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Strontium Isotope Investigations of the Haraldskær Woman – A Complex Record of Various Tissues

Analyses des isotopes du strontium de la Femme de Haraldskær – un dossier complexe de tissus divers

Karin Margarita Frei[a], Ulla Mannering[b], T. Douglas Price[c] and Rasmus Birch Iversen[d]

Résumé : Bog bodies form a unique group of archaeological human remains which offer unparalleled insight into the past. Unlike most ancient human remains, bog bodies have preserved their skin and other soft tissues through natural tanning processes in the bogs. We present the first comprehensive strontium isotope investigation of the Haraldskær Woman and her garments, dated to the Scandinavian Pre-Roman Iron Age (500-1 BC). Our interdisciplinary research applies new advances in strontium isotope tracing protocols enabling us to go a step further in unravelling the life of bog people. Our study reveals long distance travel of the Haraldskær Woman shortly before her death, leading to new speculations on to why her body ended in the bog.

Abstract: *Les corps humains conservés dans les tourbières forment un groupe bien particulier de restes archéologiques et offrent un aperçu unique du passé. Contrairement à la plupart des restes humains anciens, les corps déposés dans les tourbières sont parfois conservés avec des organes (peau, cheveux, etc.) grâce à des processus de tannerie naturels spécifiques au milieu tourbeux. Nous présentons la première étude isotopique complète de la femme de Haraldskær et de ses vêtements, datée de l'Âge du Fer pré-romain en Scandinavie (500-1 BC). Notre recherche interdisciplinaire applique de nouveaux protocoles de traçage isotopique du strontium et nous permet d'aller un peu plus loin dans l'évocation de la vie des gens des tourbières. Notre étude révèle un long voyage effectué par la femme de Haraldskær peu avant sa mort, conduisant à de nouvelles hypothèses concernant la raison pour laquelle son corps se trouve dans une tourbière.*

Keywords: Strontium isotopes, bog bodies, Iron Age, archaeological textiles, human hair.

Mots clés : *isotopes de strontium, corps des tourbières, l'âge du fer, textiles archéologiques, des cheveux humains.*

1. Introduction

Bog bodies are true windows to the past due to their exceptional preservation, which enable them to retain their human appearance even after being in the bog for several millennia (Glob, 965; Ilkjær, 2000; Van der Sanden, 1996). These unusual human remains have been found across north-western Europe. The majority of them have been unearthed in Scandinavia and date to the Pre-Roman Iron Age. The bog bodies represent individuals that were buried

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and/or sacrificed in the bogs in contrast to the customary traditions where the deceased were cremated and their ashes buried in urns (Becker, 1961). The excellent preservation of these bodies, combined with new developments in methods of isotopic tracing techniques, offers unique possibilities to learn *hitherto* unknown aspects of their life and mobility through different life stages (Bergfjord *et al.*, 2012; Font *et al.*, 2012; Frei *et al.*, 2009a; Frei *et al.*, 2015; Frei *et al.*, 2010; Lynnerup, 2007).

Here we focus on investigating the human and textile remains of the bog body referred to as the "Haraldskær Woman" (figure 1), also known as "Queen Gunhild", with the overall aim of gaining information on her provenance.

The Haraldskær Woman was unearthed by peat-cutters in the autumn of 1835 in the Haraldskær bog near Vejle, Jutland, Denmark (figure 2). The woman was probably strangled and died at an age of c. 40 years. Inspired by the Islandic Sagas, it was suggested immediately after the recovery that this bog body belonged to the Viking queen Gunhild from Norway, who was to marry the Viking king of Denmark, Harald Bluetooth, but who instead was killed and cast into a bog. Her Viking origin was later refuted, but the name persisted through time (Worsaae, 1842). Recent ^{14}C analyses resulting in 2110±41 ^{14}C cal. BP (Mannring *et al.*, 2010) have now securely placed the find in the Danish Pre-Roman Iron Age (500-1 BC). Like many other bog bodies,

Figure 1: The bog body of the Haraldskær Woman as it is preserved today (Photo by courtesy of The Vejle Museums).
Figure 1 : Le corps de la femme de Haraldskær trouvé dans la tourbière tel qu'il est conservé aujourd'hui (photo avec la permission des Musées de Vejle).

the Haraldskær Woman was found with a rich set of wool textiles, a wool sprang cap (sprang being an ancient needlework technique), several wool cords and a skin cape (Hald, 1980) (figures 3 and 4). Moreover, her long hair (> 50cm, figure 4) as well as some of her teeth are also preserved, thereby providing a unique opportunity to study mobility during different life stages through recently developed strontium isotope tracing methods (Frei *et al.*, 2015). We conducted a total of 27 strontium isotope analyses in order to investigate the provenance and mobility pattern of the Haraldskær Woman (table 1).

2. Methods

Recent advances in methodological strontium isotopic tracing techniques in keratin-rich animal and human tissues, provide us with new possibilities to investigate both archaeological textiles as well as ancient human hair (Frei *et al.*, 2015 ; Frei *et al.*, 2009a ; Frei *et al.*, 2010). These studies focus on developing pre-cleaning procedures that enable the recovery of the nutritional strontium fraction in hair (Font *et al.*, 2012; Frei *et al.*, 2015; Frei, 2014; Lynnerup, 2007). The present study applies these chemical protocols. Our sampling strategy included threads from the wool textile remains, scalp hair of the Haraldskær Woman (sampled at both ends), tooth enamel, as well as archaeological fauna, soil extracts and water samples in order to create a local reference map/isoscape.

Pre-cleaning/decontamination of wool and hair samples

Wool and human scalp hair samples were washed in 1N hydrochloric (HCl) acid and subsequently in 20% dilute cold hydrofluoric (HF) acid under ultrasonic treatment for 1 hour in a 7ml Teflon beaker (Savillex™). The samples were rinsed twice with 1ml of deionized water (MilliQ™) in an ultrasonic bath between the acid washes. The respective acid washes were subsequently pipetted off from the wool samples and the remaining wool samples were thereafter deeply rinsed (several times) with 1ml of deionized water (MilliQ™) and dried off.

In order to remove traces of dyestuff in the textiles, the rinsed wool samples were immersed in 3ml of 0.2M ammonium peroxodisulfate $(NH_4)_2 S_2O_8$ (a strong oxidant, abbreviated as "APDS") on a hotplate (preferably at 130°C) for c. 30 minutes. The residual wool sample was once again deeply rinsed with 1 ml of deionized water (MilliQ™) several times and subsequently dried off.

The final residual wool/hair portions were dissolved in a 1:1 mixture of 30% HNO_3 (Seastar™) and 30% H_2O_2 (Seastar™). The samples tended to decompose within 30 minutes. After decomposition the solutions were dried off on a hotplate at c. 80°C.

Samples were taken up in a few drops of 3N HNO_3 and loaded on especially prepared, disposable pipette-tip columns containing 0.2 ml intensively pre-cleaned mesh 50-100 SrSpec™ (Eichrome Inc./Tristchem) ion chromatographic resin. The elution recipe essentially followed that of (Horwitz *et al.*, 1992).

Strontium from enamel-, bone-, soil extract- and water samples was separated according to the analytical procedures and protocols described by Frei and Frei (2010), and Montgomery (2010) and Sr fractions from these samples, analogues for wool textile and hair samples were measured on the same facility described below.

Thermal ionization mass spectrometry

The samples were dissolved in 2.5µl of a Ta2O5-H3PO4-HF activator and subsequently loaded onto outgassed 99.98% single rhenium filaments. Samples were measured in a dynamic mode on a VG 54 Sector IT mass spectrometer (at the Danish Center for Isotope Geology, University of Copenhagen), at temperatures between 1300 and 1450°C. The mass 88 ion beam was kept above 300mV during an analytical run which consisted of over a minimum of 6 blocks with 10 mass scan cycles each.

3. Results and materials

New achievements in the field of ancient wool textile and human hair analyses (Font *et al.*, 2012, Frei *et al.*, 2015; Frei 2014, Frei *et al.*, 2009a, Frei *et al.*, 2010; Lynnerup, 2007), have for the first time made it possible to conduct a complete provenance investigation of a bog body (including teeth, scalp hair and garments) using the strontium isotope tracing system. The exceptional preservation of the Haraldskær find provides a unique opportunity to build a sequence of time-snapshots indicating where the woman lived and where her garments were produced (Table 1).

Local baseline

The isotopic range of bioavailable strontium for Denmark has recently been defined by surface waters and soil extracts (Frei and Frei, 2011; Frei and Frei 2013) and by modern and archaeological fauna samples (Frei and Price, 2012).

Sample identification	Material	Weight (mg)	Procedure	[Sr] (ppm)	$^{87}Sr/^{86}Sr$	2σ (abs)
Textiles						
NM 3706 weft	textile/wool	11,81	HF + HCl leach	29	**0,70995**	0,00004
NM 3706 weft	textile/wool	11,81	APDS leach	32,8	**0,70929**	0,00003
NM 3706 weft	textile/wool	11,81	residue	0,54	**0,70946**	0,00002
NM 3706 warp	textile/wool	12,43	HF + HCl leach	27,95	**0,70995**	0,00004
NM 3706 warp	textile/wool	12,43	APDS leach	31,84	**0,70929**	0,00003
NM 3706 warp	textile/wool	12,43	residue	0,26	**0,70993**	0,00003
NM 3707 C2	textile/wool	3,48	HF leach	4,48	**0,71910**	0,00006
NM 3707 C2	textile/wool	3,48	HCl leach	1,05	**0,71712**	0,00007
NM 3707 C2	textile/wool	3,48	APDS leach	3,3	**0,71137**	0,00004
NM 3707 C2	textile/wool	3,48	residue	1,15	**0,71283**	0,00006
NM 3707 C1*	textile wool	17,53	residue	3,14	**0,70924**	0,00002
NM C 37143 net	wool hair net/sprang	27,13	HF + HCl leach	15,96	**0,70921**	0,00003
NM C 37143 net	wool hair net/sprang	27,13	residue	4,68	**0,70839**	0,00009
NM C 37143 cord	wool hair net/outer cord	11,78	HF + HCl leach	29,29	**0,70995**	0,00004
NM C 37143 cord	wool hair net/outer cord	11,78	APDS leach	33,81	**0,70921**	0,00003
NM C 37143 cord	wool hair net/outer cord	11,78	residue	0,53	**0,70921**	0,00003
Human remains						
NM 3708 (segment 1)	Human hair	7,21	HF + HCl leach	121,09	**0,70992**	0,00003
NM 3708 (segment 1)	Human hair	7,21	residue	10,72	**0,70687**	0,00006
NM 3708 (segment 2)	Human hair	15,51	HF + HCl leach	17,73	**0,70967**	0,00004
NM 3708 (segment 2)	Human hair	15,51	residue	7,29	**0,70856**	0,00006
E 1	Enamel from front tooth	1,35	HCl - H_2O_2		**0,70847**	0,00003
Baseline samples						
H3	Tooth enamel from archaeological rodent	6,64	HCl - H_2O_2		**0,70935**	0,00002
H4	Tooth enamel from archaeological rodent	5,13	HCl - H_2O_2		**0,70936**	0,00001
H5	Tooth enamel from archaeological rodent	8,95	HCl - H_2O_2		**0,70936**	0,00001
H6	Jaw bone fragment from archaeological rodent	8,76	HCl - H_2O_2		**0,70975**	0,00002
H7	Jaw bone fragment from archaeological rodent	19,77	HCl - H_2O_2		**0,70944**	0,00001
W1	Surface water, Haraldskær creek	*10 ml*			**0,70894**	0,00001
S1	Soil, Haraldskær peat bog	*1 g*	0.05N HNO_3 extract		**0,70943**	0,00001
Median of fauna, water and soil samples					**0,70936**	
Baseline range					**0.70894-0.70975**	

* Sample previously analyzed by Frei et al. (2009a)

Table 1: Strontium isotopic compositions of the Haraldskær woman and her textiles as well as baseline materials
Tableau 1 : Compositions isotopiques du strontium de la femme de Haraldskær et ses textiles ainsi que des matériaux de référence.

This baseline characterization resulted in a range of $^{87}Sr/^{86}Sr$ values between ~ 0.708-0.711 (island of Bornholm excluded). In addition to this, we measured $^{87}Sr/^{86}Sr$ ratios in a variety of materials from the Haraldskær site where the body was discovered and hence further narrowed down the isotopic range of local bioavailable strontium (Table I) to $^{87}Sr/^{86}Sr$ = 0.7089-0.7097.

Teeth and hair

Most bog bodies (not to be confused with bog skeletons), unlike most other ancient human remains, have preserved parts of their soft tissues, such as skin, and in some cases, even internal organs. This is due to the bio- and geochemical conditions in ombrotrophic bogs developing an acidic, anoxic

Figure 2: (See colour plate IV) Map indicating the location of the Haraldskær bog (red star). The red spots mark areas characterized by isotope ratios of bioavailable strontium with values of $^{87}Sr/^{86}Sr < 0.707$ which could match the strontium isotopic composition measured in one of the scalp hair segments of the Haraldskær Woman (segment 1) (Map by Christian Schmidt).
Figure 2 : (Voir planche couleur IV) Carte indiquant l'emplacement de la tourbière de Haraldskær (étoile rouge). Les taches rouges marquent les zones caractérisées par des rapports de strontium biodisponible isotopiques avec des valeurs de $^{87}Sr/^{86}Sr$ <0,707 qui pourrait correspondre à la composition isotopique de strontium mesurée dans l'un des segments de cheveux du cuir chevelu de la femme de Haraldskær (segment 1) (Carte de Christian Schmidt).

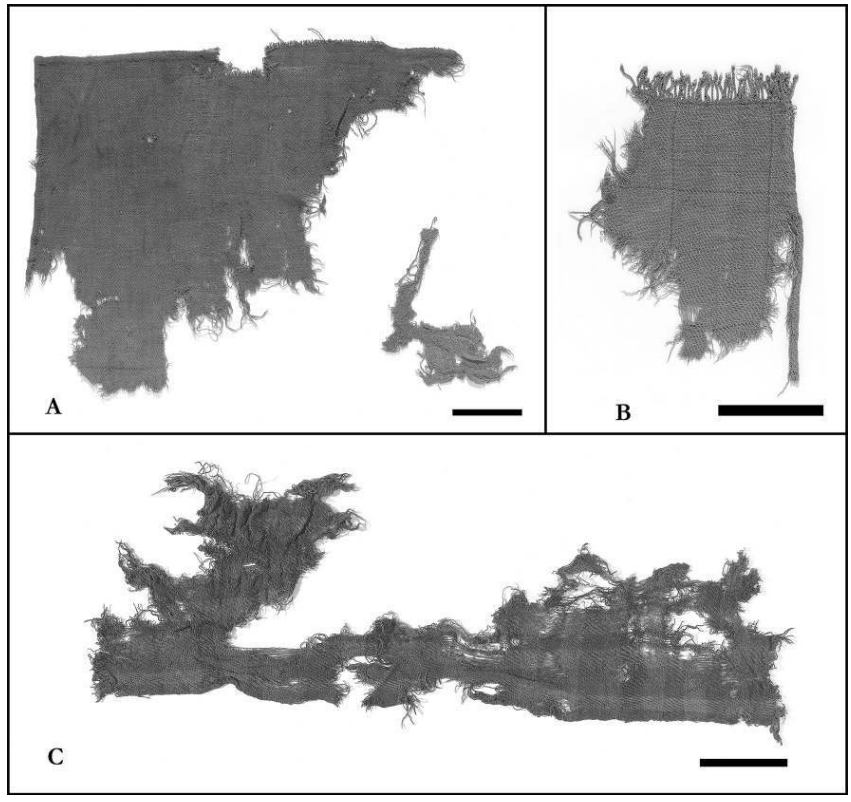

Figure 3: (See colour plate V) Textile remains from the Haraldskær Woman; a) NM 3706 which measures 64 x 49 cm and was sampled in both thread directions, b) NM 3707 C1 which measures 30 x 24 cm and has fringes in one end and narrow stripes in both thread directions, and c) NM 3707 C2 measures 76x26cm and has a chequered pattern. Black bars indicate 10 cm scale. The chequered textile is made of wool characterized by a strontium isotopic ratio that is too radiogenic to be of local provenance (Photos by the National Museum of Denmark).
Figure 3 : (Voir planche couleur V) Restes de textile de la femme de Haraldskær; a) NM 3706 qui mesure 64 x 49 cm et a été échantillonné dans les deux directions du fil, b) NM 3707 C1 qui mesure 30 x 24 cm et a des franges dans une extrémité et des bandes étroites à rayures dans les deux directions de fil, et c) NM 3707 mesures C2 76 x 26 cm et dispose d'un motif en damier. Des barres noires indiquent 10 cm en échelle. Le textile en damier est fait de laine caractérisée par un rapport isotopique du strontium qui est trop radiogenique pour être de provenance locale (Photos du Musée national du Danemark).

and nitrogen-rich environment (Verhoeven *et al.*, 1990) which enables protein-based tissues to be preserved. Hair is a unique archive of, e.g. diet which can be traced by stable isotopes (Wilson *et al.*, 2012), or of movement, potentially traceable by strontium isotopes (Frei *et al.*, 2015). The scalp hair of the Haraldskær Woman measures over 50 cm in length and represents approximately 50 months of hair growth prior to death. We analyzed both ends of the scalp hair: segment 1 (near the scalp) represents the final 4-5 months of her life and yields $^{87}Sr/^{86}Sr = 0.70687$; segment 2 represents a period approximately four years prior her death for 3 to 4 months time, and yields $^{87}Sr/^{86}Sr = 0.70856$. Finally, the tooth enamel sample from one of her incisors yields a $^{87}Sr/^{86}Sr$ ratio of 0.70847 (table 1).

Textiles

The Haraldskær Woman was recovered together with three wool textiles, two wool accessories and a skin cape (figures 3 and 4). The textiles were severely damaged during the recovery and the largest textile (NM 3706) now measures 64 x 49cm. It is woven in 2/2 twill with z-twisted yarn in both directions (Hald, 1980). The weft sample yields a $^{87}Sr/^{86}Sr$ ratio of 0.70946 and the warp yields a $^{87}Sr/^{86}Sr$ ratio 0.70993. The second textile (NM 3707 C2), measuring 76 x 26 cm and woven in 2/2 twill in s-twisted yarn, has a large chequered pattern. This textile has recently been shown to contain trace amounts of organic dyestuffs (luteolin and quercetin) (Vanden Berghe *et al.*, 2009). Hence, all the textiles were analyzed following a new methodology developed for ancient textiles dyed with organic dyes (Frei *et al.*, 2010). The thread sample from this textile yields a $^{87}Sr/^{86}Sr$ ratio of 0.71283. The third textile (NM 3707 C1) has a fringe and is woven in 2/2 twill in z-twisted yarn in both directions. It measures 30 x 24cm. A thread sample from this textile was analyzed in an earlier investigation, and yielded a $^{87}Sr/^{86}Sr$ ratio of 0.70924 (Frei *et al.*, 2009a). The accessories consist of a wool sprang cap (NM C 37143) and several wool cords. Finally, we analyzed two samples from the cap, which yield a $^{87}Sr/^{86}Sr$ ratio of 0.70839 and a $^{87}Sr/^{86}Sr$ ratio of 0.70982.

4. Discussion and conclusion

The remarkable preservation of bog bodies provides an immense research potential for multidisciplinary investigations, however, key questions related to their identity and provenance still remain unanswered. In this study we have investigated the provenance of the bog body of the Haraldskær Woman dated to 2110 ±41 ^{14}C cal. BP (Mannering *et al.*, 2010).

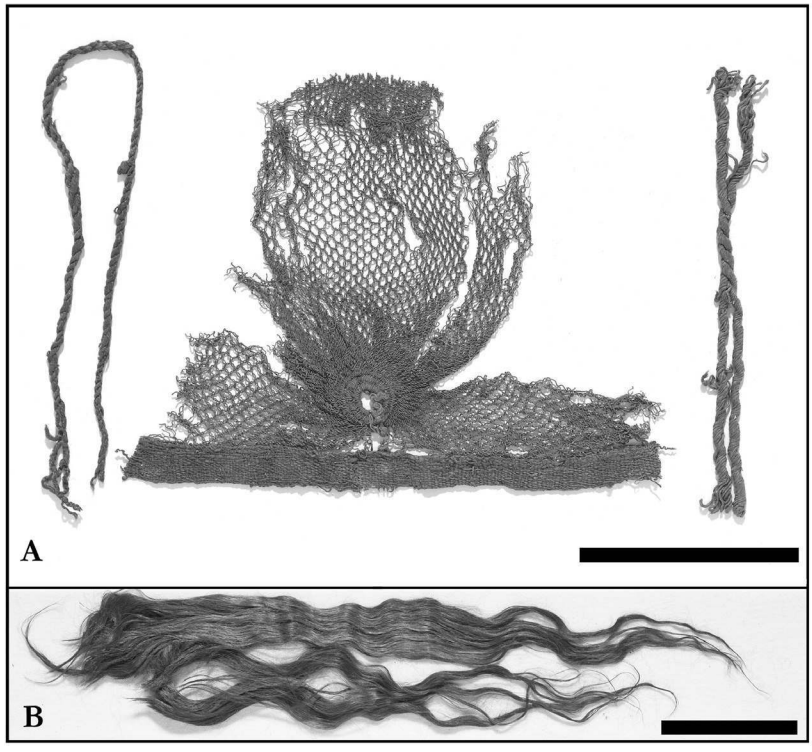

Figure 4: (See colour plate) a) Sample NM C 37143, a wool sprang cap or hairnet which was sampled at the edge (cord) and in the middle part. b) Detached scalp hair from the Haraldskær Woman measuring over 50 cm in length. The hair was sampled at both ends. Black bars indicate 10 cm scale. The wool accessory samples all have strontium isotope ratios that fall within the Danish bio-available isoscape. However, one of the Haraldskær Woman's scalp hair segments is of non-local provenance, indicating mobility outside Denmark (Photos by the National Museum of Denmark).

Figure 4 : (Voir planche couleur) a) échantillon NM C 37143, un fichu de laine fait de la méthode « sprang » ou un bonnet qui a été échantillonné au bord (cordon) et dans la partie médiane. b) Une partie de la chevelure de la femme de Haraldskær mesure du cuir chevelu plus de 50 cm de longueur. Les cheveux ont été échantillonnés aux deux extrémités. Des barres noires indiquent 10 cm d'échelle. Les échantillons d'accessoires de laine ont tous les rations des isotopes du strontium qui relèvent du isoscape biodisponible danois. Cependant, l'un des segments de cuir chevelu des cheveux de la femme de Haraldskær n'est pas de provenance locale, indiquant la mobilité en dehors du Danemark (Photos par le musée National du Danemark).

The strontium isotope analyses of the Haraldskær Woman's tooth representing the period of childhood, fall within the isotopic range of Danish bioavailable strontium, indicating that the Haraldskær Woman probably spent her childhood in the present Danish area (excluding Bornholm). The strontium isotope composition of hair segment 2 (representing a period of approximately four years prior to her death) is similar to that of the tooth enamel. This can be interpreted in several ways. The woman either lived in a place with a similar bioavailable strontium signature or she spent most of her life in the Haraldskær area. However, hair segment 1 near the scalp (representing a few months prior to her death) has a strontium isotopic composition that lies significantly below ($^{87}Sr/^{86}Sr$ ratio of 0.70687) the range of bioavailable strontium typical of present day Denmark. Such low strontium isotope values are not found in areas adjacent to Denmark and therefore this value could indicate long distance movement shortly before her death. Figure 2 shows areas with such low bioavailable strontium isotope values (Frei and Frei, 2011; Heidal *et al.*, 2007; Löfvendahl *et al.*, 1990; Maurer *et al.*, 2012; Montgomery *et al.*, 2006; Voerkelius *et al.*, 2010; Aarberg and Wickman, 1987).

Furthermore, the analyses of two of the three textiles as well as the accessories have primarily yielded strontium isotope values which are indicative of a raw material of local provenance. However, the chequered textile is characterized by a strontium isotope value implying a non-local provenance. Altogether, the strontium isotopic evidence presented via the human remains and the textiles shows an unexpected complexity in the mobility of the Haraldskær Woman, and challenges previous held assumptions on why these people ended in the bogs as well as hypotheses about their status in Early Iron Age society. For example, the high quality of the textiles of the Haraldskær Woman indicates that she was of high status, and the strontium isotope analyses reveal that she had access to wool or textiles produced outside the present Danish area (excluding Bornholm). Additionally, she had been on a long journey probably to more southern parts of Europe, shortly before her return to Denmark where she died soon after.

The Danish Pre-Roman Iron Age has often been characterized by scholars as a period where Scandinavia became marginal in relation to other European areas, as the development that Central and especially Southern Europe went through bypassed it (Jensen, 2003). In contrast to the preceding Bronze Age society, the Early Iron Age society was characterized by a much lower import of high value goods, representing a less stratified society and possibly a higher sense of communal feeling. However, there is still some evidence of contact between southern Scandinavia and Central Europe in the centuries before the Common Era, and an indirect influence from the Celtic areas may still be observed in the practice of sacrificing weapons in lakes and bogs as known from the Danish Hjortspring and Krogbølle finds, dated between 350-250 BC. Furthermore, it is likely that some of the old exchange and trading networks were maintained, and the Haraldskær Woman and her textiles definitely support this assumption (Bergfjord *et al.*, 2012; Frei *et al.*, 2015). The unusual manner and environment in which bog bodies from this period were buried/placed instead of being cremated and buried in local communal cemeteries indicate that the bog people had a special social position. The trauma observed, sometimes leading to death, that some of the bog bodies were exposed to, has often been interpreted as a kind of social punishment (Van er Sanden, 1996). Yet, a recent study of the bog bodies indicates that violence, and especially post-mortem violence, could have been an integral part of sacrificial rituals, similar to those observed on sacrificed weapons (Möller-Wiering, 2011; Ravn, 2010). Moreover, it is important to be aware that some earlier observed evidence of violence and traumas could have occurred subsequent to death, e.g. by the turf diggers when the bodies were discovered (Lynnerup, 2007). Nevertheless, their unusual location in the bog makes a sacrificial nature most likely, especially when the large number of other artefacts unearthed from the Danish bogs is taken into consideration (Jansen, 2003). Yet, it cannot be excluded that other bog bodies should be interpreted as burials, and the relative large number of the Danish bog bodies (34 %) wearing or wrapped in textiles and different skin materials that could be interpreted as grave goods definitely support this interpretation (Hald, 1980; Ravn, 2010).

The new information about the Haraldskær Woman that can be extracted on the basis of the strontium isotope analyses of human remains and textiles thus amplify our knowledge of the bog bodies, their social status and way of living. Furthermore, the analysis supports the results from earlier strontium isotope analyses of other Pre-Roman Iron Age textiles, like those found in the Huldremose bog in Denmark, revealing that, in this period, wool of both local and non-local provenance was used in textile production (Frei, 2009b). At present it is difficult to assess where exactly the Haraldskær Woman stayed shortly before her death, as this requires the establishment of broader and more detailed European strontium isotope isoscapes. In the future, continued investigations will hopefully provide better and more detailed databases that permit us to re-assess this question. Until then, the interdisciplinary study of the Haraldskær Woman and her textiles can be used to demonstrate the complexity and mobility in prehistoric human life and sheds

new light on the choices and rituals that led to the depositions of human remains in the North European bogs.

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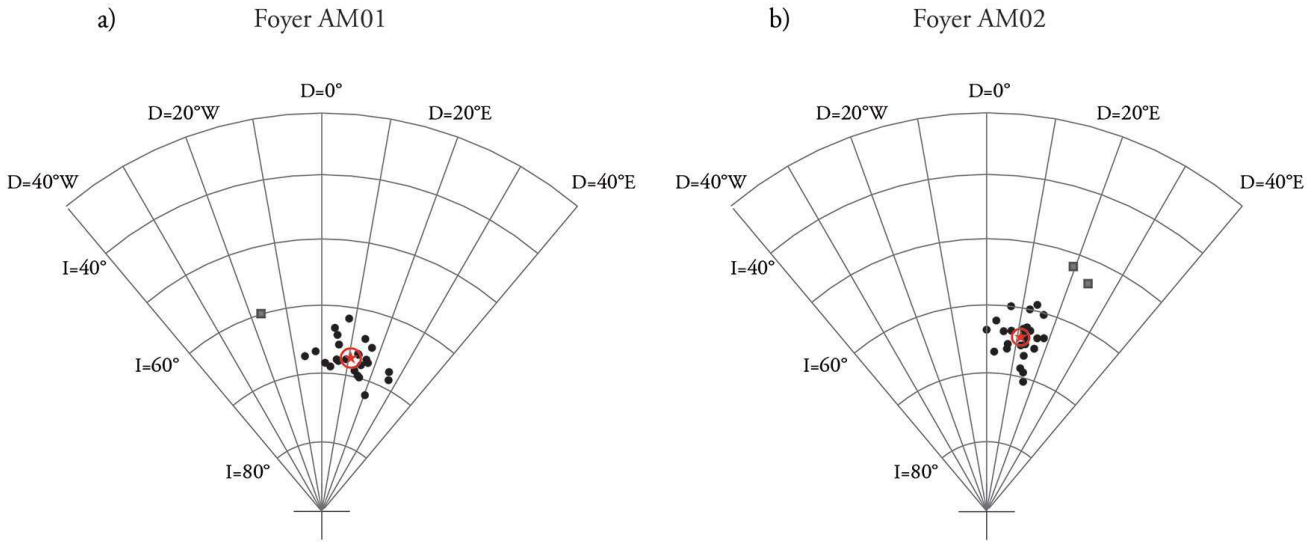

Figure 3 : Benoît Rouzeau *et al.*, L'activité métallurgique à l'abbaye de Morimond (Haute-Marne) : nouvel éclairage de la fouille à partir de l'analyse archéomagnétique de deux foyers (p. 40)

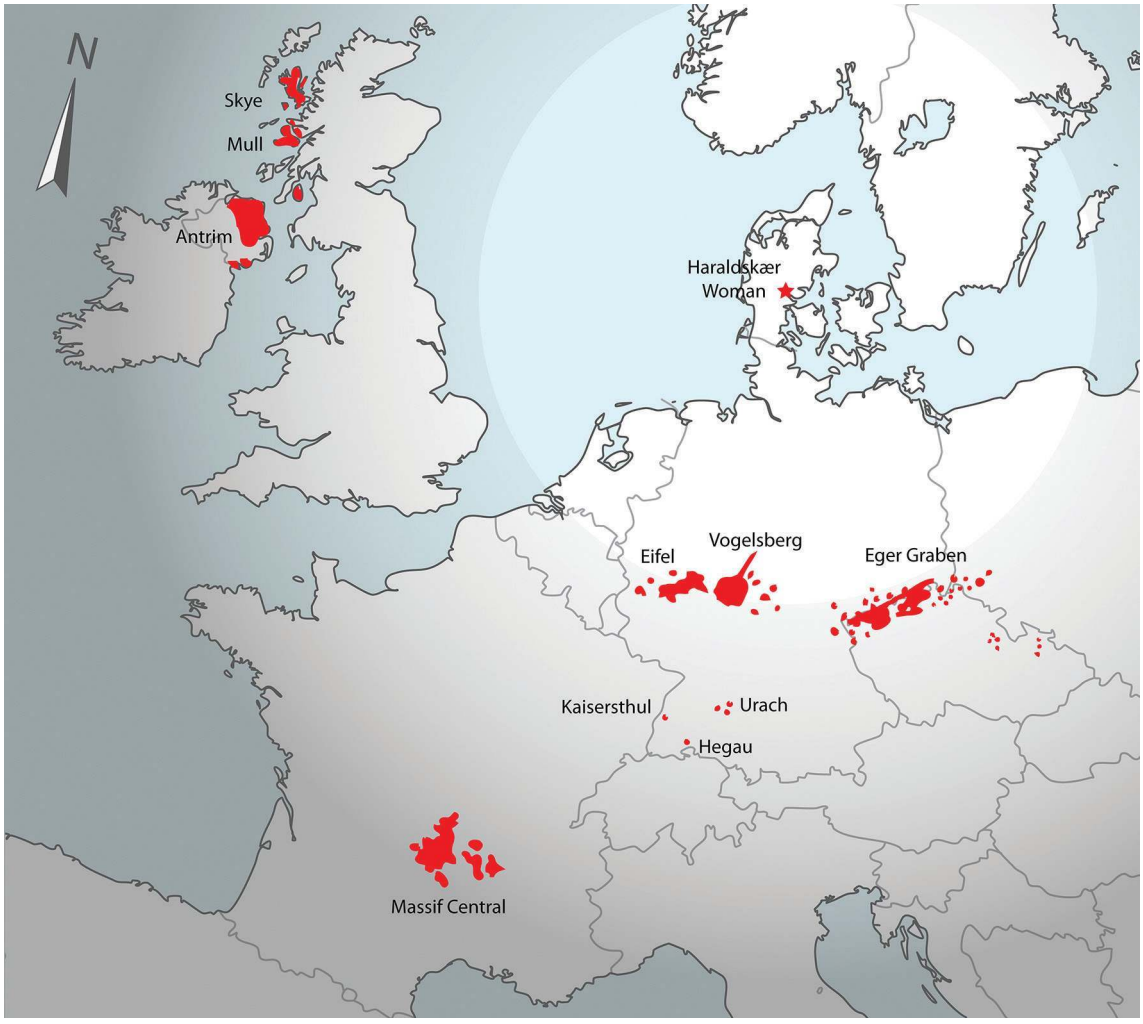

Figure 2 : Karin Margarita Frei *et al.*, Strontium Isotope Investigations of the Haraldskær Woman – A Complex Record of Various Tissues (p. 97)

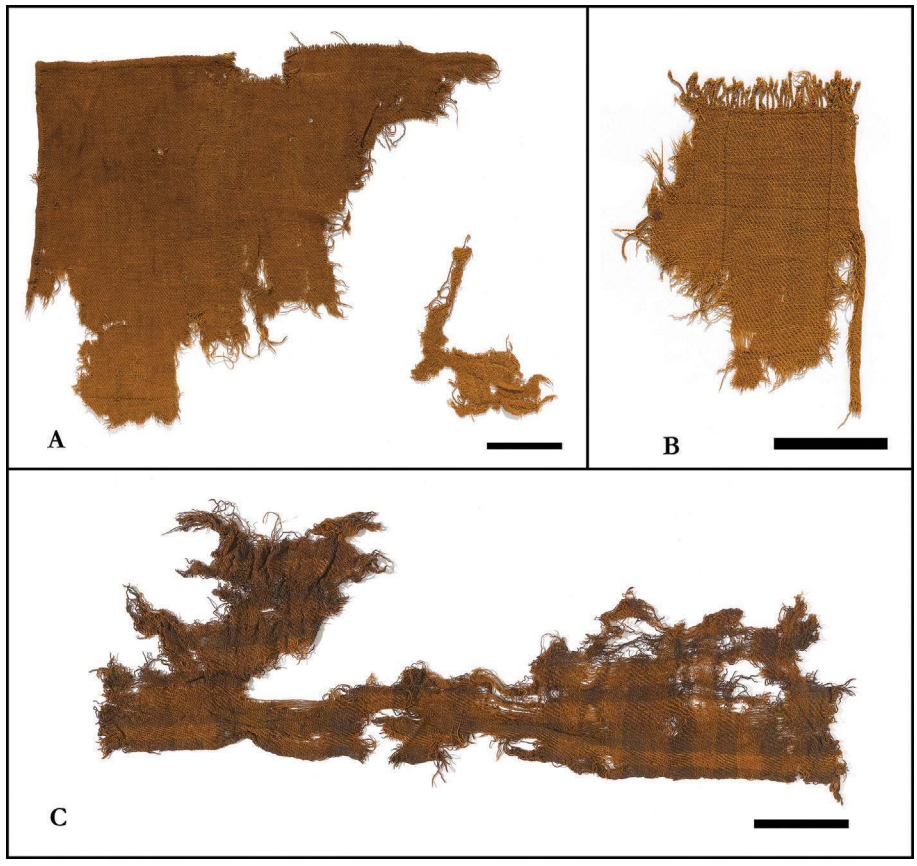

Figure 3 : Karin Margarita Frei *et al.*, Strontium Isotope Investigations of the Haraldskær Woman – A Complex Record of Various Tissues (p. 97)

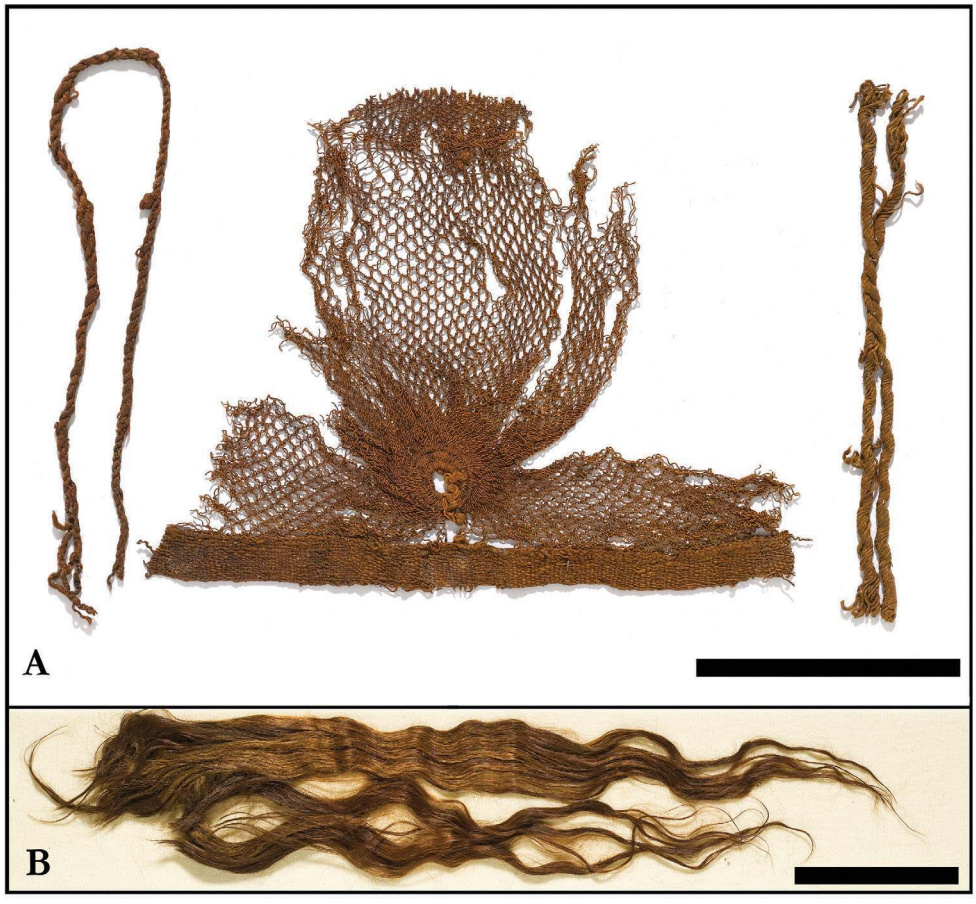

Figure 4 : Karin Margarita Frei *et al.*, Strontium Isotope Investigations of the Haraldskær Woman – A Complex Record of Various Tissues (p. 98)