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Dorset, Norse, or Thule? Technological transfers, marine mammal contamination, and AMS dating of spun yarn and textiles from the Eastern Canadian Arctic

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ABSTRACT

Yarn and textiles recovered from prehistoric Dorset and Thule culture sites in the Eastern Canadian Arctic have raised questions about the extent and timing of indigenous and Norse interaction in the New World, whether the yarn represents technological transfers between Greenland's Norse settlers and the Dorset, or whether these Indigenous Arctic groups had independent fiber technologies before contact with Europeans. However, the extensive use of marine mammals in northern cultural contexts, and the penetration of oils from these animals' tissues into datable terrestrial materials, has posed general problems for reliably dating sites in the Arctic and has raised questions specifically about previous efforts to date these fiber objects. In this paper, we use a recently developed protocol for removing marine mammal organic contaminants entirely from radiocarbon samples, making AMS dating possible and reliable for Arctic research. This study uses those protocols to directly date a suite of woven and spun animal fiber artifacts from five Dorset and Thule archaeological sites in the eastern Canadian Arctic. Directly dating these artifacts with marine mammal oils removed helps to answer questions about Norse contact with Dorset and Thule communities, sheds new light on the topic of indigenous fiber technologies in the North, and raises new questions about European contacts with the people of the North American Arctic prior to sustained efforts at colonization after the 18th century.

1. Introduction

Spun yarn and textiles woven from wool and hair, from contexts pre-dating the early modern period's sustained episodes of European exploration and colonization, have been recovered from a number of sites scattered across the eastern fringe of the North American Arctic. The sites where *spun yarn* has been found – on parts of coastal Baffin Island, Ellesmere Island, and Labrador that face Greenland – led Sutherland (2000, 2002, 2009) to suggest that these could represent evidence of technological transfers between the Norse settlers of the North Atlantic and the indigenous Dorset people of the eastern Canadian Arctic. Others (Holtved, 1944; Schledermann, 1978, 1980; McGhee, 1984; McCullough, 1989; Gulløv, 2008) have similarly argued that *woven textiles* recovered from northern contexts in Arctic Canada and Greenland represent evidence of direct or indirect contact between the Norse and early Thule culture Inuit ancestors moving eastward from homelands in northern Alaska and across the Canadian Arctic to Greenland. These textile objects, therefore, may potentially bear important witness to incidents and processes of interaction that were linked to the earliest contacts between the populations of the Old and New Worlds. Alternatively, however, some or all of these objects may provide new information on the dynamic nature of North American Arctic people as innovators of fiber-based technologies or on the contexts within which new materials are accepted and new technological complexes are adopted across cultural borders.

When the Norse expanded across the North Atlantic, they brought with them a well-developed complex of spinning and weaving technologies, as well as the animals (primarily sheep and goats) whose wool and hair they spun and wove using warp-weighted looms and yarn spun with drop spindles (Hayeur Smith, 2014a, 2014b; 2015; Rogers, 1989; Østergård, 2004, 2005). Occasionally, Greenlandic Norse women integrated hair from Arctic species, such as caribou (*Rangifer tarandus*) and Arctic hare (*Lepus*

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arcticus), into their yarn, but elsewhere domesticates provided the raw materials (Østergård, 2004; Walton Rogers, 1989; Sinding et al., 2015; Sinding et al., 2017). Archaeological evidence (including more than 9000 textile fragments analyzed by Hayeur Smith), indicates that spinning and weaving was practiced at nearly every excavated Norse farm in Iceland and Greenland, while the recovery of a soapstone spindle whorl at L'Anse aux Meadows, Newfoundland, implies that yarn production was significant enough to be part of the activities undertaken even at this farthest west known Viking Age Norse exploration base (Wallace, 2003).

From the 1970s onward, a small number of spun yarn pieces, plied but not woven, were recovered at a number of Middle and Late Dorset culture sites on Baffin Island, including Nanook and Tanfield (Maxwell, 1973: 205; 1985: 206), Willows Island 4 (Odess, 1998: 429), Nunguvik (Mary-Rousselière, 2002: Plate 12b; 2009), as well as at Avayalik Island, Labrador (Fitzhugh et al., 2006), and Cape Ray, Newfoundland (Linnamae (1975: 174–175) (Fig. 1). These initially elicited little attention; however, the recovery of woven woolen cloth along with other objects of Norse material culture at the Thule culture Skraeling Island site, in the Canadian High Arctic (Schledermann, 1980: Figure 9), the recovery of similar cloth from the Early Thule Ruin Island site in northwestern Greenland (Holtved, 1944; Østergård, 2004), and an apparent Thule carving of a Norseman from the Okivilialuk site on southern Baffin Island (Sabo and Sabo, 1978; Sabo and Jacobs, 1980), raised important questions about the extent and timing of interactions between indigenous Dorset communities, Thule Inuit pioneers, and voyagers from Greenland's medieval Norse colonies (McGhee, 1984).

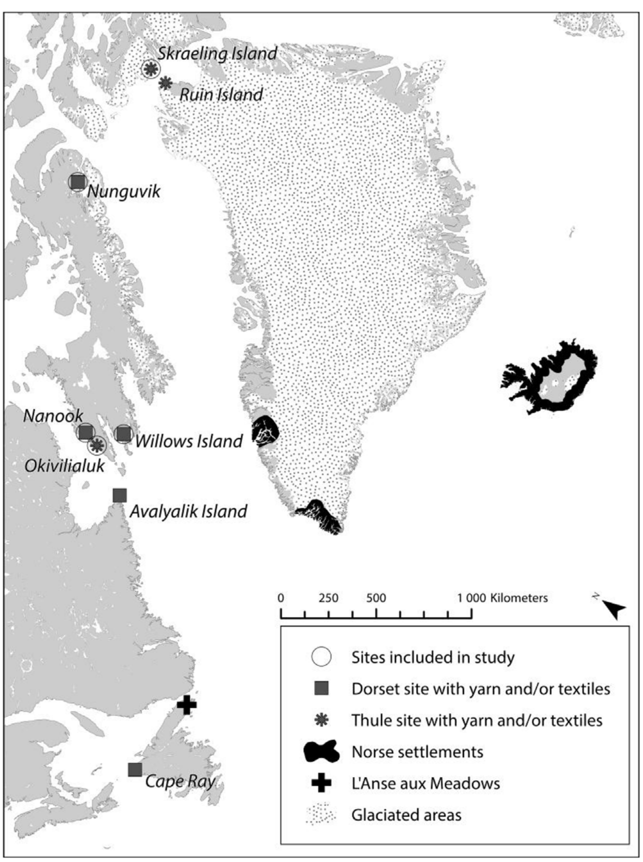

Fig. 1. Dorset and Thule sites with archaeologically documented yarn or textiles and locations of Norse settlements in the western North Atlantic. Map by Johan Eilertsen Arntzen, UiT.

Somewhat later, Walton Rogers (1998, 2004 in Østergård) used optical (microscopic) fiber identification to identify hairs woven into several Greenlandic Norse textiles from the site of GUS (Gården Under Sandet) as having come from a range of North American subarctic and Arctic wild species, including bison (*Bison bison*), brown bear (*Ursus arctos*), and black bear (*Ursus americanus*), although recently these identifications have been questioned by Sinding et al. (2015) on the basis of aDNA analyses. On similar bases, Walton Rogers suggested that domesticated goat hairs were attached to a few pieces of Dorset yarn from Baffin Island. This led Sutherland (2000, 2002, 2009), nearly two decades ago, to propose the intriguing hypothesis that the interchange of these fibers and the production of spun threads in Dorset contexts could reflect techniques taught by the Norse to local Dorset people in the context of long-term interactions during the period of the Norse Greenland colonies' existence, 1000–1450 AD. If the sites where spun yarn was found were Norse trading bases or the residential camps of Dorset Paleoeskimos who had learned to spin and perhaps weave fibers through sustained contact with Norse traders (Sutherland, 2000, 2002, 2009), these would be critically important places for understanding the duration, spatial extent, and nature of Norse contact with indigenous North American cultures.

Fitzhugh et al. (2006) and others (Odess and Alix, 2004; Park, 2004) noted, however, that the radiocarbon dates on spun yarn – often referred to as "cordage" – and related materials from the sites of Nunguvik, Nanook, Willows Island 4, and Avayalik Island – were generally centuries older than the period of Norse exploration in the western Atlantic. This has led to three contrasting arguments to explain these dates.

First, those who argue that the cordage pre-dates the presence of the Norse in the North Atlantic contend that the yarn represents an otherwise unknown, indigenous Dorset fiber technology (Odess and Alix, 2004; Park, 2004; Fitzhugh et al., 2006). Second, Sutherland (2002, 2009) has suggested that the dates may be accurate and that the yarn could be the product of otherwise unknown European contacts with Dorset communities during the 7th-8th centuries AD. Third, Sutherland (2000, 2002, 2009) also argued that the dates may be errantly old through contamination by "older carbon that is not likely to have been temporally associated with the manufacture of the cordage". Citing McGhee (2000, 188) – who identified four factors producing inaccurate radiocarbon ages in the Arctic: (1) broad age ranges from standard radiocarbon dates due to natural fluctuations in atmospheric radiocarbon levels, (2) use of diverse materials and mixed samples for radiocarbon dating, (3) potential release of ancient carbon from melting permafrost, and (4) the presence of sea mammal oil contamination – Sutherland concluded that it "is not considered useful to publish the dates obtained" (Sutherland, 2009, 294).

The question of *sample contamination* is an enduring one for dating archaeological sites and objects, not only in the Arctic, and is especially vexing with these materials. As Jull et al. (1996), Possnert and Edgren (1997), Rageth (2004) and Hajdas et al. (2014) have argued, and as Hayeur Smith (2014a, 2014b, 2015; Hayeur Smith et al., 2016) has demonstrated specifically for the North Atlantic region, textiles made from the hair and wool of terrestrial herbivores, produced and shed over spans of 1–3 years, should be ideal materials for high-resolution dating. The most likely ways that such materials can become contaminated with ancient carbon are either through the use of petrochemical products in post-excavation conservation treatments (Hayeur Smith et al., 2016) or through in-situ contamination with marine mammal oils during use or after deposition.

In this paper we report an effort to date fibers and textiles in the Canadian Museum of History's permanent collection from archaeological sites in the Eastern Canadian Arctic using a new pre-treatment method developed by Nilsen, in collaboration with Beta Analytic Laboratories, for removing marine mammal contamination from archaeologically recovered materials. By focusing on high-precision AMS dates run on a single class of material (hair/wool) with short growth-spans, and removing marine mammal contamination, we shed light on the nature of early European contact with Indigenous North American Arctic communities and the question of those communities' independent production, use, or adoption of fiber technologies.

2. Arctic chronologies and sea mammal contamination

The expansion of human populations across the Arctic was fueled by the development of techniques for hunting marine mammals and exploiting their fat, bones, meat, skin, and baleen. In North America, the development of toggling harpoons and associated technological innovations linked to marine mammal hunting led to the expansion of Arctic Small Tool tradition communities across the Arctic from Alaska to Greenland ~3000 BC (Raghavan et al., 2014). Recent analyses of early Arctic Small Tool tradition colonists' material culture, lipid biomarkers, and analyses of aDNA from well-contextualized samples of permafrost-preserved sediments imply high levels of reliance upon marine mammals, including whales, for subsistence as well as for heating residential spaces (Buonasera et al., 2015; Seersholm et al., 2016). Over the span of nearly 3000 years of local adaptation and interaction, these communities developed, across the eastern North American Arctic, into regional phases of the Dorset cultural tradition (Early Dorset, ca. ~800 BC-0 AD; Middle Dorset, ca. 0–600/800 AD; Late Dorset, ca. 600/800–1300 AD). Marine mammal hunting remained a consistent element in this continuum.

Subsequent developments during the first millennium AD, around the Bering Strait, led to another round of technological innovations linked to hunting whales and another wave of migration through which Thule phase ancestral Inuit expanded from Alaska across the Canadian Arctic in one or possibly two pulses, replacing or absorbing Dorset communities during the 12th-13th centuries (Mathiassen, 1927; Maxwell, 1985; Dumond, 1987; Harritt, 1995; Mason, 1998; Friesen, 2004). Sea mammal hunting was integral to the subsistence efforts and culture of these ancestral Inuit communities and remains so for their descendants today.

To the east, in Scandinavia, the use of marine mammal products, including rendering marine mammal fat for oil, intensified after 600 AD (Nilsen, 2016a, 2017). The expansion of Norse colonies across the North Atlantic has also been tied, in part, to the colonists' search for walruses and their ivory (Roesdahl, 2003; Enghoff, 2003; Vésteinsson et al., 2002; Dugmore et al., 2007; Keller, 2010; Einarsson, 2011; Frei et al., 2015). While the Norse Greenland colonies remained most heavily invested in the ivory trade through the Middle Ages, all of the North Atlantic Norse colonies engaged at some level with marine mammal hunting and the consumption of marine mammal flesh, fat, and oil (McGovern, 1985; Enghoff, 2003; McGovern et al., 2007; Perdikaris and McGovern, 2007; Keller, 2010). While pastoral farming focused on European domesticated livestock was an essential foundation for these Norse colonies' economic systems, marine mammals played important roles, especially in Greenlandic Norse subsistence strategies, leading to the possibility of marine mammal oil/fat contamination even on inland farms (Nelson et al., 2012a).

Throughout the Arctic, and especially on coastal sites, the intensive use of marine mammal products for subsistence, heating, lighting, water-proofing, and as raw materials for producing high status objects has been argued to have potentially significant implications for dating sites and objects accurately (Morrison, 1983, 1989; Nilsen, 2017; Park, 1994; McGhee, 2000, 2009; Anderson and Freeburg, 2013; Ledger et al., 2016). The potential for marine mammal tissues to present problems in dating Arctic archaeological sites has been recognized since the 1970s and early 1980s, when McGhee, Tuck, and Arundale brought attention to problems with using marine mammal bones and tissues for radiocarbon dating in the Eastern North American Arctic (McGhee and Tuck, 1976; Arundale, 1981). Soon afterwards, Morrison (1983, 206; 1989) and Park (1994, 30-31) suggested that marine mammal oils could easily penetrate sediments onto which they spilled or spread, to coat or be absorbed by organic materials lying on or in those matrices. Even if not visibly present, the possible admixture of marine mammal oil into dated samples has, since then, been considered sufficient reason for archaeologists to reject as many as half the ”errant“ radiocarbon dates from specific Arctic sites on the suspicion of contamination from marine mammal oils (e.g. Mason and Ludwig, 1990; Dumond and Griffin, 2002; Darwent and Darwent, 2016: 376, 387). Although Ledger et al. (2016) caution that the “marine mammal oil effect” has not yet been empirically demonstrated, work by Buonasera et al. (2015) and Seersholm et al. (2016) have documented the presence of sea mammal oil in archaeological sediments from Arctic maritime sites up to 4500 years old, and in Sweden organic residues from marine mammals have been identified as contaminants of a 10,000 year old occupation layer at Tyrestad (Petterson and Wikell, 2013; Isaksson, 2010), demonstrating that such contamination can be pervasive in sites where marine mammals were hunted or harvested and can endure for millennia.

Marine mammals incorporate carbon from both marine and atmospheric reservoirs into bodily tissues from the food and water they consume and the air that they breathe. The marine reservoir incorporates both “old” carbon accumulated over long periods of time through surface atmospheric mixing and “ancient carbon” derived from deep oceanic sediments, decaying carbonate rocks, hydrothermal vents, and other sources. Consequently, radiocarbon dates on marine organisms can be hundreds of years older than contemporary terrestrial organic samples (Craig, 1957; Mangerud, 1972; Tauber, 1979; Olsson, 1980; Taylor, 1995).

As the oceans are relatively poorly mixed due to local currents, deep-water upwelling, submarine topography, prevailing wind currents, sea ice cover, and stratigraphic separation within the water column, “old” carbon is unevenly distributed within the oceans. Consequently, C14 residence times vary widely by geographic locations and depths, requiring the development of regional marine reservoir offsets, **Δ**R, to bring radiocarbon dates from marine organisms into alignment with those obtained from terrestrial materials (Stuiver and Braziunas, 1993; Stuiver et al., 1986; Reimer and Reimer, 2001; Owen, 2002; Mangerud et al., 2006; Austin et al., 2006; Reimer et al., 2009, 2013; Coulthard et al., 2010). In the North, cold polar waters may exhibit reservoir ages of 400 to 800 radiocarbon years, or more (Dumond and Griffin, 2002; Ascough et al., 2005, 2006; 2007, 2009).

On sites where marine mammals were processed or their by-products were discarded, the potential therefore exists for contamination by marine mammal oils and fat – produced during the transformation of blubber to liquids using high or low temperatures (Nilsen, 2016b) or through the decomposition of solid tissues (blubber, skin, bones) – to introduce marine reservoir effects into radiocarbon dates received from any organic materials, including terrestrial mammal or vegetal tissues. The scale of these effects may vary not only by location and the **Δ**R value for the local marine reservoir, but also by the amount of marine mammal oil present in the sample. Without knowing the amount of marine mammal oil contaminant present, correcting for reservoir effects may be, at best, a guessing game. The most common and most obvious effects of marine mammal contamination are to produce radiocarbon dates older than the actual use or production of the organic sample being dated. However, re-use and reoccupation of sites may also lead to samples being contaminated by younger marine mammal oils soaking into older cultural sediments. Across the Arctic, where most sites are shallow, reoccupation episodes thousands of years apart may be separated from one another by mere centimeters of soil development. Sea mammal oil from relatively recent occupations penetrating earlier deposits may therefore produce younger dates than expected for samples from underlying, older components.

Given the complexities of calculating the amount of marine mammal oil contamination in any given sample, as well as its associated **Δ**R correction factor, most Arctic archaeologists have given up on running dates on marine mammal bones or on samples that might have been contaminated with marine mammal oils and have focused instead on dating samples of material from short-lived terrestrial plant and animal species (Arundale, 1981; McGhee, 2000, 2009), including hair and wool (Hayeur Smith et al., 2016). However, if marine mammal oils could have penetrated sediments on prehistoric archaeological sites as frequently, as ubiquitously, and over as long time spans as recent aDNA and GC-MS analyses of Arctic sediments suggest it may have (Heron et al., 2010; Buonasera et al., 2015; Seersholm et al., 2016), the potential for marine mammal oil contamination of even these terrestrial materials should raise significant concerns. Given these uncertainties, accurately dating materials from many Arctic coastal sites may require a more direct strategy to ensure confidence – the direct removal of potential marine mammal oil from samples to be dated through pre-treatment.

3. Developing a protocol for marine mammal oil extraction from archaeological materials

Concerns for documenting the presence of marine mammal oil contamination at terrestrial sites and structures in Arctic Norway (Heron et al., 2010, Petterson and Wikell, 2013), and especially evaluating C14 dates from contexts that may have been exposed to marine organics in a specific category of “slab lined pits” (Nilsen, 2016a, 2016b, 2017), led Nilsen to undertake a pilot study utilising a few dated samples from the Arctic and existing solvent extraction protocols to determine whether marine mammal oil contamination could be removed from archaeological samples by pre-treatment. The results of that pilot study, presented by Nilsen (2017), were inconclusive but suggestive.

As a result, a new protocol was developed in collaboration with Beta Analytic Testing Laboratory. In 2017, Nilsen sent experimentally produced marine mammal oils (minke whale [*Balaenoptera acutorostrata*] and harp seal [*Pagophilus groenlandicus*], see Nilsen, 2016b for descriptions of processing methods) to Beta Analytic as a methodical development prior to re-dating a new series of samples from slab-lined pits. These experimentally produced modern marine mammal oils, at 104 pMC (percent Modern Carbon), were then infused into a sample of wood of known age (41,000–44,000 BP, ~0.5 pMC) at 100 °C for several days, under vacuum, to ensure that the marine mammal oil penetrated into the pores of the wood. The sample of known age, once infused with marine mammal oil, was then treated according to different pre-treatment protocols to evaluate the efficiencies of extraction methods when applied to organic samples.

Treating the infused marine mammal oil sample with a standard acid/alkali/acid pre-treatment provided a radiocarbon age of 15,610 ± 50 BP, with 13% of the oil-based carbon remaining in the sample (Darden Hood, pers. comm.), demonstrating that the standard pre-treatment, alone, was insufficient to extract the added marine mammal oils.

Beta then proceeded with two further tests on samples of the same marine-mammal-oil-infused ancient wood matrix: The first of these included solvent extraction with acetone (6 h) followed by 100% alcohol (6 h), and then cellulose extraction with (sodium chlorite/acid)/alkali/acid. The resulting C14 age of 42,550 ± 630 BP matched the known age of the wood prior to any addition of experimental marine mammal oils and indicated successful removal of all experimentally introduced marine organics.

Finally, an extended extraction using acetone alone (without the alcohol step) was applied. This last run, pre-treated with acetone solvent extraction (72 h) and then the (sodium chlorite/acid)/alkali/acid cellulose extraction step, produced a result of 42,720 ± 630, indicating that a Soxhlet still extraction step with a highly extended acetone extraction was also sufficient to remove the infused marine mammal oil carbon when followed by cellulose extraction/alkali pre-treatments.

It is important to note that the protocol was successful when it was used on samples in which the marine organic material was not burnt into the wood. Additional tests determined that when the dated materials are a mix of organic materials of terrestrial and marine origin that were charred together in the archaeological context, it may not be possible to chemically extract the marine infusion (Nilsen, in prep). However, the yarn and textiles dated in this study have not been charred, and hence the protocol should be considered viable.

4. Materials and sampling methods

In the winter of 2017, Hayeur Smith sampled objects of spun cordage and textiles in the Canadian Museum of History's permanent collections from Rousselière's 1967–89 excavations (1976, 2002) at the Nunguvik site; Maxwell's (1973, 1980) and Arundale's (1976) investigations in the early 1970s at the Nanook site; and excavations undertaken in the 1990s by Odess (1996, 1998) at Willows Island 4. Woven woolen textile fragments were also sampled from Schledermann's excavations at Skraeling Island (Schledermann, 1980; McCullough, 1989) and from Maxwell and Sabo's investigations at Okivilialuk on southern Baffin Island (Sabo and Sabo, 1978; Sabo and Jacobs, 1980).[1] This sampling program was undertaken with support and permission from the Canadian Museum of History to work on the permanent collections as part of Hayeur Smith's ongoing, multi-year project documenting textile production, trade, and use across the North Atlantic.

Hayeur Smith recorded 181 fragments of spun sinew, spun yarn, woven textiles, and raw wool of unknown species in the Canadian Museum of History's permanent collections from these excavations of the 1960s-1990s. Samples of *yarn*, approximately 1 cm in length, were removed from 12 items by Hayeur Smith with a conservator from the Canadian Museum of History (Fig. 2). These were sub-sampled, with part of each sent to Beta Analytic for AMS dating. Microscopic examination of fibers in the intact yarn objects, also done while at the Canadian Museum of History, supports findings reported by Fitzhugh et al. (2006) for similar plied yarns from Avayalik Island, that the wool and/or hair used to ply the yarn from Dorset sites came from musk ox (*Ovibos moschatus*), Arctic hare, or a combination of the two. In contrast, the woven textiles from Skraeling Island and Okivilialuk all appear to have been woven from sheep's wool. We do not consider these initial observations definitive, however, without further analyses, especially in light of recently published findings by Sinding et al. (2015, 2017) comparing Walton Rogers' microscopic identifications with the findings of aDNA analyses on fibers from the Norse Greenlandic site GUS (Gården Under Sandet). Consequently, aDNA analyses of subsamples from these same fragments of yarn are currently in process and will be described in forthcoming publications.

[1] In keeping with the regulations issued by the government of Nunavut, no samples recovered in excavations undertaken by Sutherland's on-going Helluland project were examined or sampled as a part of this investigation.

Fig. 2. Two examples of Dorset culture spun yarn from the Nanook Site (KdDq-9): 4384 (above) and 4268 (below). Photograph by M. Hayeur Smith.

Based on its diagnostic artifact assemblage and Arundale's (1976, 1981) analyses of its radiocarbon dates, Maxwell interpreted Nanook (KdDq-9) as a Middle Dorset site occupied from 420–270 BC through 123 AD (Maxwell, 1985: 201). Sutherland returned to Nanook several decades later to explore the possibility that it was later a site of Norse occupation and possible interaction with Late Dorset people (Sutherland, 2000, 2002, 2009).

The Nunguvik site (PgHb-1) has Middle through Late Dorset, as well as Thule, occupations (Mary-Rousselière, 1976, 1979, 2002). Two pieces of spun yarn were recovered from Nunguvik's House 73, where eleven standard radiocarbon dates run by Rousselière on botanical materials and caribou bone spanned a remarkably long range: calBC 200-1400 calAD. Three of his dates clustered in the first half of the first millennium AD, one (SI-1615) was a clear outlier at calAD 1200-1400, and seven clustered around calAD 425-800 (Rousselière, 2002: Table 6). Sutherland felt that some of the artifacts from Nunguvik, including the spun yarn, could reflect later interaction with medieval Norse Greenlanders, yet acknowledged that the five additional AMS dates she ran on yarn, caribou bone, antler, and "heather" from Nunguvik's House 73 still fell within the span calAD 615-860, or the transition from Middle to Late Dorset (Sutherland, 2002: 118).

Willows Island 4 (KeDe-14) is a stratified Dorset site in southeastern Baffin Island's Frobisher Bay. Nine standard and two AMS dates run on driftwood, willow charcoal, twigs, and moss by Odess (1998) document occupations spanning the period 350 calBC – 650 calAD. Spun musk ox hair yarn was recovered at Willows Island 4 from a stratum bracketed by three standard radiocarbon dates. Willow (*Salix* spp.) and crowberry (*Empetrum nigrum*) twigs from an immediately underlying stratum were dated to calAD 90-400 (Beta-70917); crowberry twigs from the stratum with the yarn provided a date of calAD 60-400 (Beta-61071); and crowberry and willow twigs from an overlying stratum dated to calAD 400-689 (Odess, 1998: Table 1; Odess and Alix, 2004). However, a single AMS date run on unmixed willow charcoal from the stratum with the yarn was somewhat older (calBC 165-calAD 85, Beta-83251). All of these dates are consistent with artifacts from the site implying a Dorset occupation early in the first millennium AD.

Woven textiles were only identified in the Canadian Museum of History's collections from the Skraeling Island (SfFk-4) and Okivilialuk (KeDq-7) sites. Skraeling Island is an early Thule, Ruin Island phase (1200-1300 AD) site from the Canadian High Arctic (Ellesmere Island) that produced, in addition to a full Thule culture assemblage, a wide range of Norse material culture including chainmail, an oak carpenter's plane, boat rivets, and two pieces of woven woolen cloth. Standard radiocarbon dates and typology suggest the site was occupied in the late-13th or early 14th centuries (Schledermann, 1980; McCullough, 1989). Both pieces of cloth from House Ruin 15 were unplied 2/2 twills: the larger was spun Z/S[2] with a thread count of 9 warp to 6 weft threads; the smaller patch was Z/S-spun with a thread count of 8/6.

The Okivilialuk site (KeDq-7) was reported to have both Thule (12th-13th century) and Historic (19th-20th century) components dated on the basis of stylistic cross-dating and assemblage composition (Sabo and Jacobs, 1980). At least sixteen pieces of cloth representing at least four different cloth types or weaves were recovered from the lower component of House 8. Sabo and Jacobs (1980, 40) attributed these to the site's Thule component, which also produced a carved wooden figure that has been interpreted as an Inuit representation of a Norseman (Sabo and Sabo, 1978; McGhee, 1984). Regarding this figurine and possible contacts between the early Inuit and the Norse, Sabo and Sabo (1978:40) noted, "Other potential sources of information bearing on the question of trade include the identification of cloth fragments from Thule contexts at Okivilialuk... accurate radiocarbon dating of these assemblages is highly desirable."

The textiles from Okivilialuk include large fragments, some more than 20 cm across. The two that we dated were both twills: one (#77) was woven with Z spin in one system (poor preservation made it impossible to characterize the other system); while the other (#75) was a 2/2 twill woven with probable plied[3] yarns in both systems, spun Z2S/S2Z, and with 15 threads per centimeter in both warp and weft. Such balanced weaves are uncommon in Norse textiles from medieval Iceland or Greenland, which tend to be warp-dominant (Bender Jørgensen, 1992) or weft-dominant in Greenland after ca. 1300 AD (Hayeur Smith, 2014a).

5. Testing the protocol on archaeological materials

To test the efficacy of the marine mammal oil extraction pre-treatment on archaeological samples, a thread (KdDq-9 4797 [3/3]) from Maxwell's excavations at Nanook was subsampled: one portion (Beta-463257) received a standard acid/alkali/acid pretreatment prior to dating, while the other (Beta-463258) received the full acetone/alcohol, cellulose, and acid/alkali/acid marine mammal oil extraction protocol.

The pretreatment process for marine mammal oil extraction involved a series of rinses with hot AR Acetone (8 h each) until no color change (if any) was seen, after which the samples were rinsed with Ethyl Alcohol (8 h each), again until no color changes were observed.

The samples were then put through a standard acid/alkali/acid pretreatment series at 90 °C to remove carbonates and soluble humic acids. Initial acid was applied (0.1 N HCl) and no samples showed any carbonate reaction. After 30 min the samples were rinsed to neutral. For the first alkali application at 2% (50/50 wt NaOH) the samples soaked for 2 h. The 2% alkali was then changed and a second alkali application

[2] The terms Z-spin and S-spin refer to whether yarn was spun clockwise or counter-clockwise, respectively. I-spin refers to no spin.

[3] Plying is a term used to refer to multiple "single" spun yarns that are twisted together to create a thicker strand or cord. Plying can be done with two yarns, three, four and so on.

Table 1
List of samples dated.

Beta ID	Site	Museum ID	Artifact	Fiber	Final Spin	Weave	Spin	Thread count
469299	KdDq-9	4797 (1/3)	Plied yarn	Musk Ox?	Z2S	–	–	–
463258[b]	KdDq-9	4797 (3/3)	Plied yarn	Musk Ox?	Z2S	–	–	–
463257[b]	KdDq-9	4797 (3/3)	Plied yarn	Musk Ox	Z2S	–	–	–
469300	KdDq-9	747	Plied yarn	Musk Ox?	Z2S	–	–	–
469305	KdDq-9	4310	Plied yarn	Musk Ox?	Z2S	–	–	–
469306	KdDq-9	4440b	Plied sinew	Sinew	Z2S	–	–	–
[a]469301	PgHb-1	14765	Plied yarn	Arctic Hare/goat?[a]	Z2S	–	–	–
469307	PgHb-1	8424	Plied yarn	Arctic hare?	I2S	–	–	–
480200	KeDe-14	4879	Plied yarn	Musk Ox?	Z2S	–	–	–
469302	KeDq-7	75	Textile	Sheep	–	2/2 twill	Z2S/S2Z	15/15
469303	KeDq-7	77	Textile	Sheep	–	Weave unknown	Z/S	?/10
464733	SfFk-4	1234a	Textile	Sheep	–	2/2 twill	Z/S	9/6

[a] Identified as a mix of goat and Arctic hare by Walton Rogers (Sutherland, 2000).
[b] KdDq-9 4797 3/3 was split for analysis with and without marine mammal oil solvent extraction.

was repeated for 1 h until no color change was seen. The samples were then rinsed to neutral. The final acid application was applied (0.5–1.0 N HCL) for 30 min to ensure that any remaining alkali was neutralized. After 30 min they were rinsed to neutral with deionized water.

All of the samples received the full acid/alkali/acid pretreatment *and* the acetone/alcohol marine mammal oil extraction processing. However, one item (KdDq-9-3 4797 3/3) was split before the marine mammal oil extraction process; one subsample from this piece received *only* the acid/alkali/acid pretreatment, while the other subsample received *both* the acid/alkali/acid pretreatment and the full acetone/alcohol marine mammal oil extraction protocol. Finally, one sample (KdDq-9-3 4797 1/3, Beta-469299) was given an additional pre-treatment step using toluene and hexane in an effort to remove small black nodules present on the sample. The samples were then dried by desiccation and processed for AMS dating according to Beta Analytic's standard protocols and calibrated using OxCal v4.3.2 (Bronk Ramsey, 2017) and the r:5 IntCal13 atmospheric curve (Reimer et al., 2013).

The sample run without the marine mammal solvent extraction protocol produced a date far older than any other evidence for occupation at Nanook (3621-3356 calBC, Beta-463257) and older, in fact, than the earliest known evidence for human occupation of the Canadian Arctic (Tremayne and Rasic, 2016; Friesen, 2016). However, the portion that received the marine mammal oil extraction pretreatment returned a calibrated age of calAD 73-226 (Beta-463258), not only consistent with Maxwell and Arundale's estimates of the site's age based on their knowledge of its artifact assemblage but also with their radiocarbon dates on wood and twigs from the site (Fig. 3).

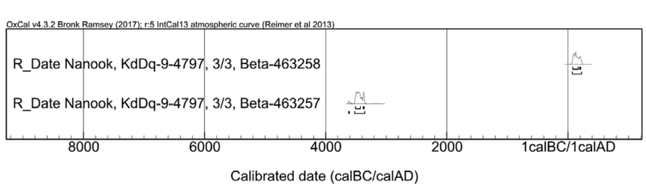

Fig. 3. Graphic comparison of dates obtained on Nanook site yarn fragment 4797 (3/3), with only acid/alkali/acid pretreatment (Beta-463257) and with the marine mammal oil extraction protocol (Beta-463258).

While pre-treatment of this sample for marine mammal oil extraction produced a result consistent with other evidence for the site's age, the difference between the dates received on this thread raises questions about the nature of the contamination responsible, since 3500 years is too great a span of time to be accounted for by marine reservoir effect alone. Two possible explanations for this difference may be accidental contamination of the sample with petrochemical compounds in the field or treatment of the yarn with conservation chemicals at the Canadian Museum of History. Conservators at the museum confirmed to Hayeur Smith that petrochemicals were commonly used in conservation at the museum until the early 1980s, but could not confirm they were used specifically on this, or other yarn from these sites (Marchand, pers. comm.). Sutherland (2009, 294) also reported finding offsets of up to 2000 years when comparing dates on two pieces of cordage from Nanook with dates that were run on paired samples of the residues that remained after the cordage itself had been chemically disintegrated. This strongly suggests the presence of contaminants from conservation, potentially in addition to marine mammal oils. Nevertheless, the marine mammal oil extraction protocol appears to have removed any such contaminants and brought the resulting AMS dates into alignment with prior estimates of the site's age.

As a second test of the method, we dated a sample of woven cloth from House 15 at Skraeling Island (SfFk-4 1234a) using the marine mammal oil extraction protocol to assess whether the pre-treatment process itself would affect the apparent age of a piece of cloth that had already been radiocarbon dated and whose age appeared to be accurate based on the known ages of other artifacts from the site. A standard C14 date had previously been obtained on this piece of cloth by Schledermann, along with another date on a piece of willow from the same house, where both Thule and Norse artifact types independently indicated a 13th-14th century age for the site. Schlederman's C14 dates on the willow twigs and cloth (GSC-2924, 700 ± 70, calAD 1192-1410 and GSC-3038, 700 ± 50, calAD 1223-1394, respectively) supported this estimate, suggesting that neither the cloth nor the twigs had been contaminated by marine mammal oils (Schledermann, 1980: 459).

Our new AMS date received on this cloth sample, after pretreatment with the marine mammal oil extraction protocol, replicated Schledermann's original C14 date with a tighter calibrated date range (Beta-464733, 720 ± 30, calAD 1246-1383, incorporating a 90.5% internal probability of calAD 1246-1302 within the 2-sigma range). The absence of any offset between Schledermann's standard date and the new AMS date confirms that this piece of cloth had not been saturated with marine mammal oils *and also* that the marine mammal extraction protocol produced no alteration of the material itself that could affect its dating.

As these two tests indicated that the marine mammal oil extraction protocol successfully removed marine mammal oil contaminants, as well as other conservation chemicals or contaminants, without negatively affecting the samples for dating, we applied the full acetone/alcohol plus acid/alkali/acid marine mammal oil extraction protocol to all of the remaining samples from the Canadian Museum of History's permanent collections.

6. Results

Hajdas et al. (2014) recommend using C/N ratios to identify the kinds of fiber used in textile production (e.g. silk versus wool, cotton, or

Table 2
AMS dates obtained for the Canadian Arctic samples. Beta-463257 was processed without marine mammal oil extraction protocols; all other samples reported here received the acetone/alcohol pretreatment discussed in the text. Conventional radiocarbon ages, with internal probabilities, calibrated using OxCal v4.3.2 (Bronk Ramsey, 2017) and r:5 IntCal13 atmospheric curve (Reimer et al., 2013).

Sample ID	Sample Number	δ13C o/oo	Radiocarbon Age (BP)	Calibrated Age, 1 sigma; *mean* [median]	Calibrated age, 2 sigma; *mean* [median]
Okivilialuk KeDq-7 #77	Beta-469303	−22.0	360 ± 30	1466-1522 calAD (37.5%) 1575-1625 calAD (30.7) *1543* [*1536*] calAD	1450-1530 calAD (47.7%) 1540-1635 calAD (47.7%) *1543* [*1536*] calAD
Okivilialuk KeDq-7 #75	Beta-469302	−22.6	380 ± 30	1451-1514 calAD (53.8%) 1600-1617 calAD (14.4%) *1524* [*1503*]	1445-1524 calAD (61.6%) 1558-1632 calAD (33.8%) *1524* [*1503*]
Skraeling Island SfFk-4 1234a	Beta-464733	−22.1	720 ± 30	1265-1290 calAD (68.2%); *1282* [*1278*]	1246-1302 calAD (90.5%) 1367-1383 calAD (4.9%) *1282* [*1278*]
Nunguvik PgHb-1 14765	Beta-469301	−23.4	1290 ± 30	675-715 calAD (42.8%) 744-766 calAD (25.4%) *718* [*714*]	664-770 calAD (95.4%); *718* [*714*]
Nunguvik PgHb-1 8424	Beta-469307	−21.5	1390 ± 30	626-664 calAD (68.2%); *643* [*647*]	602-674 calAD (95.4%); *643* [*647*]
Nanook KdDq-9 747	Beta-469300	−21.7	1820 ± 30	139-199 calAD (45.4%) 206-235 calAD (22.8%) *192* [*190*]	90-100 calAD (1.0%) 124-257 calAD (90.7%) 297-321 calAD (3.7%); *192* [*190*]
Nanook KdDq-9 4797 3/3 pretreat	Beta-463258	−21.7	1870 ± 30	82-170 calAD (58.6%) 194-210 calAD (9.6%) *144* [*138*] calAD	73-226 calAD (95.4%); *144* [*138*] calAD
Nanook KdDq-9 4310	Beta-469305	−21.7	1920 ± 30	56-125 calAD (68.2); *84* [*83*]	3-139 calAD (95.1%) 199-204 calAD (0.3%) *84* [*83*]
Nanook KdDq-9 4797 1/3	Beta-469299	−21.3	1940 ± 30	23-86 calAD (68.2%); *61* [*62*]	20-12 calBC (1.2%) 1 calBC-130 calAD (94.2%) *61* [*62*]
Willows Island 4 KeDe-14 4879	Beta-480200	−21.0	2010 ± 30	45 calBC-25 calAD; *10* [*10*] calBC	92-68 calBC (4.2%) 61 calBC-65 calAD (91.2%) *10* [*10*] calBC
Nanook KdDq-9 4440b	Beta-469306	−20.1	2040 ± 30	92-3 calBC (68.2%); *51* [*46*] calBC	162-131 calBC (6.9%) 118 calBC-26 calAD (88.1%) *51* [*46*] calBC
Nanook KdDq-9 4797 3/3 untreated	Beta-463257	−21.7	4650 ± 40	3508-3426 calBC (57.9%) 3382-3366 calBC (10.3%) *3451* [*3454*] calBC	3621-3608 calBC 3522-3356 calBC *3451* [*3454*] calBC

linen), in order to determine the appropriate pre-treatment protocols for AMS dating different fiber types. However, direct examination of the samples investigated here, using high- and low-power magnification (5x-200x), in comparison to reference samples of hair, wool, and plant fibers, showed that no silks or plant fibers were present; that wool was present only in the woven textiles from Skraeling Island and Okivilialuk; and that all of the fibers but one from Nanook, Nunguvik, and Willows Island were spun from animal fiber that conformed closely to Arctic hare and musk oxen hair, comparable to identifications by Fitzhugh et al. (2006) for yarn from Avayalik Island. DNA analyses, currently underway to confirm or extend these identifications, will be published separately. One piece of spun and plied sinew (4440b) from the Nanook site was also incorporated into the suite of dated samples.

To assess whether C/N ratios might allow us to determine whether the hair of wild or domestic terrestrial northern herbivores, omnivores, or carnivores had been used in producing these Eastern Arctic yarn and woven textile specimens, extrapolating from Hajdas et al. (2014), we consulted published C/N ratios for more than 200 samples of domesticated and wild Northern terrestrial and marine faunal remains published by Nelson et al. (2012a, 2012b). These showed no statistically significant differences among the C/N ratios of tissues from Northern/Arctic domesticated cattle, sheep, goats, horses, pigs, and dogs, or between these and wild musk oxen, Arctic hare, caribou (*Rangifer tarandus*), hooded seals (*Cystophora cristata*), harbor seals (*Phoca vitulina*), or ringed seals (*Phoca hispida*).

Eleven AMS dates were run on spun and/or woven fiber artifacts from these five sites using the marine mammal oil extraction protocol. As the δ13C ratios for all of these samples (−21.0 ‰ to −23.4 ‰) fell

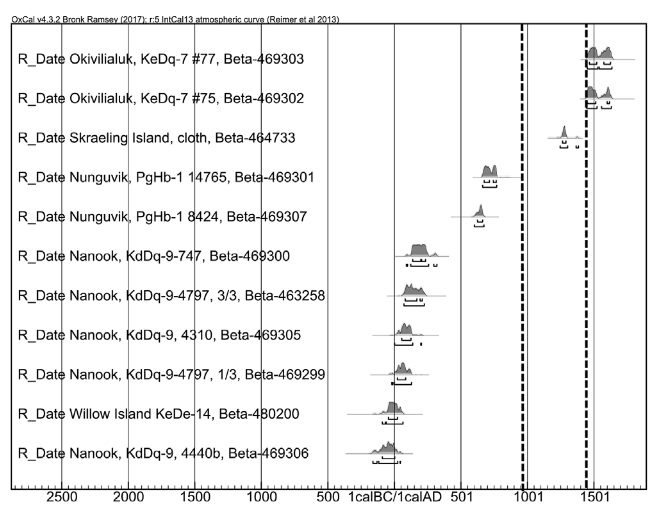

Fig. 4. AMS dates obtained in this study on yarn and textiles from Dorset and Thule sites, all run with the full marine mammal oil extraction protocol. Dashed lines bracket the period of Norse occupation in Greenland.

well within the reported ranges for wild and medieval domesticated terrestrial fauna from the Arctic and North Atlantic regions (Coltrain et al., 2003; Nelson et al., 2012a, 2012b; Ascough et al., 2014; Sayle et al., 2014, 2016), their conventional radiocarbon ages were calibrated using OxCal v4.3.2 (Bronk Ramsey, 2017) and the r:5 IntCal13

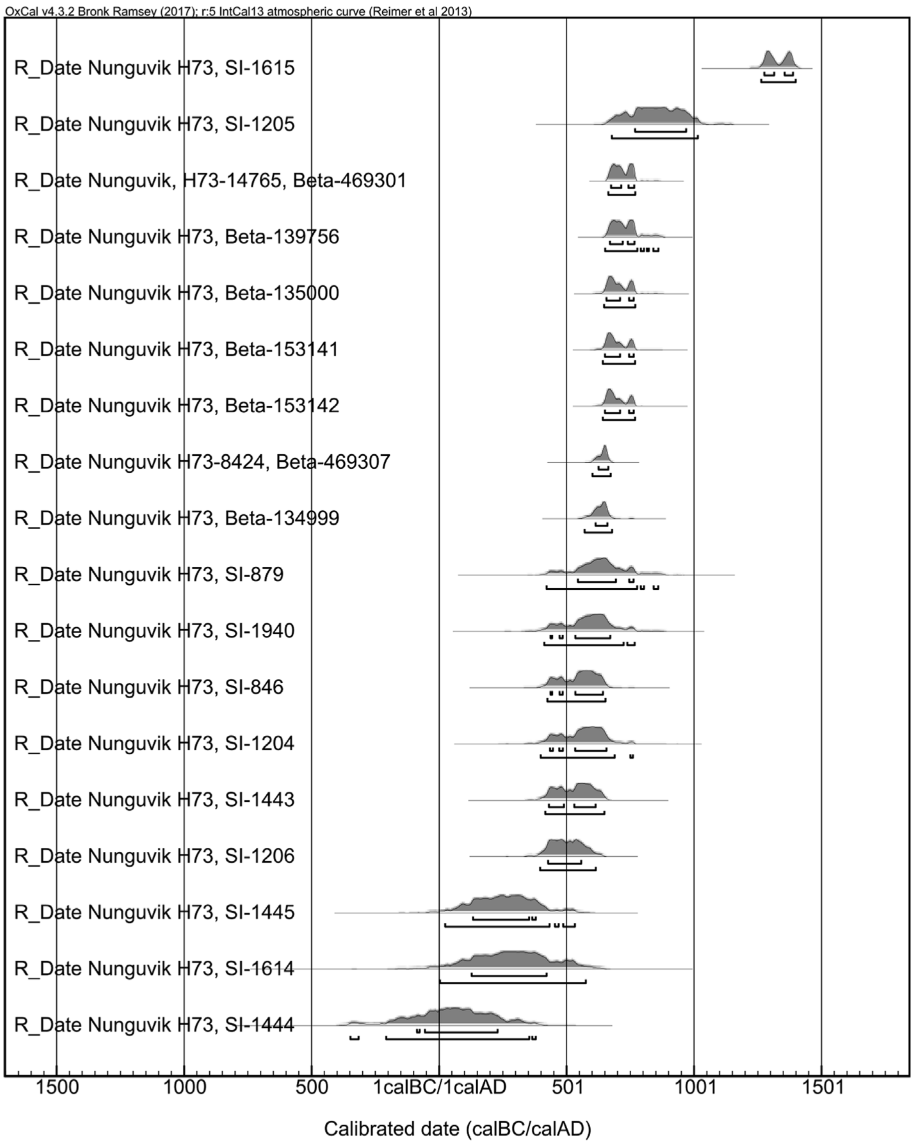

Fig. 5. Calibrated AMS and standard radiocarbon dates from the Nunguvik site (PgHb-1), Baffin Island. Beta-134999 (Sutherland, 2000:163), run with acid/alkali/acid pretreatment only, and Beta-469307 (this study), which received the marine mammal oil extraction protocol, were run on the same piece of yarn (8424). Beta-13756 (Sutherland, 2000:163, acid/alkali/acid only) and Beta-469301 (marine mammal oil extraction) were similarly run on a second fragment of yarn (14765) from the site. These paired dates on the same objects are statistically indistinguishable, despite marine mammal oil extraction, implying there was little or no marine mammal oil contamination on these pieces. Dates from Rousselière (2002): SI-1444, SI-1614, SI-1445, SI-1206, SI-1443, SI-1204, SI-846, SI-1940, SI-879, SI-1205, SI-1615; from Sutherland (2000, 2002): Beta-134999, Beta-153142, Beta-153141, Beta-135000, Beta-139756; this study: Beta-469307, Beta-469301.

atmospheric curve (Reimer et al., 2013). Finally, these results were plotted using the 1σ and 2σ ranges and their median and mean ages; internal probabilities were calculated for all modes within each date's probability curve (Table 2 and Fig. 4).

Three dates on yarn from the Nanook site (Beta-469299, -469300, -469305) and one on spun and plied sinew (Beta-469306), in addition to Beta-463258 (discussed above), indicate that spun yarn was being produced and used at Nanook during the first half of the Middle Dorset period, ca. 100 BC - 300 AD, at least 700–1100 years before the Norse colonization of Greenland. These dates overlap with the latter part of Maxwell and Arundale's interpretation of the site's age.

The single date on musk-ox hair yarn from Willows Island 4 (Beta-480200; 61 calBC - 65 calAD) matches the AMS date that Odess received on willow and crowberry twigs from the test unit where the cordage was recovered, is consistent with the material culture assemblage from the site, and falls within the range of early Middle Dorset dates on cordage from Nanook.

The two dates from Nunguvik (Beta-469300, Beta-469307) indicate that yarn was produced there during the 7th/8th centuries AD, during the transition from the Middle Dorset to Late Dorset periods. These new dates are statistically identical to ones that Sutherland received on the same objects, removing any uncertainty about their age, and fit within the core sequence of dates run by Rousselière and Sutherland from Nunguvik's House 73 (Fig. 5). As our results were run with the new marine mammal oil extraction protocol, it is clear that these samples' dates were not affected by marine mammal oil and should be treated as accurate estimates of these objects' age.

The woven woolen textile from Skraeling Island produced a late 13th century date (Beta-464733) that is consistent with an earlier date (GSC-3038) run on this same piece of cloth and also with a date (K-1489) on a comparable piece of woolen twill recovered from the Ruin Island site, Inglefield Land, across Davis Strait from Skraeling Island in Greenland (Holtved, 1944; Schledermann, 1978, 468; Schledermann, 1980; McCullough, 1989; Schledermann and McCullough, 2003, 189).

The two dated pieces of woven textile from the Okivilialuk site provided similarly consistent results. However, rather than documenting either Norse contact during the Classic Thule period (12th-14th centuries) or the movement of cloth into Inuit hands during the 19th-20th centuries, as earlier assessments of the site's age would have suggested, both pieces of cloth provided calibrated dates with bimodal probability curves spanning the mid-15th through early 17th centuries, suggesting interaction between this Inuit community and Europeans during a period for which limited evidence of contact is otherwise recorded.

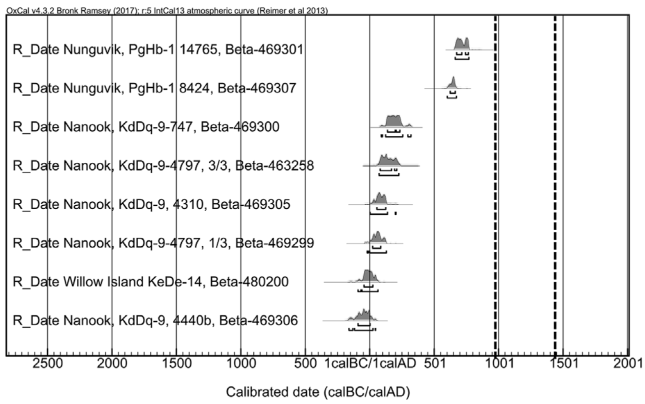

Fig. 6. Dorset culture dates (this study) on spun yarn and sinew (4440b only) from the Nanook (KdDq-9), Willows Island 4 (KeDe-14) and Nuguvik (PgHb-1) sites, Baffin Island, Nunavut, Canada. All samples pretreated with the full marine mammal oil extraction protocol, as described in text. Dashed lines bracket the earliest and latest dates of Norse exploration and settlement in Greenland and adjacent North America.

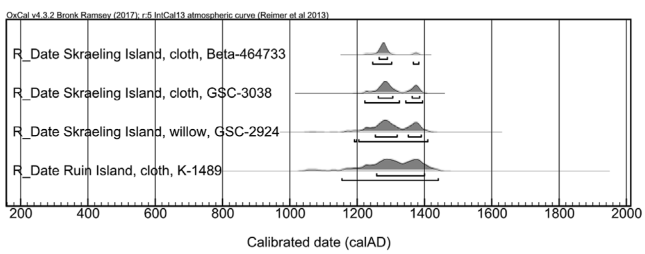

Fig. 7. New AMS date (Beta-464733) on woven Norse textile from House 15 at Skraeling Island, Nunavut, Canada, compared to earlier standard radiocarbon dates on the same piece of cloth, on willow twigs from the same structure, and on comparable cloth from the Ruin Island site (Holtved, 1944; Schledermann, 1978).

7. Discussion

Tests of the marine mammal oil extraction protocol confirmed that this method removes contaminating oils thoroughly and safely and provided dates on uncharred fiber artifacts that were consistent with other evidence from the sites. Similarly, comparisons of the marine mammal oil pretreated textiles from both Nunguvik (Fig. 5) and Skraeling Island (Fig. 7) with earlier-run dates on wood and cloth from those sites suggest that the pre-treatment process has no negative impacts on the samples' suitability for AMS dating, even where no marine mammal oil contamination, or limited contamination, was present. When the marine mammal oil pretreatment protocol was consistently applied, previously reported uncertainties in dating were consistently resolved.

Nine new dates from Nanook, Nunguvik, and Willows Island 4 (Fig. 6) provide a continuous sequence indicating that Dorset communities in the Eastern Canadian Arctic had been making spun and plied yarn for at least 1000 years before the Norse arrived in the North Atlantic, as suggested by Odess and Alix (2004), Park (2004), and Fitzhugh et al., (2006).

Technical analyses of these spun fibers also document numerous differences in the production and end-uses of Dorset and North Atlantic Norse yarn that suggest these represent very different technological traditions rather than a transfer of technologies from Norse to Dorset spinners (Hayeur Smith et al. in prep). Dorset yarn appears to have been remarkably uniformly produced from initially spun and subsequently plied strands of varying lengths that were, for the most part, first spun Z with S as a final twist (Z2S). They also appear to have been well combed or sorted as the fibers are aligned and parallel to each other, a feature

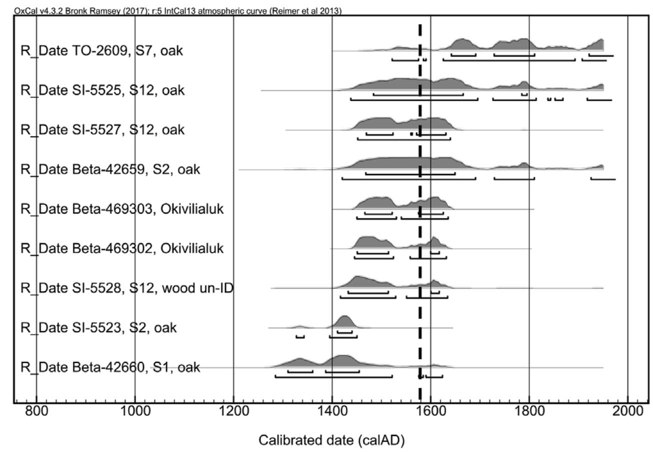

Fig. 8. New AMS dates (Beta-469302, Beta-469303) from the Okivilialuk site (KeDq-7) compared with standard radiocarbon dates on samples of oak and oak charcoal from structures associated with the Frobisher expedition on Kodlunarn Island (KeDe-1), Nunavut, Canada (Fitzhugh, 1993: Table 5.3). Dashed line indicates the period of the Frobisher expeditions, 1576–78.

also noted at Avayalik (Fitzhugh et al., 2006, 162). In these assemblages, Z2S-plied yarn accounted for 98.1% of 105 plied pieces from Nanook, Nunguvik, and Willows Island 4; less than 2% were spun S2Z. Thread diameters are also extremely homogenous across the Baffin Island Dorset material. Further, several pieces of plied yarn from Baffin Island have ends that terminate in a small loop suggesting they had been twisted (plied) on a stick or other implement. This feature is also present on specimens from Avayalik Island, Labrador (see Fitzhugh et al., 2006, Fig. 8) but has rarely been observed in the vast corpus (9000+ specimens) of Icelandic and Greenlandic Norse textiles.

The presence of both spun and plied yarn as well as similarly spun and plied sinew at the Nanook site shows that Dorset people knew how to spin rope and string from various materials, while the presence of basketry woven from grass and other fibers, attested from Avayalik Island, documents additional familiarity with manipulating fibers for diverse needs. The data at hand is insufficient to resolve whether this complex cultural repertoire of fiber use is derived from earlier Paleoeskimo practices developed in Siberia or western Alaska, or whether it represents Dorset cultural innovation within the Canadian Arctic. However, the date received on Sample 4440b from Nanook clearly indicates that sinew was being spun and plied at least as early, if not earlier, than yarn at this site. We feel that the most parsimonious explanation of this data is that the practice of spinning hair and wool into plied yarn most likely developed naturally within this context of complex, indigenous, Arctic fiber technologies, and not through contact with European textile producers.

In marked contrast to Dorset practices, North Atlantic Norse yarn was spun either Z or S, and in a wide range of single or plied yarn diameters. The vast majority of yarn that Norse women produced in Iceland and Greenland was woven into twills, tabbies, and other textiles. However, plied yarn was never used for making cloth in Greenland and was not used for weaving in Iceland until the 16th century (Hayeur Smith, 2012). In the medieval Norse colonies, with the exception of this later Greenlandic cloth, plied yarn was normally used to make garment ties in the absence of buttons, to suspend items, or to make ropes of varying diameters and often from horsehair.

Although some pieces of Dorset yarn were clearly knotted to other cords, suggesting that they had broken and been knotted back together or that they were parts of more complex knotted objects, most pieces of Dorset yarn are recovered as individual strands. There is no evidence that the Dorset ever wove their plied yarn into cloth, implying that their intended end-uses were entirely different than the goals that motivated Iron Age/Early Medieval European women to spin. Given its soft and pliable texture, it seems likely that Dorset yarn was most often used as an element of adornment – perhaps to suspend amulets (Richard Jordan, pers. comm., 1979), to decorate parkas, or as decorative threading or embroidery on garments. Arctic women of the recent past practiced unparalleled sewing skills (Issenmen, 1997) and these threads suggest that unknown prehistoric fiber technologies remain to be described in the North.

The new AMS date from Skraeling Island (Beta-464733, Fig. 7) indicates that the Norse cloth recovered from Ruin Island phase sites was produced in the late 13th century. The Skraeling Island textiles match the criteria for Icelandic *vaðmál* – a specific type of warp dominant, Z/S spun, 2/2 twill produced according to legally defined criteria for use as currency in Iceland and for trade abroad (See Hayeur Smith, 2012, 2014a, 2014b, 2015). However, they also match the characteristics of Greenlandic cloth made before the early 14th century. By the mid-14th century, Greenlandic women began weaving a weft-dominant cloth, using unplied threads, as an adaptation to increasingly cold conditions during the onset of the Little Ice Age (Hayeur Smith, 2014a). Østergård (2004) called this weft-dominant textile "Greenlandic vaðmál". The cloth from Skraeling Island lacks the later Greenlandic cloth's weft-dominant structure, consistent with its 13th century date.

The Skraeling Island textiles show no evidence of having been parts of a sail, as Østergård (2004: 116–118) and others have suggested (Gulløv, 2008: 17, 20). Norse ships' sails were brushed with emulsions of warm water, horse fat, and ochre, then dried and rubbed with hot liquid beef tallow to reduce airflow through sails' otherwise porous surfaces (Cooke et al., 2002). The Greenland Annals also suggest that the Norse produced "seal tar" by pouring melted seal blubber into skin sacks dried in the wind. Seal tar was used, ethnographically, to waterproof wooden boats and ships, and might also have been used on sails (Birgisson, 2013, 348, fn).[4] However, no evidence of this treatment (*smörring*) was noted on the Skraeling Island textiles, nor were they stiff or fulled. The weave was easily visible, unlike fully prepared sailcloth, and there were no eyelets, another distinguishing feature of sails, on the Skraeling Island fragments. It is likely that this was a fragment of a Norse garment that may have been reused and recycled once traded (Hayeur Smith et al., 2016).

Finally, the two dates on textiles from Okivilialuk (Fig. 8) document interaction between Inuit and Europeans on the southern shore of Baffin Island at some point during the 15th-16th centuries. Okivilialuk is 240 km by coastal sailing from Kodlunarn Island (KeDe-1), in Baffin Island's Frobisher Bay, where Martin Frobisher led ill-fated mining operations from 1576 to 1578. Seven samples of wood and charcoal from the Smithsonian Institution's excavations on Kodlunarn Island produced calibrated dates that intersected the time of Frobisher's voyages (Fitzhugh, 1993:Table 5.3). Those dates' probability curves match the new samples from Okivilialuk, raising the possibility that the Inuit acquired these textiles directly from Frobisher's expedition or from his camp after its abandonment. This raises questions about whether the stratum at Okivilialuk from which these textiles were recovered dates to the 13th-14th centuries, as originally assumed (Sabo and Sabo, 1978; Sabo and Jacobs, 1980), or from the 16th century, after Greenland's Norse colonies collapsed (Arneborg et al., 2012a, 2012b). If these textiles were recovered from the same deposits as the Okivilialuk figurine (Sabo and Sabo, 1978), their dates raise important questions about that figurine's identification as a representation of a Norseman. Might it represent, instead, a member of Frobisher's crew, a priest attached to his expedition, or simply an Inuit person wearing garments that were stylized in their representation, or simply unusual? Or were there actually three phases at Okivilialuk, dating to the 13th, 16th, and 19th-20th centuries?

[4] Experiments at Lofotr Vikingmuseum, soaking woolen cloth with harp seal and minke whale oil, suggest that marine mammal oils may have similarly functioned to reduce air flow on sails. According to Nilsen, those experimentally produced cloths have however not yet been systematically investigated.

8. Conclusions

This assessment of spun yarn and textiles from five sites in the eastern Canadian Arctic demonstrates the importance of adequately pretreating organic samples from the Arctic to remove the potential of marine mammal oil contamination. Tests on yarn from Nanook and Skraeling Island demonstrated that this process successfully removed external contaminants without changing the suitability of the fibers for providing accurate dates. Identifying the range of oils and contaminants present in these samples, and their ubiquity within the sites that produced them, using analyses such as gas chromatography/mass spectroscopy, lay outside the scope of this paper but would be a productive focus for future analyses.

Our investigations indicate that Paleoeskimo (Dorset) communities on Baffin Island spun threads from the hair and also from the sinews of native terrestrial grazing animals, most likely musk ox and arctic hare, throughout the Middle Dorset period and for at least a millennium before there is any reasonable evidence of European activity in the islands of the North Atlantic or in the North American Arctic. These results support dates previously reported by Fitzhugh et al. (2006) on similar yarn from Avayalik Island, northern Labrador. Yet, how much earlier or how much later Dorset people spun these threads, or what they used them for, remain questions to be addressed. The absence of such spun fibers from Greenlandic Saqqaq period (2400–900 BC) sites with exceptional preservation, such as Qeqertasussuk and Qajaa (Grønnow, 2017), raises interesting questions about whether this technology was carried to the Canadian Arctic with early Arctic Small Tool tradition colonists from Siberia or western Alaska as part of their original "cultural package" or represents innovative adaptations by the Dorset in the eastern Arctic. While we cannot assess those possibilities with these samples, we note that our oldest date was, in fact, on plied and spun sinew, rather than on spun hair or wool, which raises the possibility that the origins of spinning yarn from hair and wool in the Eastern Arctic may have developed from a pre-existing indigenous tradition of spinning, plying, and braiding sinew, and perhaps also plant fibers or baleen. Expanding the number of dates available on Dorset period spun sinew and basketry, as well as increasing the number of sites with dates on spun hair and wool yarn, represent productive avenues for future investigations. Regardless of when the practices of spinning and plying began, no dates yet document the production of these fibers at any times during which Dorset/Norse interaction was possible.

In contrast, Norse woven textiles definitely *were* acquired by Thule people much farther to the north and during the late 13th century. The AMS date received from Skraeling Island helps to narrow the age of the woven woolen cloth recovered there, and implies that interactions between the Norse and Thule Inuit may have begun almost as soon as these Arctic pioneers arrived from Alaska. In this context, it is worth considering the possibility that the integration of Arctic hare fur into Norse textiles by Greenlandic Norse women (Sinding et al., 2017) may have been the result of Inuit women instructing the Norse how best to use local resources, rather than the Norse teaching Arctic North Americans to spin.

Finally, rather than extending evidence for Norse interaction with Thule people into southern Baffin Island, the textiles from Okivilialuk appear to document contacts between ancestral, post-Thule, Inuit communities and Europeans around the time of the Reformation – perhaps with the Frobisher expedition at nearby Kodlunarn Island in 1576–78, possibly with Sebastian Cabot's 1508–09 reported expedition to locate the Northwest Passage, or potentially with another undocumented contact in Hudson Strait before or after Frobisher's voyages.

Directly dating yarn and textiles from Eastern Arctic sites after pretreatments to remove potential marine mammal oil contamination suggests a far more complex history of fiber use and technological diversity in the Arctic than was previously anticipated, while reducing uncertainties in the dating of these materials at individual sites. Dorset yarn was produced differently, to different standards, and put to different uses than the yarn that Norse women spun from sheep's wool and goats' hair; most significantly, Dorset yarn was never woven into cloth, which was the principal use of yarn in Norse contexts. Such spun yarn appears to have been produced by Dorset people for nearly a millennium before any evidence of European contact and over a region stretching at least from Newfoundland to northern Baffin Island. European yarn-based products, in contrast, are present in the North American Arctic in very small numbers and arrived at Thule sites (but thus far not in Dorset sites) as woven textiles in the late 13th and early post-medieval periods. Thus, rather than documenting a brief period of contact and technological transfers from European Norse traders to Indigenous peoples in the North American Arctic, our analyses document nearly 1500 years of innovation, acquisition, and use of textiles by indigenous Arctic communities that require further analysis.

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