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Edited by Stephen Trow, Vincent Holyoak
and Emmet Byrnes

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Meon Hill, a statutorily protected Iron Age hillfort situated in Warwickshire, England. The monument, lying partly within woodland and partly in farmland and with its eastern side levelled by cultivation, encapsulates the management challenges faced by thousands of archaeological sites in Europe. © *English Heritage NMR 15369.27*

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Looking to the Future

8 | Environmental monitoring of archaeological deposits

Vibeke Vandrup Martens

Abstract: Methods of environmental monitoring of archaeological deposits, covering urban and rural areas, and varying depositional situations including saturated or unsaturated zones, are described. An example is given from the farm of Aaker in Hamar, county of Hedmark, Norway. A method for standardised archaeological documentation of depositional conditions and definition of the state of preservation is shown. The implementation of the method, the underlying legislation, and its consequences for archaeology and *in-situ* site conservation are discussed.

Introduction

Archaeological deposits are a part of our cultural heritage containing physical evidence of our past practices and interactions with nature. Physical or 'tangible' cultural heritage is often unique and irreplaceable. Besides buildings, monuments and historic places it includes hidden objects, structures and soil layers of importance for archaeology. The meanings of this physical evidence can be interpreted within the context of socio-economic, political, ethnic, religious and philosophical values of particular groups of people (Sandvik 2006; Sillasoo & Hiie 2007). The importance of the preservation of cultural heritage is stressed by several conventions. The Convention Concerning the Protection of World Cultural and Natural Heritage was adopted by the General Conference of UNESCO in 1972 (http://whc.unesco.org). The European Convention on the Protection of the Archaeological Heritage (www.conventions.coe.int, also known as the Malta or Valletta Convention), which was agreed in 1992, and was in turn designed to protect the archaeological heritage as a source of the European collective memory and as an instrument for historical and scientific study. It has been ratified by most European countries. The Valletta treaty calls for 'the conservation and maintenance of the archaeological heritage, preferably *in situ*'. This means that archaeological sites must be actively maintained, or investigated, and not just left to natural deterioration or subject to anthropogenic destruction.

The Norwegian Directorate of Cultural Heritage has proposed that it will in future undertake its statutory duty of preserving the national heritage primarily by seeking to preserve archaeological sites *in situ*. This is in accordance with the Norwegian Ministry of Environment's stated aim to 'preserve the underground archives and at the same time establish conditions for continued use of the pertinent areas and the development of vital inner cities' (Parliamentary Report No. 16, 2004–2005). It is also adhering to the guidelines in the new standard from 2009 (NS 9451:2009) about 'Cultural property. Requirements on environmental monitoring and investigation of cultural deposits'.

Besides being part of our cultural heritage, archaeological deposits of various ages present in the rural and urban landscapes are geo-ecosystems affected by environmental processes. The changes to the environment caused by global warming and other environmental threats, including human activities such as intensive land use or the continuous development of towns, will put archaeological evidence at risk and are a challenge for present and future future management of cultural heritage. How fast do archaeological materials and soil features degrade? At which point will the contextual value of the deposits become unreadable and impossible to interpret? And what measures can we take in order to promote a sustainable *in-situ* preservation? During the past 15 years or more, work on *in-situ* preservation of archaeological remains has taken place as a consequence of the Valletta charter of 1992 (Williams & Corfield 2003; Willems 2008). However, much of the work so far has dealt with questions of the feasibility of *in-situ* preservation without debating to what extent it is the desired solution, or if preservation through excavation and documentation is a safer way (Membery 2008).

The method puts a large responsibility on future generations, as the concept of *in-situ* preservation implies that the deposits remain unchanged 'for ever'. To ensure that *in-situ* preservation may be considered a possibility, knowledge about the present state of preservation as well as the physical and chemical conditions for future preservation capacity is necessary. Environmental monitoring of archaeological deposits is the study of degradation processes and a search for mitigation strategies and remedial actions if or when critical levels are reached.

Methods

Degradation of archaeological deposits is caused first and foremost by oxidation of organic or inorganic material (Matthiesen 2004; Matthiesen *et al.* 2006, fig. 3; Huisman 2009). Monitoring of environmental conditions in deposits may be used to describe the present state of preservation and the physical and chemical conditions for future preservation (Smit *et al.* 2006). The management, preservation and conservation of archaeological sites *in situ* are complex tasks requiring a basis of multi-disciplinary competence. It is a relatively new tool to be used in the management of cultural heritage (Peacock 2002; Kars & Kars 2002; NIKU & RA 2008; Reed & Martens 2008). Good preservation conditions for archaeological deposits are characterised by stable physical and chemical conditions and relatively low micro-biological and chemical activity.

Research on *in-situ* preservation of archaeological deposits has so far concentrated mainly on the deposits in the saturated zone below the ground-water table (Vorenhout & Smit 2006; Vorenhout 2008). Research projects conducted in the deposits at Bryggen in Bergen in Norway (http://www.natmus.dk/graphics/bevaring/arkaeologi/pdf-filer/HenningMatt/matt2004woampos-terbryggen.pdf) and at a number of sites in the UK, the Netherlands and other European countries (Christensson 2004; NIKU & RA 2008; Keevill *et al.* 2004; Matthiesen *et al.* 2006) are examples of this type of research and have shown that archaeological deposits are usually very well preserved under strongly anoxic conditions (lacking oxygen) that are predominantly observed in waterlogged environments (Caple 1998; Caple & Dungworth 1998).

However, large volumes of archaeological deposits in most parts of medieval towns are situated in the unsaturated zone, where the layers are not permanently waterlogged (Gardelin 2002; Martens 2008b; Williams & Corfield 2003). In this zone, oxygen can be transported by percolating rainwater to the archaeological deposits or by diffusion of oxygen through unsaturated soil layers. Very little information is available about the environmental conditions determining the preservation conditions of archaeological deposits in the unsaturated zone. This is mainly due to the lack of adequate methods to measure the physical, chemical and biological conditions in the unsaturated zone and thus a combination of different scientific disciplines for the characterisation of the preservation conditions is required.

Archaeological deposits outside the towns are also often in the unsaturated zone. This means that the problems of dryness and porosity are augmented by the extra threats of cultivation: harrowing, ploughing, drainage, fertilisation and additions of other chemical components to fight weeds, improve the soil and get larger and/or healthier crops. Crops that require more soil processing, such as potatoes or strawberries, are harder on the deposits than cereals because of the additional soil operations undertaken to cultivate them (Durham 2008; Trow, this volume).

Monitoring techniques have so far been developed mainly for the saturated zone where ground water is monitored or sampled. These techniques cannot be transferred to the unsaturated zone because of the lack of soil water (Peacock 2002). Other techniques for *in-situ* monitoring and laboratory measurements must therefore be developed, implemented and evaluated (Hartnik *et al.* 2000; Huisman 2009). In addition, the state of preservation and the environmental conditions in the unsaturated zone are expected to deviate more in time and space than those in the saturated zone because the aqueous phase does not govern the environmental conditions to the same extent. Maintaining equilibrium between artefacts, ecofacts and their surroundings ensures long-term preservation *in situ*. Even small changes in the conditions of deposition, as caused by global environmental development or structural changes, may accelerate deterioration (Peacock 2002; Kars & Kars 2002).

To evaluate the possibilities for *in-situ* preservation, a necessary starting point is an assessment of the present state of preservation. Information may be gained from excavation profiles or from drilling or auguring into the deposits.

In a fieldwork situation, a relatively easy assessment of the state of preservation should be based on the following principal criteria/indicators (from NIKU & RA 2008, 37):

- Odour
    - for organic deposits: presence and strength of 'rotten-egg' smell
    - for wood: presence and strength of 'freshly cut' smell
- Colour/colour change (the brighter the soil's colour when first exposed and the faster the colour change after exposure, the better the preservation)
- Amount of force required to snap pieces of wood (the more force, the better the preservation – for this purpose, relatively thin woodchips or twigs should be chosen, not naturally hard pieces like knots)
- Amount of force required to pull apart a strand of moss
- Sponge reaction of soil block; squishiness of woodchips; springiness of strands of moss or hair/fur
- General appearance (colour, visibility of structure) of macroscopically visible organic components.

That should allow a description of the state of preservation in accordance with Table 8.1.

In addition to this kind of archaeological observation, reasonably good standards have now been developed for sampling and measuring (NS 9451:2009) to obtain information on the future conditions for preservation. Archaeologists work with geochemists, geophysicists, microbiologists and hydro-geologists, measuring soil humidity, soil temperature, porosity and water content, loss on ignition (content of organic material), pH (acidity), and redox potential.

Redox conditions in soil (Table 8.2) may be characterised by measuring redox-sensitive parameters in soil and in pore water (oxygen, nitrate, ammonia, manganese (II), manganese (IV), iron (III), iron (II), sulphate, sulphide, methane) (Stumm & Morgan 1996). High oxygen concentrations indicate that micro-organisms feed on oxygen

Table 8.1 State of preservation scale (SOPS) after NIKU & RA 2008 and NS 9451:2009.

Preservation scale		Degree of preservation						
		null-value	lousy	poor	medium	good	excellent	
Position in relation to groundwater	over	A0	A1	A2	A3	A4	A5	A
	over/in	B0	B1	B2	B3	B4	B5	B
	in	C0	C1	C2	C3	C4	C5	C
		0	1	2	3	4	5	
fill etc. later than *c* 1900		D0	D1	D2	D3	D4	D5	D

Nitrate NO_3	Ammonia NH_4	Sulphide H_2S	Iron (II) Fe_2	Iron (III) Fe_3	Redox conditions	Preservation
Low	Low	Low	Low	High	oxidising	Lousy
High	Low	Low	Low	High	nitrate to oxidising	Poor
High	Low	Low	High	Low	nitrate to iron reducing	Medium
Low	Low	Low	High	Low	iron reducing	Medium
High	High	High	High	Low	nitrate to sulphate reducing	Good
Low	High	High	High	Low	sulphate reducing	Good
Low	High	High	High	Low	sulphate red. to metanogene	Excellent

Reducing conditions
Oxidising conditions

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Table 8.2 **Concentration levels for parameters used to evaluate preservation capacity.**

to degrade organic matter. In such conditions one may expect nitrogen to be present as nitrate and not as ammonia, and iron as oxidised iron (III); the concentration of sulphide will mostly be very low. However, if the conditions are instead iron reducing, all the oxygen and nitrate will already have been used up by micro-organisms, nitrate will be present as ammonia, and high concentrations of iron (II) should be present (Hartnik *et al.* 2000; Martens *et al.* 2008, 13). Thus organic matter may have already degraded, or no degradation takes place.

In nature, degradation of organic matter or corrosion of metals takes place parallel to reduction of other chemical combinations. The slowest degradation of organic matter, and the least oxidation of metals, takes place in metanogene conditions. By contrast, the fastest degradation of organic matter happens in oxygen-rich conditions. Oxidising and nitrate-reducing conditions may mostly be classified as poor preservation conditions, while sulphate-reducing and metanogene conditions are mostly excellent preservation conditions.

Other environmental factors that affect the preservation conditions of archaeological deposits are the permeability and water content of the masses. These factors control the transport of (oxygen-rich) water through the deposits and diffusion of oxygen into the pores. Presence of poisonous combinations may slow the degradation of organic matter. Acid and highly soluble salts corrode the surface of metal objects. Increased acidity and salt concentration increases corrosion of metal objects and detrition and decaying of bone (Kars & Kars 2002; Huisman 2009).

The development of mitigation strategies is the next logical step. It is of vital importance to know what to do when critical levels are reached, and to enable the decision whether to excavate (that is, choose preservation by record) as the final solution for preserving knowledge. Monitoring of archaeological deposits gives baseline data that can contribute to our understanding of the natural processes of degradation that do occur within the deposits. These data must be the basis for action in management (Huisman 2009; Martens 2008a; NS 9451:2009).

The alternative to *in-situ* preservation is preservation by record, that is, through detailed archaeological investigation and documentation. All artefacts, ecofacts, soil samples and other physical remains from the past, as well as all documentation material, need to be secured as a physical archive for the future. Knowledge about the conditions for conservation of this physical archive can be compared to the conservation possibilities *in situ* (Bergstrand & Nyström Godfrey 2006; Rimmer & Caple 2008). These archaeological considerations can be built into the overall societal planning and thus reduce the impact on archaeological deposits, allowing such deposits to be preserved *in situ* and more sustainably managed in the future (Martens 2008b; Willems 2008; NS 9451:2009).

Material and results

The chosen sample site in this context is Aaker, a magnate (or high-status) farm from the Roman period until the 18th century, since then used for farming and, later, as a military area. Aaker is situated at the Aakersvika bay, on the eastern shore of Lake Mjøsa, immediately east of the town of Hamar. The farm and its surrounding land are now owned by the Norwegian state, and plans were made to transform it into a new state archive. This would require major building activity, mostly underground, so inventories were made to assess the extent of the archaeological remains. This work was carried out by the county archaeologists (Hedmark fylkeskommune). When the remains had been mapped, NIKU, Bioforsk (the Norwegian Institute for Agricultural and Environmental Research) and Multiconsult, the consulting engineering company, were hired to evaluate the state of preservation of the archaeological remains, the conditions for future *in-situ* conservation, the soil properties and possible building methods (Martens *et al.* 2007; Martens *et al.* 2008).

Aaker (Fig. 8.1) is known particularly for its very rich metal finds, first and foremost a gold-plated bronze bird-shaped belt buckle from the Merovingian period (7th century AD) (Mikkelsen & Larsen 1992), and for the fact that archaeological deposits are preserved up to more than 1 metre in thickness, which is unusual for the southern Norwegian countryside. The buckle and other equally spectacular finds from the same period were found on the fields belonging to the farm.

As seen in Figure 8.2, the terrain slopes away from the farm, leaving the impression of a mound comparable to the medieval farm mounds of northern Norway (Bertelsen 1978), and after the recent investigations, that is also how

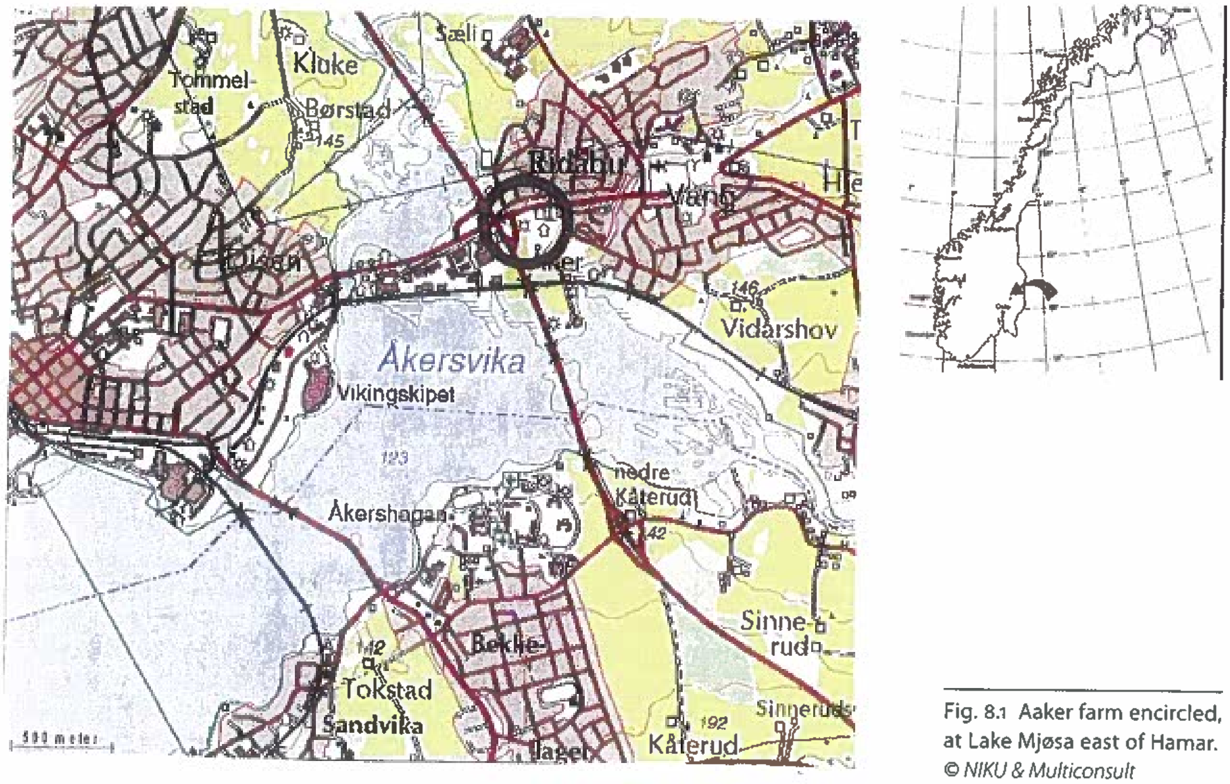

Fig. 8.1 Aaker farm encircled, at Lake Mjøsa east of Hamar. © *NIKU & Multiconsult*

Aaker farm has been interpreted (Martens *et al.* 2007; Martens *et al.* 2008).

As is shown in Figure 8.3, these deposits are rather dry and porous, leaving little potential for the preservation of organic finds, and ecofacts are badly preserved, although bone, burnt as well as unburned, has so far been well preserved, as has metal. Iron, bronze and gold have been found in much larger quantities than expected, thus leading to the interpretation of the site as a magnate farm (Mikkelsen & Larsen 1992; Pilø 2005). However, the porosity of the layers leads to accelerated degradation, enabling oxygen carried through air or water to penetrate deep into the deposits. This may eventually lead to the ultimate destruction of the deposits, and it is gradually rendering them less legible. Even if some ecofacts and artefacts are preserved, their stratigraphical context may soon be lost.

In an attempt to at least secure the maximum information on the deposits as they are disturbed by archaeologists,

Fig. 8.2 Aaker main building seen from the east. Terrain sloping to a farm mound. © *NIKU*

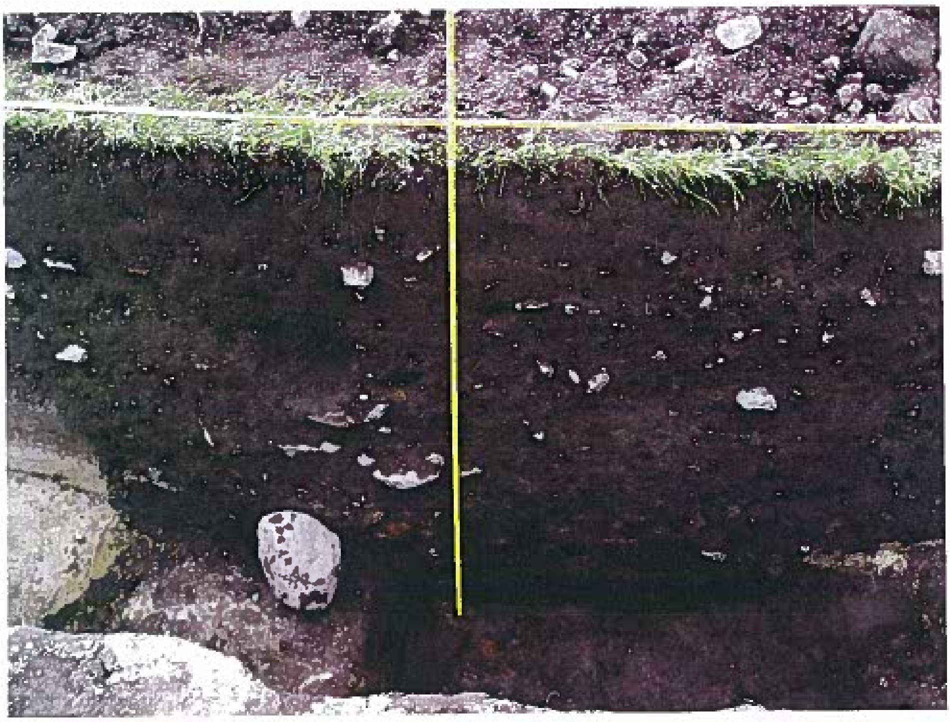

Fig. 8.3 Section through archaeological deposits at Aaker. © *NIKU*

a standardised documentation sheet is used (NIKU & RA 2008, 29–31), classifying the components of the layer and their internal distribution, as well as trying to define their present state of preservation, as shown in Table 8.1.

In 2007, two ditches and two auguring profiles were investigated (for example, Fig. 8.3), and in 2008 the investigation continued with auguring at four locations within the protected area. One profile, borehole 4, consisted of only disturbed layers and sterile subsoil. The archaeological deposits in boreholes 3 and 5 are in the unsaturated zone. They are dry and porous. Archaeologically, the state of preservation was characterised as very poor (borehole 3) and poor (borehole 5) (Table 8.3). In both cases, the geochemical evaluation of future preservation conditions for organic material is equal to the archaeological evaluation, whereas the conditions for the preservation of inorganic material are better, classified as medium (Table 8.3).

At borehole 6, 2 metres of medieval deposits were found beneath modern infill (Table 8.4). All the medieval deposits are in the saturated zone, and so their states of preservation as well as the conditions for future conservation differ considerably from the other investigated deposits at Aaker. Layer 3 was evaluated as being in a poor state of preservation, and the future conservation properties were considered poor to medium for organic material, and medium for inorganic finds. By contrast, layer 4 was in an excellent state of preservation, and the conditions

Table 8.3 Auger profile 5, Aaker, 2008.

Top level (m asl)	Depth (m)	Deposit type	Material	Layer nr	Sample nr	SOPS *	Preservation chemical-physical	
							organic matter	inorganic
129.1	0–0,05	Lawn	Top soil					
129.05	0,05–0,58	Sand	Added soil	1	5-1	D1	poor	medium
128.52	0,58–0,82	Arch deposit	Undisturbed	2	5-2	A2		
128.28	0,82–1,36	Moraine clay	Sub soil	3	5-3			
GW 127,8								
127.74	1,36–1,92	Moraine silt	Sub soil	4	5-4			
127.18	1,92–2	Blue clay	Sub soil	5				

S1	Analysis
S3	Analysis
*	SOPS: Archaeological state of preservation status
░	Low organic content 10%
▒	Medium organic content 10-20%
▓	High organic content 20-30%
GW	Average ground water level

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Top level (m asl)	Depth (m)	Deposit type	Material	Layer nr	Sample nr	SOPS *	Preservation chemical-physical	
							organic matter	inorganic
125.1	0-0,02	Meadow	Top soil					
125.08	0,02-0,64	Sand	Added soil	1		D3		
GW 124,6								
124.46	0,64-0,80	Moraine clay	"	2	6-1	D2	poor	medium
124.3	0,80-1,49	Arch deposit	Undisturbed	3	6-2	C2	poor-medium	medium
123.61	1,49-1,90	Arch deposit	"	4	6-3	C5	excellent	excellent
123.2	1,90-2,42	Arch deposit	"	5	6-4	C3	good	good
122.68	2,42-2,81	Arch deposit	"	6	6-5	C4	good	good
122.29	2,81-3	Blue clay	Sub soil	7				

S1	Analysis
S3	Analysis
*	SOPS: Archaeological state of preservation status
▨	Low organic content 10%
▨	Medium organic content 10-20%
▨	High organic content 20-30%
GW	Average ground water level

© NIKU & Bioforsk

Table 8.4 Auger profile 6, Aaker, 2008.

for future conservation were measured and evaluated as excellent for both organic and inorganic material. Further down, the conditions were not excellent, but still good (Table 8.4; Martens *et al.* 2008, 57–58).

Good preservation conditions for archaeological deposits are characterised by stable physical and chemical conditions and relatively low micro-biological and chemical activity. Stable chemical and physical conditions lead to a decrease in the natural gradients causing chemical processes (for example, hydraulic gradients), thus slowing degradation of the deposits (Martens *et al.* 2008, 13). An evaluation of the archaeological deposits at Aaker shows that the ones in the unsaturated zone are in a rather poor state, and also have poor conditions for *in-situ* conservation, due to their porosity and dryness. The dryness causes cracks that go deep into the soil, thus allowing oxygen and oxygen-filled rainwater to penetrate deep into the deposits. If no mitigating intervention is carried out, for example by covering the deposits with a protective clay layer, the deposits will most certainly degrade further. New and better tools to measure and gain information directly from the soil are needed. Since 2007, probes measuring soil humidity and temperature have been installed in a profile (Fig. 8.3). This simple monitoring may indicate how fast the degradation can happen, so that decisions can be taken whether to excavate or accept the loss of contextual information from a very important site (Martens *et al.* 2007).

From 2007 to 2008, the monitoring showed considerable variation, especially in the top half-metre of deposits. This shows clearly that the uppermost archaeological deposits are the most vulnerable in all respects: mechanical disturbances, dewatering, temperature variations and added access to oxygen (Martens *et al.* 2007, 30). In these deposits, degradation takes place continually. In the areas where the soil is worked, or at other sites in farmed areas with known archaeological locations, it may be necessary to impose restrictions on ploughing depths, drainage and crop types to enable *in-situ* preservation (Johnsen 2009).

The archaeological deposits at Aaker are very similar in composition and content to those of the nearby medieval town of Hamar, and it is probably safe to conclude that the threats to Aaker – continued degradation of deposits due to dewatering and ultimately loss of contextual information – also hold true for Hamar. After the latest investigations, it was decided that building a new state archive would pose too great a risk to the archaeological remains, and at present, the future of the site is undecided.

Discussion

When do measurements from environmental monitoring signal danger to the archaeological remains, and what are our options then? How may the contextual information be saved? Is it possible to use chemicals to alter the environment of a site, fill in or drain away water, or cover a site with a protective layer, or do we need to excavate to preserve as much knowledge about the past as we can gain from each site? All these are pertinent questions that must be raised when considering *in-situ* site preservation. At Aaker, after the recent development where building plans were cancelled, there are still no answers to what may be done to mitigate the harm already caused to the site during the preliminary inventories and through natural deterioration.

Another important issue is, who should be asked to pay for mitigation? If data loggers signal danger, 10 or 15 years after they were installed, can we then ask the original developer to pay for the rescue operations, or must mitigation be government funded? Norwegian legislation is not clear on that subject, and the practice is even more muddled. It would not suffice to refer to the 1992 Malta Convention (the European convention on the protection of the archaeological heritage) and the Norwegian Standard (NS 9451:2009), considering that large sums may be involved. On the other hand, a developer who is allowed to build, for example, on piles but on the condition that the preservation state of archaeological remains are evaluated, and the possibilities for *in-situ* preservation are checked and monitored, might reasonably be made to set aside funds (for example, in a closed bank account) to be used for mitigation strategies if and when the need arises. Such a condition should be weighed against the demands that would otherwise have been made to finance a full archaeological investigation of the site before development.

If the archaeological remains cannot be preserved *in situ*, they may be rescued for the future by excavation and conservation in museums and research institutes. However, both artefacts and ecofacts may be degraded during storage. It is therefore of interest to compare preservation *in situ* with preservation *ex situ*, in order to create a basis for reliable protection and conservation of the archaeological deposits and their contextual historical information.

Conclusion

Environmental monitoring of archaeological deposits is a good tool for evaluating the conditions for *in-situ* preservation of archaeological remains, although the methods have so far concentrated on measuring saturated rather than unsaturated sites. We need new and better tools to measure and gain information directly from the soil and not from water. However, an archaeological and contextual evaluation of the site and its state of preservation is a necessary first step. Remains in the unsaturated zone are far more vulnerable than the saturated ones, and it is therefore uncertain whether *in-situ* preservation is a practical solution, or if it will simply lead to a complete loss of contextual information. Thus, an issue to be addressed further is the financing of mitigation strategies for monitored sites.

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