be a few tens of meters to the east of our profile and near its end to the north. The CMP spread was oriented perpendicular to the assumed delta succession direction.

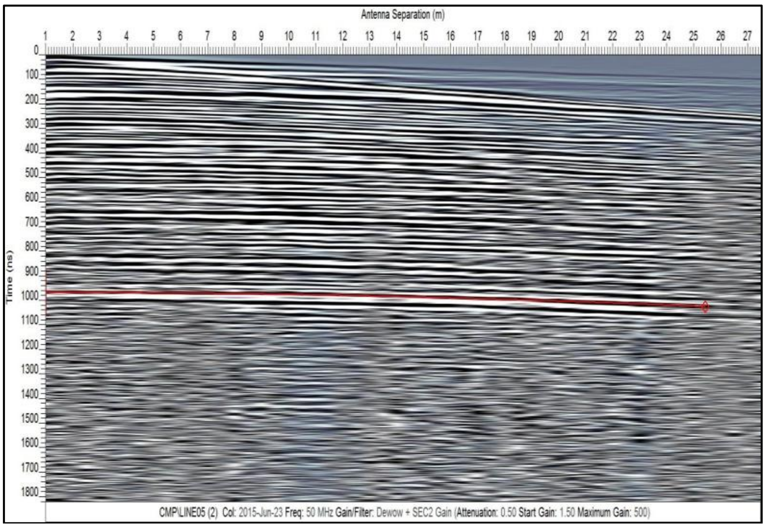

Figure 4: *CMP hyperbola fitting to determine the propagation velocity (0.06 m/ns).*

PulseEKKO Georadar is the only one between the two in-house GPR systems which can be used to perform a CMP measurement due to the fact that its transmitter and receiver antennas are detachable as opposed to the Snake system where they are built in. Therefore, by using this particular georadar's antennas we were able to perform such a measurement and later determine the propagation velocity in the sediments equal to 0.06 m/ns through CMP analysis done in EKKO_project software (**figure 4**). This means that the registration depth for our profiles is 60 meters for the utilized time window of ~2000 ns.

4. PROCESSING AND RESULTS

The following section describes the processing software and routines, performance review and a comparison of results.

4.1 Software and routines

EKKO_project V1 R3 software (Sensors & Software 2013) has been employed for the processing of data from both systems in order to produce coherent results. In addition to that, there are extra tools offered by the aforementioned software which are very useful when the task is radargram comparison. The choice of software has been done on the basis of the unique comparative and qualitative tool offered by EKKO_project called the Average Trace Amplitude (ATA) plot which is the best suited tool for our purpose. Malå data have been converted into readable EKKO_project format with the use of ReflexW software (Sandmeier 2010). All data have been processed with simple but identical routines in EKKO_project and have been imaged by using the same visualization settings. The results have been grouped according to the antenna frequency used and therefore, we present two sets of results: one set for 50 MHz and one for 100 MHz antenna frequency. These results were juxtaposed in terms of overall performance, signal quality resolution and depth penetration.

All data have been handled with identical EKKO_project routines which contain dewowing, first break editing (applicable on the Malå data), SEC2 gain control type and conversion to depth. Dewowing is implemented before any other module of the routine and removes unwanted low frequency 'wow' from GPR trace while preserving high frequency signal. Editing the first break changes the time of arrival of the first break. The first break is the best estimate of the time of the first onset of signal in the dataset and is automatically picked for PulseEKKO datasets as opposed to Malå data where first break editing has to be picked manually. Spreading & Exponential Compensation (SEC2) applies a combined constant and exponentially increasing gain as a function of time. Applying this process with suitable parameters makes the amplitudes of signals returned from similar targets at different depths appear similar. We have used increased attenuation rates (32.00) and high maximum gain (2000) in order to increase gain for signals from deeper targets (later times) to clarify the maximum depth penetration limit. Conversion to depth has been achieved with the use of the CMP calculated velocity of 0.06 m/ns. Visualization of the EKKO_project results has been done using the default grey scale and settings (Sensitivity 100%, Contrast 0%).

4.2 Performance review

The first step of comparing the two systems includes the determination of the functioning frequency for all antennas. The Average Frequency Spectrum (AFS) plot helps us determine the central frequency our data has been collected with. For 50 MHz antennas the central frequency for both systems is around 35 MHz (**figure 5 - left side**) while for 100 MHz the central frequency is closer to 75 MHz (**figure 5 - right side**). This affirms that both systems function with similar frequencies which are lower than their specified ones. In addition, both AFS plots indicate that PulseEKKO signal amplitude is higher than Malå RTA. For 50 MHz the PulseEKKO signal amplitude is much higher than Malå RTA while for 100 MHz the discrepancy is not that significant.

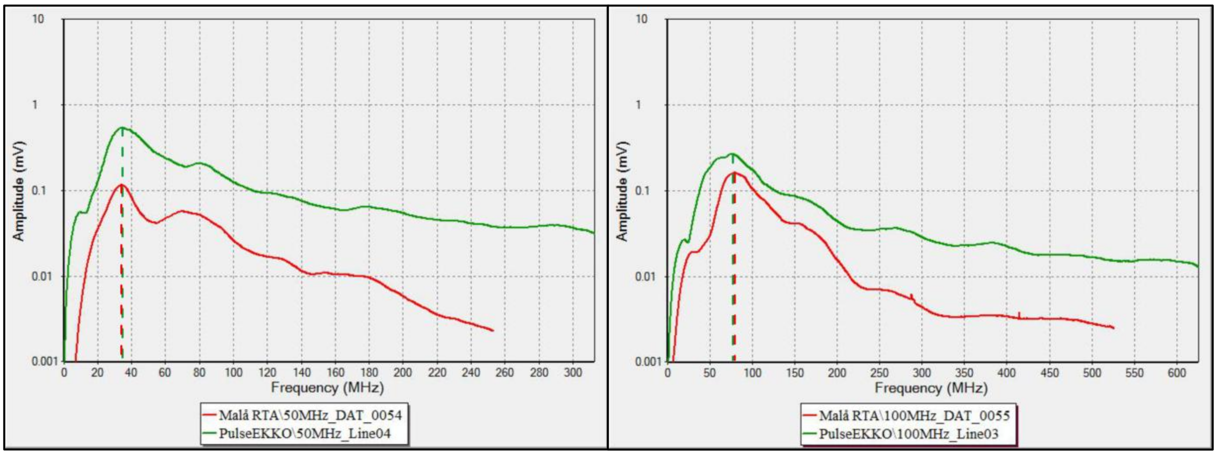

Figure 5: *Average Frequency Spectrum (AFS) plots for radargrams measured with Malå (red) and PulseEKKO (green) georadars using the 50 MHz (left) and the 100 MHz (right) frequency antennas, as extracted from EKKO_project.*

The second tool that and most essential in comparing the performance of the GPR systems is the Average Trace Amplitude (ATA) plot. **Figure 6** displays the ATA plot for 50 MHz antenna frequency from which we conclude that PulseEKKO transmits a stronger signal than Malå RTA, however, its noise levels are also relatively higher. Both signals decay on a steady rate until 1600 ns where they reach noise levels. A bend on the curve around 1000 ns observed in both systems could indicate a change in underground properties, higher attenuation due to higher electric conductivity.

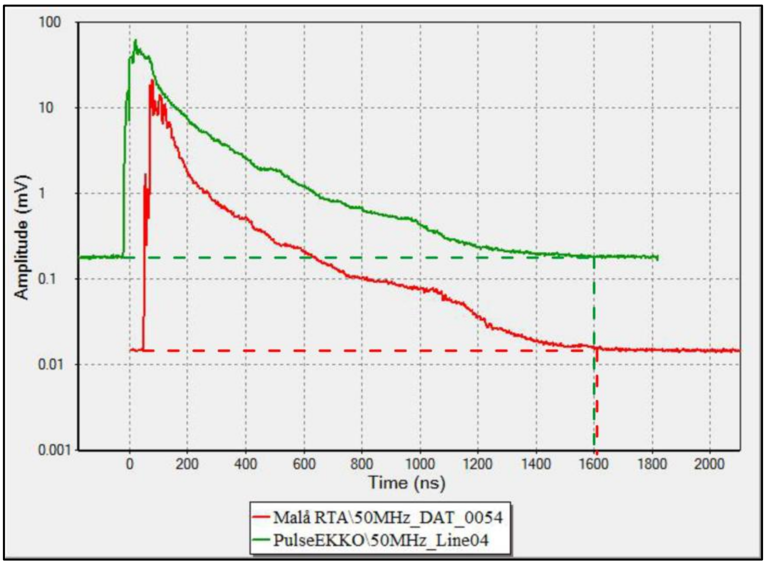

Figure 6: *Average Trace Amplitude (ATA) plot for the profiles measured with 50 MHz antenna (Malå: red line, PulseEKKO: green line).*

For 100 MHz the above described pattern seems to be repeated on both the signal and noise levels. Again PulseEKKO functions with a slightly stronger signal but also higher noise levels than Malå RTA. In this case however, the Malå RTA signal decays over time slightly faster than PulseEKKO and reaches noise levels at about

900 ns while as opposed to PulseEKKO whose signal is higher than noise until about 1100 ns. This could result in a higher penetration depth for PulseEKKO for the same 100 MHz antenna frequency.

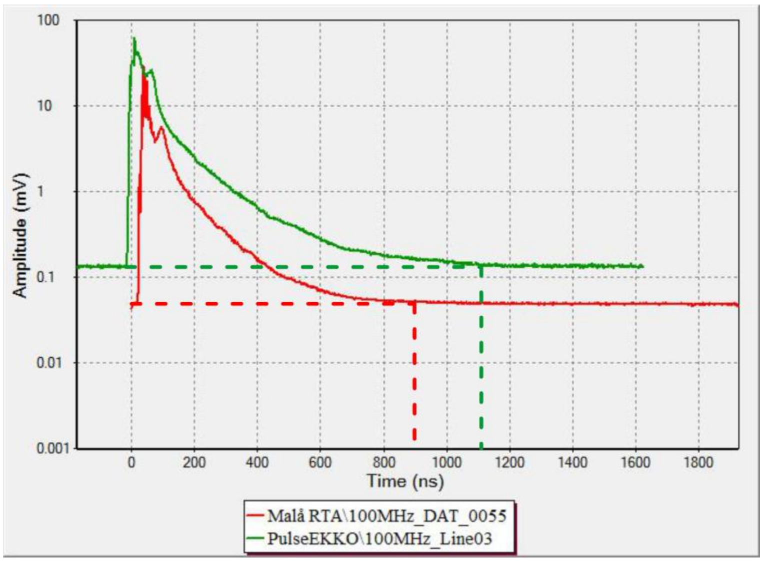

Figure 7: *Average Trace Amplitude (ATA) plot for the profiles measured with 100 MHz antenna (Malå: red line, PulseEKKO: green line).*

4.3 Comparison of results

The processed radargrams derived with the use of 50 MHz frequency antennas are shown in **figure 8** for Malå RTA and **figure 9** for PulseEKKO PRO. Overall results appear to be quite similar in quality as already implied by the ATA plot shown in **figure 6**. However, the profile acquired with PulseEKKO PRO shows higher superficial resolution. A layer, which can be interpreted as the water table horizon, is depicted quite clearly at about 2 m depth whereas in Malå RTA profile this reflector is mixed with the direct waves. Taking a look at the ATA profile once more we may interpret this as a result of a more continuous signal emission that Malå equipment produces creating a lengthier time with direct waves. This maximum signal emission lasts for about 50 ns for Malå while no more than 10 ns for Sensors & Software georadar. Therefore, whatever reflector lies roughly within those first 50 ns is lost due to the strong direct wave between transmitter and receiver. This is not the case for PulseEKKO which detects the aforementioned layer quite consistently except for when the reflector is extremely superficial before jumping above ground surface. In any case, both profiles reveal a huge variety of clear inclining reflectors down to a penetration depth which varies between ~25 m at the beginning of the profiles and ~50 m at the end (~1600 ns). A hyperbola appearing at around 25 meters of horizontal distance is due to a ditch dug to prevent sheep from leaving a local farm with a use of a metallic pipe overlay.

The processed profiles measured with 100 MHz antennas are shown in **figures 10** and **11** for Malå RTA and PulseEKKO PRO respectively. In this case, there is a distinct difference in quality between the resulting radargrams. PulseEKKO data demonstrate a more detailed imaging of the underground with a higher penetration depth (max. 33 m - 1100 ns) while Malå RTA data are more limited (max. 28 m - 900 ns). The water table layer described above is now depicted at circa 2 meters depth on both profiles due to the fact that this time around, the maximum signal emission (wavelength) for Malå is relatively shorter since the utilized frequency is higher (ATA plot - **figure 7**). Regardless, the detection of this reflector is much sharper and clearer with PulseEKKO. As for the other reflectors and especially the inclining ones, there is a different regime controlling the 100 MHz profiles. It appears that a number of these inclined layers that were clearly mapped with 50 MHz antennas, are absent from the 100 MHz profiles and seems to be replaced by a series of small hyperbolas. This might be caused by different scattering effects at the two frequencies. The wavelength of the 50 MHz system is about 12 m and may pass through the deposit without any scattering. The wavelength of the 100 MHz signal is about 6 m, and energy may be scattered by boulders of the same size. However, the hyperbolas do not collapse when migration is applied and therefore, cannot be assigned to boulders. In addition to that, migration on the profiles measured with 50 MHz antennas did not diminish those inclining surfaces at the least. For the time being, no satisfying answer can be given as for the origin of this effect. However, this is not due to any of the two utilized GPR systems since it is observed in both results.

5. CONCLUSIONS

In this report we have further investigated the performance of two NGU in-house GPR systems, namely the Malå RTA and PulseEKKO PRO georadars. A single profile has been measured with both systems using two antenna frequencies (50 and 100 MHz) resulting in four radargrams which have been processed with identical routines in EKKO_project software. For the qualitative and quantitative evaluation of the results we have used the processed images but also additional tools such as Average Frequency Spectrum analysis and Average Trace Amplitude plot.

The **Average Frequency Spectrum (AFS)** analysis has validated that both systems function at a frequency level which is lower than their specified ones, but equal nonetheless. Both 50 MHz antennas operate with a central frequency of ~35 MHz while the same parameter for a specified 100 MHz is about 75 MHz. Essentially, this means that all available antennas achieve larger penetration depths than expected. However, their central frequency values remain equal for each respective antenna regardless of GPR system used i.e. the systems' performances are equivalent for this particular parameter.

The **Average Trace Amplitude (ATA)** plots on the other hand disclose differences referring to the quantitative characteristics of the transmitted signal for each manufacturer. PulseEKKO PRO emits a signal of higher amplitude than Malå RTA. However, its noise levels are equally higher. This effect is more pronounced for the case of 100 MHz while the ATA plots for 50 MHz antennas display a relatively smaller discrepancy. The situation reverses when the signal decay time is investigated. For 50 MHz antennas the signal decay follows the same pattern and reaches noise level after 1600 ns in both cases. On the other hand, the signal decays faster for Malå RTA 100 MHz antenna (900 ns) than for PulseEKKO PRO (1100 ns). This translates into higher penetration depth for Sensors & Software equipment for the 100 MHz frequency antenna.

The ATA plots also decipher another problem with Malå RTA equipment influencing the **superficial resolution**. Its early maximum signal amplitude (direct waves) lasts longer especially for 50 MHz which leads to strong direct wave arrivals. During this effect, superficial reflectors are masked. This is the case in our data where Malå RTA georadar fails to successfully map a superficial reflector which is clearly depicted in PulseEKKO PRO. In the profile measured with the 50 MHz antenna by Malå RTA, this reflector is completely undetectable.

The **penetration depth** as explained in the above paragraph is higher for PulseEKKO PRO when 100 MHz antenna is employed. The difference is attributed to the 200 ns delay between the time when both signals decay to noise. For the CMP defined velocity of 0.06 m/ns this converts to ~6 meters of depth penetration discrepancy (about 18 % less for the Malå RTA). On the other hand, when 50 MHz antennas are utilized the penetration depth between the two systems is almost identical (~50 m).

As for the **resolution** both systems produce data which differ little throughout their penetration depth. A pattern recognized both in Malå and Sensors & Software equipment is that when 100 MHz antennas are used, some nicely depicted inclined reflectors at 50 MHz are lost and replaced by hyperbola looking shapes. For the time being, no satisfying answer can be given as for the origin of this effect. However, this does not affect our comparison results since it is verified in both systems.

In summary we may conclude that 50 MHz antenna results are equally good for both systems while for 100 MHz antenna usage, PulseEKKO PRO performs better in terms of depth penetration. With the Malå 50 MHz system, the initial direct wave signals last longer and hide near surface reflections from groundwater table. It also offers the possibility of performing CMP measurements which is a feature not available with Malå GPR due to the built-in transmitter/receiver configuration employed. Therefore, when the terrain is favorable, PulseEKKO PRO usage is recommended especially for 100 MHz antenna surveying.

Acknowledgements.

Isabelle Lecompte at NORSAR and University of Oslo provided the image of the first Malå RTA data from the area (**figure 1**). Louise Hansen (NGU) gave input to the geological interpretation.

6. REFERENCES

Lauritsen, T. 1995: Georadarålinger ved Eikesdalsvannet, Nesset kommune, Møre og Romsdal 1995. NGU Rapport 95.105 (10 s.).

Sandmeier, K.J. 2010: ReflexW 2D GPR Data Analysis Module Manual. Sandmeier Geophysical Software/Research.

Sensors & Software Inc. 2013: EKKO Project and Processing module, User's Guide. Subsurface imaging solutions, 2011-00125-03, pp. 119.

Tassis, G.; Rønning, J.S.; Hansen, L.; Tønnesen, J.F. 2015: Comparison between Sensors & Software and Malå GPR equipment based on test measurements at Bøaøyna, Stryn Municipality, Norway. NGU Report number: 2015.014.

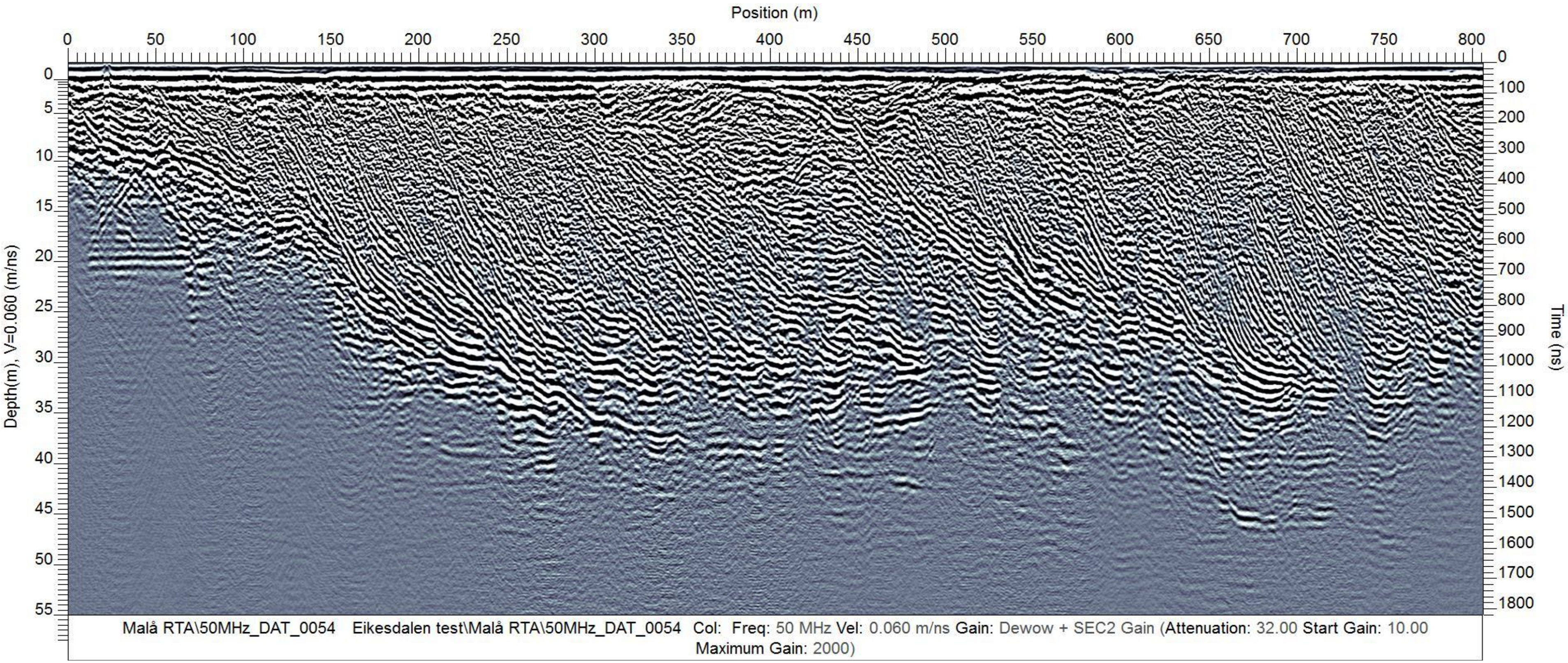

Figure 8: *50 MHz Malå RTA Georadar radargram processed with routines compiled in EKKO_project (Parallel endfire antenna configuration).*

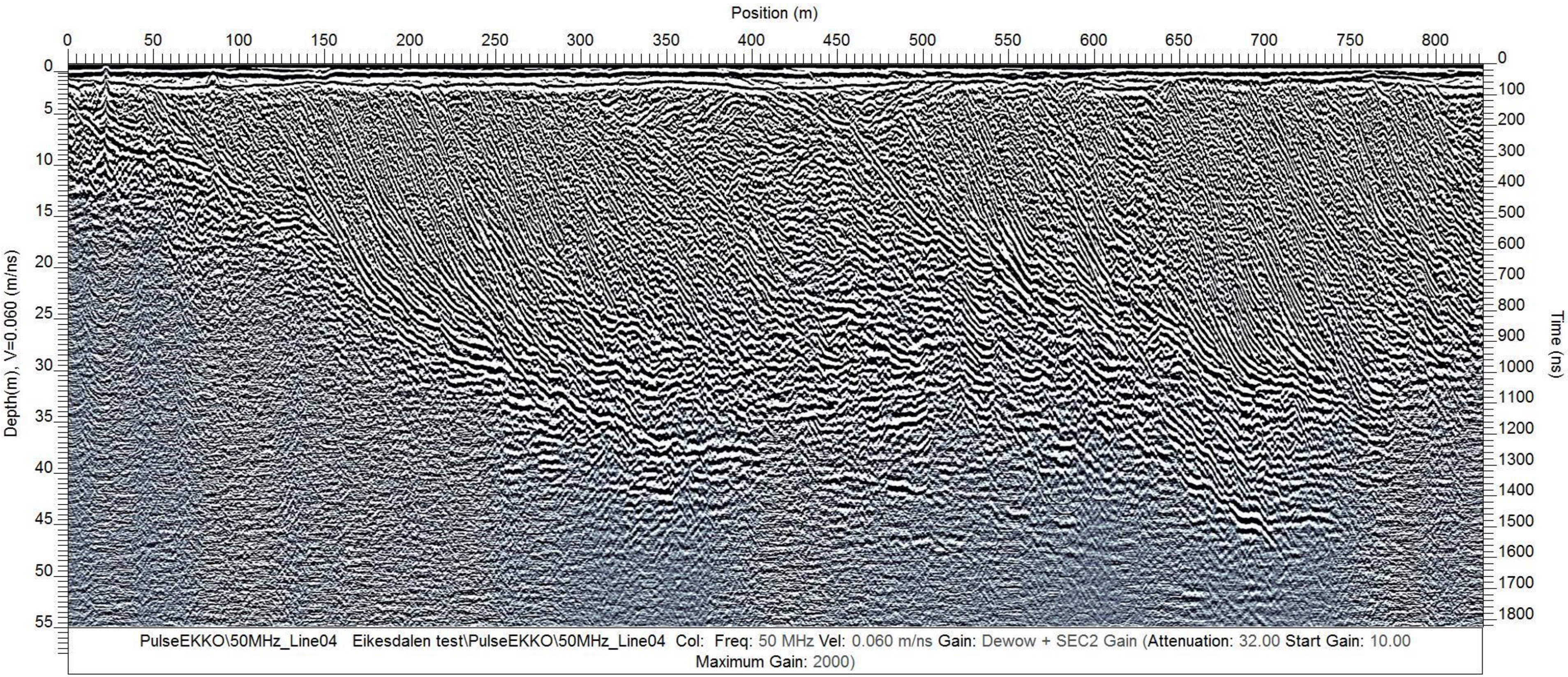

Figure 9: *50 MHz PulseEKKO PRO Georadar radargram processed with routines compiled in EKKO_project (Perpendicular broadside antenna configuration).*

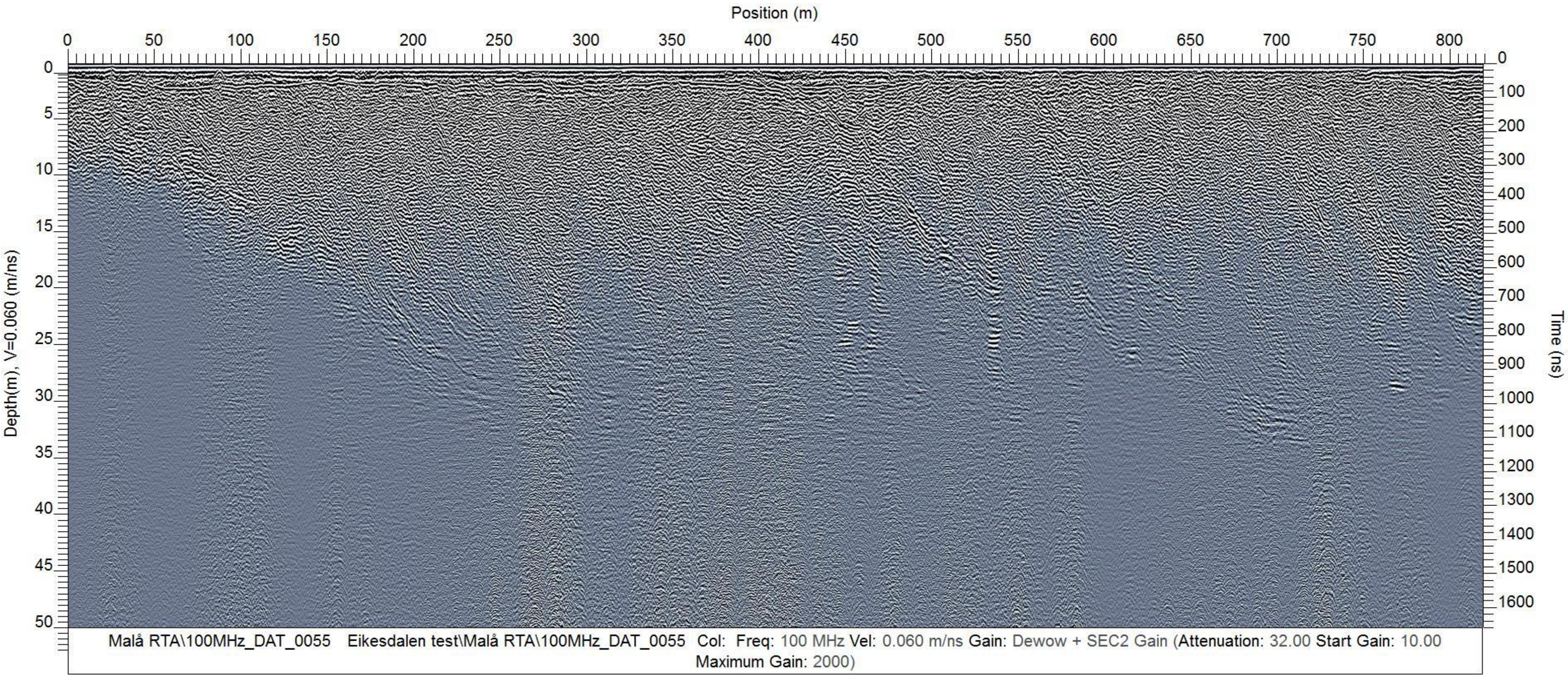

Figure 10: *100 MHz Malå RTA Georadar radargram processed with routines compiled in EKKO_project (Parallel endfire antenna configuration).*

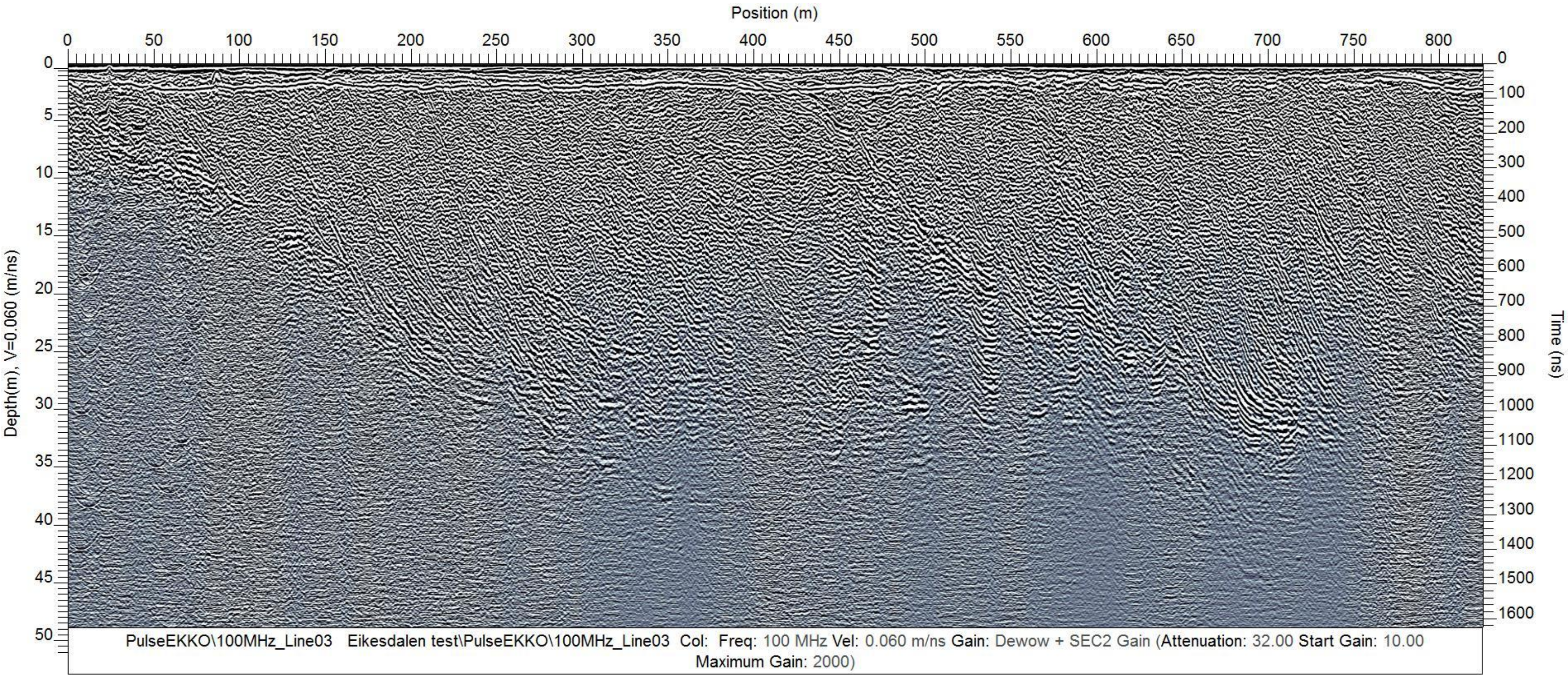

Figure 11: *100 MHz PulseEKKO PRO Georadar radargram processed with routines compiled in EKKO_project (Perpendicular broadside antenna configuration).*

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