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Moseforsøg - two generations of bog burial studies : interim textile results

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1. Introduction

The Textile Workshop at the Historical-Archaeological Research Center Lejre in Lejre, Denmark have carried out several long-term experiments on the effects of burial in a bog on undyed and natural-dyed wool fabrics [Nordgaard et al. 1983]. At the time these studies were initiated techniques for the analysis of dyestuffs in water-degraded archaeological textiles had not been developed. It was known that dyeing was practised in the Iron Age, yet it was difficult to find evidence for this in the spectacularly preserved Danish textile finds. The Workshop sought to replicate the famous oak coffin bog burials, and see what effect there would be on both the colour of the fabrics and the dyestuffs.

The Conservation Laboratory at Vitenskapsmuseum at the Norwegian University of Science and Technology became interested in the Lejre bog studies with regard to both the burial protocol and the results. In particular, changes to fibre morphology as the result of burial. The recovered samples provided the opportunity to examine fibre damage in a set of new fabrics exposed to actualistic experimental degradation that simulated archaeological burial environments. Samples of the fabrics included in the Lejre burial studies were obtained for damage analysis using light and scanning electron microscopy.

In 1998 Lejre and Vitenskapsmuseum together initiated another bog study, which builds upon the experience and results of the earlier Lejre studies and laboratory-based, soil burial studies carried out by Vitenskapsmuseum [Peacock 1996, 1990]. The new study is different in that it includes a range of organic materials in addition to textiles, and that the materials are not packed in a closed container and thus isolated from direct interaction with the bog. In addition, burial has been replicated in a different climatic zone than that at Lejre. The second installation is at the Rørmyra Nature Preserve outside of Trondheim, Norway.

2. Moseforsøg I (1972-93)

The Textile Workshop at the Historical-Archaeological Research Center Lejre initiated and carried out the original Moseforsøg studies. These are described here, but are reported in detail in Nordgaard et al. [1983].

Two bog burial studies (Series I, Series II) were undertaken by the Textile Workshop to investigate the preservation of fabric colour and dyestuffs in new wool textiles that have been exposed to the burial environment of a bog. The experimental textiles were a selection of fabrics produced by non-industrial methods of manufacture by the Workshop. The yarns were a combination of hand-prepared and machine spun. The specimens were exposed to a naturally waterlogged environment with seasonal cycling of temperature and precipitation. They were exposed to biodeteriogens but were not in direct contact with soil or bog sediment.

2.1. Experimental method

2.1.1. Fabrics

A wide range of woven wool textiles were included in the two initial studies (Tables I, II). The seven fabrics in Series I were woven from undyed yarn and fulled. Four fabrics were made using hand-spun yarn and woven on the warp-weighted loom. The remaining three fabrics were woven with machine-spun yarn and dyed with natural plant dyes. All ten fabrics in Series II were woven using undyed hand-spun yarn. Eight fabrics were dyed with natural plant dyes. For both series the dyed textiles were dyed in the fabric. Each fabric specimen was divided into four (Series I) and three (Series II) samples and 1:1 drawings were made of each prior to burial.

2.1.2. Burial protocol

Sets of fabric samples were packed into small lidded boxes constructed of well-seasoned oak, simulating miniature oak coffins, and submerged in the Landbohus bog at the Lejre Research Center to a depth of one metre. Series I, consisting of seven

Table I. Fabrics in Series I [Nordgaard et al. 1983].

Fabric	Dyestuff	Wool	Spun	Weave	Finish
1	None – natural pigment	Gotland wool	Hand	Twill	Fulled
2	None – natural pigment	Gotland wool	Hand	Twill	Fulled
3	None – natural pigment	Blended wool	Hand	Tabby	Fulled
4	Green alder - 1st bath		Machine*	Broken lozenge twill	Fulled
5	Green alder - 2nd bath		Machine*	Broken lozenge twill	Fulled
7	Hazel		Machine*	Twill	Fulled
8	None – natural pigment	Blended wool	Hand	Tabby	Fulled

*probably mothproofed

fabrics in replicate, was packed into three boxes, submerged in January 1972, and recovered after 1, 4, and 11 years. Series II, consisting of ten fabrics in duplicate, was packed into two similar oak boxes, submerged in December 1976, and recovered after 2 and 17 years.

Upon recovery the fabric samples were carefully removed from the boxes, rinsed in cold running water, blotted between newspaper, and air dried at ambient temperature. Samples were visually inspected for changes in fabric colour, shape and integrity in comparison with the control samples and pre-burial drawings.

2.1.3. Dye analysis

Thin-layer chromatography was used to investigate the presence of dyestuffs and chemical species absorbed from the oak boxes and bog water [Nordgaard et al. 1983]. Dyestuffs were extracted from approximately 150 mg of fabric with a solution of concentrated HCl and ethanol (1:4) by heating to the boiling point and holding for 30 min. The extract was allowed to evaporate until dry. The residue was dissolved in 1 ml of a solution of $CHCl_3$, CH_3COOH and H_2O (2:3:1). The resulting mixture was analysed using thin-layer chromatography.

Table II. Fabrics in Series II [Nordgaard et al. 1983].

Fabric	Dyestuff	Spun	Warp (spun)	Weft (spun)	Weave
1	None – natural dark brown pigment	Hand	Hairy wool (s) 4-5/cm	Fine wool (z) 4-5/cm	Tabby
2	None – natural white pigment	Hand	Hairy wool (z) 4-5/cm	Fine wool (z) 4-5/cm	Tabby
3	Madder, alum mordant	Hand	Hairy wool (z) 4-5/cm	Fine wool (z) 4-5/cm	Tabby
4	Sloe, alum mordant	Hand	Hairy wool (z) 6-7/cm	Fine wool (z) 5/cm	Tabby
5	Indigo, in chemical bath	Hand	Hairy wool (z) 3-4/cm)	Fine wool (z) 3-4/cm	Tabby
6	Marigold, alum mordant	Hand	Hairy wool (z) 5-6/cm)	Fine wool (z) 5-6/cm	Tabby
7	Weld, alum mordant	Hand	Hairy wool (z) 5-6/cm)	Fine wool (z) 4-5/cm	Tabby
8	Indigo, powder in fermented urine	Hand	Hairy wool (z) 3-4/cm)	Fine wool (z) 3-4/cm	Tabby
9	Birch, alum mordant	Hand	Hairy wool (z) 5-6/cm	Fine wool (z) 5-6/cm	Tabby
10	Heather, alum mordant	Hand	Hairy wool (z) 3-4/cm	Fine wool (z) 3-4/cm	Tabby

Fig. 1. Series I. Undyed fabric (3) woven with handspun wool before and following 11 years' burial in a lidded oak box in the bog at Lejre. left – fabric following burial; right – fibres following burial exhibiting extensive biodeterioration. *Scanning electron photomicrograph E. Peacock.*

2.1.4. Microscopy

Fabric samples from both burial series were examined and compared with the control fabrics for changes in fabric integrity and in the morphological structure of the fibres.

Light microscopy. Fabrics were analysed using a binocular microscope with fibre optic illumination.

Scanning electron microscopy. Samples of the fabrics were mounted onto 15-mm diameter aluminium stubs using electrically conducting copper tape. The examination surface was sputter-coated with 99.99% pure gold. Coated samples were examined using a scanning electron microscope (ISI 100) at 2 KeV accelerating voltage in secondary electron (SE) mode.

2.2. Results

All samples in Series I were successfully recovered from the bog. Samples from 1-year and 4-year burial were robust enough to be handled. The 11-year box had accumulated a substantial amount of sediment in it. Several fabrics (1, 3, 8) were badly deteriorated and could only be handled with difficulty. Three fabrics (6, 9, 10) were lost during the 2-year recovery of Series II. Recovered samples were robust enough to handle. No fabrics were found in the box when Series II was recovered after 17 years in 1993.

2.2.1. Visual and dye analysis [Nordgaard et al. 1983]

Series I. Nordgaard et al. [1983] reported that following one year in the bog there was little change in sample dimensions. Visually fabric colours were the same for undyed fabrics 1 and 2, slightly darker for undyed fabrics 3 and 8, and much changed for dyed fabrics 4, 5 and 7. Results of the chromatographic analysis indicated the presence of dyestuffs in reduced concentrations but also the presence of other chemical species.

Nordgaard et al. [1983] reported that following four years in the bog there was little change in sample dimensions with the exception of fabric 1 which shrunk. Fabric colours were compared with photographs taken of the control and with 1-year samples. Undyed fabrics 1, 2, 3 and 8 and dyed fabric 7 were lighter. Dyed fabrics 4 and 5 were lighter than 1-year samples but darker than the controls. Results of the chromatographic analysis indicated the presence of dyestuffs in much reduced concentrations but also the presence of other chemical species. Undyed samples took up the most from the burial environment, and strongly dyed samples the least.

Nordgaard et al. [1983] reported that following eleven years' burial in the bog there was little change in sample dimensions for the four intact samples, three of which were dyed. Fabric colours were compared with photographs taken of the control and with earlier samples. All were much darker. Results of the chromatographic analysis indicated the weak presence of dyestuffs and strong presence of other chemical species. Results follow upon those for the 4-year samples where undyed samples took up the most from the burial environment, and strongly dyed samples the least.

Series II. Nordgaard et al. [1983] reported that following two years' burial in the bog there was little change in sample dimensions, and all the fabrics were faded in colour compared to the controls. The exception was undyed fabric 1 which was quite degraded, perhaps as the result of becoming caught between the lid and the box. All the plant dyestuffs were detectable by thin-layer chromatography although in reduced concentration. The presence of other chemical species from the bog water or oak box was inconsequential.

2.2.2. Fabric and Fibre Morphology

Series I. None of the fabric samples show signs of degradation after one year of burial. Following four years in the bog, only one fabric is noticeably changed and this is in the form of adhering particles. Burial in the bog for 11 years brought about no apparent changes in the three dyed fabrics (4, 5, 7) at either the fabric

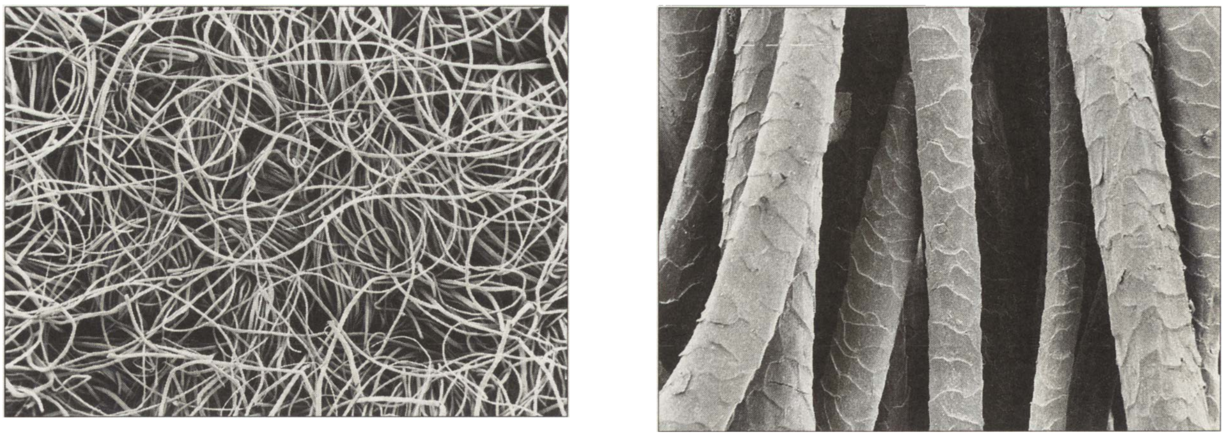

Fig. 2. Series I. Dyed fabric (4) woven with machine-spun wool before and following 11 years' burial in a lidded oak box in the bog at Lejre. left – fabric following burial; right – fabric following burial. *Scanning electron photomicrograph E. Peacock.*

or fibre level (Fig. 1a). These had been produced with machine-spun yarn and were dyed. Fibrês in the remaining – undyed – fabrics have adhering particulate matter and broken ends. Eleven-year samples of fabrics 1 and 3 are severely biodegraded. Fibres exhibit boring, erosion, pitting, areas missing cuticle revealing interior cortical cells, and fibres broken where the cuticle is completely removed and only cortical cells remain (Fig. 1b). Some fibres are covered in particulate matter such that the scales on the wool fibres are obscured.

Series II. The 2-year fabric samples are thin and have a flattened appearance in comparison with the original fabrics which are full and springy, fabric 4 excepted. The crowns are slightly flattened where they cross over the underlying yarns. This is the result of either being held in place while in the oak box or of being dried between sheets of newspaper following post-retrieval rinsing, but is not the result of microbial activity while in the bog. The weaves of fabrics 1 and 2 are noticeably more open than their respective controls indicating the yarns have contracted upon themselves.

Fabric 1. The weave of the 2-year sample is more open than the control indicating the yarns have contracted upon themselves, especially in the warp direction. Fibres of the control are interspersed with some particulate matter and the scales are not completely distinct on the coarser fibres suggesting some residual coating. There is a greater concentration of particulate matter adhering to the 2-year samples. Individual yarns are compacted and have a matted surface appearance. Fibres exhibit boring, erosion, pitting, areas missing cuticle revealing interior cortical cells, and fibres broken where the cuticle is completely removed and only cortical cells remain.

Fabric 2. The weave of the 2-year sample is more open than the control indicating the yarns have contracted upon themselves. The fabric is almost completely devoid of surface fibres in contrast to the 'fluffy' control fabric. Fibres of the control have a clear scale pattern and show no adhering particulate matter. Two-year fibres exhibit biodegradation. There is some erosion and pitting, but mostly shallow broad cavities where the cuticle is removed and cortical cells are exposed. There are no collapsed fibres but some fibres are broken where the cuticle is completely missing. This damage supports the "tendering" of the sample noted by Nordgaard et al. [1983]. Surface scales on many fibres are not visible but appear to be coated rather than missing.

Fabric 3. Light microscopy reveals that the yarns in the control are unevenly coloured indicating different take-up of dyestuff by the fibres during pre-deposition dyeing. The 2-year sample is flattened out with contracted yarns and there are some broken crowns in the warp direction. There is no readily apparent difference in the density of surface fibres or physical appearance of the fibres.

Fabric 4. The control fibres have distinct scale patterns and little adhering particulate matter. There is some shrinkage of yarns in the 2-year sample. There is no readily apparent difference in the density of surface fibres or physical appearance of the fibres after two years' burial in the bog.

Fabric 5. Light microscopy reveals that the yarns in the control are unevenly coloured indicating different take-up of dyestuff by the fibres during pre-burial dyeing. The weave is more open and there is a considerable reduction in density of surface fibres on the 2-year sample in contrast to the "fluffy" control. Many fibres have collapsed into flat ribbons indicating the loss of interior substance. There are extensive broad, shallow cavities and areas where the cuticle is removed (Fig. 3).

Fabric 7. The weave of the 2-year sample is slightly tighter than the control and there is a reduction in the density of surface fibres. The fabric is flat and compact in contrast to the "fluffy" control fabric. Fibres exhibit some broad, shallow cavities but no complete removal of cuticle and broken fibres. No removal or damage to surface scales could be detected.

Fabric 8. Control fibres are visually similar to those in fabric 1 in that they are interspersed with some particulate matter. Moreover the scales are not completely distinct on the coarser fibres suggesting some residual coating. Following two years' burial the fibres have more adhering particulate matter but no readily apparent degradation or reduction in the density of surface fibres.

2.3. Conclusion

The intensity of residual dyestuff decreased with increased burial time in the bog for dyed fabrics in Series I. The uptake of chemical species from the bog water or oak box was greatest for undyed fabrics made of handspun wool and least for dyed fabrics made from machine-spun wool. Nordgaard et al. [1983] postulated that the dyestuffs competed with chemical species from the bog water and perhaps mothproofing agents for place on the fibres. Dyestuff intensity decreased in dyed fabrics in Series II with burial; however, the increasing to substantial uptake of other chemical species registered for Series I fabrics was not repeated.

Problems with the covers of the burial oak boxes coming undone, samples escaping into the bog, and samples being caught between the lid and the box can all contribute to differences in experimental degradation of the fabric samples in both series. The fabrics were newly produced and not subjected to wear-and-tear, and are viewed in this study as 'damage free' when place in the boxes. SEM analysis shows control fibres to be generally free of broken ends and adhering particulate matter, and to have clearly distinct, undamaged scales. Some fabrics were less than free of particulate matter and had slightly coated surfaces indicative of a residual coating.

Despite the variation and uncertainties in the degraded sample population, patterns of damage do emerge. Disregarding adhering particulate matter, degradation in the form of broad, shallow cavities where the cuticle has been removed revealing cortical cells is common. Areas of complete removal of cuticle led to fibre fracture. There is no evidence of removal of scales. Nordgaard et al. [1983] report the 11-year box (Series I) had a substantial amount of sediment in it. This would have provided a source of biodeteriogens for those samples. Fabrics woven with machine-spun wool (Series I, fabrics 4, 5, 7) are distinctly free of damage even after 11 years in the bog. These same fabrics were also dyed, but some of the dyed fabrics in Series II exhibit biodegradation already following two years' burial. It seems improbable that machine spinning alone (i.e., a more uniform, perhaps tighter, yarn) would be the source of this protection from damage. It is more likely that some additive, be it to reduce friction during spinning (and later, during weaving) or confer biocidal protection in use, led to reduced microbial degradation during burial.

Table III. Colour of Experimental Fabrics*.

Dye	Wool			Linen		
	L*	a*	b*	L*	a*	b*
None	79.69	-0.27	13.31	59.59	1.46	8.15
Indigo	28.03	-2.19	-14.42	Not dyed		
Weld	71.09	-3.77	62.66	Not dyed		
Madder	30.61	41.01	26.87	Not dyed		

* Mean of five measurements

3. Moseforsøg II (1998-2006)

In 1998 Lejre Research Center and Vitenskapsmuseum initiated another bog study, which builds upon the experience and results of both the earlier Lejre studies [Nordgaard et al. 1983] and laboratory-based, soil burial studies carried out by Vitenskapsmuseum [Peacock 1996, 1990]. The new study is different in that it includes a range of organic materials in addition to textiles, and that the materials are not packed in a closed container and thus isolated from direct interaction with the bog. In addition, burial has been replicated in a different climatic zone than that at Lejre. The second installation is at the Rørmyra Nature Preserve outside of Trondheim, Norway.

The Rørmyra installation is located in a raised bog in a subarctic climate; whereas, the site at Lejre represents a lowland bog in a humid oceanic climate zone shared by Northwest Europe and the British Isles. The two sites lie approximately on the same longitude but Trondheim lies almost 900 kilometres to the north of Lejre. Soil water chemistry and air and soil temperatures are being monitored at both sites.

3.1. Experimental method

3.1.1. Materials

Organic materials selected for inclusion in the study comprise those commonly represented in the archaeological record of Northwest Europe. These include: vegetable-tanned leather, unbleached linen fabric, dyed and undyed wool fabric, raw and boiled bovine bone, antler, and raw pigskin. Whenever possible dyestuffs, tanning agents and pre-treatments of experimental materials were been kept as close to those used in antiquity as practically possible.

The unbleached wool fabric is a highly fulled twill (vadmel) produced by Røros Tweed A/S (Røros,

Fig. 3. Series II. Dyed fabric (5) woven from hand-spun wool before and following 2 years' burial in a lidded oak box in the bog at Lejre. left – fabric following burial, right – fibres following burial exhibiting biodeterioration. *Scanning electron photomicrograph E. Peacock.*

Norway). Three pieces were dyed by colleagues at the Textile Workshop at Lejre using madder (alum mordant), weld (alum mordant), and indigo (fermented urine). The linen is an unbleached tabby weave.

3.1.2. Burial protocol

Protocols were established for reproducible burial of preshaped and standard samples in such a manner as to cause minimal disturbance to the surrounding sediment using a highly reproducible installation procedure [Peacock 1998]. Boreholes are hand-drilled through the overburden to the target burial layers. The experimental samples are packed, together with the sediment from the target environment, into the lower section of the sample module, which then is lowered into the borehole (Fig. 4). The sample module is a perforated PVC plastic pipe (16mm diameter). At each site, a total of four modules have been installed and are being retrieved on a progressive scale over a period of eight years.

Four modules were submerged in September 1998 in the Landbohus bog at Lejre Research Centre to a depth of one metre. An additional four modules were installed in November 1998 in a bog at Rørmyra Nature Preserve outside Trondheim. Sample modules at both locations were recovered after 1, 2, and 4 years, with the fourth and last modules scheduled for retrieval in 2006 after 8 years.

Following retrieval, the sample modules were cut in two, and the portions containing sample materials were frozen. The frozen soil-sample core is removed from the PVC module tube and freeze-dried. Samples are then excavated from the freeze-dried soil mass.

A full suite of analytical techniques to characterise the burial-degraded materials continues to be established. In this paper changes in areal density and colour, and results of initial microscopic studies of the 1-year and 2-year textiles are reported. Samples have been examined and compared with the control fabrics for changes in fabric appearance, colour and integrity, and in the morphological structure of the fibres.

3.1.3. Microscopy

Light microscopy. Fabrics were analysed using a binocular microscope with fibre optic illumination.

Scanning electron microscopy. Samples of the fabrics were mounted onto 10-mm diameter copper-alloy stubs using electrically conducting tape. Uncoated samples were examined using a low vacuum scanning electron microscope (Hitatchi S-3500N) at low accelerating voltage in both secondary and backscatter electron (BSE) mode. Coated samples were examined also at low accelerating voltage using a field emission scanning electron microscope (Hitatchi S-4300SE).

3.1.4. Colour Difference

Colour measurements were made using a Minolta CR200 series chroma meter. Each measurement was the average of five separate measurements, made in different positions over the sample. The Minolta CR200 series chroma meter was use in conjunction with a CR200 measuring head, which provides diffuse illumination to a sample area 8mm in diameter and measures the reflected light perpendicular to the surface of the sample. The measurements were converted into Commission Internationale de l'Eclairage (CIE) *L, a* and b* chromaticity coordinates under standard illuminant D65 using data for the 2° observer [Commission Internationale de l'Eclairage 1978]. The colour difference (ΔE) between the control fabrics and the buried fabric samples was calculated using the 1976 CIE colour difference equation.

Colour in L*, a*, b* colour coordinates and colour differences (Δ*L, Δa*, Δb*, ΔE) were measured for the pre-deposition and buried wool samples, and pre-deposition linen (Tables III, IV). Following burial adhering soil particulate matter could not be removed from the degraded linen samples. This obstructed the surface for measuring representative colour and for determining colour differences.

3.1.5. Areal Density Difference

Sample areal density (mg/cm^2) was calculated before and after burial, with the exception of the dyed wool samples buried at Lejre. These samples were not available to determine areal density prior to installation. Following burial adhering soil particulate matter could not be completely removed from the degraded linen samples. Areal density difference could not be calculated for these samples because the adhering soil gives a misleading value for areal density.

3.2. Results

The 1-year and 2-year modules were successfully recovered from Lejre in September 1999 and September 2000 respectively, and the 1-year and 2-year modules at Rørmyra were successfully recovered in November the same years. Frozen storage and freeze-drying better facilitate the practical aspects of transport, storage and excavating the sample materials from the module cores. The linen samples and the increasingly degraded wool samples were difficult to extract from the freeze-dried soil mass. Of note were the already detached surface fibres of the Lejre wool fabrics. However, if excavation had been carried out on the wet soil mass, the lack of integrity of the fabric

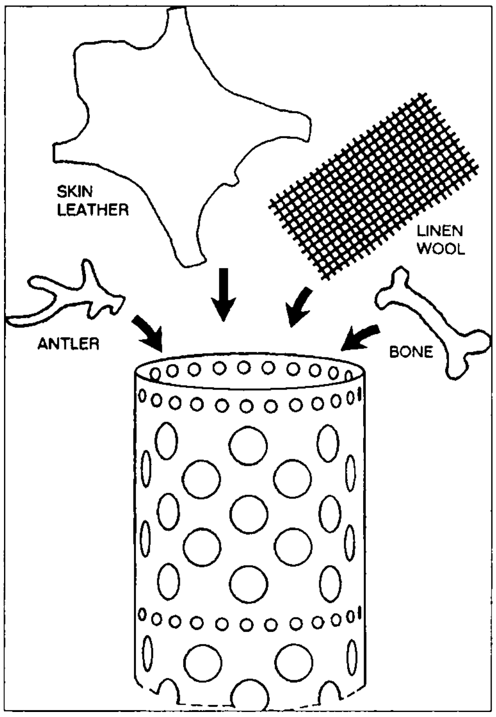

Fig. 4. Sample materials and module for the current installations at Lejre (Denmark) and Rørmyra (Norway). Sample materials are packed together with target soil into the perforated end, and the inverted module is installed into a hand-bored hole. *Drawing G.H. Turner-Walker.*

samples combined with their wet, weaken state would have presented difficulties as well. All the wool samples were recovered from the freeze-dried soil cores.

Table IV. Burial-induced Colour Differences*.

Dye	Burial	Wool ΔL*	Δa*	Δb*	ΔE
Lejre					
None	1 yr.	-20.59	3.25	2.16	21.02
	2 yr.	-18.84	3.68	1.56	19.30
Indigo	1 yr.	19.24	-1.85	14.83	24.38
	2 yr.	21.38	-1.16	16.81	27.24
Weld	1 yr.	-16.43	2.31	-28.48	33.05
	2 yr.	-13.71	5.96	-40.62	43.44
Madder	1 yr.	-3.09	-11.82	-8.88	15.11
	2 yr.	2.06	-16.00	-9.04	18.78
Rørmyra					
None	1 yr.	-20.79	2.88	1.79	21.07
	2 yr.	-13.95	2.94	6.48	15.70
Indigo	1 yr.	-1.82	-0.49	5.75	6.23
	2 yr.	1.08	-1.35	7.64	7.88
Weld	1 yr.	-12.47	3.63	-18.19	22.36
	2 yr.	-12.78	4.45	-25.43	28.82
Madder	1 yr.	0.14	-8.29	-4.37	9.43
	2 yr.	0.62	-4.96	-3.44	6.11

* Mean of five measurements

Linen samples were recovered from all but the Lejre 2-year core.

3.2.1. Appearance and Integrity

The deterioration of the fabric samples is relatively uniform throughout each sample. There is a marked difference in degree of preservation between the wool and linen fabrics regardless of burial site. The linen is affected much quicker and more extensively by soil burial than the wool fabric. Rørmyra samples are better preserved than the Lejre samples, but the linen samples exhibit different fabric degradation between the two sites. The Rørmyra fabric is intact, linen-coloured, buckled and shrunken, and has tightly adhering soil particulate matter on and embedded into the surface. The samples shrank approximately 20% although some of the shrinkage is taken up in the buckled structure. The Lejre fabric is inflexible, flat, dark, paper thin, and completely coated with a fine clayey soil. The 1-year Rørmyra sample is almost complete; whereas, the 1-year Lejre sample is fragmentary. The 2-year Rørmyra sample is thinner and missing areas; no evidence of the 2-year Lejre sample was found in the soil core.

The wool fabric is highly fulled with the high density of surface fibres masking the weave of the fabric. The colours of the dyed fabrics are strong.

Fig. 5. Wool fabric (madder-dyed) following two years' unprotected burial in the bog at Lejre. The fibres illustrate morphological changes characteristic of biodeterioration. *Scanning electron photomicrograph E. Peacock.*

Closer examination of the dyed fabrics reveals that the dyes did not penetrate the inner core of the yarns. Dyeing was even except for the indigo-dyed fabric, which has a mottled colouring.

As is the case for the linen samples wool samples buried at Rørmyra are better preserved than those buried at Lejre. All samples have retained their flexibility although the more-degraded Lejre fabrics are limp. Disregarding soiling, the Rørmyra dyed samples retain their strong colour following burial and the undyed, off-white samples become slightly beige in colour. The samples are robust. The density of surface fibres is about the same, but they are pressed down onto the surface forming more compact fabrics. The 1-year Lejre samples are thinner and have lost surface fibres. This has resulted in a mottled dark-faded appearance to the fabrics because of the incomplete dyeing. Consequently, these fabrics have not retained their strong colour as the Rørmyra fabrics have. This fibre loss is most for the indigo-dyed sample and least for the madder-dyed sample. The trend is further advanced in the 2-year fabric samples. In general, fabrics are thin and faded and there is a marked loss of material. There is substantial removal of surface fibres revealing more areas of incomplete dyeing and the weave of the cloth. The undyed sample is very thin and beginning to break up.

3.2.2. Fabric and fibre microscopy

Linen. There is a loss of definition of the planar fabric surface in the 1-year Lejre sample. Yarns collapsed and shrank resulting in flattened crowns and a thin, open, netlike structure. The woody linen fibres exhibit broken ends, longitudinal splitting, cleavage and cavities. Decomposed fibres form a surface smearing over the fibres and yarns. The Rørmyra linen exhibits a different pattern. The yarns retain their circular cross-section but have been pulled together to form the tight buckled weave. Both patterns of degradation resemble those documented in previous studies of archaeological fragments and laboratory soil-degraded linen [Peacock 1996].

Wool. As is the case for the linen, the wool is better preserved at Rørmyra. The density of surface fibres appears similar to the unburied fabrics. There is some adhering particulate matter but the fibres have a clear scale pattern. The loss of surface fibres from the Lejre samples has left the surface of the fabrics littered with broken ends, although not at the crowns of the yarns. The loss of surface fibres was seen in samples from the earlier bog studies. Some fibres are covered with a thin layer of fine particle clay masking the scales. Fibres are collapsed into flat ribbons indicating loss of interior substance or structure (Fig. 5). Others show an extensively pitted/eroded surface. There are cavities where the cuticle is removed or lifting and interior cortical cells are exposed. With the exception of the extensive pitting, the pattern and severity of fibre biodegradation resembles that exhibited by the poorly preserved fabric samples from the earlier bog studies (1972-1993) at Lejre. The pattern, but not the severity, resembles that seen in the laboratory-based soil burial studies [Peacock 1996, 1991].

3.2.3. Colour difference

Colour and colour difference measurements are presented in Tables III and IV. In general the total colour differences (ΔE) are larger for the Lejre samples with the exception of the 1-year undyed wool samples, which are similar for both sites. The undyed and weld-dyed wool samples changed most of the Rørmyra samples; whereas, the madder-dyed samples from Lejre changed much less than the other Lejre samples. The undyed wool became darker, although the 2-year samples not to the same extent. The weld samples became less yellow (more blue) and darker; indigo samples became less blue (more yellow) and darker (Lejre); and, madder samples became less red (more green) and less yellow (more blue) (Lejre).

3.2.4. Areal density difference

Pre-deposition areal densities were calculated for the undyed wool and linen fabric samples buried at Lejre. Compared with the unburied controls the reduction in areal density for the 1-year and 2-year undyed wool samples was 21% and 65% respectively. Adhering soil precluded the calculation of post-depositional areal density and areal density differences.

Pre-deposition areal densities were calculated for all the samples buried at Rørmyra. The dyed wool samples experienced no change or a slight increase (0-2%) in areal density following burial at Rørmyra for one or two years. Meanwhile the undyed wool samples experienced a slight loss (2-7%). There was little difference between one- and two-year samples. Adhering soil precluded the calculation of post-depositional areal density and areal density differences.

3.3. Discussion

Visual inspection of samples of all recovered materials points to better preservation at Rørmyra than at Lejre. This is seen dramatically in the preservation of the textiles. Two factors appear to be involved in this differential preservation. Of these, soil temperature is thought to be an important factor, as is the denser cover of sphagnum peat and lack of neighbouring cultivation at Rørmyra. Soil temperatures at Rørmyra are approximately 4 degrees cooler than those at Lejre.

Patterns of degradation for both the linen and wool fabrics are similar to those seen in archaeological fragments and previous soil-degradation studies. The linen fabric was affected quicker and more extensively than the wool fabrics. This is in line with results of earlier studies [Peacock 1996, 1991], and the general nature of the biodeterioration of cellulose-based and protein-based textile fibres. The compacted nature of the post-depositional wool samples mirrors archaeological fragments that have become compressed from the weight of overburden of the archaeological deposit.

4. Conclusion

The difference in degree of preservation of the textile materials between the two current installations is initially surprising, especially when compared to the earlier Lejre studies. The more recent samples are much more deteriorated following burial for two years than Series I four and eleven years and Series II two years. Closer study of the earlier specimens does show a range of preservation/degradation. Fabric samples in these studies were packed in lidded oak boxes and isolated from direct contact with bog sediment. The excellent preservation is present in the samples that were exposed only to bog water. Samples that experienced degradation were ones that were unintentionally exposed to sediment (e.g., Series I, 11-year). When the condition of these is compared to the more recent Lejre burial samples, which were in contact with the bog sediment, results correspond. The long-term preservative conditions of the Lejre bog are not good except for samples that are exposed to bog water only, which was the case for Series I and some Series II samples. Results thus far indicate that the conditions at Rørmyra are leading to longer-term preservation.

BIBLIOGRAPHY

Commission Internationale de l'Eclairage

1978 *Recommendations on uniform color spaces, color difference equations, psychometric color terms.* Supplement no. 2 to CIE publication no. 15 (E-2.3.1), 1971/(TC1.3).

Nordgaard A, Dokkedal L., Jensen E.

1983 *Moseforsøg. Natur- og plantefarvede stofprøver*, Tekstilhistorisk Forsøgsværksteds Rapporter 10/72. Lejre.

Peacock E.E.

1998 *Moselik på kunstigvis*, "SPOR", 13(2), 1998, 49-51.

1996 *Biodegradation and characterization of water-degraded archaeological textiles for conservation research*, "International Biodeterioration and Biodegradation", 38(1), 49-60.

1991 *A case for water-degraded archaeological textiles*, [in:] *Proceedings of the 4th ICOM Group on Wet Organic Archaeological Materials Conference*, ed. P. Hoffmann, Bremerhaven, 177-188.

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