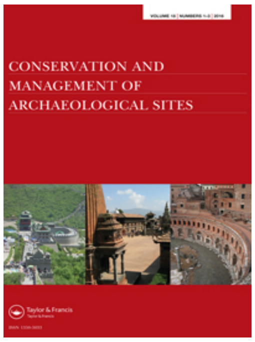

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Research and Monitoring on Conservation State and Preservation Conditions in Unsaturated Archaeological Deposits of a Medieval Farm Mound in Troms and a Late Stone Age Midden in Finnmark, Northern Norway

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This paper presents archaeological observations and results of palaeoecological and geo-chemical analyses of archaeological deposits from two rural sites in

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northernmost Norway. These are combined with climate data and the first period of continuous monitoring of soil temperature, moisture, and redox potential in sections. This data constitutes the basic research material for evaluations of conservation state and preservation conditions. The data has been collected in collaboration with the partners of a cross-disciplinary project: 'Archaeological Deposits in a Changing Climate. *In situ* Preservation of Farm Mounds in Northern Norway' funded by the Norwegian Council for Research (http://www.niku.no/en/archaeology/environmental_monitoring/archaeological_deposits_in_a_changing_climate_in_situ_preservation_of_farm_mounds/). This is an important Norwegian research initiative on monitoring of rural archaeological deposits, and the results have consequences for heritage management of a large number of sites from all periods. Palaeoecological analyses and redox measurements have revealed ongoing decay that might not otherwise have been detected. Decay studies indicate that both site types may be at risk with the predicted climate change. Some mitigating acts are suggested.

KEYWORDS climate change, extreme environment, *in situ* preservation, monitoring temperature, moisture, redox, palaeoecology

Introduction

Archaeological sites in northern Norway are often characterized by remarkable preservation conditions due to low temperatures and favourable moisture conditions and are therefore important sources of organic remains. Degradation of archaeological materials depends on environmental conditions. Future climate change is expected to increase temperatures and change the overall precipitation patterns, with a potentially negative effect on preservation conditions. Microbial decay of organic archaeological materials is known to increase exponentially with increasing soil temperature (Hollesen & Matthiesen, 2015; Matthiesen, et al., 2014), but at the same time, very dry and very wet conditions may hinder microbial processes (Hollesen & Matthiesen, 2015). Soil parameters such as pH, organic matter and water content, oxygen content, and redox potential form the boundaries in which archaeological materials can be preserved (Huisman, et al., 2009).

Oxygen is the most reactive and powerful oxidant, and some decay processes such as fungal attack will only take place when oxygen is available (Froelich, et al., 1979). When oxygen is depleted, for instance at waterlogged sites, the microbes in the soil will use other electron receptors in this process, and anaerobic degradation occurs at a much slower rate. A parameter that describes soil aerobicity is the redox potential (Mitsch & Gosselink, 2000; Pezeshki & DeLaune, 2012; Vorenhout, et al., 2004). In cold areas, the temperature of the soil can be an overruling parameter. When the soil is frozen, nearly all degradation processes are presumed to halt (Hollesen, et al., 2015a).

This paper evaluates conservation state and preservation conditions at two different types of rural sites located north of the Arctic Circle in Norway: Gressbakken houses and farm mounds (Figure 1). These two monument types were chosen as sites because of their high abundance, national importance, and because they are located in a part of

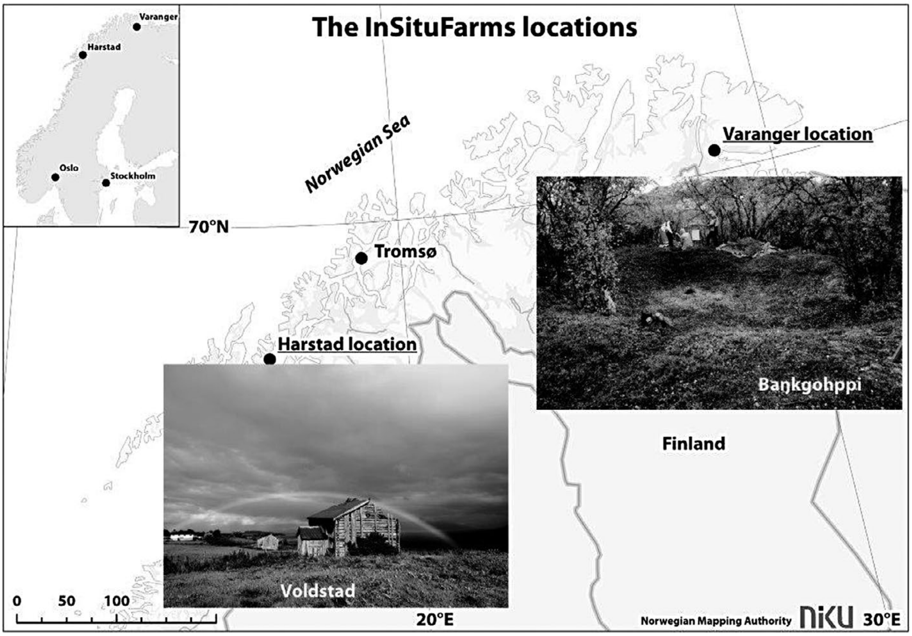


FIGURE 1 Map of chosen sites with inserted site photographs.

Norway where climate change is predicted to cause a significant increase in temperature and precipitation rates.

The northernmost site, Baŋkgohppi, by the Varanger Fjord in eastern Finnmark, is a midden belonging to a Neolithic house of the Gressbakken type (Simonsen, 1961), dated to approximately 2000 BC. The Troms site, Voldstad, is a farm mound dated to the medieval period (Bertelsen, 1984). Fieldwork at both sites was carried out in late August 2013 and monitoring equipment was installed.

This paper combines archaeological research with the first results of environmental monitoring in Gressbakken houses and farm mounds. Furthermore, laboratory measurements of degradation rates are used to access the vulnerability of the different deposits to changes in temperature and soil water content.

Study sites

Gressbakken houses

Approximately 900 Gressbakken houses found in northern Norway belong to a settlement type that was common in fjord areas in Finnmark and at the coast of the Kola Peninsula in Russia during the final phase of the late Stone Age. Such houses had turf walls and central fireplaces and were located along the shoreline. They had two entrances, one of which was oriented towards the sea. Middens on both sides of the door contain bones of animal, bird and fish, shells, charcoal, and other plant remains and artefacts. All these remains are information sources of great value, also at a national level, constituting the largest assemblages of preserved Neolithic deposits in the country. The relatively large size of the houses has promoted interpretations that they may have sheltered multi-families or extended family units (Myrvoll, 1992; Schanche, 1989).

The joint investigation led by Norwegian Institute for Cultural Heritage(NIKU) of the Gressbakken house site at Baŋkgohppi, Unjárgga/Nesseby municipality, Finnmark County (ID7547), considered house 'n' (according to Simonsen, 1961) is representative for this site type since it was undisturbed by earlier archaeological investigations or other known encroachment. The surface remains indicated a typical layout of this heritage type (Simonsen, 1961).

Farm mounds

Farm mounds are rural settlements dated mostly from late Iron Age to modern times (Bertelsen, 1984; Brox & Stamsø Munch, 1965; Myrstad, 2001). Almost 900 farm mounds are listed monuments, and they are the largest assemblages of medieval archaeological deposits outside the towns. Deposits from centuries of settlement have accumulated to form a mound, making them distinct landscape features. The main elements of farm mound deposits are house remains of turf sods and wood and general household waste (Griffin, 1985; Sandvik, 1995, 2009). Husbandry as a main subsistence factor is the major reason for the fixation of settlement and the subsequent formation of the farm mounds (Bertelsen, 1984, 1989, 2011; Lind, 2002). The fixation of settlements may further find its cause in more structured rights of property and a strict social hierarchy, which again caused a need for optimal use of the arable land and building on the non-arable land (Martens, 2015). A farm mound or settlement mound may support only a single farm, or several farms clustered together. Many farm mounds are still inhabited, while others were deserted in the past.

In this study we included the farm mound Voldstad, Harstad municipality, Troms County (ID9382). Voldstad was chosen as a site because it is a typical representative of farm mounds still in active use.

Materials and methods

Archaeology

Archaeological investigations were made at each of the sites. At Baŋkgohppi a 0.7 by 3 m hand-dug trench from the edge of the northern wall cutting through the NW midden towards the sea, from the turf/forest surface through the midden layers and down to undisturbed natural subsoil, gave access to deposits for description, sampling, and monitoring (Figure 2). At Voldstad a 0.7 by 2 m trench was hand dug from the grass turf surface to bedrock (Figure 3). The trench was placed between the modern and the eighteenth century main buildings to not interfere with any previous buildings (Martens, et al., 2015a, 2015b). Both sites were excavated stratigraphically with documentation and evaluation of the state of preservation in accordance with the Norwegian Standard (NS9451, 2009). Furthermore, at Baŋkgohppi a geophysical mapping was completed in autumn 2013 (data not shown here).

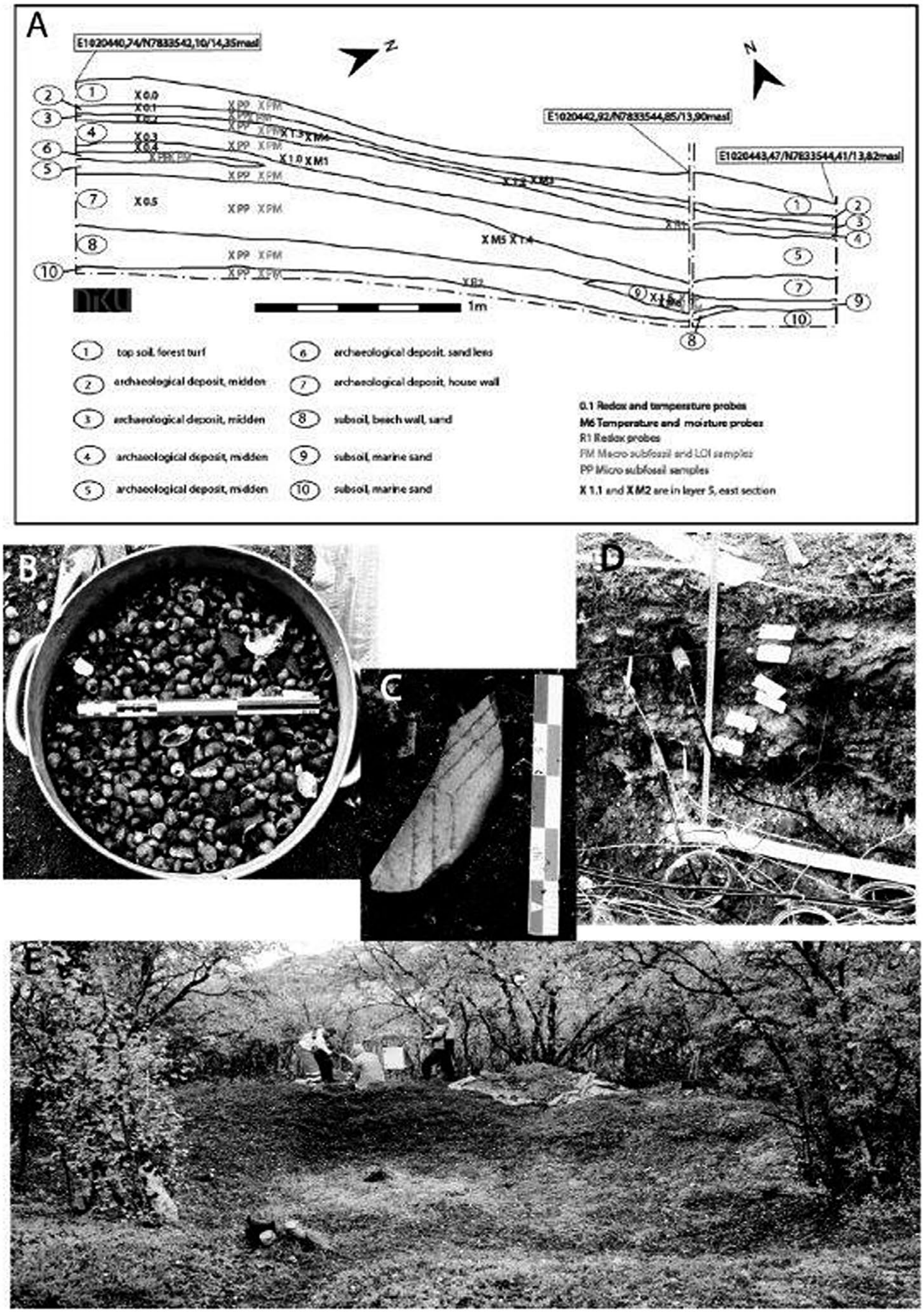


FIGURE 2 Baŋkgohppi. Section drawing (A) and site photos. B shells; C decorated antler; D installed equipment; E house ‘n’.

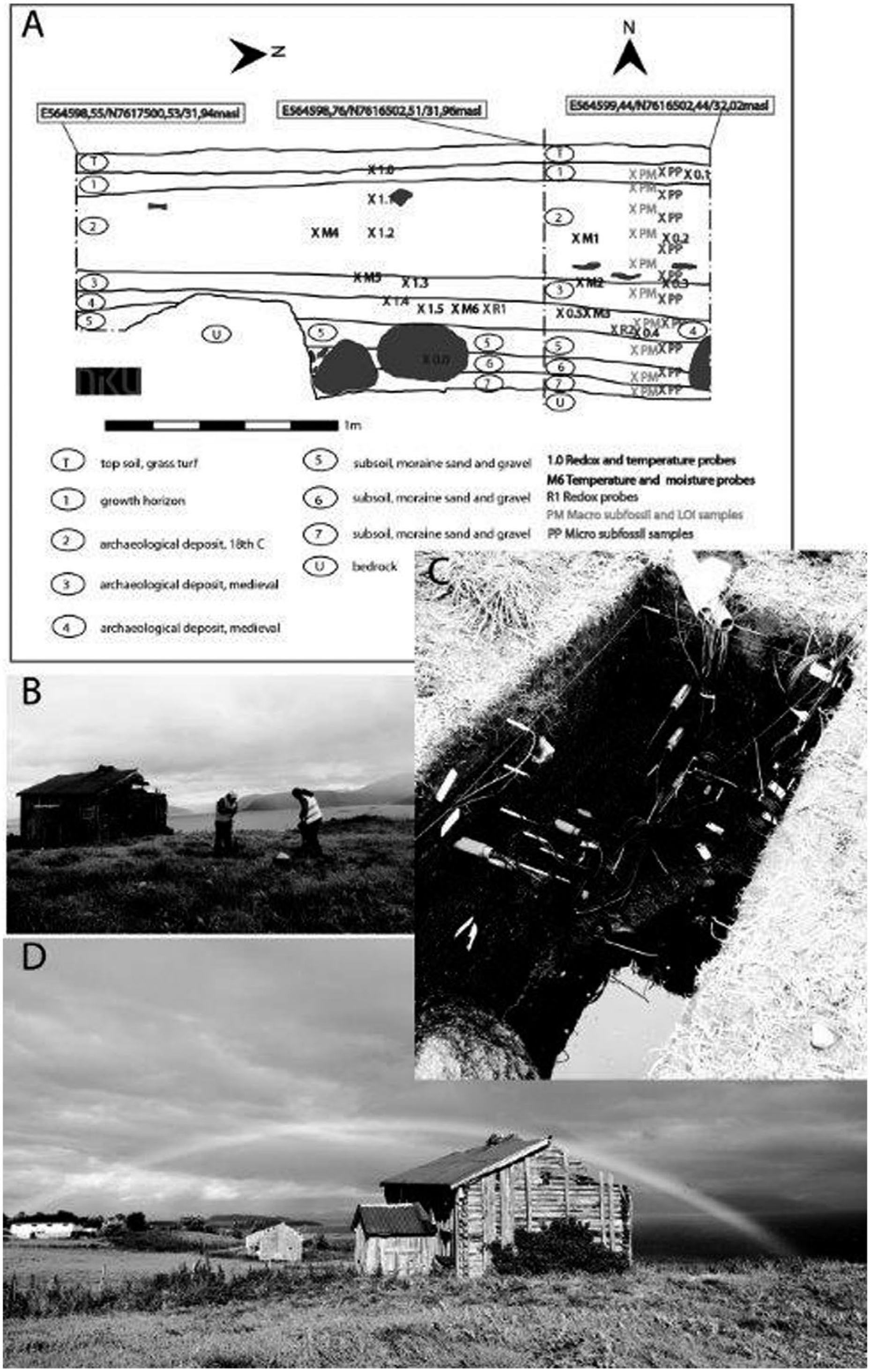


FIGURE 3 Voldstad section drawing (A) and site photos. B excavation start; C installed equipment; D old main building.

Palaeoecological analyses

Palaeoecological samples were taken from each deposit and at specific depths within the deposit (Figures 2 and 3). The strategy for the analyses was to quantify the amount of inorganic and organic materials in each sample and reveal data sets for evaluation of the organic components and the preservation condition for these as a basis for comparison between the composition of each deposit and the preservation status of different types of material, (cf. NS9451, 2009: 35). A sequential loss-on-ignition (LOI) as recommended by Heiri et al. (2001) was performed on subsamples from all deposits. The preparation of sediments for analysis of macroscopic subfossil (plant macro fossils) was according to Wasylikowa (1986) and Griffin (1988). Samples for absolute analysis of microscopic subfossils (pollen) were prepared according to Stockmarr (1971) and Fægri et al. (1989). These analyses (Figure 4) were carried out by the Archaeological Museum, University of Stavanger (AM UiS).

Geophysical and geo-chemical analyses

Soil samples were taken from equipment installation points by NIBIO (Figures 2–3; Tables 1–4). Packaging and handling was done according to the National Standard (see Martens & Bergersen, 2015: 70–72). The samples were analysed according to the required parameters stated in the national standard (NS9451, 2009: 12, 21) as far as this was possible and practical to follow; in this case temperature (measured onsite), humidity/soil water content (onsite measurement), dry matter content (DM), pH/acidity, electric conductivity (Shirokova, et al., 2000), sulphate/sulphide (Rickard & Morse, 2005), reduced/oxidised iron (Stookey, 1970), ammonium/nitrate and redox evaluation. The analyses were partly carried out at the Norwegian Institute of Bioeconomy Research (NIBIO), partly at Eurofins AS.

Long-term monitoring equipment

Both sites were equipped with two sets of permanent probes: to test equipment efficiency at these site types and enable recommendations for the heritage management. One set consisted of six probes for soil moisture and temperature (TRIME PICO32 from IMKO Modultechnik Gmbh), and two redox probes (Hanna instruments HI2930B/5). These probes were connected to an automatic logger *from SEBA Hydrometrie GmbH* [*UniLogCom* MSD 115] with MET-Controller). The second set consisted of twelve redox potential/temperature probes (Paleo Terra, Amsterdam) and one Ag/AgCl in 3 M KCl reference probe (QM710X, Q-I-S, Oosterhout, NL), connected to a HYPNOS IV datalogger (MVH Consult, Leiden, NL) (Vorenhout, et al., 2011).

All probes were either pushed or installed approximately 25 cm into the section.

Eh was calculated by adding 220 mV to the measured potential (Em), and for simplicity, no correction for pH was applied. Information on precipitation and air temperatures was taken from the meteorology website, Yr (www.yr.no).

Degradation studies

Decay rates of archaeological deposits were investigated by measuring oxygen consumption in soil samples from the two sites. The measurements were carried out at the

Table 1
GEOPHYSICAL, GEO-CHEMICAL AND ARCHAEOLOGICAL EVALUATIONS OF PRESERVATION CONDITIONS AND STATE OF PRESERVATION IN THE MONITORED DEPOSITS AT BAŊKGOHPPI. IN THIS CONTEXT, INORGANICS INCLUDING BONES.

Samples / sensors	Depth (m)	Depth (masl)	Layer	Organic matter (%)	Water content (%)	pH	Conductivity uScm^{-1}	Preservation: Organic material	Preservation: Inorganic material	Preservation: Redox conditions *	Preservation: Archaeological state *
Sensor 4 west	0.24	30.91	Layer 2	68	72	7.2	166	Excellent	Medium	A5	**A3-4**
Sensor 5 west	0.40	30.75	Layer 3	47	68	7.4	166	Excellent	Medium	A5	**A4**
Sensor 6 west	0.56	30.59	Layer 4	59	69	7.6	379	Good	Good	A5	**A4-5**
Redox 1 west	0.57	30.58	Layer 4								**A4-5**
Sensor 1 north	0.26	30.89	Layer 2	57	69	7.3	65	Excellent	Medium	A5	**A3-4**
Sensor 2 north	0.44	30.71	Layer 3	52	69	7.7	291	Good	Good	A4	**A4**
Sensor 3 north	0.52	30.63	Layer 4	43	61	7.3	424	Excellent	Medium	A5	**A4-5**
Redox 2 north	0.58	30.57	Layer 4-5								**A4-5**
Sample A east	0.51	30.64	Layer 3-4	35	60	7.8	218	Good	Good	A4	**A4-5**
Sample B east	0.57	30.58	Layer 4	42	62	8.0	443	Good	Excellent	A5	**A4**

Low organic matter 10%
Medium organic matter 10-20%
High organic matter 30-40%
Low water content10-20%
Medium water content 30-40%
High water content 50-60%

Lousy to poor
Medium
Good to excellent
Oxidizing condition
Reduced condition

* SOPS : NS 9451:2009

Table 2
GEO-CHEMICAL COMPOSITION OF SOIL SAMPLES FROM BAŊKGOHPPI.

Voldstad, Harstad										
Samples / sensors	Depth (m)	Depth (masl)	Layer	Nitrate - N (mg/kg DM)	Ammonium-N (mg/kg DM)	Sulphate (mg/kg DM)	Sulphide (mg/kg DM)	Iron (II) (mg/kg DM)	Iron (III) (mg/kg DM)	% of Iron (II)
Sensor 4 west	0.24	30.91	Layer 2	< 0.1	18.2	< 3.8	124	317	10	97%
Sensor 5 west	0.40	30.75	Layer 3	< 0.1	13.9	< 3.7	109	395	0.1	100%
Sensor 6 west	0.56	30.59	Layer 4	< 0.1	5.6	478	382	761	0.1	100%
Redox 1 west	0.57	30.58	Layer 4							
Sensor 1 north	0.26	30.89	Layer 2	< 0.1	17.8	140	181	371	38	91%
Sensor 2 north	0.44	30.71	Layer 3	3.68	12.3	< 3.6	28	534	94	85%
Sensor 3 north	0.52	30.63	Layer 4	< 0.1	19.5	272	611	1204	31	98%
Redox 2 north	0.58	30.57	Layer 4-5							
Sample A east	0.50	30.64	Layer 3-4	< 0.1	13.3	< 2.9	51	443	65	87%
Sample B east	0.57	30.58	Layer 4	< 0.1	9.1	< 3.1	120	495	19	96%

DM= dry matter

Table 3
GEOPHYSICAL, GEO-CHEMICAL, AND ARCHAEOLOGICAL EVALUATIONS OF PRESERVATION CONDITIONS AND STATE OF PRESERVATION IN THE MONITORED DEPOSITS AT VOLDSTAD.

Baŋkgohppi, Varanger

	Depth			**Organic matter**	**Water content**			**Preservation**			
Samples / sensors	**(m)**	**(masl)**	**Layer**	**(%)**	**(%)**	**pH**	**Conductivity uScm $^{-1}$**	**Organic material**	**Inorganic material**	**Redox conditions***	**Archaeological state***
Sensor 4 west	0.30	14.10	Layer 3	4	6	8.3	226	**Poor**	Excellent	**A2**	**A3-4**
Sensor 3 west	0.05	13.75	Layer 2	10	16	7.7	365	**Poor**	Good	**A2**	**A3**
Redox 1 west	0.20	13.60	Layer 4	12	12	8.2	297	**Medium**	Excellent	**A3**	**A4**
Sensor 1 west	0.37	13.53	Layer 4	4	1	8.8	209	**Poor**	Excellent	**A2**	**A4**
Sensor 5 west	0.34	13.46	Layer 7	5	11	8.7	221	**Poor**	Excellent	**A2**	**A3**
Redox 2 west	0.63	13.17	Layer 8	3	11	9.2	168	**Poor**	Excellent	**A2**	**A3**
Sensor 6 west	0.86	13.04	Layer 9	2	6	8.9	144	**Poor**	Excellent	**A2**	**A2**
Sensor 2 east	0.38	13.52	Layer 5	3	9	8.9	210	**Medium**	Excellent	A3	**A3**
Section south	0.70	13.10	Layer 8	10	18	8.5	252	**Medium**	Excellent	A3	**A3**

Low organic matter 10%
Medium organic matter 10-20%
High organic matter 30-40%
Low water content10-20%
Medium water content 30-40%
High water content 50-60%

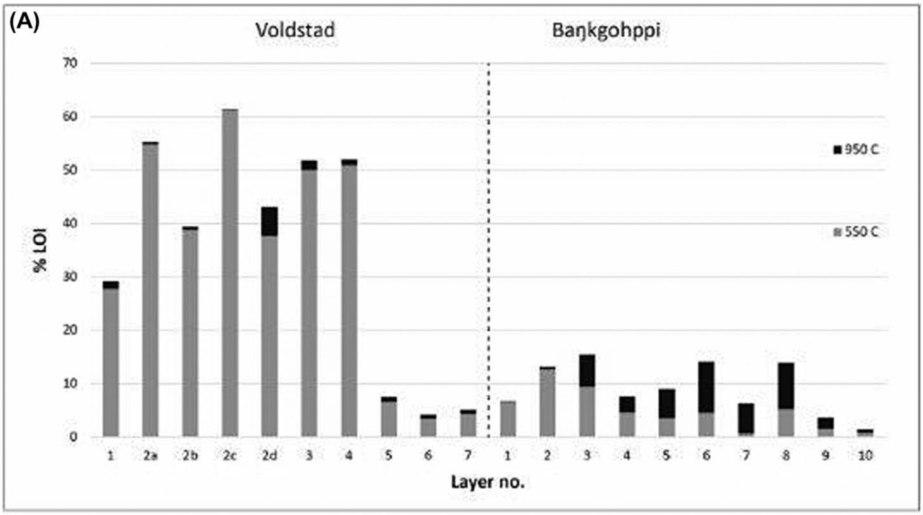
Lousy to poor
Medium
Good to excellent
Oxidizing condition
Reduced condition

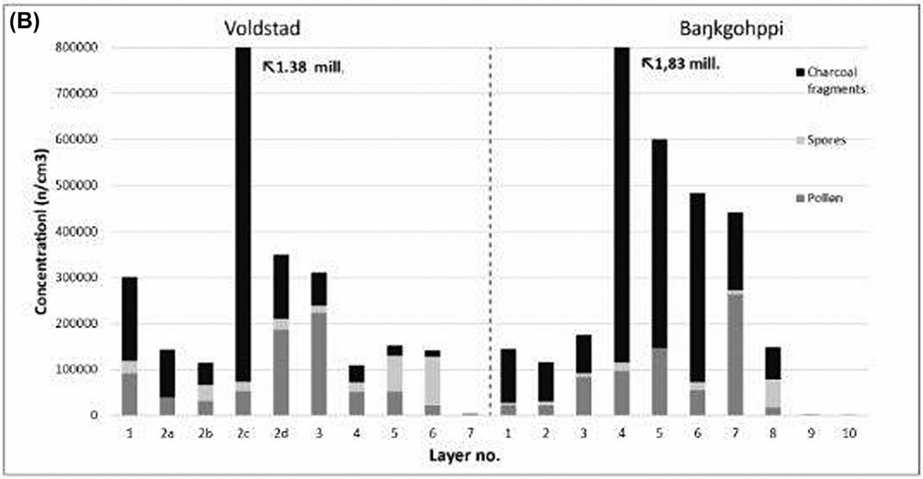
* *SOPS : NS 9451:2009

Table 4
GEO-CHEMICAL COMPOSITION OF SOIL SAMPLES FROM VOLDSTAD.

Baŋkgohppi, Varanger										
	Depth	Depth		Nitrate - N	Ammonium-N	Sulphate	Sulphide	Iron (II)	Iron (III)	
Samples / sensors	(m)	(masl)	Layer	(mg/kg DM)	(mg/kg DM)	(mg/kg DM)	(mg/kg DM)	(mg/kg DM)	(mg/kg DM)	% of Iron (II)
Sensor 4 west	0.30	14.10	Layer 3	< 0.1	3.9	< 1.2	n.d	124	128	49%
Sensor 3 west	0.05	13.75	Layer 2	< 0.1	4.9	< 1.6	n.d	1.9	1.9	50%
Redox 1 west	0.20	13.60	Layer 4	< 0.1	3.8	< 1.3	n.d	76	37	67%
Sensor 1 west	0.37	13.53	Layer 4	< 0.1	11.6	< 4.4	n.d	3.1	2.5	56%
Sensor 5 west	0.34	13.46	Layer 7	< 0.1	2.9	< 1.3	n.d	0.9	1.3	40%
Redox 2 west	0.63	13.17	Layer 8	< 0.1	2.8	< 1.3	n.d	0.9	0.9	50%
Sensor 6 west	0.86	13.04	Layer 9	< 0.1	2.5	< 1.2	n.d	84	178	32%
Sensor 2 east	0.38	13.52	Layer 5	< 0.1	2.8	< 1.2	n.d	1.4	0.3	80%
Section south	0.70	13.10	Layer 8	< 0.1	2.8	< 1.4	n.d	215	52	81%

DM= dry matter
n.d. not detected because of high pH and lots of shells (from snails, clams and mussels).





(C)	Voldstad										Baŋkgohppi									
Types of macroscopic subfossils	1	2a	2b	2c	2d	3	4	5	6	7	1	2	3	4	5	6	7	8	9	10
Seeds, charred	x	x	x	x	x	x	x	x					x							
Fungi	x	x	x	x	x	x	x	x					x		x	x	x			
Charcoal	x	x	x	x	x	x	x	x	x											
Bones	x	x		x	x	x	x	x												
Snails											x	xx	xxx	xxx	xxx	xxx	xx			xxx
Mussels	x	x				x	x					x			xxx		x			
Sea-urchin												xx		x	x	x	x			
Unspecified fragments												xx	xx	x	xx	x	x	xx	x	

FIGURE 4 Results of palaeoecological investigations. A: Loss-on-ignition (LOI %). B: Concentration (n/cm³ sample) of groups of microscopic subfossils. C: Groups of macroscopic subfossils. x = present, xx = common, xxx = abundant.

National Museum of Denmark according to Matthiesen (2007). To investigate temperature dependency of the reactivity, measurements were made at 0.5, 5, 10 and 15 °C on three replicate samples of each of the included archaeological layers (Figure 7). In addition, oxygen consumption rates were measured at different water contents to estimate the sensitivity of the decay processes to changes in soil water content (Hollesen, et al., 2015b; Møller, et al., 2015).

Results

Archaeology

The trench at Baŋkgohppi (Figure 2) had dry, porous deposits with a high content of marine remains. Bones from terrestrial and sea mammals, fish, and birds were found with clams, shells, and mussels, well-preserved antler artefacts, and stone artefacts. Six archaeological deposits or contexts were identified in the midden (Figure 2(A)), layers 2–7 (1: topsoil, 8–10: subsoil). The archaeological deposits investigated belonged to parts of the wall and the midden. Layer 5 was particularly rich in information and in archaeological finds, including an antler artefact fragment decorated with incised lines — typical of the period (Figure 2(C)).

Seven samples of charcoal from trees and heather from layers 4–8 were processed at Beta Analytic and gave dating results that span from 2460 to 1915 BC (Beta 383557–383563, cal., 2 sigma). The dates are systematically older downwards in the midden layers (Martens, et al., 2015a).

The Voldstad farm mound site (Figure 3) had wet, humus-rich deposits dominated by terrestrial remains. The archaeological deposits consisted of typical household waste, wood, and leather, a little pottery, and single objects of glass, iron, and stone, in addition to large amounts of animal and fish bones and a few bird bones. These finds confirm a mixed economic background of husbandry and fishing. Layer 2 (Figure 3(A)) was artefact dated through pottery finds to the eighteenth century, layer 3 to the fourteenth century. Based on stratigraphy, layer 4 was also presumed to be medieval. In general, layers 2–4 seemed to be well-preserved and thus good sources of information. The subsoil layers (5–7) had decreasing amounts of in-washed humus until bedrock was reached. No house remains were found, because known house sites were deliberately avoided (Martens, et al., 2015b).

Palaeoecology

Samples from each deposit at both sites were prepared for sequential loss-on-ignition (LOI) (Heiri, et al., 2001), making it possible to distinguish between organic and inorganic carbon on loss-on-ignition at respectively 550 °C and 950 °C (Santisteban, et al., 2004).

At Voldstad the total LOI is an average of 30% at the top while the values increase to 40–60% in deposits 2–4 (Figure 3). The main part of LOI at this site is at 550 °C, but some loss also occurs at 950 °C. At Baŋkgohppi the total LOI never reaches more than 17% and is less than 10% for most layers. Most LOI in the topsoil, (Figure 2), occurs at 550 °C, while LOI at 950 °C increases in layers 3–4 and becomes dominant from layer 5 and towards the subsoil (Figure 4(A)). The LOI analyses reveal significant differences between the sites as well as between the different deposits. The LOI at 550 °C reveals the amount of macroscopic organic remains such as seeds, twigs, and other plant remains and soft tissue, and microscopic remains such as pollen, spores, and severely decomposed material, while LOI at 950 °C occurs by loss of bone and shell. All these types of materials are sources of knowledge about the past that might be lost to researchers in the future.

The microscopic and macroscopic subfossils (Figure 4(B) and (C)) reveal further differences between the sites. Absolute analyses of microscopic subfossils (Stockmarr, 1971) enable calculation of the concentration of microfossils for each identified type. Figure 4(B) presents concentration values for the groups of microscopic subfossils: pollen, spores, and charcoal fragments, and these are the most abundant finds at both sites. Charred remains have high resistance towards biological degradation and might be present in archaeological deposits of all ages, even when no other organic remains are preserved. Another observation shown in Figure 4(B) is the relatively high concentration of spores from ferns and fungi in layers 5 and 6 at Voldstad (Martens, et al., 2015b). Fungi participate in the decay of organic material while fern in the genus *Polypodium* is resistant and thus preserved even when most organic remains are decayed.

Macroscopic subfossils differ between the sites (Figure 4(C)). Despite the promising organic matter content at Voldstad, remains of botanical origin were present, but not abundant. Identified finds are one single charred grain of barley (*Hordeum vulgare*), small amounts of the fungi *Cenococcum geophilum*, and some charcoal, while most organic remains seem to be decayed to a level were identification is impossible. At Baŋkgohppi shells of snails, clams, mussels, and fragments of sea urchins dominate the deposits (Martens, et al., 2015a). Earlier investigation of Gressbakken sites (Soot-Ryen, 1968) reported no finds of sea urchin.

Geophysical and geo-chemical analyses and monitoring

The analysed deposits at Baŋkgohppi had low organic content and low water content (Table 1). All deposits had low conductivity: <350 uScm-1, and pH was slightly alkaline to alkaline/basic (8–9). The high pH was caused by the large amount of zoological content. Poor to medium preservation conditions for organic (botanical) matter were measured in all samples (medium where conditions were iron reducing). For inorganic materials (here including bones and shells) high pH and low conductivity cause good to excellent preservation conditions. Both reduced (Fe^{II}) and oxidised iron (Fe^{III}) was present in all deposits in varying quantities (Table 2).

Monitored data at Baŋkgohppi from August 2013 to January 2015 shows an average soil temperature of around 2 °C. Most of the time, the temperatures in the deposits were below zero. Snow cover insulated the deposits during periods with low air temperatures. Maximum measured temperatures in summer were 10–14 °C in the upper parts of the section. Even with oxygen present in the deposits, low temperatures will mean low chemical and biological activity. Soil moisture content has been consistently low: 4–8%, excepting the topsoil with 16%. Low water content means oxidising conditions, and the redox potential measurements show full aeration of the soil profile (Figure 5).

At Voldstad, all analysed deposits had high organic matter content and high water saturation (Table 3). This should in general lead to good preservation conditions. Conductivity was low: <400 uScm-1, and pH was neutral to slightly basic (7–8). The

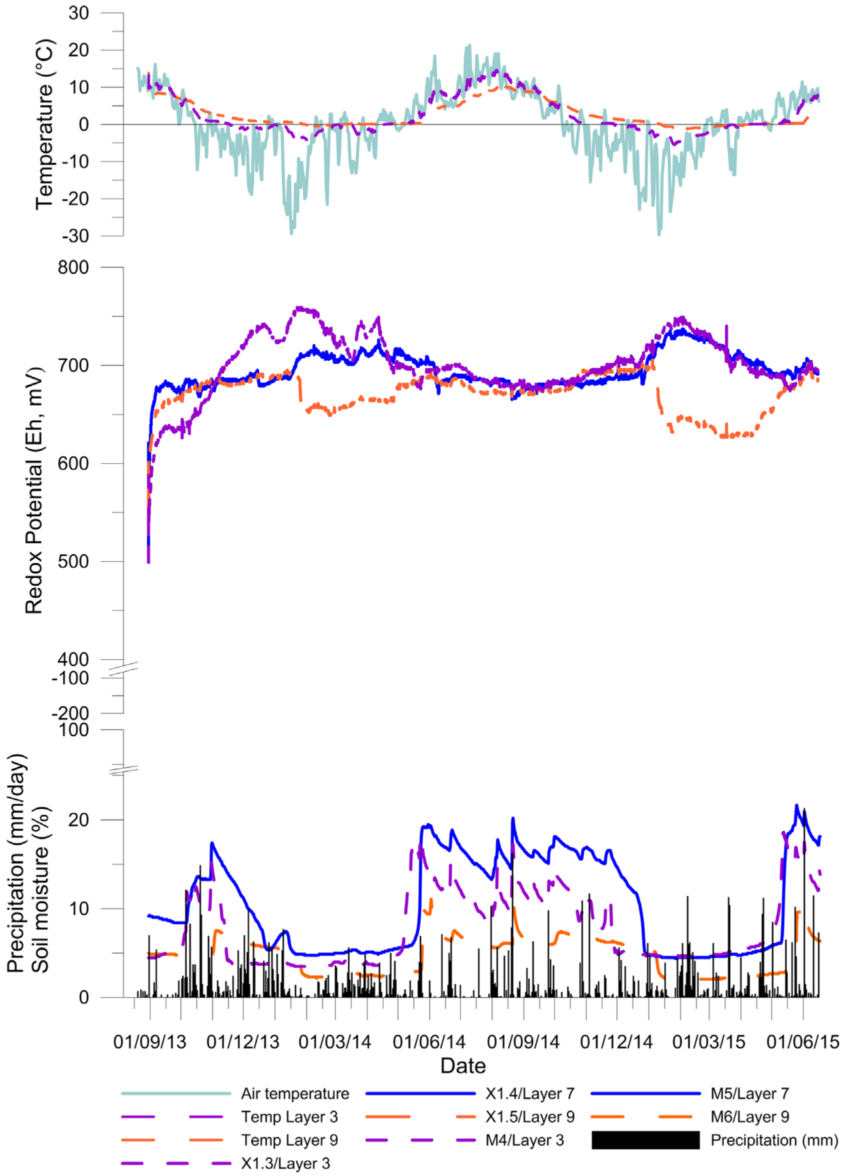


FIGURE 5 Selection of soil temperatures, redox potentials (Eh) and soil moisture values as measured in the western profile of Baŋkgohppi. Coding follows Figure 2. The complete profile is oxic, and shows freezing during winter time. Precipitation (black bars) influence moisture content only in summer periods.

amount of reduced iron (Fe^{II}) was high compared to oxidised iron (Fe^{III}) (Table 4); the nitrate content was low, whereas the amount of ammonium and sulphide were high. The conditions were overall reduced, sulphate reducing to methanogenic.

Mean soil temperature at Voldstad was 4 °C (Figure 6). Temperatures below zero were only found in the top deposits during a few weeks, whereas the rest of the section seemed not to freeze. Mean air temperature was also above zero for large parts of the 2014–15 winter. Maximum temperatures measured in the upper deposits were 9–13 °C. Soil temperatures were slightly higher in the western profile than in the northern profile, probably because it is affected by precipitation flow. Soil moisture in the upper deposits in the western section averages 49%, while the lower ones reach 69–73%. In the northern section, the upper deposits average 65% water content, the lower ones 78%. Fluctuations caused by precipitation were observed, but always slightly delayed. Water content was lower during winter than during summer. The values measured just above the bedrock show high redox potentials there that follow the patterns found high up in the profile (Figure 6).

Degradation studies and sensitivity to temperature and soil water content

The samples from Voldstad consumed 25.2–60.5 µg O_2/day/g dry soil at 5 °C and *in situ* water content, and the decay rate increased by 8.7–14.0% per 1 °C increase in temperature (Hollesen, et al., 2015b). At *in situ* water contents the samples from Baŋkgohppi consumed oxygen at a very low rate (<0.1% saturation per day) and were below or very close to the detection limit of the method. Thereby the results show that at *in situ* water content the decay of the samples from Baŋkgohppi is close to negligible. However, the rates of oxygen consumption increased significantly when adding water to the samples. At 5 °C, the samples from Baŋkgohppi consumed 1.7–4.4 µg O_2/day/g dry soil and the decay rate increased by 3.8–5.0% per 1 °C increase in temperature. At both sites the decay rate was limited at high water contents and very strongly limited at dry conditions. At Voldstad the decay rate was at its maximum at a water content of 40–75% volume (40–95% of saturation), and at Baŋkgohppi the decay rate was greatest at a water content of 20–30% volume (40–60% of saturation).

Discussion

The overall archaeological evaluation of state of preservation at Baŋkgohppi shows well preserved and varied artefacts of bone, antler, and stone, because the site is dry and cold. The zooarchaeological finds are kept stable by a high pH caused by the sheer number of shells in the midden. This is confirmed by the palaeoecological analyses. If present conditions continue in a stable fashion in future, then continued *in situ* preservation should be possible.

Monitoring of the site has so far shown stable low humidity and low temperatures in the deposits. Redox potential measurements have shown that oxygen is present throughout the section year-round. This correlates well with the type of finds at this site; only the calcareous parts of the organic remains are well preserved. Increase in precipitation because of higher temperatures/climate change, could be detrimental for the site, as zooarchaeological remains might be damaged by dissolution due to water flow. The decay experiments also showed that decay will increase with increased moisture content. Other threats might come from the physical disturbance caused by rooting from encroaching

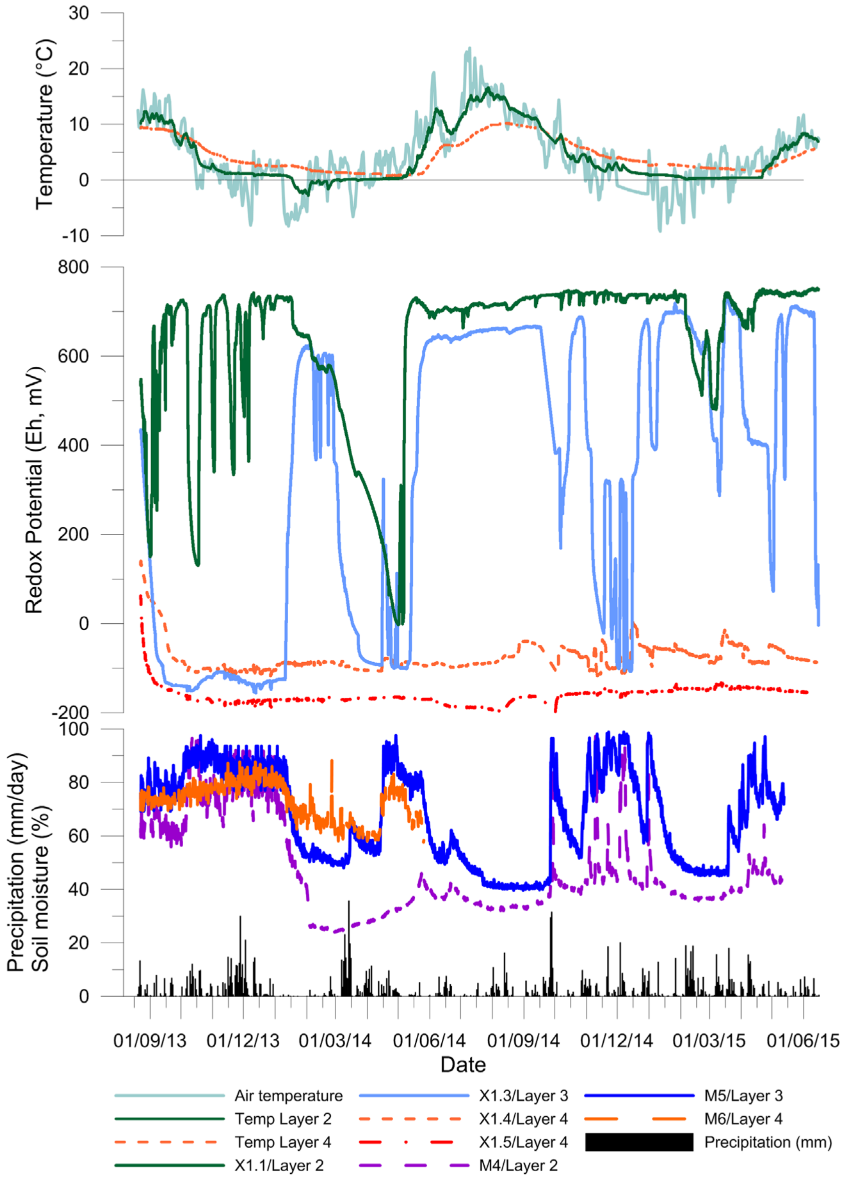


FIGURE 6 Selection of soil temperatures, redox potentials (Eh) and soil moisture values as measured in the western profile of Voldstad. Coding follows Figure 3. During the two winter periods, the Eh in intermediate layers shows a drop, but in non-freezing periods the Eh is relatively high and variable. Precipitation (black bars) appears to influence the Eh in layer 2 only in the first month after the excavation and not so much after the first winter, even though there is a strong link with soil moisture content (bottom part).

vegetation, unless a physical heritage management plan of the site is applied, reducing vegetation.

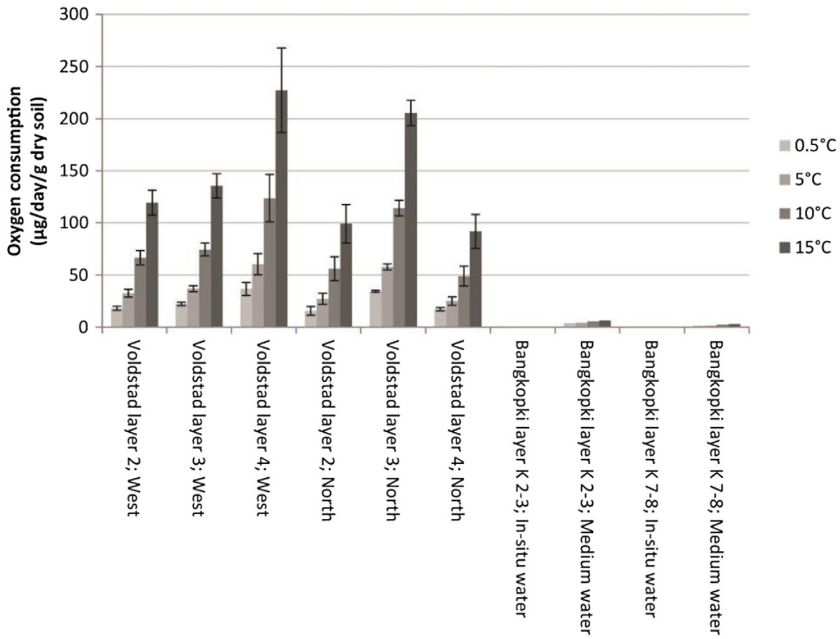


FIGURE 7 Oxygen consumption rates at variable temperatures in soil samples from Voldstad and Baŋkgohppi. Bars mark ± 1 standard deviation.

At Voldstad farm mound, the state of preservation was deemed good to excellent by the archaeologist, and this was confirmed by the geo-chemical analyses of deposits with high organic matter content and high water saturation. The conditions in the soil samples were overall reducing (sulphate to methanogenic). All these factors indicate good conditions for *in situ* preservation. However, soil water content is controlled at this site by infiltration of precipitation into the deposits. The redox potential measurements show large fluctuations, which indicate that oxidizing conditions are occurring even in the lower layers. Reduction occurs in spring time. The change in redox potential in spring 2014 shows that the site responds to the thawing of the topsoil, which stimulates microbial (reducing) activity resulting in a decreasing redox potential.

Reducing conditions can only occur when soil moisture content is high enough and limits the oxygen diffusion, showing the need for enough water infiltration, which at Voldstad probably occurs at higher areas, not just at the test pit. Overall, the preservation conditions at Voldstad are perhaps not as excellent as perceived on site. The variation in redox potential and the high amount of partly degraded organics show that this site has active, though slow, degradation. The degradation has probably occurred throughout the complete lifespan of the site, but will continue in future. In order to preserve this site, the water supply to the soil should not be hindered. This water is crucial in maintaining a reduced environment. Due to the slope, it will be very hard to reduce water flow itself.

The use of two sets of equipment have ensured that even if some probes fail, information will be secured, and palaeoecological analyses and redox measurements have revealed ongoing decay that might not otherwise have been suspected.

For both Voldstad and Baŋkgohppi the mean annual temperature is expected to increase by approximately 3 °C within the period 2071 to2100 (relative to 1961 to1990) and the mean annual precipitation sum is expected to increase by approximately 30% (Norwegian Meteorological Institute, Yr). This may have a direct effect on the preservation conditions. The measurement of oxygen consumption showed that the decay rate could increase by 8.7–14.0% for Voldstad and 3.8–5.0% Baŋkgohppi per 1 °C increase in temperature. The soil at Voldstad is much wetter than the soil at Baŋkgohppi. For this reason, the decay of the organic materials at Voldstad is primarily limited by the high water contents and the resulting exclusion of oxygen. On the other hand, the decay of the organic materials at Baŋkgohppi is limited by the dryness of the soil. Consequently, the decay rates in the archaeological deposits of the two sites are likely to react very differently to future changes in precipitation. At Voldstad the expected increase in precipitation could help to keep the deposits wet and counteract the direct effect of a warmer climate. However, a decrease in net precipitation (precipitation minus evaporation) could threaten the continued preservation of the archaeological deposits, as more oxygen would diffuse into the soil. At Baŋkgohppi the expected increase in precipitation is likely to accelerate the decay rate, as it would no longer be limited by the dry conditions in the soil.

Conclusion

If continued *in situ* preservation is to be possible at these site types with the predicted climate changes, heritage management plans should be applied that reduce encroaching vegetation on the Stone Age sites and possibly added chalk to keep an alkaline environment. The calcareous remains may not be affected much by changes in temperature, but increased precipitation will accelerate decay of the deposits themselves, making site interpretation more difficult.

For the farm mounds, increasing precipitation may help preserve the sites even if temperatures rise. The worst possible scenario for organic deposits is increased temperatures but less water, since that would accelerate decay there. Covering sites with clay to help preserve soil humidity and protect them from higher temperatures might be a possible mitigation act.

The two sites presented here constitute a small selection of their respective sites, making it difficult to draw general conclusions for all the sites. Given the general morphology at the Baŋkgohppi site, that can be said to be representative of a typical dwelling. For the farm mounds, more monitoring projects have begun, enabling scaling up at a later stage.

If not all sites can be preserved, should they then be excavated and preserved *ex situ*, or should they simply be left to decay? It may be necessary for the cultural heritage management to choose between sites. This should preferably be an informed choice, made in collaboration between research and management.

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archaeology/environmental_monitoring/archaeological_deposits_in_a_changing_climate_in_situ_preservation_of_farm_mounds/).

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