Competing hypotheses, ordination and pollen preservation: landscape impacts of Norse *landnám* in southern Greenland

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Abstract

Peat sequences in close proximity to former Norse farmsteads in southern Greenland are valuable palaeoecological archives for exploring the impacts of the 10th century Norse colonisation. Unfortunately they are far from widespread and many would be considered suboptimal for palaeoecological analysis owing to the taphonomic complexities perceived to be associated with their depositional environments. This paper explores the value of one such archive from the Vatnahverfi region of southern Greenland. On the basis of field observations, a problematic depositional context was anticipated and this is borne out in the contradictory palynological results which demonstrate evidence for agriculture and abandonment in contemporary horizons and radiocarbon age-depth reversals. Multiple working hypotheses are developed to explicitly demonstrate the equally plausible, but starkly different, interpretations that are possible from these data. To refine our interpretations we apply pollen preservation analysis and multivariate statistical analysis of this dataset with a large well dated fossil dataset from the same region. In so doing, this paper highlights the value of ordination as a chronological tool and the importance of pollen preservation analysis in interpreting taphonomically-complex depositional environments.

Keywords

Greenland, Norse, taphonomy, pollen preservation, ordination, multiple working hypotheses.

Introduction

Over the past decade, the environmental impact of the 10th century colonisation of Greenland by Norse settlers from Iceland has been subject to renewed and extensive palynological study (Edwards et al., 2004a, 2009). Integral to this work has been a methodological focus on palaeovegetational reconstructions from small depositional contexts – typically mires, but also ponds and peaty hollows – that are closely associated with Norse archaeology (Edwards et al., 2008, 2011b; Schofield et al., 2008; Ledger et al., 2013). These have been favoured over larger basins (although see Gauthier et al., 2010 for an exception) in order to maximise the responsiveness of the palynological signal for individual farm units, as the impacts arising from human activity appear reduced at the landscape-scale (Ledger et al., 2014a). Following this strategy, it has been possible to not only confirm patterns established in the pioneering work of Johannes Iversen (1934) and Bent Fredskild (1973), but also to investigate resource usage and landscape change around individual farms alongside the provision of settlement chronologies independent of the archaeology (Edwards et al., 2008; Schofield et al., 2008; Schofield and Edwards, 2011; Ledger et al., 2013; Ledger et al., 2014b).

This approach is not without risk, as the taphonomy of mires and peaty hollows can often be complex. Sedimentary hiatuses are common (Schofield et al., 2008; Schofield and Edwards, 2011) and the highly dynamic nature of the Greenlandic landscape (Kuijpers and Mikkelsen, 2009) provides ample opportunity for the re-working and deposition of old microfossils through erosion (Ledger et al., 2015). This is compounded by the fact that Norse *landnám* triggered localised periods of soil erosion as settlers introduced grazing herbivores into a previously ‘pristine’ landscape and stripped turf for the construction of dwellings (Dugmore et al., 2005).

To gain meaningful insights into human impacts from palaeoecological archives, it is necessary to appreciate and overcome such difficulties. This is not always readily achieved. Used alone, palynological data can frequently suggest multiple interpretations; as additional lines of evidence are introduced (lithostratigraphic data, ^{14}C dates etc.), the number of plausible interpretations may increase further. For this reason the use of multiple working hypotheses (MWH), whereby numerous hypotheses are formulated, tested and consecutively eliminated, could be considered a tenet of palaeoecology (Birks and Birks, 1980; Edwards, 1983; Edwards et al., 2004b, 2005), although the method is seldom implemented in a systematic manner. Even when the MWH method is adopted formally, it does not necessarily lead to an adequate resolution as it is not always possible to espouse a preferred hypothesis (cf. Ledger et al., 2015).

This paper uses the MWH approach to explore palaeoevegetational and radiocarbon data from a taphonomically complicated sedimentary sequence from the Vatnahverfi region of the former Norse Eastern Settlement of Greenland. Rather than resisting the potential contradictions posed by the existence of MWH, this paper embraces them to explore what is a problematic sequence. We present equally intricate, and starkly different, perspectives on the same data in order to highlight the dangers and complexities of explaining palynological data from such contexts. We then apply pollen preservation data – an underutilised form of analysis (Tipping, 2000; Tweddle and Edwards, 2010) – and ordination in an attempt to help resolve some interpretational conundrums. In so doing, we aim to offer meaningful insights on the impacts of Norse settlers from a deposit which may otherwise be considered unsuitable for palynological study.

Background

Vatnahverfi

Vatnahverfi is a predominantly-inland region within the former Eastern Settlement of Greenland (Fig. 1) containing approximately 50 groups of Norse ruins. The area is dominated by a series of long valleys and lakes, with topography ranging from sea level to 1000 m asl. The geology comprises a suite of granites (Allaart, 1976) with a drift cover of glacial and glaciofluvial deposits of Quaternary age (Feilberg, 1984). Soils in this region are typically podzols (Jacobsen 1987). Thick deposits of fine windblown sand (loess) are present, particularly in eastern areas (cf. Jakobsen 1991; Kuijpers and Mikkelsen 2009), and the mires of the region exhibit a relatively high minerogenic (aeolian and slopewash) component (Ledger, 2013). Climatically the region is within the sub-arctic/sub-oceanic climate belt of southern Greenland with the nearest observational data (for Narsarsuaq [Fig.1] over the period 1961-90) indicating a mean summer (July) temperature of 10.3°C and annual precipitation of 615 mm (Cappelin et al., 2001).

The study site

Tasilikulooq (Ø171) is a medium-sized group of eleven Norse ruins located in a small valley (c. 200 x 500 m) near the centre of Vatnahverfi between Lake Saqqaata Tasia and Tasersuaq (Figs 1 and 2). The eleven ruins were first recorded by Christian Vebæk (1992) and are dispersed throughout the area, with the largest concentration located on a low mound to the east of the valley (Fig. 2). A modern sheep farm was established on the site in 1986 and is situated c. 50 m northeast of the ruins. The valley floor slopes gently from northeast to southwest and is dominated by hayfields associated with the farm. To the east, the relief rises sharply to a rocky outcrop c. 50 m asl on which the slopes are covered by *Salix glauca-Betula glandulosa* scrub (plant nomenclature follows Böcher et al., 1968). The land to the west rises more gently and is covered with a mix of scrub and improved grassland.

Methods

Fieldwork and sampling

The Tasilikulooq profile was identified following the inspection of open sections in a drainage ditch (Fig. 2) which had been cut through the valley in 1990. Although this is now somewhat overgrown, a ~85 cm deep profile (N 60° 50.007’, W 45° 24.176’) was visible approximately 100 m southwest of the Norse ruins. In July 2010 the profile was cleaned and a 50 x 13 x 13 cm monolith tin was used to sample between 80 and 30 cm. Stratigraphy was described in the laboratory and loss-on-ignition (LOI) was measured following 3 h combustion at 550°C.

Pollen analysis

Pollen preparations followed standard techniques and comprised NaOH, sieving, acetolysis and floatation procedures (Moore et al., 1991; Nakagawa et al., 1998). *Lycopodium* tablets (Stockmarr, 1971) were added to allow the calculation of concentration data. After processing, samples were dehydrated and suspended in silicone oil (viscosity 12,500 cSt). Counting was undertaken using a light microscope until a sum of 500 total land pollen (TLP) had been achieved. Identifications were confirmed using modern reference material aided by the key in Moore et al. (1991). Pollen nomenclature follows Bennett et al. (1994) and Bennett (2015a), with taxa otherwise absent following Moore et al. (1991) and informed by Böcher et al. (1968). *Betula* pollen was separated into tree (*Betula pubescens*) and shrub (*Betula glandulosa*) categories using grain size diameter measurements (cf. Fredskild, 1973; Schofield and Edwards, 2011) with grains <20 μm classified as *B. glandulosa*. The preservation status of each enumerated pollen grain was also recorded as either well preserved, degraded, broken, corroded, or folded (cf. Havinga, 1964; Cushing 1967). Microscopic charcoal was measured using a microscope eyepiece graticule at a magnification of ×400 and both charcoal concentration and charcoal to pollen ratios (C:P) were calculated (cf. Swain, 1978; Patterson et al., 1987). Coprophilous fungal spores were identified using van Geel et al. (2003). Diagrams were constructed using TILIA and TGView software (Grimm, 1993, 2015) with percentages based upon the TLP sum.

Numerical analysis

Biostratigraphic zonation of both the pollen preservation (cf. Tweddle and Edwards, 2010) and conventional percentage diagrams was undertaken using CONISS (Grimm, 1987) following square root transformation of percentage data. Rarefaction analysis (Birks and Line, 1992) was performed in *psimpoll* (Bennett, 2015b). Principal components analysis (PCA) was undertaken using CANOCO 4.5 (ter Braak and Šmilauer, 2002).

Radiocarbon dating and age-depth modelling

Samples were disaggregated in weak NaOH and washed through a 125 μm sieve. Residues were examined under a binocular microscope to identify macrofossil remains for dating. Samples were cleaned to remove roots of Ericaceae, Cyperaceae and fungal mycelium, stored in slightly acidified water, and AMS ^{14}C-dated at SUERC, East Kilbride. Where macrofossils were absent, subsamples of peat were cut from the core and submitted for dating. Calibration of ^{14}C dates was undertaken using the IntCal13 calibration curve (Reimer et al., 2013) and CALIB v7.0. Age-depth modelling was undertaken using the classical techniques in *Clam* (Blaauw, 2010).

Results and initial interpretation

Lithology

The profile from Tasilikulooq is highly minerogenic (LOI typically <40%) and can be divided into four distinct depositional units (Fig. 3). The base of the sequence comprises sands and gravels. These are overlain (78-63 cm) by brown, sandy, moderately-humified peat with relatively constant LOI. Above this (63-41 cm) is a silty, organic sand (LOI < 30%). Within this unit there are two inferred erosional pulses at 63-61 cm and 59-56 cm, where LOI drops to very low values (<10%). A gradual rise in the input of minerogenic material is evident from 51-45 cm. At 41 cm there is a shift towards a less sandy, highly humified peat. This is visible as a U-shaped contact in section and may reflect the modern plough line.

Radiocarbon dates

Six radiocarbon dates are available for Tasilikulooq (Table 1). All but one of these determinations (SUERC-34404) were undertaken on plant macrofossils. The ^{14}C dates form an inconsistent series. Age reversals occur at 70.5-68.0 cm (SUERC-36601) and at 46-45 cm (SUERC-34404). Nevertheless, all data (Table 1) indicate that peat growth in the Tasilikulooq valley began after the date (AD 985) that is conventionally accepted for the arrival of the Norse in Greenland (Seaver, 2010).

Age-depth modelling

Two possible radiocarbon age-depth models can be generated from the radiocarbon dates. The first of these (model A; Fig. 4a) assumes that the two lowest dates (SUERC-34408 and SUERC-36601) in the sequence and SUERC-34405 are correct. In this model a smoothed spline is used to connect these three dates, and those at 70.5-68 cm (SUERC-34407), 63-62 cm (SUERC-34406) and 46-45 cm (SUERC-34404), which form an older series, are assigned as outliers. The second model (model B; Fig. 4b) treats the SUERC-34408, SUERC-36601 and SUERC-34405 as outliers and again fits a smoothed spline through the remaining dates.

Figure 4a suggests a record of the end of Norse settlement and the post-Norse period in Vatnahverfi. Conversely, if model B is correct, the sequence under analysis is much younger (~AD 1050-1550), with peat formation beginning during the early stages of the settlement.

Pollen and associated proxies

Herbaceous taxa dominate local pollen assemblage zone (LPAZ) TASI-1a (c. 85% TLP) and suggest an open landscape. *Salix* (10-12%) is the only woody taxon present at significant values. *Betula glandulosa* and *B. pubescens* are poorly represented at c. 2-3% (Fig. 5). The high percentages witnessed for *Potentilla*-type (20-37%) and Rosaceae (4-10%) pollen are unusual and therefore seem likely to be derived from plants growing on the mire surface (e.g. *Potentilla palustris*). Grassy heaths are indicated by pollen from Poaceae (c. 20-26%) and *Ranunculus acris*-type (c. 2-4%). Microscopic charcoal is registered from the base of the profile, as is *Rumex acetosella*, a probable Norse introduction (Fredskild, 1973; Schofield et al., 2013).

TASI-1b is also suggestive of an open landscape with limited scrub or heath, albeit with some significant differences from the previous sub-zone. Poaceae rises to 25-36% (Fig. 5) and there is an increase in palynological richness which may reflect an expansion of grassy heath. Declining *Potentilla*-type (c. 12-19%) may indicate a reduction in the area covered by mire. The presence of grazing animals and people is also implied by an increase in *Sporormiella*-type values (reaching c. 10%) and a slight rise in microscopic charcoal.

LPAZ TASI-2 is characterised by a further increase in indicators representative of human activity. C:P rises, *Sporormiella*-type peaks at 32-33%, and there is a marginal increase in Norse apophytes such as Brassicaceae and *Rumex acetosella* (Schofield et al., 2013) to 6% and 3% respectively (Fig. 5). Yet a small rise in pollen from *Betula pubescens* and *B. glandulosa* may imply some regeneration of birch woodland and/or scrub and a decline in human impact.

The onset of LPAZ TASI-3 broadly corresponds with a lithological change from fibrous moderately-humified peat to silty, organic sand containing frequent fine (1-2 cm thick) sandy lenses (Fig. 5). Increased minerogenic input to the mire is also demonstrated through a decline in LOI to 6.7% by the middle of the zone. This is associated with an increase in pollen concentration to c. 80,000-100,000 grains cm^{-3}. The pollen assemblage primarily suggests the expansion of grassland/herbslope reflected by Poaceae percentages of between 45-60% TLP. *Ranunculus acris*-type also rises to c. 5-7% and there are rare occurrences of other taxa such as *Cerastium*-type and Lactuceae, which are common in modern grasslands (Schofield et al., 2007). Alongside these changes are declines in *Betula* and *Salix*, collectively falling from c. 20% in TASI-2 to c. 7% by the end of TASI-3.

The opening of LPAZ TASI-4 is marked by a sharp decline in pollen from Poaceae to c. 30% (Fig. 5), implying a decline of grassland/herbslope communities. Cyperaceae rises to c. 30-35% and there is a gradual increase in *Potentilla*-type, perhaps pointing towards an expansion of mire. Scrub and dwarf shrub pollen remain muted at c. 10% and apophytes such as Brassicaceae, *Rumex acetosella* and *Montia fontana* continue to be recorded at trace values. Microscopic charcoal is noted at low levels and there continue to be sporadic traces of *Sporormiella*-type.

In LPAZ TASI-5 there is evidence for increasing human impact, seen through the rises in microscopic charcoal, *Sporormiella*-type and the pollen from *Rumex* spp. (Fig. 5). Conversely, the re-emergence of *B. pubescens* (c. 10%) and *B. glandulosa* (c. 5-7%) is similar to changes noted in TASI-2 and appears to reflect the regeneration of scrub and dwarf-shrub heath and to imply declining human impact. These developments coincide with a lithological change and consistent decline in the LOI from 42.1% to 12.6%, indicating increased input of allochthonous material or disturbance of the stratigraphy by modern ploughing (the base of TASI-5 is ~40 cm, placing it around the depth of the plough-line).

Discussion

Low scrub percentages, the presence of *Rumex acetosella*, microscopic charcoal, and *Sporormiella*-type from the start of the profile indicate that the sequence records the period following Norse *landnám* in Vatnahverfi. This is in agreement with the results of both age-depth models (Table 2) which demonstrate that, in all likelihood, peat accumulation in the Tasilikulooq valley began around either AD 1345 (model A), or AD 1025 (model B). Nevertheless, and critically, it is unclear which model is more reliable. The following section discusses the pollen-analytical data in relation to each of the chronological possibilities and highlights the contradictory interpretations that arise (Table 3). We then apply the results of pollen preservation data and multivariate analyses in an attempt to refine the interpretations.

Contradictory working hypotheses

Age-depth model A (Fig. 4a) indicates that peat formation dates to AD 1290-1385, a period that dates towards the end of Norse occupation in Greenland (Ledger et al., 2014a). Throughout TASI-1a and -1b, *Betula* and *Salix* values are low, and comparable to values from mature farms elsewhere in southern Greenland (e.g. Edwards et al., 2008; Ledger et al., 2014a). Poaceae pollen percentages of c. 20-35% are relatively low compared to other sites in Vatnahverfi (e.g. Ledger et al., 2013; 2014a, b), limited microscopic charcoal concentrations are not indicative of extensive burning, and *Sporormiella*-type concentrations do not imply widespread grazing. Taken together these data may be interpreted as a signal for a farm in decline, although this is difficult to ascertain without observing the preceding environmental baseline. Alternatively, these patterns could be interpreted as the regional signal of a *landnám* whereby the apparent grazing signature may reflect animals associated with nearby farms, with microscopic charcoal deriving from fires at those locations. Similar patterns, possibly as a precursor to the establishment of a full farm on site, have been noted at other places in Vatnahverfi (e.g. The Mountain Farm [Ledger et al., 2013]), and the Eastern Settlement (e.g. Qinngua [Schofield and Edwards, 2011]). This interpretation is compatible with model B (Fig. 4b) which indicates an age of AD 935-1120 (Table 2) for the beginning of TASI-1a.

The interpretation of TASI-2 is also problematic. Rises in *Betula* pollen are suggestive of increasing scrub and woodland cover, which theoretically might follow a relaxation in grazing intensity around an area (such as that which follows farm abandonment). The end of the Eastern Settlement is conventionally placed at around AD 1450 (Seaver, 2010) and model A indicates a date of AD 1442-1540 (Table 2) for the beginning of TASI-2, which would be consistent with the interpretation of abandonment from the palynological data. However, a sharp increase in microscopic charcoal and *Sporormiella*-type points to a significant escalation in burning and grazing, implying increasing rather than decreasing human activity. Collectively these changes are incongruent with the late 15th to early 16th century date from model A.

Notwithstanding the slight increases in *Betula*, model B, which suggests TASI-2 dates to AD 1051-1177 (Table 2), seemingly provides a more plausible age estimate for the opening of the zone. An interpretation that sees an upsurge in burning and grazing reflecting growing human activity is compatible with observations elsewhere in Vatnahverfi (Ledger et al., 2013, 2014a, b). Declining LOI from the opening of TASI-3 is also consistent with model B and a date of AD 1120-1219 (Table 2) for the beginning of this zone. Rising minerogenic inputs to the mire may have resulted from turf stripping, an activity associated with the construction of farm buildings (Roussell 1941), and/or an intensification of grazing. Poaceae percentages are very high (up to 60% TLP) and compare favourably with those values recorded from modern hayfields in the Qassiarsuk district (Schofield et al. 2007). Again, this implies the presence of Norse settlers. However, the fall in microscopic charcoal and near absence of *Sporormiella*-type spores run contrary to this interpretation. These developments are more comparable to palynological signatures associated with the absence of human activity in southern Greenland (Edwards et al., 2011a). The date of AD 1522-1639 from model A for the opening of TAS-3 is more – although not wholly – consistent with this interpretation.

Reduced Poaceae percentages, rising Cyperaceae, and low *Sporormiella*-type and charcoal in LPAZ TASI-4, signify reduced human activity, or an abandoned landscape (cf. Ledger et al., 2013). The age-depth models suggest that TASI-4 begins either between AD 1616-1777 (model A), or AD 1237-1322 (model B); both of which could be reasonable age estimates for the changes observed given that some sites in Vatnahverfi (such as Atikilleq and Nimerialik) seem to have been abandoned from as early as the beginning of the 13th century (Ledger et al., 2014b, 2015).

Nevertheless, the pollen assemblages in TASI-5 are once again problematic and compare with those noted in TASI-2. *Betula* and *Salix* increase to comprise 20-25% TLP which seems indicative of regenerating woodland and scrub. Yet there is a strong representation from apophytes, notably *Rumex acetosella*, as well as rises in *Sporormiella*-type and microscopic charcoal, implying enhanced human impact. Moreover, both age-depth models (Table 2) provide estimates for the opening of TASI-5 that are incompatible with the changes observed. Model A suggests the zone dates to AD 1683-1898, a period after the Norse had abandoned Greenland, while model B indicates a date of AD 1371-1470, a period when farms elsewhere in Vatnahverfi and southern Greenland were being abandoned (e.g. Edwards et al., 2008; Ledger et al., 2013, 2014b).

Ordination of the Tasilikulooq samples

Given the two chronological possibilities, and the seemingly contradictory developments in the biostratigraphy, it is difficult to interpret the Tasilikulooq pollen data in a conventional manner. In an attempt to refine the interpretations and the chronology, the relationship between the Tasilikulooq samples and a larger pollen dataset from Vatnahverfi were explored through Principal Components Analysis (PCA; Fig. 6). The larger dataset derives from four well-dated mire sequences (Ledger et al., 2013, 2014b, 2015) which cover the pre- to post-Norse periods (c. AD 700-1700) in Vatnahverfi. These data were treated as 'active' samples in the PCA with those from Tasilikulooq being supplementary, or 'passive', samples within the ordination.

The PCA displays good differentiation of samples from each period (Fig. 6), suggesting that the assemblage of a sample can be a function of its age. Pre-Norse assemblages (prior to AD 985) are characterised by high frequencies of *Betula* and *Salix*, and negative scores along axis 2. Norse age samples are notable for their elevated concentrations of apophytes such as *R. acetosella*, Brassicaceae and Lactuceae (cf. Fredskild, 1973; Edwards et al., 2011), and positive scores along axis 1. Post-Norse samples (after AD 1400) generally contain higher frequencies of Cyperaceae pollen (e.g. Schofield et al., 2008; Schofield and Edwards, 2011), and this pollen type plots in isolation in the top left quadrant of the ordination space.

The clearest, and most important, finding of the supplementary ordination of samples from Tasilikulooq (Fig. 6) is that they are most similar to those from Norse-age environments elsewhere in Vatnahverfi. This result supports the conclusions arising from the age-depth modelling which indicate that the profile post-dates the Norse *landnám*. More importantly, the ordination implies that the profile solely reflects a record of Norse settlement; the assemblages clearly appear dissimilar to those recorded at other sites for pre- and post-Norse environments. Indeed, each of the samples from Tasilikulooq record positive scores along axis 1, with this most clearly being the case for LPAZs TASI-2 and TASI-3. This generates little support for the adoption of age-depth model A which, if correct, would indicate that both these zones post-date the mid-15th century, i.e. following the Norse abandonment of Greenland. Nonetheless, the ordination also places samples from TASI-5 firmly within the cluster of Norse age samples, which both models suggest post-date Norse settlement. Whilst these findings support the conclusions that the profile post-dates the Norse *landnám*, they also raise doubts over the reliability of both models A and B, and the stratigraphic integrity of the archive.

Applying pollen preservation data

With the exception of TASI-1a and b, all of the LPAZs provide contradictory pollen-analytical and chronological data. Importantly, two of the transitions between pollen zones (TASI-2/3 and TASI-4/5) occur across lithostratigraphic contacts, and all are associated with fluctuating LOI values (Figs 3 and 5) suggesting possible links between the composition of the pollen assemblages and the sedimentation regime. These associations may imply that some of the observed contradictions are related to secondary (non-contemporaneous) pollen deposition and/or post-depositional biasing.

Pollen preservation analysis is a valuable, but underutilised, approach that may help resolve some of these observed inconsistencies (Tipping, 2000; Tweddle and Edwards, 2010). These data (Fig. 7) immediately highlight possible problems with pollen assemblages in LPAZ TASI-2. This corresponds with Local Pollen Preservation Zone (LPPZ) TASIP-2 and a sharp decline in the quality of pollen preservation. Indeterminable grains increase to 14% (Fig. 5), well preserved pollen declines from c. 60% to c. 40%, and degraded pollen rises to c. 30-35% in most samples. Degraded pollen is frequently associated with the deposition of reworked silts and sands (Birks, 1970), but can also be indicative of *in-situ* decay (Havinga, 1984) and values of >35% are considered by Bunting and Tipping (2000) to be evidence of post-depositional biasing. Similarly, corroded pollen is suggestive of biasing through bacterial activity, whereby less resistant microfossils are destroyed or 'ghosted' beyond recognition, and more resistant palynomorphs are concentrated (Hall, 1981). The marked decline in the pollen concentration during TASI-2, where there is an increase in the number of corroded grains, may be related to the aforementioned processes. Given the decrease in pollen concentrations, the increase in C:P in TASI-2 may also be a taphonomic artefact, whereby pollen loss through deterioration and corrosion has enhanced the relative abundance of inert charcoal (Patterson et al., 1987). A similar argument could be applied to explain the rise in *Sporormiella*-type spores which frequently show no sign of corrosion and appear to preserve equally well in dry and waterlogged sediments (Wood and Wilmhurst, 2012). Alternatively, increases in *Sporormiella*-type spores and microscopic charcoal could reflect secondary deposition of older materials eroded, washed or blown into the mire from its catchment. This might explain the enigmatic rise in *Betula* pollen, much of which is poorly preserved, rising frequencies of which have been linked with minerogenic inwash at sites in Iceland (Gathorne-Hardy et al., 2009).

The apparently contradictory signatures for both increasing and decreasing human impact in TASI-2 should therefore be treated with caution as the pollen assemblages have likely been affected by either post-depositional biasing and/or inputs of allochthonous sediment. This finding has important chronological implications. When the full series of six ^{14}C dates for the profile is considered, the AMS dates SUERC-34407 and SUERC-34406 (Table 1) present an age-depth reversal (and 'anchor' model B) and are both located within this zone. This might be explained through the secondary deposition of 'older' (eroded) macrofossils (cf. Ashmore et al., 2000). The fact that these ^{14}C assays only form a consistent age model (model B; Fig. 4b) when matched with SUERC-34404 – a measurement on the humic acid fraction of peat – may be of further significance. Paired ^{14}C measurements on macrofossils and humic acid from Greenlandic peats frequently provide significant age differences (e.g. Edwards et al., 2008; Schofield et al., 2008). It is therefore plausible that none of the dates used to construct model B reflect the ‘true’ age of the horizons from which they are drawn.

Although there are contradictory patterns to the pollen assemblages in LPAZs TASI-3 and -4, there is little evidence that they are related to issues surrounding pollen preservation. These zones are coincident with TASIP-3 and are characterised by a general increase in the quality of pollen preservation relative to TASIP-2. The same can be argued for TASI-5. This LPAZ coincides with LPPZ TASIP-4 in which 75-80% of the pollen is well preserved. The bases of both TASIP-4 and TASI-5 correspond with declining LOI and a lithostratigraphic boundary that is close to (~40 cm below) the modern ground surface of the hayfield. The shallow depth of this horizon could signify the position of the modern plough line with mixing of the profile occurring above this depth. Indeed, ploughing would likely result in introduction of relatively recent pollen to lower depths and this may explain the increase in well preserved pollen in TASI-5.

Is it possible to adopt a preferred hypothesis?

The Tasilikulooq profile is seemingly beset by taphonomic issues that limit the interpretability of the dataset. Nevertheless, this does not mean that meaningful insights cannot be drawn from the data. Palaeoenvironmental archives regarded as sub-optimal have frequently made useful contributions to understanding of environmental change in the North Atlantic region and further afield. For example, the pollen content of soils has informed debates surrounding pre-Norse cereal agriculture in the Faroe Islands (Jóhansen, 1979; Edwards and Borthwick,

2010) and putative cultivation in Greenland (Ledger et al., 2015). Similarly, anthrosols have been demonstrated to contain stratified archives pertaining to agriculture and landscape change in environments as diverse as the North Atlantic island of St Kilda (Donaldson et al., 2009) and the coastal plains of the Netherlands (e.g. Waateringe, 1992). Highly minerogenic sediments have proven valuable in revealing information about human-environment interactions in both the Shetland Islands (Whittington and Edwards, 1993) and the Outer Hebrides of Scotland (Edwards et al., 2005; Whittington and Edwards, 1996). Despite many of these studies presenting strikingly similar issues to those encountered at Tasilikulooq (e.g. radiocarbon age-reversals and post-depositional biasing of pollen assemblages), reasonable interpretations were constructed. On balance, it should therefore be possible to adopt a preferred hypothesis for the patterns that are evident within the Tasilikulloq profile using evidence from the profile investigated through this study.

Ordination and pollen preservation data have helped to refine the interpretation of data from the site. Firstly, PCA shows that the pollen assemblages from Tasilikulooq display strong similarities with those seen in Norse-age palynological samples from other sites in Vatnahverfi. Secondly, preservation data demonstrate that the contradictory signals within the assemblages of LPAZs TASI-2 and 5 can be explained by taphonomic factors linked to the long-term survival of pollen and/or the re-working and re-deposition of secondary microfossils. The palaeoenvironmental record and data from these affected horizons must therefore be treated as suspect. Nevertheless, the age-depth models remain problematic.

Contradictory radiocarbon chronologies are common for Holocene peat deposits (Edwards et al., 2011; Whittington et al., 2015). Age-depth reversals –similar to the one noted at Tasilikulooq – are frequent in lake and mire sediments from Greenland (Gauthier et al., 2010; Schofield and Edwards, 2011; Blockley et al., 2015) and have been encountered in a range of palaeoenvironmental studies conducted in other locations (e.g. Faroe Islands

[Borthwick, 2007]; Scotland [Ashmore et al., 2001; Edwards and Whittington, 2010]; Iceland [Gathorne-Hardy et al., 2009]; Scandinavia [Berglund et al., 2005]; France [Jouffroy-Bapicot et al., 2013; Ledger et al., 2015]). To advance interpretation in these instances, researchers often make suppositions to reject dates that do not conform to expectations (cf. Edwards and Whittington, 2010); however, a lack of firm evidence to corroborate such judgments can lead to a degree of subjectivity in such assessments. In the case of Tasilikulooq the preservation data, pointing to disturbance of the sedimentary regime and allochthonous deposition in LPAZ TASI-2, might be taken in support of rejecting dates from this horizon. The only other corroborating evidence that these data are reliable is that they form a consistent time series with the ^{14}C assay at 46-45 cm (SUERC-34404; 600±30 BP), which was undertaken on the humic acid extract of the peat (material that may be compromised by 'old carbon' error; cf. Edwards et al. 2008). It seems to us that the arguments in support of Model B and the attendant hypothesis are stronger than those for Model A. The profile might then – at least for the first two sub-zones – record a snapshot of the terminal phase of the farm at Tasilikulooq. Model A could therefore be said to reflect the most plausible age-depth relationship for the Tasilikulooq sequence.

Conclusions

The pollen assemblages from Tasilikulooq are suffused with conundrums. Signs of agriculture and abandonment are present within the same pollen zones and the radiocarbon dates produce modelled age-depth chronologies which are problematic. Although one solution is to assess the data with the aid of multiple working hypotheses, this has not been shown to be conclusive. Instead, the ordination of data with well contextualized fossil pollen archives and the addition of preservation analyses have resulted in insights that help refine interpretations. With this in mind the base of the Tasilikulooq profile could, on balance, be said to reflect a palaeoecological snapshot (beginning in the interval AD 1290-1385) of the landscape impacts associated with the terminal phase of the Norse farm at Tasilikulooq. Disturbance to the sedimentary environment from the beginning of the 15th century precludes further conclusions being drawn about the end of Norse farming at this site. Despite these challenges, this paper demonstrates: (i) the value of multivariate ordinations of large palynological profiles as an interpretative tool; (ii) the long advocated recording of pollen preservation data is a worthwhile exercise; (iii) the importance of considering and understanding taphonomy when evaluating site histories.

The Tasilikulooq profile does not provide the neat results desired at the outset of such a study (i.e. an interpretable landscape history for the Norse farm), and it could be argued that the examination of such compromised sequences is likely to be flawed. We believe, though, that such judgements should be made on a case-by-case basis. If southern Greenland was a landscape in which optimal palaeoenvironmental archives were abundant, then the Tasilikulooq profile would potentially have been avoided. However, this is not such a landscape; organic deposits located close to Norse ruins are rare, and access and sampling can be both difficult and expensive. The Tasilikulooq profile demonstrates that, although complicated, demanding sites can still inform debates and that perceived taphonomic complexities should not prohibit investigation of seemingly sub-optimal archives in the absence of apparently ideal ones.

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Table captions

Table 1 Radiocarbon dates for the Tasilikulooq profile.

Table 2 Comparison of the two age-depth models presented in Figure 5. Age ranges in the table are cal. AD with the end points derived from the minimum and maximum (95%) estimates drawn from the *Clam* age-models. Dates in parentheses are the best estimate from the *Clam* model.

Table 3 The two competing hypotheses for the sediment profile.

Figure captions

Figure 1 Location maps: (A) Greenland (B) Vatnahverfi within the Eastern Settlement; (C) Tasilikulloq and other locations mentioned in the text.

Figure 2 Photographs of the study site: (A) view northeast across Tasersuaq and the modern hayfield towards ruin group Ø171 (Photo: P. M. Ledger, July 2010); (B) looking northeast over ruin group Ø171 towards the modern farm (Photo: K. J. Edwards, July 2010).

Figure 3 The lithology of the sampled profile at Tasilikulooq. Also displayed are a photograph of the profile (sand and gravel not visible), loss-on-ignition, sediment description and Troels-Smith formulae.

Figure 4 Two alternate age-depth models for the Tasilikulooq profile generated using a smoothed spline in *Clam* (Blaauw, 2010).

Figure 5 Percentage pollen and spore diagram for Tasilikulooq displaying selected taxa (minimum sum = 500 TLP). Also shown are the uncalibrated ^{14}C dates, lithology, loss-on-ignition, microscopic charcoal, pollen concentration and the rarefaction index. + indicates <1% TLP

Figure 6 PCA plot combining results from this study with data from sites elsewhere in Vatnahverfi (Ledger et al., 2013, 2014, 2015). (A) Selected pollen types; (B) Sample scores for the combined dataset. (Key to abbreviations: BetG, *Betula glandulosa*; BetP, *Betula* *pubescens;* Bras, Brassicaceae; Cyp, Cyperaceae; Lac, Lactuceae; Poa, Poaceae; Pol.avi, *Polygonum aviculare*; Ran, *Ranunculus acris*-type; Rsella, *Rumex acetosella*; Rtosa, *Rumex acetosa*; Sal, *Salix*.

Figure 7 Pollen preservation diagram for selected taxa from Tasilikulooq. Also displayed are C:P, *Sporormiella*-type spores, and the CONISS dendrogram that was used to aid the assignment of the Local Pollen Preservation Zones (LPPZs *sensu* Tweddle and Edwards, 2010).