

Krista Wright, Maarten R. van Bommel, Tuija Kirkinen,
Jenni Suomela, Jani Seitsonen and Janne Ruokolainen

A chieftain's colourful garments: microinvasive analysis of Norwegian Snartemo V textiles

Abstract

Several microinvasive methods were applied to analyse the fibre materials from the Snartemo V burial from the Migration Period (fifth century CE) in Norway. The morphological parameters of the textile fibres and furs were examined with optical (TLM) and electron microscopy (SEM, SEM-EDX and TEM) and dyes with UHPLC-PDA method. According to TLM and TEM analyses, the Snartemo textiles were spun of very fine wool, that consisted of white and naturally pigmented fibres. The dye analysis revealed colourants referring to dyer's madder, weld and woad in several textiles. The reddish hue in the warp of the wide geometrically patterned tablet-woven band was interpreted a result of the fading of the natural dark pigmentation of the wool. Respectively, the warp yarns that now appear yellow were interpreted as originally white, undyed wool. In addition, fibres from a bear's (*Ursus arctos*) fur and a Mustelidae sp. were identified in the previously unexamined Snartemo materials.

Key words: Microscopy, dyes, wool, fur, pigment cells, moulds

Introduction

To provide new insights on a Migration Period chieftain's costume, microinvasive analyses were applied to the Snartemo V textile material from Norway. An updated analysis of dyes was estimated to be essential, since although there is previous research published by Penelope Walton of the Snartemo II and V textiles as result of her extensive work with Iron Age textile materials (Walton 1988a, 148) some interpretations still rely on visual analysis made by Bjørn Hougen in 1935 (Hougen 1935, 73–74) (details of previous dye research in table 1). For example, the geometrically (swastika) patterned tablet-woven band was reported as woven with red, yellow and green colours (Rolfesen 2003, 90), based on observations by Hougen. Updated results of fabrics were seen useful for garment reconstructions in order to visualise the colours of clothing and the textile craft of fifth century CE Norway.

The Snartemo V fragments are stored at the

Kulturhistorisk Museum in Oslo (KHM) on cardboard trays, often containing textile materials from several different garments. The fragments were treated with Modocoll, a conserving medium used especially in Scandinavia in the 1960s–1980s to strengthen the finds. Over the following decades, Modocoll formed a tight, glass-like layer over the fibres (fig. 1) (Geijer et al. 1961; Peacock 1992, 204). One aim of this study was to test how modern dye analytics can manage with Modocoll-treated textiles. The dye analysis performed by Walton was extraction into a series of solvent systems followed by absorption spectro-photometry of the extracts, backed up by chromatography where appropriate. Four absorption spectra were published in Walton 1988a. The extraction into solvent systems, and chemical manipulation of the extracts, was an essential part of the diagnostic procedure (Walton 1988a; 1988b). Since it was assumed by KHM that Modocoll treatment could be a problem for the currently frequently used dye analysis method, namely



UHPLC-PDA, sampling permission was granted only for 12 KHM yarns. Thus, many interesting textiles from Snartemo V and comparable materials from the Snartemo II burial remained outside this analysis.

For this study, samples were taken from the edges of the textile fragments, where the wool fibres can be worn and decayed. The aim was to estimate the effect of the sampling spot; the best-surviving wool is usually in the centre area of the fragments, but that is an impossible sampling area in microinvasive research. The fibres were measured carefully, and results were compared to the values reported by Hougen soon after the excavations (1935) and the pigment and wool type analysis by Walton (1988a).

The Snartemo V textile materials have been identified as an elite warrior's clothing (Bender Jørgensen 2003), with influences from the Roman Empire and German tribes (Bender Jørgensen 2003, 62–64). However, the Haraldskjær type z/z twill, found in the Snartemo textiles, has been identified as a north European product connected with the spread of the warp-weighted loom (Bender Jørgensen 1986, 137–140, 345–346). By examining the textile structures, thread counts and spinning properties, the fragments were sorted into groups by several scholars, providing the starting point for garment identification (Hougen 1935; Nockert 1991, 62–63; Thingnæs 2007). The groupings revealed colourful twill fragments and tablet-woven bands, as well as pelt remains (Halvorsen 2012, 282; Hougen 1935; Nockert 1991). The fabrics have been reported to be from a few centimetres to 40 cm long (Bender Jørgensen 1986, 250–251).

In addition to the KHM collection, small fragments of twill and fur from Snartemo V burials exist in a private collection near the site, in the area of Vest-Agder

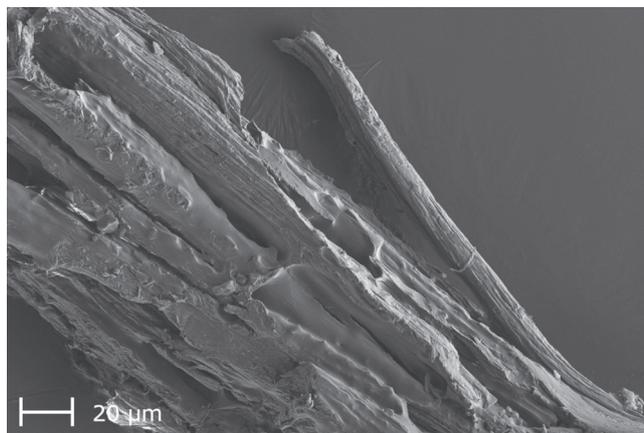


Fig. 1: Modocoll-treated wool fibres of the light-coloured yarn of the geometrically-patterned tablet-woven band (sample 2) (Image: Krista Wright)

Museum. These stray finds were collected from the archaeological site by a local schoolboy soon after the 1933 excavations and were not previously examined microscopically. Visual observation suggests there are furs from two species: a specimen from a coarse-haired, brown-coloured animal and a finer-haired, dark and brown-coloured specimen. The aim of analysing these items was to understand how they fit with the other Snartemo V findings.

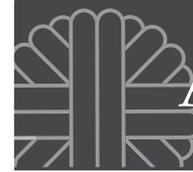
Materials and methods

Samples

A total of 12 samples (table 1) were taken from the KHM collections (diary number C26001) and five from the private museum collection (table 1). Sampling was microinvasive; that is, only a few millimetres of yarn or hair were cut with dissection scissors, sharp tweezers, and a scalpel from places that least damaged the fragments. Each yarn sample was 2 to 3 mm long except when the yarn was very thin. In those cases, the samples were 4 to 5 mm long. The sample preparation was not easy because the textiles were mineralised and Modocoll had made them very brittle.

Samples 1 to 3 belong to the geometrically patterned tablet-woven band. Previous research (table 1) detected indigotin and possibly a mordant dye (Walton 1988a). While sampling the yarns for this study in Oslo in 2018, it was found that there were several stitching holes and even some remains of a wool stitching yarn at the edges of the band. It has been suggested that the band was a sword baldric, although the interpretation was presented as a hypothesis (Hougen 1935, 25, 90). If serving as a baldric, the band probably would have needed a supportive material such as leather (Nockert 1991, 63), but no leather fragments have been found attached to it. A very similar-looking, geometrically-patterned tablet-woven band from Øvre Berge (450 CE, Norway) was sewn as a border of a twill fabric. Animal-patterned bands from Snartemo V, Evebø-Eide and Högom burials belonged to clothing (Hougen 1935, XVI, XVII, XVIII; Raknes Pedersen 1988, 119; Nockert 1991, 63; Thingnæs 2007; Halvorsen 2012, 281–289). Accordingly, it was not possible to exclude the idea that the Snartemo V band originally belonged to a garment.

The samples 4 and 5 may originate from twill trousers or legwear (Hougen 1935, 71; Nockert 1991, 63; Thingnæs 2007, 63–64), and indigotin has been detected in previous research (Walton 1988a). Samples 6 and 7, a dark twill, were possibly from part of a tunic (Thingnæs 2007, 63). The plied yarns (samples 8 and 9) have been interpreted as cloak remains (Thingnæs 2007, 63–64). In this plied yarn twill, madder has



previously been detected (Walton 1988a; table 1). Sample 10a is a weft of the horsehair-patterned band that bordered the tunic or cloak (Nockert 1991, 62–63; Thingnæs 2007, 63–64). It was woven using a visually blueish wool warp and two differently-pigmented horsehairs (sample 10b) as active weft and a visually reddish sheep wool yarn as the passive weft (Nockert 1991, 83–87). Horsehair has been reported to withstand wet conditions well, having good resistance to wear (Rast-Eicher 2016, 215; Kalayci et al. 2019). Because

of its silk-like lustre, it was used with long weft floats in the Migration Period bands to increase the shining effect (Nockert 1991, 88–89).

Sample 11 belonged to the plied yarn fabric in which madder has been detected previously (Walton 1988a; table 1). This textile might have been a cloak or tunic (Hougen 1935, 71; Nockert 1991, 62–63; Thingnæs 2007, 63). The two-coloured and spin-patterned fragments could have been a shroud (Hougen 1935, 70; Nockert 1991, 63; Thingnæs 2007, 63). Sample 12 was the dark

No.	Sample description, catalogue number	Yarns	Thread count/ cm	Previous dye analyses
1	Purplish yarn soumak stripe, KHM C26001:71	Sz	-	Walton 1988a: all yarns: indigotin and mordant dye
2	Yellowish warp KHM C26001:71	Sz	-	
3	Reddish warp KHM C26001:71	Sz	-	
4	Twill KHM C26001:50	z	11/10	Walton 1988a: Haraldskjær type z/z twill, indigotin
5	Twill KHM C26001:50	z	11/10	
6	Dark twill KHM C26001:42	z	11/10	Walton 1988a: Haraldskjær type z/z twill, no dyes detected
7	Dark twill KHM C26001:42	z	11/10	
8	Dark yarn of 2-coloured twill, KHM C26001:37	Sz	15/14	Walton 1988a: madder
9	Light yarn of 2-coloured twill KHM C26001:37	Sz	15/14	
10a 10b	Reddish wool weft Horsehair weft KHM C26001:72	unclear	-	No previous dye analyses
11	Dark reddish twill, warp KHM C26001:58	Sz	13/13	Walton 1988a: madder
12	2 coloured twill, dark z yarn KHM C26001:47	z/s+z	8/8	Hougen 1935, 84: two shades of brown Walton 1988a: no dyes detected, natural pigmentation
13	Red twill, warp VAM collections	Sz	13/13	No previous analyses Same fabric as number 11
14	Red twill, weft VAM collections	Sz	13/13	
16	Fur 1, VAM	-	-	No previous analyses
17	Fur 2, VAM	-	-	
18	Fur 3, VAM	.	-	

Table 1. Sampled textiles, spin directions and results of previous research



z-twisted yarn from this textile, in which the previous analysis had not detected colourants (Walton 1988a; table 1).

The samples 13 and 14 come from a private collection curated by Vest-Agder Museum (VAM). They are from a reddish Sz/Sz twill, approximately 4 x 5 cm in size. They are attached to a coarse-haired fur fragment, approximately 10 x 15 cm in size, with a small piece of dark, fine-haired fur (sample 17). In addition, the assemblage contains two more fur fragments (approximately 2 x 4 cm), with coarse light brown hairs (samples 15 and 16). From the furs, 3 to 5 hairs were sampled for analysis (table 1).

Macroscopic and microscopic analyses

Textile properties such as thread count and weave were observed when cutting the yarn samples from the textiles, to ensure the identification of different fragments. Yarn properties, including thickness, spin direction, ply and number of ply twists per cm were measured under a stereomicroscope while cutting fibres with a scalpel for microscopy and UHPLC-PDA analysis.

A few fibres of each sample were picked up with sharp tweezers and placed on an objective slide to analyse their inner structure. A few drops of Entellan New mounting medium were dropped on the fibres, which were finally covered with a cover slip. Diameter

values measured with different microscopes can vary (Skals et al. 2018), so to avoid this, the samples were measured with one microscope throughout the study. These samples were imaged with a Leica DM 4500 P transmitted light microscope (TLM) with a 5-megapixel DFC420 camera and Las Core 4.5 software.

To observe the surface features, a few fibres of each sample were imaged with a scanning electron microscope (SEM), using Jeol 7500 FA for high performance SEM imaging, while Zeiss Sigma VP was applied for basic SEM imaging. The fibres were picked up with sharp tweezers and placed on double-sided carbon tape fixed on a carbon stub. The samples were then coated with a 10 nm-thick layer of carbon (C), using a Leica ACE 600 sputter coater, to increase the electrical conductivity of the samples and to ensure better imaging conditions. Energy-dispersive X-ray spectroscopy (EDX) was applied to detect mordants of organic dyes. This analysis was performed with Jeol 7500 FA, simultaneously with SEM imaging. For EDX analysis, acceleration voltage was 15 kV, while the basic SEM imaging was done with 1–2 kV.

The hairs of VAM private collection underwent careful microscopic examination with TLM and SEM, in which their scale pattern, shape of the inner fibre medulla and shape of the cross section, as well as length, diameter, and pigmentation were observed to detect the species related features (Appleyard 1978; Teerink

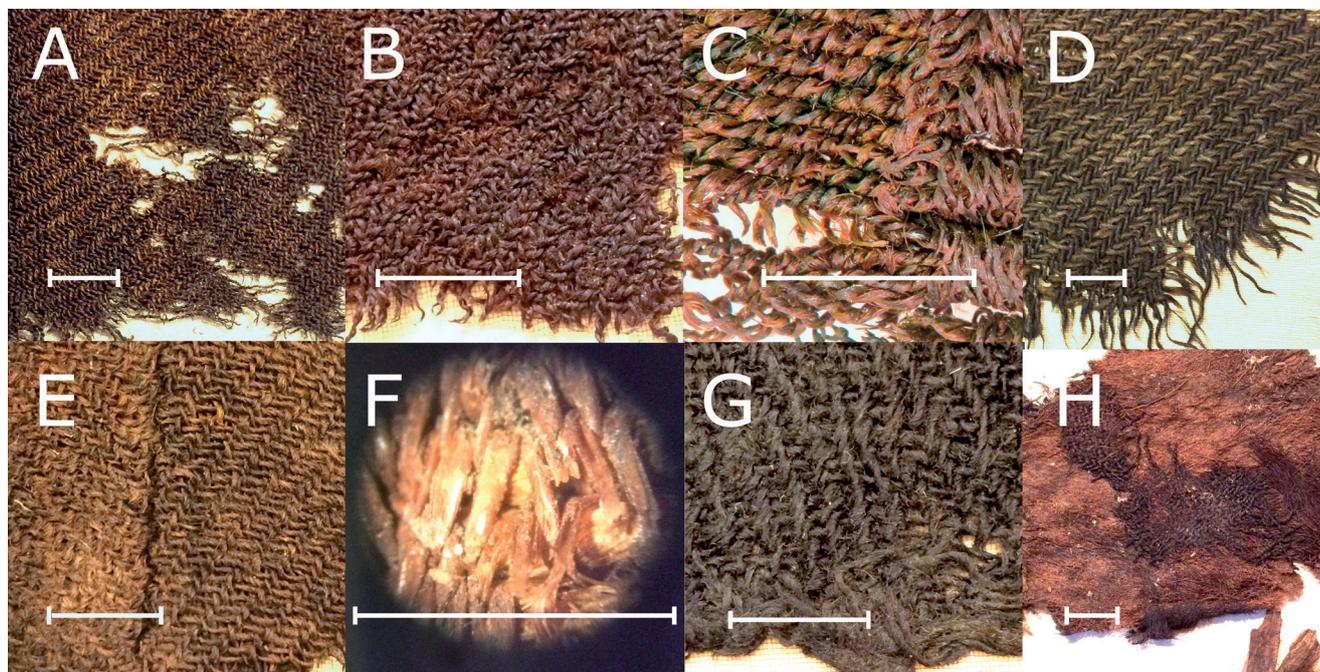
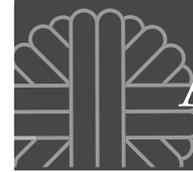


Fig. 2: Sampled textiles. A – two-coloured plied yarn twill (samples 8+9); B – dark red twill (sample 11); C – patterned tablet-woven band (samples 1–3); D – two-coloured z/z twill (sample 12); E – z/z twill (samples 4+5); F – horsehair band (sample 10a); G – dark z/z twill (samples 6+7); H – twill from private collection (sample 14) (Images: Krista Wright)



Sample	Spin angle, ply angle, ply twists/ 10 mm	Scales, Fibre diam. (μm)	Yarn diam. (mm)	Dyes, elements
1. Soumak stripe	10–30° spin angle 30–45° ply angle	Scales 10–14 Fibres 20–25	Tablet woven band 0.3–0.5	Alizarin, purpurin C, O, Si, S, Cu
2. Yellow warp	0–10° spin angle 20 ply twists/ 10	No scales (Modocoll) Fibres 11–20	0.3 mm	Indigotin, indigotin equivalent C, O, S, P, Al, Si, K, Ca, Fe
3. Red warp	0–10° spin angle 45–55° ply angle 20 ply twists/ 10	Scales 14–15 Fibres 23	0.3 mm	No detected colorants C, O, S, P, Al, Si, Fe
4. Twill	40–45° spin angle	Scales 15 Fibres 14–40	0.3–0.5 mm	Indigotin, isatin C, O, S, Al, Si, Fe, Cu
5. Twill	45° spin angle	Scales 8–20 Fibres 18–49	0.3	Indigotin, isatin C, O, S, Al, Si, Fe
6. Dark twill	45° spin angle	Degraded scales Fibres 17–25	0.3	Indigotin, isatin, unknown UV absorbing component C, O, Na, S, Al, Si, Fe
7. Dark twill	45° spin angle	Degraded scales Fibres 23–40	0.2–0.3	Indigotin, isatin, unknown UV absorbing component, two unknown yellow components C, O, Na, S, Ca, Al, Si, Fe
8. Twill, 2-colored, dark yarn	0–5° spin angle 45° ply angle 20 ply twists/ 10	Degraded scales Fibres 10–37	0.2–0.3	Alizarin, purpurin, rubiadin, indigotin C, O, Na, S, Ca, K, Al, Si, Fe, Cu
9. Twill, 2-colored, light yarn	0–5° spin angle 45° ply angle 20 ply twists/ 10	Scales 12–14 Fibres 16–49	0.2–0.3	Indigotin, luteolin glucoside?, unknown UV absorbing component C, O, Al, S, Fe
10a. Reddish weft	Low spin angle, unclear spin direction	Scales 9–16 Fibres 25	0.3	Indigotin, luteolin-7-glucoside?, unknown UV absorbing component C, O, Na, Al, Si, S, K, Cu
10b. Horse hair weft	Single fiber	113	-	Horse tail hair
11. Twill, warp	Ply angle 45° 9 ply twists/ 10 mm	Degraded scales Fibres 14–37	0.5–0.75	Alizarin, rubiadin, unknown yellow component C, O, P, Si, S, Fe, Cu
12. Twill, dark yarn	30–50° spin angle	Fibres 13–17 μm , white and dark fibres	1.0	Indigotin, luteolin-7-glucoside?, luteolin?, unknown UV absorbing component C, O, Al, Si, S, Fe

Table 2: Textile, yarn and fibre properties as well as colourants



Sample	Spin angle, ply angle, ply twists/ 10 mm	Scales, Fibre diam. (μm)	Yarn diam. (mm)	Dyes, elements
13. Twill, warp	15–20° spin angle 45–75° ply angle 9 ply twists/ 10 mm	Fibres 11–25	0.5	No dye analysis, too small sample C, O, Si, Cu, Fe
14. Twill, weft	10–15° spin angle 30–45° ply angle 15 ply twists/ 10 mm	Scales 14–22 Fibres 15–36	0.5	No detected colorants, too small sample C, O, Al, P, Si, S, Ca, Fe, Cu
15. Fur 1	Coarse light brown hairs	Guard hair 70 Under hair 23	-	Bear (<i>Ursus arctos</i>) C, O, S, Al, Si, K, Cu
16. Fur 2	Coarse light brown hairs	Guard hair 74 Under hair 23	-	Bear (<i>Ursus arctos</i>)
17. Fur 3	Fine dark hairs	Guard hair 50 Under hair 7	-	Mustelidae sp.

Table 2 (continued): Textile, yarn and fibre properties as well as colourants

2003; Rast-Eicher 2016). More recent DNA and protein sequencing methods were available (Schmidt et al. 2011; Brandt et al. 2014), but this was assumed to be unsuitable for the glass-like mineralised hairs that had clear contamination of moulds and micro-organisms. Since the analytic techniques are improving all the time, more sensitive methods could be available in the future.

To examine the natural pigmentation of the wool, samples 2, 3, 10a and 12 were analysed by transmitted electron microscopy (TEM). The fibres were embedded in epoxy (LR White) for 24 hours; the epoxy blocks were cut with a Leica 125 Ultracut microtome with Diatome's histo diamond knife into 70 nm slices. The slices were placed on holey carbon aperture slot grids (2 × 1 mm) and then treated for 10 minutes with uranyl acetate ($\text{UO}_2(\text{CH}_3\text{COO})_2 \cdot 2\text{H}_2\text{O}$) to increase the contrast. The samples were imaged with FEI Tecnai 12 with acceleration voltage of 120 kV.

Dye analysis

The UHPLC-PDA analysis method required a sample of 0.2 to 0.5 mg (Vanden Berghe et al. 2009, 1912). In the UHPLC-PDA method, the extraction protocol of the organic colourants was two-phased, which permitted the detection both of vat and mordant dyes (Serrano et al. 2013, 102–111). First, the sample was extracted by the addition of 50 microliters (μl) dimethyl sulfoxide (DMSO) to the sample in a 1 ml vial. The vial was heated at 80°C for 10 minutes in a water bath. Next,

the DMSO fraction was removed and set apart. The remaining sample was then hydrolysed by the addition of 50 μl of reagent (water/methanol/hydrochloric acid, 1/1/2) to the sample in the small insert vial. The vial was heated for 10 minutes in a water bath at 100°C to extract and dissolve the remaining dyestuff. After the hydrolysis, the sample was evaporated to dryness and dissolved in the first DMSO fraction. The two extractions were thus combined. Next, the samples were centrifuged for 10 minutes at 6000 rpm to remove small particles.

During the actual analysis, the organic colourants were separated from each other, and their ultraviolet-visible spectra (UV-VIS) were recorded by PDA. The UHPLC conditions consisted of a Waters Chromatography Acquity H-Class UPLC system with a BEH-Shield C18 column, and the PDA detection was made with a Waters Acquity PDA. Compounds were identified by comparison of these UV-VIS spectra and their respective retention times with known reference material (van Bommel 2018).

Findings

In the Snartemo V yarns, the UHPLC-PDA analysis detected several compounds (table 2). Indigotin or isatin were the most abundant (samples 2, 4, 5, 6, 7, 8, 9, 10a and 12). In addition, an indigotin equivalent was found, which is a component with a similar UV/VIS spectrum that correlates to the main component but elutes at a different retention time and often represents

an unknown by-product from the same biological source. Anthraquinones were detected, too: alizarin, purpurin or rubiadin were detected in samples 1, 8 and 11. Yellow colourants were detected often, but not always identified. Of these, luteolin or luteolin-7-glucoside were found in three yarns (samples 9, 10a and 12). Unknown yellow colourants were found in two yarns (samples 7 and 11) and unknown UV-absorbing compounds in five yarns (samples 6, 7, 9, 10a and 12). SEM-EDX analysis detected carbon (C), oxygen (O) sulphur (S), aluminium (Al), silicon (Si), phosphorus (P), calcium (Ca), potassium (K), sodium (Na), chlorine (Cl), iron (Fe) and copper (Cu) (table 2). The predominant spin direction of the Snartemo V yarns was z (table 1 and fig. 2), which is typical for Norwegian Migration Period textiles (Halvorsen 2012, 282). Only one textile had both s-spun and z-spun yarns (sample 12, a spin-patterned twill). The yarns were fine; the thinnest ones were less than 0.3 mm (samples 6, 7, 8 and 9) and the thickest ones only 1 mm in diameter (sample 12). The spinning angles were low in all yarns, from 0° to 10–15°. Ply angles were 40° to 75° and there were approximately 20 ply twists per cm. Thread counts varied from 8 to 13 yarns per cm. The fibres were 11–49 µm in diameter. One yarn (sample 10a) had a scale pattern typical of sheep wool (Rast-Eicher 2016). In several yarns the scales were long, the longest ones 22 µm (samples 1, 2, 3, 4, 5 and 12), while in others the surfaces were too damaged for

measurements or completely without scales. Pigment cells were present in samples 3, 10a and 12, while sample 2 lacks them (fig. 3).

The coarse-haired fur samples (samples 15 and 16) were identified as bear (*Ursus arctos*) according to Tóth (2017) and the reference collection. The guard hairs were a maximum of 74 µm wide and 7 to 10 mm long, broad scales transversally elongated, medulla tubular, medullary index 0.26. Pigments were arranged into lines in the cortex. The fine hairs were 23 µm wide and 5 to 7 mm long, scales broad rhomboidal, medulla tubular uniserial or missing. The dark guard hair fragments were a maximum of 46 µm wide and 5 to 7 mm long, scales rhomboidal elongated and broad, transversally elongated, medulla not preserved. Fine hairs were a maximum of 7 µm wide, scales coronal and petal elongated. The fine-haired, dark fleece (sample 17) was identified as predator hair, possibly of Mustelidae sp. (fig. 4) according to Tóth (2017) and Teerink (2003). The horsehair (sample 10b) was 113 µm in diameter, with scales waved with rippled scale margins. In addition, several microorganisms were found on the fur fibres (table 2; fig. 5).

Discussion

Dyestuffs

Natural colourants have been grouped into mordant dyes, vat dyes and other categories that all need different chemistry in the dyeing process (Dean 1999;

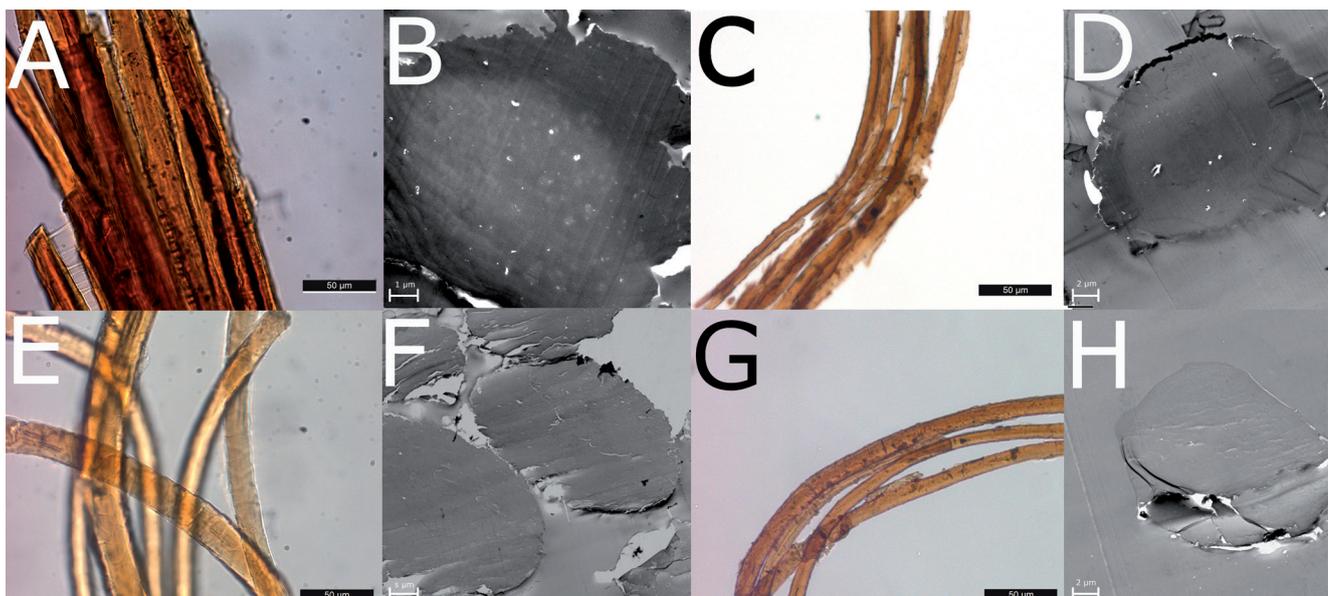


Fig. 3: A and B – reddish yarn of the patterned tablet-woven band with undyed and naturally-pigmented wool (sample 3); C and D – woad-dyed, naturally pigmented wool (sample 12); E and F – undyed white wool (sample 2); G and H – madder-dyed white wool (sample 1) (Images: Krista Wright)

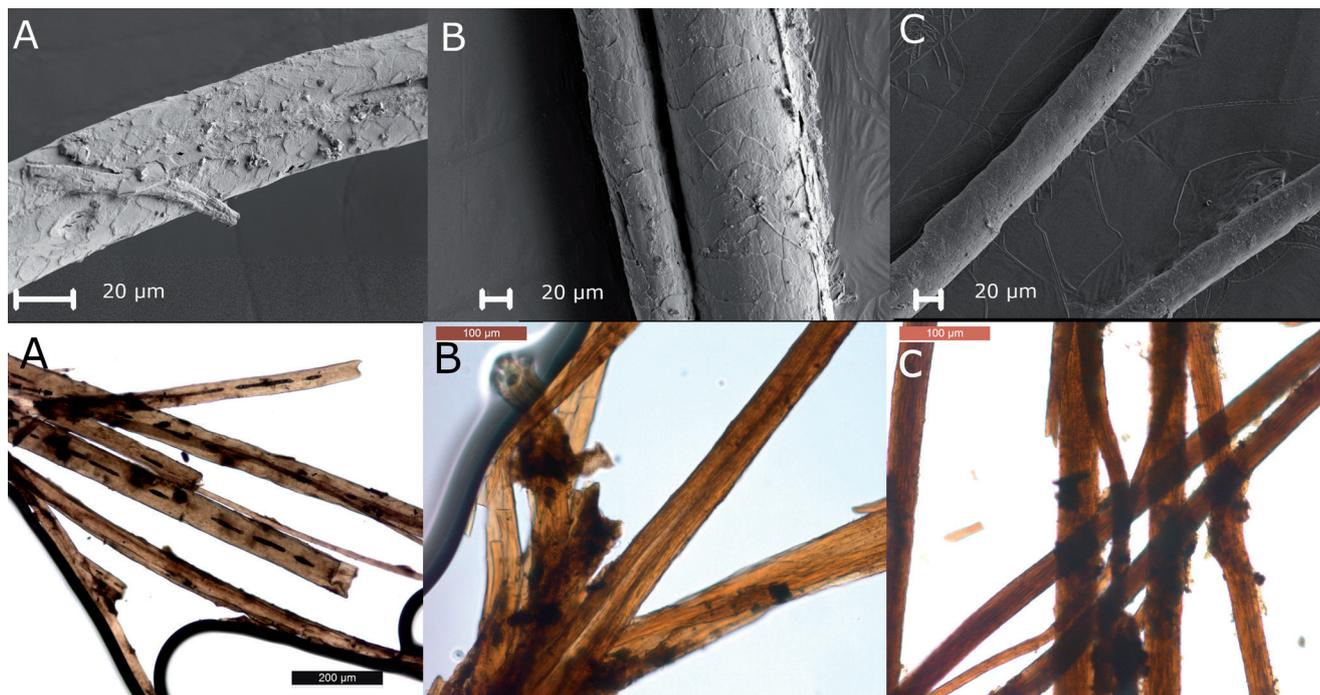


Fig. 4: A and B – brown bear (*Ursus arctos*) hairs (samples 15+16); C – Mustelidae sp. (sample 17) (Images: Krista Wright and Tuija

Cardon 2007; Hofmann-de Keijzer et al. 2013). Red anthraquinones and yellow flavonoids need a mordant that fixes the dye compounds to the wool fibres. A mordant can be metallic salt or tannin, and it can be added to the dye bath during the dyeing. Blue colour can be created with the vat dyeing technique. It needs extraction of indigotin precursors from woad, turning them into indigo pigment, with their reduction to a leuco-state in alkaline solution and oxidation for the blue (Cardon 2007; Dean 1991; Hofmann-de Keijzer et al. 2013). In the Snartemo V samples (table 2), the UHPLC-PDA analysis detected both mordant and vat dyes in 11 of 13 samples (van Bommel 2018). It was obvious that Modocoll is not a problem for this method.

Red anthraquinones (alizarin, purpurin and rubiadin) were found in the soumak stripe of the geometrically patterned tablet-woven band (sample 1), in the dark yarn of the two-coloured twill (sample 8), and in the warp of the cloak/tunic fabric (sample 11) (fig. 2). These colourants indicate the use of a *Rubiaceae* species: alizarin is the main component in dyer's madder (*Rubia tinctorum* L.), while purpurin is predominant in bedstraws (*Galium* species), and rubiadin can be found in many *Rubiaceae* species (Hofenk de Graaff et al. 2004; Cardon 2007, 127, 676; Hofmann-de Keijzer et al. 2013, 148).

Early Iron Age Scandinavian madder/bedstraw-dyed

textiles are rare when compared to more often detected woad compounds. In general, dyer's madder has a 3,000-year-old history in Europe, including, for example, the dyed textiles from Hallstatt and paintings of the Graeco-Roman and Hellenistic world (Hofmann-de Keijzer et al. 2005; 2013; Cardon 2007, 120). The oldest madder dyed textile in Scandinavia is from the Danish site, Skærsø (Walton 1988a) dated to the first century before the common era. In north Germany, purpurin of *Rubiaceae* species has been detected in Roman Iron Age Thorsberg textiles (Vanden Berghe and Möller-Wiering 2013, 103–104). *Rubiaceae* dyes have been detected in the Migration Period finds from Tegle (Vanden Berghe et al. 2009, 1918), Enebø-Eide, Tofte and Veiem (Bender Jørgensen and Walton 1986, 182; Walton 1988a), Røvsberghøj (Walton 1988a), Sande (Vedeler et al. 2018, 17) and Högom (Nockert 1991, 73–75).

The spread, trade and cultivation history of dyer's madder to Scandinavia is unclear, but it is notable that Early Iron Age Scandinavia was not ignorant of the potential of dyer's madder and/or bedstraw dyes as a source of red colour. Madder dye was probably imported (Bender Jørgensen and Walton 1986, 184). It seems likely that Migration Period dyers and weavers had an efficient trade network to obtain foreign dyestuffs: for example, non-local insect dyes such as Polish cochineal (*Porphyrophora polonica*) and

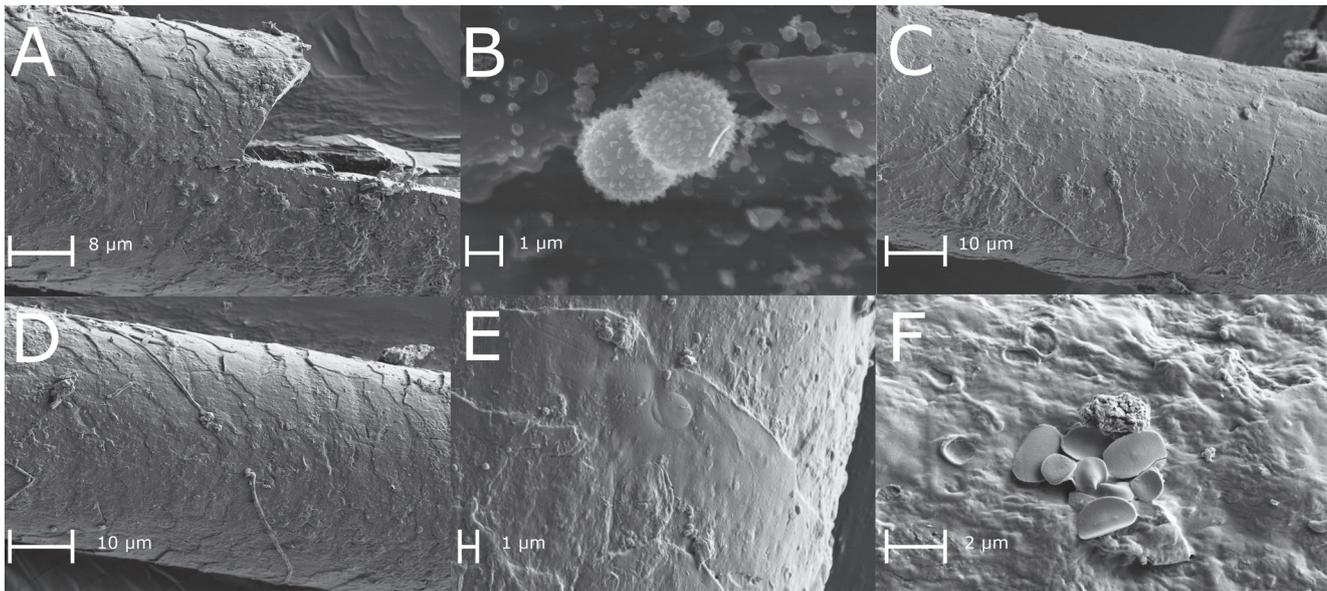


Fig. 5: Microorganisms on fur hairs: A – rod-shaped bacteria (sample 16); B – smut fungus teliospores (sample 10b); C – *Aspergillus* sp. mould (sample 15); D – *Penicillium* sp. mould (sample 15), E – amoeba-like microorganisms (sample 15); F – lenticular shaped spores (sample 15) (Images: Krista Wright)

kermes insect (*Kermes vermilio*) were imported to dye Norwegian Veien and Enebø-Eide textiles (Walton 1988a, 148, 156).

Blue colourants (indigotin, indigo equivalent and isatin) were found in several yarns (samples 2, 4, 5, 6, 7, 8, 9, 10a and 12) (van Bommel 2018). Indigotin and isatin are present in woad (*Isatis tinctoria* L.) and tropical indigo (*Indigofera tinctoria* L.). Woad is the probable source of these colourants because it is a species native to Europe. Although tropical indigo was known already in the Greco-Roman world, it was used mainly as a pigment for painting rather than a textile dye, for which purpose its importance began to rise during the Middle Ages thanks to improved seafaring (Cardon 2007, 363–364; Balfour-Paul 2011, 41–42). Woad seeds found in Early Roman Iron Age Lønne Hede in Denmark (Nordquist and Ørsnes 1971) might attest to the early availability of local Nordic woad.

In north European Early Iron Age textiles, indigotin has been detected quite often, for example in Norwegian sites, of Hallem, Veiem, Saetrang, Enebø/Eide, Snartemo, Øvre Berge (Walton 1988a), Sande (Vedeler et al. 2018, 17) and Blindheim (Bender Jørgensen and Walton 1986, 182), and in Helgeland and Tegle textiles (Vanden Berghe et al. 2009). In Danish sites textiles containing indigotin have been found at Huldremose, Krogens Mølle, Elling, Bredmose, Corselitze, Rebild, Sørgårds Mose (Vanden Berghe et al. 2009, 1914–1918), Lønne Hede (Bender Jørgensen and Walton 1986,

181; Walton Rogers 1997; Demant et al. 2018) and Røvsberghøj burials (Walton 1988a). Indigotin is also in Swedish Högom textiles (Nockert 1991, 73–75) and North German Thorsberg textiles (Vanden Berghe and Möller-Wiering 2013).

In the Snartemo V samples, a pure blue colour was present in samples 4 and 5 from the legwear. Indigotin and unknown yellow colourants in samples 6 and 7 from the dark twill of the tunic suggest a greenish fabric. One yarn system in the two-coloured twill (sample 8) had a purplish or brownish hue due to indigotin, alizarin, purpurin and rubiadin. The yarns in the other system (sample 9) contained indigotin and luteolin glucoside, which gave a green shade.

In previous research, indigotin had been detected several times with luteolin, this could be the result of contamination from surrounding archaeological context, especially if there are plant materials available, but the more likely explanation is that luteolin-based dye with woad had been used to achieve green hues (Vanden Berghe et al. 2009, 1919; Vanden Berghe and Möller-Wiering 2013). When mixing indigotin and plant anthraquinones, the intended shades of colour would have been purplish or brownish. Indigotin can migrate in burials and contaminate other textiles (Ringgaard 2010), but to evaluate this activity, more samples from the Snartemo burials would be useful.

Yellow flavonoids, luteolin and luteolin-7-glucoside were detected in samples 9, 10a and 12 (van Bommel 2018). These components occur in many plants, such



as weld (*Reseda luteola* L.), dyer's broom (*Genista tinctoria* L.), saw-wort (*Serratula tinctoria* L.) and dyer's chamomile (*Anthemis tinctoria* L.). Possible sources for luteolin are several uncultivated plants, too, such as yarrow (*Achillea millefolium* L.) and dandelion (*Taraxacum officinale* L.) (Hofmann-de Keijzer et al. 2013, 151–153). It is likely that a luteolin-containing plant was used with blue dyeing to create different nuances of green in samples 9, 10a and 12.

Furthermore, several unknown yellow components as well as UV-absorbing components were found. These could indicate unknown yellow dye sources, originating from the woad dyeing process, or be the result of a degradation process of dyes or contamination from the burial. It seems likely that an unidentified plant was used to dye the dark tunic fabric (samples 6 and 7), for which the hue was probably green instead of blue. This distinguishes the tunic fabric from the legwear fabric (samples 4 and 5), in which only indigotin and isatin were found.

Moreover, in the two-coloured twill fabric, the unknown colourants were detected in the blue/green yarn (sample 9), but not in the reddish yarn (sample 8). This possibly indicates intentional use of an unknown dyestuff instead of contamination from the burial context, as a contamination would be present in both yarns. Unknown colourants have been detected in other Scandinavian textiles, too; some of these could be lichen dyes or their degradation products, possibly originating from yellow wall lichen (*Xanthoria parietina*) or Scandinavian orchil (*Ochrolechia tartarea*) (Taylor 1983; Walton 1988a; 1988b; 2004; Vanden Berghe et al. 2009, 1918–1919). In Late Iron Age textiles, lichen colourants have been identified by UHPLC method in Finnish material (Vajanto 2015, 59). However, without a match with dye reference material, nothing certain can be said of the unknown colourants of the Snartemo V textiles.

Mordants

Traditionally, the most utilised mordant has been aluminium, which keeps colours bright. Iron and copper mordants change the colour hues. The colours achieved depend on the quantity of iron or copper mordant: yellow colourant with iron turns the colours green or brown, or copper mordant changes the colours from more yellowish to dark brownish (Dean 1999, 59–63).

The search for mordants was challenging, since the elements detected by EDX analysis can be explained in many ways. On one hand, carbon (C), oxygen (O) and sulphur (S) are the main elements of keratin of wool. On the other hand, carbon can be explained by

the carbon coating and graphite stubs, and oxygen can be atmospheric contamination.

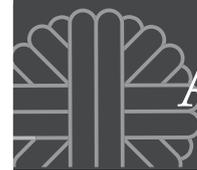
Aluminium (Al) and silicon (Si) can indicate mineralisation of fibres or sand from the burials; phosphorus (P), calcium (Ca), potassium (K), sodium (Na) and chlorine (Cl) can originate from the bones and body fluids of the chieftain's body. Aluminium, potassium and sulphur can indicate alum, $KAl(SO_4)_2 \cdot 12H_2O$, a well-known mordant for organic dyes. Alum can be obtained in its native state at certain geological areas, manufactured from alunite or alum shale, or be extracted from alum accumulating plant species, especially from the clubmoss species (*Lycopodium*) (Cardon 2007, 21–34; Vajanto 2015, 55, 110). Iron (Fe) and copper (Cu) have a long history in dyeing and can refer to mordant use, for example, as iron sulphate, $FeSO_4 \cdot xH_2O$, or copper sulphate, $CuSO_4 \cdot 5H_2O$, or their other chemical forms (Cardon 2007, 37–47). Alternatively, iron and copper can originate from the metallic burial goods.

The different state of preservation in the yarns of the two-coloured twill (samples 8 and 9) was interpreted as indicating two different mordants and two different dyeing methods (fig. 2a). The reddish yarn was mordanted with alum, copper and iron, and dyed in an acidic bath with red anthraquinones. That process was less damaging to wool than alkaline vat dyeing with indigotin and a possible iron mordant. With respect to the other samples, it is not possible to distinguish the intentional use of mordants from metals originating from the bronze and iron objects of the burial. Since the elements C, O, S, Al, Si, K and Cu were detected in the bear hairs, too, in-burial contamination is likely.

Wool and yarns

In the finest yarns (samples 2, 3, 8, 9, 11, 13 and 14), only 20 to 30 individual wool fibres were used in a thread. Of these, the spin angle was very low, only 0° to 5° in samples 8 and 9. This suggested that the individual fibres were long, which helps in spinning and adds tenacity. More strength was gained by plying two threads together, with a 45° ply angle. Using a small number of individual fibres, it was possible to create plied yarns with a diameter of only 0.2 to 0.3 mm (samples 6 and 7). This was probably the minimum diameter and extent of twist needed in the yarns to withstand the mechanical and longitudinal stress caused by weaving. The similarities in VAM samples 13 and 14 and KHM samples 8 and 9 suggest that these are from the same reddish textile.

In many Snartemo samples there was heavy



deterioration of the fibre surface (samples 2, 6, 7, 8, 12 and 13), in which the coating scales were partly or completely lost and the microfibrillar structures were visible. These effects were possibly the result of wear on the textiles, or a heavy dyeing process, or activity of microorganisms in the grave. In some cases (samples 4, 9, 11 and 14), the fibres looked polished and/or had longitudinal cracks—these may also point to heavy use of the textiles. An undamaged surface was present only in samples 1, 3, 5 and 10a.

According to the scale pattern, sheep wool was used in the Snartemo yarn sample 10a. However, in samples 1, 3, 4, 5 and 14, the scales were quite long (the longest ones 22 μm). This feature did not match with the reference collection consisting of wools of Norwegian Spelsau, Villsau and adult Finnsheep, in which the scale pattern was always denser and scales shorter. Long scales (16 to 19 μm) existed only in lamb's wool of Jaalasheep, which is a primitive variant of Finnsheep. That feature has been found occasionally in wool of some breeds of sheep (Brax 1951, 31–37; Rast-Eicher 2016, 264–267). The long scales may have been a special feature of Migration Period sheep wool. Long scales are also a feature typical of goat fleece, in which the underwool hairs are approximately 20 μm (Rast-Eicher 2016, 251, 253–258). It is difficult to distinguish hairs of sheep from hairs of goat, but raw fibre from a goat kid has been identified among the Norwegian Roman Iron Age textile materials, in the Sætrang find (Hougen 1935, 65–67; Walton 1988a, 147, 150). It can be challenging to find wool that has the same parameters as the Snartemo yarns, so it might be useful to test fine goat wool when spinning yarn for textile reconstructions.

In microscopy measurements (table 2), the finest fibres were found to be 11 μm in diameter, while the coarsest ones were 49 μm , and the typical diameters were 20 to 25 μm . According to Walton (1988a, 149), the wool in the Haraldskjær type z/z twill was a hairy medium type (14 to 82 μm), in the spin-patterned twill the wool was a medium type (13 to 54 μm) and in the other Haraldskjær z/z twill the wool was a generalised medium type (12 to 49 μm) – in these, the mode values were between 22 and 31 μm . All the results were very similar to the 22 to 44 μm diameters reported by Hougen (1935, 84). This suggests that sampling at the fragment edges can give reliable results of the morphology of fibres and does not require sampling in the best-preserved centre area of the textiles. In microinvasive sampling, edge yarns can be used both for dye analysis and fibre analysis.

The horsehair (sample 10b) was 113 μm in diameter. It corresponded well with horse tail (75 to 400 μm)

and mane (50 to 200 μm) (Von Bergen 1961; Kalayci et al. 2019). The distance between the scale margins is relatively short, which might indicate that the hairs were from the tail. Under SEM, the surface of the horsehair appeared relatively intact.

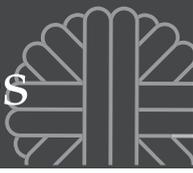
Wool pigmentation

In three cases, the chromatographic analysis gave unexpected results (van Bommel 2018). The visually reddish warp (sample 3) yarn of the geometrically-patterned tablet-woven band contained no dyestuffs. The yellowish yarn (sample 2) of the same band contained blue colourants, but that can be explained by contamination from the neighbouring blue warps. It seems that no yellow colourants were used to dye this warp yarn. In addition, no red dyes were detected in the visually reddish weft yarn (sample 10a) of the horsehair-patterned band either. It contained indigotin, luteolin-7-glucoside and an unknown UV-absorbing component. These are possibly contamination from the visually blueish warp.

Visually reddish yarns with no extracted colourants have been explained with condensed tannins (Vajanto 2015; Demant et al. 2018) and the natural pigmentation of wool (Bruselius Scharff 2018). Pigment granules have been detected in TEM observations, by imaging cross-sections of the wool fibres (Bruselius Scharff and Jørgensen 2017; Bruselius Scharff 2018). In waterlogged and slightly acidic conditions, the pigment granules are very vulnerable and can be damaged, and these appeared as empty granule holes in the cross-section images (Bruselius Scharff 2018, 237, 240).

Previous research has reported pigmented yarns in the two-coloured twill (Walton 1988a), and because of this, sample 12 was used as a reference for the samples 2, 3 and 10a. In the TEM images of the Snartemo samples (fig. 3), dark granules and empty granule holes were found in samples 3, 10a and 12, while sample 2 lacks any pigment cells. Accordingly, the horsehair-patterned band had dark, naturally pigmented wool weft yarns (sample 10a); possibly the detected blue and yellow dyes were contamination from the visually bluish warp. The visually yellowish hue in the warps (sample 2) of the geometrically-patterned band was explained by white and undyed wool because no pigment cells were detected. The yellowish hue was probably degradation of keratin, which turns yellowish with ageing due to fraction of sulphur bonds (Asquith and Brooke 1968; Timar Balázs and Eastop 1999, 51).

Since only a few fibres were sampled, it was not possible to estimate the frequency of the pigmented fibres in the yarns. The visually homogeneous hues in yarns 3, 10a and 12 suggested a systematic selection of pigmented wool.



Furs

The VAM private collection samples 15 and 16 matched hair references of bear (*Ursus arctos*), and it was reasonable to assume that they belong to the same bear pelt material as found previously (fig. 4). According to Hougen, bear hairs were found both at the bottom layers of the burial, but also attached to and between textile layers – possibly a waterflow had occurred in the burial chamber and spread the bear hairs across the burial items (Hougen 1935, 16, 72).

The Snartemo burial was one of the most richly furnished Migration Period warrior graves in which bear skin remains have been found (Grimm 2013). Bear hairs together with remains of bear claws indicated the wrapping of the deceased in a bear pelt or furnishing the grave pit with pelts (Hougen 1935, 16). The interpretation for the use of bear skins in pre-Christian ritual practices has been investigated in Old Norse mythology, which may offer a proper cultural context for interpreting the Snartemo find. In this context, skins have been seen as attributes of *berserkers* (etymologically *ber*, 'bear' and *serker*, 'skin, cloth'), who were legendary soldiers dressed in bearskins associated with the god Odin (Ström 1980; Price 2002, 366–378; Bender Jørgensen 2003, 69–71; Gräslund 2006, 125; Hedeager 2011, 91–95; Pluskowski 2006, 120–121). Although skin-wearing soldiers have been illustrated, for instance, on helmet-plates in Sweden, this does not necessarily mean that the soldiers were literally dressed in skins. It has been suggested that the men were as fearless and strong as bears, or even that they acted as *berserkers* in battle being mad or furious (*berserkerang*) (Price 2002, 364, 366–378; Gräslund 2006, 125; Back Danielsson 2007, 42–43; Hedeager 2011, 93–95). However, a short cape made of bearskin, called a *sieppuri* in Finnish, is known from historical Sámi populations (Schwindt 1893, 145; Sirelius 1912, 47–52; Itkonen 1948, 339). The remains of this kind of garment may also have been identified in an 11th century female grave in Luistari, Finland (Kirkinen et al. 2020). These examples suggest that garments made of bear pelts may have been used earlier, too.

Remains of Iron Age fur garments are scanty and hard to interpret, since the skin material itself (collagen) does not usually survive. Hair (keratin) survives better, but without clear textile structures such as seams and stitching, it is difficult to interpret them as garments. For example, hare fur with sinew thread has been identified in the Enebø burial, but the purpose of the item is unknown (Raknes Pedersen 1982, 80). Even if the fur material is rich, interpretation of the function of pelts has been difficult. In the Högom grave (Nockert 1991, 31, 106–107), hairs of bear,

reindeer/roe deer, beaver, marten, sable, polecat, pinniped, or muskrat were found under and around the body. Only beaver fur was suggested to have had a clothing function as a cap from its location around the head area of the body; the rest of the furs were interpreted as pelt remains used for furnishing the burial (Nockert 1991, 36).

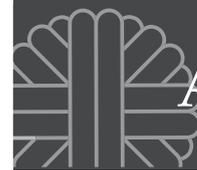
Dark, fine fur material (sample 17) from the VAM private collection was not easy to define because of the fragmentary nature of the hairs. The hairs originated from a Mustelidae sp. (for example, pine marten, sable and stoat), which are difficult to determine by species. The fur sample contained not only dark, soft fibres, but also the light brown hairs of a bear. This was probably contamination, since the dark fur was in direct contact with the bearskin fragment. Possible Mustelidae hairs were found in sample 14 too, attached to sheep wool yarn, but without other hair finds from the same context, their identification was not possible, and their role in clothing remains unresolved.

Mustelidae furs have been exploited especially for linings, trimmings, and collars, as well as for pouches and fur-lined sheaths and scabbards (Ågren 1995; Rast-Eicher 2016, 181; Kirkinen 2019). In the Migration Period female burial from Sande, small pieces of possible marten fur had survived underneath the clasp on the right arm side (Vedeler et al. 2018, 20). The fur was interpreted as a stola or fur lining of a cloak rather than a blanket (Vedeler et al. 2018, 21).

Moulds

In archaeological research, identification of moulds, bacteria and other microorganisms has been marginal (Ivanova and Marfenina 2015); in forensic science, the use of mycological evidence has become increasingly common (Tranchida et al. 2021). Since different species thrive in different microclimates, it could be possible to discover the time of year of the burial and what environmental processes (such as long frost or water flow) it has undergone (Lipkin et al. 2021). Microorganisms can also indicate conditions during the excavation, storage in museums or non-museum conditions, and the state of conservation. Some of these are health risks. Although it was not possible to explain in detail all the findings, their documentation was relevant for archaeological research in the future.

Several 0.3 µm long rod-shaped particles were found on a bear hair (sample 16) (fig. 5). These were interpreted as bacteria, possibly *Bacillus mesentericus*, *B. cereus* or *B. subtilis*, that are common in soil (Hearle et al. 1998, 397). On the horsehair (sample 10b), SEM imaging revealed spherical particles that were 3 µm



in diameter. These were most likely smut fungus teliospores from *Ustilago* or *Tilletia* genus (Sánchez-Elordi et al. 2016). Smut is a plant disease, and probably the hairs were contaminated by spores spread in the air either in the burial context or afterwards.

In addition, the Snartemo bear furs had suffered mould attacks (fig. 5). In sample 15 and 16, the most often detected mould species are *Aspergillus* and *Penicillium* species (Hearle et al. 1998, 397). *Aspergillus* has round or ellipse-shaped conidia while *Penicillium* moulds have fan-shaped conidia at the end of hyphae. In the references, the fan-like structures were often broken, with only short phialide at the end of hyphae. Possibly, both mould species were in sample 15. Other evidence of mould attack was unidentified amoeba-like round and flat objects, 1–2 x 2–3 µm in size, and unidentified lenticular-shaped spores, 1 x 1.5 µm in size, forming groups with same-sized granules of elliptical form and uneven surfaces.

Conclusions

The microanalysis methods (TLM, SEM, SEM-EDX, TEM, UHPLC-PDA) used on the textile materials of the Snartemo V burial brought new information that can be applied to the reproduction of Migration Period-style yarns and fabrics. The chieftain was resting under a blanket that had dark green and light-coloured yarns. He had blue legwear and a dark, blueish-green tunic. He had another bright red tunic or upper body garment, too. This was bordered with a tablet-woven band, woven with a dark, naturally pigmented weft, shiny horsehair wefts, and a green warp. His cloak was woven with green and reddish-brownish yarns. When new, the wide, geometrically-patterned band had a striking appearance, woven with white, naturally black and blue warps with red soumak stripes. It was possibly sewn to a fabric as a border instead of serving as a baldric as previously suggested.

It became clear that microinvasive sampling can be very fruitful and bring a lot of new information. In the Snartemo burial V, dyed textiles were not a rarity: of 13 samples, 11 contained plant dyes. Moreover, it was proven that Modocoll treatment is not a problem for the UHPLC analysis of textiles and adequate sampling for dye analysis and wool morphology studies can be done by utilising the edges of the fragments.

The different colourants showed that the dyers of these textiles were able to perform two different dyeing techniques, mordant and vat dyeing, and that they had knowledge of over dyeing and mordanting. Colourful yarns were used as a decorative element in the tablet-woven bands, to create textured twill with differently coloured warp and weft and to weave monochrome

fabrics. Both white and pigmented wools were used, either dyed or undyed, which increased the amount of available colour tones. The detected colourants, dyer's madder, woad and weld, were not from local sources, but transported to Iron Age Norway either as dyestuffs or as dyed yarns or textiles. Along with imported dyes, local bedstraws and yellow yielding plants were probably utilised too.

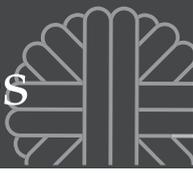
Bear and Mustelidae species fur were interpreted as indicating the use of pelts as wrapping, as well as furnishing of the Snartemo V burial. It was not possible to exclude the possibility that furs were part of the chieftain's clothing. Systematic fibre research would be helpful in fully understanding the role of the pelts and furs of this burial. The detected micro-organisms indicate inadequate storage conditions, but they also bring information about burial conditions and time. This is an area that would be useful to study further in archaeological textile research.

Acknowledgements

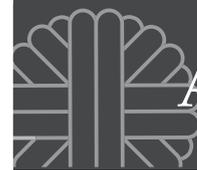
This paper was written with funding from the Emil Aaltonen Foundation. Dye analysis was funded by the Vest-Agder Museet. All microscopy was performed in the Aalto University's Nanomicroscopy Center of Ota-Nano Infrastructures.

References

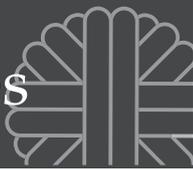
- Appleyard, H.M. (1978) *Guide to the identification of animal fibers*. Leeds: Wira.
- Asquith, R. S and Brooke, E. (1968) Yellowing of Wool Keratin on Exposure to Ultraviolet Radiation. *Journal of the Society of Dyers and Colourists* 84(3), 159–165.
- Ågren, T. (1995) Fur in Birka: an Examination of Hair Residue on Penannular Brooches. *Laboratio Arkeologi* 8, 50–58.
- Back Danielsson, I.-M. (2007) *Masking Moments. The Transitions of Bodies and Beings in Late Iron Age Scandinavia*. Doctoral dissertation. Stockholm: Department of Archaeology and Classical Studies, University of Stockholm.
- Balfour-Paul, J. (2011) *Indigo. Egyptian Mummies to Blue Jeans*. London: The British Museum Press.
- Bender Jørgensen, L. (1986) *Förhistoriske textiler i Skandinavien. Prehistoric Scandinavian Textiles*. Nordiske Fortisminder series B, volume 9. Copenhagen: Det kgl. nordiske Oldskriftselskab.
- Bender Jørgensen, L. (2003) Krigerdragten i folkevandringstiden. In P. Rolfsen and F. A. Stylegar (eds), *Snartemofunnene i nytt lys*. University Museum of Cultural Heritage, Occasional Papers 2. Oslo: Universitetes kulturhistoriske museer, 53–79.
- Bender Jørgensen, L. and Walton, P. (1986) Dyes and Fleece Types in Prehistoric Textiles from Scandinavia and



- Germany. *Journal of Danish Archaeology* 5, 177–188.
- Brandt, L. Ø., Schmidt, A. L., Mannering, U., Sarret, M., Kelstrup, C. D., Olsen, J. V. and Cappellini, E. (2014) Species Identification of Archaeological Skin Objects from Danish Bogs: Comparison between Mass Spectrometry-Based Peptide Sequencing and Microscopy-Based Methods. *PlosOne* 9(9), 1–10.
- Brax, E.K. (1951) *Suomalaisen villain käyttöarvosta kutomateollisuudelle. Arvosteltuna sen rakenteellisten ja fysikaalisten ominaisuuksien perusteella. Value of Finnish wool for Weaving Industry*. Unpublished Doctoral dissertation. Helsinki: Helsinki University of Technology.
- Bruselius Scharff, A. (2018) The Assessment of Natural Pigmentation in Archaeological Wool. In M. Bravermanová, H. Březinová and J. Malcolm-Davies (eds), *NESAT XIII. North European Symposium for Archaeological Textiles XI*, 22–26 May 2017 in Liberec. Prague: Technical University of Liberec and Institute of Archaeology of the CAS, 235–242.
- Bruselius Scharff, A. and Jørgensen, L. B. (2017) Evaluating transmission electron microscopy as a method for assessing the condition of archaeological wool. In J. Brigland (ed), *ICOM-CC 18th Triennial Conference: Linking Past and Future*. Copenhagen: International Council of Museums, 1–8.
- Cardon, D. (2007) *Natural Dyes. Sources, Tradition, Technology and Science*. London: Archetype Publications.
- Dean, J. (1999) *Wild colour. The Complete Guide to Making and Using Natural Dyes*. New York: Watson Guptil publications.
- Demant, I., Frandsen, L. B., Ræder Knudsen, L., Lorange, T., Bruselius Scharff, A., Vanden Berghe, I., Skals, I., Lund Hansen, U. and Mannering, U. (2018) Lønne Hede – an Early Roman Iron Age burial site with well-preserved textiles. In Römisch-Germanische Kommission des Deutschen archäologischen Instituts (ed), *Bericht der Römisch-Germanischen Kommission, Band 99*. Berlin: Gebr. Mann Verlag, 205–293.
- Grimm, O. (2013) Bear-skins in northern European burials and some remarks on other bear-related furnishings in the north and middle of Europe in the 1st millennium AD. In O. Grimm and U. Schmölcke (eds), *Hunting in northern Europe until 1500 AD. Old traditions and regional developments, continental sources and continental influences*. Neumünster: Wachholtz Verlag, 277–296.
- Geijer, A., Boström, H. and Axelsson, H. (1961) Modocoll som prepareringsmedel för textilier. *Svenska museer* 1, 11–14.
- Gräslund, A.-S. (2006) Wolves, serpents, and birds. Their symbolic meaning in Old Norse belief. In A. Andrén, K. Jennbert and C. Raudvere (eds), *Old Norse Religion in Long-term Perspectives: Origins, Changes, and Interactions. An International Conference in Lund, Sweden, June 3–7, 2004. Vägar till Midgård 8*. Lund: Nordic Academic Press, 124–129.
- Halvorsen, S. (2012) Norway. In M. Gleba and U. Mannering (eds), *Textiles and textile production in Europe – From Prehistory to AD 400*. Ancient Textiles Series 11. Orford: Oxbow Books, 275–290.
- Hearle, J. W. S., Lomas, B. and Cooke, W. D. (1998) *Atlas of Fibre Fracture and Damage to Textiles*. Cambridge: Elsevier Science & Technology.
- Hedeager, L. (2011) *Iron Age Myth and Materiality. An Archaeology of Scandinavia AD 400–1000*. London and New York: Routledge.
- Hofenk de Graaff, J., Roelofs, W. G. T. and van Bommel, M. R. (2004) *The Colourful Past: Origins, Chemistry and Identification of Natural Dyestuffs*. Riggisberg: Abegg-Stiftung and London: Archetype Publ.
- Hofmann-de Keijzer, R., van Bommel, M. R. and Joosten, I. (2005) Dyestuff and element analysis on Textiles from the prehistoric Salt-mines of Hallstatt. In P. Bichler, K. Grömer, R. Hofmann-de Keijzer, A. Kern and H. Reschreiter (eds), *Hallstatt Textiles. Technical Analysis, Scientific Investigation and Experiment on Iron Age Textiles*. BAR International Series 1351. Archaeopress: Oxford, 91–96.
- Hofmann-de Keijzer, R., van Bommel, M. R., Joosten, I., Hartl, A., Proaño-Gaibor A. N., Heiss, A. G., Kralofsky, R., Erlach, R. and de Goot, S. (2013) The colours and dyeing of prehistoric textiles from the salt mines of Hallstatt. In K. Grömer, A. Kern, H. Reschreiter and H. Rösel-Mautendorfer (eds), *Textiles from Hallstatt. Weaving Culture in Bronze Age and Iron Age Salt Mines*. Budapest: Archaeolingua, 136–162.
- Hougen, B. (1935) *Snartemo funnene*. Studier i folkevandringstidens ornamentik og tekstilhistorie. Norske oldfunn VII. Oslo: Universitetets oldsaksamling.
- Itkonen, T. (1948) *Suomen lappalaiset vuoteen 1945. Part 1*. Porvoo: WSOY.
- Ivanova, A. and Marfenina, O. (2015) Soil fungal communities as bioindicators of ancient human impacts in medieval settlements in different geographic regions of Russia and southwestern Kazakhstan. *Quaternary International* 365, 212–222.
- Kalayci, E., Avinc, O. and Yavas, A. (2019) Usage of horse hair as a textile fiber and evaluation of color properties. *Annals of the University of Oradea: Fascicle of Textiles, Leatherwork* XX(2), 57–62.
- Kirkinen, T. (2019) *Between skins – animal skins in the Iron Age and historical burials in eastern Fennoscandia*. PhD thesis, University of Helsinki. Helsinki: Unigrafia.
- Kirkinen, T., Vajanto, K. and Björklund, S. (2020) Animal hair evidence in an 11th century female grave in Luistari, Finland. *Archaeological Textiles Review* 62,



- 109–125.
- Lipkin, S., Ruhl, E., Vajanto, K., Tranberg, A. and Suomela, J. A. (2021) Textiles: Decay and Preservation in Seventeenth to Nineteenth-Century Burials in Finland. *Historical Archaeology* 55, 49–64.
- Nockert, M. (1991) *The Högom find and other Migration period textiles and costumes in Scandinavia*. Archaeology and environment 9, Högom part II. Umeå: Riksantikvarieämbete.
- Nordquist, J. and Ørsnes, D. (1971) Pige i blått. *Skalk* 1971(3), 9–15.
- Peacock, E. E. (1992) Drying archeological textiles. In L. Bender Jørgensen and E. Munksgaard (eds), *Tidens tand nr. 5. Archaeological Textiles in Northern Europe – Report from the 4th NESAT symposium, 1st–5th May 1990* vol. 5. Copenhagen: Konservatorskolen, Det Kongelige Danske Kunstakademi, 197–207.
- Pluskowski, A. (2006) Harnessing the hunger. Religious appropriations of animal predation in early medieval Scandinavia. In A. Andrén, K. Jennbert and C. Raudvere (eds), *Old Norse Religion in Long-term Perspectives: Origins, Changes, and Interactions. An International Conference in Lund, Sweden, 3–7 June 2004*. Vägar till Midgård 8. Lund: Nordic Academic Press, 119–123.
- Price, N. (2002) *The Viking Way. Religion and War in the Late Iron Age Scandinavia*. Aun 31. Uppsala: Uppsala University.
- Raknes Pedersen, I. (1982) The Analyses of the Textiles from Enebø-Eide, Globben Norway. In L. Bender Jørgensen and K. Tidow (eds), *Textilsymposium Neumünster, Archäologische Textilfunde. 6.5.–8.5.1981*. Neumünster: Textilmuseum Neumünster, 74–80.
- Raknes Pedersen, I. (1988) The Analysis of the Textiles from Blindheim, Giske. In L. Bender Jørgensen and E. Munksgaard (eds), *Archaeological Textiles. Report from the 2nd NESAT symposium 1.–4.5.1984*. Arkæologiske skrifter 2. Copenhagen: University of Copenhagen, 116–125.
- Rast-Eicher, A. (2016) *Fibres. Microscopy of Archaeological Textiles and Furs*. Budapest: Archaeolingua.
- Ringgaard, M. (2010) *To par strixstrømper oc en nattrøie naccarat: Filtede og strikkede tekstiler fra omkring år 1700, fundet i Københavnske byudgravninger – og sammenhænge mellem tekstilers farve og bevaring*. Doctoral dissertation. Copenhagen: University of Copenhagen.
- Rolfen, P. (2003) Snartemosverdet – kopier og NS-propaganda. In P. Rolfen and F. A. Stylegar (eds), *Snartemofunnene i nytt lys*. University Museum of Cultural Heritage, Occasional Papers 2. Oslo: Universitetes kulturhistoriske museer, 81–131.
- Sánchez-Elordi, E., Vicente-Manzanares, M., Diaz, E., Legaz, M. E and Vicente, C. (2016) Plant-pathogen Interactions: Sugarcane Glycoproteins Induce Chemotaxis of Smut Teliospores by Cyclic Contraction and Relaxation of the Cytoskeleton. *South African journal of botany* 105, 66–78.
- Schmidt, A. L., Gilbert, M. T. P., Cappellini, E. and Velgaard Olsen, J. (2011) Identification of animal species in skin clothing from museum collections. In ICOM-CC 16th Triennial Conference: *Triennial Conference in Lisbon, The Role of Conservation*. Lisbon, 19–23 September 2011, 1–8.
- Schwindt, T. (1893) *Tietoja Karjalan rautakaudesta ja sitä seuraavilta ajoilta Käkisalmen kihlakunnan alalta saatujen löytöjen mukaan*. Suomen Muinaismuistoyhdistyksen Aikakauskirja 13.
- Serrano, A., van Bommel, M. R. and Hallet, J. (2013) Evaluation between ultrahigh pressure liquid chromatography and high-performance liquid chromatography analytical methods for characterizing natural dyestuffs. *Journal of Chromatography A* 1318, 102–111.
- Sirelius, U. T. (1912) Über einige Traggeräte und Umschlagetücher bei den finnisch-ugrischen Völkern. *Suomen Muinaismuistoyhdistyksen Aikakauskirja XXVI*, 29–58.
- Skals, I., Gleba, M., Taube, M. and Mannering, U. (2018) Wool textiles and archaeometry: testing reliability of archaeological wool fibre diameter measurements. *Danish Journal of Archaeology* 7(2), 161–179.
- Ström, Å. (1980) Björnfällar och Oden-religion. *Fornvännen* 75(4), 266–270.
- Taylor, G. W. (1983) Detection and identification of dyes on Anglo-Scandinavian textiles. *Studies in Conservation* 28, 153–160.
- Teerink, B. (2003) *Hair of West-European Mammals: Atlas and Identification Key*. Cambridge: Cambridge University Press.
- Thingnæs, S. (2007) *I enden av en tråd – om textilhåndverk i folkevandringsstid*. Hovedfagsoppgave i arkeologi. Oslo: Det humanistiske fakultetet, University of Oslo.
- Timar Balázs, Á. and Eastop, D. (1999) *Chemical principles of textile conservation*. London and New York: Routledge.
- Tóth, M. (2017) *Hair and Fur Atlas of Central European Mammals*. Nagykovácsi: Pars Ltd.
- Tranchida, M. C., Pelizza, S. A. and Eliades, L. A. (2021) The use of fungi in forensic science, a brief overview. *Canadian Society of Forensic Science Journal* 54(1), 34–46.
- Vajanto, K. (2015) *Dyes and dyeing methods in Late Iron Age Finland*. Doctoral dissertation, archaeology. Helsinki: University of Helsinki.
- Vanden Berghe, I., Gleba, M. and Mannering, U. (2009) Towards the identification of dyestuffs in early Iron Age Scandinavian peat bog textiles. *Journal of Archaeological Science* 16, 1910–1921.
- Vanden Berghe, I. and Möller Wiering, S. (2013) Dye



- Analyses on the "Prachtmantel" from the Thorsberg. In J. Banck-Burgess and C. Nübold 2013 (eds), *The North European Symposium for Archaeological Textiles XI, held in Esslingen am Neckar in 10–13 May 2011*, 101–105. Rahden/Westf.: Verlag Marie Leidorf GmbH.
- Van Bommel, M. R. (2018) *Dyestuff analysis from samples of the Snartemo textile, Vest-Agder museum, Norway*. University of Amsterdam, Unpublished analysis report.
- Vedeler, M., Kristoffersen S. and Rødstas, I. M. (2018) Dressed for Ritual, Dressed for Life. A Migration Period Grave from Sande in Norway. *Medieval Archaeology* 62(1), 1–27.
- Von Bergen W. (1961) *Wool Handbook I*. New York: Textile Book Publishers Inc.
- Walton, P. (1988a) Dyes and wools in Iron Age textiles from Norway and Denmark. *Journal of Danish Archaeology* 7, 144–158.
- Walton, P. (1988b) Dyes of the Viking Age: a summary of recent work. *Dyes in History and Archaeology* 7, 14–20.
- Walton Rogers, P. (1997) Analysis of Samples from Lønne Hede in Denmark. *Archaeological Textiles Newsletter*, Spring issue, 14–16.
- Walton Rogers, P. (2004) Fibres and dyes in Norse textiles. In E. Østergård (ed), *Woven into the Earth: Textiles from Norse Greenland*. Aarhus: Aarhus University Press, 79–92.

Corresponding author:
kristamerikki.wright@gmail.com