UNIS

Department of Arctic Technology

AT-205 – Frozen Ground Engineering for Arctic Infrastructures

Investigating the underground using Ground Penetrating Radar around the 2018 landslide area

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1 Introduction

Longyearbyen, serving as the primary gateway to the Svalbard archipelago, has experienced significant inhabitant growth over the years. From 2085 residents in 2009, the population has risen to 2530 in 2023 (according to ssb.no). However, the population figures mentioned do not account for the transient influx of people during the summer season due to numerous cruise ships arriving regularly. Consequently, concerns about the health and safety of the residents have emerged in the past decade. This is especially true in light of various natural events, such as avalanches and landslides, which are now being closely monitored to prevent any repetition of the 2015 disaster that killed two people and caused significant property damages. The focus is now on predicting such events to facilitate timely evacuations.

Given the current scenario of rapid environmental transformation caused by global warming, characterized by higher temperatures and significant alterations in precipitation patterns, the understanding of events such like land slide is very important and we need to to determine the underground geological and stratigraphic structure.

In this project, we will use a Ground Penetrating Radar in order to investigate the underground structure on the place where a landslide happened in 2018 [4] with the main objective to provide open data to understand the subsurface and help to develop a model like in the PermaMeteoCommunity project [3].

Finally, the second objective is to gain some experience on the ground penetrating radar and try to identify some characteristics structure in the subsurface.

2 Ground penetrating radar

2.1 Principle

Ground penetrating radar, or GPR, is a technology to investigate the subsurface using radars. A transmitter (in orange marked Tx on the figure 1) generates an electromagnetic wave which is transmitted into the ground via an antenna. This signal will propagate into the ground at different velocities depending on the material ($0.13m/ns$ for sandstone or $0.5m/ns$ for fresh water [2]) and will be both reflected and transmitted on the interface between two different materials. The reflected part will be received by the reception antenna connected to the receiver (Blue marked Rx on the figure 1).

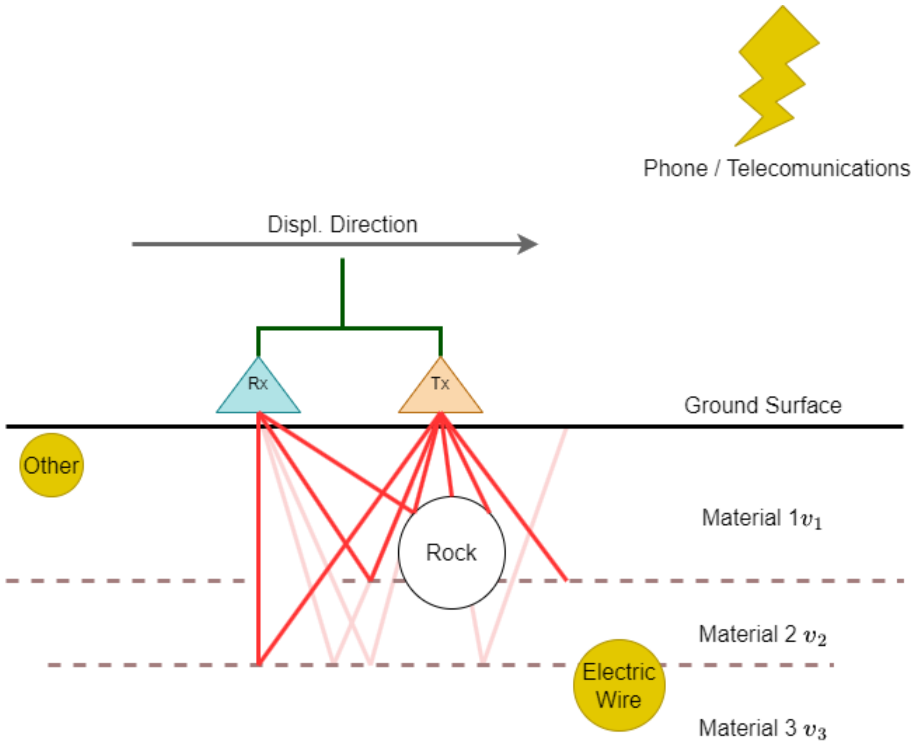

Figure 1: Ground penetrating radar principle

Now that we have the basis of the principles of GPR, we could consider different positioning for both antennae. Indeed, we could choose to keep the receiver fixed and the transceiver moving, at the opposite, both transmitter and receiver moving around a common midpoint... In this report, we will only use the set up with the transmitter and the receiver moving together, antenna perpendicular to the moving direction. This usage of GPR permits to investigate a big area by doing multiple lines. On each line, each measurement point will represent the ground under the GPR and so we can have an overview of the subsurface along the line. [5]

2.2 Limitations

As the GPR uses a range of frequency from Mhz to Ghz which is also the range for many communication and electronics devices, GPR is very sensitive to all radio-electric perturbations. So it must be operated far from any noise source as electric grid, GSM antenna...

An other limitation is that propagation characteristics depend on the material where the electromagnetic wave propagates. Consequently the energy lost by the wave during its propagation depends on the material as well as the velocity. So for the same time window[1], if the signal propagates fast or slow, the depth where we can see will be changed. Also, a material with a huge attenuation limits the depth of the survey because the signal will lose very quickly the power.

Finally, every saline environments are almost impossible to investigate with GPR because the conductivity of salty water is very good, too good[7].

2.3 Settings

Tension The tension gives an indication about the energy given to the emitted signal. The higher the tension is, deeper the signal will propagate but also higher the GPR will disturb the communication devices. The maximum tension allowed for civil survey is $400V$ even if in the past some GPR with a tension of $1000V$ were used.

Frequency The frequency is one of the most important parameters for a GPR survey because it defines the resolution of the GPR. Figure 2 shows that the frequency used is the most important factor which affects the resolution. Also, a higher frequency will penetrate less deep than a low frequency for the same wave energy.

Center Frequency f_c (MHz)	*Range Resolution* Δr (m)	*Lateral Resolution* Δl (m)		
		r = 2m	r = 5m	r = 10m
20	1.25	2.2	3.5	4.9
50	0.5	1.4	2.2	3.1
100	0.25	1.0	1.6	2.2
200	0.125	0.71	1.1	1.6
500	0.05	0.45	0.71	1.0
1000	0.025	0.31	0.5	0.71

Figure 2: Exemple of resolution length and depth versus frequency ($v = 0.1m/ns$) from Sensor and Software [7]

Number of stacks The stacking consists in measuring the same data many times to take the medium or mean value and reduce the noise. The number of stacks should be as higher as possible but will depend on the capabilities of the data-logger, of the receiver and on the different other parameters.

Time windows As defined before, the time window is the time during which the receiver waits for the signal reflected inside the ground. If we use a short time window, we risk to miss information. On the contrary, if the time window is too wide, the data logger will record only noise which will reduce the capability of the data logger.

Sampling interval The reception antenna received an analog signal coming from the ground but the data-logger only record digital signal. Therefore it is important to have a sampling interval which corresponds to the signal. A sampling interval which is too low will lead a completely different signal. The important criteria is the Nyquist Criteria which indicates that the sampling interval should be smaller than the minimum expected period in order to catch all the expected frequencies.

[1]Time during the receiver is waiting the wave to come back before emitting a new signal. See 2.3

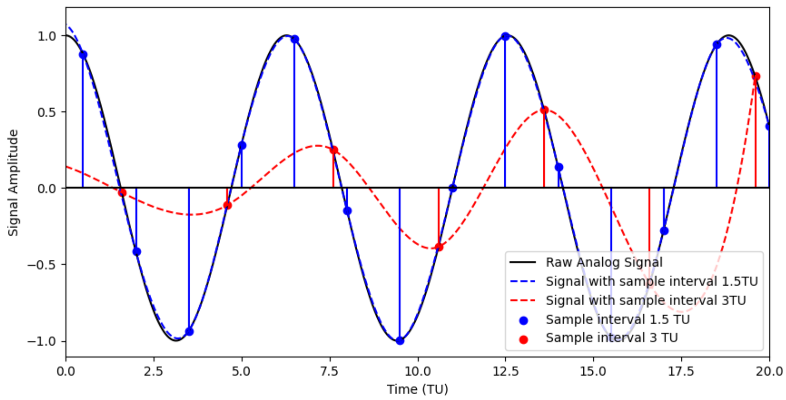

Figure 3: Sample rate illustration

On the example from figure 3, we see that the sample interval of 3 TU[2] is too low where the sample interval of 1 TU is better.

Antenna separation The antenna separation will influence the quality of the signal due to the coupling between the two antennae. In order to set this parameter, we will just refer to the manufacturer documentation.

Antenna orientation The orientation of both antennae will be chosen for practical purposes : both antennae are perpendicular to the moving direction even if other solutions are possible but leading to a more complicated setting up on the pulk (See 3). We chose to have the reception antenna the furthest away from any electronic devices.

Sampling distance The sampling distance will be the distance between two traces, this will give the horizontal resolution. The shorter the distance is, the higher the horizontal resolution will be but also the slower the speed of the displacement will be.

Velocity The velocity (of displacment of the signal in the ground) is a secondary parameter for a GPR because in many cases the velocity is determined using GPR data. The key thing to know is that the velocity will convert the time window into a depth window defining the depth where the GPR can see.

[2]TU = Time Unit

3 Methodology

3.1 GPR Setup

Figure 4: GRP setup used for the survey during the tests (see 3.2) realised in the main street of Longyearbyen. *Photo : Gunnhild Næss - UNIS*

The setup to run a GPR in a steep slope as described in 3.3 should be easy to carry and quite compact but compelling with all the requirements of the GPR. The picture on figure 4 shows all the elements as listed bellow.

- *The pulk* will be the support for the GPR receiver and transmitter. The challenge is to fix both antennae on it and the simpler solution was to tape the antenna on the pulk.
- *The antennas* placed directly above the pulk (rectangular black plate)
- *The transmitter*, black box above the back antenna on the figure, 4 will generate the signal send by a fiber optic from the DVL[3]. The transmitter we used requires to disconnect the output wire.
- *The receiver*, yellow box above the front antenna, will be the most critical part of the set up. The receiver which receives reflection signal from the ground is also the most sensitive to all external perturbations. That is why for the 'real' survey, we chose to invert the receiver and the transmitter to keep the receiver the furthest away from all other electronics devices.
- *The GPS receiver* located on the top of the backpack will allow to have the position of each measurements and to correct the position of the lines during the processing. It will also give the indication about the elevation which is very important during a slope survey.
- *The DVL* will receive and send all the data and save it. It also allows to set up the whole GPR (Frequency, Antenna separation... as presented in 2.3)

3.2 Test survey

In order to try the whole setup which was new (especially the data logger), we went in the streets of Longyearbyen to draw few lines for tests. This survey allows to fix few issues with the GPS and to improve the organisation of the receiver and the transmitter for the "real survey". During these preliminary tests, Gunnhild Næss took a picture presented on figure 4. We only present one of the lines performed during this survey because it is very characteristics of a buried pipe (see figure 11 in the 4).

[3]Data logger

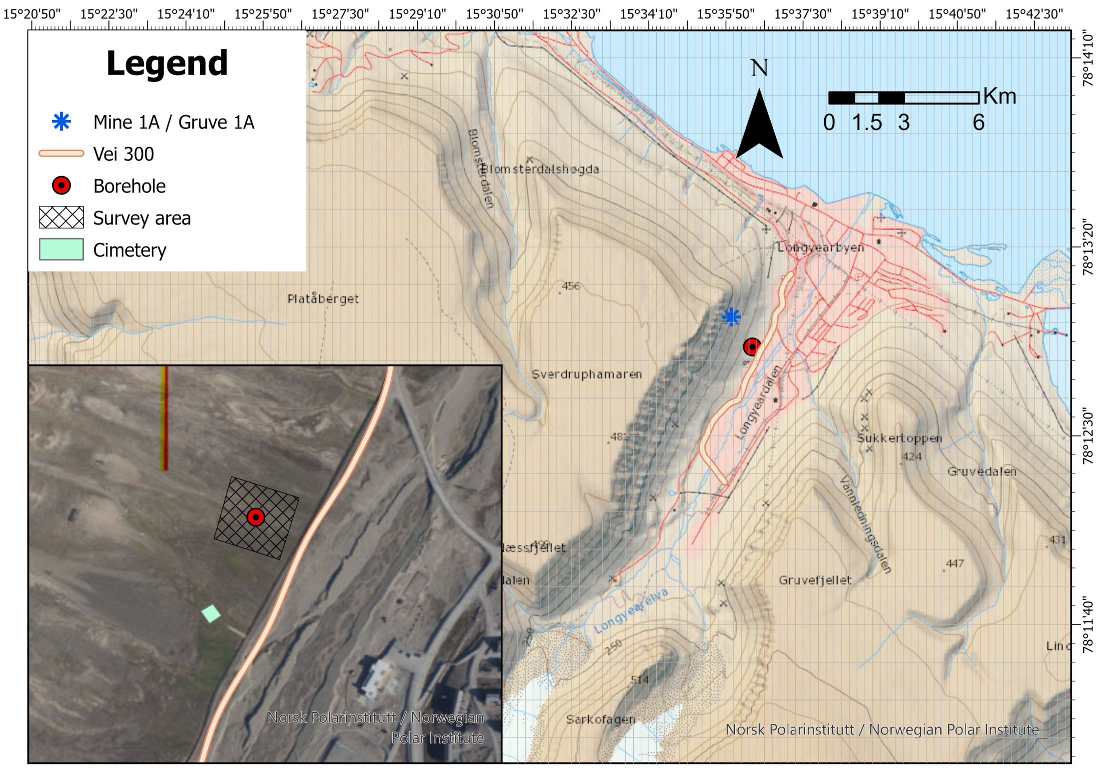

Figure 6: Location of the survey area in Longyearbyen

3.3 Field work organisation

Site description One of the key concern in Longyearbyen is the safety of people and in the recent years few major events happened. One of the most important was the avalanche in 2015 which killed 2 people and destroyed many houses. In 2018, a landslide went down on the side of Platåberget and crossed the road close to the cemetery. Even if no one was injured, it was obvious that a system to monitore the permafrost and the conditions around the town was required in order to prevent any serious event. This project is the PermaMeteoCommunity [3] which creates a model to predict event such as landslides. That is why we chose to do a survey close to the borehole which are used to monitor the temperature of the permafrost where the landslide happened in 2018. The localisation of the area is shown on figure 6.

Figure 5: Landslide in Longyearbyen in 2018 *Photo: Alexander Lembke* [4]

Geology Using a GPR as for goal to "see" the subsurface and also some geological consideration are required. We had the information from the survey on the Geological map of Svalbard [1] and the result is presented on figure 7. This map gives us the information that the bedrock will be most likely sandstone and shale which give us an information about the expected velocity around 0.130 m/ns [2].

Weather conditions The field work takes place in a very perturbed but sunny spring period. The day of the field work, April 28th, the weather was very sunny and warm with a temperature

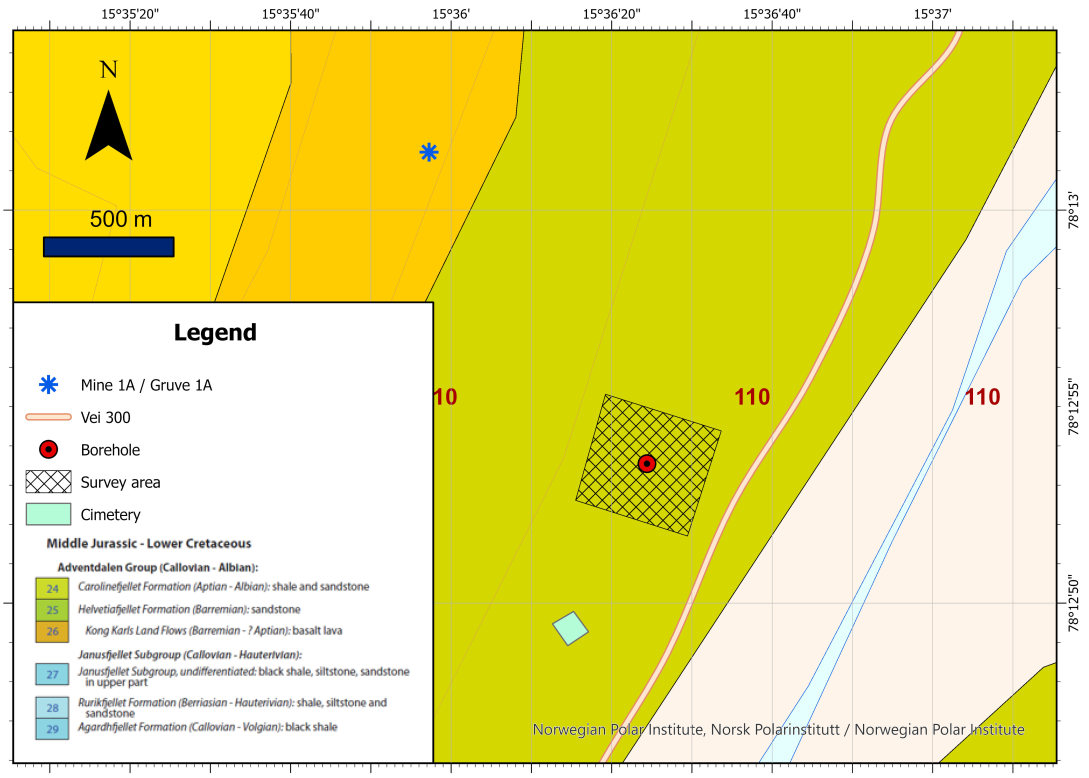

Figure 7: Geological background under the survey area [1]

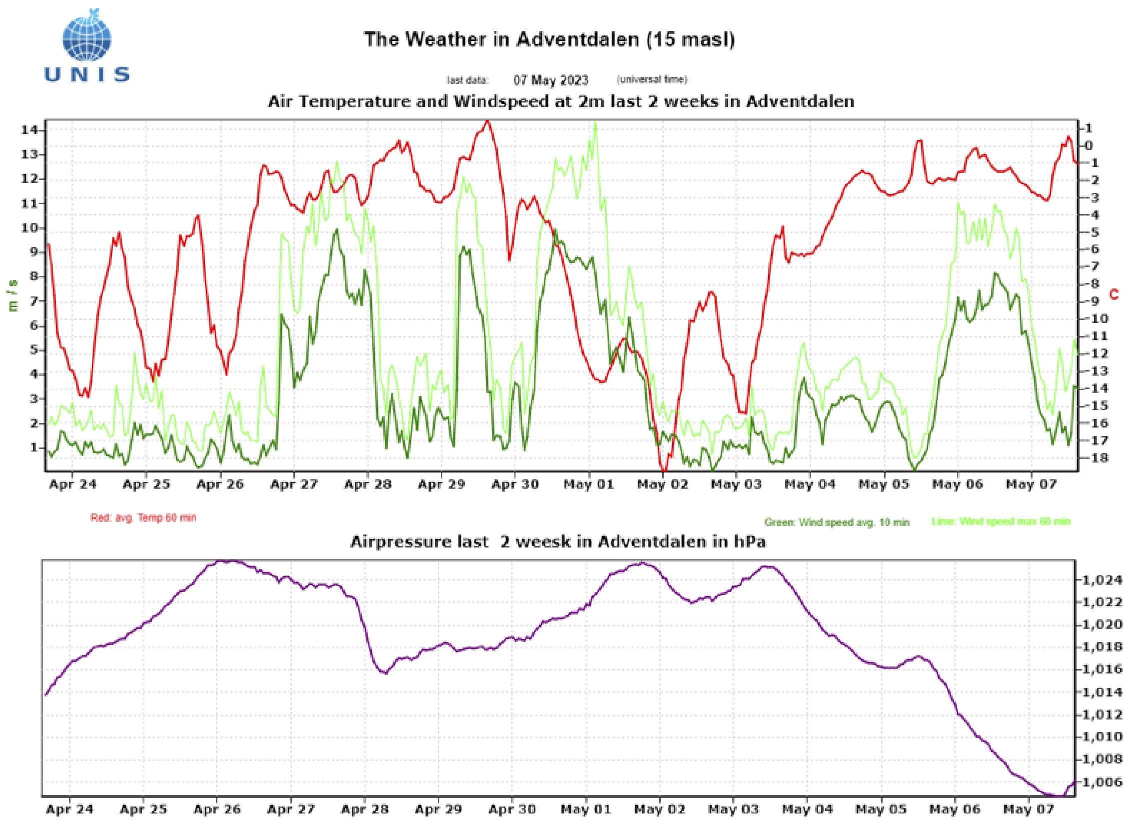

Figure 8: Weather condition around Longyeabyen from the UNIS weather station in Adventdalen between April 24 and May 7 2023

reaching 0.5°C. Figure 8 shows the history of the weather 2 weeks around the field work. We see an high variability of the temperature (between -18 and 2°C) as well as a high variability of wind.

Safety consideration In the arctic, safety for field operation is one of the most important concern, even when the field activity are close to the town. According to cold weather, the risk of landslides as it happended in 2018 is very unlikely, because the active layer is still frozen. But a more important concern is avalanches because of the steep slope of the survey and even with a risk of 2 over 5. That's why we have with us all the avalanche safety equipments (avalanche beacon, probe and shovel). Finally, we stay close to a very crowdy area (cross country ski track), in town and we always stay under phone coverage in case of any emergency.

Planned grid The initial plan was to realize a grid as presented in blue on figure 9 in order to have a resolution under the ground as good as possible. The issue was that to follow the line with the GPS was very hard and the irregularity of the surface increased this complexity. Finally, the main concern was that the initial grid was very ambitious about the physical activity and the long path to be walked.

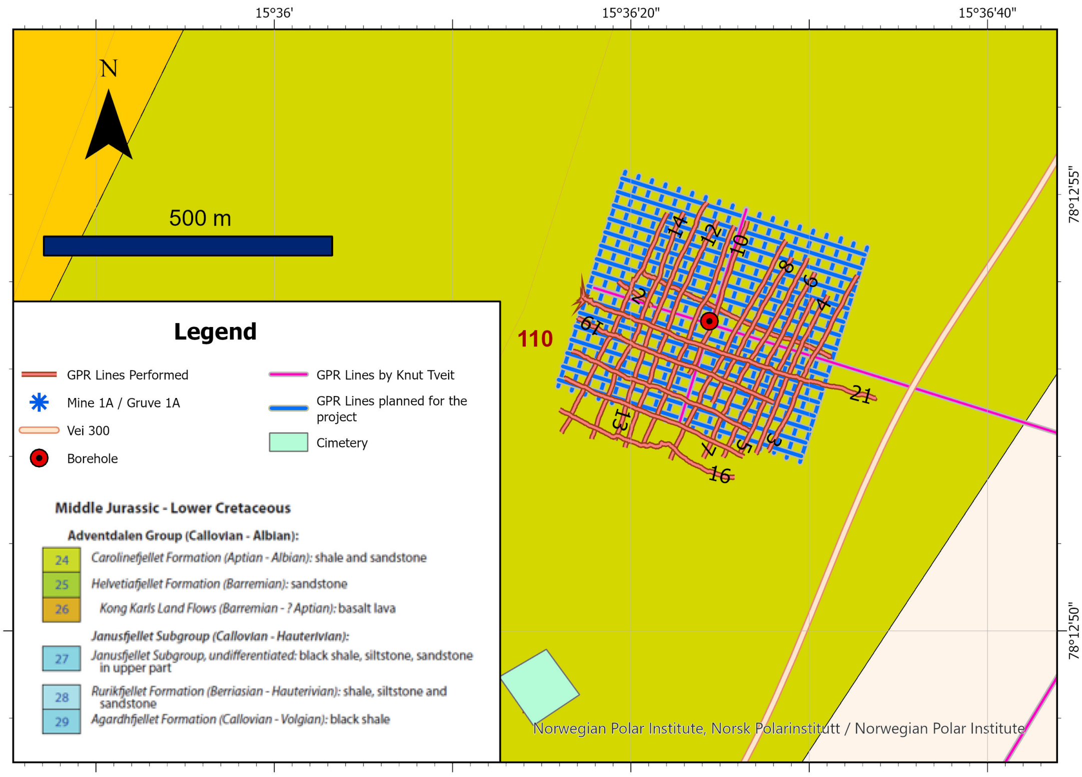

Figure 9: Lines planned and performed during the main survey

3.4 Processing

The processing in the most important part of the survey, because it allows to show what is interesting. The easier way is to use the software Ekko Project provided with the GPR by Sensor and Software (GPR manufacturer).

The first step is to import all the data in the software, correct the position of the lines with GPS data and export the data set as CSV as a backup.

After applying a bandpass filter from 50 MHz and 150 MHz, we open one of the line and do the following processing :

1. Change the color scale in order to keep my eyes alive...
2. Use the dewow filter in order to remove the electronics wow effect
3. Apply a gain in order to be able to see some details in the depth. For that part, it's mostly trial and error in order to get a GPR line where we have some contrast everywhere. For our data set, we use the SEC gain which will try to amplify more the deeper layer than the upper layer in order to have an homogeneous picture.
4. Use a background subtraction to remove the layering created by electronics noise mainly

The next step is to find the velocity using the hyperbolas. Unfortunately, we get only two nice hyperbolas due probably to the electric grid which give a velocity around $0.235 m/ns$ where some other very thin and small hyperbolas give a velocity closest from $0.109 m/ns$. For all the lines, I choose to use the velocity of $0.235 m/ns$ but it might be the wrong one and so the penetration depth should be taken only as an indication, because depending of the velocity.

Finally, we apply the same settings to all the lines (knowing that the survey was done in the same place with the same settings) and change the visualisation from depth to elevation to have an idea of the upper geometry of the terrain.

4 Results and interpretation

We use the same code for the interpretation of all lines and the meaning of the different colors are presented bellow on the figure 10.

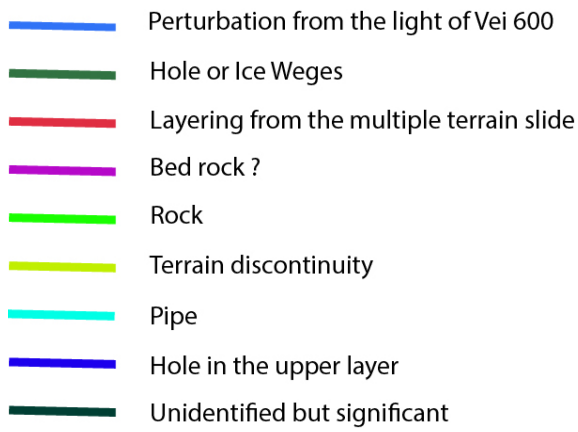

Figure 10: Legend for the interpretation of the figure

4.1 Test survey

For the test survey to test the equipment, we went walking in the streets of Longyearbyen and found a very characteristic echo from pipes under the road.

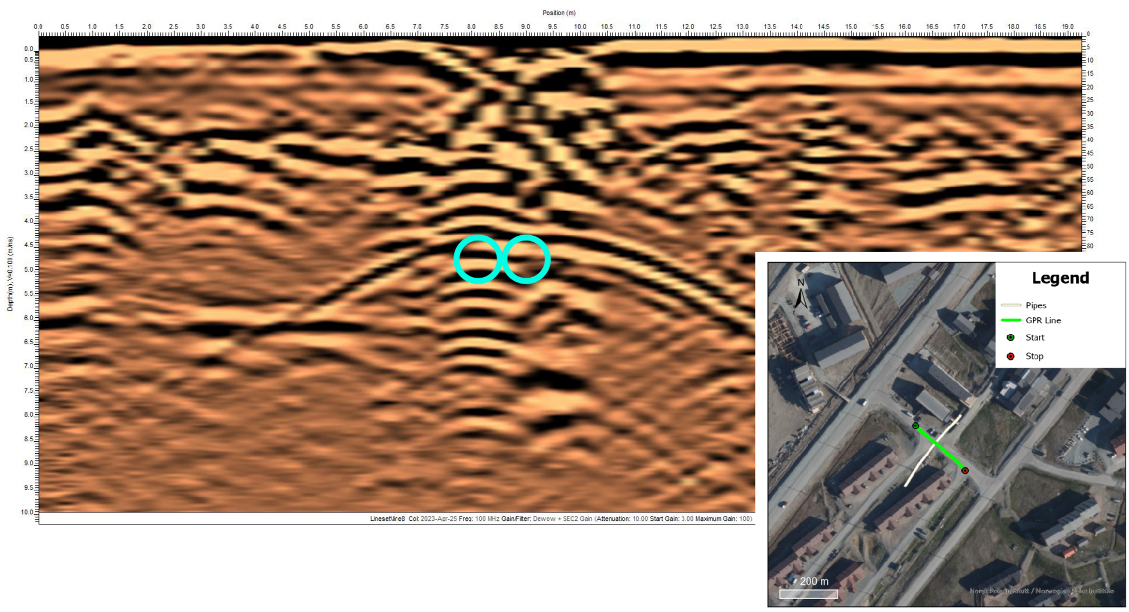

Figure 11: Test Line

The figure 11, shows a lot of small hyperbola around the position of the pipe which is very characteristics of a single buried object. We also see some change in the upper layer due to the different materials used for the road surface.

4.2 Main Survey

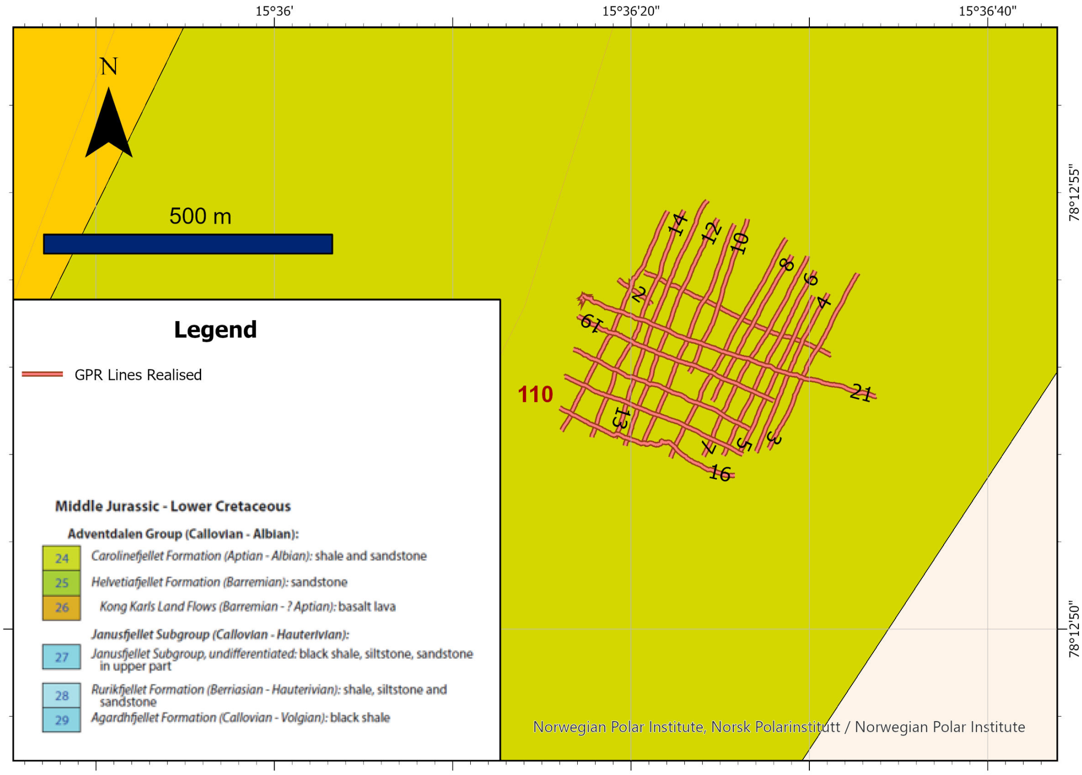

Figure 12: Location of the different lines realised during the survey and the line number.

Results from the lines parallel to the slope First we will present the lines realised parallel to the slope because they allow to understand some of the limitations of the GPR and the ground. During that part, when start the line 2 and 20, the fiber optic of the receiver had some connection issue and we restarted the line and didn't process it (because no data were available but only noise).

On all the lines we easily see the layering of the upper sedimentary part of the subsurface. This layering is most likely linked to the different land slides and avalanche deposits in this run out area. This layering might also be generated by some kind of interference with the pulk even if this second hypothesis is very unlikely because of the irregularity of the layering.

On the line 1 presented on figure 13, we might be able to see the bed rock (pink annotation). It's with the line 19 (figure 17) the two figures where we could see an underground layer which could correspond to the base rock. This hypothesis must be confirmed with some data providing the depth of the base rock at this position (borehole, geological archives...) and I didn't manage to find such a documentation. So according to this data the bed rock might be at a depth around 20m.

Unfortunately, it was the only good hyperbola to compute the velocity underground and so we get a velocity of $0.235 m/ns$ which is quite high according to the velocity we could expect for permafrost area [2].

Finally, we have some structure which are quite complicated to understand. My better guess is that structure could be some ice wedges as we captured in Adventdalen during the semester [6].

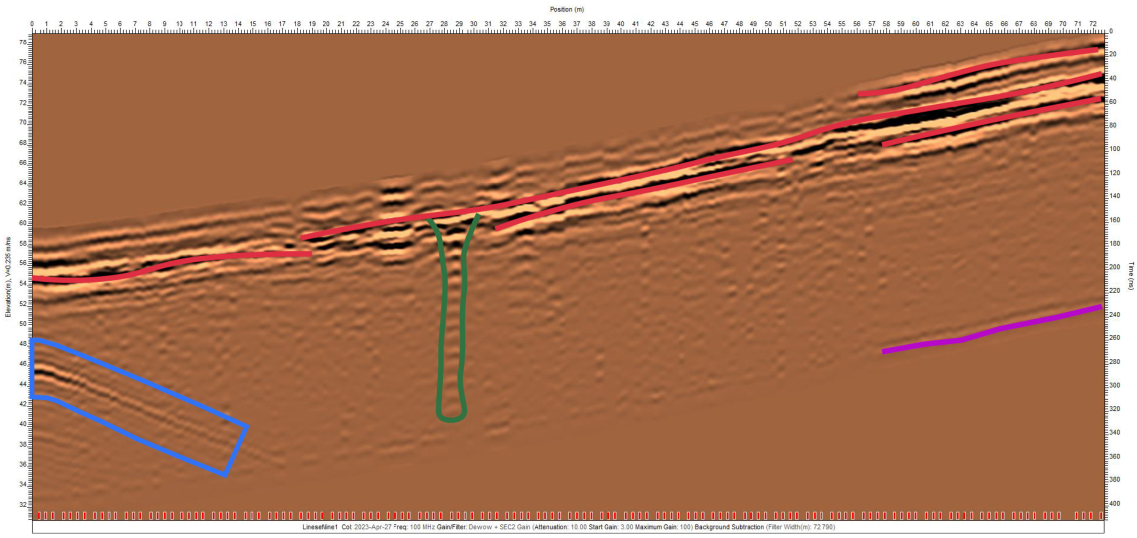

Figure 13: Line 1 with interpretations, legend on figure 10

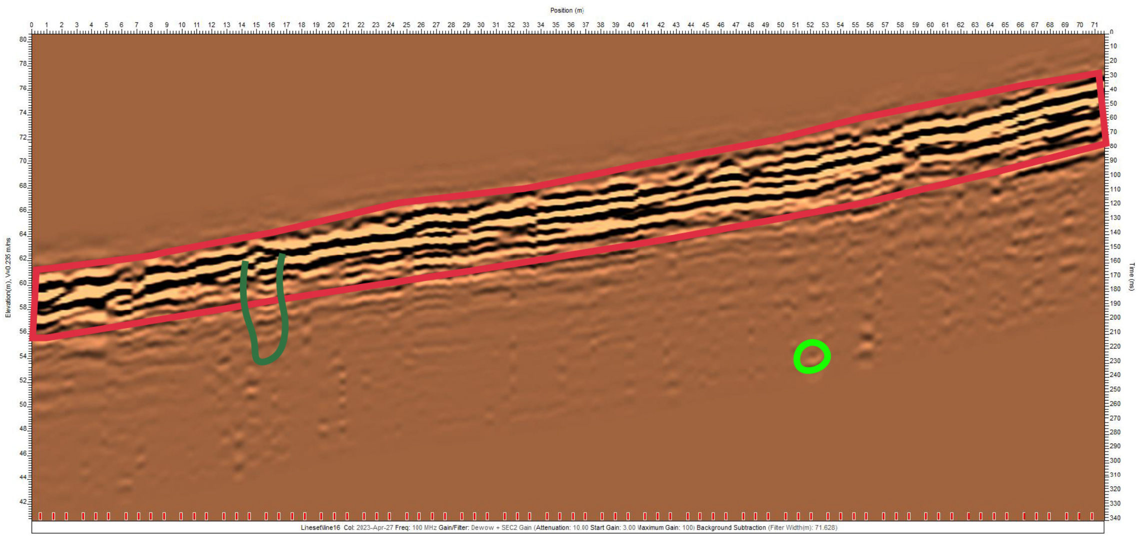

Figure 14: Line 16 with interpretations, legend on figure 10

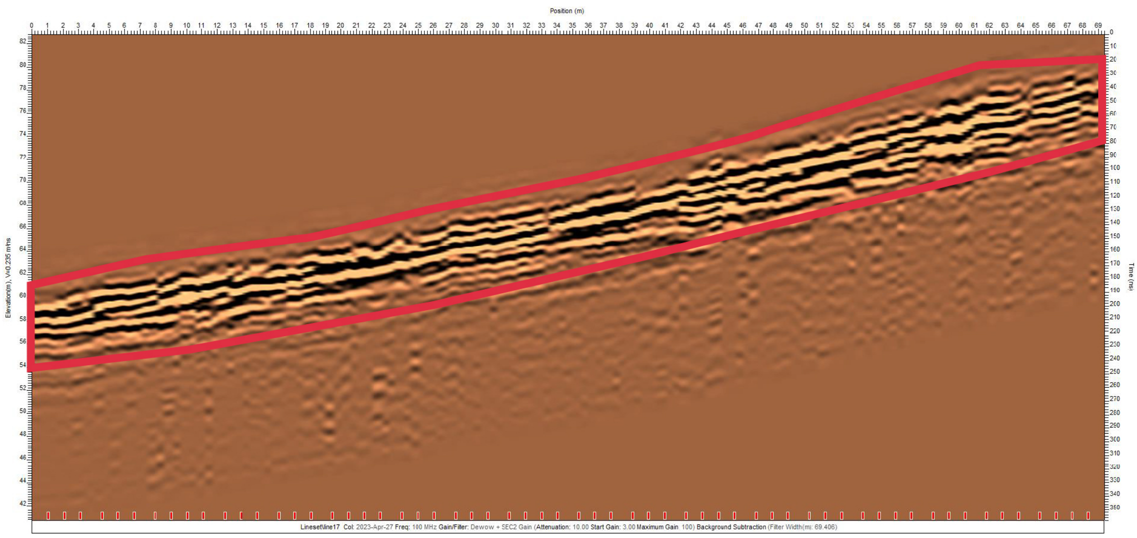

Figure 15: Line 17 with interpretations, legend on figure 10

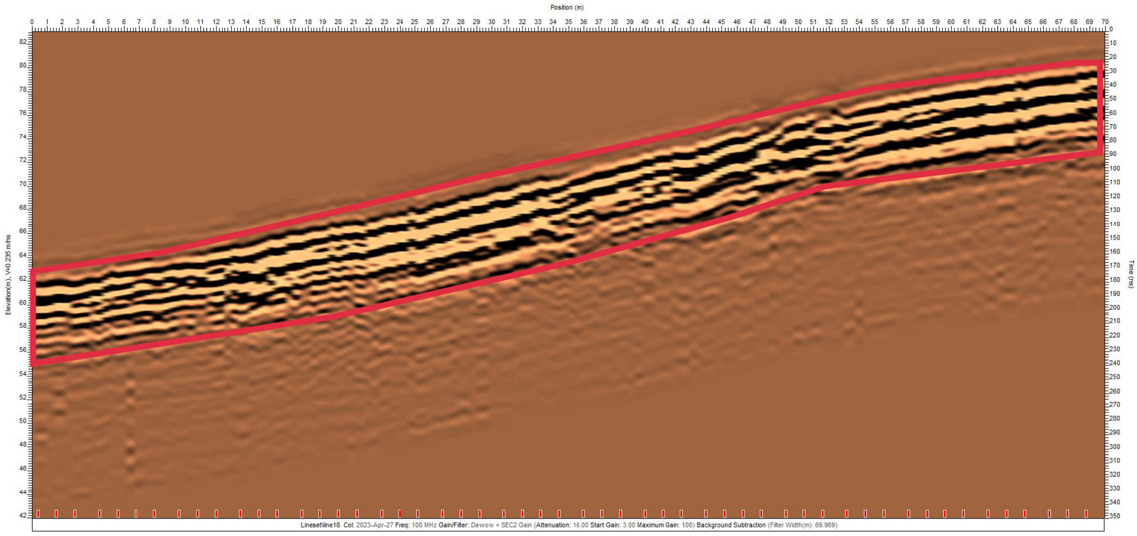

Figure 16: Line 18 with interpretations, legend on figure 10

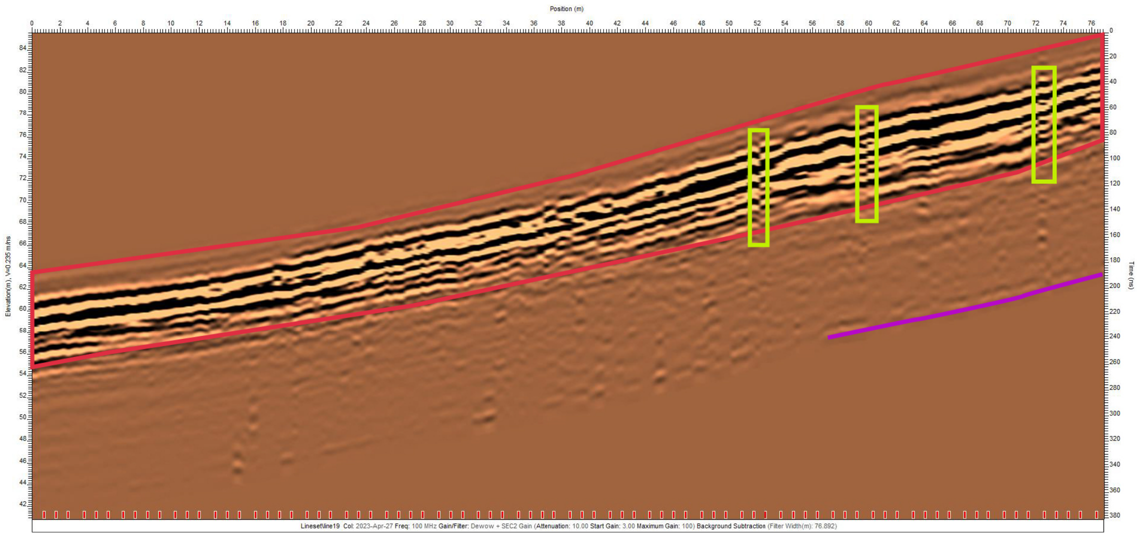

Figure 17: Line 19 with interpretations, legend on figure 10

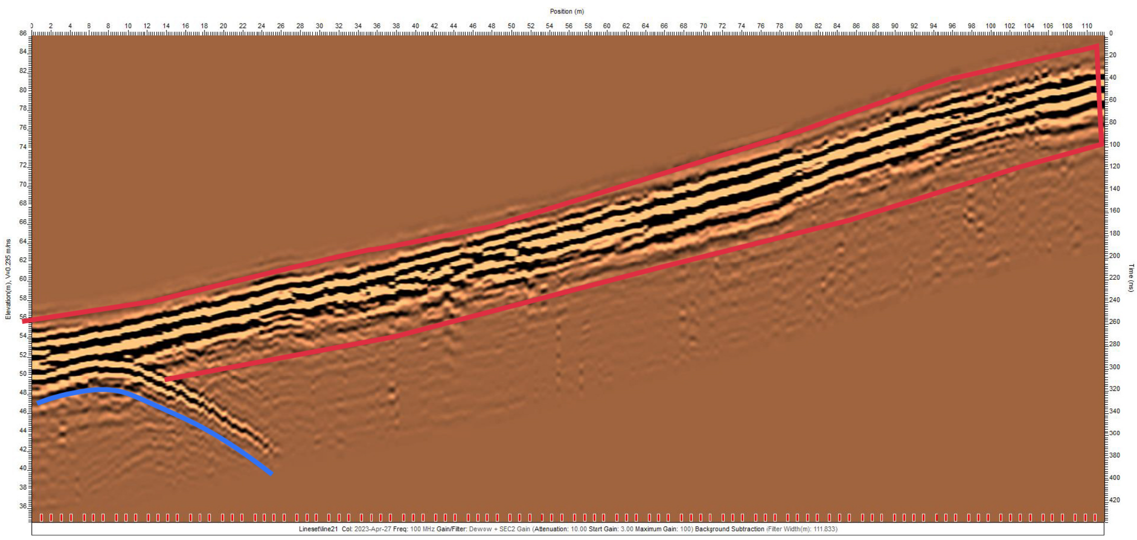

Figure 18: Line 21 with interpretations, legend on figure 10

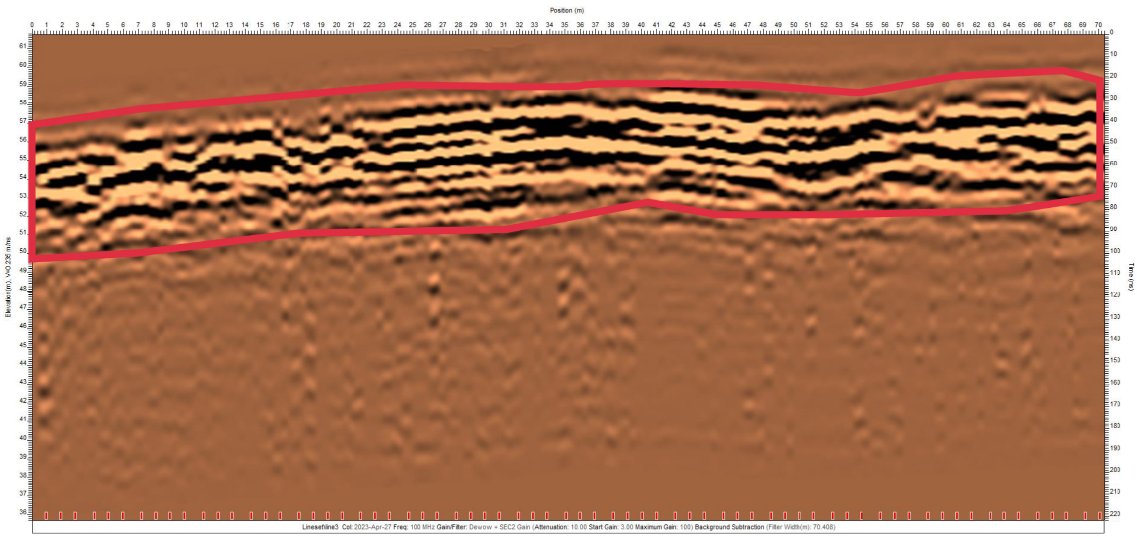

Figure 19: Line 3 with interpretations, legend on figure 10

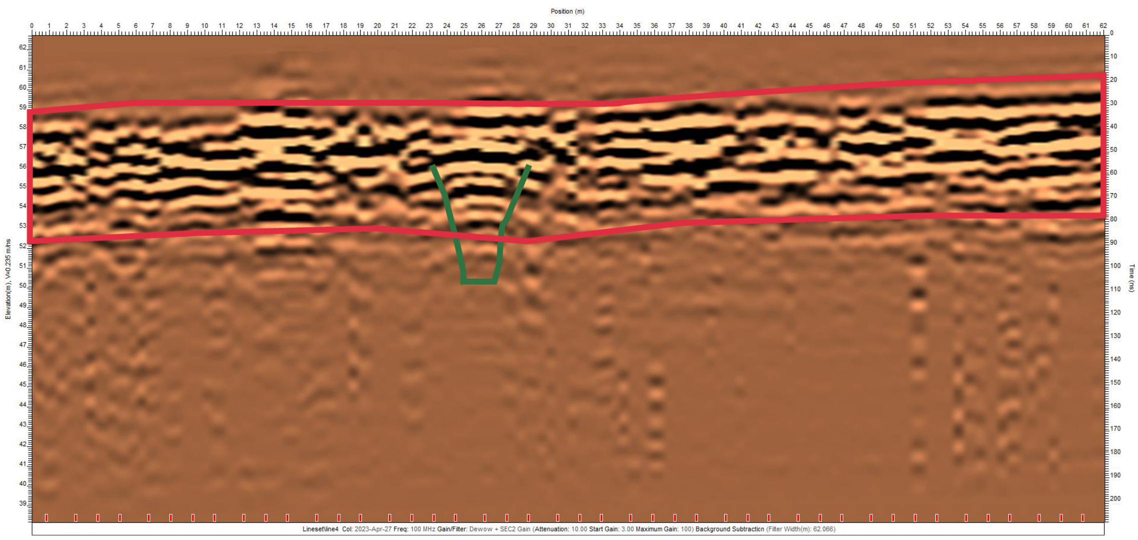

Figure 20: Line 4 with interpretations, legend on figure 10

Results from the lines perpendicular to the slope On the horizontal lines, we see mostly only the layering on the upper part as well as sometimes few structures which might be some ice wedges.

On lines 6 and 9 (figure 22 and 25), there is a structure which is much more detailed than the rest of the lines. My knowledge and research didn't allow me to understand which is this structure and thus we have to organise additional researches to figure out.

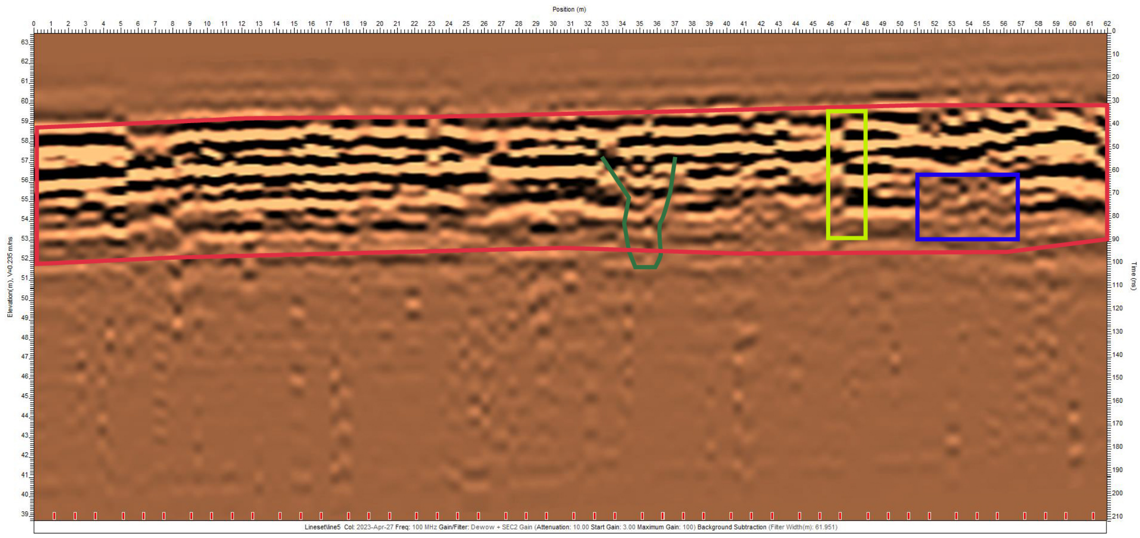

Figure 21: Line 5 with interpretations, legend on figure 10

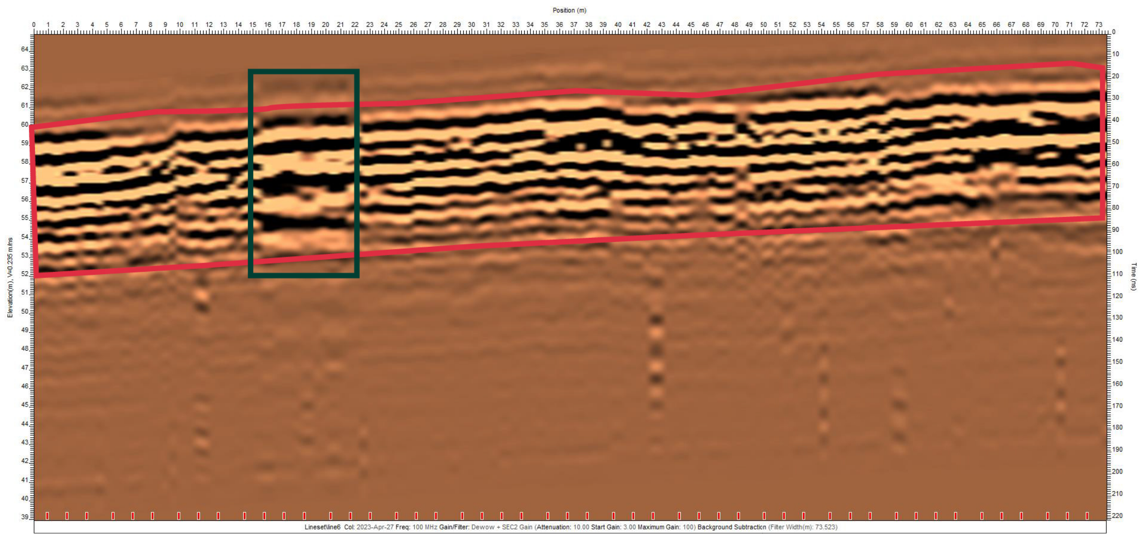

Figure 22: Line 6 with interpretations, legend on figure 10

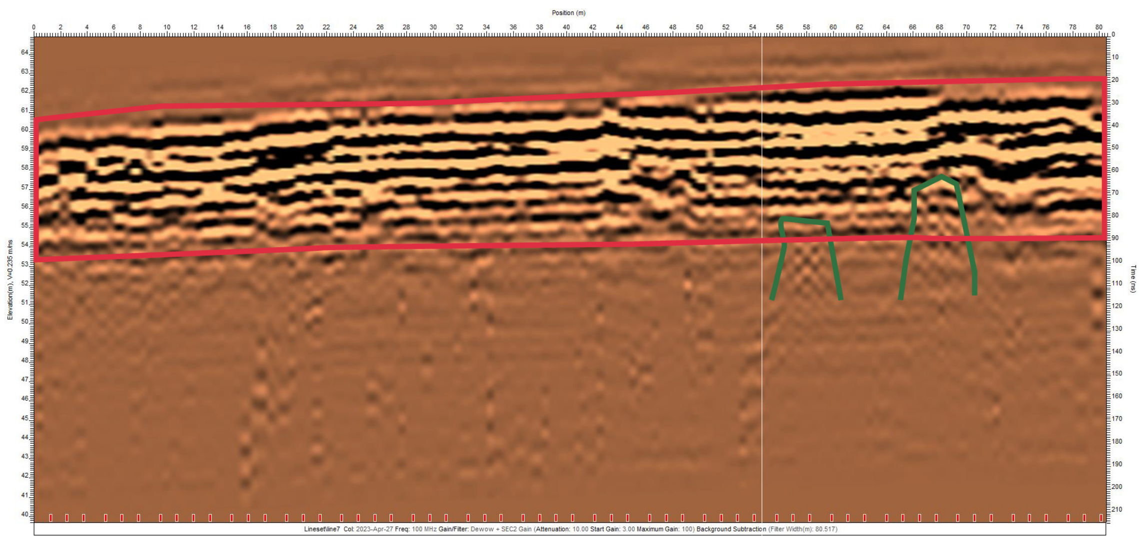

Figure 23: Line 7 with interpretations, legend on figure 10

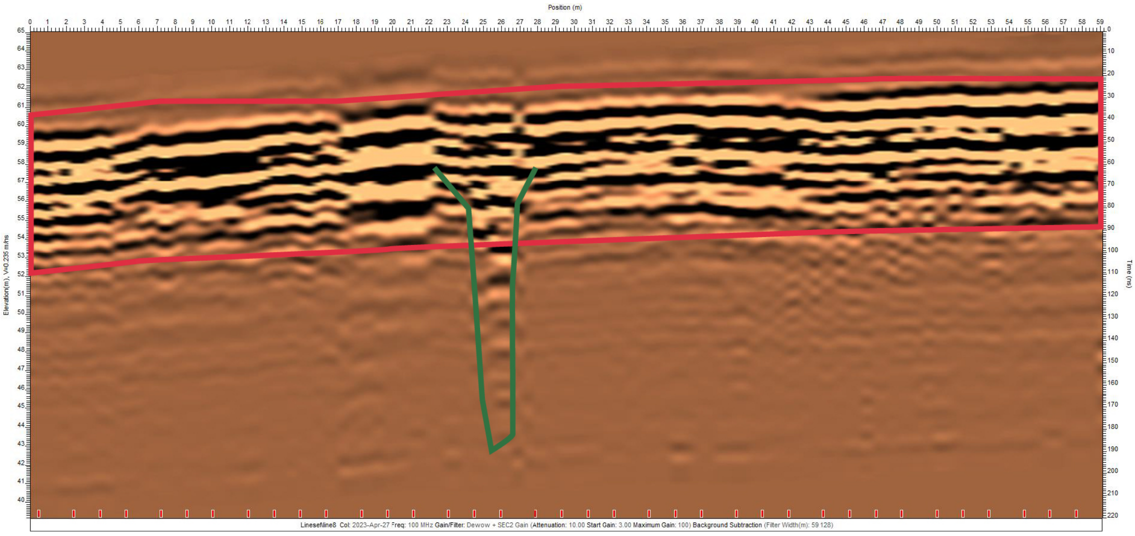

Figure 24: Line 8 with interpretations, legend on figure 10

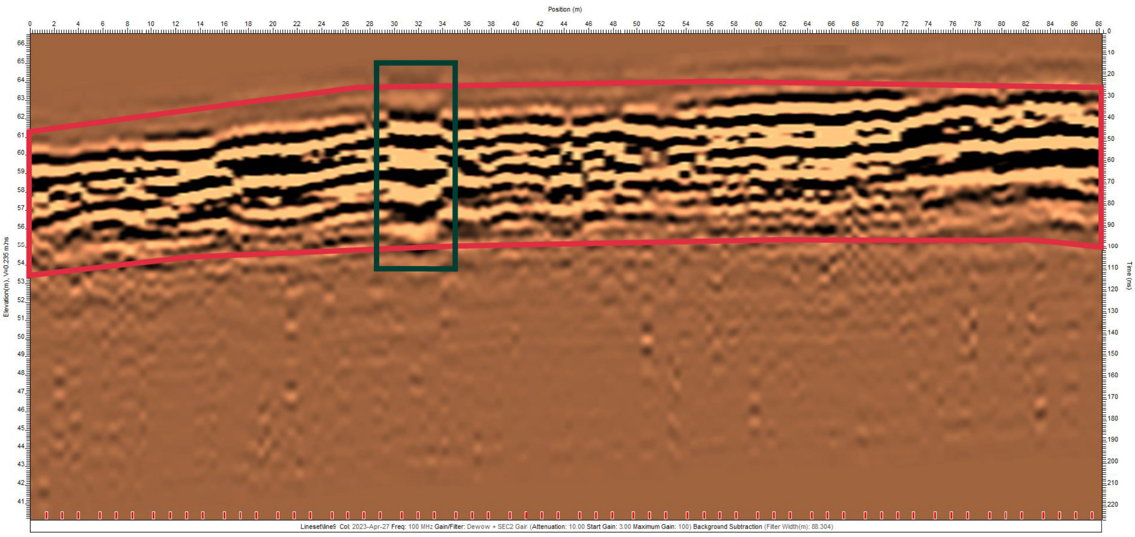

Figure 25: Line 9 with interpretations, legend on figure 10

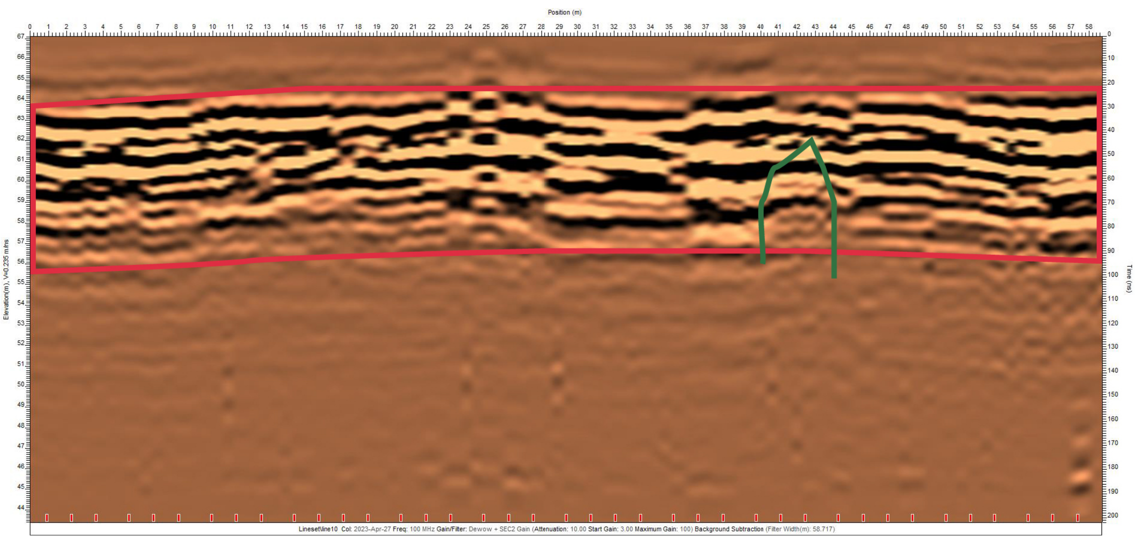

Figure 26: Line 10 with interpretations, legend on figure 10

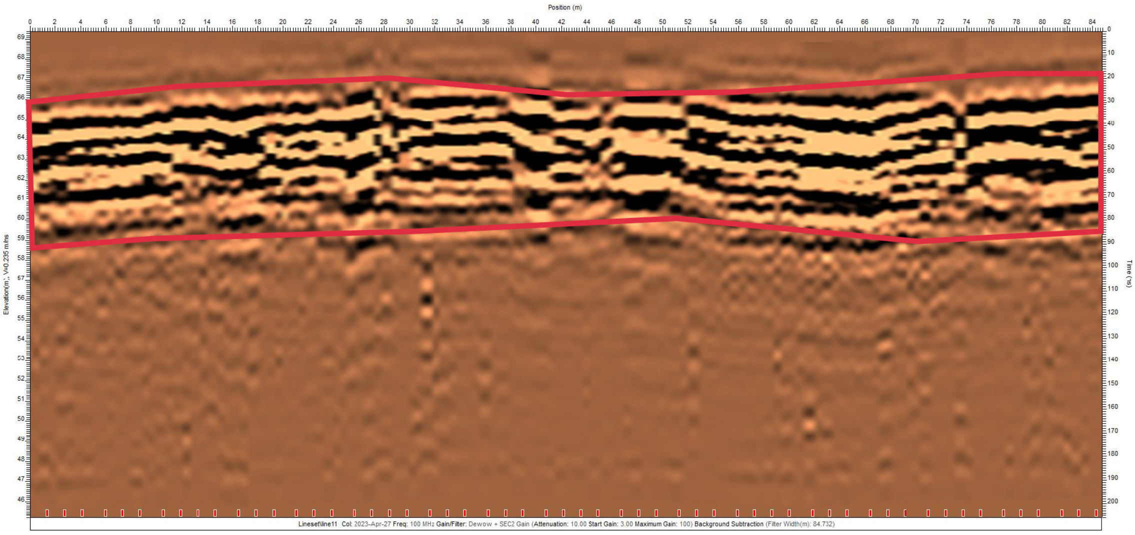

Figure 27: Line 11 with interpretations, legend on figure 10

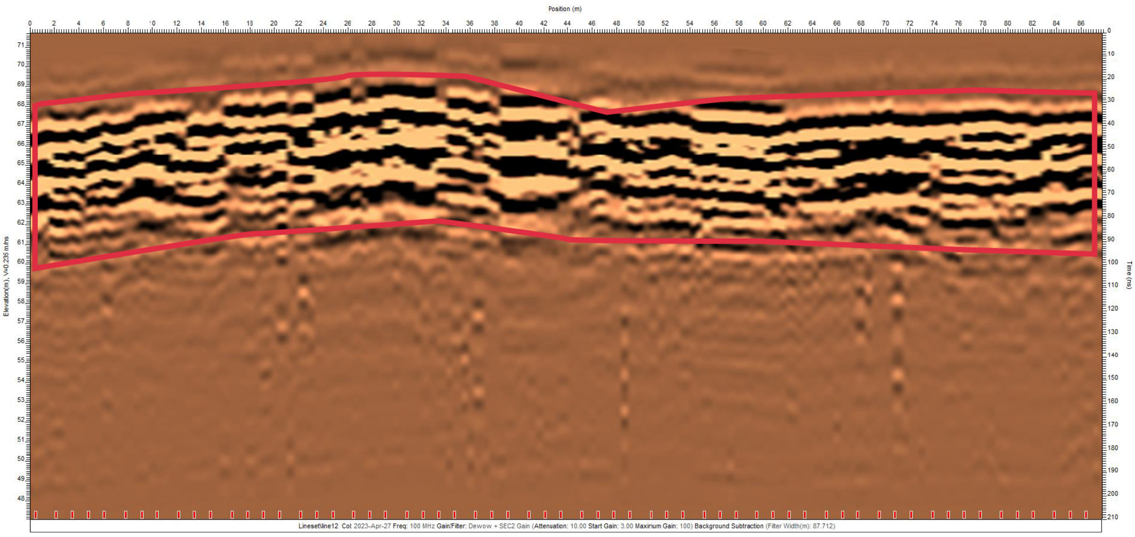

Figure 28: Line 12 with interpretations, legend on figure 10

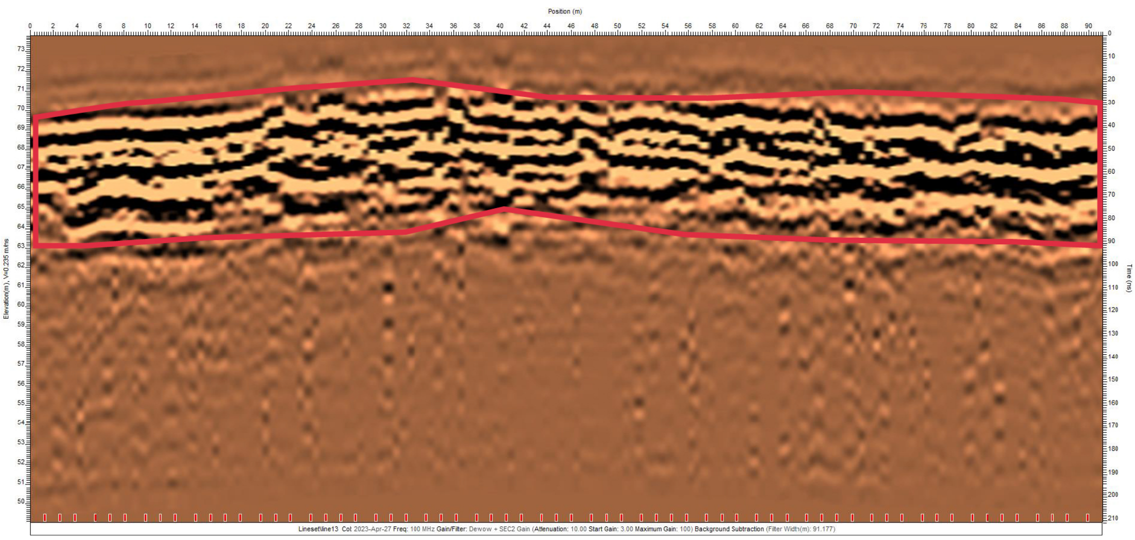

Figure 29: Line 13 with interpretations, legend on figure 10

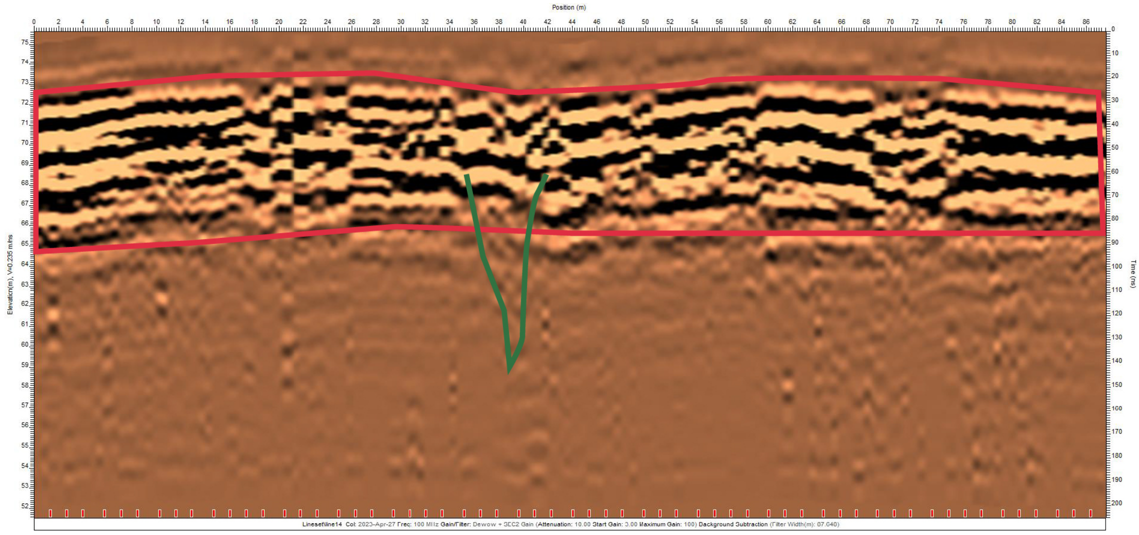

Figure 30: Line 14 with interpretations, legend on figure 10

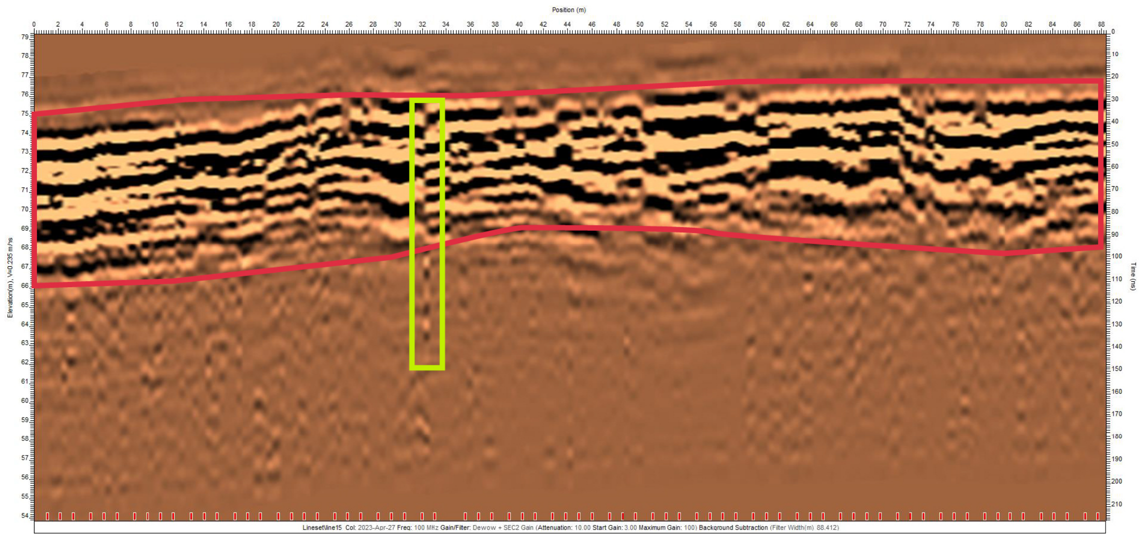

Figure 31: Line 15 with interpretations, legend on figure 10

Spacial representation As we do a grid, we are able to try to represent the survey in 3D environment. For that, we just export the data from Ekko Project as a point cloud and import it in Cloud Compare in order to display the survey in 3D.

This technique is unfortunately not detailed enough to do any correct interpretations.

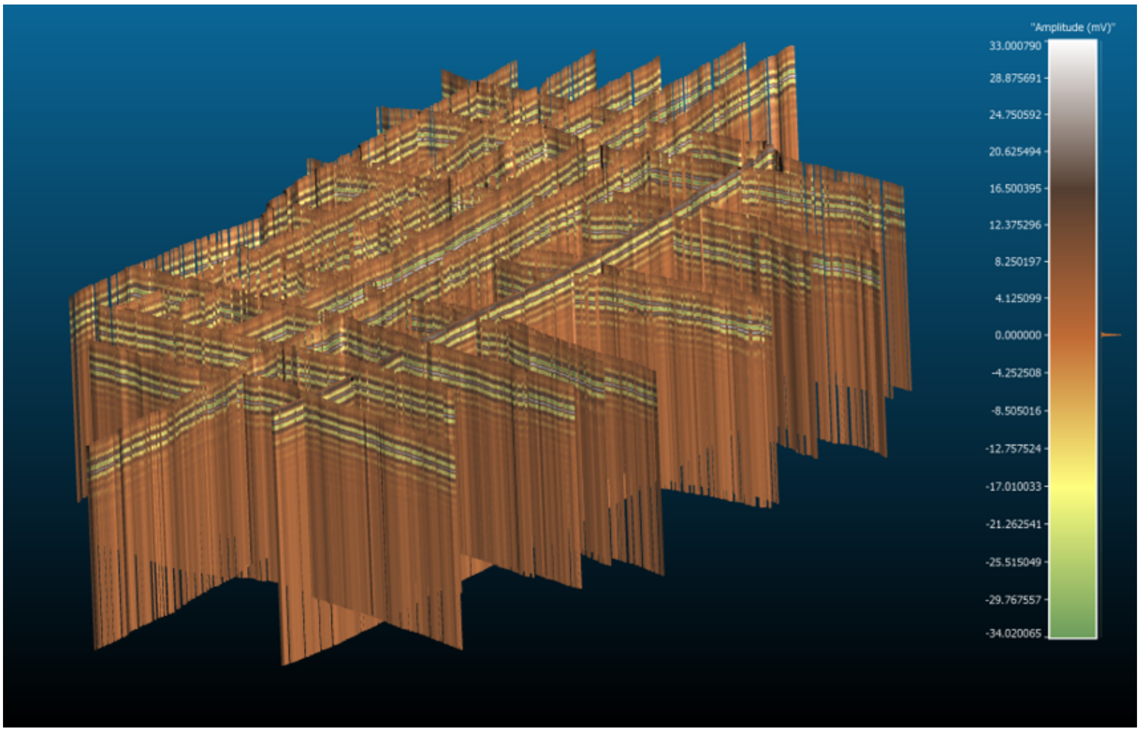

Figure 32: 3D representation of the survey

5 Discussions

The GPR investigation confirmed the nature of the upper sedimentary subsurface, characterized by the presence of multiple layers due to many avalanche and landslide deposits through the geological time. This layering is crucial to understand the history of the ground because each layer correspond to a geological event.

Unfortunately, the ground penetrating radar is very insufficient to be able to precisely characterise each echo even if we are able to do some hypotheses. To increase the accuracy of the characterisation of the subsurface, additional investigations will be required by people specialized in geological survey and stratigraphy.

The survey confirms also one of the limitation of the GPR in term of perturbation with the "nice view" of the public light electric infrastructure close to the road on the figures 13 and 18 representing the lines 1 and 21. Even if the perturbation due to the electric wire is the most easy and likely hypotheses, we should confirm it using the mapping of the road infrastructure around the Vei 600.

More globally, the limitation of the GPR in that location is the time and man power to realise the survey. Indeed, the survey as planned and the performed lines show on the figure 9 is very characteristics of the difficulties to operate a GPR in a steep slope with a lot of rocks. Especially, using a pulk to carry the transmitter and receiver makes almost impossible to operate the setup above rocky area. A the GPR mounted on a wheel rig should have been very complicated to operate on the snow. An other way to move the antennae manually between each measurement should have led to an more accurate survey (longer time for each measurement) but increase a lot the time needed.

The resolution of the data is quite good even if there is still a lot of noise due mainly to the little amount of stacks (64) done because the receiver is now quite old.

6 Conclusions

The ground penetrating radar is an underground investigation techniques which give a lot of information about the structure of the subsurface and provide accurate and precise data about the subsurface. The difficult part reside in the interpretation of the data using the geological and stratigraphic as well as the surface indications.

Operating the ground penetrating radar on a steep slope with a lot irregularities is quite challenging to keep a regular survey and is definitely quite exhausting for the person pulling the pulk.

Even with a quite old receiver and transmitter, the quality of the data is still very good even if quite noisy sometimes.

Finally, we confirm the upper sedimentary structure of the area even if we was not able to obtain very accurate information due to the complexity of the interpretation.

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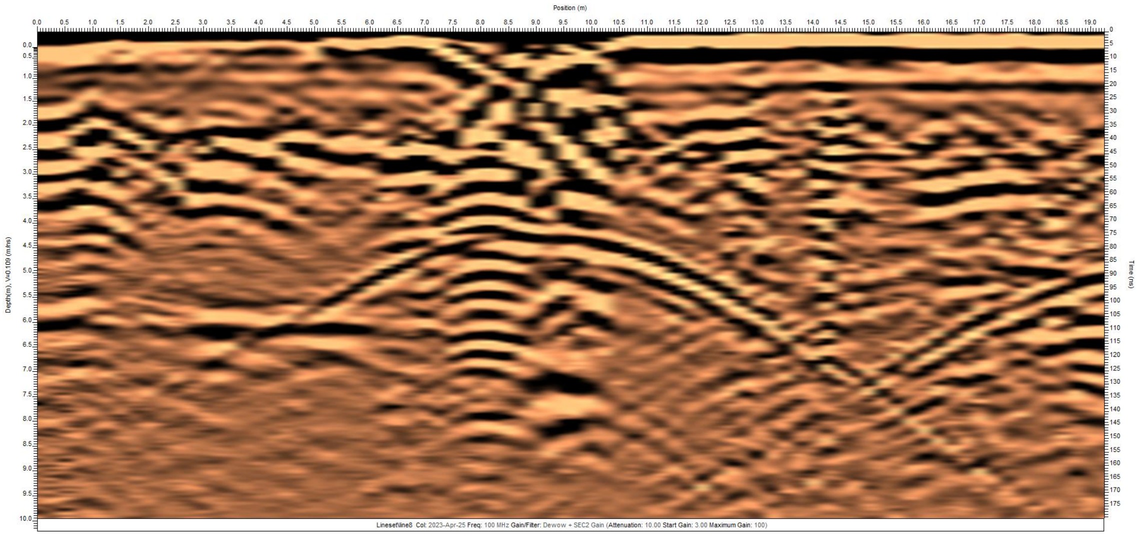
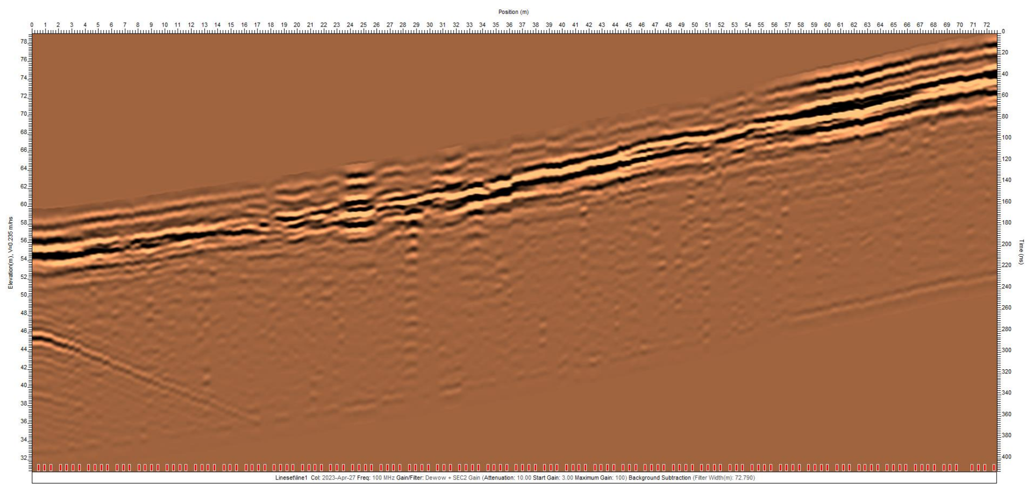


Figure 33: Test Line

B GPR Lines parallel to the slope without interpretation



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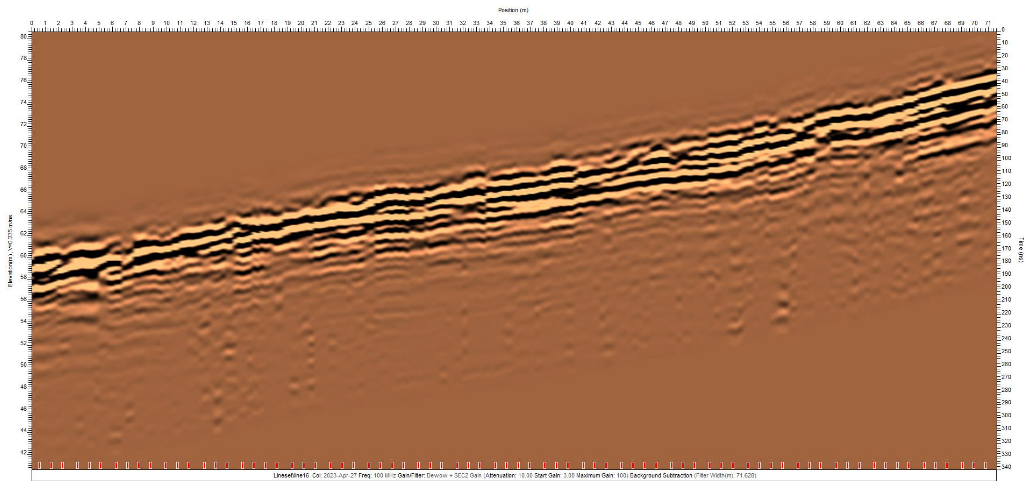

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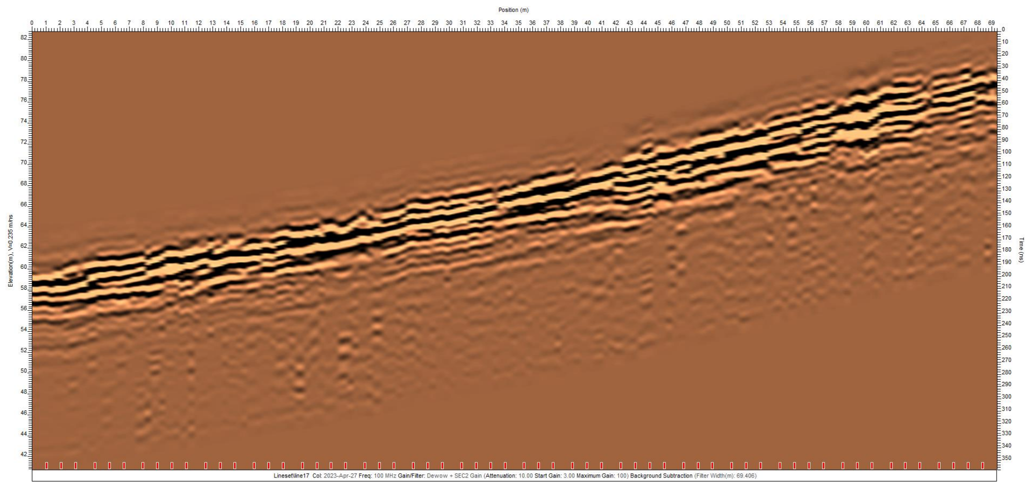

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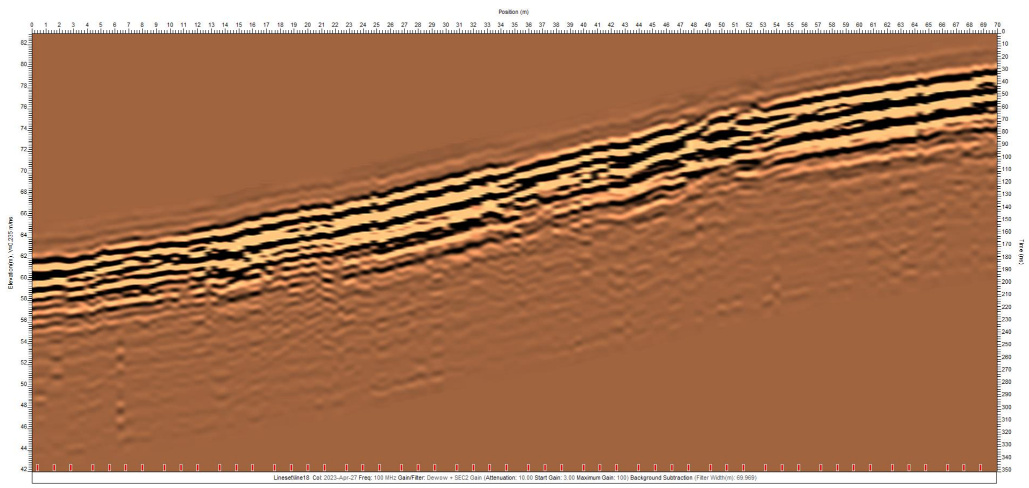

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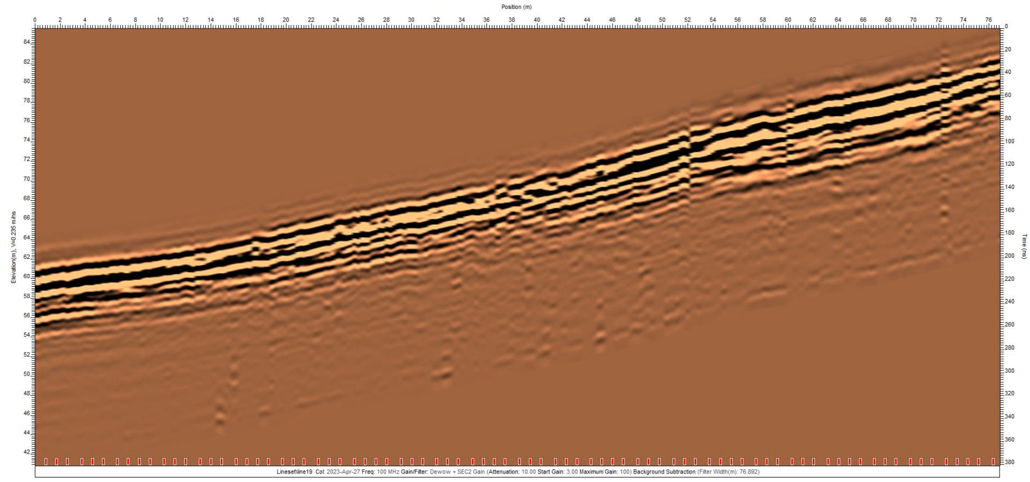

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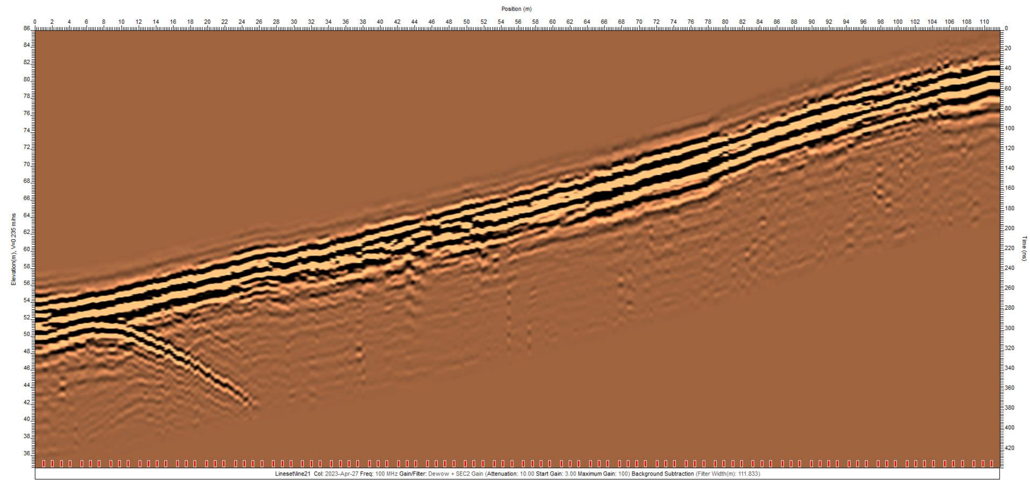

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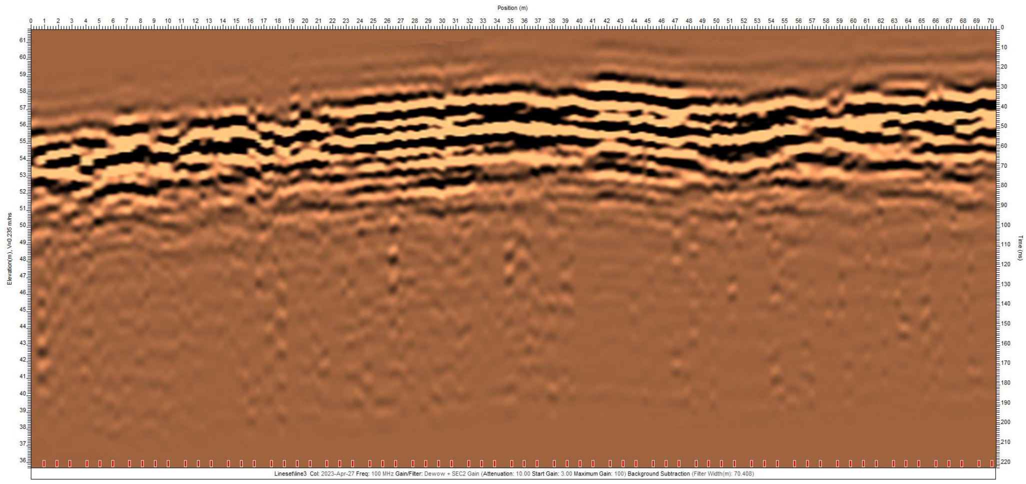

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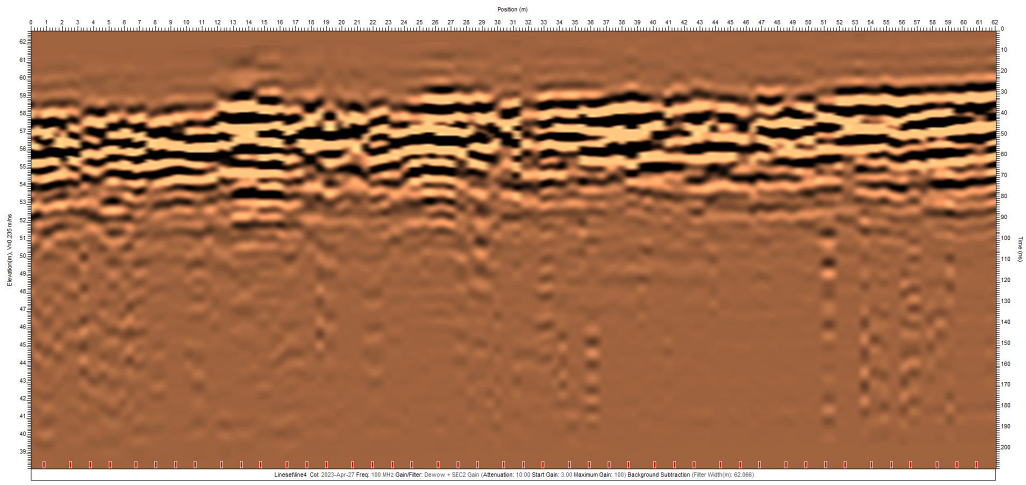

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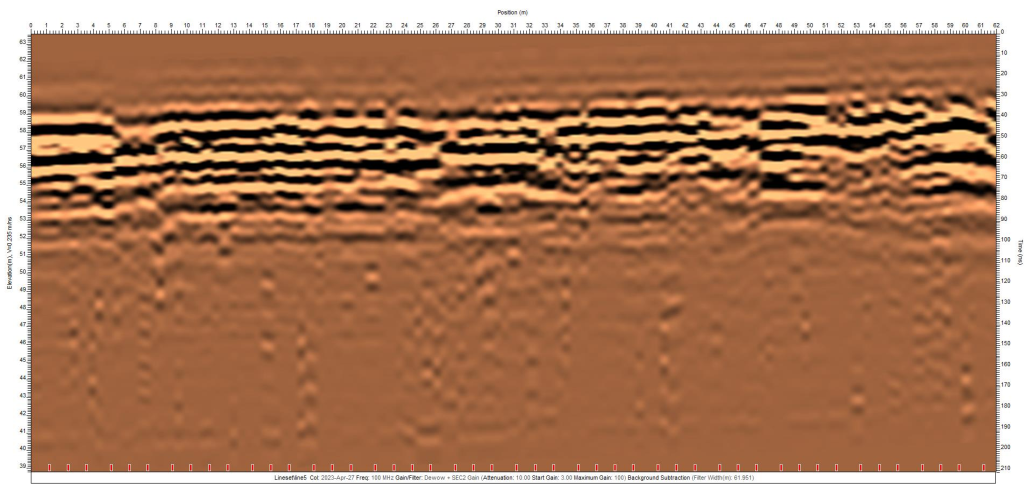

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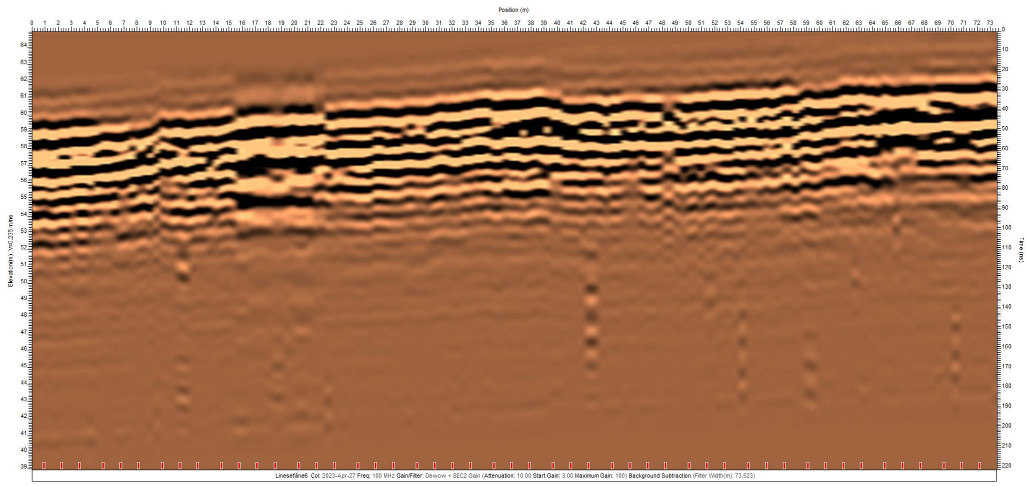

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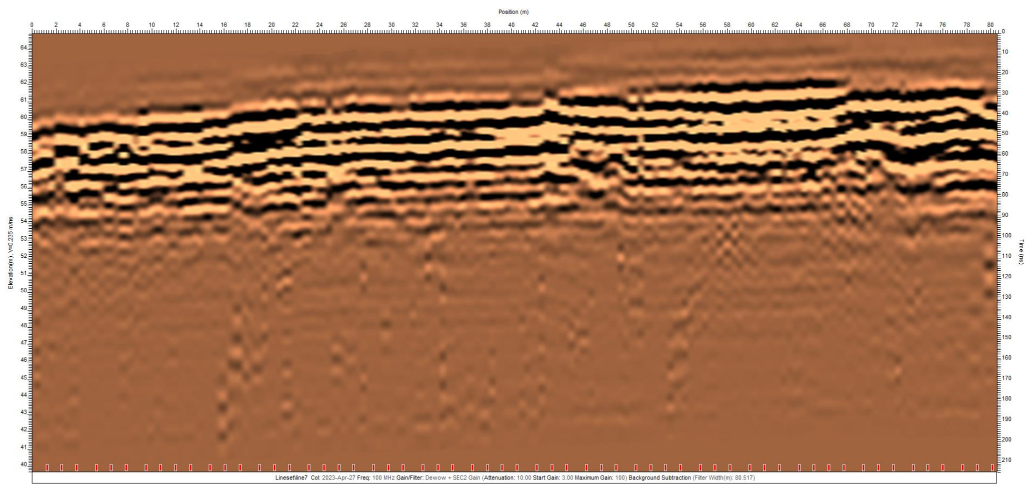

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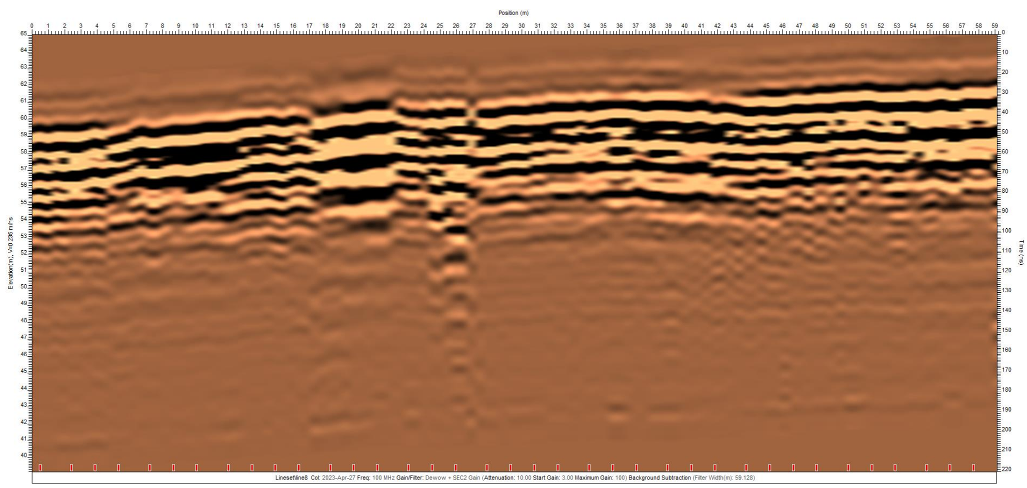

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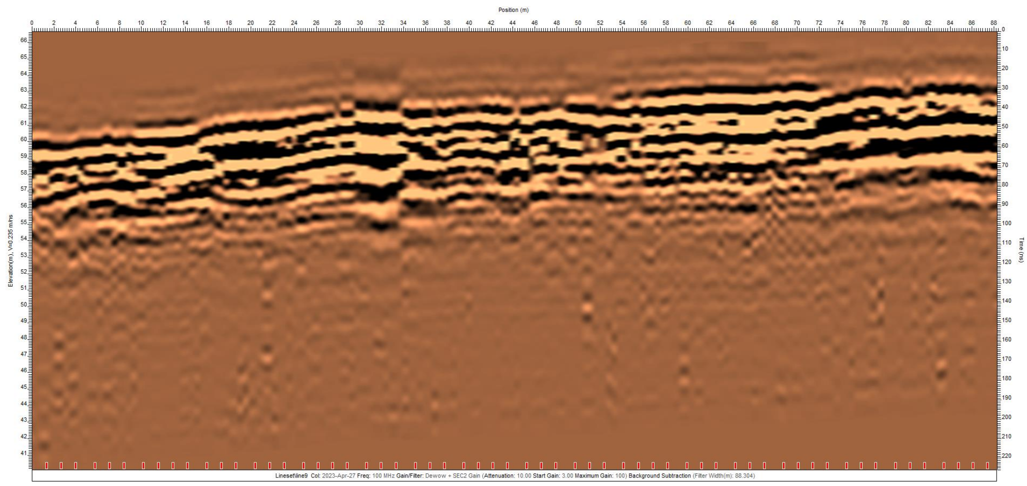

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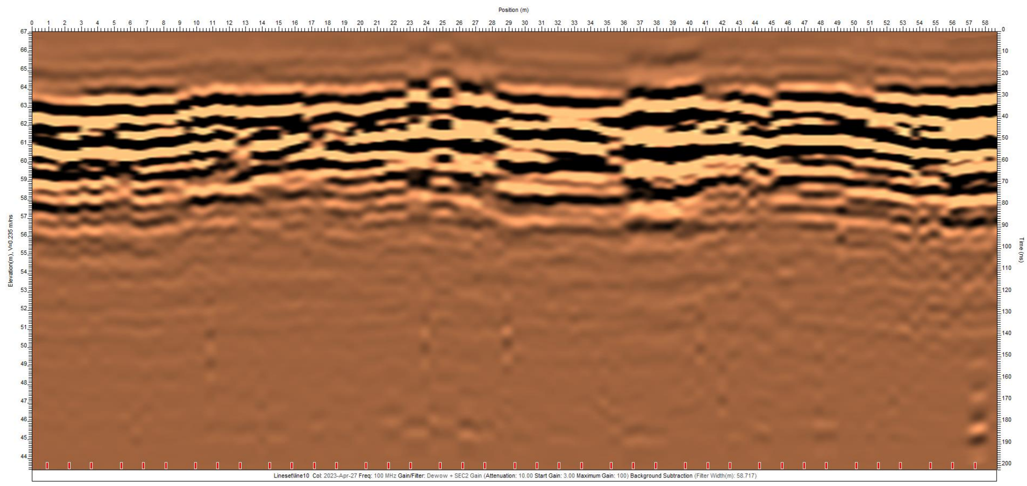

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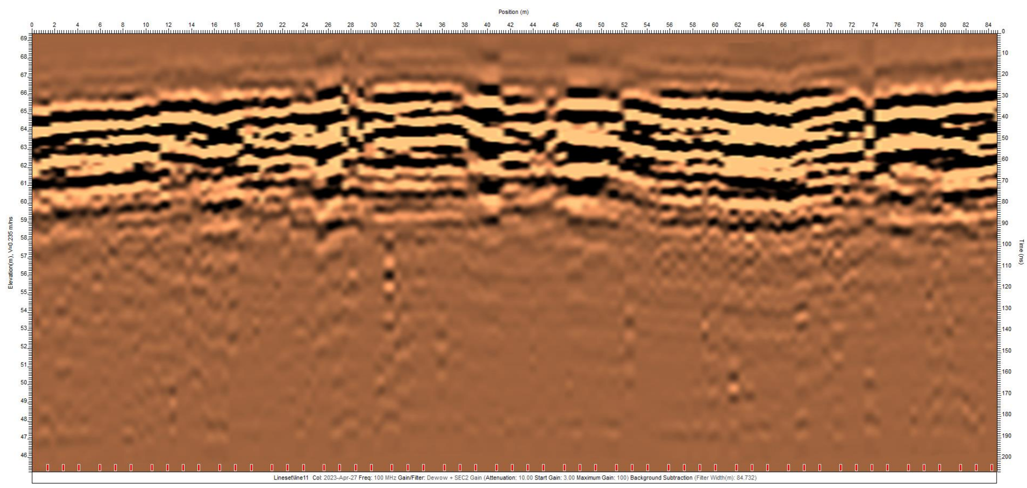

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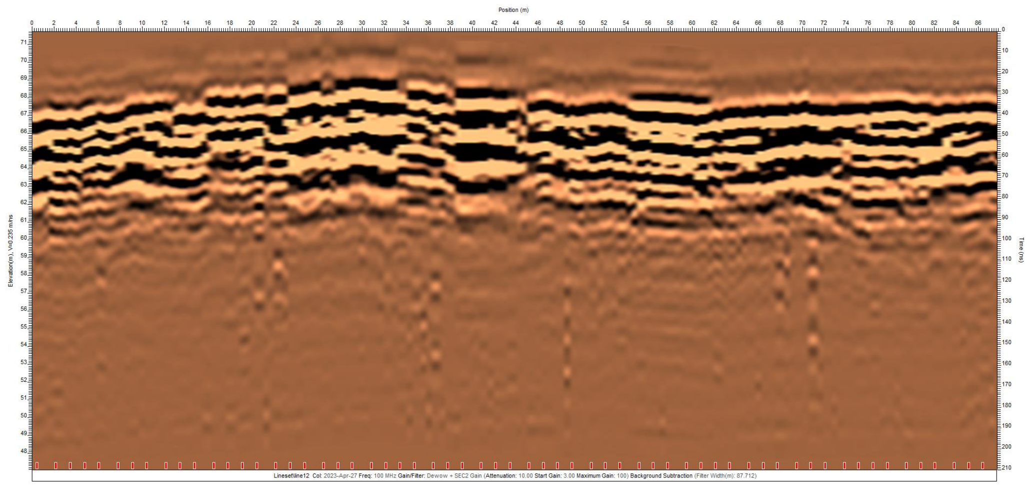

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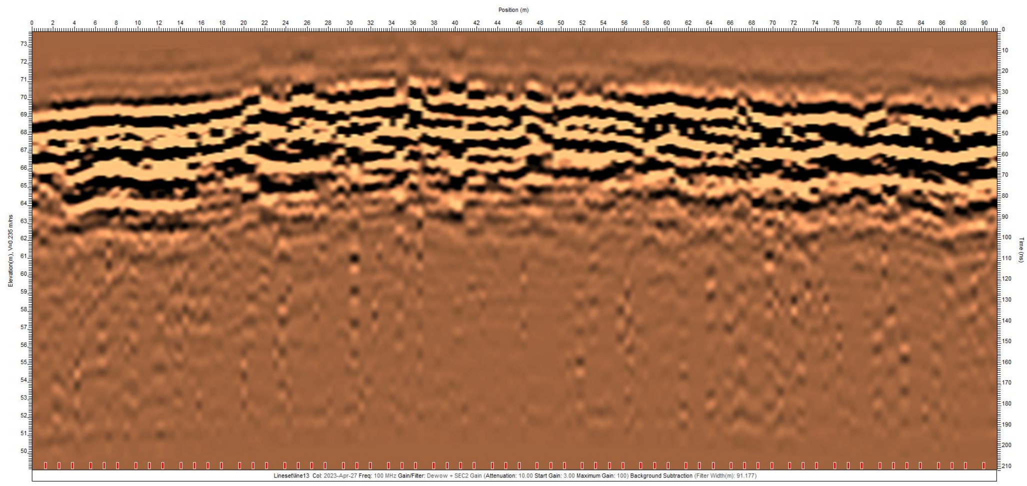

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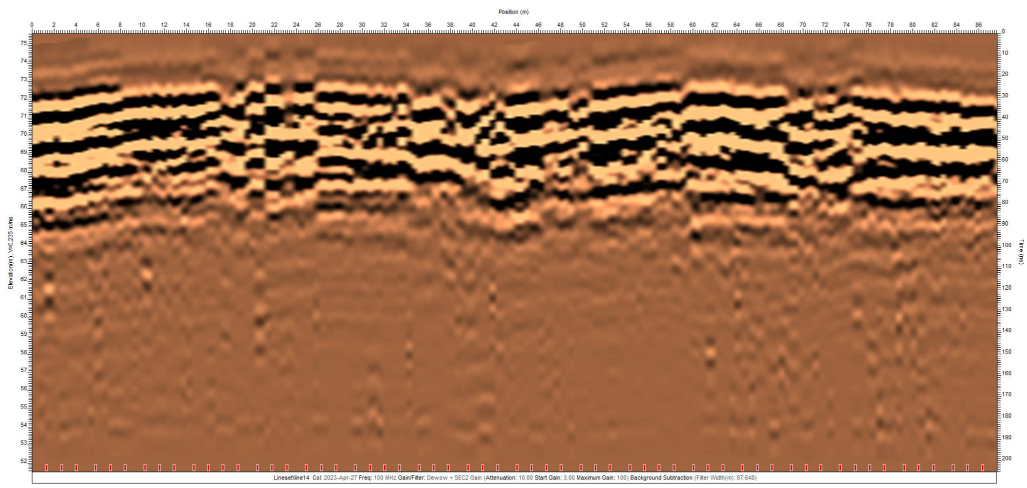

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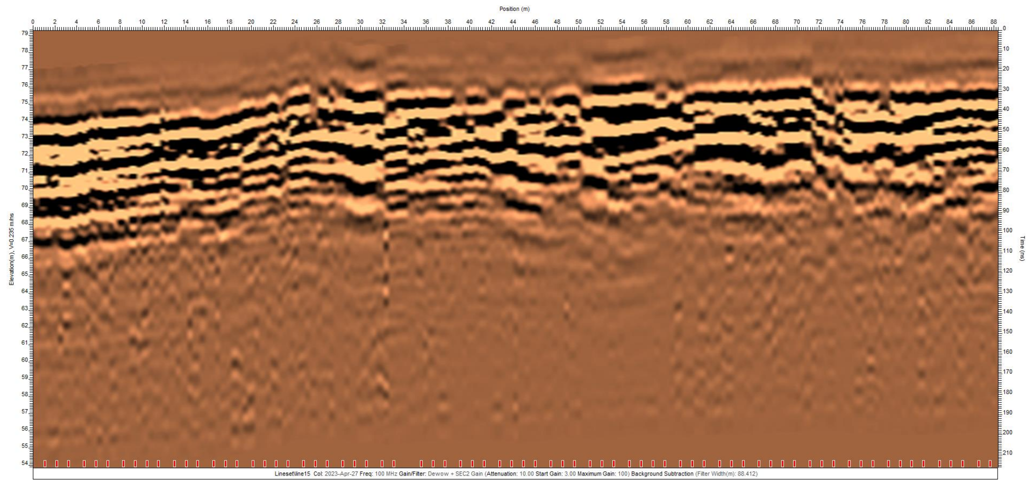

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