Mapping and interpretation of Holocene lake infill deposits

Strynevatnet, Norway

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Introduction

As part of my Bachelor Applied Earth Sciences a final research project was done, about the Holocene infill deposits in Strynevatnet, Norway. Strynevatnet is an isolated lake that used to be part of Nordfjord. About 8150y BP a huge tsunami, caused by the Storegga landslide, stirred up sediments in the shallow part of the lake and deposited in the deeper part. (Vasskog et al, 2013) This deposit is well preserved and therefore a good time marker. I will focus on the sediment on top of the Storegga deposit.

The TU Delft has collected geophysical data of Strynevatnet in 2010. To collect the data a Parametric Echosounder has been applied. The aim of the research was to map the floor sediments and reconstruct the influx of sediment during the Holocene. Sediments that accumulate in Strynevatnet come from several catchments of which Erdalen is the biggest one (Hansen et al, 2009). Beside this it is the only one that nowadays is glaciated by the Jostedalsbreen ice field. The Norwegian Geological Survey monitored the sediment supply of Erdalen over the past years.

The objective of this research is to create a palao sediment influx curve based in stratigraphic mapping using the geophysical data. The overall goal will be to compare the palaeo influx curve to published data on Holoceen ice sheet dynamics of the Jostedalsbreen ice sheet.

I have investigated the geophysical data by identifying the top of the Storegga deposit. With this information it was possible to determine the volume of the sediments deposited after 8150y BP. Earlier work by Vasskog (2013) showed that deposition rate of post Storegga sediments in the most distal and shallow part of the lake was constant in time. I will extrapolate this observation to use as an age control on the more proximal sediment that are mapped in this study.

Setting

The studied lake, called Strynevatnet, is situated upstream of Nordfjord, one of the biggest fjords in western Norway (figure 1). The lake has a depth of 210m and an area of about 30km^2. Strynevatnet is the outer basin in a lake system. The inner basin, Nerfloen, is a lot smaller and less deep with an area of only one square kilometer and a depth of 20m (Vasskog et al, 2012).

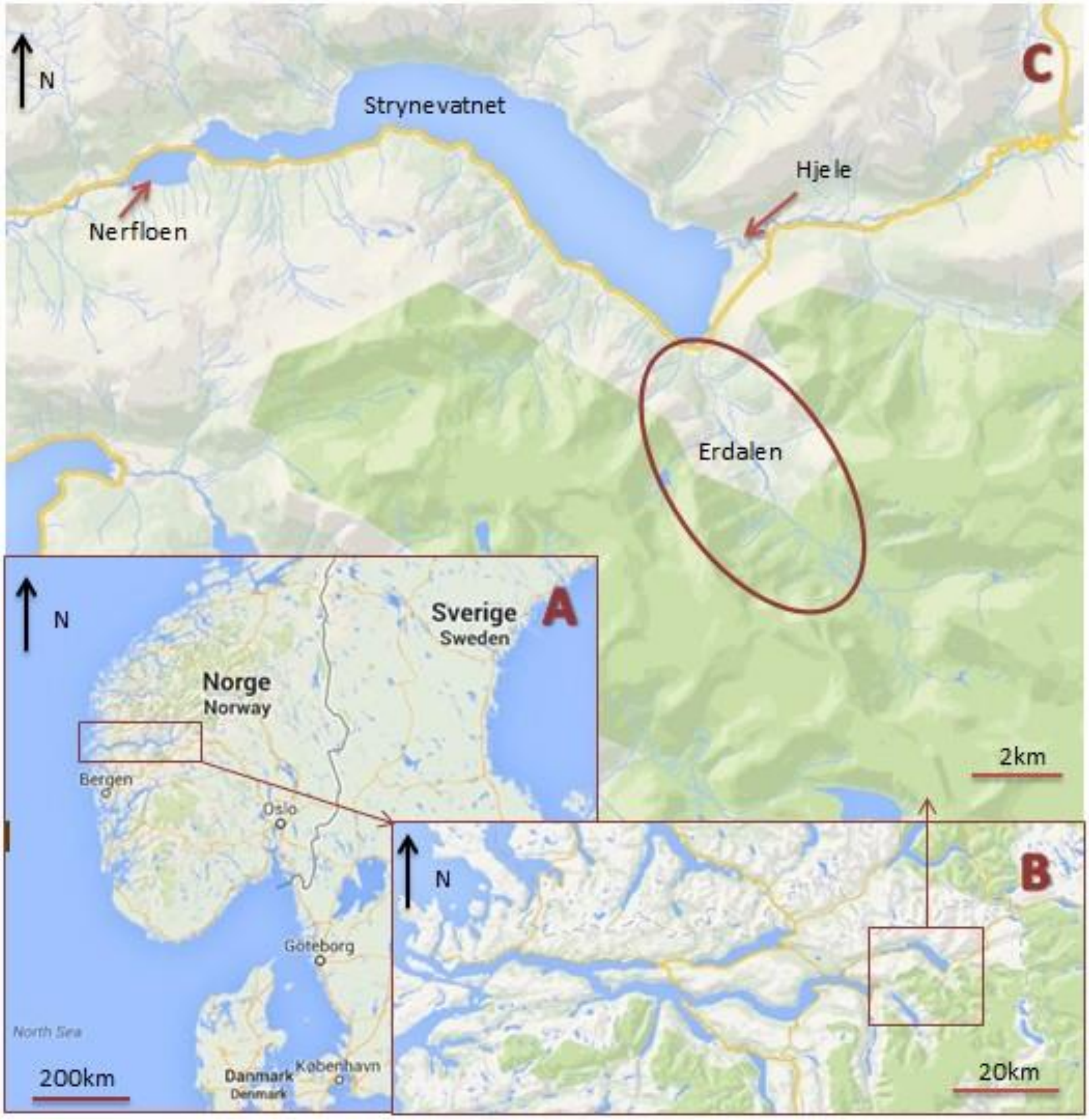

Figure 1: The location of Strynevatnet. 1A gives the location of Nordfjord, 1B the location of Strynevatnet at the head of Nordfjord and 1C the locations of Erdalen and Nerfloen. (Google maps)

About 11.000 years ago the Scandinavian Ice Sheet withdraws from the area, causing isostatic uplift. Because of this the lake became isolated from the fjord about 2.000 years later (Vasskog et al, 2013). Nowadays the lake is located 29m above sea level (Hansen et al, 2009, Vasskog et al, 2012). A river connects Strynevatnet to Nordfjord. Because of the isolation the majority of the sediments are preserved at the bottom of the lake.

Since the lake is a glacier carved fjord it's shore has a typical U-shape. The shore dips steeply and the bottom of the lake is mostly flat as visible in figure 2, here the -200m line is not displayed so the bottom is less flat than the figure implies. Most sediment comes in at the southeast part of the lake. Here Erdalen is located which is the only catchment presently glaciated. Erdalen is being monitored by the Norwegian Geological Survey. This valley is fed by the Jostedalsbreen icecap, which is one of the biggest land ice formations on European land.

Figure 2: Depth profile of Strynevatnet. The innermost line represents a depth of 180m and the lines are separated by 20m. The -200m line is missing so the bottom looks flatter than it is in reality. (With courtesy of L. Hansen)

After the isolation of the lake not much has changed. The water level stayed almost on the same height and the feeding catchment stayed at almost the same location even with the varring amount of ice on the glacier and thus the varying amount of water and sediment supply. This is caused by the overflow point of the lake, it remained constant so extra water flows easily out of the lake into Lake Nerfloen and further downstream in Nordfjord.

Methodology

In 2010 the TU Delft has collected geophysical data of Strynevatnet. This data was collected by use of a parametric echosounder, a SES light (http://www.innomar.com /ses2000light.php). Because the objective was to map the floor sediments and reconstruct the influx of fine grained sediment the penetration depth is only a couple of meters.

A parametric echosounder uses nonlinear sound pulses that are transmitted to the seafloor (Innomar Technologie GmbH). These pulses will be reflected by the sea bottom and sediment layers. The reflected signals are used to calculate an echo print showing the sub-seafloor structure along the sailed track. With an assumed sound speed the obtained travel time can be converted into a distance, which can be used to determine water depth and layer thickness. The echo strength depends on the reflection coefficient, the attenuation of the signal and the roughness of the boundary layer. The penetration depth is mainly controlled by sediment parameters like roughness and attenuation, sub bottom profiling properties like source level and footprint and by environmental conditions like the noise level (Innomar Technologie GmbH).

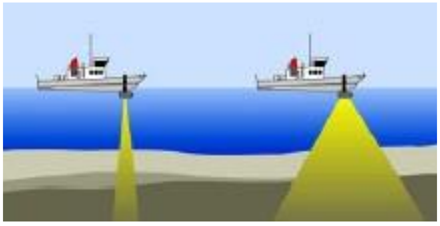

Figure 3: The footprint of a sound source is dependent of the width of the beam and water depth. A small angle and shallow water gives a good horizontal resolution.

The footprint of a sound source is the size of the sounded area of the seafloor. The footprint is an important parameter since the horizontal resolution cannot be better than the size of the footprint. To provide a small footprint a narrow sound beam is necessary (figure 3), so the transducer's aperture angle must be small. Beside this the water depth influences the footprint but this parameter cannot be varied (Innomar Technologie GmbH).

The frequency range is important for the vertical resolution. The attenuation of sound waves in marine sediments strongly depends on their frequency. For most sediment the attenuation coefficient increases linearly with the used frequency. Therefore the frequency should be as low as possible the get the best penetration. On the other hand a high frequency is in favor to provide a high vertical resolution. The pulse length does influence the vertical resolution as well, short pulses give a better resolution but longer pulses enhance the signal-to-noise ratio (Innomar Technologie GmbH).

Parametric echo sounders uses two slightly different frequencies that are transmitted at high sound pressures simultaneously, the waves interact in the water. New frequencies are generated, for example the difference frequency of the transmitted waves. The difference frequency is low enough to penetrate the bottom while the primary-frequency signals can be used to determine the water depth even in difficult situations such as soft sediments on top of the seafloor. Using a parametric echo sounder has the advantage compared to linear sound generation that high penetration and excellent resolutions in both the horizontal and vertical direction are possible due to transmission of short low-frequent pulses (Innomar Technologie GmbH).

Data

To obtain a good overview of the lake, three lines were made in the length of the lake and fourteen across, see figure 4. The data was gathered by the SES light with settings as mentioned in table 1. Because there was no information of the depth of Strynevatnet all data was provided without any knowledge in advance. This causes some of the data does not show the bottom of the lake, mostly because they were shot at the steep walls.

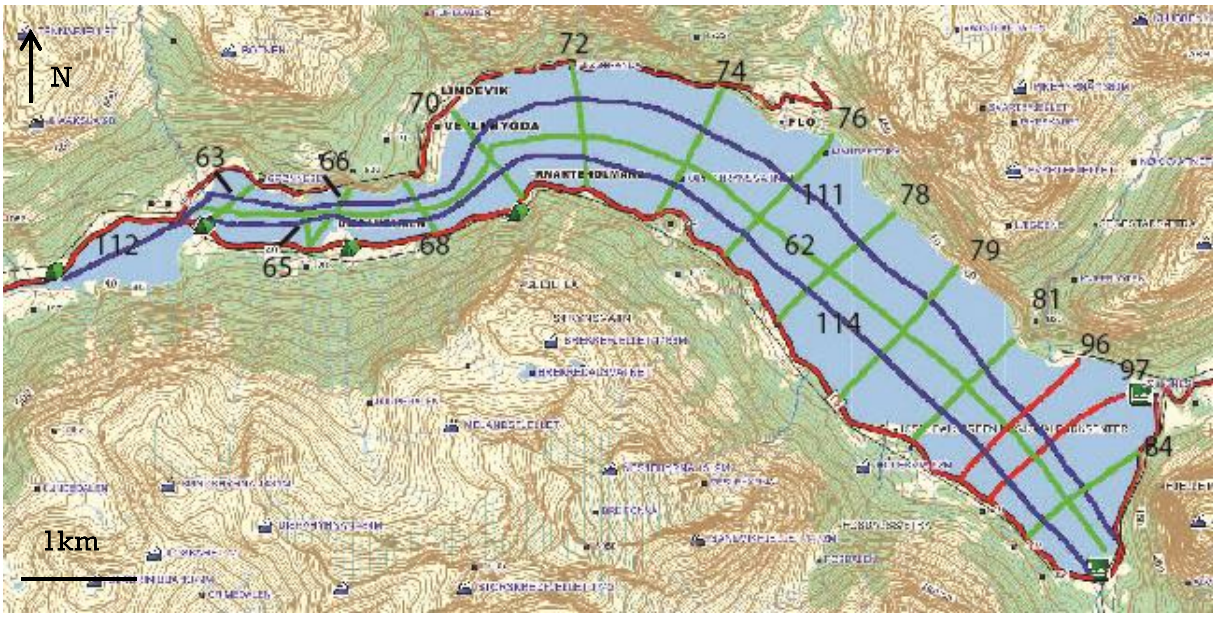

Figure 4: Location of the geophysical lines.

Figure 2 shows the bottom of the lake but is missing the -200 line. With use of this figure it is possible to eliminate some lines for my project. Since I'm interested in the preserved sediments it is important the bottom is a big part of the line, therefore the lines at the west side of the lake can be left out. Next to these only the middle of the three length lines is very well usable, the others are partly shot at the slope of the lake. Figure 5 shows the bottom part of line 62, with al cross lines located.

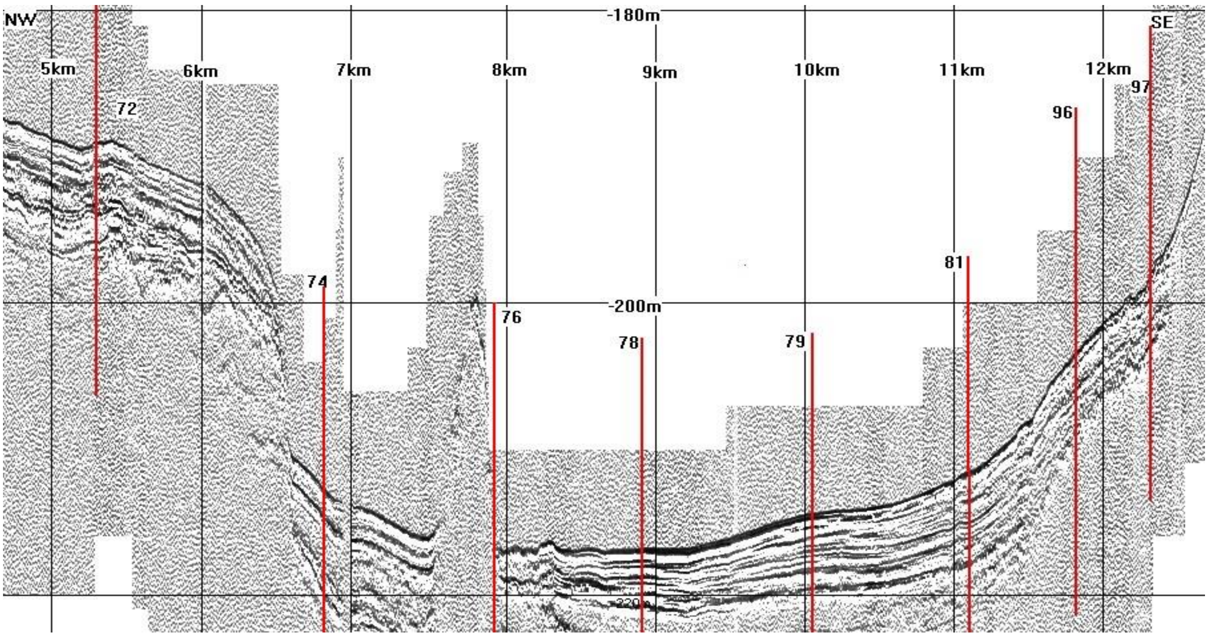

Figure 5: Location of the cross sections on line 62.

Line	Total number of Echos	Frequency (kHz)	pulses	Gain level (dB)	Transducer depth (cm)
62	14155	8	4	58	35
72	1571	8	4	60	35
74	1735	10	4	60	35
76	2023	10	4	60	35
78	2008	10	3	58	35
79	2283	10	3	18	35
81	1760	12	5	52	35
96	2123	10	4	52	35
97	2159	10	5	40	34

Table 1: The settings from the SES light for the used lines. The location of the lines can be found in figure 4.

Storegga deposit

Shortly after the isolation of Strynevatnet the area was hit by a tsunami. The Storegga tsunami generated waves in Strynevatnet with a maximum of 7.5m (Vasskog et al 2013) and stirred up all sediments in the shallow part of the lake which were deposited at the bottom of the lake. The top of these sediments now function as a time marker of 8150 years before present.

The Storegga deposit is a very transparent layer in the data, the upper boundary is formed by a high reflection layer. In figure 6 the top is visible as the blue line. Since the tsunami stirred up sediments they were suspended into the water of the lake. The small particles sunk and were uniformly deposited. Therefore there will not be any direction visible in the Storegga deposit. Despite this there are fluctuations in the thickness, changing from a maximum of at least three meters to a very thin layer who is almost invisible (Vaskogg et al, 2013). The top of the deposit turns out to be relatively flat and follows the contours of the bottom at most places.

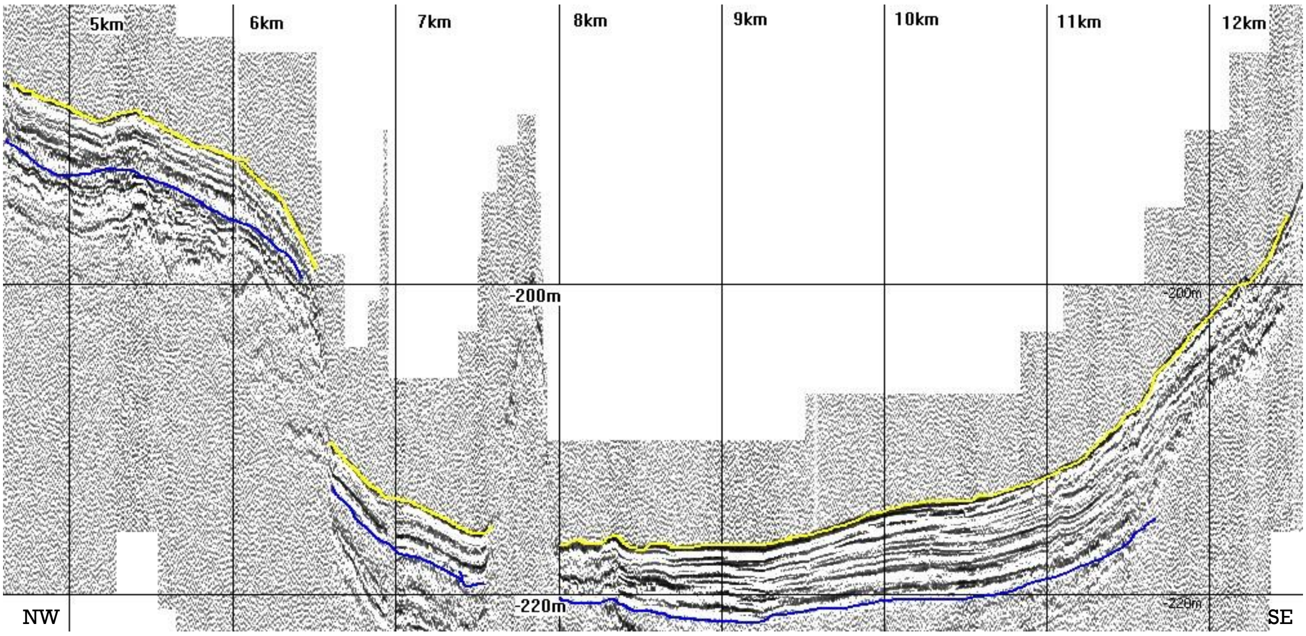

Figure 6: The top of the Storegga deposit at line 62, indicated with the blue line. This line functions as a time marker, 8150 year before present.

Results

Since the Storegga deposit is well visible in the stratigraphic record of the lake the thickness of the overlying sediments can be determined. The overall thickness does vary between 2.5±0.2m at the west side and 7.5±0.2m at the east side of the lake. At the inclined parts the thickness decrease compared to the flat bottom. This all is visible in figure 7, all sediment deposited after 8150 yr BP is located between the blue and yellow lines. Figure 8 makes the layer thickness even more clear. The graph has been made with the date from line 62 and this causes the dip in the data at the location of the bedrock exposure.

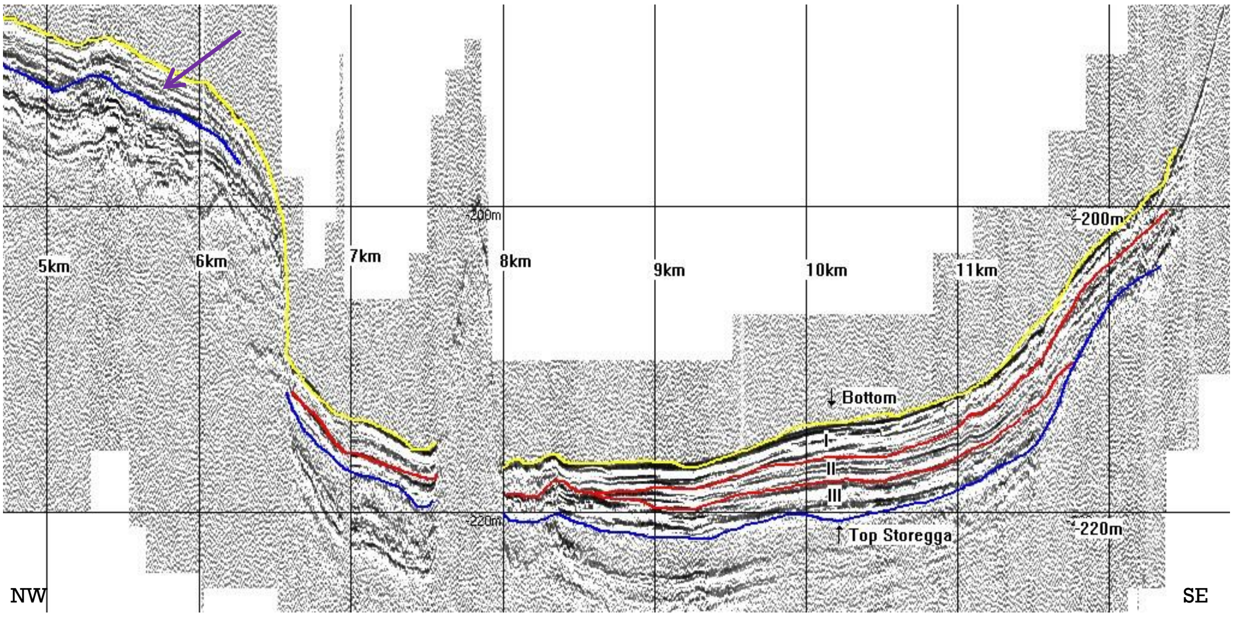

Figure 7: Line 62, bottom part of the lake. The indicated distances are measured from the west side of the lake. Unit I, II and III are described in the text. The deposit indicated by the green arrow is not assigned to eighter one of the units.

Most cross sections show a very uniform sediment thickness. The reflectors are nearly horizontal and cover most times only a little of the inclined walls, since they often are very steep. Because the walls are very steep the upper and lower boundary of the reflectors are equal of length. There are two exceptions, namely line 79 (figure 9) and 96 (figure 10). Line 79 shows almost a horizontal bottom but the south wall is less steep as the north wall so the upper part of the deposit is longer as the bottom part, 1250m and 1000m respectively. More extreme width differences are visible in line 96, here the north wall is clearly dipping less steep (figure 10). The inclination of the wall even allows the sediments to propagate against it and causes the layers are deposited horizontally at the south part and inclined at the north part.

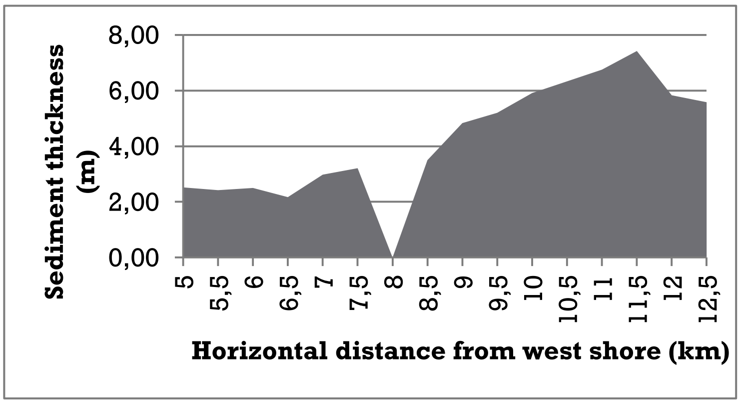

Figure 8: Total thickness of the sediments above the Storegga deposit. The dip at 8km is caused by the bedrock exposure in line 62.

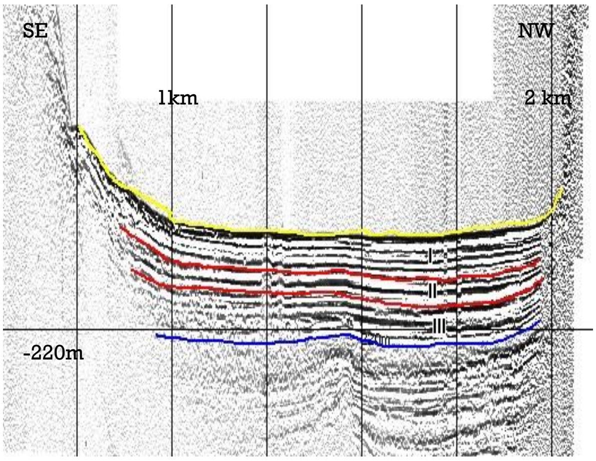

Figure 9: Line 79, the blue line indicates the top of the Storegga deposit and the yellow one the bottom of the lake. The total thickness is 5.5m. The biggest part is layered horizontally but the south side does show layers going upwards. Because of this the upper part is wider than the bottom part.

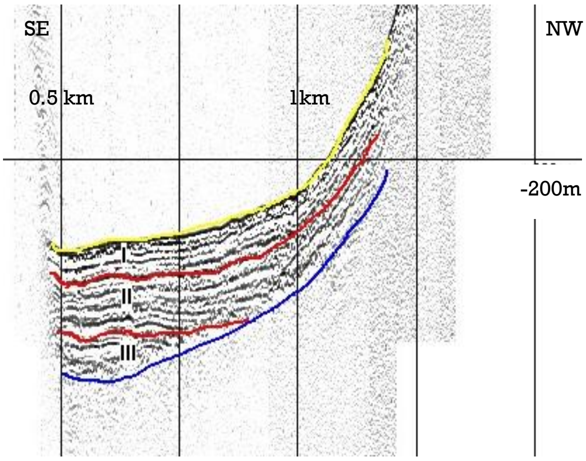

Figure 10: Line 96, the blue line indicates the top of the Storegga deposit and the yellow one the bottom of the lake. The south side of the line shows a layer thickness of 6.8m where the north side only reach 3.8m. Because the north slope is less steep than the south one the layer isn't of equal length, the upper part is significantly longer than the bottom, 900m and 200m respectively.

Three main units can be identified in the sediments on top of the Storegga deposit, shown in figure 7. These units only are found at a depth of at least -190m of the lake, on the most horizontal parts. As visible in figure 7, unit I and III are deposited all over the lake bottom in comparison to unit II which only is present at the east side. In figure 11 it is even clearer how the main units propagate along the lake floor. The three units are distinguished in the geophysical data by their internal reflectors.

Unit I is delimited with the lake floor at the top and a strong consistent reflector at the bottom. In between there are three to five reflectors. These reflectors are not continuously all over the unit but all are parallel to the lake bottom. Unit I has a fairly uniform thickness of about 2.2±0.2 meters.

Unit II is only present at the east part of the lake. This unit is characterized by lot reflectors, mostly short and very thin ones. Therefore unit II appears more greyish as the other two units. Unit II is thinning towards the west side of the lake, with a maximum thickness of 2.4±0.2 meter.

Unit III directly overlies the Storegga deposit and is characterized by a very consistent reflector at the top. In between two to three, continuous and clear, reflectors are visible. The unit propagates along the lake thinning out towards the west. The layer thickness varies between 3.0±0.1 and 0.6±0.05 meter.

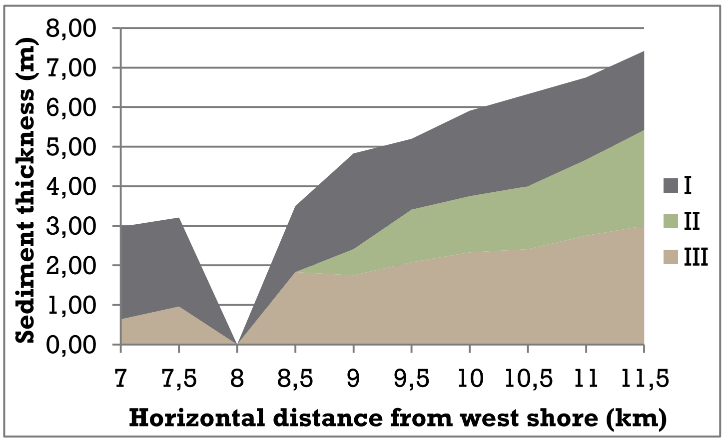

Figure 11: Individual thicknesses of the three main units.

Volumes

Since the unit thickness is known in both the length and the width of the lake it is possible to estimate the volume of sediment deposited, width times length times thickness is volume. The total volume of sediment deposited after the Storegga tsunami is $26.8 \cdot 10^7 \pm 0.5 m^3$. This volume only takes the sediment below -180m of the lake into account. All sediment in the shallow part of the lake is left out and so are the deposits on the slopes. The total volume indicates an average sediment supply of 2966 ± 600 m^3 per year since the Storegga land slide. Unit I is responsible for the biggest volume of sediment, $8.40 \cdot 10^6 \pm 2 \cdot 10^6$ m^3, followed by unit III with an amount of $5.40 \cdot 10^6 \pm 1.5 \cdot 10^6$ m^3 and unit II with a volume of $3.36 \cdot 10^7 \pm 1.0 \cdot 10^6$ m^3. This al is listed in table 2.

	Total deposit	Unit I	Unit II	Unit III
Length (km)	8,5 ± 0,2	5,0 ± 0,2	3,0 ± 0,1	4,5 ± 0,2
Average width (km)	0,7 ± 0,1	0,8 ± 0,1	0,7 ± 0,1	0,6 ± 0,1
Minimal width (km)	0,5 ± 0,5	0,5 ± 0,05	0,5 ± 0,05	0,5 ± 0,05
Maximal width (km)	1,1 ± 0,1	1,2 ± 0,05	1,1 ± 0,05	1,0 ± 0,05
Average thickness (m)	4,5 ± 0,2	2,1 ± 0,2	1,6 ± 0,2	2,0 ± 0,2
Minimal thickness (m)	2,2 ± 0,1	1,6 ± 0,1	0,7 ± 0,1	1,8 ± 0,1
Maximal thickness (m)	7,4 ± 0,1	2,4 ± 0,1	2,4 ± 0,1	3,0 ± 0,1
Volume (m3)	2,68E+07	8,40E+06	3,36E+06	5,40E+06
Minimal volume (m3)	2,14E+07	6,38E+06	2,44E+06	3,87E+06
Maximal volume (m3)	3,27E+07	1,08E+07	4,46E+06	7,24E+06

Table 2: Characteristics of the total deposit above the Storegga deposit and the different units. Maximal and minimal width are determined at the upper and lower reflectors of the cross lines. The maximum and minimum thickness is determined at long line 62.

The total volume of sediment is higher than the sum of the individual units, there is a difference of 9.62·106±2.5·105 m3. This is caused by the sediments overlying the Storegga deposit which cannot be assigned to one of the three units, see the purple arrow in figure 7. Therefore figure 8 and 11 do have different lengths. The three kilometer of length difference contains a volume off 9.62·106±2.5·105 m3 of unassigned sediment which was deposited after 8150 yr BP.

Interpretation

As discussed in the results the total sediment deposit overlying the Storegga unit in the east is much thicker than in the west. In the cross direction of the lake hardly any difference in unit thickness is visible. Therefore it is very likely the sediment supply came from the south-east side of the lake. Erdalen is located here, see figure 1, which indicates this is the most obvious catchment and probably the only one with significant sediment supply. The Hjele river at the east does not seem to contribute a lot. When this catchment would have a significant sediment supply a difference in thickness should be visible along the width profiles and this is not the case.

Assuming Erdalen is the only catchment responsible for sediment supply it seems unit II and unit III are both gravity flow driven. These sediments were not able to travel along the whole lake bottom, which they would have done when they were fully suspended. Fine sediments don't need as much energy as the more coarse ones and therefore the suspended sediments travel further. The coarser particles aren't suspended that easily and will travel down in a turbidity current, depositing near shore. This causes the decreasing layer thickness away from the catchment, see figure 11. Both the suspended and gravity driven sediments are deposited near the shore while only the suspended materials are able to travel further away. It is very likely unit II and III both have a range in grain size, and given the extent of unit II this unit does have coarser particles as unit III. The incoming water stream was probably rapidly moving and sunk by the density difference. From the extent of unit III it seems that most sediment indeed was transported by gravity flow but partially by suspension as well.

In comparison to the other units unit I has a uniform thickness all over the lake bottom, see figure 11. This indicates the sediment was suspended in the water and settled down slowly. Gravity driven flow does probably not play a significant role in this deposit, otherwise there would be visible a slight difference in the thickness of the unit. The grain size of this deposit is very uniform and small enough to get suspended and transported all over the lake. Next to this the energy of the supplying river will not have been very high because the sediments were both deposited further away and close to the shore. Still it was high enough to get most sediment into suspension. Since unit I has been suspended material it is reasonable to assume the sediments on the higher locations, see figure 12, are unit I as well. When the thickness from this location is compared to the thickness of the whole unit, it might correspond. This is visible in figure 8, even though there are no units indicated it is visible the thickness of the layer remains constant. With this new information a new graph has been made, figure 13. In this graph the unit thickness slightly increases with about fifty centimeters. It is not very likely the unit thickness increases this much so probably not the

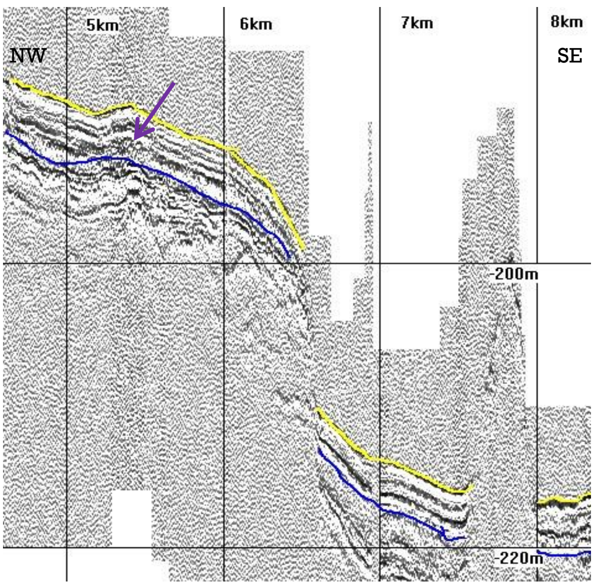

Figure 12: At the west side of the outcrop the lake bottom goes up. The sediments on this higher plateau are very likely the same as unit I, since the thickness is comparable to the whole unit.

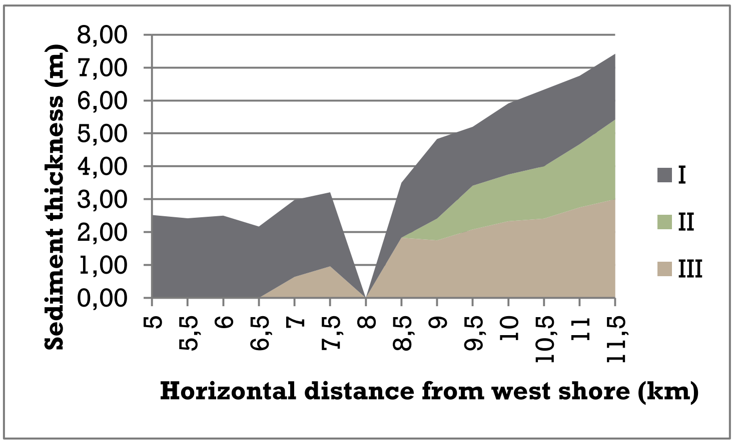

Figure 13: The distribution of the units with the sediments on the higher plateau interpreted as unit I, see text for explanation.

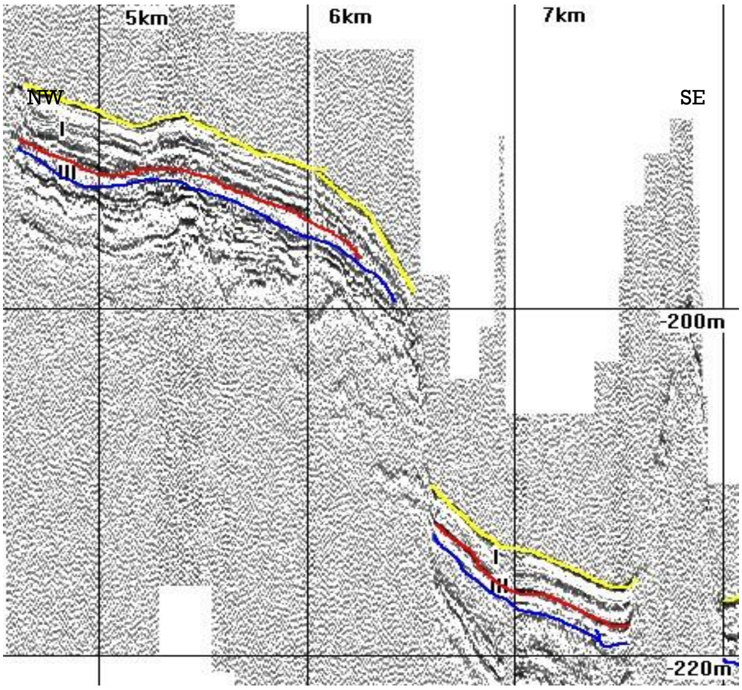

Figure 14: West side of the lake with unit I and unit III interpreted. See text for explanation.

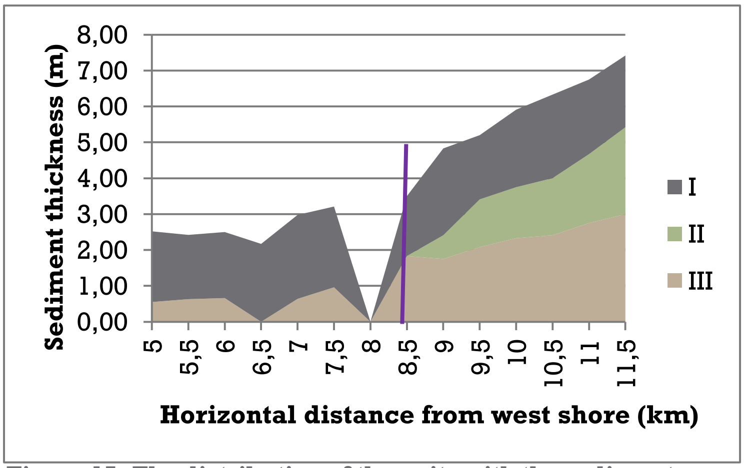

Figure 15: The distribution of the units with the sediments on the higher plateau interpreted as both unit I and III. The purple line indicates the time location, see text.

entire deposit consists out of unit I. It is possible the Storegga deposit is not defined very well but another, more likely, possibility is unit III has formed a little deposit at this plateau as well. This would imply that unit III consist partially off suspended sediment and this would consist out of very fine material. In figure 12 a consistent reflector, indicated with the purple arrow, can be seen which might be the boundary between unit III and unit I. This is visualized in figure 14, the red line indicates the border between unit I and unit III while the blue line represents the top of the Storegga deposit. Figure 15 does give a bright overview of the situation by then.

With this information the volume of sediment for unit I and III has been changed. Now unit I deposited an amount of sediment of $12.6{\cdot}10^7{\pm}2.5{\cdot}10^6$ m^3 instead of the $8.40{\cdot}10^6{\pm}2{\cdot}10^6$ m^3 calculated before. Unit III now is responsible for an amount of $5.76{\cdot}10^6{\pm}2.0{\cdot}10^6$ m^3 instead of $5.40{\cdot}10^6{\pm}1.5{\cdot}10^6$ m^3. The undefined amount of sediment is reduced to only $5.06{\cdot}10^6{\pm}1.0{\cdot}10^6$ m^3 coming from the east side of the lake, where the slope is too steep to see differences in the seismic record. The bedrock exposure at the lake bottom, at about 8km from the west shore, probably is only a regional disturbance which would mean the amount of sediment is even higher than now estimated. This assumption is made because there is no evidence for a big lateral outcrop on the bathymetric map of the lake, see figure 2.

Looking to the type of deposit it seems there is some difference between unit I and unit III. The decreasing amount of sediment further away from the catchment indicates a range in grain size of the sediment in unit III which won't be very plausible for unit I. This indicates unit III was a more uniform sediment supply. Beside the type of sediment also the amount of energy has changed, the supplying river did increase energy after unit III has been deposited. Still both units did have suspended material which has been transported all over the lake bottom, indicating the river had enough energy to get the particles into suspension.

Compared to unit I and III unit II is a totally different deposit. As mentioned before the extent of this deposit is much smaller than those of the other two units. This gives the indication the sediments are coarser than those of the other units causing a high density stream. There would have been needed more energy to transport those particles. Since the shore is very steep it is possible this deposit comes from a landslide causing a turbidity current. Next to this the unit shows more reflections than the others, which might indicate there are no clear beds in the unit.

In figure 11 the division between the units is clearly visible. Unit III roughly is responsible for thirty-eight percent of the total amount of sediment along the lake bottom, varying between twenty-one at the west and fifty-two at the center of the lake. The low percentage at the east probably comes due to the bedrock exposure. Even though suspended sediments were able to travel across the lake the thickness of sediment west of the bedrock exposure is less than the thickness on the east side. When unit II is being interpreted as a landslide this will be deposited in a short amount of time. Here for it is reasonable to assume that sediments before the bedrock exposure (west side) but after unit II give the best sight in time. This will be at about 8.5km from the east shore, following line 62 , see the purple line in figure 15. Vasskog 2013 states that the sediments at the shallow part of the lake are linearly deposited and I assume it still is at the deeper parts of the lake as well. This would mean unit III has been deposited in about 4000 years followed by unit I, taking just a little more time and possibly still being deposit. Unit II could have been triggered by the changing environment causing the change between unit I and III. This would mean that unit III has been deposited with an average of 1440.0 m^3 a year against unit I with an average of 3036.1 m^3 a year.

Discussion

In the interpretations some assumptions were made because of too little information. It woulde be very useful to have some cores since it is nearly impossible to see any differences in the seismic data. Different layers might be determined and the boundaries might be visible. Beside this it would give an indication what is separated by a boundary, whether the sediments become coarser, or finer. Sequences might become visible which makes it easier to reconstruct the history of the lake. Next to this there might be different kind of sediments, apart from the grain size, caused by different rocks.

I made the assumption unit II represents a landslide. This was based on the decreasing thickness of the unit and the fact the layer propagates for only several kilometers. With a core it might become clear whether this is a correct assumption or not. When it is, one would find a bouma sequence (Bouma, 1962). Otherwise something else would have happened. Another possibility is a laminar flow with very low energy so it was unable to propagate along the whole lake bottom. In this case the grains will only have a small size range and be just too big to get suspended into the water. This is very important for the history of deposition. When unit II did not interrupt suddenly like a landslide it must have taken a lot more time to be deposited. This would mean the whole time setting would be totally different. Unit II would be part of the timeline and there would be a gap between unit I and unit III. With this theory unit III had only 3000 year time to be deposited and unit I just 3100 year. This is a whole lot less than estimated with the landslide theory and de deposition speed would increase significantly. Unit III would have been deposited with 1920.0 m^3 a year, unit II with 1680.0 m^3 a year and unit I with 4064.5m^3. Now unit II has about 2000 years for deposition, instead of the quick interruption. The fact the energy of deposition in unit III is lower than with unit I still holds but there must have happened something in between. The energy of deposition during unit II was lower than that during both unit I and III. This very low energy is an indication for a growing glacier, the water supply decreases en so does the sediment supply. At the boundary between unit II and I the glacier started melting and the sediment supply increases.

Another assumption I have made was the bedrock exposure is only locally. The sediments were able to travel around it even though it was not easy and therefor a little barrier to cross. If this is true it is not necessary the particles were suspended into the water and the possibility of a low energy current into the lake is possible, and the decreasing thickness is also logical. Since the data is not so accurate it also is possible that the outcrop is laterally extended. When this would be the case it is impossible unit III is only gravity flow driven because there is no possibility for the sediment to cross the outcrop by then. When the sediment was suspended, totally or only partially, this means the energy has to be higher or the particles finer. It is also possible that a wide range of particle sizes was deposited and the coarse ones settled down earlier than the fine ones. This might be visible in cores.

When these results are combined with the theoretical data there is a difference. Nesje 2009 states that: There was a climatically warm period between 7100 and 6100 year BP. Subsequently the glaciers grew and the maximum extent was about 2200 years ago. The most extensive glaciers existed at about ~5600, 4400, 3300, 2300, 1600 cal. yr BP, and during the 'Little Ice Age'. Times with overall less glacier activity were apparently around

5000, 4000, 3000, 2000, and 1200 cal. yr BP (Nesje, 2009; Hansen et all, 2009). My own data comes up with only one major change, maybe two. This is probably affected by the minor amount of data, seismic is hard to use on thin layers.

Conclusion

During the Holocene at least $2.68 \cdot 10^7$ m^3 of sediment is deposited in Strynevatnet. This amount can be divided into three main units:

- Unit III was deposited on top of the Storegga deposit. $5.76 \cdot 10^6 \pm 2.0 \cdot 10^6$ m^3 sediment is deposited in about 4000 year time, an average of 1440.0 m^3 a year.
- Unit II is deposited on unit III. This unit has been a turbidity current caused by a landslide with a sediment amount of $3.36 \cdot 10^6$ m^3.
- Unit I is deposited on both unit II and III just after the deposition of unit III, starting about 4150 y BP. The sediment supply is 3036.1 m^3 a year, coming to a total of $12.6 \cdot 10^7 \pm 2.5 \cdot 10^6$ m^3.

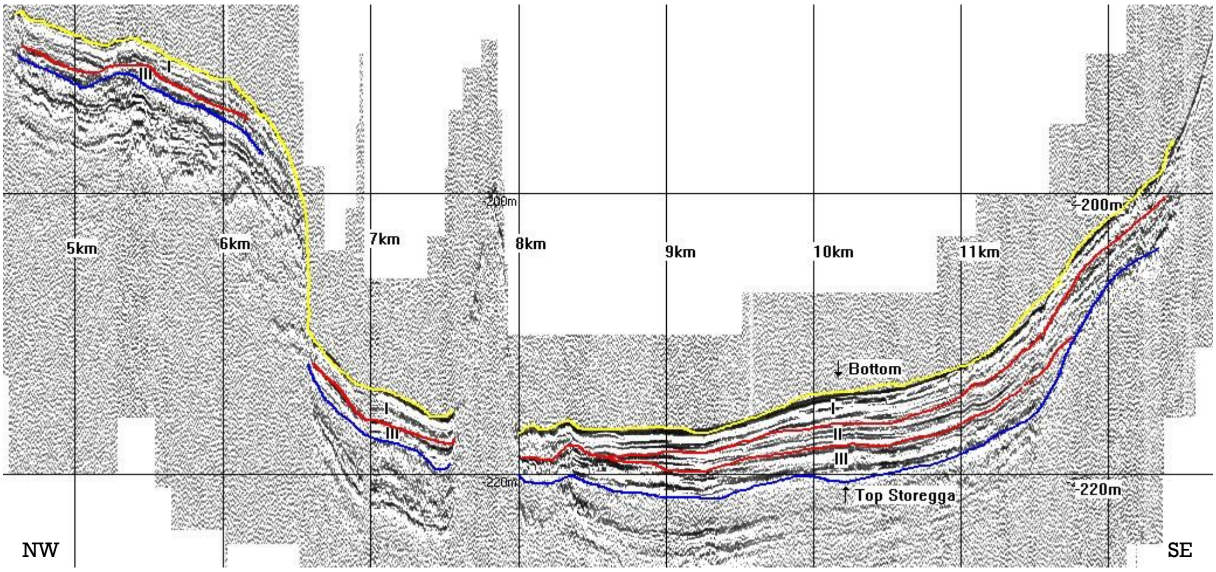

Figure 16: The final overview off sediments in Strynevatnet. Unit I, II and III are explained in the text.

The huge difference in sediment supply combined with the assumption the river increased the amount of energy does indicate more water was flowing down. Since the lake is only fed by the catchment of Erdalen, and thus the Jostedalsbreen ice cap, this leads to the conclusion the glacier started melting about 4150 years ago.

Recommendations

This project was done to get insight in the Holocene infill of Strynevatnet. During the project I encountered one major obstacle, the lack of information.

It is very hard to start out of nowhere and therefor the data was gathered on a logical way, equally spread across the lake. This causes a lot of data was practically unusable because the line was partly shot at the slope of the lake, showing a lot of difference in elevation. Still information is gathered from these shots, namely the profile of the lake (figure 2) although some information was lost here with the vanished -200m line. This information can be very useful for a second seismic survey, since the bottom of the lake gives the best information this area can be recorded. When this had been done more accurate volume estimations can be done.

Another very useful source of information would be cores. These could give a lot of detailed information about the sediments. Only a few might give a whole lot of information to use as a framework for the seismic data. Beside the expected boundaries it is becomes visible what kind of sediment you're dealing with and the internal sequences, which is only a guess by now. It is very plausible more layers are discovered which might correspond to the literature. And this would become easier when the sediment is dated, it might be non-linear aged at the bottom of the lake.

Also another approach could be used. Since the glaciation of Jostedalsbreen ice cap is known one might look to the different layers in the seismic data instead of vice versa which I did. This approach might be unsecure because if you are searching for something it is more likely you find it, even when it is not there in reality. Still it can helps to see more details.

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