DANMARKS OG GRØNLANDS GEOLOGISKE UNDERSØGELSE RAPPORT 2011/133

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Jakobsen, P. R., Nielsen, A. M. & Møller, I.

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Dansk sammendrag

Det Geologiske kort over området og tilgængelige boringsoplysninger viser, at der langs den nuværende kyst ligger barriereøer, hvorpå der er aflejret klitter og flyvesandsdækker. Bag barriereøerne, ind mod det glaciale landskab, er der en tørlagt lagune med marine aflejringer. I lagunen består sedimenterne af skiftende lag af sand, gytjeholdigt sand og gytje, der er aflejret ovenpå moræneler. Ofte ses et lerlag lige over moræneleret. Boringsoplysninger viser at tykkelsen af de marine aflejringer er op til 2,5 til 3 m. Havniveauet nåede kote -3 m for ca. 6500 til 7000 år siden i dette område (Bennike & Jensen, 2011).

Gytjeholdigt sand, gytje og siltholdige lag svækker georadar signalet. I de centrale dele af lagunen kan man derfor ikke kortlægge selve morænefladen. Men lagunens geologiske opbygning kan erkendes ca. til 2 - 2,5 m under terræn.

Grundvandsspejlet er ikke observeret på georadar profilerne. Det skyldes antagelig at de kapilære kræfter i de finkornede sedimenter skaber en gradvis overgang mellem den mættede og umættede zone. Det kan også skyldes at grundvandsspejlet ligger så højt at det ikke kan skelnes fra overflade reflektoren.

På georadarprofilerne er der overordnet tre forskellige typer enheder. Den ene enhed har kraftige reflektorer og kraftig amplitude (stor sort-hvid kontrast). Den er tolket som sandlag. Den anden enhed har svage reflektorer og lille amplitude (grålig, strukturløs enhed). Den er tolket som lag af finkornet materiale, så som gytje, gytjeholdigt sand eller siltet sand. Den tredje type har ingen reflektorer og er tolket som moræneler.

Georadar undersøgelsen viser at lagunen er udviklet, og opbygget, i forskellige stadier, med skiftende sandede og gytjeholdige lag.

Den yngste, og højest beliggende, strandlinje følger 0 kurven. Den er markeret i terrænnet som en svag stigning på marken, hvor linjerne 39 og 40 er målt. Marken ind mod strandlinjen består af moræneler, muligvis med mindre lag eller lommer af sand. Beliggenheden af strandlinjen er vist på figur 15.

I den Nordlige del af det undersøgte område, ved georadar linjerne 1 til 7 og 29 til 38, kan man kortlægge kontakten til den underliggende moræneflade. Morænefladen dykker mod SØ ud mod lagunens midte. De marine lag lægger sig ind mod den hældende moræneflade, og der er således antagelig flere ældre strandlinjer fra forskellige stadier af havspejlsstigningen. Udbredelsen af den hældende moræneflade er vist på figur 15.

Nord for søen i rampeområdet, er der strukturer, der er tolket som en udbygning af sandbarrer, med overskyldsfaner. Toppen af barrerne ligger ca. i kote -1 m. Det kunne være en landværts udbygning af en ældre barriereø, eller udbygning af et ældre krumodde kompleks, således at man i dette område muligvis har en druknet overflade og ældre strandlinjer. Udbredelsen af fladen er vist på figur 15.

I det sydøstligste hjørne af rampeområdet er der klitter og flyvesandsdække r, der er aflejret oven på marine aflejringer. Kontakten mellem dem kan være svær at fastsætte, men det ser ud til at de marine aflejringer kommer op i kote 0 lige inden for diget, hvor de opbygger en barierreø, hvorpå klitterne så er opbygget.

Der er ikke observeret store objekter I de marine sedimenter. Der er dog to gruber i den druknede overflade nord for søen (Figur 13). De er meget kantede, og kunne tolkes som antropogene, men en sikker tolkning kan ikke gives på baggrund af georadar data.

Der blev målt en linje på søen i området. Det gav dog ikke noget resultat, da saltholdigheden i søen var så stor, at signalet blev dæmpet for meget.

Introduction

Objective

The objective with the Ground Penetrating Radar survey is to

- Map the thickness of the marine deposits
- Map the internal sedimentary structures of the marine deposits in order to determine the position of former coastlines
- Map possible anomalies, which could be of archaeological interest
- Map the ground water table if possible

Figure 1. Map showing the position of the investigation area.

Fieldwork

The fieldwork is carried out from the 31st of October to 2nd of November 2011. The first two days the lines 1 to 40 were measured and on the third day there was a test to see if it is possible to measure on the lake.

In the area SW of the lake it was not possible to measure any lines. The vegetation is high and dense and the terrain is appraised to bee a problem too – se photo in Appendix A1. This area has been a lake and swampy area until mid 20th century.

The Ground Penetrating Radar lines

The measured Ground Penetrating Radar lines are mostly placed perpendicular or in a high angle to the expected old coastline and considering the obstacles such as e.g. ditches and vegetation. The orientation is roughly SSW to NNE except the few lines perpendicular to these and goes roughly from WNW to ESE, Figure 2.

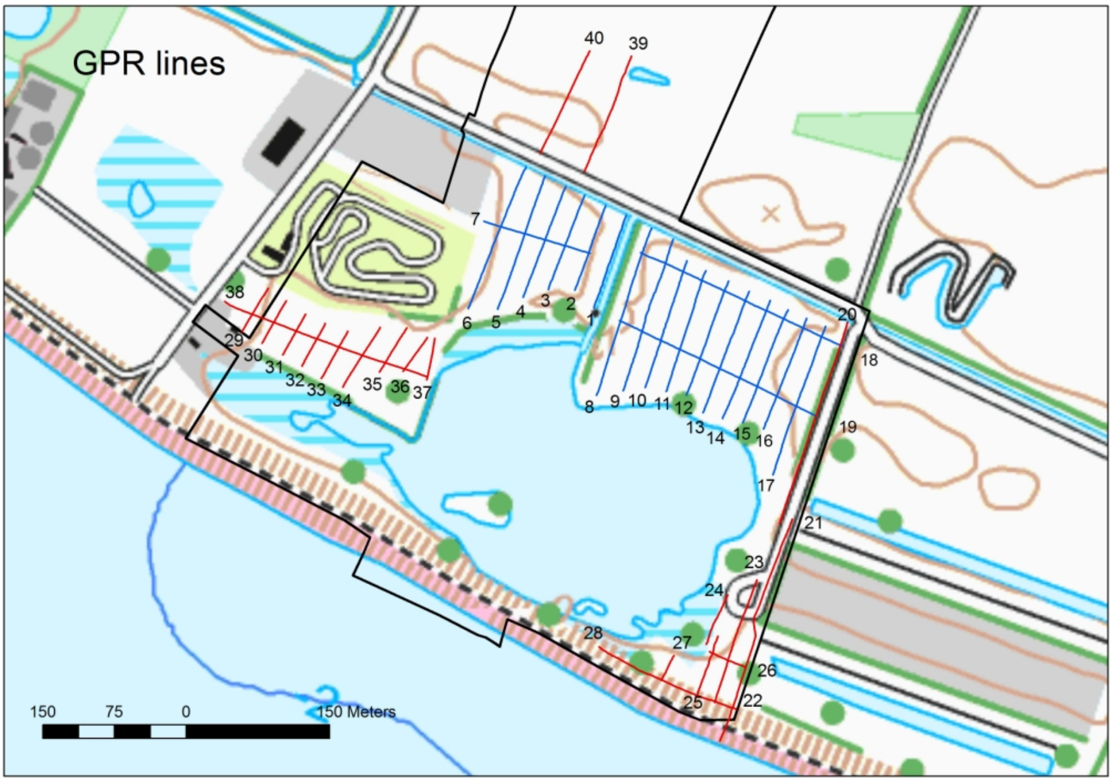

Figure 2. The investigation area where the blue and red lines are the measured GPR lines. The black line is the tunnel ramp area.

The test line at the lake within the ramp area did not bring any results.

Figure 3. The test line at the lake – orange line.

Methods

Ground Penetrating Radar (GPR)

The GPR method maps structures in the ground related to changes in dielectric properties. The GPR method operates by transmitting a very short electromagnetic pulse into the ground using an antenna. In this survey we have used a nominal centre frequency of 250 MHz. Abrupt changes in dielectric properties cause parts of the electromagnetic energy to be reflected back to the ground surface, where it is recorded and amplified by the receiving antenna. The recorded signal is registered as amplitude and polarity versus two-way travel time. The signal is processed and displayed as GPR sections. The vertical axis on the sections is two-way travel time in ns (=nanoseconds) and the horizontal axis is a distance axis along the measured line. The vertical axis can be converted to depth or elevation if the radar wave velocity in the penetrated material is determined. A detailed description of the GPR method can be found in e.g. Neal (2004).

The data acquisition

GPR data are acquired in step mode with a Sensors & Software pulseEKKO PRO system. The system is equipped with a 165 V transmitter and a transducer with a nominal centre frequency of 250 MHz. The nominal centre frequency of 250 MHz is chosen for the survey since experience show that this frequency is a good compromise between resolution and penetration for shallow investigation of the upper 5 m of the ground. The specific data acquisition parameters are listed in Table 1.

Table 1

Data acquisition parameter	**Reflection mode**
Nominal centre frequency	250 MHz
Transmitter voltage	165 V
Stepsize	0.05 m
Antennae separation	0.38 m
Time window	220 ns
Sample distance along trace	0.4 ns
Stacks	8

The GPR system is shown in Figure 4. The system use shielded antenna to avoid reflections from obstacles above ground surface e.g. trees and fences in the investigation area.

Figure 4: The left picture show the GPR acquisition system. The two yellow boxes are the transmitter and receiver transducers and the wheel behind is the odometer that measures the distance. The DGPS is placed between the GPR antennas. The right picture shows how it works. The GPR is pulled slowly and the operator can look at the data displayed on a screen during the data acquisition. The operator is also carrying the battery for the GPR system. The GPS measurement is managed of another person who is carrying a backpack with the antenna, cell phone and the computer all connected to the receiver.

Data editing and processing

Editing the GPR data includes that trace comments about bends on the lines, special terrain forms and road crossing are added. Some lines are reversed and repositioned, so all line distances increase from west towards east and from south towards north. The time axis for the GRP recordings is adjusted for all lines, so the time 0 ns is set to the start of the first pulse.

A standard processing is applied including a dewow reducing the inductive part of the signal, a low pass filtering reducing high frequency electromagnetic noise, a migration at constant velocity and a scaling of data by automatic gain control. The processing parameters are listed in Table 2.

Table 2

Processing procedure	**Processing parameter**
Dewow	
Lowpass filter	Cut of frequency 500 MHz
Migration (constant velocity)	Velocities of 0.08 m/ns, 0.09 m/ns or 0.10 m/ns
Gain	AGC, Gain_max=200, window length is 4 pulses
Topographic correction	At velocity of 0.10 m/ns

All sections are migrated with different velocities to obtain the best suited migration velocity for each section. For each section a migration velocity is chosen that make the most diffraction hyperbola collapse.

The velocities are evaluated through a simple matching of diffraction hyperbola in the GPR sections. The velocities vary both laterally and vertically along the profiles. Although there is a general trend showing decreasing velocities from 0.11 m/ns just below ground surface over 0.08 m/ns about 25 ns to about 0.06 m/ns in 40 ns. With an assumption of linear decrease in velocity in two steps from ground surface to 40 ns and constant velocity of 0.06 m/ns below 40 ns the average velocity of the interval 0 ns to 80 ns is 0.073 m/ns. This average velocity is used for the depth conversion of the GPR sections. The decrease in velocity is mainly controlled by the water saturation of the ground material.

The GPR sections are corrected for topography. The topographic shift is carried out with a velocity of 0.10 m/ns. The elevation information along the GPR sections is extracted from the GPS data.

DGPS

For positioning of the GPR survey Leica System 1200 DGPS was used. The antenna was placed between the GPR transmitter and receiver (Figure 2) and the GPS data were collected along with the GPR data, but stored separately. Subsequently the GPS and GPR data where merged in the processing procedure.

Data editing

The stored GPS data are converted before import in the GPR data. The time is recalculated to seconds after midnight and the line distance are calculated from the measured positions. Time stamps in GPS and GPR data are used for aligning the two data sets. From the GPS data the elevation information is extracted for the topographical correction of the GPR data.

Data presentation

Line lengths

The lengths of the lines from the GPR and from the GPS are not exactly the same. In Appendix A2 is a Table where the deviations are calculated and lay between 0.07 and 3.96 % with an average of 1.01 %. The highest deviations are in areas with relatively high and dense grass (see photos from the field site in Appendix A1) but all together the extents of the deviations are insignificant to the results.

GPR profiles

All GPR sections are shown in Appendix B. The horizontal scale of the sections is 1:400 and they are displayed with a vertical exaggeration of 4.

Results

Geological setting

The southern part of Lolland is very flat with a small topographic relief. It consist of a till plain which has a general dip towards south, and large areas in the southernmost part of Lolland are situated below sea level. The low lying areas have been reclaimed and they are covered with post glacial marine deposits.

The marine deposits are situated on the southwards dipping till plain. Although the landscape is overall flat, there is a system of elongated low hills that form a linear ESE-WNW trending pattern. Individual elongated hills can be traced for up to 40 km, and occur at intervals of 1-1.5 km from adjacent hills, and the hills rise only 3-6 m above the till plain.

The marine deposits east of Rødbyhavn consist of a series of barrier islands along the coastline with lagoonal deposits behind them (Klint & Rasmussen, 2004) (Figure 5). The barrier islands are covered with aeolian dunes. In a few places till deposits are seen in the coastal area indicating that in places there is a core of glacial deposits in the barrier islands. This could be because one of the elongated hills of the till plane is situated along the shore line and thereby facilitate the formation of the barrier island. The sediment transport along the coast in the Rødbyhavn area is from west to east and at Hyllekrog a spit-bar system is developing towards east.

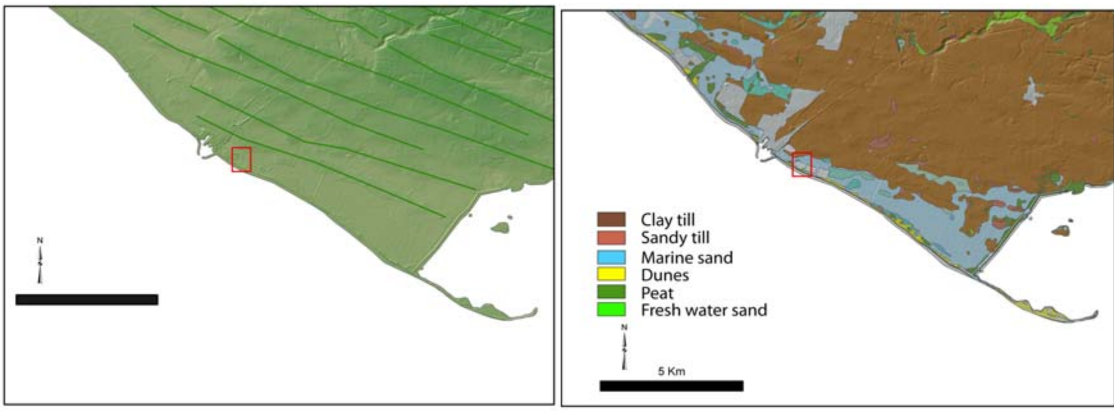

Figure 5. To the left a morphological map of South Lolland. The green lines show the mega lineations on the till plain. To the right a geological map of South Lolland. The investigated area is indicated with a red rectangle.

In the ramp area dunes are situated along the coastal dike (Figure 6). Clay till constitutes the surface in the northern part of the ramp area. Marine deposits make up the area from the clay till to the coastal dunes.

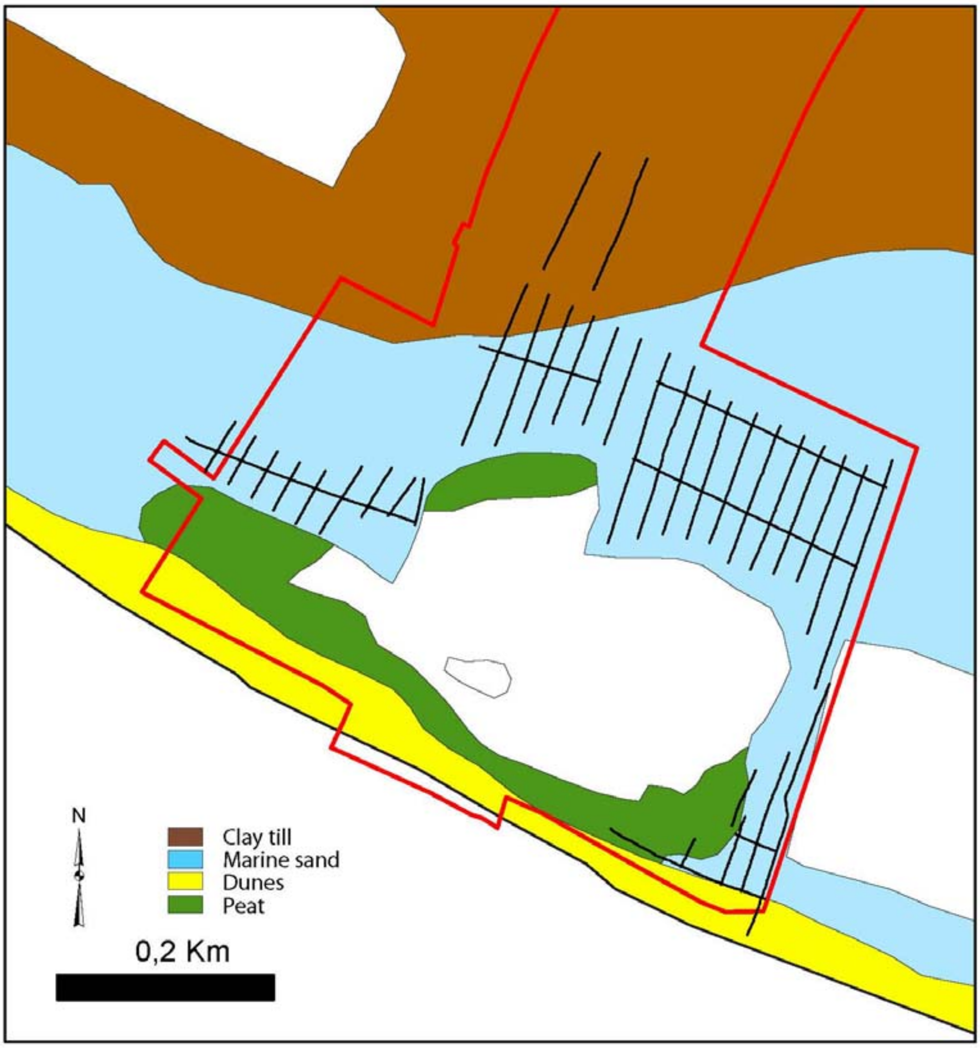

Figure 6. Close up of the geological map, with the position of GPR survey lines.

The marine sequence is described in numerous borehole logs from geotechnical borings in adjacent areas. The position and descriptions of the borings are available from the Jupiter database which is accessible from the GEUS web-page (www.geus.dk). They generally show marine sand, sandy gyttja, gyttja bearing sand and gyttja layers deposited on top of the underlying till. Often, there is a marine clay layer on top of the till.

The time of transgression above level -3 m in this area is about 6500 to 7000 years ago (Bennike & Jensen, 2011). In an excavation at the nearby waste water treatment plant, a profile through the marine sediments are described (K.E.S. Klint pers. comm.). Here the marine succession is 2.2 m thick, and rests on a clay till (Figure 7). The marine sediments are alternating layers of sand and gyttja layers.

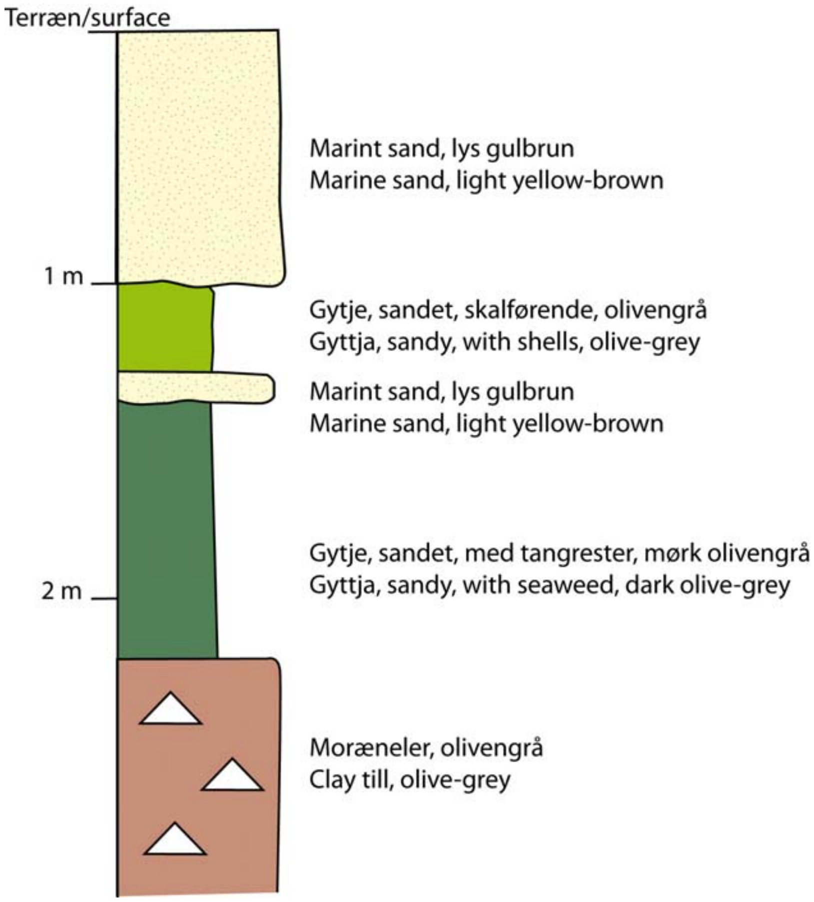

Figure 7. Sedimentological log of an excavation at the waste water treatment plant, just west of the investigated area

Interpretation of GPR data

The groundwater table has not been detected in this investigation. Probably because the capillary forces in the relatively fine grained deposits creates a gradual interface between the saturated and unsaturated zone. Another reason could be that the ground water table is to close to the surface.

Georadar facies

The radar profiles are differentiated into radar facies with distinct reflection characteristics such as reflection strength, amplitude and contrast. The georadar profiles have been subdivided into three georadar facies. The three georadar facies have been interpreted from there reflection pattern (Figure 8), and the knowledge of the lithology from borings and the excavation shown in Figure 7.

Georadar facies 1 has strong reflection strength, large amplitude contrast. The reflectors can generally be followed for tens of meters. Georadar facies 1 is interpreted as being sand layers, as sand usually gives good and strong reflections.

Georadar facies 2 is characterised by weak reflection strength and low amplitude contrast. The low reflection strength in Georadar facies 2 is believed to be caused by the presence of silt or gyttja. Georadar facies 2 is interpreted as being layers with fine grained materials, such as silty sand, gyttja rich sand or sand rich gyttja.

Georadar facies 3 has no reflectors and the top of this unit emerges at the surface, where clay till is present on the geological map, and it is interpreted as being clay till.

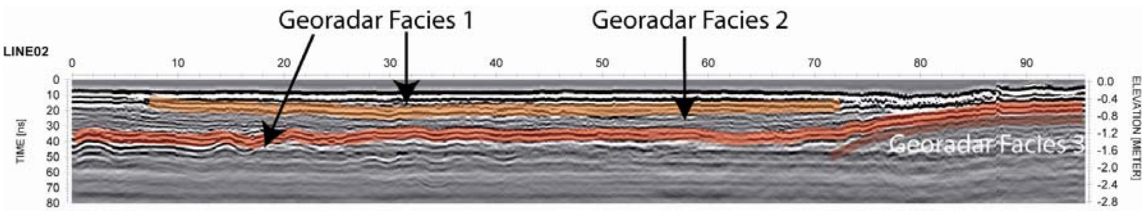

Figure 8. Examples of the three georadar facies.

Georadar profiles 1 to 7.

The profiles 1 to 7 are measured in the northernpart of the area of investigation. The geological map shows that the lines 4, 5 and 6 should have clay till at the surface, or at least close to the surface, in the northern part of the profiles (Figure 6). This is in good agreement with the presence of georadar facies 3 at the surface in the northern part of lines 4, 5 and 6, with only a thin or no sand layer on top.

The clay till surface is diving towards SE, towards the centre of the lagoon (Figure 8 and Appendix B). The marine sediments are on-lapping onto the inclined clay till surface. There are therefore several older shorelines on this declining surface, belonging to different stages of the rising sea level. The area distribution of the declining surface is shown on figure 15.

Georadar profiles 39 and 40

These two lines are measured in the field just north of the lines 1 to 7. The highest shoreline is indicated by the gentle topographic rise at the northern end of the lines (Figure 9). There is no or hardly any penetration (georadar facies 3), which is in good agreement with the geological map, which shows clayey till (figure 6). There are though indications of small pockets of sand on the clayey till.

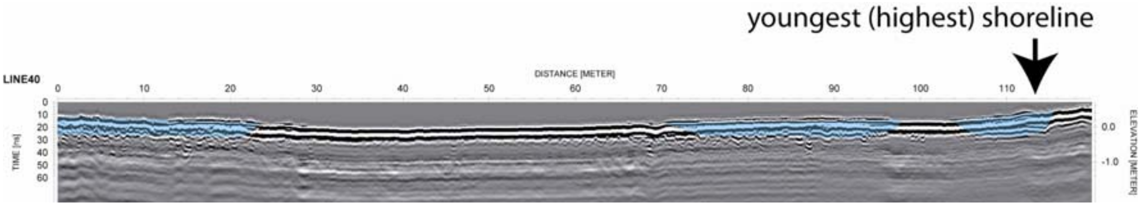

Figure 9. Line 40 with no penetration except for some thin sandy layers on top of the clay till, marked with blue.

Georadar profiles 29 to 38

The georadar profiles are measured in the western part of the ramp area, north of an excavated area and south of the go-kart track. In these georadar profiles georadar facies 1, 2 and 3 are recognised. On Line 29 there is no signal from 26 m to 49 m (Figure 9). On the orthophoto in Figure 3 it is noticeable that material has been removed or placed in this area, and the lack of signal is interpreted as an area covered with clayey filling.

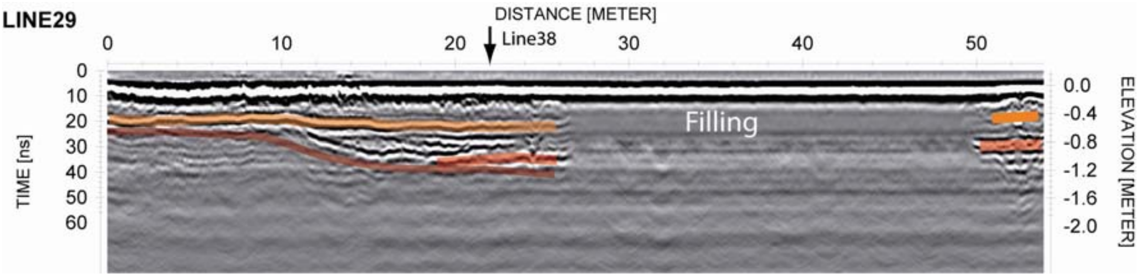

Figure 10. Filling at the surface, resulting in loss of signal in part of line 29.

In the start on profile 38 and on profiles 29 and 30 there is only a shallow penetration depth (Figures 10 and 11). This is interpreted as a clay till surface, with georadar facies 3 (no reflections) below the till surface. This corresponds well with the depth to the clay till surface in borehole 240.415, situated about 70 m North-West of the start of profile 38. The clay till surface is situated about 1 m below surface and declining towards East. Along this declining surface earlier shorelines must have been present during sea level rise up to about level – 1m. This surface continues probably underneath the go-kart track to the similar declining till surface in the area where georadar profiles 1 to 7 was measured (Figure 15).

On line 37 and the eastern part of line 38, a distinct unit of georadar facies 1 is seen at approximately the same depth as on the southern part of line 6. This is probably the same unit, and the same red marker line has been assigned on lines 29 to 38.

Above the red marker, there is a unit which generally is characterised as georader facies 2, but stronger reflections occur and cross-bedding indicating northerly and easterly or northeasterly sediment transport (Appendix B). The uppermost part of the profiles is a unit of georadar facies 1.

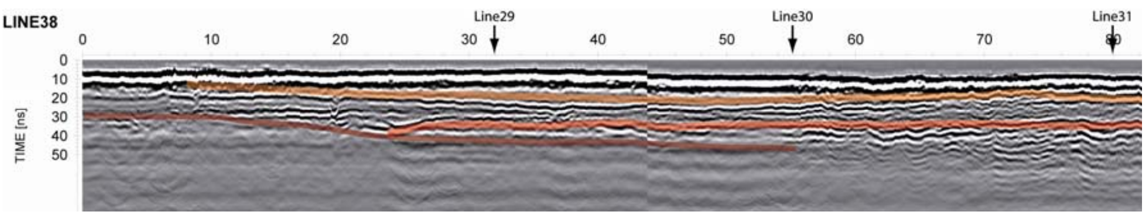

Figure 11. The declining till surface is indicated with the brown marker line

Georadar profiles 8 to 20

In the georadar profiles 8 to 20, georadar facies 1 and 2 are observed. The northern part of the profiles, show the general structure of the lagoon. It is build up with alternating units of georadar facies 1 and 2, with concave reflections (Figure 12 and Appendix B). They represent different stages with shifting sedimentary environments during the development of the lagoon, and the central part of the lagoon is at the Northern end of the profiles (Appendix B).

North of the lake in the ramp area, there are internal structures within a sandy unit (georadar facies 1). The structures are interpreted as large scale foresets, with a northerly inclination (georadar profiles 8 to 17 and 19). Furthermore they are interpreted as wash over fans, and the unit is interpreted as a prograding system of wash over fans. The top of this unit represents probably an old surface at a depth of about 30 ns, which roughly correspond to about level -1 m. This unit could be an extensional growth of an older barrier island, or the prograding of a spit system. The areal distribution of this unit is shown on Figure 15.

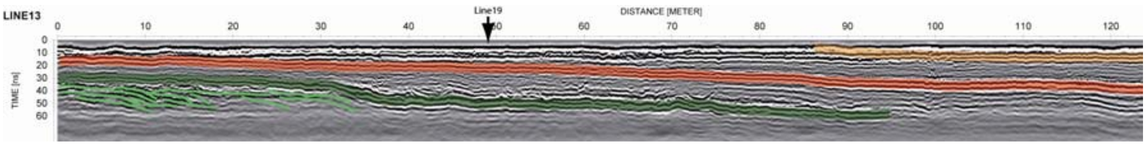

Figure 12. Part of line 13. The red and orange lines outline two georadar facies 1 units, which outline the general structure of the lagoon. Georadar facies 2 units are seen in between. The thick green line outlines the top of the unit with large scale foreset, which are outlined with the pale green lines.

No larger objects within the marine sediments are observed. However, there are two hollows on top of the sand unit with wash over fans (Figure 13). They have quite angular outlining, and they might be interpreted as being of anthropogenic origin, rather than of natural origin, but it is not possible to evaluate this positively from the georadar data.

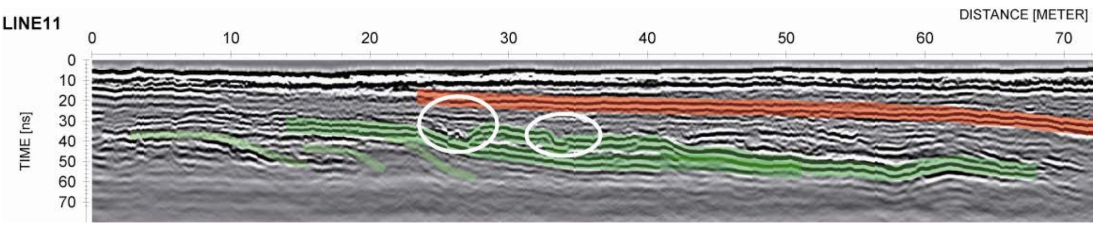

Figure 13. The dark green line outlines the top of a sand unit, with internal large scale foreset (light green lines), interpreted as wash over fans. On top of the sand unit two hollows are seen. They could have a natural origin, but they might also be interpreted as having an anthropogenic origin.

Georadar profiles 21 to 28

The profiles 21 to 28, in the South-Eastern part of the ramp area, differ to some degree from the other areas, as dunes and cover-sand are deposited on top of the marine sediments. Some of the lines also pass through areas, which presumably has been excavated. It is difficult to extrapolate the marker lines from the other areas. In Figure 14 an attempt has been made to differentiate dunes from marine sediment, but it is very difficult to distinguish positively, without borehole information to compare with.

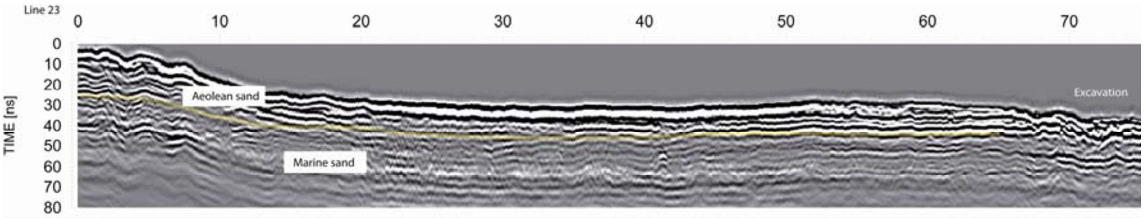

Figure 14. Part of line 23. The yellow line is the interpreted surface between dunes and marine sand. However the marine sand units is building up under the dunes, indicating the presence of a barrier at this position.

Conclusion

The youngest shoreline towards North is marked with the blue line on Figure 15. From this shoreline there is a 100 m broad stretch of clay till, where no marine deposits are found. In the area where lines 1 to 7 are measured, the clay till surface declines, and marine sandy sediments are deposited upon it (red shade on Figure 15). A similar, and probably the same declining till surface, is interpreted South-West of the gokart track, although at a lower level. It might be the same declining till surface which probably continues under the gokart track.

On the north side of the coastal dike dunes are deposited. Aeolian sand deposited upon marine sand is interpreted in the South-Eastern part of the investigated area (yellow shade on Figure 15. In thrs area there is a core of a barrier or spit, covered with dunes.

Just north of the lake within the ramp area, a series of wash over fans is interpreted (green shade on Figure 15). The top of this unit could be an old surface at about level -1. Younger marine deposits are deposited upon this unit subsequently.

The deepest part of the lagoon is marked with the blue shade on Figure 15. Here reflectors can be followed over long distances. The are concave and outline events that affected the whole lagoon, and the outline the general build up of the lagoon.

The penertration depth was not sufficient to map the thickness of the marine deposits in the central part of the lagoon, probably because high ground water level, gyttja and silt weakened the radar signal.

No larger objects within the marine sediments are observed. However, there are two hollows on top of the sand unit with wash over fans (Figure 13). They have quite angular outlining, and they might be interpreted as being of anthropogenic origin, rather than of natural origin, but it is not possible to evaluate this positively from the georadar data.

The ground water table was not recognised on the georadar profiles. Probably because the capillary forces in the relatively fine grained deposits creates a gradual interface between the saturated and unsaturated zone. Another reason could be that the ground water table is to close to the surface.

The salinity in the lake was to high to perform GPR measurements on the lake.

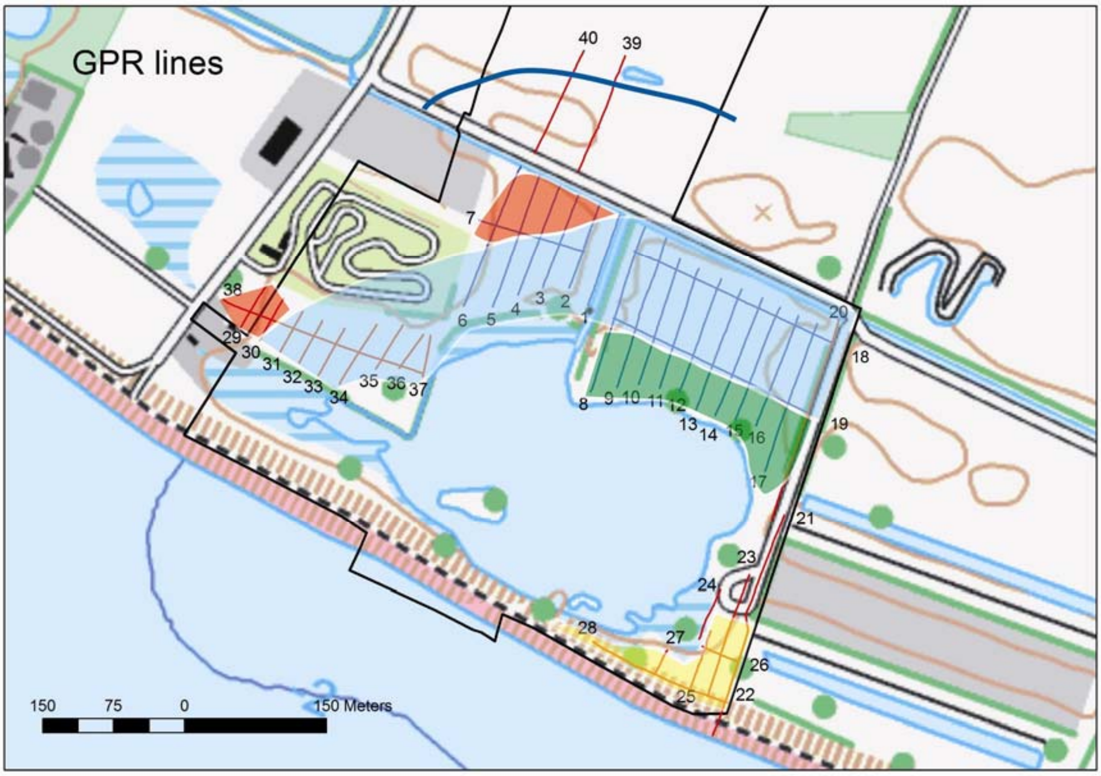

Figure 15. Conclusions from the interpretation of the GPR survey. The red shade shows the outline of the declining till surfaces. They are probably connected underneath the go-kart track. There are probably several older shorelines on this declining surface, belonging to different stages of the rising sea level since about 6500 to 7000 years ago. The green shade shows the outline of the sand unit with wash over fan structures, representing an old surface at about level -1m. The yellow shade shows the outline of dunes and cover sand on top of a barrier island or spit. The blue shade shows the outline of the lagoon basin. The blue line shows the youngest and highest shore line.

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Appendix

Appendix A

A1 Photos from the field site.

The field area seen from the start at line 1 and looking towards west.

The field area seen from the first bend at line 21 towards SW.

Direction as the photo above but with zoom.

The field area seen from the top of the dike (line 22) looking towards NW.

The field area seen from the top of the dike (line 22) looking towards N.

The area not measured seen from the top of the dike looking towards NW.

A2 Table showing the difference between the lengths of the lines measured with the GPR and the DGPS, se page 8.

Line	GPS length	GPR length	Deviation – % GPS from GRS	Comment to the deviation
1	103,5	105,15	1,57	
2	94,67	95,5	0,87	Dyb rende i den ene ende af linien
3	106,02	107,35	1,24	Dyb rende i den ene ende af linien
4	124,54	126,25	1,35	Dyb rende i den ene ende af linien
5	148,55	150,4	1,23	Dyb rende i den ene ende af linien
6	160,68	162,65	1,21	Dyb rende i den ene ende af linien samt højt græs hvor georadaren vipper lidt
7	116,54	118	1,24	
8	184,73	184,55	-0,10	
9	168,32	169,05	0,43	Sidste halvdel af linien er ujævn og har furer på langs
10	140,02	140,55	0,38	
11	133,4	134,2	0,60	
12	127,93	128,6	0,52	
13	136,36	137,55	0,87	
14	133,57	134,55	0,73	
15	127,97	128,75	0,61	
16	124,67	125,25	0,46	
17	165,52	167,5	1,18	
18	233,95	234,3	0,15	
19	230,07	232,05	0,85	
20	222,96	222,05	-0,41	
21	192,12	192,75	0,33	
22	55,01	55,05	0,07	Diget har jævne hældninger men i starten af linien er terræ-net ujævnt
23	136,42	139	1,86	
24	56,59	57,65	1,84	Højt græs og ujævnheder langs hele linien, georadaren hælder lidt mod vest på dele af strækningen
25	67,2	68,55	1,97	Højt græs og ujævnheder langs hele linien, georadaren hælder lidt mod vest på dele af strækningen
26	40,74	42	3,00	Ujævnheder på de sidste meter af linien
27	29,34	30,55	3,96	Ujævnt terræn og højt græs
28	158,58	159,7	0,70	Noget af linien på toppen af små klitter og på dele af stræk-ningen har georadaren hældt mod nord
29	53,33	53,85	0,97	
30	51,35	52	1,25	
31	48,8	49,55	1,51	
32	50,66	51,25	1,15	
33	56,64	57	0,63	
34	73,67	74,35	0,91	
35	54,34	55,45	2,00	
36	43,45	44	1,25	
37	44,33	44,9	1,27	
38	226,9	228,85	0,85	
39	132,2	131,6	-0,46	
40	119,61	119,85	0,20	

Appendix B

Appendix B1: GPR-lines 1 to 7 and 29 to 40 (inserted at the back)

Appendix B2: GPR-lines 8 to 28 (inserted at the back)

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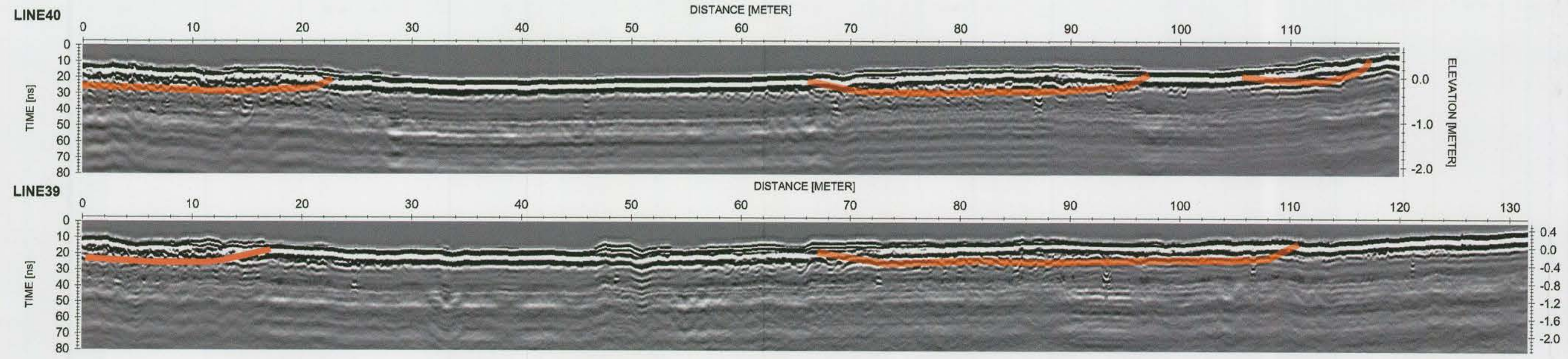
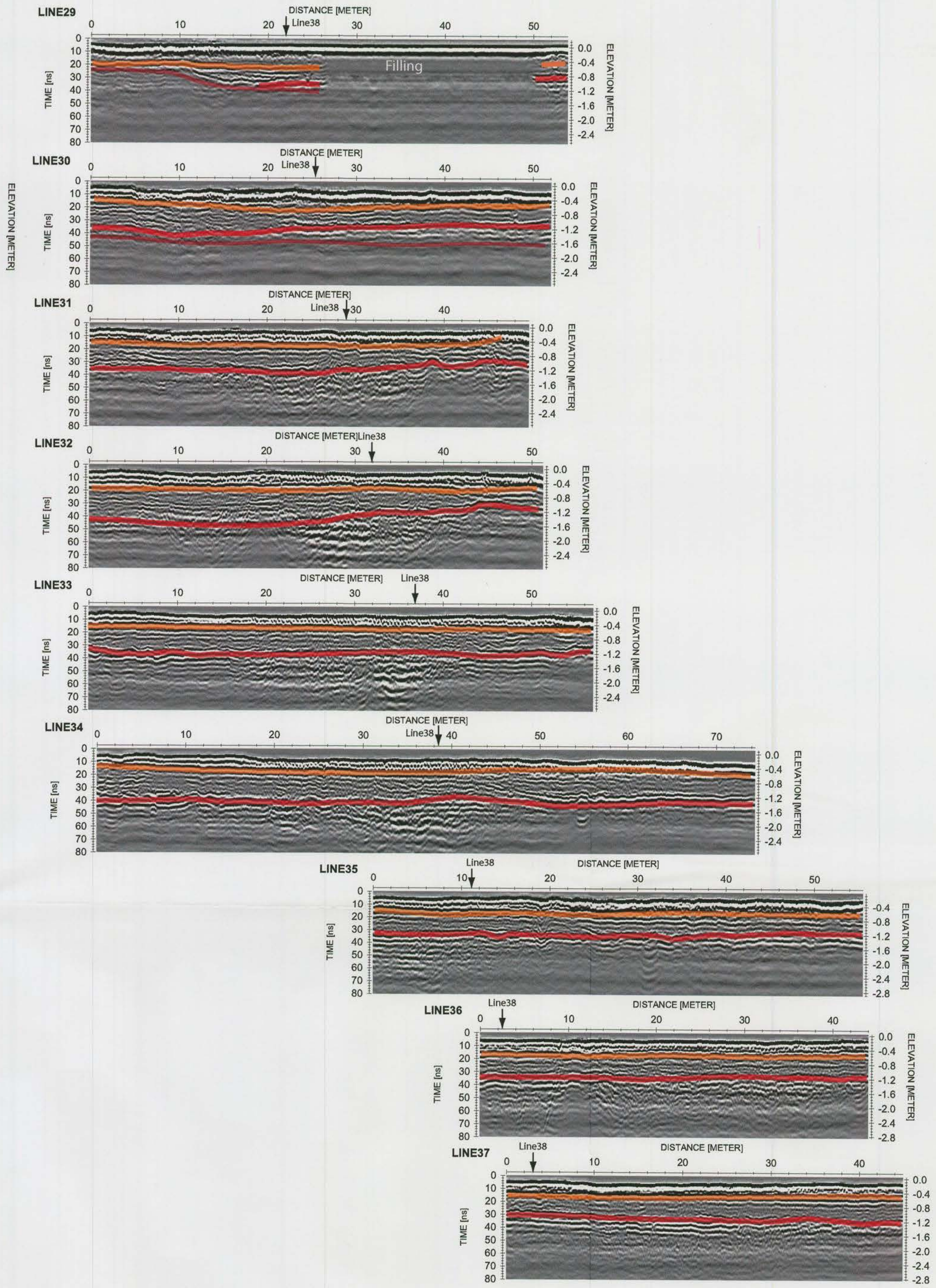
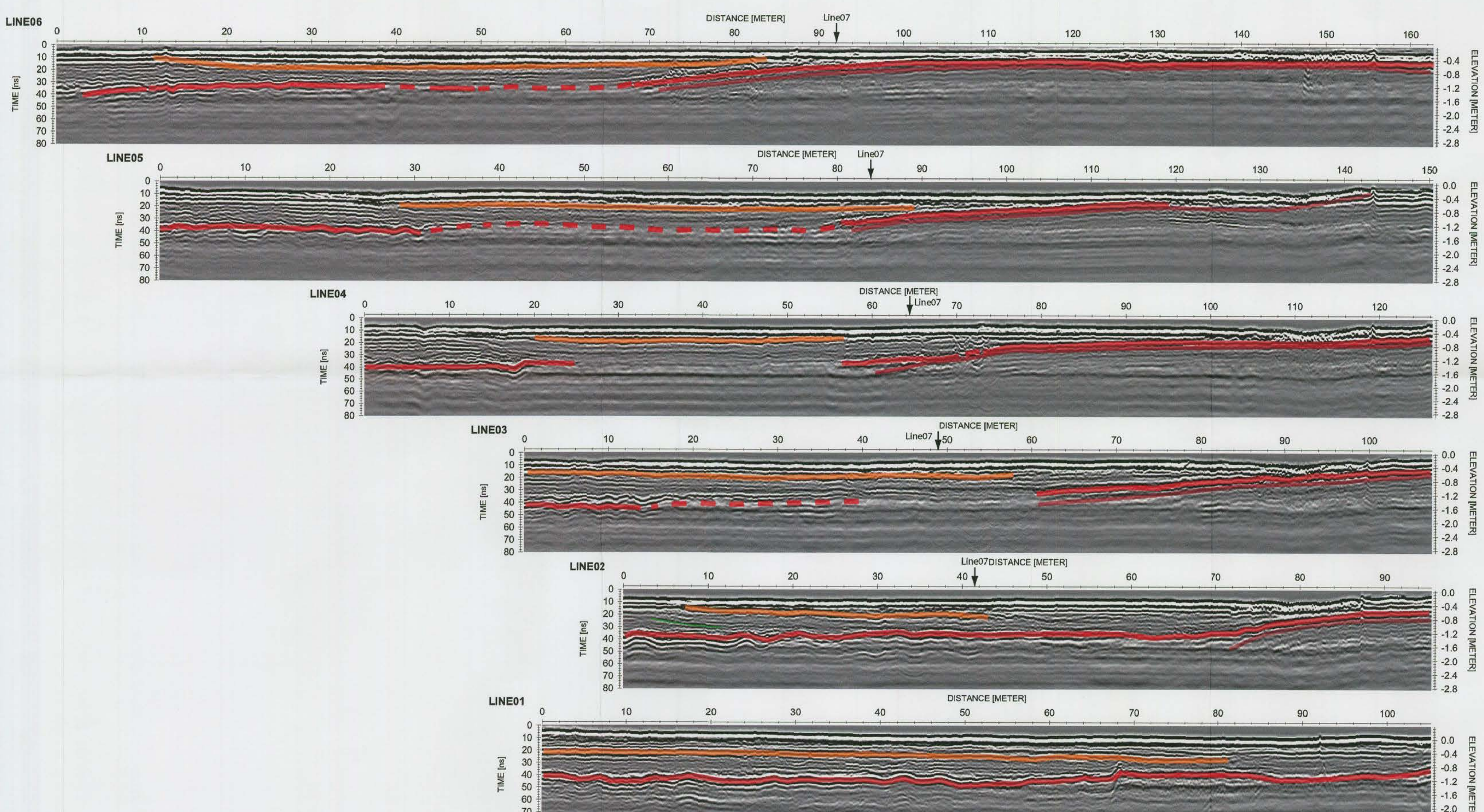
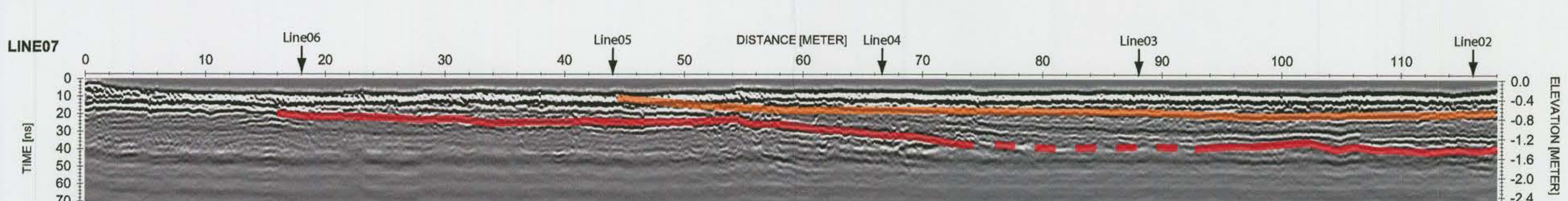
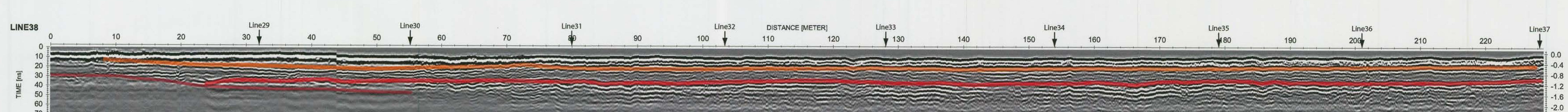
Appendix B1











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Report file no.
Enclosure
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Appendix B2