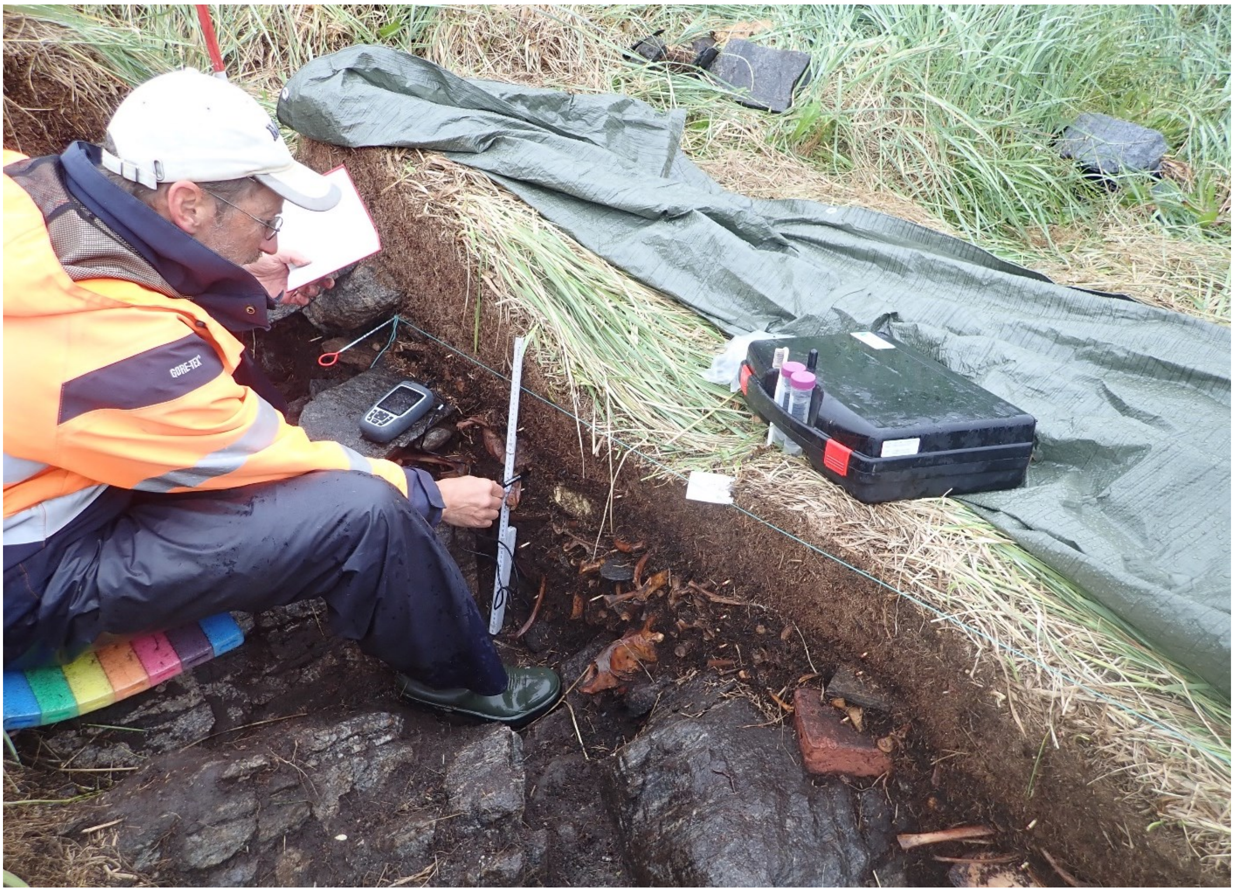


Aasivissuit-Nipisat field report 2019-23: Investigations at Nipisat, Arajutsisut, Saqqarliit and Aasivissuit.

Activating Arctic Heritage, WP2.1 Hidden in the Midden

NKAH numbers 5534, 5526, 285, 2609 and 2845 / KNK numbers 4202, 4203, 4201,

WP 2.1 Hidden in the Midden. Report no 20803-5

Authored by Henning Matthiesen, National Museum of Denmark, October 2023.

Sponsored by The Carlsberg Foundation

Introduction

Activating Arctic Heritage is a research projects coordinated by the two National Museums in Greenland and Denmark, respectively. The present report describes field work carried out by one of the work packages (WP2.1 Hidden in the Midden) in the Aasivissuit-Nipisat World Heritage area from 2019 to 2023. It serves as a data deposit for all field data, and updates and replaces two previous reports (Matthiesen, 2021, 2022). Prospections and small test pits from 2019 is not included in detail here but may be found in an earlier field report (Matthiesen, 2020).

Monitoring equipment was installed in 2019 and 2021, where especially the 2021 fieldwork involved excavation of larger trenches and test pits at Nipisat, Arajutsisut, Saqqarliit and Aasivissuit. Most sites were revisited in 2022 for download of data and change of batteries in the logging equipment. In 2023 fieldwork focused on download of data and removal of monitoring equipment from Nipisat and Saqqarliit (August 2023). Monitoring equipment at Arajutsisut and Aasivissuit was not removed as the monitoring will continue at these two sites also after the AAH project.

This report presents measurements of environmental conditions in the trenches, comprehensive sampling of soil for different analyses, installation of monitoring equipment at four locations, along with all monitoring data from Nipisat and Arajutsisut from the period 2019-2023, and from Saqqarliit and Aasivissuit from the period 2021-2023. It should be read in context with the archaeological reports (Jensen et al., 2022) where the trenches and find material is described in more detail, and with reports by Anne Birgitte Gotfredsen describing the composition and the preservation state of the sampled bone material (Gotfredsen, 2020;Gotfredsen, 2023). The report shall inform a discussion of the preservation conditions at the sites and help interpreting site formation process and future preservation.

Background

The environmental measurements and monitoring focuses on a few key parameters that are decisive for the preservation of (most) archaeological materials, that is the pH, temperature, oxygen presence and soil moisture, which is supplemented by a few other parameters (soil porosity, soil components, grain size and conductivity). Details about these parameters are described in e.g. Gregory and Matthiesen (2023), but a very brief description is given here concerning their importance and requirements for monitoring.

pH: Influences the degradation of for instance bone and shell, where a low pH gives increased leaching of their mineral content (Matthiesen et al., 2021). However, the influence goes both ways as a high content of bone or shell in the soil can also buffer soil pH toward the neutral region. pH is a relatively stable parameter (except in the upper most root zone) with limited annual variation and continuous logging is not necessary

Temperature: Influences the degradation of most materials, where increased temperature results in increased decay rates. The transition between frozen/not frozen conditions is especially important, as decay is very slow under frozen conditions (Matthiesen et al., 2014) and as freeze/thaw transitions may physically damage some objects. Spot measurements of temperature in open soil profiles are of little use, instead continued logging is used to map annual variations.

Oxygen presence: Oxygen is a key controlling factor for the degradation of buried archaeological materials, as it is the most reactive and powerful oxidant in the natural environment. Direct measurement of oxygen is possible, but difficult, and in this project its presence or absence is estimated indirectly. Evidence from other sites with organic soils indicate that oxygen is mainly present when the air content of the soil exceeds

10-15% vol (Matthiesen et al., 2015). The air content may be calculated as the porosity minus the water content of the soil.

Water content: Influences the oxygen transport in the midden as the diffusion of oxygen through water is extremely slow, which means that high water contents can decrease oxygen supply and decay rates. However low water contents can also influence the decay, as the microbial activity may be lowered if the soil becomes sufficiently dry, and very dry conditions can also cause shrinkage and collapse of materials such as wood (Lauridsen et al., 2023). This drying is monitored through soil matrix potential measurements. The water content may be highly variable over time, and spot measurements should be supplemented by continuous logging.

Soil porosity and soil components: The soil porosity determines the maximum water content and air content in the soil, which is important in relation to oxygen supply (above). The organic content is important both in relation to the vulnerability towards degradation and for the water retention of the soil, as organic matter has a large water binding capacity.

Grain size and conductivity: The grain size is important in relation to water retention, as for instance fine grained material such as silt will bind water better than sand. Furthermore, grain size may help understand the source of the (inorganic) material, e.g. whether it is fluvial or aeolian. The conductivity may help tracing soil water sources and movement in the soil, where for instance a supply of salt spray from the sea will give a high conductivity.

Measurements of the environmental parameters must be supplemented with an understanding and/or measurements of how the parameters influence the different archaeological materials, but this is not covered in the present report.

Sites

The fieldwork focused on four locations in the Aasivissuit-Nipisat World Heritage area, that is: Nipisat, Arajutsisut, Saqqarliit and Aasivissuit (Figure 1)

Figure 1: Locations visited during 2019-23 fieldwork. Map from Google Earth.

At Nipisat two long trenches (ca 1x6 m) were excavated: one at Våningshuset (NKAH 5526 / KNK 4203, at N 66°48.790' W 053° 30.705'), and one in the midden next to the Thule long house (NKAH 5534 / KNK 4202, at N 66°48.759' W 053° 30.952') – Figure 2. The locations were based on results from a number of testpits in 2019 (Matthiesen 2020).

At Arajutsisut (NKAH 285 / KNK 4201) two trenches were made: One was placed at the entrance of an old Thulehouse (ca 1x3 m, at N 66°52.581' W 053° 36.365') termed Ara7 – this was an extension of the 2019-excavation (termed “section 2” in Appelt et al 2020) which stopped at frozen soil layers at 60 cm depth in 2019. The other (ca 1x3 m, at N 66°52.581' W 053° 36.365') was placed in the midden at Ara9 where frozen midden layers occurred already at ca 30 cm depth and where the excavation had to take place with a few cm every day - Figure 3. Continued excavation of the Ara9 trench was carried out in 2022.

At Saqqarliit (NKAH2609) a small test pit (ca 0.3x0.3 m, at N 66°52.137' W 052°27.486') was made in the midden area, close to Jens Fog Jensens test excavation from 2019 (Appelt et al., 2020, p 17). The pit was mainly dug in order to install soil sensors for monitoring and time did not allow a detailed description of the layers - Figure 4.

At Aasivissuit (NKAH2845) a 2 m section of a former excavation trench from 1978 was widened by ca ¼ m (termed Aasivissuit2 trench) in 2021 (Jensen et al 2022). Ca. 2 m from the trench a small test pit (50x50 cm, at N 67°05.998' W 051° 07.726') was dug in undisturbed midden layers (termed Aasivissuit1 test pit) – Figure 5. A number of photos were taken at Aasivissuit to document changes in the vegetation between 1978 and 2021 (appendix 1).

Apart for the excavation trenches, natural reference samples were taken at Nipisat, Arajutsisut and Aasivissuit.

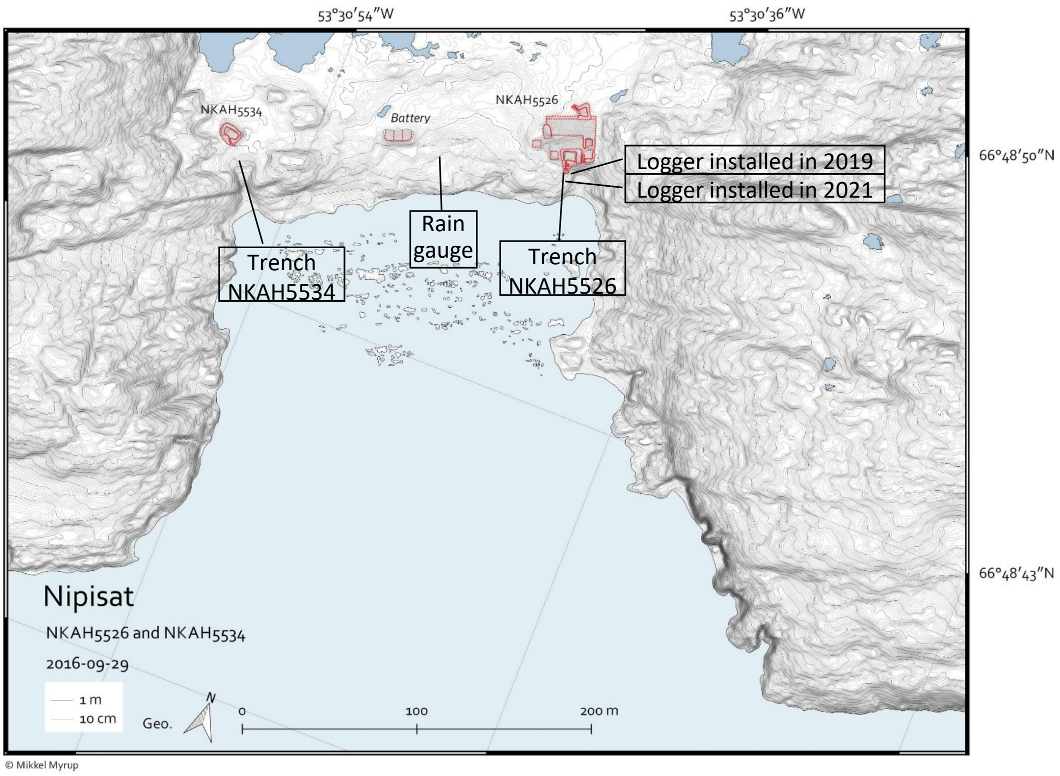


Figure 2: Location of test pits and monitoring equipment at Nipisat

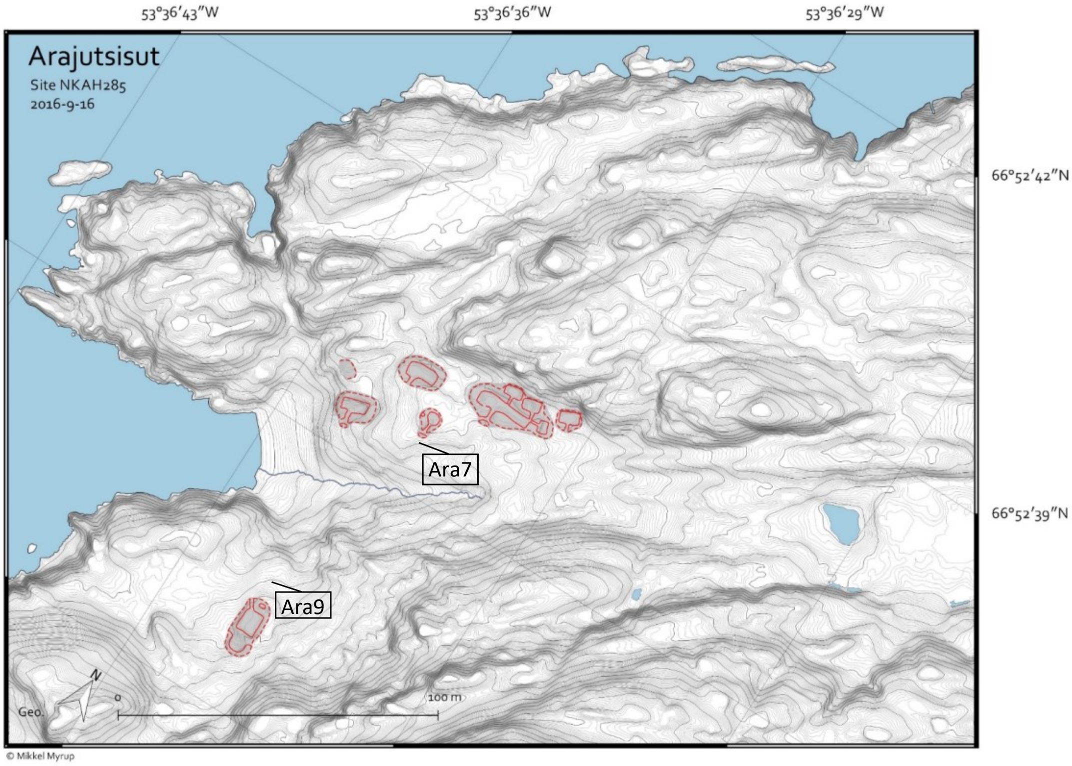


Figure 3: Location of test pit and monitoring equipment at Arajutsisut

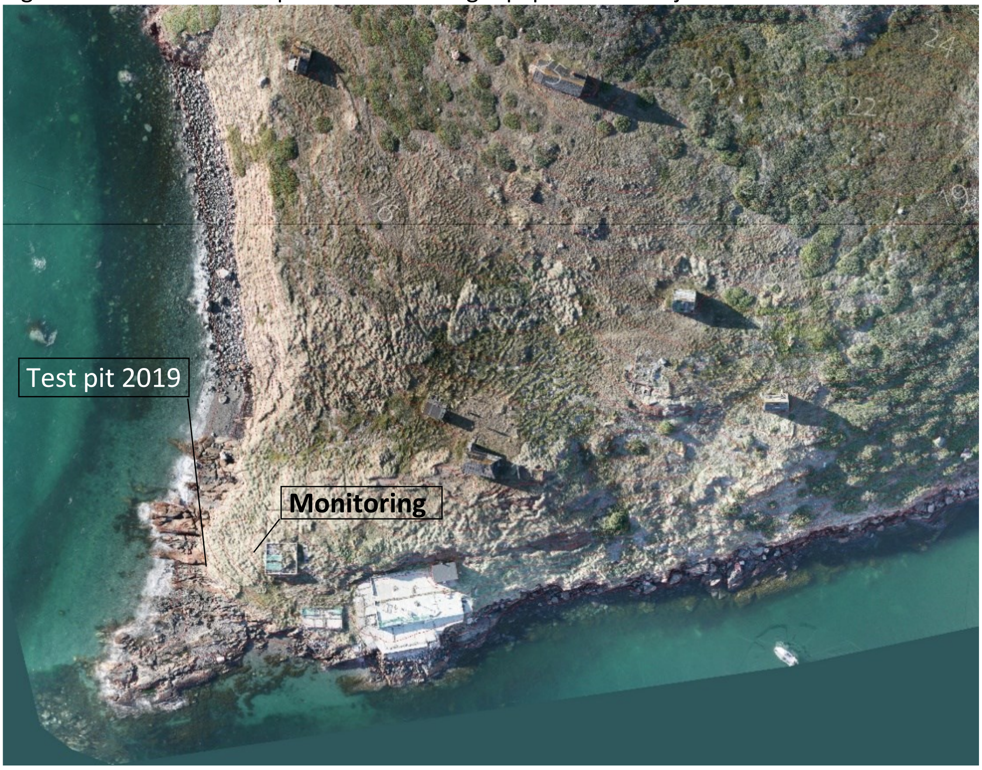


Figure 4: Location of monitoring equipment at Saqqarliit. Map: Mikkel Myrup

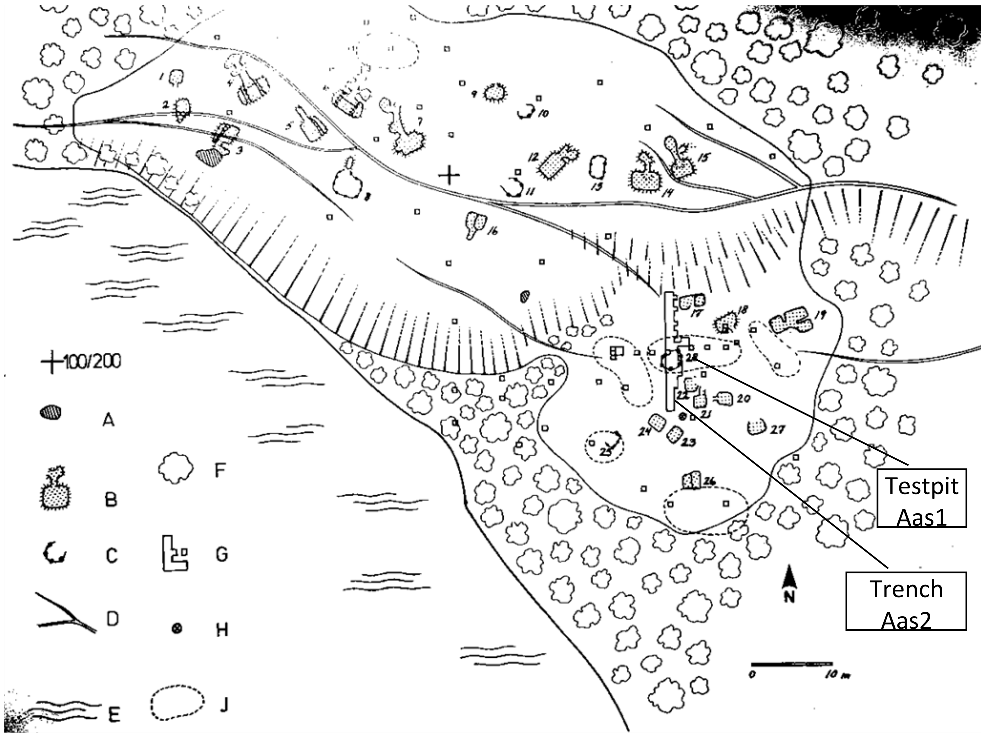


Figure 5: Location of excavations at Aasivissuit. Monitoring equipment was installed in testpit Aas1. Map from (Grønnow et al., 1983)

Methods

Environmental measurements were made in the trenches and test pits during and immediately after excavation. pH was measured for each 5-10 cm depth using a solid state pH electrode (LanceFET from Sentron) that was pressed directly into the soil profile. Water content and conductivity was measured with a WET-probe (Delta T instruments) for each 5-10 cm depth. Soil ring samples of 100 cm^3 volume were taken at selected depths, for subsequent laboratory measurement of water content (drying at 105 °C), organic content (loss-on-ignition when heated to 450 °C), and inorganic content (weight after ignition). The data were used to calculate the soil porosity and soil air content as described in Matthiesen et al. (2015). Soil ring samples could not be taken in all layers due to a high content of bone. Grain size analysis was carried out on soil samples after ignition, i.e. where all organic material had been removed. The grain size was measured by sieving samples in a standard rack of sieves with aperture ranging from 0.0625 mm to 2 mm.

Sterile samples for eDNA studies and lipid analysis was taken at selected profiles. All tools for sampling were cleaned in between each use with 15% sodium hypochlorite and rinsed with 96% ethanol. The outer 2-3 cm of the profiles were removed with sterile tools, before the actual sampling took place. Two samples of a few cm^3 volume were taken from each depth, and transferred to sterile bags.

Bulk soil samples (non-sterile) were taken from each archaeological strata, using the material that was removed before sterile sampling. Samples of bone, antler, wood, feather, baleen, and iron were selected for preservation studies in the laboratory. Modern wood samples of birch and pine were installed at NKAH 5526 for degradation studies.

Monitoring equipment for logging of temperature, soil water content and soil matrix potential was installed in four trenches/pits (details below). For the water content, ML3 or SM300 sensors (Delta T Instruments) connected to a DL6 logger (Delta T) were used, with a logging frequency of 6 or 12 hours. For the soil matrix potential EQ3 sensors (Delta T) connected to the DL6 loggers were used. For soil temperature, TinyTag and HOBO sensors were used, with a logging frequency of 2 or 6 hours. All cabling was protected by armoured hose. The loggers were placed in Pelicases with cable glands, and the glands were sealed with silicone in order to make them more water tight.

A rain gauge and air temperature/RH sensor (both from HOBO) was installed on a 2 m mast at Saqqarliit. The rain gauge is not equipped with a heating element and will not measure precipitation in the form of snow. A rain gauge with TinyTag logger was installed at Nipisat in 2019, which was supplemented by a HOBO logger with air temperature/RH sensor and more soil temperature sensors in 2021.

TinyTags and DL6 logger at Arajutsisut were installed at Ara7 in 2019, and was moved to Ara9 in 2021, after download of data and exchange of batteries. Unfortunately, a polar fox disturbed the setup and spoiled all cables at Ara9, so in 2022 it was replaced by Tinytags and a DL6 logger from Nipisat.

Results and preliminary discussion

The results are presented and discussed separately for each site.

NKAH 5526 (Våningshuset / Nipisat east), excavation trench.

A trench of 1x6 m was made in the midden downhill of NKAH 5526 in the period 3/8-24/8/2021 in an area covered by Lyme grass (*Elymus Mollis*). A grid was laid out with x100/y200 in the SE corner closest to the sea, and x99/y206.5 in the NW corner uphill close to the Vaaningshus. Details of the excavation are given in Jensen et al. (2022). Figure 6 shows the whole profile. Five different strata were identified: Layer 1: dense root felt from Lyme grass, Layer 2: cultural deposit with degraded bones, Layer 3: compact dense layer, very rich in bones, Layer 4: similar to layer 3 but with different orientation of bones, Layer 5: degraded natural organic layer. Beneath layer 5 was bedrock. The layers were far from horizontal but followed the topography of the underlying rocks. A more comprehensive layer description is given in Jensen et al 2022, p 17-18, along with dating of the midden (in their Appendix 7). Most of the midden postdates the Danish colony (1729-31), and the site was abandoned in the late 18th or earliest part of the 19th century, i.e. the material in the midden is between 200-300 years old.

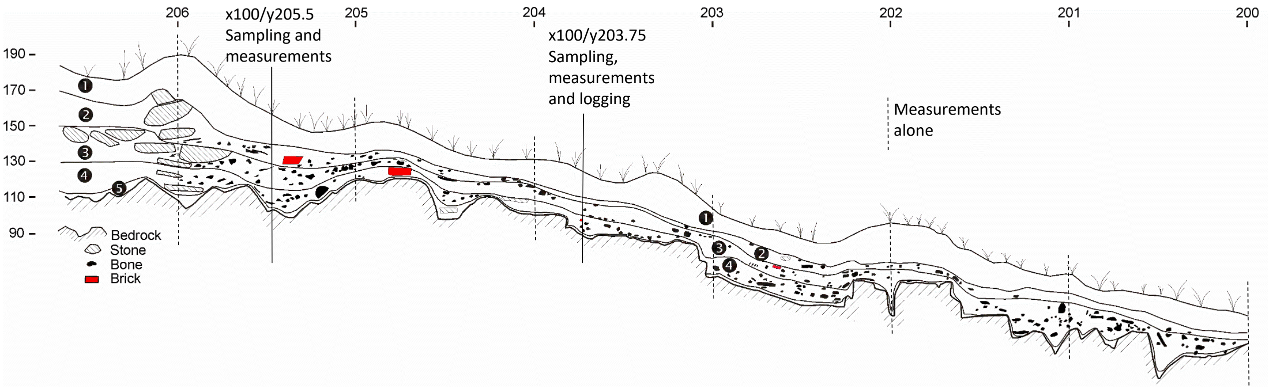


Figure 6: Drawing of excavated profile at NKAH5526 with measuring, sampling, and monitoring positions

Environmental measurements were carried out at 9 positions along the x100 profile on the 15/8 and 19/8/2021. Figure 7 presents results from all measurements showing some general tendencies for the whole profile: The conductivity is relatively constant around 50 mS/m, with slightly higher values in the upper layers and at x100/y200 (closest to the sea) which could be due to sea spray. The pH increases with depth from typically pH 4-5 in the upper layers to pH 7 in the deeper layers (discussed below). The water content is typically 20-40 %vol (with drier top layers) but should be interpreted with caution as the trench had been open and the upper layers exposed for ca 3 weeks before the measurements took place, which may dry out some of the layers.

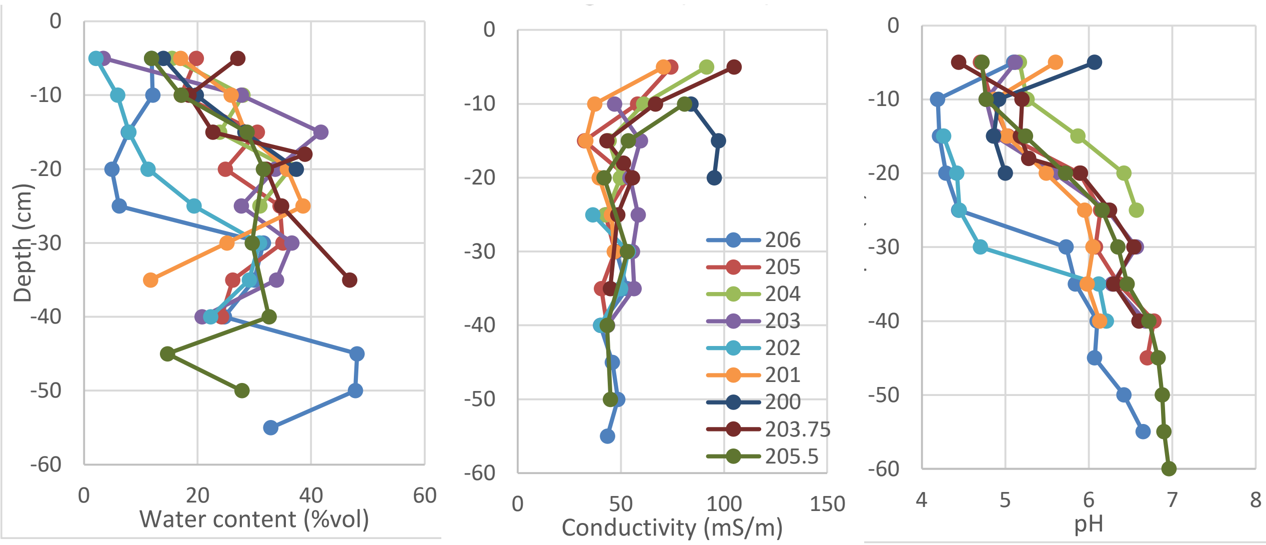


Figure 7: Environmental measurements at 9 y-positions along the x100 profile at NKAH5526

Two places on the profile were selected for more detailed studies: x100/y203.75 and x100/y205.5 (Figure 8).

Figure 8. Trench at x100/y205.5, ruler 61 cm

Trench at x100/y203.75, ruler 41 cm.

At position x100/y205.5 the stratigraphy was: 0-17 cm: layer 1; 17-29 cm: layer 2; 29-41 cm: layer 3; 41-55 cm: layer 4; 55-66 cm: layer 5. Bedrock beneath 66 cm. Bulk samples were taken from each layer. Sterile samples were taken at 10, 18, 23, 28, 31, 36, 39, 42, 49, 54, and 60 cm depth.

At position x100/y203.75 the stratigraphy was: 0-17 cm: layer 1; 17-20 cm: layer 2; 20-29 cm: layer 3; 29-39 cm: layer 4; 39-42 cm: layer 5. Bulk samples were taken from each layer. Sterile samples were taken at 7, 17, 22, 25, 28, 30, 34, 38, and 41 cm depth. Ring samples were taken at 10, 18, 25 and 38 cm depth. Installation of monitoring equipment included ML3 sensors for water content at 10, 18, 25 and 38 cm depth, and EQ3 sensors at 18 and 25 cm depth, measuring every 6 hours. HOBO temperature sensors were installed at surface, 10, 18, 25 and 38 cm depth, monitoring every 6 hours. Modern wood samples from Nanna Bjerregaard were installed at surface, 10, 18, 25 and 38 cm depth, attached to ML3 sensor cables – these samples were retrieved in August 2023 when the sensors and datalogger was removed. Results from in situ measurements and ring samples are given in Figure 9.

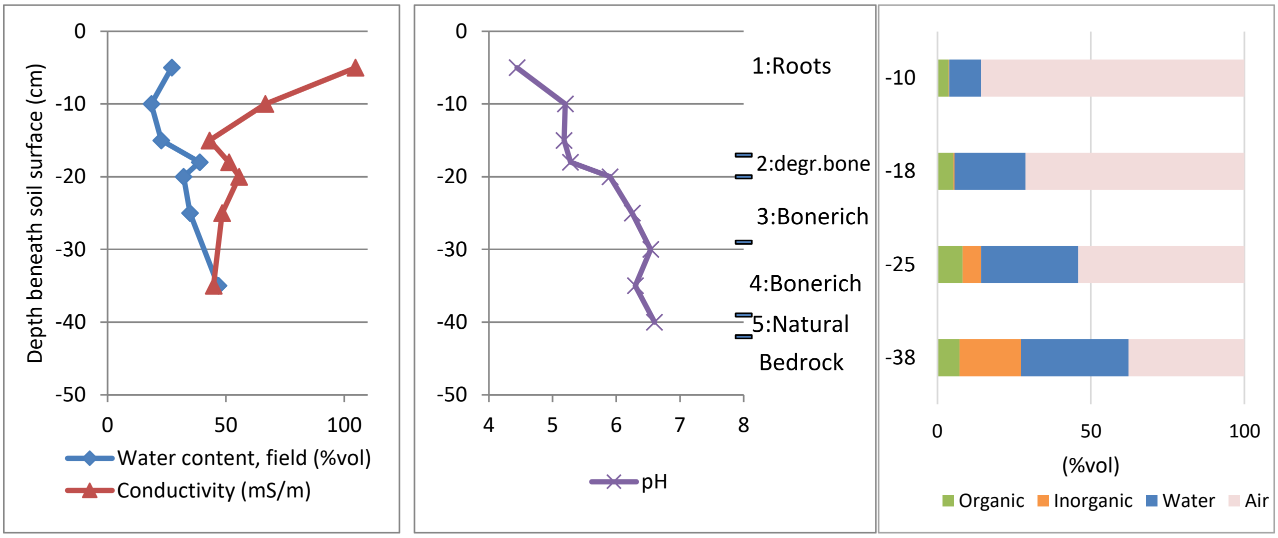


Figure 9: Field measurements and results from ring samples taken at position x100/y203.75 at NKAH5526

The results show that the deposits are highly porous: the soil porosity is 94-96 %vol in the upper layers, and only decreases to 73 %vol at 38 cm depth. There is a high air content in all layers, which indicates fully oxygenated conditions, and this seems to be the case for most of the year as indicated by the continuous logging of water content in the backfilled trench (Figure 13). The conductivity values are moderate with higher values in the top layers, which indicates a small influence from sea water/salt spray. Regarding pH, the results indicate a correlation to bone preservation as observed at other sites (Matthiesen et al., 2021): the pH is low (4-5) in the upper soil layers (possibly due to root respiration and low buffering effect of the soil), whereas in the deeper soil layers the pH raises to 6-7 due to buffering from the massive amounts of bones. Grain size analysis of the inorganic part of layer 4 (Figure 10) shows that it mainly consists of poorly sorted, fine to medium sand. The grain size may influence the water retention in the midden, however, there will also be an effect from the large amounts of organic material in the midden.

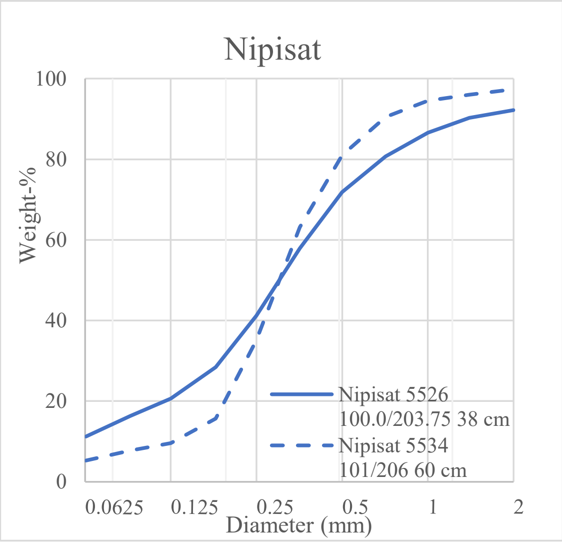


Figure 10: Grain size analysis for samples from Nipisat (NKAH5526 and 5534). All organic material was removed by ignition of samples before analysis.

Monitoring data 2019-2023:

In 2019, a weather station with a rain gauge was installed by Jørgen Hollesen <100 m away from the excavation trench (Figure 3), and with this two sensors for measuring temperature in air (unshielded, ca 1 m above the soil surface) and in natural soil at the frozen/thawed interface (the exact depth was not registered). In August 2021 this was supplemented with a HOBO logger with a shielded air temperature/RH sensor at 1 m above ground, and temperature sensors at the soil surface and at 20 cm depth. Data from these temperature measurements are presented in Figure 11. The rain gauge tends to become clogged, and there are long periods where it registers significantly less rain than at the DMI weather station in Sisimiut – therefor the Sisimiut data are used in the following.

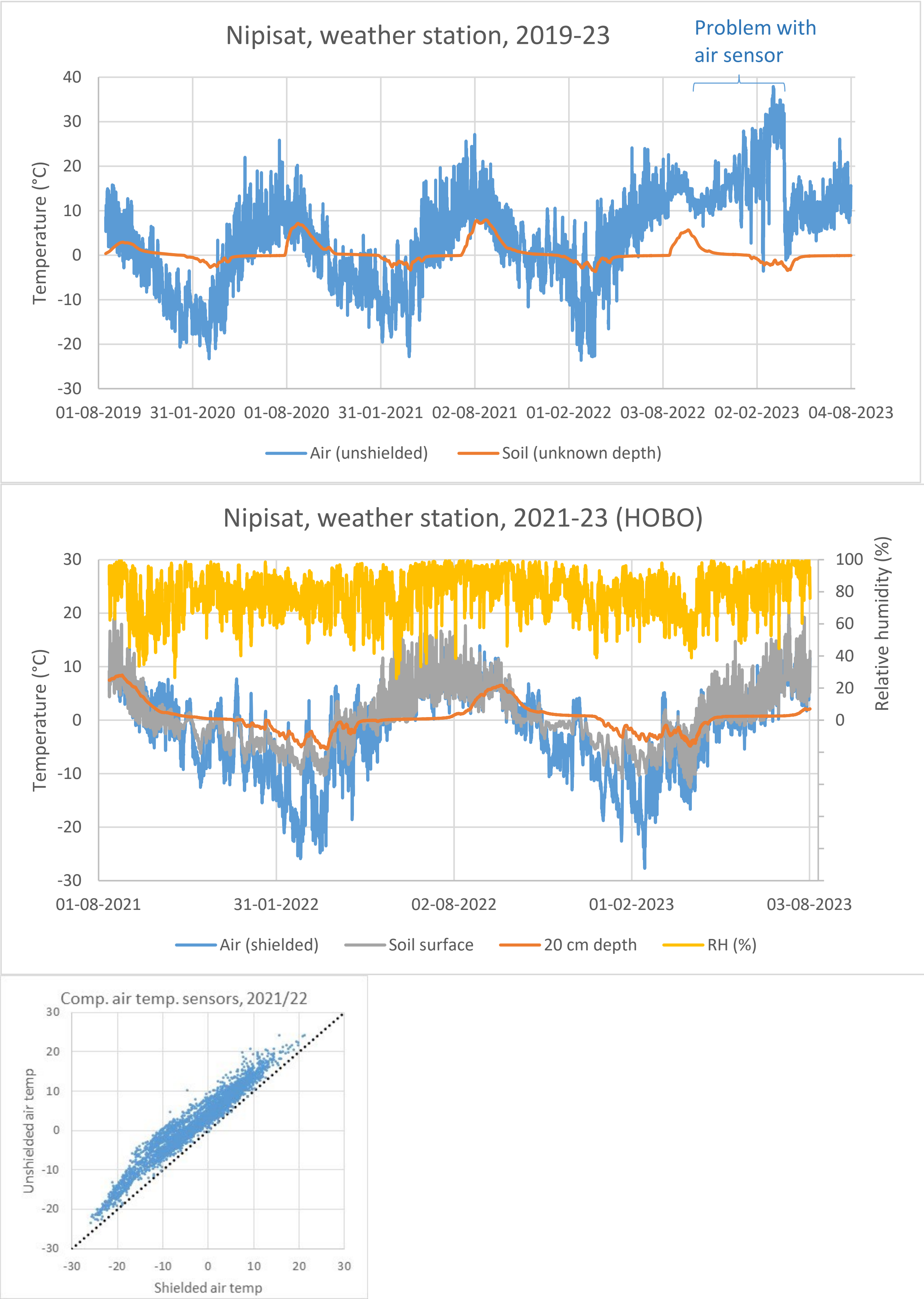
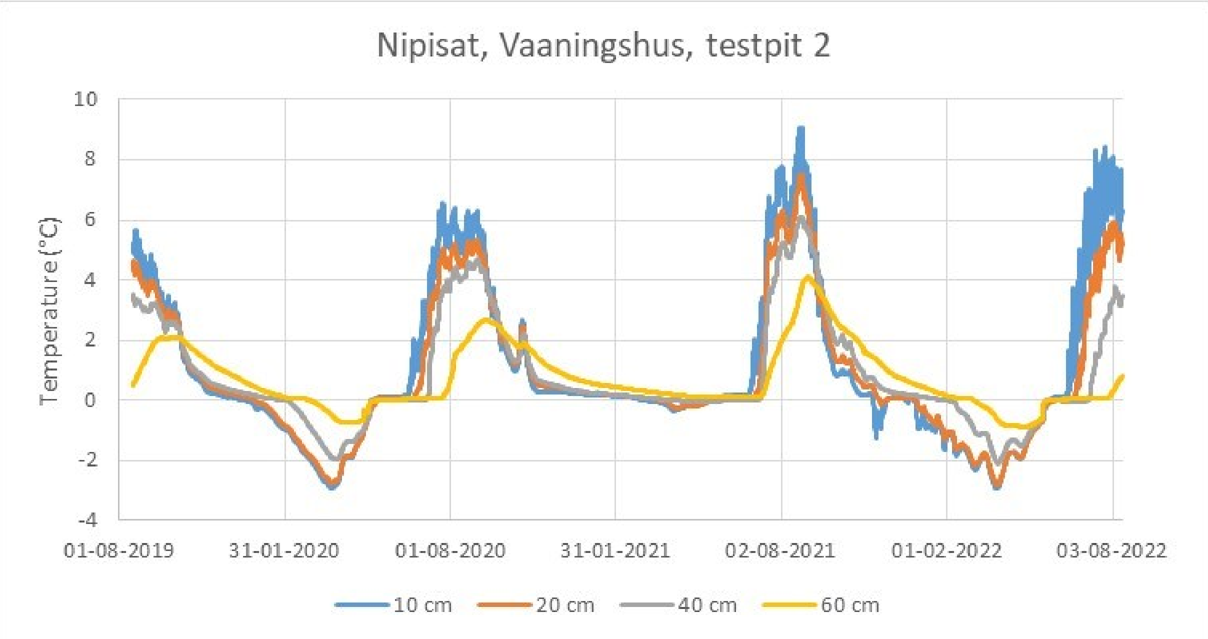


Figure 11: Temperature measurements at the weather station. Top: 2019-22 (with unshielded air temperature sensor), middle: 2021-22 (with shielded air temp. sensor), bottom: comparison between the two air temp. sensors

Comparison between the two air temperatures sensors (Figure 11, bottom) shows that the unshielded sensor mounted in 2019 gives significantly higher temperature values (typically 0-10 °C higher) probably due to direct sun on the sensor or due to direct contact with the heat conducting mounting pole. Furthermore, the temperatures from November 2022 to April 2023 seem unrealistically high for the unshielded probe. Thus the absolute values should not be over-interpreted, but still they give an impression of the temperature fluctuations over the last 4 years (Figure 11, top). Data from 2021-23 with the shielded air temperature sensor (Figure 11, middle) shows that the air temperature drops down to -25 °C during winter, but also that there are several occasions during winter with air temperatures above 0 °C. The data also shows that the air is relatively moist in this coastal location, with an average relative humidity of 80 % RH.



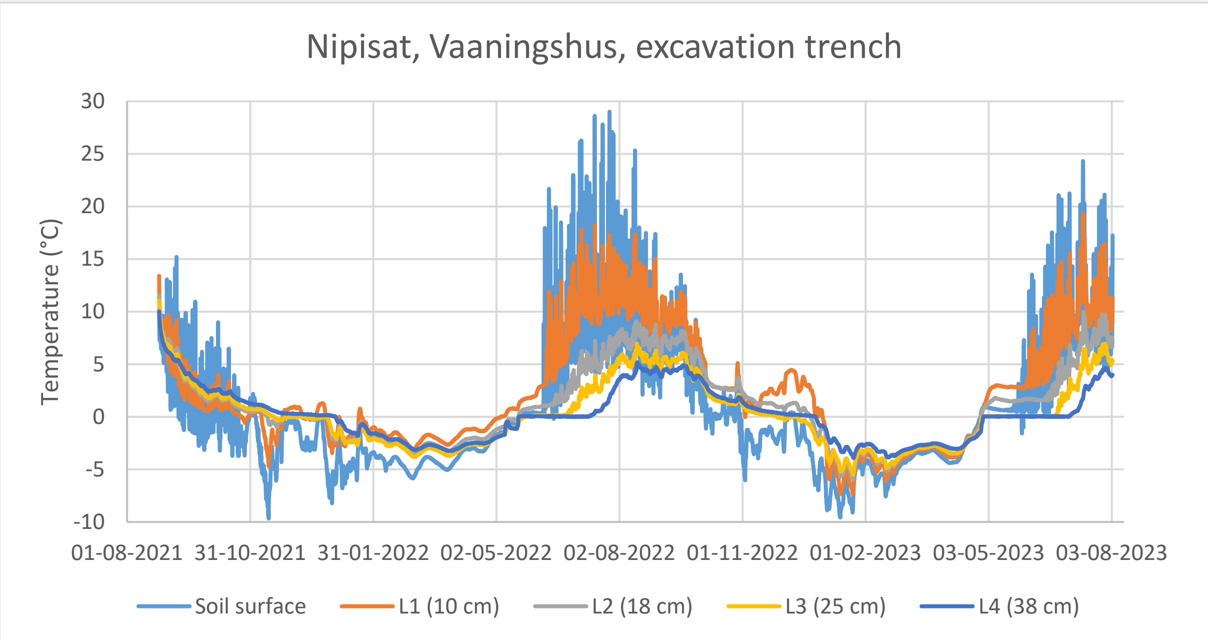


Figure 12: Temperature measurements in midden at Vaaningshuset. Note different scales for the test pit (upper) and the excavation trench (lower). L1-L4 indicates layer 1-4.

Moving to the midden, the first monitoring equipment was installed in 2019 in a small test pit (#2) approximately 2 m from the 2021-trench, as described in the previous report (Matthiesen, 2020). It consisted of four SM300 soil moisture sensors and four TinyTag temperature sensors installed at 10, 20, 40, and 60 cm depth. No drilling equipment was available so all sensors were installed in soil layers that were thawed at the site visit. The last data were downloaded in August 2022 (by Malte Skov Jensen) after which the data logger and sensors from test pit #2 were moved to Arajutsisut (Ara9) to replace sensors destroyed by a polar fox. In 2021 different data loggers and sensors were installed directly in the excavated profile as described above, and here the last data were downloaded in August 2023 (by Jørgen Hollesen) after which the sensors were removed.

The soil temperature data in the test pit shows variations between -3 to +9 °C over the 3 year monitoring period (Figure 12, top). The upper three sensors at 10, 20 and 40 cm show a close correlation to fluctuations in air temperature with a modest delay, whereas the deepest sensor at 60 cm shows a delay of ca 1 month in both thawing and freezing. The long period around 0 °C indicates ongoing freezing or thawing of water in the deposits, a phenomenon called the “zero curtain effect”. The temperatures do not get very low during winter, and in the winter 2020/21 the cultural deposits at 40 and 60 cm depth do not reach negative temperatures. The winter 2021/22 shows fluctuating temperatures in the ground, but the soil layers don’t thaw. Compared to this the temperature measurements in the excavation trench (Figure 12, bottom) show a larger variation and more abrupt fluctuations. It cannot be excluded that the temperatures are influenced by the opening and backfilling of the excavation trench, even if it was attempted to re-establish the conditions as good as possible. The sensor at 10 cm depth shows repeated freezing and thawing during the winter, and only the deepest sensor at 38 cm depth shows a well developed zero curtain where the temperature is stable at 0 °C for a prolonged period. The sensor at 10 cm depth seems to show some drift as it shows an unexpected increase in temperature during December 2022, and as it appears to have a “zero curtain” at 2.8 °C during spring 2023. Around mid-May the upper soil layers thaw, and from the beginning of June in both 2022 and 2023 the daily temperature variations increase substantially as the soil dries out (below). The soil at 38 cm depth thaws around mid-July, which is also the case for the 40 cm sensor in test pit 2.

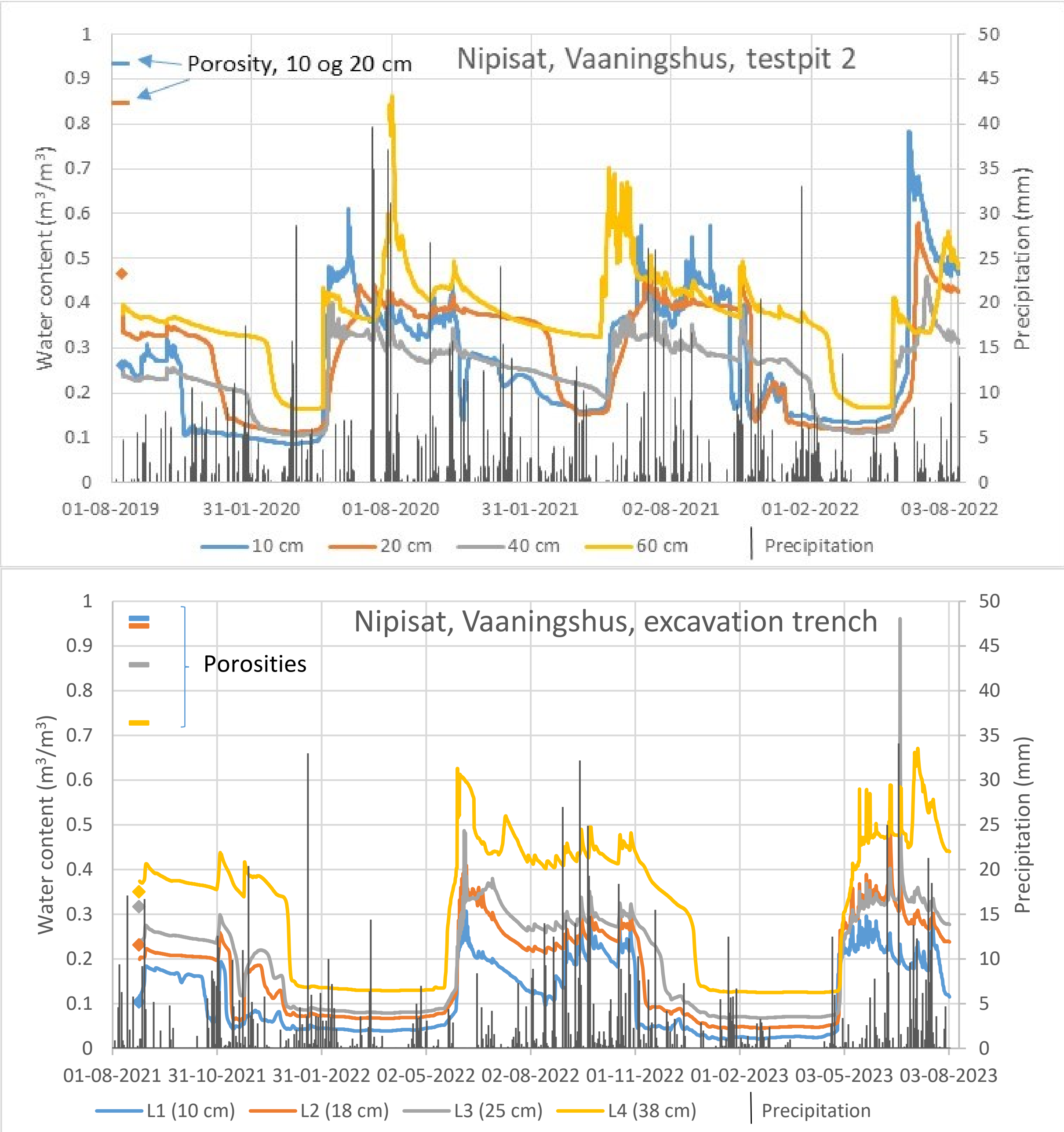


Figure 13: Water content measurements in midden at Vaaningshuset.

Results on soil moisture are presented in Figure 13, along with precipitation data. The rain gauge at Nipisat was clogged and gave unrealistic low precipitation values so precipitation data from a weather station in Sisimiut have been used instead (downloaded from DMI at https://www.dmi.dk/vejrarkiv/ station Mitt.Sisimiut).

The water content sensors are designed to measure fluid water whereas ice only gives a weak response. This means, that the low water contents during winter do not indicate loss of water, but rather that the water has been frozen to ice. In test pit 2 (Figure 13, top) there is a gradual freezing of water in the different layers and in 2019 it is observed that for instance at 10 cm depth the soil water freezes around 1.

September, at 20 cm all water is frozen by the end of December, at 40 cm it takes until beginning of February and at 60 cm it takes until end of February before all water is frozen, which is also reflected in the temperature data. In 2020/21, there is fluid water at 60 cm depth during the whole winter, which was also reflected in the temperature values that didn't reach negative values (Figure 12, top). The winter 21/22 is similar to the 2019/20 winter, but this time even the deepest layer at 60 cm freezes. In spring, there is an abrupt input of water in all layers at the beginning of May in both 2020 and 2021 and end May/beginning og June in 2022, probably due to melting snow. During summer there is a fair correlation between the precipitation at Sisimiut and the water content in the soil, and for instance the heavy rain events in July and August 2020 show up clearly in the soil moisture. Moving to the excavation trench (Figure 13, bottom), the data show a similar pattern as in test pit 2 with a good correlation between precipitation and water content increases. The uppermost layer 1 shows an extra freeze-thaw event in October 2021, where the soil is first frozen, then thaws before it re-freezes mid-November. For layer 2 and 3 there seems to be a thawing event during December before these layers are frozen again in January. The summer 2023 is characterised by relatively high water content in the different soil layers due to frequent precipitation events.

Concerning the absolute numbers, the water contents of the test pit and excavation trench are between 15-50% vol most of the time. For comparison the soil porosity at 10 and 20 cm in test pit 2 were measured to 94 and 85% vol, respectively, while the excavation trench shows porosities between 73 and 96 %vol. The high porosity and relatively low water content means that the deposits have a high air content, and it is estimated that there have been oxic conditions in the deposits most of the monitoring period. The only exception is a short period during spring 2022 and summer 2023, where the air content in the lowermost layer 4 at 38 cm depth is less than 15%vol for some weeks – it cannot be excluded that there may be temporary anoxic conditions in the deepest layers at this point.

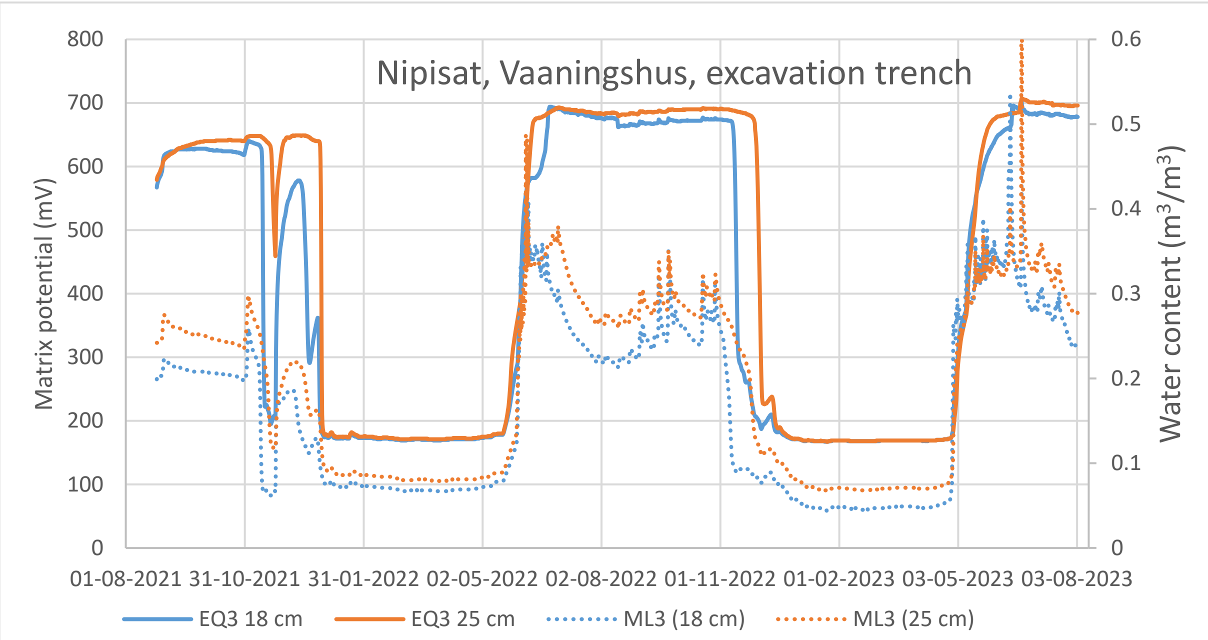


Figure 14: Matrix potential measurements in excavation trench (solid lines). Volumetric water content measurements in the same soil layers are shown for comparison (dotted lines)

Measurements of water matrix potential are shown as raw data (mV) in Figure 14. The matrix potential is also called suction pressure and has the unit –kPa; it may be calculated from the raw data using a calibration curve. The measuring range for the sensors goes up to ca 600 mV (corresponding to a matrix potential of approx. -10 kPa), and any measurement above 600 mV indicates that the soil is moist and that we cannot document drying-out effects. Like the ML3 sensors the EQ3 sensors only measure fluid water and not ice, and the low values measured during winter are caused by freezing rather than drying. Overall, the data in Figure 14 shows that there is no severe drying of the midden deposits during summer.

To summarize, Figure 12-14 indicates that the midden deposits are permanently moist but not waterlogged, and the decay through oxidation is not limited by neither very dry nor anoxic conditions. The deposits are quite acidic in the uppermost layers which may cause degradation of the uppermost bones. However, the deposits are frozen for several months every year, where the decay will be limited due to lack of fluid water.

NKAH 5534 (langhuset / Nipisat west), excavation trench.

A trench of 1x5 m was made in the midden downhill of NKAH 5534 in the period 3-24/08/2021 in an area covered by Lyme grass (*Elymus Mollis*). A grid was laid out with x101/y201 in the SE corner closest to the sea, and x100/y206 in the NW corner uphill closer to the longhouse. Details of the excavation are given in Jensen et al (2022). Figure 15 shows the whole profile. Six different strata were identified: Layer 1: dense root felt from Lyme grass, Layer 2: cultural deposit from colonial time with degraded bones, Layer 3: compact dense layer, rich in bones, Layer 4: pre-colonial, very rich in bones, with some sand, Layer 5: degraded natural organic layer, Layer 6: sand/gravel. Beneath layer 6 was bedrock. The layers were far from horizontal but followed the topography of the underlying rocks. More detailed layer descriptions may be found in Jensen et al (2022) page 18-19, including dating of the layers on page 19 and in Appendix 7: layer 4-5 are pre-colonial (carbon dates 1470-1625 CEcal, 1 std.dev), layer 3 is uncertain if it is pre-colonial or if parts of it has accumulated after the Vaaningshus was abandoned in 1731, layer 2 is probably no later than 18th or early 19th century. Thus the material from layer 4-5 is probably 400-550 years old, and from layer 2 probably 200-300 years old.

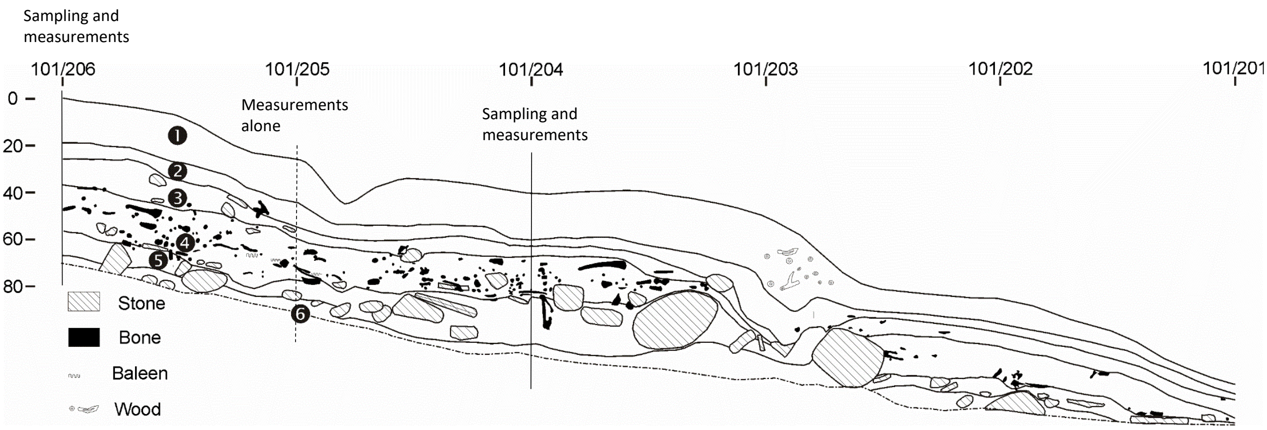


Figure 15: Drawing of excavated profile at NKAH 5534 with measuring, sampling, and monitoring positions

Environmental measurements were carried out at 3 positions along the x101-profile on the 15/8 and 20/8. Figure 16 gives results from all measurements showing some general tendencies along the profile: The conductivity is relatively constant around 50 mS/m, with slightly higher values in the upper layers which could be due to sea spray. The pH increases with depth from typically pH 4-6 in the upper layers to 7 in the deeper layers. The water content increases with depth from 10-20 %vol in the top layers to 50-70 % vol in the deepest layers. The water contents should be interpreted with caution as the trench had been open and the upper layers exposed for ca 3 weeks before the measurements took place, which may dry out some of the layers. All in all, the data are similar to what was observed at NKAH5526 (Figure 7).

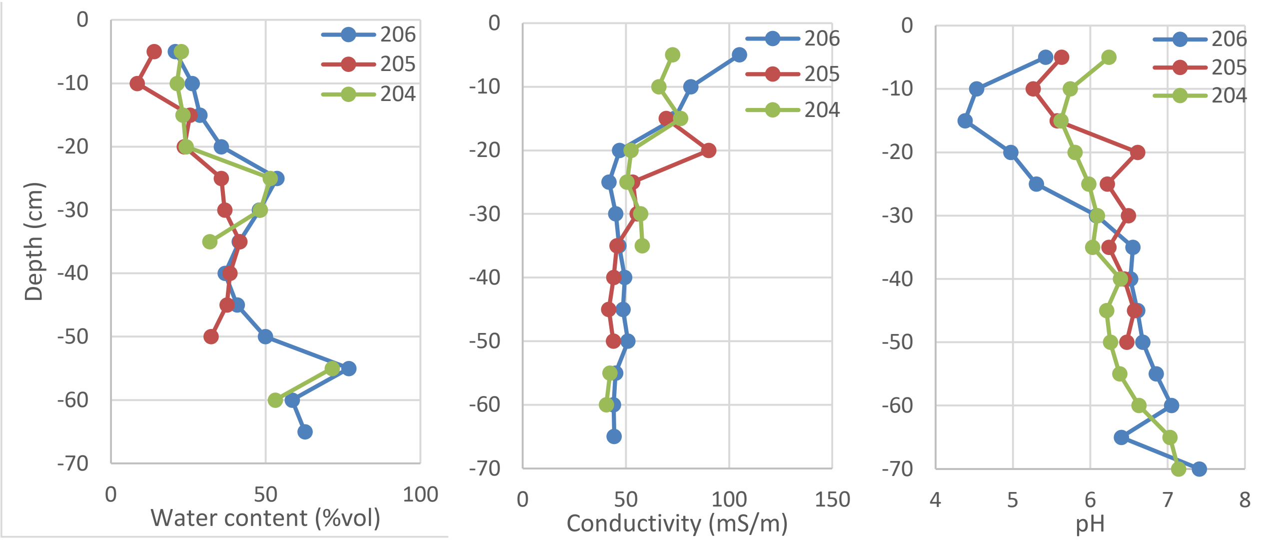


Figure 16: Environmental measurements at 3 positions along the x101 profile at NKAH5534

Two places on the profile were selected for more detailed studies: x101/y204 and x101/y206 (Figure 17).

Figure 17. Trench at x101/y206, ruler 69 cm

Trench at x101/y204, ruler 69 cm.

At position x101/y206 the stratigraphy was: 0-19 cm: layer 1; 19-26 cm: layer 2; 26-39 cm: layer 3; 39-57 cm: layer 4; 57-68 cm: layer 5; 68-74 cm: layer 6, bedrock beneath 74 cm. Bulk samples were taken from layer 1-5. Sterile samples were taken at 10, 20, 25, 27, 32, 37, 42, 47, 52, and 61cm depth. Ring samples were taken at 10, 22, 33, 46 and 60 cm depth. At position x101/y204 the stratigraphy was: 0-19 cm: layer 1; 19-25 cm: layer 2; 25-29 cm: layer 3; 29-47 cm: layer 4; 47-69 cm: layer 5; 69-70 cm: layer 6; bedrock beneath 70 cm. Bulk samples were taken from layer 1-5. Sterile samples were taken at 10, 21, 26, 28, 31, 38, 43, 52, 58, and 63 cm depth. No logging equipment was installed. Results from in situ measurements and ring samples at x101/y206 are given in Figure 18.

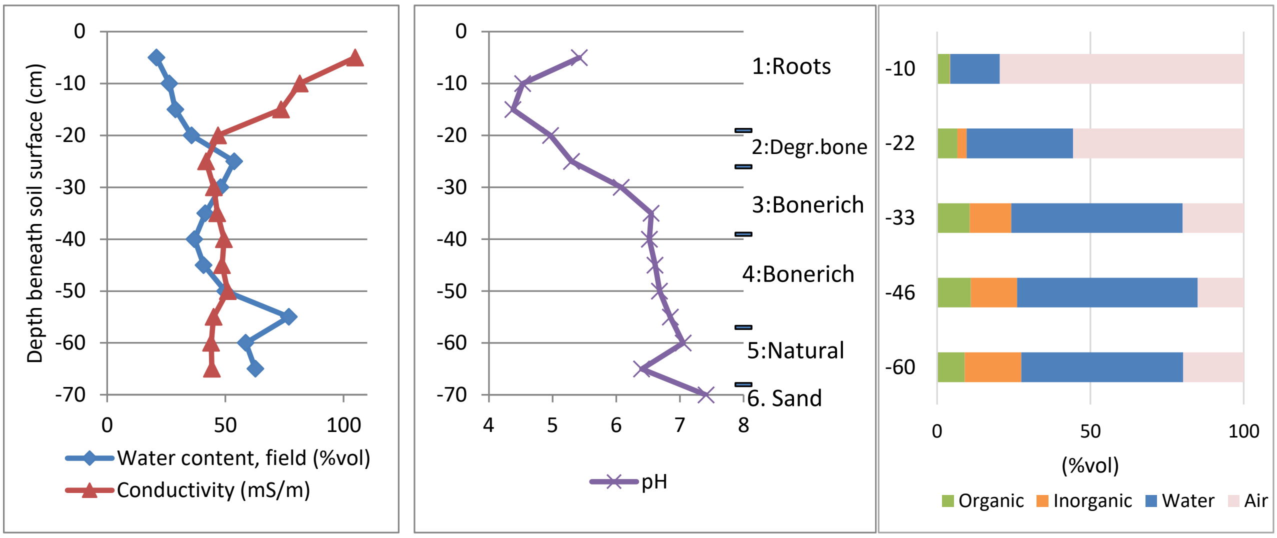


Figure 18: Field measurements and results from ring samples taken at position x101/y206 at NKAH5534

The results show that the deposits are highly porous: the soil porosity is 90-96 %vol in the upper layers, and only decreases to 73-75 %vol in layer 3-5. The air content is high in the upper layers, but decreases to 15-20 %vol in layer 3-5. Normally, oxic conditions are expected at air contents above 10-15 %vol, which could indicate oxic conditions in all layers. However, water contents are highly variable and the water content can be both lower and higher in other periods – on the one hand the measurements shown in Figure 18 were carried out in a quite wet period, but on the other hand opening the trench is likely to cause loss of water from the open profiles. It is considered likely that there can be (almost) waterlogged and anoxic conditions at least in some periods, but without logging it is difficult to be sure. The conductivity values are moderate and indicate a limited influence from sea water/salt spray. Regarding pH, the results indicate a correlation to bone preservation as observed at other sites (Matthiesen et al 2021): the pH is low (pH 4-5) in the upper soil layers (possibly due to root respiration and low buffering effect of the soil), whereas in the deeper soil layers the pH raises to 6-7 due to buffering from the massive amounts of bones. Grain size analysis of the inorganic part of layer 5 (Figure 10) shows that it mainly consists of relatively well sorted, fine to medium sand. The sand is better sorted than at NKAH5526, which could indicate a different source or transport of the sand. The grain size may influence the water retention in the midden, however, there will also be an effect from the large amounts of organic material in the midden.

To summarize, the midden deposits at NKAH5534 have a higher water content than at NKAH5526, and there may be periods with anoxic conditions – however the extent and duration cannot be estimated without continuous logging of water content. The deposits are quite acidic in the uppermost layers which may cause degradation of the uppermost bones, but the deeper layers are pH neutral and relatively thick. Overall, the conditions for bone preservation seem to be slightly better here than at NKAH5526.

NKAH 285 (Arajutsisut), Ara7, at the entrance to ruin 7.

A trench of 1x4 m was made in the midden at the entrance to ruin 7, as a continuation of a 60 cm deep test pit from 2019 (Appelt et al 2020), in the period 8-26/08/2021 in an area covered by grasses. A grid was laid out with x300/y400 in the SE corner and x301/y404 in the NW corner. There deeper layers were frozen, and could only be excavated after thawing. Details of the excavation are given in Jensen et al (2022). Figure 19 shows the whole profile. Five main strata were identified: Layer 0: root turf with sphagnum, Layer 1: sandy humus with degraded bones, Layer 2: sandy humus with many bones and wood, Layer 3: alternating layers of yellowish sand and sandy humus, Layer 4: greasy black humus with low amounts of sand, Layer 5: brown-yellow sand without any finds. The stratigraphy is described in more detail in Jensen et al (2022) page 31, and dating in Appendix 7. Layer 2-3 are difficult to date but may go back to 16th century, layer 1 is dated to the 18th century, and the site was abandoned in the late 18th or earliest part of the 19th century. Thus the material from layer 2-3 is probably up to 500 years old, and from layer 1 probably 200-300 years old.

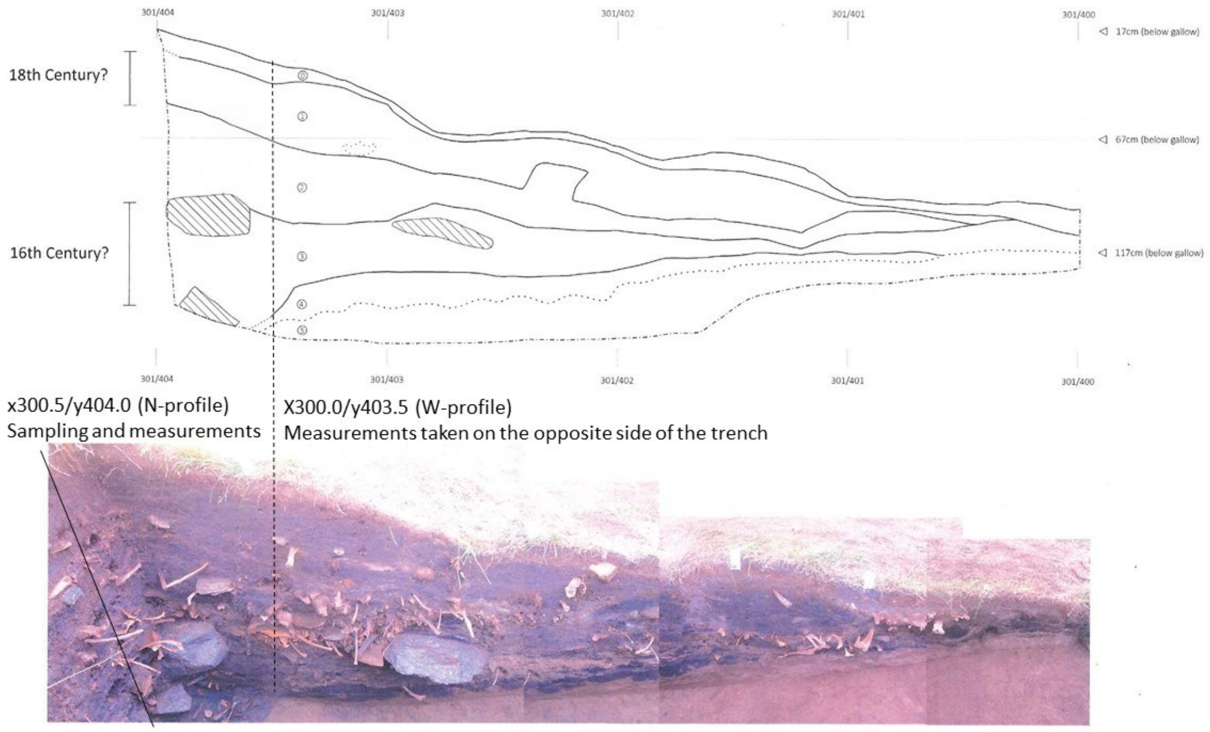


Figure 19: Drawing and photo of excavated East-profile at Ara7 (by M.Appelt) with measuring and sampling positions added. Note that measurements and monitoring took place on W-profile (not visible here), and that it had markedly fewer bones than the E-profile shown here

Environmental measurements were carried out at 2 positions on the 16/8 (at x300/y403.5) and 23/8/2021 (at x300.5/y404.0). Figure 20 shows the results from all measurements from the trench. Included are also measurements from the test pit in 2019 as described in Matthiesen (2020) – they were carried out 22/8/2019 approximately at x300.0/y403.75 in the 2021 measuring system. The results show some general tendencies: The conductivity is relatively constant around 40 mS/m, with slightly higher values in the deepest layers. The pH increases with depth from pH 4-6 in the upper layers to 7-8 in the deeper layers. The water content increases from 30-40 %vol in the top to 50-60 %vol in the deeper deposits. The results from 2019 and 2021 are very similar.

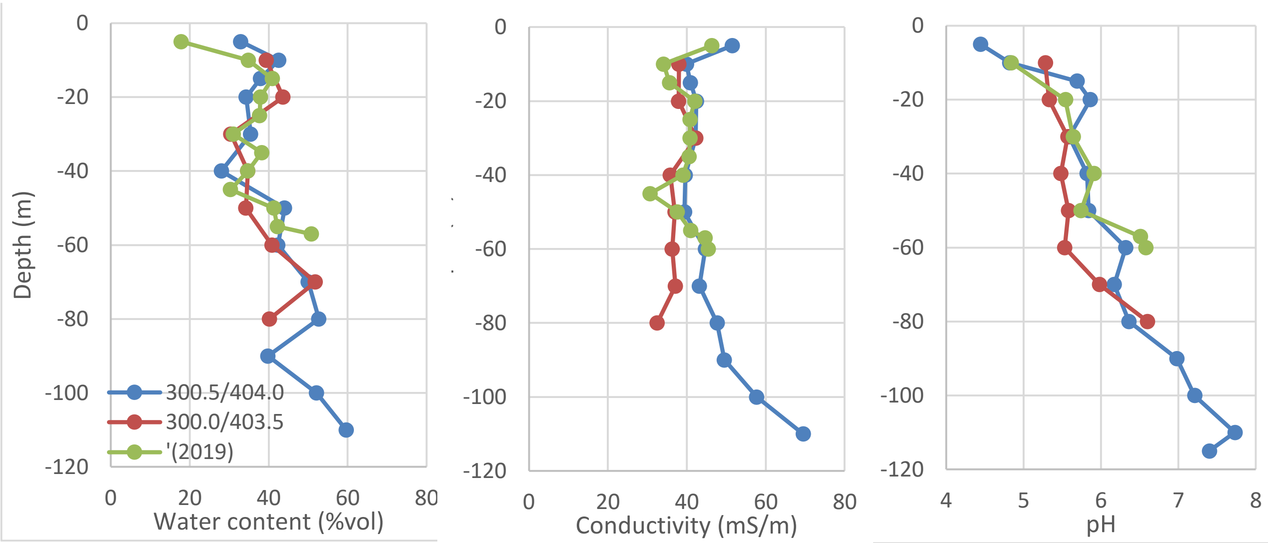


Figure 20: Environmental measurements at 3 positions in the excavation trench at Ara7

More detailed studies were carried out at x300.5/y404.0 (Figure 21).

Figure 21. Ruler placed at x300.7/y404.0, and sampling took place on both sides of it. Ruler length 118 cm

At position x300.5/y404.0 the stratigraphy was: 0-8 cm: layer 0, 8-48 cm: layer 1, 48-75 cm: layer 2, 75-118 cm: layer 3 (layer 4 was not reached at this position due to frozen soil). Bulk samples were taken for each 10 cm. Sterile samples were taken at 5, 10, 20, 30, 40, 50, 60, 70, 80, 90, 100, 110 cm depth (supplemented by a sample from layer 4 at 300.0/403.2). Pollen samples were taken at 30, 50, 70, 90 and 110 cm depth.

Ring samples were taken at 10, 30, 50, 70, 90, and 110 cm depth. Results from in situ measurements and ring samples are given in Figure 22.

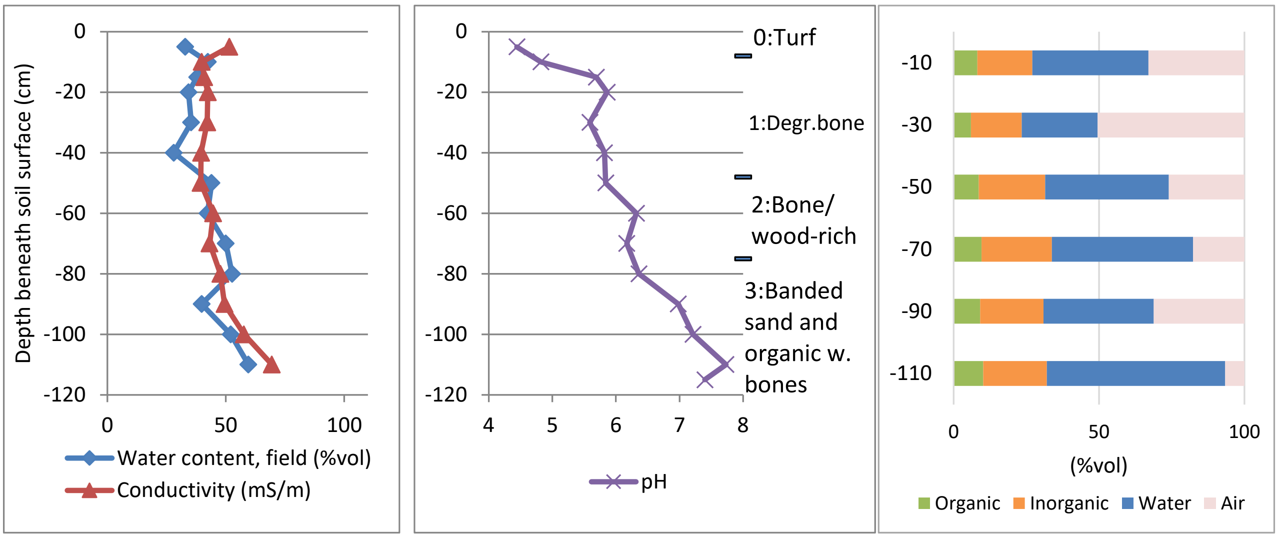


Figure 22: Field measurements and results from ring samples taken at position x300.5/y404.0 at Ara7

The results show that the deposits are less porous compared to the two trenches at Nipisat (above): the soil porosity varies between 66-77 %vol, and there is a higher content of inorganic material, which consist of material from surrounding degrading rock/sandstone. Grain size analysis of two samples from Ara7 shows a well sorted sediment with most material in the range 0.2 to 1 mm (Figure 23), i.e. medium to coarse sand. There are high air contents in most layers (apart from the deepest at 100 cm depth), but this may be influenced by the open test pit (where water may be able to drain from the sandy layers) so it should be compared to the continued logging of water from 2019-2021 (Figure 24). The conductivity values are moderate and indicate a limited influence from sea water/salt spray. Regarding pH, the results indicate a correlation to bone preservation as observed at other sites: the pH is low (pH 4-5) in the uppermost soil layers (possibly due to root respiration and acidic sphagnum turf), between 5-6 in the intermediate layer 1 with degraded bone, and in the deeper soil layers with substantial amounts of bone the pH raises to 6-8.

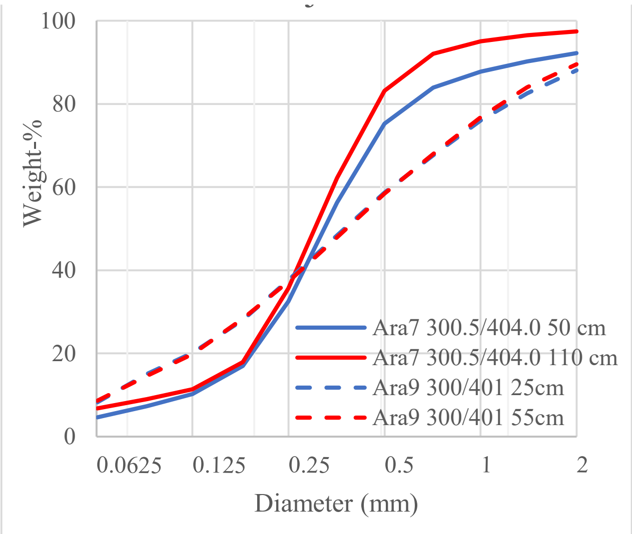


Figure 23: Grain size analysis for samples from Arajutsisut (Ara7 and Ara9). All organic material was removed by ignition of samples before analysis.

Monitoring data 2019-2023:

In 2019, monitoring equipment was installed in the trench at x300.0/y403.75 as described in the previous report (Matthiesen 2020). It consisted of four SM300 soil moisture sensors at 10, 20, 40, and 60 cm depth and four TinyTag temperature sensors at 10, 20, 40, and 73 cm depth. No drilling equipment was available so all sensors were installed in soil layers that were thawed after the 2019 excavation. Data from the loggers were downloaded in 2021 and are presented in Figure 24, together with precipitation data from Sisimiut. After download of data the monitoring equipment was moved to Ara9 on the 23/8/2021.

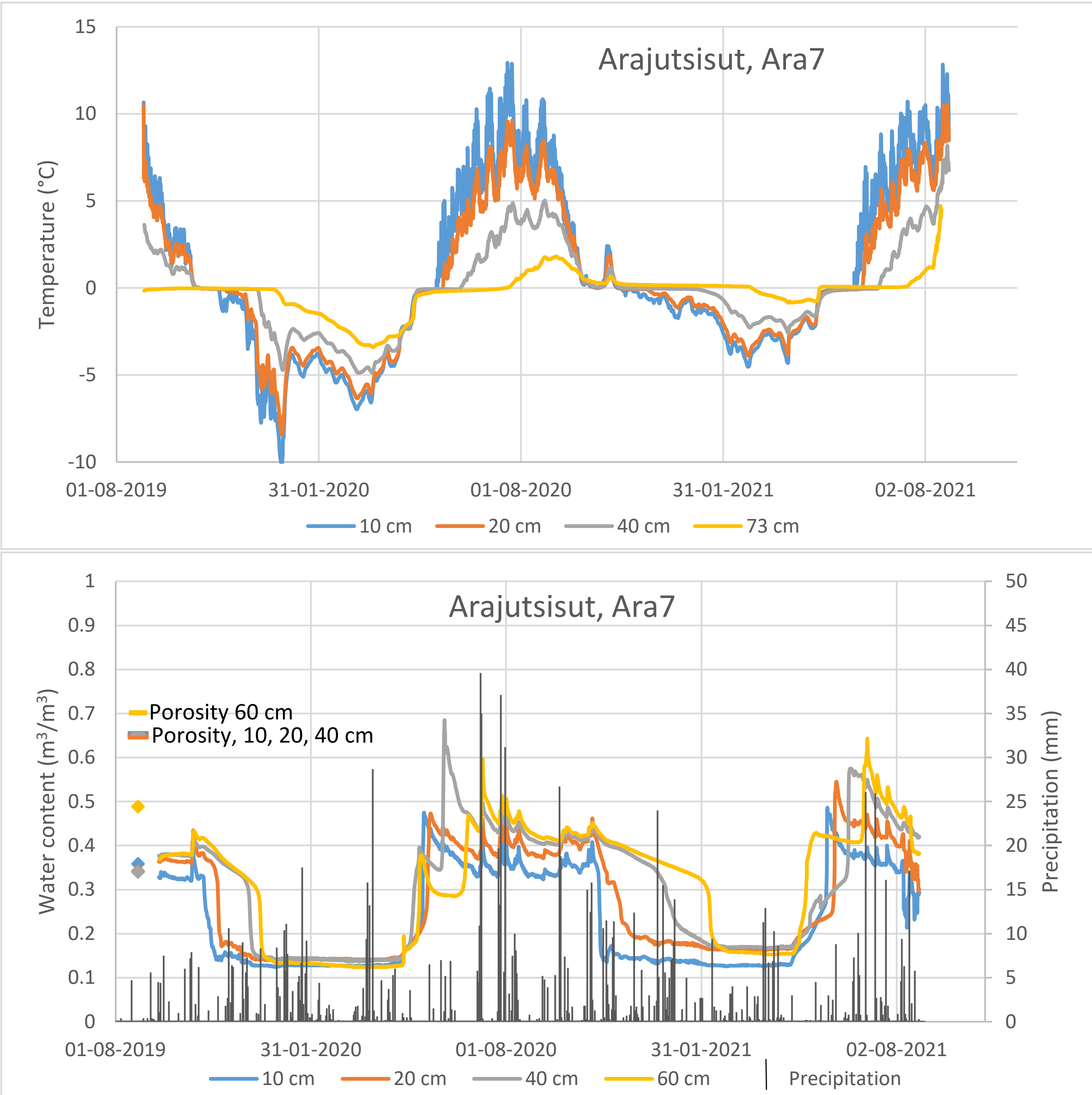


Figure 24: Monitoring data from Ara7 trench from the period 2019-2021

The soil temperature varies between -10 to +13 °C at 10 cm depth and between -3 to +5 C at 73 cm depth. These fluctuations are larger than observed at Nipisat (Figure 12), and there seems to be a faster temperature response in the sense that the periods at 0 °C (where soil water freezes or thaws) are shorter than at Nipisat. Regarding water content, there is a distinct influence from precipitation which gives an immediate increase in the water content in all soil layers. In absolute values, the water content during summer is typically between 35 and 50 %vol, while the porosity of the layers is 65-70 %vol. The air content will be 20-30 %vol, which is lower than at Nipisat, but still it is unlikely that there are completely anoxic conditions except for a few very wet periods. The pH in the uppermost deposits is low but it increases in the deeper, more bone rich deposits. Overall, the preservation conditions are considered similar to what is observed at Nipisat.

NKAH 285 (Arajutsisut), Ara9, midden on small plateau at ruin 9.

A trench of 1x3 m was made in the midden in front of ruin 9 in the period 8-24/08/2021, and continued in August 2022, in an area covered by sphagnum moss and crowberry (*Empetrum hermaphroditum*). A grid was laid out with x301/y400 in the SE corner and x300/y403 in the NW corner. Frozen soil layers were already found at ca 30 cm depth, after which excavation could only take place by a few cm every day as the layers thawed. Details of the excavation are given in Jensen et al (2022). Figure 25 shows the profile at the end of the 2021 excavation. Three main strata were identified: Layer 0: sphagnum turf w. crowberry, Layer 1: dark brown humus with some sand and degraded bones, Layer 2: dark very organic soil with excellent preservation of all organic material (wood, bone, antler, feather, leather, baleen, hair), initially frozen and with a distinct smell of urine/faeces upon thawing, Layer 2a: lenses of buried old vegetation layers (sphagnum with well-preserved crowberry on top). The stratigraphy is described in more detail in Jensen et al (2022) page 36, and dating is described in Appendix 7. Layer 1 and 2 at Ara9 both contains bead types datable to both the 17th and 18th century, and the site was abandoned in the late 18th or earliest part of the 19th century, i.e the material in the midden is probably 200-400 years old.

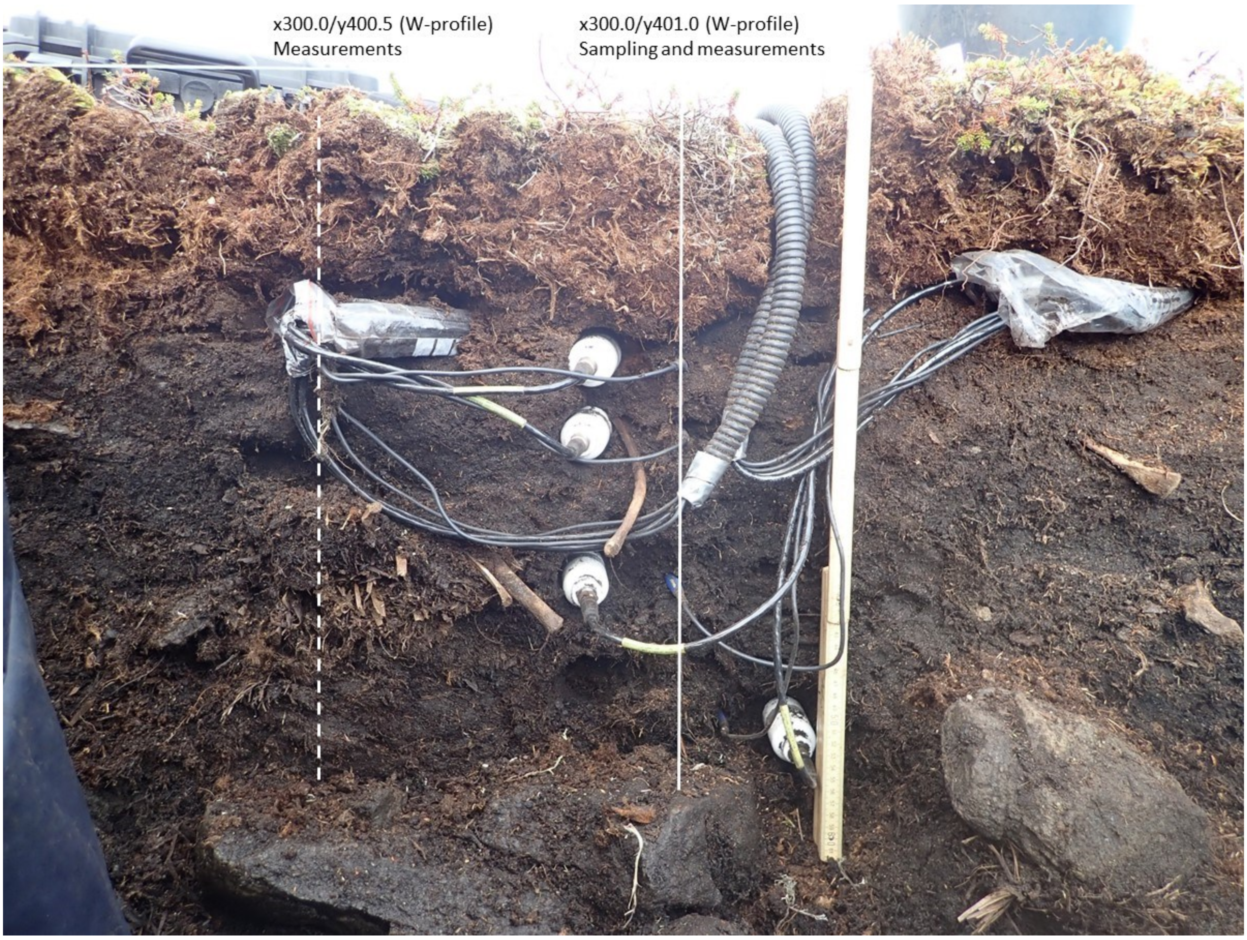


Figure 25: Photo of excavated West-profile at Ara9 with measuring and sampling positions added. Ruler 62 cm.

Environmental measurements were carried out at 2 positions on the W profile on the 16/8 (at x300.0/y400.5) and 22/8/2021 (at x300.0/y401.0). Figure 26 shows the results from all measurements on the two days. The conductivity is low with values between 20-40 mS/m except for the deepest layer. The pH increases with depth from pH 4-5 in the upper layers to 5-6 in deeper layers. The water content increases from 10-20 %vol in the top to 40-55 %vol in the deeper deposits. It cannot be excluded that some of the water contents are too low, as the sensor only measures fluid water and not ice.

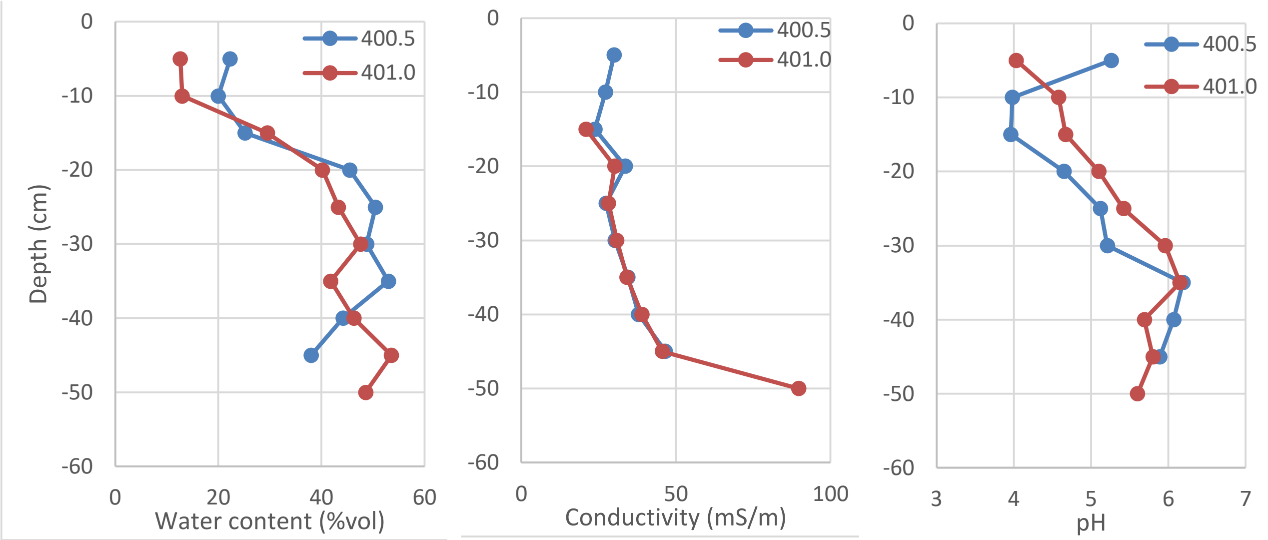


Figure 26: Environmental measurements at 2 positions at the x300 profile at Ara9

Figure 27 shows the profile before installation of equipment.

Figure 27. Ruler placed at x300.0/y401.0 where measurements and sampling took place. Ruler length 52 cm

At position x300.0/y401.0 the stratigraphy was: 0-13 cm: layer 0; 13-20 cm: layer 1; 20-58 cm: layer 2, soil frozen below 58 cm. Bulk samples were taken from layer 1 and 2. Sterile samples were taken at 10, 14, 19, 20, 25, 30, 35, 40, 45, 50, and 55 cm depth. Pollen samples were taken at 15, 25, 35, 45 and 55 cm depth.

Ring samples were taken at 18, 25, 38, 45 and 55 cm depth. Installation of monitoring equipment in 2021 (moved from Ara7) included SM300 sensors for water content and TinyTag temperature sensors at 18, 25, 38 and 55 cm depth, as shown in Figure 25. Results from in situ measurements and ring samples are given in Figure 28.

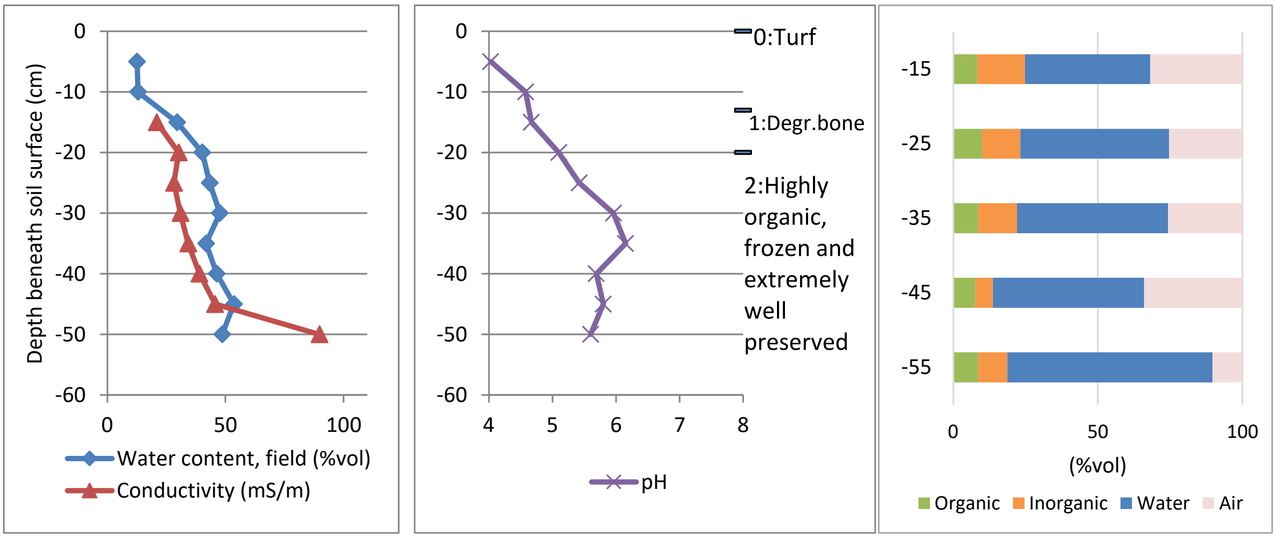


Figure 28: Field measurements and results from ring samples taken at position x300.0/y401.0 at Ara9

The results show that the soil porosity (the sum of the water and air content) varies between 75-86 %vol. The water content is relatively high (43-71 %vol) which is probably due to the high content of well-preserved organic material that is able to bind water. At the same time the water helps to keep the soil frozen and thus to preserve the remains. The pH is low in the top (pH 4) which relates well to the occurrence of sphagnum mosses. It only increases to pH 5.5-6 in the deeper deposits, which is lower than observed at other places. However, as long as the soil is frozen and the water present as ice this is not critical in terms of leaching and degradation of the archaeological material. The inorganic content of the samples varies between 6-16 % vol, which is somewhat lower than at Ara 7 (17-24 % vol). Grain size analysis (Figure 23) shows a poorly sorted material that is markedly different from the material at Ara 7, indicating a different source.

Monitoring data 2021-23:

Monitoring equipment was installed in the trench at x300.0/y401.0 on the 23/8/2021 as described above, and the trench was backfilled on the 24/8/2021. It consisted of four SM300 soil moisture sensors at 18, 25, 38, and 55 cm depth and four TinyTag temperature sensors at the same depths. Unfortunately, a polar fox dug down into the midden and chewed on the wires starting with one of the temperature sensors already on the 3/9/2021 and finishing off the last one around the 6/11/2021. The trench was re-opened for excavation from 1/8 – 24/8 2022. New monitoring equipment (from Nipisat) was installed in 18/8/2022 (by Malte Skov Jepsen) and it was attempted to protect the sensors from polar fox attacks by chicken net. Data from the loggers were downloaded in August 2023 (by Jørgen Hollesen) and are presented in Figure 29, together with precipitation data from Sisimiut. The equipment was left at the site to continue monitoring.

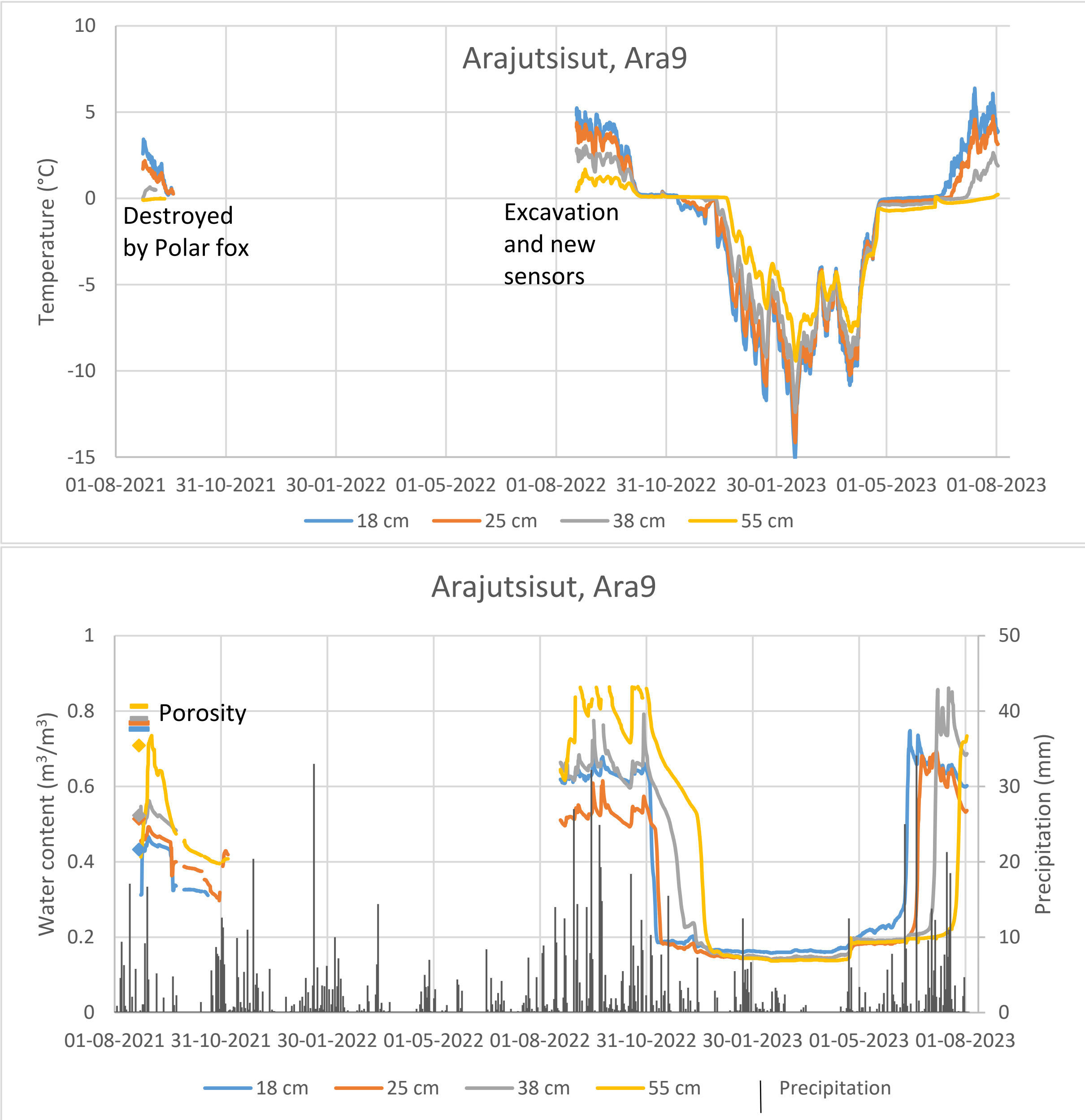


Figure 29: Monitoring data from Ara9

Temperature drops towards 0 °C for all depths by mid September, it decreases down to – 15 °C in the upper layers and -10 °C in the deeper layers over the winter 22/23, before it increases to 0 °C beginning of May 2023. The temperature reaches 5 °C in the upper layer (at 18 cm depth) and ca 1 °C at 55 cm depth when it is warmest. The first measurements in 2022 may be influenced by the excavation, but the temperature increases above 0 °C also in 2023 where no excavation takes place. The water content shows a correlation to the precipitation during summer. All water is frozen by mid November 2022 in the upper layers and by mid December in the deeper layers, and all ice is thawed by mid June in the upper layers and end July 2023 in the deepest layer. This shows that none of the layers are formally “permafrozen” – even at 55 cm depth there are some months where the ice has melted. However, the temperatures are low and more importantly the water content is very high, so it is likely that there are permanent anoxic conditions in the deeper layers which helps explaining the outstanding state of preservation found in the midden.

Furthermore, the temperatures in the lower layers reach extraordinary low temperatures compared to other sites: e.g. at 38 cm depth -12 °C is measured in January 2023 at Ara9, whereas it is only -4 °C at nearby Nipisat and Saqqarliit, and -10 °C at inland Aasivissuit where the air temperatures are much lower.

Saqqarliit

Saqqarliit was only visited for a few hours in August 2021 and the installation of equipment was done quickly due to incoming strong winds. A small pit of ca 0.3x0.3 m was dug on the 13/8/2021 in an area dominated by Lyme grass and close to the erosion profile investigated by Jens Fog Jensen in 2019 (Figure 4). Figure 30 shows the profile before installation of equipment. Four strata were identified: Layer 1, 0-24 cm: roots; Layer 2: 24-26 cm: gravel with some organic material; Layer 3, 26-47 cm: alternating organic and sandy layers; Layer 4, 47-62 cm: red coarse sand. At 62 cm rock was found. No artefacts or bone were found .

Figure 30: Test pit excavated at Saqqarliit. Ruler 62 cm

Ring and bulk samples were taken from at 10, 20, 40 and 60 cm depth. Results from in situ and laboratory measurements are presented in Figure 31.

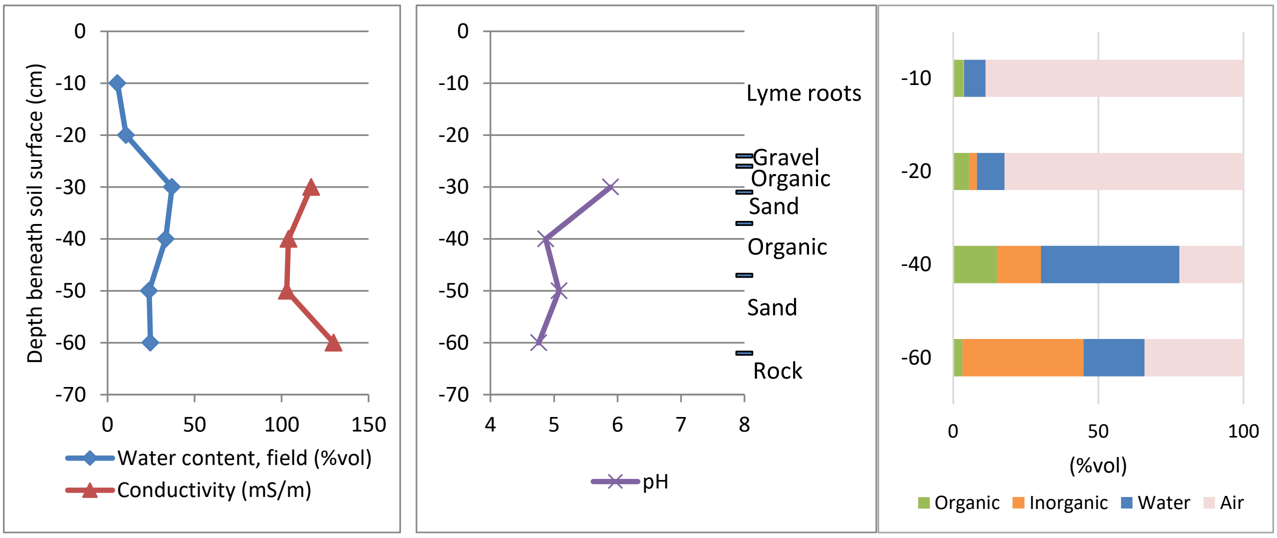


Figure 31: Field measurements and results from ring samples taken at Saqqarliit

The soil porosity in the deepest sandy layer is relatively low (55.1 %) and the organic-poor coarse sand has a low water retention. However, the layer just above is relatively organic rich (15% vol) which helps keeping the layer wet. There were no visible artefacts in the deposits at the test pit, but still the pit may be used to monitor how the conditions in an organic-rich soil varies over the year at this site.

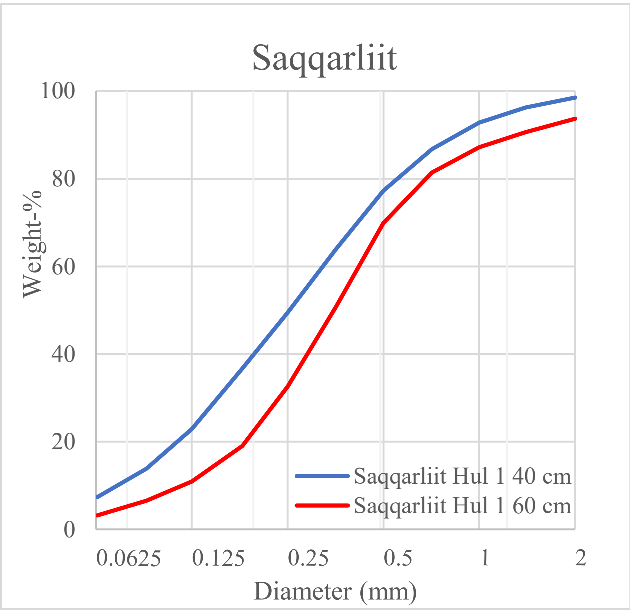


Figure 32: Grain size analysis for samples from Saqqarliit. All organic material was removed by ignition of samples before analysis.

Figure 32 shows grain size analysis of samples from Saqqarliit. The deepest layer at 60 cm is medium to coarse sand that is expected to be relatively well drained, especially as there only is a low organic content to retain water. The layer at 40 Cm depth is slightly more fine grained and has a higher organic content, which both give a higher water retention.

Installation of monitoring equipment included SM300 sensors for water content at 10, 20, 40, and 60, measuring every 6 hours. HOBO temperature sensors were installed at surface, 20 and 40 cm depth. A

HOBO rain gauge and air temperature sensor were installed on a 2 m high pole next to the test pit. Data were downloaded in August 2023 and the monitoring equipment removed (by Jørgen Hollesen). The memory capacity of the datalogger for soil moisture was full so the first 8 month of data were over written.

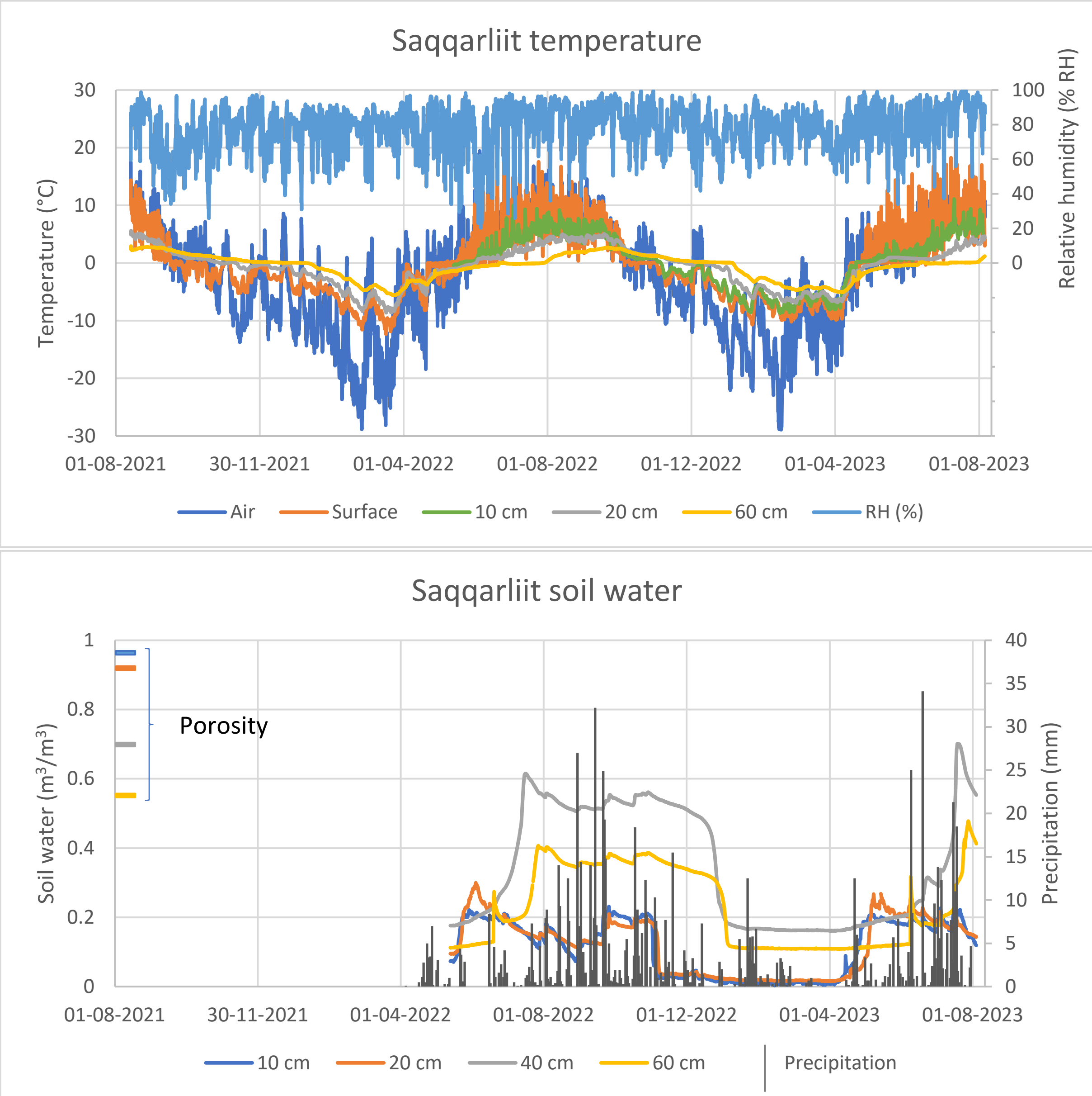


Figure 33: Monitoring data from Saqqarliit

The soil temperature varies between -8 to +5 °C at 20 cm depth and between -5 to +3 °C at 60 cm depth. The mean temperature is slightly lower than observed at Nipisat (Figure 12), which could be due to colder winters, where the air temperature at Saqqarliit drops to – 30 °C compared to -20 °C at Nipisat. The uppermost layers have a very low water content and freezes quickly, whereas the deeper layers are more wet and shows a delayed freezing. The organic layer 3 is nearly waterlogged end July 2023 due to a large precipitation, and there are long periods during 2022 where the air content is only 15-20% vol and where there could be reduced oxygen access. In summary the preservation conditions in the organic rich layer is fair with a near-neutral pH and a high water content, but it is difficult to compare with actual archaeological material as no artifacts or identifiable materials were found in the testpit.

Aasivissuit

A 2 m long section of the main trench from 1978 was re-opened in the period 2-7/9/2021 in an area covered by short grass (Figure 5). Backfilled dirt was removed from the southern end of the main trench. Using the grid from Grønnow et al. (1983) the re-opened part had its NE corner at x128.5/y171, and its SW corner at x127.5/y169. The trench was expanded by 25 cm towards E into undisturbed midden layers. Details on the excavation is given in Jensen et al (2022). Figure 34 shows the whole profile. Six strata were identified: Layer 1: root mat with silt and peat, few finds; Layer 2: laminated silt and peat, bone- and find-rich; Layer 3: laminated silt and peat with twigs of dwarf birch, bone- and find rich; Layer 4; laminated silt and peat, some bones, but no artefacts; Layer 5: silt with few bones and Dorset stone tools; Layer 6: silt, sand and gravel. Detailed descriptions of the different layers are given in Grønnow et al (1983). Layer 5 (Dorset) has been dated to 200 BC (Grønnow et al 1983). As for layer 4 a discussion of new radiocarbon dates is given in Jensen et al (2022) page 46, suggesting that the lower part of layer 4 was formed in the first half of the 13th century AD (825+30/1210 – 1265 calCE, with 1. St. dev.), while the upper part has been dated to at least the 16th century, with most activity at the end of the 15th century (Grønnow et al, 1983, p 63). Layer 3 is probably from late 17th to second half of the 18th century, where part of it postdates the Nepisene colony (1729-31) and probably also the Sisimiut Colony (1764) (Jensen et al 2022 Appendix 7). At some point people stop coming to Aasivissuit (probably due to a collapse of the reindeer population), and the midden is covered by thin layers of silt and peat. Layer two is from the 19th century with the most intense activity from 1820-1850, and layer 1 is from the end of the 19th to the middle of the 20th century. Thus the material from layer 5 is more than 2000 years old, layer 4 is probably 500-800 years old, layer 3 is 250-350 years, layer 2 is ca 170-200 years, and layer 1 ca 70-140 years old.

Figure 34: Photo of excavated East-profile in trench at Aasivissuit with measuring and sampling positions added (Aas2 trench).

A small test pit (0.5 x 0.5 m) was dug 2 m from the trench to avoid disturbance from the old pit. The test pit had its NE corner at x130/y176.5 and its SW corner at x130.5/y176. The small size of the test pit made it difficult to identify the different layers with certainty during excavation, so sampling and description was made based on depth, rather than based on layer. The pit was excavated and bones were sampled at 5 cm depth intervals. Notes from the excavation and approximate layer boundaries are given in Table 1. Within each layer there were both well-preserved and less well-preserved bones, and in the field there seemed to be a tendency that the poorest preservation was found at the top of each layer. However, when comparing the different layers the overall tendency is that the poorest preservation is found in the oldest layers at the bottom, and the best preservation is found in the top layer (Gotfredsen, 2023).

Depth (cm)	Description
0-5	Very compact, with roots. Layer 1)
5-10	Mixed silt/organic. At 10 cm only few roots and rhizomes. Layer 2.
10-15	As above, but fewer bones. Degraded wooden roots/branches. At the bottom a few very degraded bones that couldn't be sampled. Layer 2 and transition to layer 3.
15-20	At the top grey silt layer with very degraded bones that couldn't be sampled, but bones significantly better preserved just a few cm down. Some bones covered with a dense mat of light-coloured roots. Layer 3
20-25	Very bone-rich, with varying state of preservation. Layer 3
25-30	Silt/humus with few bones, some birch-bark and quite a few degraded twigs. Layer 3 (and 4?)
30-35	Organic silt, with degraded twigs and roots, and few very degraded bones. Some of these had white precipitations described and analysed below. Dead rhizomes from Horsetail. Layer 4
35-40	Organic silt, with lenses of more "pure" grey silt. Some well-preserved bones that possibly could be used for dating. Probably layer 4.
40-45	Layers of organic silt and more pure grey silt. A few degraded bones. Probably layer 4.
45-50	Layers of organic silt and more pure grey silt. No finds. Most of the pit is filled by a large stone. Probably layer 4.
50-55	Layers of organic silt and more pure grey silt. Probably layer 4. A small hole at 55 cm revealed a large cavity in between rocks (down to 83 cm depth). The excavation stopped at 55 cm and the bottom of the pit was preserved in situ

Table 1: notes from the excavation of test pit 1.

Two places in the trench and test pit were selected for field measurements, sampling and monitoring: x128.7/171.0 and x130.5/y176.2 (Figure 35).

Figure 35. Test pit at x130.5/y176.2, ruler 52 cm

Trench at x128.7/171.0, ruler 52 cm. Limit between backfilled dirt (left) and newly excavated midden layers (right) is clearly visible.

At position x130.5/y176.2 the stratigraphy was (with some uncertainty due to the small size of the test pit): 0-5 cm: layer 1; 5-14 cm: layer 2; 14-34 cm: layer 3 (lower limit uncertain); 34-55 cm: layer 4; beneath 55: air pocket in between rocks (no layer 5 or 6). Bulk samples were taken from layer 1-4. Sterile samples and pollen samples were taken at 5, 7, 12, 17, 22, 27, 32, 37, 42, and 47 cm depth. Ring samples were taken at 3, 10, 20, 30, 40 and 50 cm depth. A whole midden sequence of ca 50 cm length was taken with an aluminium tin, that was pressed into the profile; the tin was excavated and wrapped. At position x128.7/y171.0 the stratigraphy was: 0-8 cm: layer 1; 8-21 cm: layer 2; 21-31 cm: layer 3; 31-48 cm: layer 4; 48 cm-bottom: layer 6 (no layer 5). Sterile samples and pollen samples were taken at 5, 13, 18, 23, 28, 33, 38, 43, and 51cm depth. Results from in situ measurements from both profiles are compared in Figure 36, while Figure 37 shows results from ring samples and in situ measurements at x130.5/y176.2.

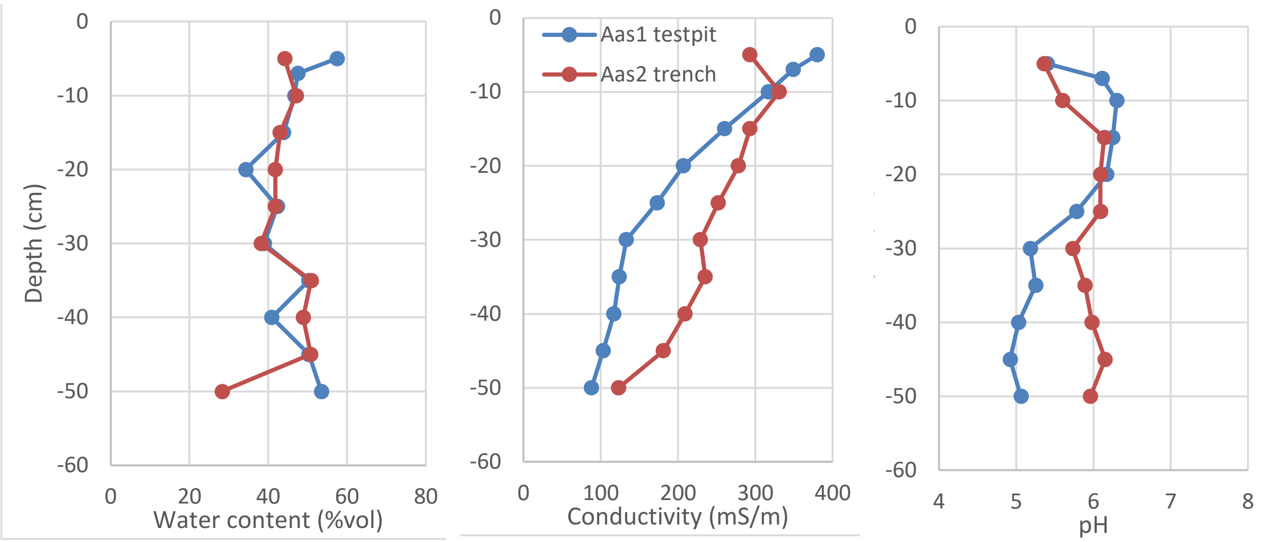


Figure 36: Environmental measurements at 2 positions at Aasivissuit

The water contents are very similar in the test pit and trench, except for the lowest sample, where the inorganic layer 6 with a low water content is reached in the trench but not in the test pit. The conductivities show similar trends in the test pit and trench, discussed below. pH in the deeper deposits is one unit higher in the trench compared to the pit: it is unknown if this is a long term effect from the old excavation (for instance an influence from mixing of soils in the backfilled dirt) or if it is due to other parameters such as differences in the bone concentration.

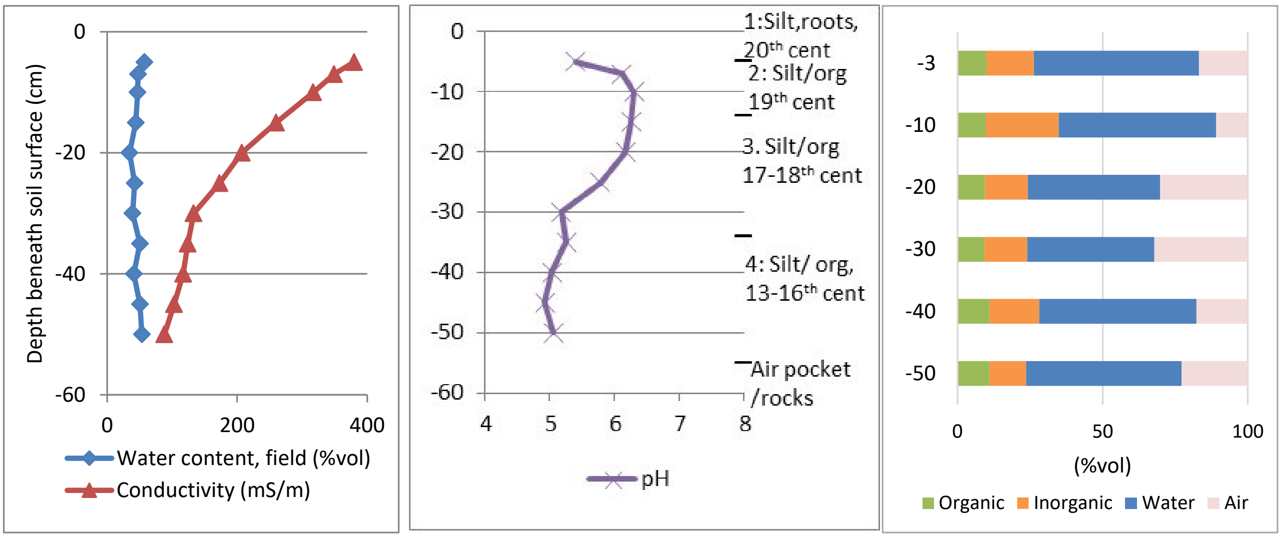


Figure 37: Field measurements and results from ring samples taken in test pit at Aasivissuit. The layer boundaries are somewhat uncertain due to the small size of the test pit.

The conductivity measurements are quite interesting: this site has by far the highest conductivities (up to 400 mS/m) and with a systematic increase in conductivity when moving towards the soil surface. Obviously, this is not due to sea spray, but may instead be explained by an upwards capillary transport of water (carrying dissolved ions) and a strong evaporation at the site, which would result in an increased salt content in the upper soil layers. Regarding pH it is remarkable that the pH values in the deeper soil layers are relatively low (at least in the testpit), which normally gives poor preservation conditions for bone, and correspondingly, Anne Birgitte Gotfredsen has noted that the deepest layers show the poorest state of preservation of the bone material (Gotfredsen, 2023). At most other sites pH increases with depth, and it is still uncertain why the opposite is observed here: it could for instance be due to a low bone content in the deeper layers, a high CO_2 pressure in the deeper layers, or possibly a decrease in the base cation content (such as Ca^{2+}) in the deeper deposits due to an upwards transport of ions.

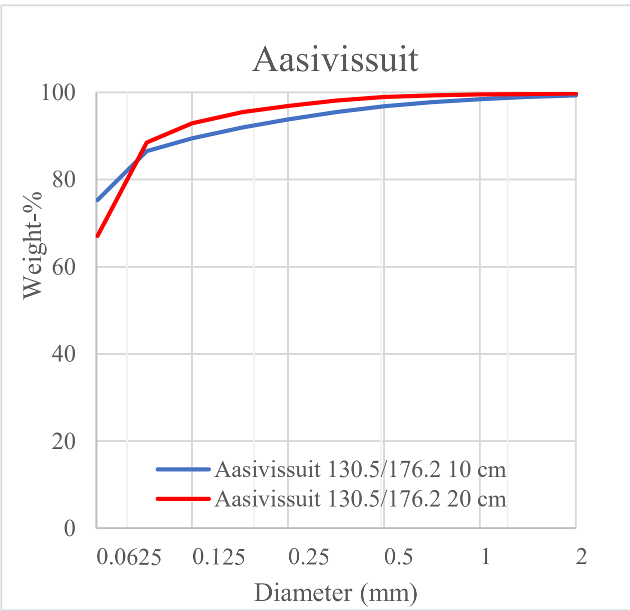


Figure 38: Grain size analysis for samples from Aasivissuit. All organic material was removed by ignition of samples before analysis.

Grain size analysis (Figure 38) shows that most grains are below 60 µm, confirming that the soil mainly consists of silt. Fine grained silt is indeed known for its strong capillary action, which makes upwards water transport a likely explanation of the increased conductivity in the topsoil – however this should be confirmed by estimates of the water balance in the area. The silt has a high porosity (65-76 %vol) but also a high water-retention capacity, leading to a relatively low air content of 11-32 %vol (Figure 37). It is likely that there will be periods with anoxic conditions in the soil layers as also indicated by the monitoring data (Figure 41).

In order to study the changes in conductivity in a bit more detail, analysis of water-soluble ions has been carried out on bulk soil samples from layer 1, 2 and 3 (0-5 cm, 5-9 cm and 20-28 cm depth) - Figure 39. The results have verified a decreasing concentration of soluble ions with depth and shown that the cations are dominated by Ca with some Mg, Na and K, while the anions are dominated by SO_4, Cl, CO_3 and PO_4. Preliminary calculations indicate super-saturation of calcium phosphates in the soil, possibly with some sulphates in the upper soil layer as well. Precipitation of calcium- and phosphate-containing minerals were indeed observed on some of the degraded bones (Figure 40) so some of the ions in the soil could stem from degradation or re-crystallisation of apatite (calcium-hydroxy-phosphate) from bones.

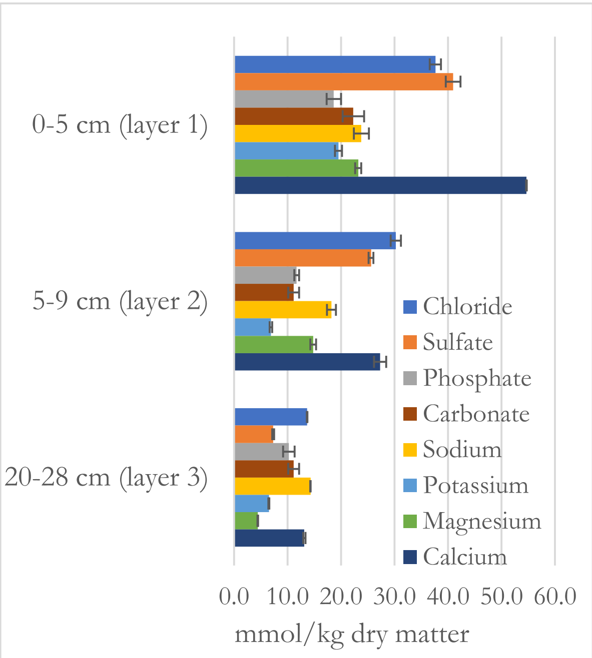


Figure 39: Concentration of water-soluble ions in selected bulk samples from test pit

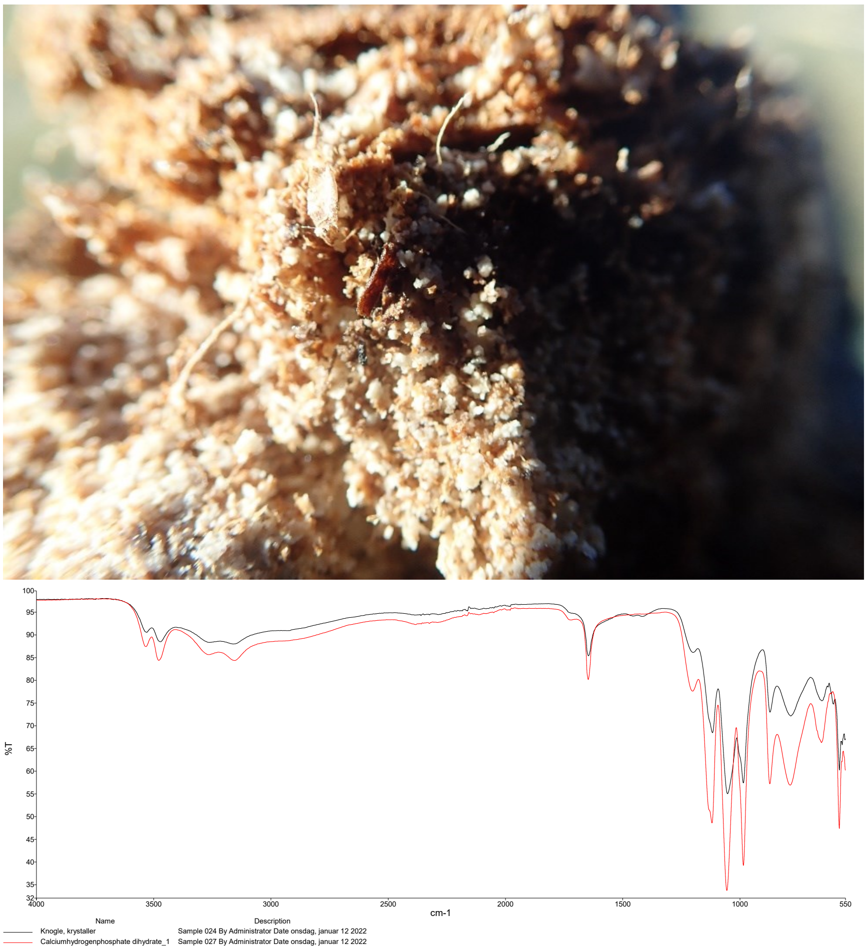


Figure 40: White precipitated were observed on some of the degraded bones in the test pit (upper). Subsequent analysis by FTIR have shown that they consist of calcium phosphates (lower)

Monitoring data 2021-23

Monitoring equipment was installed in the test pit including ML3 sensors for water content at 10, 20, 30 and 40 cm depth, and EQ3 sensors at 10 and 20 cm depth, measuring every 12 hours. HOBO temperature sensors were installed at surface, 10, 20, 30 and 40 cm depth, monitoring every 6 hours. TinyTag temperature sensors were installed at 10, 20, 30 and 40 cm depth as backups, as it is uncertain how the monitoring equipment and batteries will cope with the extremely low temperatures during winter. Optical oxygen sensors were installed at 10, 20, 30 and 40 cm depth in August 2023, to allow spot measurements of oxygen concentration when the site is re-visited. It was planned to install a rain water gauge and air temperature sensor at the site, but this had to be cancelled as the equipment was delayed. Instead, weather data from Kangerlussuaq will be used. A nearby weather station (seen at small lake at position N 67°03.593' W 051°08.038') turned out to be abandoned and not functioning, so no data could be retrieved from it.

The site was re-visited in August 2022 and August 2023, where data was downloaded and batteries were exchanged (by Henning Matthiesen). All loggers and batteries had survived the cold winters, and the monitoring data are shown in Figure 41 (only temperature measurements from the TinyTag loggers are shown, as the HOBO logger hadn't been running since August 2022 for some reason, possibly a programming error)

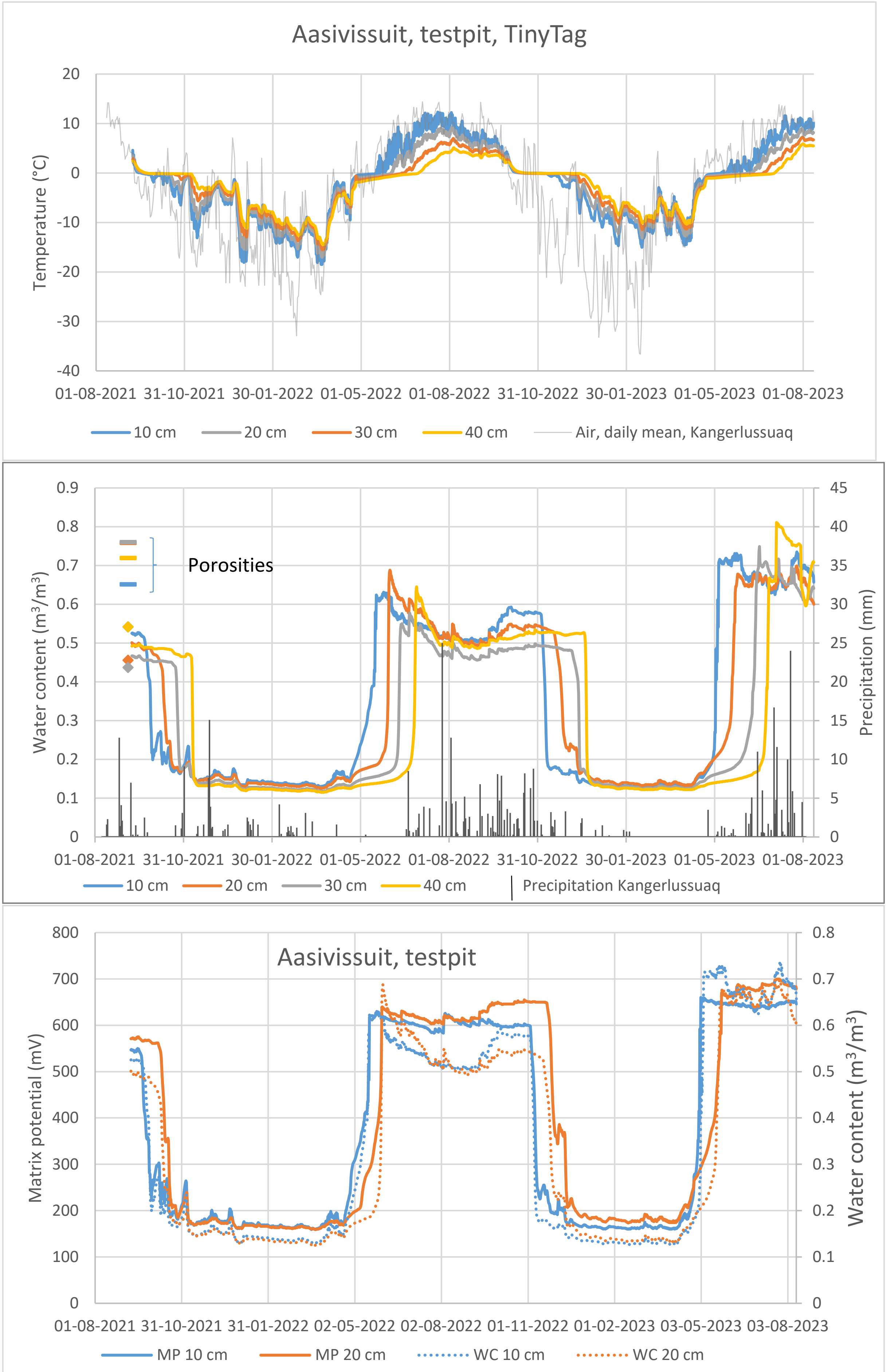


Figure 41: Monitoring data from Aasivissuit test pit. For comparison are included air temperature and precipitation from a weather station at Kangerlussuaq (from DMI at [https://www.dmi.dk/vejrarkiv/)](https://www.dmi.dk/vejrarkiv/)

The temperature data (Figure 41 top) shows how the air temperature in the area has dropped down below -30 °C during winter which isn't even cold for Kangerlussuaq. The soil temperature follows the air temperature fairly well during summer, while in winter the soil is significantly warmer than the air – this is both due to energy released when soil water freezes to ice and can also indicate that the site is covered by insulating snow. Down in the soil there is only 1 yearly freeze-thaw transition, while there are several up in the air – a comparison of daily minimum and maximum temperatures show for instance that there were 46 days with both positive and negative air temperatures in the period August-December 2021, i.e. at least 46 freeze-thaw cycles (data from DMI). The deeper sensors show that water in the midden freezes from mid/end-September to November/December, and that the different layers thaw from beginning of May to beginning of July.

Results on soil moisture (Figure 41 middle) confirms the timing of the freezing and thawing. After thawing in spring the water content is relatively high (55-70 % vol for the different soil strata) and close to the porosity of the soil (65-76 % vol), i.e. there is only a small air content. This could indicate anoxic conditions, which typically occur when the air content drops below 10-15 % (Matthiesen et al, 2005). Over the summer, the water content only drops relatively slowly, due to a strong water retention in the fine pores in silt. The summer of 2023 was extraordinarily wet, with 90 mm rain in July 2023 compared to a climate normal of only 28 mm in July. This is also reflected in a very high water-content of the soil, close to saturation. Oxygen sensors installed during the site visit in August 2023 indicated that the conditions were indeed anoxic at 30 cm depth, but ideally the sensors should have longer stabilisation time (a few weeks) to ensure that the readings are not influenced by disturbance from the installation – thus more certain measurements can be made during the next site visit, probably in 2024.

The measurements of matrix potential or suction potential (Figure 41 bottom) shows around 600 mV in spring/summer 2022 and increasing to 650-700 mV in 2023. This is above the measuring range of the sensors and indicates the presence of free water. However, back in the autumn 2021 right after the installation of the equipment the sensors give around 550 and 570 mV, which corresponds to matrix potentials around -12 kPa (at 10 cm depth) and -10 kPa (at 20 cm depth). This suction may induce an upwards water transport, as was also indicated in the discussion of the measured soil conductivity profile (Figure 37).

To summarize, the preservation conditions are considered relatively good at Aasivissuit: the sediment is fine grained with a good water retention capacity that probably gives anoxic conditions for long periods. Furthermore, the deposits are frozen for long periods every year.

Natural reference samples

In 2021 sterile soil samples to be used as references/background for lipid and DNA studies were taken at ca 20 cm depth. Three samples were taken at Nipisat (at the other side of the small lake, at positions N 66°48.869' W 053°30.966', N 66°48.867' W 053°30.929', and N 66°48.914' W 053°30.802' stored in GPS as NipNatRef1-3, respectively), two samples at Arajutsisut (uphill from Ara9 and Ara7, the latter at position N 66°52.611' W 053°36.395' stored in GPS as AraNatRef2), and one at Aasivissuit (uphill from midden, termed AasNatRef). In 2023 further natural reference samples were taken at Aasivissuit (by Anne Marie Høier Eriksen).

An undisturbed peat column of 72 cm length for pollen analysis was taken at Nipisat at N 66°48.867' W 053°30.929' (NipNatRef2), where the upper 33 cm were thawed and taken with an aluminium tin, and the lower 39 cm were frozen and sampled by diamond-drill. Another peat column of 50 cm length was sampled nearby (at “goose peninsula” at N 66°48.876' W 053°30.903') in an aluminium tin by Sascha Kruger.

Summary

The field measurements and monitoring in 6 different middens in the Nipisat-Aasivissuit area has given interesting results and the middens represent a remarkable diversity including both thawed and frozen middens, and both silty, sandy and highly organic middens. The present report is mainly intended to give an overview of the sampling and environmental conditions, which shall be used in conjunction with studies of the state of preservation and reactivity of different archaeological materials in order to understand the previous, current and future preservation.

References

Appelt,M, J F Jensen, B Grønnow, H Harmsen, M Myrup, M M Bønneløkke, A Lynge, A B Gotfredsen, P A Toft, C S Pedersen. Activating Arctic Heritage, WP 3.4: Dynamic Glocal. Field report 2019. -100. 2020.

Gotfredsen,AB. Preservation of faunal remains from the 2019 excavations at Nipisat & Arajutsisut. KNK numbers 4201, 4202 and 4203 / NKAH numbers 285, 5533 and 5526. Activating Arctic Heritage, WP2.1 Hidden in the Midden Laboratory report. 2020. Globe institute, University of Copenhagen.

Gotfredsen,AB. Preservation of faunal remains from the 2021 excavations at Aasivissuit. Activating Arctic Heritage, WP2.1 Hidden in the Midden Laboratory report. 2023. Globe institute, University of Copenhagen.

Gregory, D., and H. Matthiesen, 2023, Defining the burial environment, in AM Pollard, RA Armitage, and C Makarewicz eds., Handbook of Archaeological Sciences, Second Edition.: John Wiley & Sons, 53, 1075-1088.

Grønnow, B., M. Meldgaard, and J. B. Nielsen, 1983, Aasivissuit - The Great Summer Camp. Archaeological, ethnographical and zoo-archaeological studies of a caribou-hunting site in West Greenland: Meddelelser om Grønland, Man and Society, v. 5.

Jensen,JF, M Appelt, B Grønnow, H Harmsen, P A Toft, F F Larsen, A Olsen, M Sørensen, S Desjardins, J Kanutsen, A B Gotfredsen, N B Pedersen, H Matthiesen, M Myrup, D Gregory, R Voss, C S Pedersen, L Højer, S Krüger. Field report 2021. Activating Artic Heritage, WP3.4: Dynamic glocal networks. 2022. National Museum of Denmark.

Lauridsen,NR, H Matthiesen, D J Gregory, N B Pedersen. Collapse - or not? Effects of drying on heavily decayed archaeological wood in soil, 2023. Proceedings from 15th ICOM-CC Wet Organic Archaeological Materials (WOAM) working group conference, 59-66.

Matthiesen,H. Hidden in the Midden field report 2019: Investigations at Nipisat and Arajutsisut. 20803-1, 2020. Copenhagen, National Museum of Denmark, Conservation & Science. Reports from Activating Arctic Heritage..

Matthiesen,H. Hidden in the Midden field report 2021: Investigations at Nipisat, Arajutsisut, Saqqarliit and Aasivissuit. 20803-2, 2021. Copenhagen, National Museum of Denmark, Conservation & Science. Reports from Activating Arctic Heritage..

Matthiesen,H. Hidden in the Midden field report 2022: Investigations at Nipisat, Arajutsisut, Saqqarliit and Aasivissuit. 20803-3, 2023. Copenhagen, National Museum of Denmark, Conservation & Science. Reports from Activating Arctic Heritage.

Matthiesen, H., A. M. H. Eriksen, J. Hollesen, and M. J. Collins, 2021, Bone degradation at five Arctic archaeological sites: quantifying the importance of burial environment and bone characteristics: Journal of Archaeological Science, v. 125, no. 105296, p. 1-9.

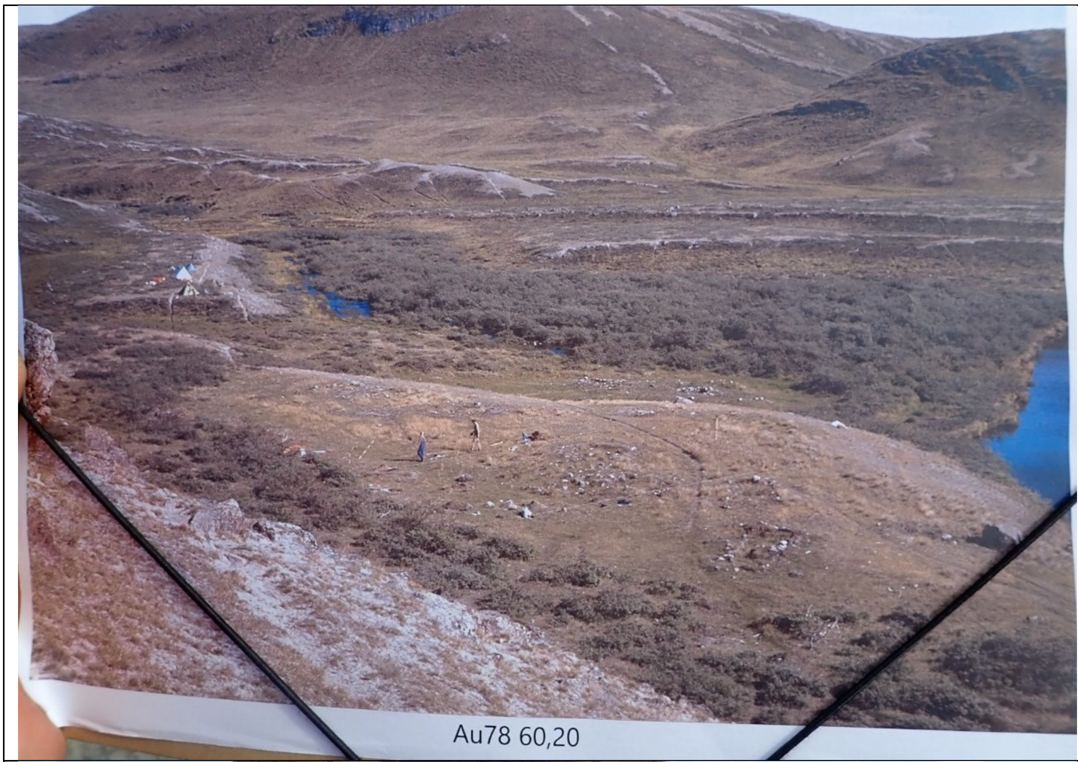
Matthiesen, H., J. Hollesen, R. Dunlop, A. Seither, and J. de Beer, 2015, In situ measurements of oxygen dynamics in unsaturated archaeological deposits: Archaeometry, v. 57, no. 6, p. 1078-1094.

Matthiesen,H, J B Jensen, D Gregory, J Hollesen and B Elberling, 2014. Degradation of archaeological material under freezing and thawing conditions - effects of permafrost and climate change. Archaeometry, 56, 476-495.

Appendix 1

During the site visit at Aasivissuit in 2021, Bjarne Grønnow had brought some prints of photos from 1978. It was attempted to reproduce some of these in 2021, in order to study changes in the vegetation

Au78 66,34


Au78 60,20


Au78 61,19

Au78 67,15

Au78 64,7