SINTEF site - soil investigation

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Contents

1 Introduction

This Report introduce lab results of geotechnical tests performed at UNIS in order to describe the site conditions at UNIS Guest House (UGH, Longyearbyen, Svalbard). The results are used in the PCCH-Arctic project, as an input data for the assessment of performance foundation of UGH. The ultimate goal is to create a knowledge base for sustainable safeguarding and future use of cultural heritage in the Arctic in conditions of changing climate and demography [2].

In this report a drilling sample from the area close to UGH is analysed to find the following properties of three different layers in the soil sample: water content, grain size distribution, density, plasticity, liquidity and salt content. The samples were not core samples but a disturbed sample collected in bags for the different layers.

2 Theory

2.1 Water content

Water content (w) is the ratio of the mass of free water in the soil to the mass of dry soil expressed as a percentage of the mass of solids [6]. The equation for water content is shown in equation 1, where m_s is the mass of moist soil, m_{dry} is the mass of dried soil and m_w is the mass of free water in the soil. Typical values of water content are shown in table 1.

$$w = \frac{m_s - m_{dry}}{m_{dry}} = \frac{m_w}{m_{dry}} \qquad (1)$$

Table 1: Typical values of water content.

Description	w
Norwegian clay [3]	20-40 %
Offshore clay [3]	70-80 %
Gilbert, UNIS East site [4]	18-30 %
Gilbert, Adentdalen site, below 5m depth [4]	25-45 %

2.2 Density

Density is defined as mass divided by volume. To find a soils particle density, ρ_s, we combine the following three equations where ρ_{dw} is the density of distilled water, V is the total volume of the distilled water, ρ_s is the density of the soil and V_s is the volume of the soil. m_1 and m_2 and m_3 is the total masses of the content in the flask when the flask is containing respectively only water, water and soil mix, and m_3 is the mass of the dried soil in a container:

$$m_1 = \rho_{dw} \cdot V$$

$$m_2 = \rho_s \cdot V_s + \rho_{dw}(V - V_s)$$

$$m_3 = \rho_s \cdot V_s$$

To find the density of the soil, we solve the set of equations for ρ_s and get the Formula 2:

$$\rho_s = \frac{m_3 \cdot \rho_{dw}}{m_3 - m_2 + m_1} \tag{2}$$

2.3 Particle size distribution

A wet sieving analysis is used to map a soils composition, and the results are presented in a graph for easier visualisation and understanding. The grain size distribution curve tells if the soil is well graded or not, and what type of fractions the soil consist of. This is used to find the grading of the material defined by the coefficient of uniformity, C_u, according to equation 3, where d_{60} is the grain diameter corresponding to 60% passing a sieve by mass, and d_{10} is the diameter corresponding to 10% passing [1]. In table 2 values of grading are presented.

The grain size distribution curve also let us categorize the soil by grain size. Table 3 shows the definition of different grain sizes. Sieving is used to analyze material coarser than $75\mu m$, while a hydrometer test is used to analyse finer materials [1].

$$C_u = \frac{d_{60}}{d_{10}} \tag{3}$$

Table 2: Grading [3]

Description	C_u
Single grained	< 5
Middle grained	5-15
Well graded	>15

Table 3: Grain size definition [3]

Description	Grain size [mm]
Rock	60-600
Gravel	2-60
Sand	0,06-2
Silt	0,002-0,06
Clay	< 0,002

Stoke's law for ideal spheres falling at a constant speed is the principal used in the hydrometer test to determine the terminal fall velocity of the particles. This velocity depends on the particle diameter and density of the fluid, and together with measurements of the particles travelled distance and time off fall it permits the calculation of particle diameter. At a certain time, the percentage of particles of a certain diameter can be determined by the density of the suspension. [1]

When the hydrometer is immersed into water containing grains it will stabilize at a given depth of the water which relates to the amount of gravity pulling downwards and the buoyancy force pushing upwards. The buoyancy force is greatest when the liquid and grains are homogeneously mixed and at the lowest when all of the grains has fallen to the bottom.

We will use Stoke's law to describe the phenomena happening in the hydrometer. To use this law, the following assumptions must be made: Laminar flow, spherical particles, smooth surfaces and that the particles do not interferes with each other.

Let's consider a particle of soil with diameter $D = 2R$ and mass m, that is falling in distilled water (ρ_{dw}, η). The unit vector $\vec{e}_y$ is in the direction of movement. Three forces applies to the particle: The weight $\vec{P} = m\vec{g} = \rho_s \frac{4}{3}\pi R^3 \vec{e}_y$, the Archimedes's force $\vec{F}_a = -\frac{4}{3}\pi R^3 \rho_{dw} \vec{e}_y$ and the drag force of viscosity $\vec{D} = -6\pi\eta R\vec{e}_y$. After applying Newton's second law of motion, assuming constant speed of the particle and initial velocity equal to 0, the distance (H) that the particle has travelled from the initial position is given by $H = \frac{g(\rho_s - \rho_{dw})D^2}{18\eta}t$. As we want to know the size of the particle, we rewrite this to get

$$D = \sqrt{\frac{1}{g}\frac{18\eta}{\rho_s - \rho_w}}\sqrt{\frac{H}{t}}. \qquad (4)$$

4

2.4 Atterberg limits

The plastic and liquid limits determine the transitions between brittle, plastic and liquid behavior and gives significant information about the behavior of clay and other cohesive soils. The Swedish chemist Albert Atterberg defines the consistency limits for this, so called Atterberg limits [7]. He found that when the moisture content is low, the clay thread will crack when molded. The Atterberg plastic limit is thus defined as the lowest water content at which the clay can be rolled into thin threads without breaking [8]. The Atterberg liquid limit, on the other hand, is the water content at which the body begins to flow and exhibits only a small shearing strength [1]. The plastic and liquid limit is calculated by Equation 1 where m_s is substituted by the mass of the plasticity or liquidity soil mass, and are shown by Formulas 5 and 1. From the plastic limit (PL) and liquid limit (LL), the plasticity index (PI) and liquidity index (LI) can be found.

$$PL = \frac{m_p - m_{dry}}{m_{dry}} = \frac{m_{w(plastic)}}{m_{dry}} \tag{5}$$

$$LL = \frac{m_l - m_{dry}}{m_{dry}} = \frac{m_{w(liquid)}}{m_{dry}} \tag{6}$$

The plasticity and liquidity index can be calculated by the following formulas where w is the free water content:

$$PI = LL - PL \tag{7}$$

$$LI = \frac{w - PL}{LL - PL} = \frac{w - PL}{PI} \tag{8}$$

The liquidity index of soil starts at zero at the plastic limit and with an increased water content it becomes 1 at the liquid limit. When the water content increases further, the liquidity index becomes larger than 1, which indicates that the soil behaves like a liquid. When the water content is lower than the plastic limit, the soil is relatively hard and more brittle. In that case, the liquidity index will become negative.

2.5 Thermal conductivity

Heat conductivity in soils involves a tranfer of kinetic energy from molecules in a warm part of the material to a cooler part. The amount of heat transferred by conduction in soil increases as dry density increases and as its degree of saturation increases [1]. The equation to express the conductivity k developed by Johansen [1] is shown in equation 10. The Kersten number K_e depends on the saturation of

the soil. Quartz has a high thermal conductivity according to Johansen $k_q = 7{,}7$ W/mK, k_0 is set to be 2,0 W/mK. The thermal conductivity of soil constituents k_s depends on the fraction of quartz in the soil and is presented in equation 11. For saturated frozen soil containing some unfrozen water the equation is presented in equation 12. The thermal conductivity of ice k_i is assumed to be 2,2 W/mK and $k_w = 0{,}57$ W/mK. n is the soil porosity as presented in equation 13.

$$\rho_d = \frac{\rho}{1 + w} \tag{9}$$

$$k = k_u = (k_{sat} - k_{dry})K_e + k_{dry} = k_{sat} \tag{10}$$

$$k_s = k_q^q k_0^{1-q} \tag{11}$$

$$k_{sat} = k_s^{1-n} k_i^{n-w_u} k_w^{w_u} \tag{12}$$

$$n = \frac{e}{1 + e} = 1 - \frac{\rho_d}{\rho_s} \tag{13}$$

3 Method

Samples from three different depths was used for the tests described below. The depths is presented in Table 4 and will be referenced to as Active, Middle and Lower layer/sample.

Table 4: Test samples

Sample	Depth [m]
Active layer	0-1
Middle layer	4,35-4,7
Lower layer	6,7-6,9

3.1 Soil type - observations

Soil samples collected from six different depths were inspected to determine stratigraphic layers. The depths chosen are shown i Table 5. Each sample was spread out on a white surface, as shown in Figure 1, and studied visually and by feeling the texture.

Table 5: Soil samples and the depth they were taken.

Sample number	1	2	3	4	5	6
Depth [m]	0-1	1-2	2-3	4,35-4,7	5,5-6,3	6,7-6,9

Figure 1: Soil samples during visual inspection and touch.

3.2 Water content

The water content was defined for four samples, taken at depths 0-1 m, 1-2 m, 4.35-4.7 m and 6.7-6.9 m, mainly following the method described in NS-EN ISO17892 Part 1. The soil was weighed before and after being dried in a drying oven at 110 °C overnight, giving respectively $m_s + m_c$ and $m_{dry} + m_c$. The masses needed were obtained by subtracting the mass of the container. The water content (w) was then calculated using Formula 1.

3.3 Density

To measure the density of the soil, we preformed a test using a flask with a defined volume and a scale. The test can be divided into three steps: The first step is to fill the flask with distilled water, remove as much air bubbles as possible with a vacuum chamber, refill if necessary, close the bottle with the lid and weigh it

as m_b. The second step is to weigh a mass of soil and mix this with a mass of water approximately ten times greater than the mass of soil. Then use a funnel to fill the bottle with this mixture, remove as much bubbles as possible with a vacuum chamber, refill with mixture if necessary, close the bottle with the lid and weigh it as m_{b+s+w}. The third step is to empty the mixture from the bottle into a pre-weighted contaier, dry it until all the water is gone and then weigh it as m_s.

The second and third step were repeated three times for the three different layers, active-, middle- and lower layer.

3.4 Particle size distribution

A sieving analysis was preformed mainly following the procedure described in NS 8005. For this test we used a mixer, 7 sieves and a bottom where the leftovers could run out into a new bowl. The sieves were stacked on top of each other in a tower with decreasing sizes downwards as follows $4,75\ mm$, $3,26\ mm$, $1,18\ mm$, $600\ \mu m$, $300\ \mu m$, $150\ \mu m$ and $75\ \mu m$. We started by mixing soil with distilled water in a blender and then we poured it onto the top sieve. Then we used distilled water to wash the soil downwards towards the smaller sieves. For each sieve we put the remaining grains into pre-weighted containers. The grains that were smaller than $75\ \mu m$ were collected in larger bowls. These were all dried in the oven and then weighted.

To further find the size distribution for grains less than $75\ \mu m$ in size, we used the hydrometer test, mainly following the procedure described in NS 8005. We used a scale, one flask with distilled water, a timer, one hydrometer and three $1\ L$ cylindrical measuring flasks.

We mixed approximately $30\ g$ of the dried soil together with $20\ mL$ of Sodium Hexametfosfat and approximately $200\ mL$ of distilled water. This solution was left for $24\ hours$. Then we put it in the $1\ L$ cylindrical measuring flasks and refilled with distilled water until the total volume was $1\ L$. Then we sealed it with a couple of rubber gloves and shook it well. Right after we put it down we removed the rubber gloves and started the hydrometer measuring. The hydrometer measuring is done by slowly immersing the hydrometer into the mixture, letting it settle and then read from the scale where the surface hits. This was done at the times $t = 0, 60, 105, 240, 900, 1800, 3600, 14400$ and $86400\ s$ for the three different soil samples, active-, middle- and lower layer. After approximately $11\ min$ we measured the temperature.

3.5 Pore water salinity

We used two different methods for measuring the pore water salinity in three different layers. For the active layer we used the first method. Here we used a container, salinity refractometer, pipette and a pressure chamber. The container was filled with soil and then closed by paper filters first and then stone filters. Then we used the pressure chamber where Nitrogen where pressed through the container pushing a few water droplets through at the bottom. These were then picked up in a pipette and put on the salinity refractometer. Here we could read the salinity percentage through the glass. The result is shown in Table 16.

The middle and lower layer soil were to dry for the first method therefore we had to use a second method. Here we weighed a mass of soil and added approximately a mass of distilled water ten times the mass of the soil. Then we used an electric conductivity meter to measure the salinity in the mixture. The details and results are shown in Table 15. Then we can use the following formula 14 to obtain the salinity for the free water content in the soil:

$$\sigma = \frac{m_\sigma}{m_w} = \frac{\sigma_1 \cdot (m_w + m_{dw})}{m_w} = \sigma_1 \left(1 + \cdot \frac{m_{dw}}{w \cdot m_s} \right) \tag{14}$$

3.6 Plasticity and liquidity

The procedure to determine a soils plastic limit is described in NS8003. This procedure has not been followed exactly, and the modified method is as follows. To determine the plasticity limit we used clay and diluted it with distilled water until we were able to roll it once into a thread with a diameter of 3 mm on a flat and non-porous surface. The rolled sample was then dried and the dried mass was measured.

For the active layer no water needed to be added to reach the desired thickness, and we therefore assumed that the plasticity limit was the same as the free water content. The sample for the active layer was therefore not dried after rolling.

The procedure to determine a soils liquid limit is described in NS 8001, and was mostly followed in this test. The soil was used directly without sieving but particles bigger than 0,4 mm was removed. The clay mixed with some distilled water was placed into a Casagrande cup and a groove of 1 cm was made with a standarized tool. The cup was repeatedly dropped 10 mm onto a hard plate about 25 times. Distilled water was gradually mixed with the soil sample and the dropping sequence repeated. The liquid limit was then defined as the moisture content at which it took 25 drops of the cup to close the groove.

When the liquid limit was reached, the water content was determined by putting the clay in a pre-weighed container and weighing it before and after being dried in an oven. We calculated the mass of both the plasticity and liquidity sample by subtracting the mass of the pre-weighted container from the sample. The plasticity and liquid limit were calculated by using Formulas 5 and 6.

3.7 Thermal conductivity

The thermal conductivity is found using the density from and the Formulas presented in 2.5 and the results from the tests above.

4 Discussion and Results

Table 6 summarise the results from the laboratory tests. The results is presented and discussed closer in the subsections below.

Table 6: Resulting index parameters from laboratory experiments.

Soil sample	Active layer	Middle layer	Lower layer
Depth $[m]$	0-1	4,7-4,9	6.7-6.9
Water content, w **[%]**	21.9	9.8	8.8
Pore water salinity, σ $[ppt]$	13	1.12	1.25
Plastic limit , PL **[%]**	21.9	14.02	14.26
Liquid limit , LL **[%]**	33.39	26.64	31.12
Plasticity index , PI	11.49	12.62	16.86
Liquidity index , LI	0	-0.33	-0.32

4.1 Soil type - observations

The soil gathered at 0-1 m depth is dark gray with a big amount of sand and rocks. It was easy to mold into a ball, but imperfect because of the bigger particles. The following soil, between 1 and 3 m depth, appears much more wet and has a lighter colour than the rest of the soils. It feels adhesive, and sticks to the fingers when touched. The soils gathered at a depth of 4,35-4,7 m, 5,5-6,3 m and 6,7-6,9 m appears dryer with more sand and rock. The colour is darker than the soil above 3 m depth. The samples are shown in Figure 2.

As a whole, all the samples felt coarse with a lot of sand and bigger particles. Three different types of soil was observed: 0-1 m with dark colour and a water

content allowing easy molding. 1-3 m with a lighter colour and sticky texture. 4,35-6,9 m with a dark colour and dry texture.

These three layers would preferably have been chosen as our stratigraphic layers where we would define index and thermal properties. But the soil samples were thawed at different days, and due to practical reasons the index properties were investigated for sample number 1, 4 and 6 (as defined in Table 4).

Figure 2: Soil samples during visual inspection.

4.2 Water content

The water contents obtained are shown in Table 7:

Table 7: Water content

Sample	m_s [g]	m_{dry} [g]	m_w [g]	w [%]
Active layer 0-1 m	35,63	29,23	6,40	21,9
Active layer 1-2 m	62,23	51,34	10,89	21,2
Middle layer	43,52	39,63	3,89	9,8
Lower layer	38,05	34,98	3,07	8,8

The active layer has a much higher water content than the middle and lower layer. In the visual inspection the sample from depth 1-2 m looked different from the sample at 0-1 m because of this we found it interesting to take the water content of this sample too. The result didn't show a big difference in the active layer.

Comparing the water content results with the typically water contents presented in Table 1 the active layer has the same water content as Norwegian clay. The middle and lower layer is dryer.

4.3   Density

The mass measurements made in the lab during the test to find the soils particle density is shown in Table 8. In addition, the weight of the empty flask was $m_b = 43,79\ g$, its specified volume was $V = 100,606\ cm^3$, and the mass of the flask with the distilled water was $m_{b+dw} = 144,12\ g$.

Table 8: Masses measured during the density test.

Sample	$m_{Ms}\ [g]$	$m_{Mdw}\ [g]$	$m_{b+s+dw}\ [g]$	$m_c\ [g]$	$m_{c+s}\ [g]$
Active layer	35,94	350,49	148,39	4,36	11,31
Middle layer	40,17	401,52	148,16	4,35	11,09
Lower layer	40,22	403,61	148,43	4,31	11,30

The weight of the bottle m_b was substracted from the masses m_{b+dw}, m_{b+s+dw} to gain the masses m_1 and m_2 respectively, and the mass of the containers m_c from the dried masses m_{c+s} to gain the masses m_3. We can find the density of distilled water using $\rho_{dw} = m_1/V = 100,33/100,606 = 0,99726\ g/cm^3$. The particle density for the soils were calculated using Equation 2, and the results are shown in Table 9.

Table 9: Calculated masses corresponding to the formulas presented in section 2.2.

Sample	$m_1\ [g]$	$m_2\ [g]$	$m_3\ [g]$	$\rho\ [g/cm^3]$
Distilled water	100,33	-	-	0,99726
Active layer	-	104,60	6,95	2,59
Middle layer	-	104,37	6,74	2,49
Lower layer	-	104,64	6,99	2,60

The results show a nearly uniform particle density for the active-, middle- and lower layer.

4.4   Particle size distribution

We calculated the dry soil mass by subtracting the mass of the containers from the mass of the containers with the dry soil mass. The results of the sieving is shown in Table 10:

Table 10: Sieving test

Grain size	Active layer m_{dry} [g]	Middle layer m_{dry} [g]	Lower layer m_{dry} [g]
4,75 mm	2,83	20,25	10,37
2,36 mm	6,23	23,76	18,68
1,18 mm	8,15	25,44	20,19
600 μm	9,00	16,88	14,30
300 μm	11,56	14,30	10,65
150 μm	6,87	11,77	9,75
75 μm	19,60	41,39	32,00
<75 μm	97,32	177,83	135,42

The masses of dried soil usied in the hydrometer test was $m_{0-1m} = 30,48$ g, $m_{4,35-4,7m} = 30,33$ g and $m_{6,5-5,7m} = 30,14$ g. The readings from the hydrometer test is shown in Tables 11, 12 and 13:

Table 11: Hydrometer test active layer

t s	Time	Elapsed	Reading [g/L]
0	10:30	0	32,5
60	10:31	59s	32,0
105	10:31	1m 45s	31,8
240	10:34	3m 58s	31,0
900	10:45	15m	27,0
1 800	11:00	30m	26,1
3 600	11:30	1t	23,4
14 400	14:30	4t	19,0
86 400	10:20	23t 50min	13,0

Table 12: Hydrometer test middle layer

t s	Time	Elapsed	Reading [g/L]
0	10:25	0	31,0
60	10:26	57s	30,9
105	10:26	1m 44s	30,7
240	10:28	3m 56s	29,8
900	10:40	15m	27,2
1 800	10:55	30m	26,2
3 600	11:25	1t	24,0
14 400	14:25	4t	19,9
86 400	10:15	23t 50min	15,2

Table 13: Hydrometer test lower layer

t [s]	Time	Elapsed	Reading [g/L]
0	10:20	0	30,8
60	10:21	62s	29,4
105	10:21	1m 46s	28,3
240	10:24	3m 56s	26,9
900	10:35	15m 3s	24,5
1 800	10:50	30m	22,9
3 600	11:20	1t	21,0
14 400	14:20	4t	17,1
86 400	10:15	23t 55min	14,0

The temperatures and times for the different layers:

- Active layer: $T = 21,0°C$ 11:08 am first day

- Middle layer: $T = 20,5°C$ 11:05 am first day

- Lower layer: $T = 20,5°C$ 11:00 am first day

The results from sieving and hydrometer test is represented in a grain size distribution curve shown in Figure 3.
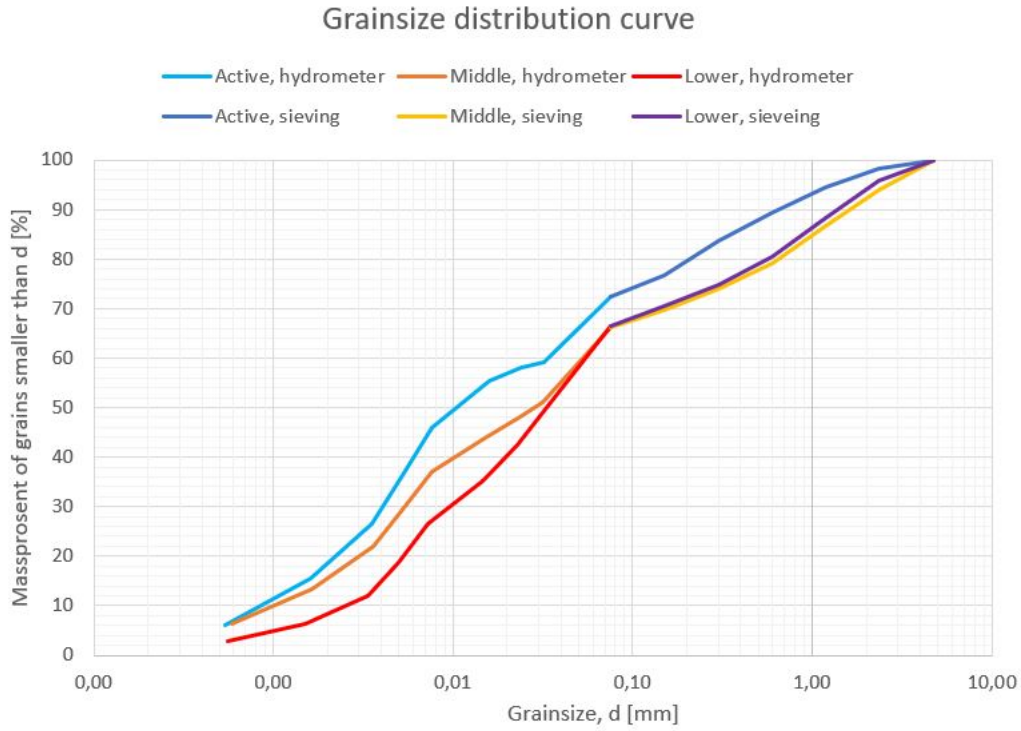
Figure 3: Grainsize distribution curve

Comparing the results in Table 14 with the values in Table 2 all the tree layers are well graded. They also have a curve very similar to each other. This means that the grain size distribution is very similar over the whole depth measured.

Table 14: Grading

	d_{10} $[mm]$	$d_{60}[mm]$	C_u
Active	0,0011	0,0232	30
Middle	0,0012	0,0491	41
Lower	0,0022	0,0471	22

4.5 Pore water salinity

From the first method of measuring salinity for the active layer we got that $\sigma_{0-1m} = 1,3\% = 13$ ppt.

The details and results from the second method is shown in Table 15 where m_s is the mass of soil, m_{dw} is the mass of added distilled water and w is the water content from Table 7:

15

Table 15: Method 2

Sample	σ_1 [ppt]	m_s [g]	m_{dw} [g]	w [%]
Middle layer	0,01	40,01	400,04	9,8
Lower layer	0,01	40,00	400,02	8,8

We then calculated the salinities using Formula 14 with values from Table 15 and the results for the whole salinity test is shown in Table 16:

Table 16: Salinity

Sample	σ [ppt]
Active layer	13
Middle layer	1,03
Lower layer	1,15

There is a clear difference in the salinity measured in the active layer and the two other layers. This can be a result of running water in the lower parts washing away the salinity over time, whilst the active layer have been less affected. If we look at [4] we see the opposite trending i salinity with increasing depth which can indicate that something went wrong under testing.

4.6 Plasticity and liquidity

The calculated plasticity- and liquidity limits are shown in Tables 17 and 18 where m_p is the mass of the plasticity sample, m_l is the mass of the liquidity sample and m_{dry} is the mass of the dried soil:

Table 17: Plasticity

Sample	m_p [g]	m_{dry} [g]	PL [%]
Active layer	-	-	21,9
Middle layer	34,08	29,89	14,02
Lower layer	17,07	14,94	14,26

Table 18: Liquidity

Sample	m_l [g]	m_{dry} [g]	LL [%]
Active layer	32,88	24,65	33,39
Middle layer	49,15	38,81	26,64
Lower layer	37,92	28,92	31,12

Then using the calculated plasticity and liquidity limits we can use Formulas 7 and 8 to calculate the plasticity and liquidity indexes. This is shown in Table 19:

Table 19: Plasticity and liquidity indexes

Sample	PI	LI
Active layer	11,49	0
Middle layer	12,62	-0,33
Lower layer	16,86	-0,32

Using Table 2-3 "Unified Soil Classification System" and Figure 2-6 "Plasticity chart" from p.28-29 from [1] we can find that all three soil samples can be described as inorganic clays of low to medium plasticity because the liquid limit and plasticity index puts it over the a-line and the plasticity index is above 7. For the active layer the liquid index is 0 because the water content is equal to the plasticity index. For the middle and lower layers, the liquid index is below zero which indicates that the soil is hard and brittle.

According to standard NS8003 describing the plasticity test, if it was possible to achieve a thread of 3,2 mm without adding water we should have remolded and rolled it multiple times until it fell apart in several places when reaching a diameter of 3,2 mm, and then weighing it. This would then give us a lower plasticity limit which then again would give an increased plasticity index and a changed liquid limit. We can therefore say that the active layer most likely has some different properties than what we have found. The simplification made when not removing grains bigger than 0,4 mm is a source of error that might have affected the liquid limit.

The active layer has a high liquidity resulting in a less firm layer compared to the middle- and lower layers which are both hard and brittle. In the case that the permafrost now present in the soil would thaw, the soil is likely to be more unstable in the active layer than further down through the middle- and lower layers.

4.7   Thermal Parameters

Using the density measured in 4.3 inserted in the equations presented in 2.5 the thermal conductivity is presented in Table 20. Assuming frozen soil and saturation $S_r \approx 1$ Kersten number K_e is also equal to 1. Using Equation 9 to find the dry density the thermal conductivity is calculated with Equation 10 with the unfrozen water content $w_u = w$ and presented in Table 20.

Table 20: Thermal conductivity

	ρ [g/cm^3]	w [%]	Thermal conductivity [W/mK]
Active layer	2,59	0,219	4,095
Middle layer	2,49	0,098	5,335
Lower layer	2,6	0,088	5,458

4.8   Geological settings

The drilling site is situated on the delta of Longyeardalen (Longyear-valley), a side valley to Adventdalen. As seen on Figure 4 and 5 it lays on the border between an area with bedrock consisting of mainly shale, siltstone and sandstone, and an area with a ground layer of glaci-fluvial deposits (KILDE TIL BILDENE?). Longyearelva (Longyear-river) transport meltwater and sediments for about four months a year, and is frozen the rest [5]. This means that the site is situated on a river delta greatly consisting of glaci-fluvial deposits. In addition it lays underneath the Holocene marine limit [5], and has a close proximity to the coastline.
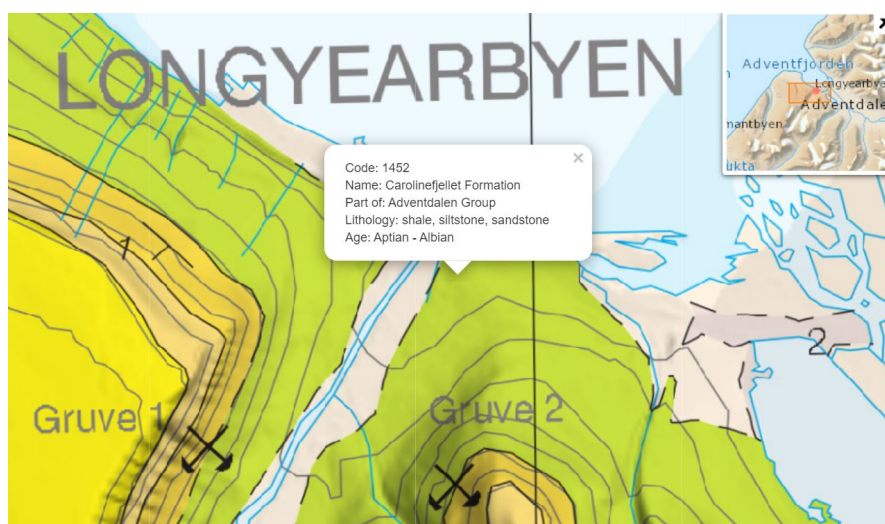

Figure 4: Caption

Figure 5: Caption

Longyearelva running thorugh the soil, the close proximity to the sea and the location below the Holocene marine limit are all factors that may have contributed to the salinity of the soil. Gilbert et al. [4] found the salinity in close proximity and just a slightly lower altitude (the UNIS East site) to be 1.0-14ppt in the active layer. Our measurements gave a salinity of 13ppt in the active layer, and we therefore considered it to be a reasonable result. The much lower salinity measured in UGH's middle and lower layer are a bit lower but also reasonable when comparing with Gilbert's measurements made for U3, D3 and D2 (see Table 23 and 22). This lower salinity value could be a result of Longyearelva washing the soil of these layers.

The grain size distribution curve of the UGH site is similar to the curve representing the active layer in the Adventdalen site (D3) [4], though D3 has slightly more fines. The water content at D3 was typically 10-30%, which places the water content found in the active layer at UGH (measured to 21,9%) to be within the values measured by Gilbert er al. The lower water content found in the middle- and lower layers at UGH are a lower than those found by Gilbert et al [4] for the same depths, but only slightly lower than the lower range of 10% found in U1 (see table 22.

The plasticity limit measured at he UGH site's active- and lower layer is very close to the results found by Gilbert [4] on the UNIS East site. The plasticity of the middle layer does however deviate from the measurements made at U2. The

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liquid limits and plasticity index found at UGH corresponds well to the liquid limits found by Gilbert at U3 and U2.

Table 21: Table 6 repeated for easier comparison to Gibson et al's results. Resulting index parameters from laboratory experiments of the soil from the UGH test site.

Soil sample	Active layer	Middle layer	Lower layer
Depth $[m]$	0-1	4,7-4,9	6.7-6.9
Water content, w [%]	21.9	9.8	8.8
Pore water salinity, σ $[ppt]$	13	1.12	1.25
Plastic limit , PL [%]	21.9	14.02	14.26
Liquid limit , LL [%]	33.39	26.64	31.12
Plasticity index , PI	11.49	12.62	16.86
Liquidity index , LI	0	-0.33	-0.32

Table 22: Characteristic index parameters found by Gilbert et al. (2019) [4] in soil stratigraphic layers, UNIS East site.

Example number of soil beds	U3	U2	U1
Depth $[m]$	0-3	Approx. 3-24	Approx. 24-30
Soil type	Interlayered sand and gravel. Gravelly, silty sand.	Weakly laminated to massive silty mud. Silty clay.	Diamicton with muddy matrix. Sandy, silty clay.
Water content, w [%]	18-30	18-30	10-21
Pore water salinity, σ [ppt]	1.0-14	20-40	30-32
Plastic limit, PL [%]	18-20	20-22	16-21
Liquid limit, LL [%]	24-32	27-37	23-34
Plasticity index, PI [%]	5-11	8-17	2-15

Table 23: Characteristic index parameters found by Gilbert et al. (2019) [4] in soil stratigraphic layers, Adventdalen site.

Example number of soil beds	D3	D2	D1
Depth $[m]$	0-3	3-16	16-30
Soil type	Silt. Sandy clayey silt. Ice-enriched permafrost.	Interlayered graded sand and silt. Silty sand.	Laminated to weakly-laminated muds. Clay or silty clay.
Water content, w [%]	Typically 10-30. Up to 150	28-35	28-35
Pore water salinity, σ [ppt]	1.0-4.8	4.8-72, increasing downwards	32-79
Plastic limit, PL [%]	-	-	20-22
Liquid limit, LL [%]	-	25-30	30-38
Plasticity index, PI [%]	-	-	-

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