

## **Pushing the limits: palynological investigations at the margin of the Greenland Ice Sheet in the Norse Western Settlement**

J. Edward Schofield<sup>1\*</sup>, Danni M. Pearce<sup>2</sup>, Douglas W.F. Mair<sup>3</sup>, Brice R. Rea<sup>1</sup>, James M. Lea<sup>3</sup>, Nicholas A. Kamenos<sup>4</sup>, Kathryn M. Schoenrock<sup>5</sup>, Iestyn D. Barr<sup>6</sup> and Kevin J. Edwards<sup>1,7</sup>

<sup>1</sup> Department of Geography and Environment, School of Geosciences, University of Aberdeen, Elphinstone Road, Aberdeen AB24 3UF, UK

<sup>2</sup> Department of Biological and Environmental Sciences, School of Life and Medical Sciences, University of Hertfordshire, Hatfield, Hertfordshire AL10 9AB, UK

<sup>3</sup> School of Environmental Sciences, University of Liverpool, Jane Herdman Building, Liverpool L69 3GP, UK

<sup>4</sup> Geographical and Earth Sciences, University of Glasgow, Gregory Building, Lilybank Gardens, Glasgow G12 8QQ, UK

<sup>5</sup> Department of Zoology, Ryan Institute, National University of Ireland Galway, University Road, Galway H91 TK33, Ireland

<sup>6</sup> Department of Natural Science, Manchester Metropolitan University, Manchester M1 5DG, UK

<sup>7</sup> McDonald Institute for Archaeological Research and Scott Polar Research Institute, University of Cambridge, Cambridge, UK

\*Corresponding author. Email: [j.e.schofield@abdn.ac.uk](mailto:j.e.schofield@abdn.ac.uk)

### **Abstract**

This paper presents two high-resolution pollen records dating to ~AD 1000-1400 that reveal the impacts of Norse colonists on vegetation and landscape around a remote farmstead in the

Western Settlement of Greenland. The study is centred upon a ‘centralised farm’ (ruin group V53d) in Austmannadalen, near the margin of the Greenland Ice Sheet (64°13’ N, 49°49’W). The climate is low arctic and considered marginal in terms of its suitability for the type of pastoral agriculture that the Norse settlers introduced. The data reveal that at a short distance (~500 m) from the farm buildings, the palynological ‘footprint’ for settlement becomes extremely indistinct, the only clear palaeoenvironmental evidence for a human presence being elevated levels of microscopic charcoal. This contrasts with the Eastern Settlement, where a strong palynological signature for Norse *landnám* is evident, from the local (individual farm) through to the regional (landscape) scale. The palynological data from Austmannadalen, and the Western Settlement more generally, imply that farming occurred at very low intensity. This aligns with ideas that promote the importance of hunting, and trade in valuable Arctic commodities (e.g. walrus ivory), ahead of a search for new pasture as the dominant motivation driving the Norse settlement of this region.

**Keywords:** Greenland, Norse, Western Settlement, pollen analysis, radiocarbon dating, microscopic charcoal.

## Introduction

It is over a century since Daniel Bruun (1917) published the first systematic archaeological survey of Norse ruins in the former Western Settlement (Old Norse [ON] *Vestribyggð*) of Greenland (Fig. 1). This revealed the presence of approximately 60 ruin groups – a number since increased to over 90 (Madsen 2014) – representing former farms, shielings and store houses clustered around the interior of the fjords between the modern Greenlandic capital of Nuuk (~64°10’N, 51°44’W) and the margin of the Greenland Ice Sheet (GrIS). Many questions relating to the occupation, function and fate of the former colony remain unanswered largely as a consequence of the logistical difficulties of conducting field research in this remote region.

*Landnámabók* relates that the first wave of Norse colonists to Greenland (arriving ~AD 985) included people who went on to found the Western Settlement (Ingstad 1966; Krogh 1967), yet details surrounding the timing of abandonment of the colony are more enigmatic.

Following a visit sometime between AD 1341 and 1363 to an unspecified part of the Western Settlement – but speculated as likely to have been Sandnes (ruin group V51; Fig. 2) (Berglund 1986) – the Bishop of Greenland’s representative, Ivar Bardarson, reported the

area as deserted, having encountered only domesticated animals roaming wild (Roussell 1936; Mathers 2009; Seaver 2010). Although Bardarson's *Description of Greenland* must be treated with caution (Berglund 1986), radiocarbon dates on animal bone and structural turves from two of the more intensively studied Norse farms – V51 and GUS (Gården Under Sandet; 'the farm beneath the sand') – support the idea that the end of settlement can be traced to the mid- to late 14th century (Buckland et al. 1996; McGovern et al. 1996; Arneborg and Gullov 1998). Precise details surrounding the societal 'collapse' (Diamond 2005) remain unclear, yet only in one instance – at Nipaatsok (V54) – is there clear evidence that points towards the end having been particularly traumatic for the residents (Panagiotakopulu et al. 2007).

The topography of the Western Settlement contrasts with that of its more southerly counterpart, the Eastern Settlement (ON *Eystribyggð*), in that the former is generally more rugged, steep and mountainous, with fewer flat areas that appear immediately suitable for farming. At ~450 km further north, the Western Settlement is beyond the treeline and much closer to the viable (climatic) limits for the type of pastoral agriculture that the Norse people typically practised during their westward expansion across the islands of the North Atlantic (Dugmore et al. 2005). Simulation models of pasture productivity demonstrate that Western Settlement farms would have been more vulnerable to changes in summer temperature relative to their Eastern neighbour, especially in situations where a number of cold years were experienced in close succession (Barlow et al. 1997). There were locational advantages, however, in that the Western Settlement is approachable by sea throughout the year. This differs from the Eastern Settlement, where shipping may be disrupted in spring and early summer by the mass of broken Arctic sea ice (*storis*; 'great ice') that is driven down the east coast of Greenland and around Cape Farewell by the East Greenland Current (Thomsen 1948; Cappelen et al. 2001). The Western Settlement is also much closer to the Arctic northern hunting grounds (*Norðrseta*; Krogh 1967) centred around Disko Bay (Fig. 1) where the annual summer hunt for walrus (*Odobenus rosmarus* L.) took place (Frei et al. 2015).

This raises questions surrounding the reasons why the Western Settlement was founded. Dugmore et al. (2007) have presented the possibility that it was established primarily to facilitate hunting, and that farming was only a secondary concern for the settlers. This forms part of the wider debate surrounding the purpose of the Norse colonisation of Greenland and Iceland. Opinion has gradually been turning away from the view that this was motivated

primarily by a search for new lands and pasture (Jones 1984) towards ideas that highlight the potential of remote Arctic regions to provide valuable trade goods for Medieval European markets (Keller 2010), although these notions perhaps now need to be counter-balanced by our knowledge that very little of the walrus ivory found in Europe can be genetically-traced to Greenland during the first (11<sup>th</sup>) century of settlement (Star et al. 2018). Studies of vegetation history can continue to play a role in debates surrounding the Greenlandic *landnám* (ON: ‘land-taking’) as they generate empirical evidence regarding the character and intensity of farming (and land use more generally) within the landscapes in which the settlers operated.

Pollen analysis has proven to be a valuable tool in revealing the impacts of pastoral agriculture in the Eastern Settlement (Fig. 1), particularly in the immediate vicinity of the farms. A widely repeated ‘footprint’ for Norse settlement can be seen in the suite of microfossils (primarily pollen, spores, and charcoal) preserved in sedimentary records from peat bogs and lakes across that region (e.g. Fredskild 1988; Edwards et al. 2008, 2011; Gauthier et al. 2010; Schofield et al. 2013; Ledger et al. 2014). Whilst similar lines of evidence are also apparent in some Western Settlement pollen records (e.g. Iversen 1934, 1952-53; Fredskild 1972, 1973; Fredskild and Humle 1991), the numbers of studies are fewer and the absolute chronologies supporting these are either missing or imprecise. Furthermore, much of the data available for the Norse period is of low resolution because many studies were designed to reconstruct vegetation changes over much longer (Holocene) timescales (e.g. Fredskild 1983), with events around the time of the Norse *landnám* only featuring in part.

This paper attempts to address these issues through an analysis of new high-resolution palynological and chronological (<sup>14</sup>C) data from the vicinity of a ‘centralised farm’ (Roussell 1941) in the Western Settlement located very close to the margin of the Greenland Ice Sheet. We present two Norse-age pollen records from contrasting infield/homefield (‘on-site’) and outfield/rangeland (‘off-site’) contexts with the aim being to investigate vegetation changes arising from the Norse *landnám* in different, but adjacent, landscape settings. In doing so, the paper will contribute information to debates regarding the timing and purpose of Norse settlement in the region.

## Background

The location featured in this investigation is the area around ruin group V53d (64°13'35" N, 49°49'11" W; ~220 m a.s.l.). This is in the upper reaches of Austmannadalen (Figs 2 and 3A), a narrow east-west orientated valley running from the watershed west of Kangiata Nunaata Sermia (KNS – a tidewater-terminating outlet of the GrIS) to *Nansens teltplads* (Nansen's tent site) at the head of the Ameralla branch of Ameralik fjord, in the southeast of the former Western Settlement of Greenland. The ruins of V53d (Fig. 3B) are not located immediately adjacent to Kuussuaq – the river running the length of Austmannadalen. Rather, the remains of the farm are found beside a tributary ~1 km north of the main branch of the valley. This stream would have provided the Norse settlers with ample fresh water. The ruins represent the remains of a 'centralized farm' in which most of the buildings – the living quarters, byres, barn, storerooms, and a postulated bath-house – were all drawn together into a single unit (Fig. 4; Roussell 1941).

The site was excavated in 1937. The dig unearthed ~150 objects including a carved wooden crucifix and an iron hunting spear (ibid.). Animal bones (655 fragments) were recovered from the main building and its midden (Degerbøl 1941). Domestic animals account for ~22% of the total collection, with most of these bones identified as being either from sheep or goat (*Ovis/Capra*; 84 fragments [~13% of the total assemblage]), or from cattle (*Bos taurus*; 56 [~9%]). These are heavily outweighed by the number of bones of seals (Phocidae; 378 [~58%]) and reindeer (*Rangifer tarandus*; 120 [~18%]) (McGovern 1985), indicating that wild animals were a very important component of diet. These proportions are similar to those observed for archaeofaunal collections recovered from neighbouring medium-status farms at GUS and Nipaatsok (V54; Enghoff 2003), and other farms within Austmannadalen (V53a and c; McGovern 1985). By contrast, the large high-status site with its church at Sandnes (V51) shows greater percentages of reindeer (~29%) and cattle (16%) bone, with similar frequencies of caprines (~11%) and fewer seals (34%) (McGovern 1985). These figures need to be viewed with the caveat that domestic animals may have been kept mainly for the secondary products these can supply (i.e. milk and wool), rather than simply raised for their meat (cf. McGovern and Jordan 1982).

The climate in this region of Greenland is low arctic. Contemporary mean statistics for temperature and precipitation are difficult to provide as there are very few meteorological stations close to the field site that possess a long series of observations. Nuuk has instrumental records for monthly/annual air temperature that extend back to AD 1784

(Cappelen 2019), but strong gradients in temperature and precipitation between the coast and ice sheet mean that this dataset cannot be used to describe conditions inland without extrapolation (e.g. Taurisano et al. 2004). Short and broken meteorological records are available for Qoornoq and Kapisillit. The station nearest to V53d – at Kapisillit (Fig. 2) – records mean summer temperatures (June to August) of 9.7 °C and annual precipitation of 255 mm, although these figures should be treated cautiously as they reflect the average conditions from AD 1939-1956 (Fredskild 1996).

The local geology is mainly gneisses with some interspersed amphibolites (Escher and Watt 1976). The dominant soil types are brown soils – often slightly podzolised – and lithosols (Fredskild 1996). The vegetation in Austmannadalen is characteristically dwarf-shrub heath composed predominantly of *Betula nana* (dwarf birch), *Salix glauca* (northern willow), and *Empetrum nigrum* (crowberry), with occasional *Juniperus communis* ssp. *alpina* (alpine juniper); plant nomenclature follows Böcher et al. (1968). Dense stands of *S. glauca* scrub up to ~2 m tall – often containing *Alnus crispa* (green alder) – are found in damp, sheltered areas beside the river and on the lower valley slopes. Grasses and herbs including *Artemisia borealis* (northern wormwood), *Potentilla tridentata* (three-toothed cinquefoil) and *Thymus praecox* (wild thyme) are found on drier slopes. Fen communities characterised by *Eriophorum angustifolium* (common cottongrass) and *Carex* spp. (sedges) are encountered over wet ground (Fredskild 1996; Rune 2011).

## Methodology

### *Fieldwork and sampling*

Prospecting with an Eijkelkamp gouge auger in the area around V53d revealed two places with organic deposits suitable for pollen analysis. Samples were collected by digging pits and inserting monolith tins into cleaned section faces. The first monolith was taken from a soil profile – regarded as likely to be an anthrosol (cf. Golding et al. 2011; Ledger et al. 2015) – within willow scrub approximately 50 m west of the dwelling (64°13'37''N, 49°49'16''W, ~220 m a.s.l. [Fig. 3B]). The second monolith contains peat from a mire situated within a relatively large basin (~300 x 800 m) around 500 m northeast of the ruins of V53d. The basin is enclosed by steep slopes and elevated relative to V53d (64°13'46'' N, 49°48'37'' W, ~320 m a.s.l. [Fig. 3C]).

### *Laboratory analyses*

Pollen samples were prepared using standard procedures (Moore et al. 1991) with tablets of *Lycopodium clavatum* spores added to enable the calculation of microfossil concentrations and influx (Stockmarr 1971). Pollen and spore identifications were confirmed using reference material held at the University of Aberdeen, and the keys and photographs in Moore et al. (1991) and van Geel et al. (2003). Palynomorph percentages were calculated on a total land pollen sum (TLP; trees, shrubs and heaths, and herbs) exceeding 300 grains. Pollen diagrams were constructed using the software TILIA (TiliaIT 2019) and were divided into local pollen assemblage zones (LPAZs) with the assistance of CONISS (Grimm 1987). Microscopic charcoal particles present in pollen sample residues were quantified. Charcoal data are presented as both ratios of charcoal to pollen concentration (C:P) and influx (Patterson et al. 1987). Rarefaction analysis (Birks and Line 1992) – a measure of species richness – was performed using the software *RStudio*. The organic content of samples was established through loss-on-ignition (LOI) following combustion at 550°C.

Plant macrofossils (byrophytes and seeds) and fragments of charcoal were extracted from the monolith tins for AMS radiocarbon ( $^{14}\text{C}$ ) measurement. In most instances, these have proven to be reliable materials for  $^{14}\text{C}$  dating from Norse sites in Greenland (cf. Edwards et al. 2008; Blockley et al. 2015). The charcoal appears to be derived from woody plants, although taxonomic identification (Schweingruber 1990) was not attempted due to the small size of the particles (longest axis <2 mm) and the need to preserve fragments intact for potential dating purposes. The humic acid fraction of small (1 cm<sup>3</sup>) peat samples was dated where suitable macrofossils for AMS could not be found.

To assist macrofossil extraction, samples were soaked in weak 10% NaOH for 24h to disaggregate the sediment prior to sieving (500 µm mesh). Macrofossil samples were stored in glass vials with distilled water prior to measurement at the  $^{14}\text{C}$ CHRONO Centre, Queen's University Belfast. The calibration of radiocarbon age-estimates was performed using the online version of Calib v.7.1 software (Stuiver and Reimer 1993) and the IntCal13 calibration curve (Reimer et al. 2013). The Bayesian modelling software *Bacon* (Blaauw and Christen 2011) was used to construct an age-depth model for the mire profile. The calendar ages used to ascribe timing to the events in the pollen diagram are the 'best' (mean) age-estimates for each depth taken from the model, unless otherwise stated. Age-depth modelling of the soil profile was not undertaken because of the limited availability of  $^{14}\text{C}$  dates.

### *Pollen source areas and other taphonomic considerations*

The characteristics of the two sites and deposits selected for this research are very different, and this will influence the vegetation reconstruction at each sampling location. The relevant source area of pollen, or RSAP, is an important consideration here. The RSAP is defined as, ‘the spatial scale appropriate for detecting variations in local vegetation from pollen records’ (Sugita et al. 1999: 410), and is the distance beyond which the relationship between pollen assemblages and the vegetation does not improve. RSAP is largely a function of the vegetation mosaic and the size/radius of the basin being sampled – whether this be a hollow, mire, or lake (Sugita 1994; Bunting et al. 2004; Hellmann et al. 2009) – making the pollen source area difficult to define with any precision for fossil records. RSAP has been estimated using various landscape and vegetation scenarios/simulations, yet very few of these apply directly to completely open (treeless) situations such as those one expects to encounter in the low Arctic. Perhaps the most instructive studies in this context come from Scandinavia. Sugita et al. (1999) have estimated the RSAP to be ~800-1000 m for small lakes and hollows (100 m radius) in open and semi-open cultural landscapes in lowland Sweden, and von Stedingk et al. (2008) predict a RSAP of ~500 m for moss polsters at the forest-tundra ecotone (a semi-open landscape) in upland west-central Sweden. The mire in Austmannadalen might be anticipated to have a RSAP at or just beyond the upper end of this range of values as the site is quite large (up to ~300 m diameter) but the contemporary vegetation mosaic (described above) is relatively simple.

The soil profile (anthrosol) presents a different set of palynological challenges given that this contains a cultural horizon that has (presumably) been largely generated through repeated additions of farm waste containing secondary (redeposited) microfossils, as well as receiving the airborne pollen rain from the surrounding vegetation (cf. Buckland et al. 2009). A range of other taphonomic issues can also influence the interpretation of pollen diagrams from soils. These include the differential preservation of pollen types, faunal mixing, and the slow downwash of grains through the soil profile (Dimbleby 1985). At Norse sites in Greenland, anthrosols appear to retain a high degree of biostratigraphic integrity; although the homefields were manured, they were not ploughed (Ingstad 1966). These contexts are thus considered to be reliable palynological archives that strongly reflect events at, and immediately around, the individual farms at which they are found (Ledger et al. 2015).



## Results and interpretation

### *The anthrosol ('on-site')*

The stratigraphy at this location (Fig. 5) comprises a base of fine yellowish-grey sand. Above this, beginning at a depth of ~35 cm, is a medium brown organic-rich layer of variable minerogenic content (LOI ~20-60%) displaying occasional narrow sandy stripes. Laboratory inspection revealed small charcoal fragments throughout the unit and abundant seeds of *Montia fontana* (blinks). These features are typical of anthrosols (Ap horizons) reported from the hay-producing homefields of Norse farms throughout Greenland (Fredskild 1978; Buckland et al. 2009; Golding et al. 2011, 2015; Ledger et al. 2015). The contact between the basal sand and the anthrosol is very sharp. This indicates that turf is likely to have been stripped from this immediate area to provide building materials (Krogh 1967) prior to it being turned over to farming. The anthrosol is capped by a root mat (~0-7 cm).

Two radiocarbon dates are available for the profile (Table 1); one date is positioned very close to the base of the anthrosol (33-31 cm; UBA-31333; 1101±49 BP; cal AD 777-1022 [95.4%]), and the other is towards the top of the same unit (15-14 cm; UBA-31334; 645±46 BP; cal AD 1278-1401 [95.4%]). Probability distributions for the calibrated dates (Fig. 6) indicate a high likelihood that the lower sample is late 10<sup>th</sup> or early 11<sup>th</sup> century AD in age, whilst the upper sample most probably dates to the 14<sup>th</sup> century. These provide corroboratory evidence that the anthrosol is of Norse age, and that this accumulated over a ~400 cal yr interval coincident with the conventionally-accepted period of occupation for the Western Settlement.

The pollen diagram constructed for this profile (Fig. 7) is divisible into three local pollen assemblage zones (LPAZs prefixed AUS-, signifying Austmannadalen). Zonation closely matches the tripartite stratigraphic sequence for the soil profile described above. LPAZ AUS-1 (38.0-34.5 cm) corresponds with the pre-settlement basal sands. Assemblages contain high frequencies of pollen from *Betula* (birch; ~35-60 % TLP), *Salix* (willow; ~10-20 %), Cyperaceae (sedges; ~10-20 %), and pteridophyte spores, particularly *Lycopodium annotinum* (interrupted clubmoss; ~10-20 %). It is possible that the high incidence of pteridophytes is a function of differential palynomorph survival in the highly minerogenic matrix (cf. Ledger et al. 2015). If accepted at face value, the data indicate relatively dense

local coverage of dwarf shrub (birch-willow) heath, possibly with some damp open areas supporting graminoid communities. Species richness – as indicated by rarefaction – is low.

Pollen assemblages within LPAZ AUS-2 – which is broadly coincident with the Ap horizon – are dominated by Poaceae (grass) pollen. Frequencies rise to ~80 % in some samples. Similar Poaceae values were observed in the plaggen soil at the Bishop's farm (Igaliku/*Garðar*) in the Eastern Settlement (Buckland et al. 2009) and must largely be derived from the *in situ* vegetation within the homefield. Shrub pollen values are heavily reduced relative to AUS-1, and a wider variety of herbaceous pollen types are recorded leading to an increase in species richness (rarefaction rises to ~20 taxa per sample). The herbs include a range of plants regarded as apophytic and often encountered as components of a settlement 'footprint' around Norse farms in Greenland (Fredskild 1988; Edwards et al. 2011; Schofield et al. 2013). Examples include *Artemisia*-type (approaching 5 % in some samples), Caryophyllaceae (pinks; ~2-5 %), *Rumex acetosella* (sheep's sorrel; rising to 2 %), and Lactuceae (dandelion tribe; exceeding 10 % in one case). Post-depositional biasing of pollen assemblages can sometimes be a problem where samples have been taken from archaeological contexts, and high frequencies of 'resistant' taxa – such as Lactuceae – have been identified as one of a number of potential indicators for this (Bunting and Tipping 2000). Yet in AUS-2 there are no obvious signs that assemblages suffer in this manner. For example, the frequencies of Pteridophyte spores and indeterminate pollen grains are under the recommended 'failure' thresholds set for problematic samples (ibid.). Although species richness/diversity is relatively low, this is probably to be expected given the limited range of vascular plants that are recorded for this region (Böcher et al. 1968; Fredskild 1996).

In the first palynological study to be conducted at a Norse farm in Greenland – at Anavík (V7), approximately 50 km north of Austmannadalen (Fig. 2) – Iversen (1934) reported an 'on-site' soil profile containing a thin (~2 cm) but distinct charcoal layer that immediately preceded a palynological signature for Norse *landnám*. This was interpreted as evidence for the use of fire in clearing birch-willow scrub at the onset of settlement. In the soil profile at V53d there are no clear macroscopic charcoal horizons within the stratigraphy to indicate the *in situ* burning of vegetation, either to clear/prepare the area for settlement or farming (although the process of stripping turf, described above, might have led to evidence for this being removed), or to suggest the regular burning of grass stubble. The elevated microscopic charcoal values witnessed in AUS-2 – particularly towards the top of the zone – and the

macroscopic fragments of charcoal encountered throughout the sediment unit seem most likely to reflect the addition of ash to the soil from domestic hearths in order to promote hay growth. Traces of spores from coprophilous fungi (HdV-55a *Sordaria*-type; van Geel et al. 2003) are recorded in AUS-2 indicating the probable addition of animal dung to the anthrosol as fertilizer, yet spore frequencies are notably lower than in similar deposits in the Eastern Settlement (Buckland et al. 2009; Golding et al. 2011; Ledger et al. 2015), and certain key coprophilous spore types are conspicuous by their absence. Most notably, spores of the dung fungus HdV-113 *Sporormiella*-type (Raper and Bush 2009) – which is typically an identifying feature of the Greenlandic Norse ‘footprint’ (Gauthier et al. 2010; Edwards et al. 2011) – are absent from this zone. This may point towards a less-intensive fertilization regime for the V53d homefield relative to Eastern Settlement farms.

The uppermost LPAZ (AUS-3) contains just two samples and must be interpreted cautiously. Assemblages appear to show the beginning of a decline in Poaceae pollen and a recovery in shrubs. This seemingly reflects the post-14<sup>th</sup> century (abandonment phase) regeneration of dwarf shrub heath. *Salix* displays peak frequencies (~35 %) at the top of the zone, and for the first time rises to dominance ahead of *Betula*. The expansion of willow scrub is a common feature of the cooler ‘Little Ice Age’ post-Norse vegetation histories of many Eastern Settlement landscapes (e.g. Schofield et al. 2008; Buckland et al. 2009; Ledger et al. 2014).

#### *The mire (‘off-site’)*

The mire stratigraphy comprises peat to a depth of at least 40 cm. This contains a significant and fluctuating inorganic component. LOI ranges from ~5-60 % and the peat contains narrow sandy horizontal bands that are most frequent at 28-20 cm. These patterns must reflect high but variable rates of soil erosion and the regular delivery of minerogenic sediment to the wetland surface via slopewash. Radiocarbon dates for this profile form a coherent series (Table 1; Figs 6 and 8) and demonstrate that the pollen diagram (Fig. 9) spans the period ~AD 450-1820.

Four LPAZs prefixed BAu – signifying the basin of Austmannadalen – have been defined for this location. LPAZ BAu-1 (32-28 cm; ~AD 450-700) pre-dates the Norse *landnám* and is very similar in composition to AUS-1. Collectively, pollen from shrubs and heaths – *Alnus*, *Betula*, Ericaceae, *Juniperus* and *Salix* – approaches 60 % in most samples indicating substantial local coverage of scrub vegetation and dwarf shrub heath. Significant quantities of

Cyperaceae pollen (~20-50 %) and *Sphagnum* spores (up to 40 % in one sample) are likely to reflect the mire surface (wetland) communities.

LPAZ BAu-2 is divided into two subzones (a and b). BAu-2a (28-25 cm) covers the period ~AD 700-870. The most significant change across the BAS-1/2a boundary is a sustained fall (to <5 %) in *Alnus* pollen. Pollen records from western Greenland show that *Alnus* pollen frequencies were in decline over an extended period through the course of the first millennium AD, a pattern that Fredskild (1983) has interpreted as reflecting a change towards generally cooler conditions relative to the mid-Holocene. The minerogenic content of the peat rises steadily through this LPAZ. Soil erosion has often been observed to increase sharply following the AD 985 *landnám* in the Eastern Settlement (e.g. Edwards et al. 2008; Massa et al. 2012), although in Austmannadalen the factor(s) driving sediment delivery to the mire surface during BAu-2a seem unlikely to be anthropogenic, given the estimated timing of events (i.e. beginning ~AD 700).

LPAZ BAu-2b (25-21 cm; ~AD 870-1250) appears to contain a signature for anthropogenic impact on the environment. The palynological ‘footprint’ left by the settlers is, however, much weaker than that typically recorded in most of the other North Atlantic island landscapes that these people colonised (cf. Edwards et al. 2011). The age-depth model (Fig. 8) provides a ‘best’ estimate of ~AD 870 for the BAu-2a/b boundary, but when the model output is viewed more elastically using the 95% confidence limits, it is possible that this biostratigraphic boundary dates to the late 10<sup>th</sup> to early 11<sup>th</sup> centuries AD – the period when the first Norse settlers arrived in Greenland.

The opening of BAu-2b witnesses a temporary decline in *Betula* pollen (from ~30 % to <15 %) and the first appearance of traces (<1 %) of coprophilous fungal spores (*Sordaria*- and *Sporormiella*-type). This could indicate a reduction in dwarf birch heath through grazing pressure, although pollen from other shrubs (*Salix* and *Juniperus*) increases such that the overall coverage of scrub vegetation probably remained largely unchanged. A range of herbaceous pollen types is recorded at trace values, but species richness shows little change relative to previous zones, and many of the taxa that are recorded can be regularly encountered as components of low Arctic heaths (Fredskild 1996). These include, for example, *Artemisia*-type, *Campanula gieseckiana* (common harebell), and *Thalictrum alpinum* (alpine meadow-rue), each of which appear consistently at <1 %.

*Rumex acetosella* pollen occurs in most samples in BAu-2b. The appearance and increase of this pollen type in Eastern Settlement pollen diagrams is regarded as a biostratigraphic marker for Norse *landnám* (Schofield et al. 2013), but Western Settlement records for this plant need to be treated more cautiously. *R. acetosella* is native to the Western Settlement, appearing as early as ~7400 cal BP (~5500 cal BC) in some pollen diagrams from the region (Fredskild 1983), and pollen from this plant appears at trace levels (<1%) in two pre-*landnám* (BAu-2a) assemblages from Austmannadalen. Nevertheless, the low frequency of occurrence of this pollen type at V53d – both in the mire and the anthrosol – is a little unexpected given that a sharp rise in *R. acetosella* pollen was identified as a defining feature of *landnám* in the ‘on-site’ pollen record from Anavík (Iversen 1934; Fredskild 1972).

The microscopic charcoal record presents stronger evidence of an anthropogenic signature. C:P rises in the uppermost sample within BAu-2a and remains above the baseline (established in BAu-1) throughout BAu-2b, a pattern also clearly reflected in the charcoal influx data (Fig. 10). Fragments of macroscopic charcoal – which would be produced by local fires – were not observed in the peat. This indicates that the charcoal seen in pollen samples was generated off-site, possibly as part of a regional signal for burning at *landnám*. In a sediment core taken from a lake (Johannes Iversen SØ) near Kapisillit, ~30 km northwest of Austmannadalen (Fig. 2), Fredskild (1983: 10) recorded a ‘sudden and pronounced’ maximum in microscopic charcoal in the late first millennium AD. He attributed this to the onset of Norse settlement, yet *landnám* appears largely unremarkable in that site’s pollen record, with contemporary changes noted in a small decrease in *Juniperus* pollen (the opposite is seen in BAu-2b) and a minor rise in *R. acetosella*.

Peak influx of microscopic charcoal ( $\sim 250 \times 10^{-6} \text{ cm}^2 \text{ cm}^{-2} \text{ yr}^{-1}$ ) is recorded in the middle of BAu-3 (21-17 cm; ~AD 1250-1490). Charcoal input then falls to, and remains around, the levels recorded in BAu-1 (prior to *landnám*). The decline in charcoal seems likely to mark the abandonment of the region by the Norse. Otherwise, BAu-3 presents little, if any, indication for the presence of people or their domesticated animals in this landscape. The main palynological event defining this biostratigraphic zone is a temporary peak (~40 %) in pollen from Ericaceae, and a decline in Cyperaceae (falling from ~50 % to <20 %). This may indicate the local expansion of ericaceous shrubs across the mire surface at the expense of sedge communities. These vegetation changes could be climatically-controlled given that

they coincide with a phase of low pollen influx to the peat (Fig. 10), the most likely explanation for which is a reduction in plant flowering in response to lowered summer temperatures. Cyperaceae pollen frequencies recover in BAu-4 (17-10 cm; ~AD 1490-1820), rising to ~40-70 %, whilst *Betula* pollen values decline, often registering under 10 %. This could indicate the replacement of dwarf birch heath by steppe communities in more exposed places with thin snow cover during what was generally a period of cool conditions within the 'Little Ice Age'.

## Discussion

As one would anticipate, the two pollen profiles from V53d provide contrasting signals for Norse impacts on the environment. This outcome is in accord with results obtained through the analysis of multiple pollen profiles in the Eastern Settlement (Ledger et al. 2014), where a more subdued 'footprint' for *landnám* (cf. Edwards et al. 2011) has been demonstrated for rangeland environments. What is surprising for Austmannsdalen is the extent to which the 'off-site' signature for Norse settlement becomes diluted at relatively short distance (~500 m) from the farm buildings. The sampling location is inside the likely pollen source area for the farm/structures (see the earlier discussion of RSAP for this site), yet other than elevated levels of microscopic charcoal, there is only equivocal palynological evidence for human activity recorded within the peat profile collected from the mire. The data hint towards the possibility of a decline in dwarf birch heath at *landnám*, but pollen values for *Betula* soon recover to match their earlier (pre-*landnám*) frequencies. Coincident with this, a very small number of coprophilous fungal spores are registered but, similarly, this signal fades quickly.

The data from the mire at V53d are in broad agreement with palynological results from similar (rangeland) landscape settings across the region. Two Holocene lake sediment records from Kapisillit show limited evidence for vegetation change during the Norse settlement period other than a dramatic rise in microscopic charcoal (Iversen 1952-52; Fredskild 1973, 1983). The situation is much the same at Karra (Fig. 2), another lake in the northern (inner Godthåbsfjord) area of the Western Settlement (Fredskild 1983). For the Western Settlement in particular, it has been argued that there was burning of scrub vegetation at *landnám* to clear areas for settlement (Fredskild 1988), although this idea is largely based upon evidence from Iversen's (1934) study at Anavík (discussed above). The observation that microscopic charcoal levels are elevated in all lake and mire records throughout the period of settlement

suggests that burning of vegetation was sustained, and/or that many of the particles were being generated from fires in domestic settings (cf. Edwards et al. 2008). In a mire around 1 km north of Sandnes (V51), a 3 mm thick charcoal horizon possibly marks burning of the local vegetation coincident with *landnám*, but the associated palynological record exhibits little immediate response other than a small rise in *Rumex acetosella* (Fredskild and Humle 1991).

The emerging picture from the Western Settlement pollen record is therefore one of use of the wider landscape by people and animals at a very low intensity. This contrasts with the situation in the Eastern Settlement where lake deposits with regional pollen source areas (e.g. Lake Igaliku [Gauthier et al. 2010]), and smaller basins that are close to the farms but somewhat removed from the archaeology (cf. Galium Kær [Fredskild 1973] and Lake Vatnahverfi [Ledger et al. 2014]), each contain clear signals for pastoral farming. These patterns appear to resonate with the zooarchaeological data from Greenland. Table 2 compares assemblages of animal bone collected from Norse farms in Vatnahverfi – a region of the Eastern Settlement generally regarded as having provided the Norse with high-quality pasture (Væbek 1992; Ledger et al. 2014) – with Austmannadalen. Whilst the information in Table 2 is selective (and also partially constrained by the available datasets), it does serve to highlight the widely-reported pattern that lower proportions of domestic animal bone are found on farms in the Western Settlement relative to its Eastern counterpart (McGovern 1985).

Within the context of an analysis of the importance of domestic grazers on the wider landscape beyond the farms, the numbers of caprine (sheep and goat) bones are most instructive, for these might be very loosely equated with the potential level of grazing pressure. The frequencies of caprine bones found on sites in Austmannadalen is low and generally one-third of that seen in Vatnahverfi. The exception is GUS, where the proportion of sheep and goat bones (~30 %) is over double that (~12-14 %) reported at Sandnes, V53c and V53d. There are currently no palynological data available for GUS – the only palaeovegetational analyses are macrobotanical remains collected ‘on-site’ (Ross 1998) – but, if such data were to become available, it would be interesting to see if a stronger signal emerges for human/animal impact on the vegetation surrounding that farm. In contrast to stocking patterns in both the Eastern Settlement and Iceland, goats appear to have equalled, and in some cases, outnumbered sheep on many Western Settlement farms (McGovern et al.

2014). Goats are more effective at metabolising woody browse than either sheep or cattle, and this has led to a belief that there was a lack of good pasture in the Western Settlement (Amorosi et al. 1998). The low grass pollen frequencies (typically under 10%) seen within the ‘off-site’ assemblages from V53d do nothing to dispel this idea.

If the farms in Austmannadalen invested little effort into pastoral agriculture, this implies that the inhabitants concentrated more of their time on other activities, the most obvious being the exploitation of wild resources. Sandnes has the greatest concentration of walrus bone fragments from any Norse site in Greenland, indicating that the processing of ivory was particularly intensive here (McGovern et al. 1996). The export of walrus ivory was an extremely profitable business; a single shipment of Greenlandic ivory sold in Bergen in AD 1327 was worth more than the annual tax from nearly 4,000 Icelandic farmers (Keller 2010; Frei et al. 2015). It would be surprising if the settlers on farms near Sandnes were not also heavily invested in this process, even if only in terms of providing tenant labour for the walrus hunt.

The other resource that was seemingly plentiful in the Austmannadalen region was reindeer. This is indicated by the high concentration of *Rangifer tarandus* bones in the middens (Table 2; McGovern 1985; McGovern et al. 1996). Norse ruins groups in the Western Settlement are generally located on the fjords allowing immediate access in and out by boat, but in the southeast of the region several of the farms – including V53d – are found many kilometres inland. This may have presented locational advantages when it came to hunting reindeer. In the Nuuk region, the pastures at the margin of the GrIS were, historically, places where reindeer congregated in large numbers during the summer (Meldgaard 1986). At least three Norse reindeer hunting stations – with blinds and/or rock fences – have been reported, whilst several other farms appear strategically well-placed (near passes or river fords) to intercept migrating animals (McGovern and Jordan 1982; McGovern et al. 1996). If reindeer were plentiful, this perhaps negated the need to keep large numbers of domesticated animals, perhaps other than to satisfy subsistence requirements for products other than meat, such as milk, butter, cheese and skyr (ibid.). This would still have required an amount of hay to be produced on the farm for the over-wintering of these animals, but possibly not on a large scale. Indeed, in his initial observations on the physical setting for the farm at V53d, Roussell (1941: 68) felt that there, ‘would scarcely have [been] any home-field proper’. Whilst the present study has established evidence for a homefield in the form of an anthrosol, time and



logistics did not allow its full extent to be ascertained. This would certainly be useful information to gather (e.g. through stratigraphic survey; cf. Buckland et al. 2009) if this site were ever to be revisited for further study.

## **Conclusions**

The westward expansion of Norse colonists across the North Atlantic region resulted in the settlement of landscapes that were increasingly Arctic in character. This must have pushed traditional European agricultural systems very close to their physical limits (Barlow et al. 1997; Dugmore et al. 2005). Nevertheless, the settlers were not deterred. In the Western Settlement of Greenland, several farmsteads were established in incredibly remote locations, sometimes even at the fringes of the ice sheet, giving, ‘a strong impression that dwellings were built in almost every place where it was possible to survive’ (Ingstad 1966: 22). This has led to the opinion that the subsistence and economy of this part of the Greenland colony was strongly orientated towards hunting (e.g. Dugmore et al. 2007), a theory which finds support in the high concentrations of non-domestic animal bone (seal and reindeer) reported in Norse middens from this area (e.g. McGovern 1985).

New palynological data presented in this paper from a remote inland farm (V53d) in Austmannadalen appear to add weight to this idea. Beyond the immediate vicinity of the farm buildings and its homefield, there is little definitive evidence within the palynological record to indicate any significant or lasting impact or pressure from Norse settlement and agriculture on the vegetation. Were it not for records of microscopic charcoal contained in mire and lake sediments, the former presence of the Norse people within the wider landscape might pass largely unnoticed in the palynological record. This contrasts with evidence from the Eastern Settlement where a palynological ‘footprint’ for pastoral farming is clearly apparent, not only immediately around the farm buildings (e.g. Edwards et al. 2008; 2011) but also at some distance from these (e.g. Fredskild 1973; Gauthier et al. 2010; Ledger et al. 2014).

The conclusions drawn for Austmannadalen should be considered as tentative when applied more widely to the Western Settlement, given that only a small number of detailed palynological studies are currently available across this region. This highlights the need for further investigations to verify the ideas being presented here. These should target polleniferous deposits not only in locations immediately adjacent to the ruins of the farms,

but also in the areas beyond these which formed part of the wider landscape in which the Norse settlers – and their animals – operated.

### *Acknowledgements*

This research was supported by the Leverhulme Trust under Project Grant 2014-093 ('Calving glaciers: long-term validation and evidence'). JMLs participation with fieldwork was funded by the Quaternary Research Association (QRA) and the British Society for Geomorphology (BSG). Staff at the Greenland National Museum and Archives in Nuuk are thanked for granting us permission to conduct fieldwork within Austmannadalen. Audrey Innes, Jenny Johnston and Jamie Bowie provided laboratory and cartographic support. Finally, we thank two anonymous reviewers who provided helpful comments that led to improvements in the manuscript.

### *Disclosure statement*

No potential conflict of interest was reported by the authors.

### **References**

- Amorosi, T., P. C. Buckland, K. J. Edwards, I. Mainland, T. H. McGovern, J. P. Sadler and P. Skidmore. 1998. "They did not live by grass alone: the politics and palaeoecology of animal fodder in the North Atlantic region." *Environmental Archaeology* 1: 41-54.
- Arneborg, J. and H. C. Gulløv. 1998. *Man, culture and environment in ancient Greenland*. Danish Polar Centre Publication No. 4. Copenhagen: Danish National Museum & Danish Polar Center.
- Barlow, L. K., J. P. Sadler, A. E. J. Ogilvie, P. C. Buckland, T. Amorosi, J. H. Ingimundarson, P. Skidmore, A. J. Dugmore and T. H. McGovern, T. H. 1997. "Interdisciplinary investigations of the end of the Norse Western Settlement in Greenland." *The Holocene* 7: 489-499.
- Berglund, J. 1986. "The decline of the Norse settlements in Greenland." *Arctic Anthropology* 23: 109-135.

- Birks, H. J. B. and J. M. Line. 1992. "The use of rarefaction analysis for estimating palynological richness from Quaternary pollen-analytical data." *The Holocene* 2: 2-10.
- Blaauw, M. and J. A. Christen. 2011. "Flexible paleoclimate age-depth models using an autoregressive gamma process." *Bayesian Analysis* 6: 457-474.
- Blockley, S. P. E., K. J. Edwards, J. E. Schofield, S. D. F. Pyne-O'Donnell, B. J. L. Jensen, I. P. Matthews, G. T. Cook, K. L. Wallace and D. Froese. 2015. "First evidence of cryptotephra in palaeoenvironmental records associated with Norse occupation sites in Greenland." *Quaternary Geochronology* 27: 145-157.
- Böcher, T. W., K. Holmen and K. Jakobsen. 1968. *The Flora of Greenland*. Copenhagen: P. Hasse & Son.
- Bruun, D. 1917. "Oversigt over Nordboruiner I Godthaab- og Frederikshaab-Distrikter." *Meddelelser om Grønland* 56: 57-147.
- Buckland, P. C., T. Amorosi, L. K. Barlow, A. J. Dugmore, P. A. Mayewski, T. H. McGovern, A. E. J. Ogilvie, J. P. Sadler and P. Skidmore. 1996. "Bioarchaeological and climatological evidence for the fate of Norse farmers in medieval Greenland." *Antiquity* 70: 88-96.
- Buckland, P. C., K. J. Edwards, E. Panagiotakopulu and J. E. Schofield. 2009. "Palaeoecological and historical evidence for manuring and irrigation at *Gardar* (Igaliku), Norse Eastern Settlement, Greenland." *The Holocene* 19: 105-116.
- Bunting, M. J., M. -J. Gaillard, S. Sugita, R. Middleton and A. Broström. 2004. "Vegetation structure and pollen source area." *The Holocene* 14: 651-660.
- Bunting, M. J. and R. Tipping. 2000. "Sorting dross from data: possible indicators of post-depositional assemblage biasing in archaeological palynology." In *Human Ecodynamics*, edited by G. Bailey, N. Winder and R. Charles, 63-69. Oxford, Oxbow Books.

- Cappelen, J. (ed) 2019. *Greenland – DMI historical climate data collection 1784-2018*. Danish Meteorological Institute (DMI) Report 19-04. Copenhagen: DMI.
- Cappelen, J., B. V. Jørgensen, E. V. Laursen, L. S. Stannius and R. S. Thomsen. 2001. *The observed climate of Greenland, 1958-99 – with climatological standard normals, 1961-90*. Danish Meteorological Institute (DMI) Technical Report 00-18. Copenhagen: DMI.
- Diamond, J. 2005. *Collapse: how societies choose to fail or survive*. London: Penguin Group.
- Degerbøl, M. 1941. “The osseous material from Austmannadal and Tungmeralik: Western Settlement, Greenland.” *Meddelelser om Grønland* 89: 345-354.
- Dimbleby, G. W. 1985. *The Palynology of Archaeological Sites*. London: Academic Press.
- Dugmore, A.J., M. J. Church, P. C. Buckland, K. J. Edwards, I. Lawson, T. H. McGovern, E. Panagiotakopulu, I. A. Simpson, P. Skidmore and G. Sveinbjarnardóttir. 2005. “The Norse *landnám* on the North Atlantic islands: an environmental impact assessment.” *Polar Record* 41: 21-37.
- Dugmore, A. J., C. Keller and T. H. McGovern. 2007. “Norse Greenland settlement: reflections on climate change, trade, and the contrasting fates of human settlements in the North Atlantic islands.” *Arctic Anthropology* 44: 12-36.
- Edwards, K. J., E. Erlendsson and J. E. Schofield. 2011. “Is there a Norse ‘footprint’ in North Atlantic pollen records?” In *Viking Settlements and Society: Papers from the Sixteenth Viking Congress, Reykjavík and Reykholt, 16-23 August 2009*, edited by S. Sigmundsson, A. Holt, G. Sigurðsson, G. Ólafsson and O. Vésteinsson, 65-82. Reykjavík: Hið íslenska fornleifafélag and University of Iceland Press.
- Edwards, K. J., J.E. Schofield and D. Mauquoy. 2008. “High resolution paleoenvironmental and chronological investigations of Norse *landnám* at Tasiusaq, Eastern Settlement, Greenland.” *Quaternary Research* 69: 1-15.

Enghoff, I. B. 2003. "Hunting, fishing and animal husbandry at The Farm Beneath The Sand, western Greenland." *Meddelelser om Grønland, Man & Society* 28: 1-104.

Escher, A. and W. S. Watt (eds). 1976. *Geology of Greenland*. Copenhagen: Geological Survey of Greenland.

Fredskild, B. 1972. "Palynological evidence for Holocene climatic changes in Greenland." *Acta Universitatis Ouluensis A* 3, 277-305.

Fredskild, B. 1973. "Studies in the vegetational history of Greenland." *Meddelelser om Grønland* 198: 1-245.

Fredskild, B. 1978. "Palaeobotanical investigations of some peat deposits of Norse age at Qagssiarssuk, south Greenland." *Meddelelser om Grønland* 204: 1-41.

Fredskild, B. 1983. "The Holocene vegetational development of the Godthåbsfjord area, West Greenland." *Meddelelser om Grønland, Geoscience* 10: 1-28.

Fredskild, B. and L. Hulme. 1991. "Plant remains from the Norse farm Sandnes in the Western Settlement, Greenland." *Acta Borealia* 1: 69-81.

Fredskild, B. 1988. "Agriculture in a marginal area – South Greenland from the Norse landnam (985 A.D.) to present (1985 A.D.)." In *The Cultural Landscape: past, present and future*, edited by H. H. Birks, H. J. B. Birks, P. E. Kaland and D. Moe, 381-393. Cambridge, Cambridge University Press.

Fredskild, B. 1996. "A phytogeographical study of the vascular plants of west Greenland." *Meddelelser om Grønland, Bioscience* 45: 1-157.

Frei, K. M., A. N. Coutu, K. Smiarowski, R. Harrison, C. K. Madsen, J. Arneborg, R. Frei, G. Guðmundsson, S. Sinbæk, J. Woollett, S. Hartman, M. Hicks and T. H. McGovern. 2015. "Was it for walrus? Viking Age settlement and medieval walrus ivory trade in Iceland and Greenland". *World Archaeology* 47: 439-466.

Gauthier, E., V. Bichet, C. Massa, C. Petit, B. Vanni re and H. Richard. 2010. "Pollen and non-pollen palynomorph evidence of medieval farming activities in southwestern Greenland." *Vegetation History and Archaeobotany* 19: 427-438.

van Geel B., J. Buurman, O. Brinkkemper, A. Aproot, G. van Reenen and T. Hakbijl. 2003. "Environmental reconstruction of a Roman Period settlement site in Uitgeest (The Netherlands), with special reference to coprophilous fungi." *Journal of Archaeological Science* 30: 873-883.

Golding, K. A., I. A. Simpson, J. E. Schofield and K. J. Edwards. 2011. "Norse-Inuit interaction and landscape change in southern Greenland? A geochronological, pedological and palynological investigation." *Geoarchaeology* 26: 1-31.

Golding, K.A., I. A. Simpson, C. A. Wilson, E. C. Lowe, J. E. Schofield and K. J. Edwards. 2015. "Europeanization of sub-arctic environments: perspectives from Norse Greenland's outer fjords." *Human Ecology* 43: 61-77.

Grimm, E. C. 1987. "CONISS: A FORTRAN 77 program for stratigraphically constrained cluster analysis by the method of incremental sum of squares." *Computers and Geoscience* 13: 13-35.

Hellman, S., M. J. Bunting and M. -J. Gaillard. 2009. "Relevant Source Area of Pollen in patchy cultural landscapes and signals of anthropogenic landscape disturbance in the pollen record: A simulation approach." *Review of Palaeobotany and Palynology* 153: 245-258.

Ingstad, H. 1966. *Land under the Pole Star*. London: Jonathan Cape.

Iversen, J. 1934. "Moorgeologische Untersuchungen auf Gr nland." *Meddelelser fra Dansk Geologisk Forening* 8, 341-358.

Iversen, J. 1952-53. "Origin of the flora of western Greenland in the light of pollen analysis." *Oikos* 4, 85-103.

Jones, G. 1984. *A history of the Vikings, 2nd edition*. Oxford, Oxford University Press.

Keller, C. 2010. "Furs, fish, and ivory: medieval Norsemen at the Arctic fringe." *Journal of the North Atlantic* 3, 1-23.

Krogh, K. J. 1967. *Viking Greenland*. Copenhagen, National Museum.

Ledger, P. M., K. J. Edwards and J. E. Schofield. 2014. "Vatnahverfi: a green and pleasant land? Palaeoecological reconstructions of environmental and land use change." *Journal of the North Atlantic*, Special Volume 6: 29-46.

Ledger, P.M., K. J. Edwards and J. E. Schofield. 2015. "Taphonomy or signal sensitivity in palaeoecological investigations of Norse *landnám* in Vatnahverfi, southern Greenland?" *Boreas* 44: 197-215.

Madsen, C. K. 2014. "Pastoral settlement, farming, and hierarchy in Norse Vatnahverfi, south Greenland." PhD, University of Copenhagen.

Massa, C., V. Bichtet, E. Gauthier, B. B. Perren, O. Mathieu, C. Petit, F. Monna, J. Giraudeau, R. Losno and H. Richard. 2012. "A 2500 year record of natural and anthropogenic soil erosion in South Greenland." *Quaternary Science Reviews* 32: 119-130.

Mathers, D. 2009. "A fourteenth-century description of Greenland." *Saga-Book* 33: 67-94.

Meldgaard, M. 1986. "The Greenland caribou – zoogeography, taxonomy, and population dynamics." *Meddelelser om Grønland, Bioscience* 20: 1-88.

McGovern, T. H. 1985. "Contributions to the palaeoeconomy of Norse Greenland." *Acta Archaeologica* 54: 73-122.

McGovern, T. H., T. Amorosi, S. Perdikaris and J. Woollett. 1996. "Vertebrate zooarchaeology of Sandnes V51: economic change at a chieftain's farm in west Greenland." *Arctic Anthropology* 33: 94-121.

- McGovern, T. H., R. Harrison and K. Smiarowski. 2014. "Sorting sheep and goats in medieval Iceland and Greenland: local subsistence, climate change, or world system impacts?" In *Human ecodynamics in the North Atlantic*, edited by R. Harrison and R. A. Maher, 153-176. Lanham: Lexington Books.
- McGovern, T. H. and R. H. Jordan. 1982. "Settlement and land use in the inner fjords of Godthaab district, west Greenland". *Arctic Anthropology* 19: 63-79.
- Moore, P. D., J. A. Webb and M. E. Collinson. 1991. *Pollen Analysis, 2<sup>nd</sup> edition*. Oxford, Blackwell Science.
- Panagiotakopulu, E., P. Skidmore and P. Buckland. 2007. "Fossil insect evidence for the end of the Western Settlement in Norse Greenland". *Naturwissenschaften* 94: 300-306.
- Patterson, W. A. III, K. J. Edwards and D. J. Maguire. 1987. "Microscopic charcoal as a fossil indicator of fire." *Quaternary Science Reviews* 6: 3-23.
- Raper, D. and M. Bush. 2009. "A test of *Sporormiella* representation as a predictor of megaherbivore presence and abundance." *Quaternary Research* 71: 490-496.
- Reimer, P. J., E. Bard, A. Bayliss, et al. 2013. "IntCal13 and Marine13 radiocarbon age calibration curves 0-50,000 years cal BP." *Radiocarbon* 55: 1869-1877.
- Ross, J. M. 1998. "Archaeobotanical remains from the hall (XVII)." In *Man, culture and environment in ancient Greenland*, edited by J. Arneborg and H. C. Gulløv, 31-36. Danish Polar Centre Publication No. 4. Copenhagen: Danish National Museum & Danish Polar Center.
- Roussell, A. 1936. "Sandnes and the neighbouring farms." *Meddelelser om Grønland* 88: 1-232.
- Roussell, A. 1941. "Farms and churches in the Mediaeval Norse settlements of Greenland." *Meddelelser om Grønland* 89: 1-354.



Rune, F. 2011. *Wild flowers of Greenland*. Hillerød: Gyldenlund Publishing.

Seaver, K. A. 2010. *The last Vikings*. London, I. B. Tauris.

Schofield, J. E., K. J. Edwards and C. Christensen. 2008. "Environmental impacts around the time of Norse *landnám* in the Qorlortoq valley, Eastern Settlement, Greenland." *Journal of Archaeological Science* 35: 1643-1657.

Schofield, J. E., K. J. Edwards, E. Erlendsson and P. M. Ledger. 2013. "Palynology supports 'Old Norse' introductions to the flora of Greenland." *Journal of Biogeography* 40: 1119-1130.

Schweingruber, F. H. 1990. *Microscopic wood anatomy, 3<sup>rd</sup> edition*. Birmensdorf, Eidgenössische Forschungsanstalt WSL.

Star, B., J. H. Barrett, A. T. Gondek and S. Boessenkool. 2018. "Ancient DNA reveals the chronology of walrus ivory trade from Norse Greenland". *Proceedings of the Royal Society B, Biological Sciences* 285: 20180978.

von Stedingk, H., R. M. Fyfe and A. Allard. 2008. "Pollen productivity estimates from the forest-tundra ecotone in west-central Sweden: implications for vegetation reconstruction at the limits of the boreal forest." *The Holocene* 18: 323-332.

Stockmarr, J. 1971. "Tablets with spores used in absolute pollen analysis." *Pollen et spores* 13: 615-621.

Stuiver, M. and P. J. Reimer. 1993. "Extended <sup>14</sup>C data base and revised Calib 3.0 <sup>14</sup>C age calibration program." *Radiocarbon* 35: 215-230.

Sugita, S. 1994. "Pollen representation of vegetation in Quaternary sediments: theory and method in patchy vegetation." *Journal of Ecology* 82: 881-897.

Sugita, S., M. -J. Gaillard and A. Broström. 1999. "Landscape openness and pollen records: a simulation approach." *The Holocene* 9: 409-421.

Taurisano, A., C. E. Bøggild, and H. G. Karlsen. 2004. "A century of climate variability and climate gradients from coast to ice sheet in West Greenland." *Geografiska Annaler* 86 A, 217-224.

Thomsen, H. 1948. "The annual reports on the Arctic sea-ice issued by the Danish Meteorological Institute." *Journal of Glaciology* 1: 140-141.

TiliaIT. 2019. <https://www.tiliait.com/>. Last accessed: 2 July 2019.

Vebæk, C. L. 1992. "Vatnahverfi: an inland district of the Eastern Settlement in Greenland." *Meddelelser om Grønland, Man & Society* 17: 1-247.

Weidick, A. and M. Citterio. 2011. "The ice-dammed lake Isvand, west Greenland, has lost its water." *Journal of Glaciology* 57: 186-188.

## List of figures

**Figure 1:** The former Norse Settlements of Greenland occupied three areas of land (boxed) between the western coastline and the Greenland Ice Sheet. W = Western; M = Middle; E = Eastern.

**Figure 2:** The inner (eastern) area of the Western Settlement of Greenland showing the locations of sites and places mentioned in the text.

**Figure 3:** (A) Ruin group V53d in Austmannadalen. Other places and landscape features of interest are labelled. Isvand is depicted as this appears on the Nuuk Tourism 1:100 000 Hiking Map of West Greenland (Nuuk – Kapisillit, Qooqut and Austmannadalen sheet), prior to drainage of the lake beginning in 2004 (Weidick and Citterio 2011). The shading in Ameralla reflects the outwash plain at the head of the fjord that is no longer navigable by boat. Dark green shading indicates land below 200 m a.s.l. (contours in metres). Norse ruin groups are shown as red filled circles. Their locations are taken from maps provided to the authors by the Greenland National Museum and Archives; (B) View southwest overlooking ruin group V53d. The dwelling is circled (much of what remains is now obscured by willow scrub). A star marks the sampling location for the anthrosol; (C) View southwest across the basin mire near V53d. The sampling location for the peat profile is indicated by the star. Photographs were taken in September 2015 by JE Schofield.

**Figure 4:** Plan of the dwelling – the centralised house – at V53d comprising 21 rooms (redrawn from Roussell [1941]). Key to *selected* rooms and their likely functions: 1. Barn; 2. Byre; 3. Bath-house; 4a-f. Living quarters.

**Figure 5:** Profile through the anthrosol at V53d displaying the sharp contact between the Ap horizon and underlying sands. Photograph by JE Schofield.

**Figure 6:** OxCal multiplot showing the probability distributions of the calibrated  $^{14}\text{C}$  dates from the anthrosol (panel A) and the mire (B).

**Figure 7:** Percentage pollen diagram for the anthrosol ('on-site') at V53d showing selected taxa. Values for loss-on-ignition, rarefaction and microscopic charcoal (depicted as charcoal

to pollen ratio) are also shown. + indicates values <1%. A diagram containing the full suite of taxa (Fig. S1) can be found in the supplementary information that accompanies this paper.

**Figure 8:** Age-depth model for the mire profile produced using *Bacon* software (Blaauw and Christen 2011). Darker shading indicates more likely calendar ages. Dashed lines show the 95% confidence limits on the model, whilst the central (solid) line shows the single ‘best’ model based on the mean age for each depth. The model adopts the default software settings with the exception of the following: section thickness (*thick* function) was reduced from 5 to 2 cm; deposition time (*acc.mean*) was increased from 20 to 75 yr cm<sup>-1</sup>; and a lower range of posterior memory values was adopted (*memory mean* was reduced from 0.7 to 0.5). The model extrapolates between the deepest <sup>14</sup>C date (29-30 cm) and the base of the pollen-analysed sequence (32 cm).

**Figure 9:** Percentage pollen diagram from the mire (‘off-site’) near V53d showing selected taxa. Values for loss-on-ignition, rarefaction and microscopic charcoal (depicted as charcoal to pollen ratio) are also shown. + indicates values <1%. A diagram containing the full suite of taxa (Fig. S2) can be found in the supplementary information that accompanies this paper.

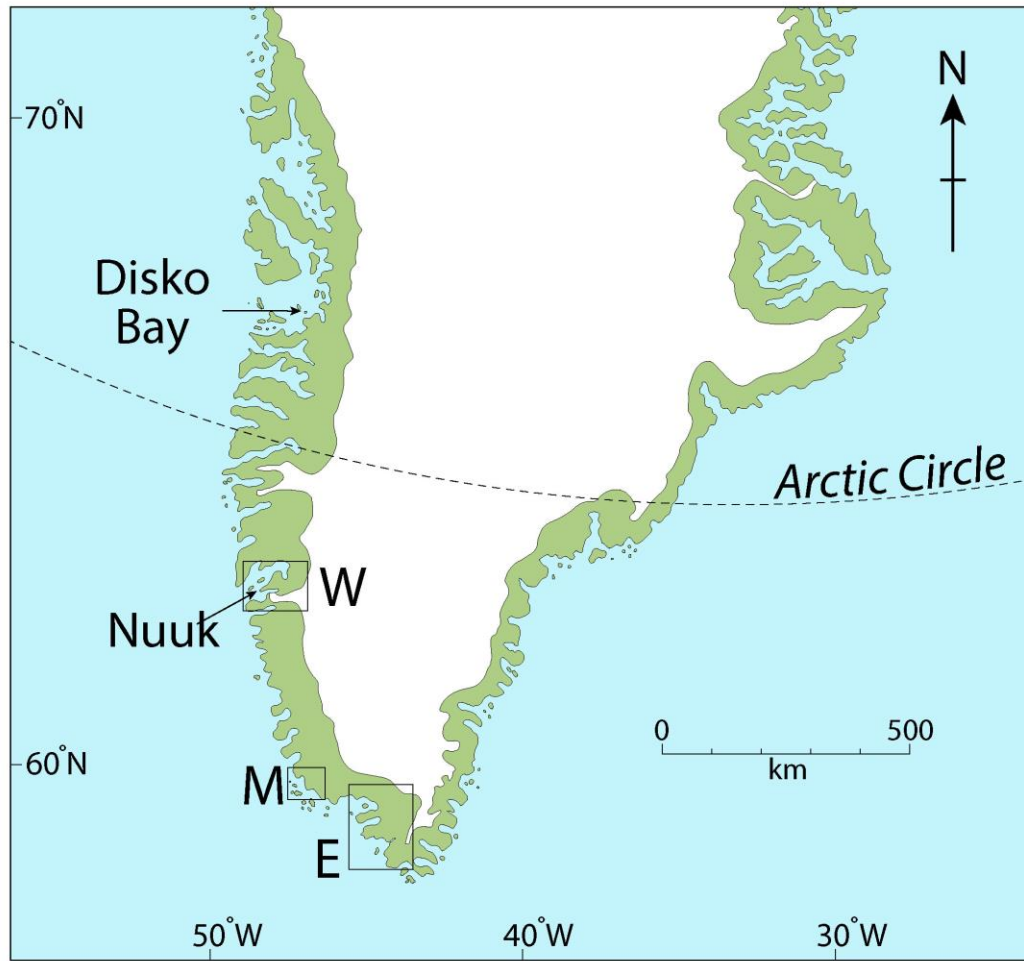
**Figure 10:** Influx of selected pollen types and microscopic charcoal particles to the mire. TLP = total land pollen. Note the differences in the scaling of the x-axes.

**Table 1:** Radiocarbon dates. The calibration procedure is explained in the Methods.

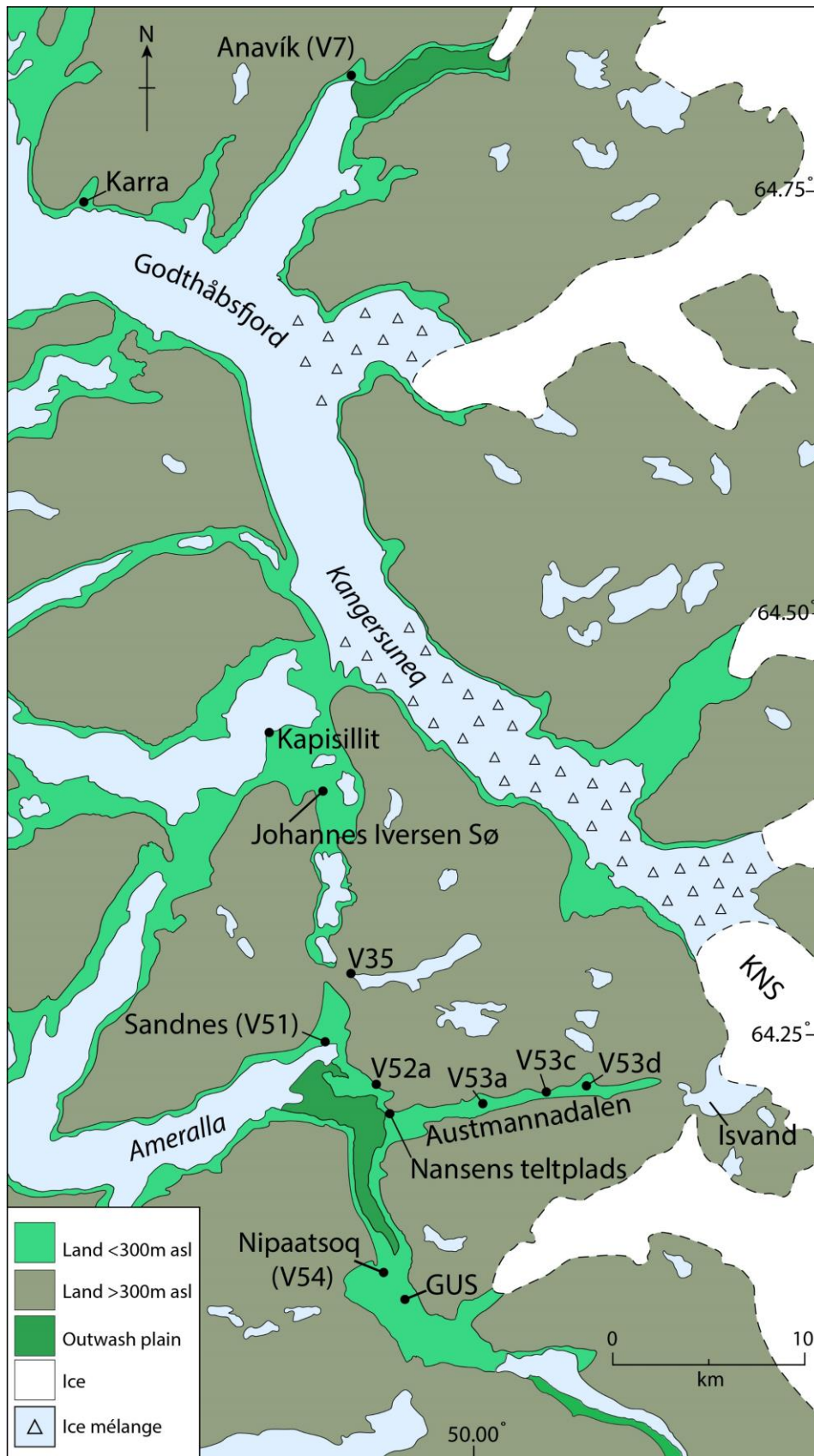
Lab code	Depth and material	<sup>14</sup> C age (yr BP)	cal AD range (95.4%)	Median (cal AD)
<i>'On-site' anthrosol</i>				
UBA-31333	14-15 cm Charcoal and <i>Montia fontana</i> seeds	645±46	1278-1401	1344
UBA-31334	31-33 cm Charcoal and <i>Carex</i> seeds	1101±49	777-1022	935
<i>'Off-site' mire</i>				
UBA-31335	10-11 cm <i>Sphagnum</i> sect. <i>Acutifolia</i>	183±34	1650-1950	1771
UBA-34313	14-15 cm Peat (humic acid fraction)	325±29	1482-1684	1562
UBA-34314	18-19 cm Peat (humic acid fraction)	454±28	1416-1468	1439
UBA-34315	22-23 cm Peat (humic acid fraction)	1011±25	981-1145	1016
UBA-34316	26-27 cm Peat (humic acid fraction)	1235±24	688-877	768
UBA-31336	29-30 cm <i>Sphagnum</i> sect. <i>Acutifolia</i>	1443±30	566-653	615

**Table 2:** Selected zooarchaeological data from Greenlandic Norse collections. The sites represent two contrasting regions within the colony; Austmannadalen in the Western Settlement (sites prefixed V), and Vatnahverfi in the Eastern Settlement (Ø). The source is McGovern (1985: Table 6), with the exception of data for GUS which were calculated using numbers appearing in Enghoff et al. (2003). The data reflect the *relative* percentages of the four major taxa, which normally comprise over 80% of Norse faunal collections.

	<i>% Cattle</i>	<i>% Caprine</i>	<i>% Reindeer</i>	<i>% Seals</i>
<b>Vatnahverfi</b>				
Ø71 (N)	15.48	37.47	0.25	46.81
Ø71 (S)	11.48	44.08	1.67	42.78
Ø167	22.96	38.98	1.72	36.34
<b>Austmannadalen</b>				
V51 (Sandnes)	17.57	12.44	32.08	37.92
V52a	10.75	18.02	27.28	43.94
V53c	7.82	14.21	10.79	67.18
V53d	8.78	13.17	18.81	59.25
GUS	9.28	30.36	16.79	43.57

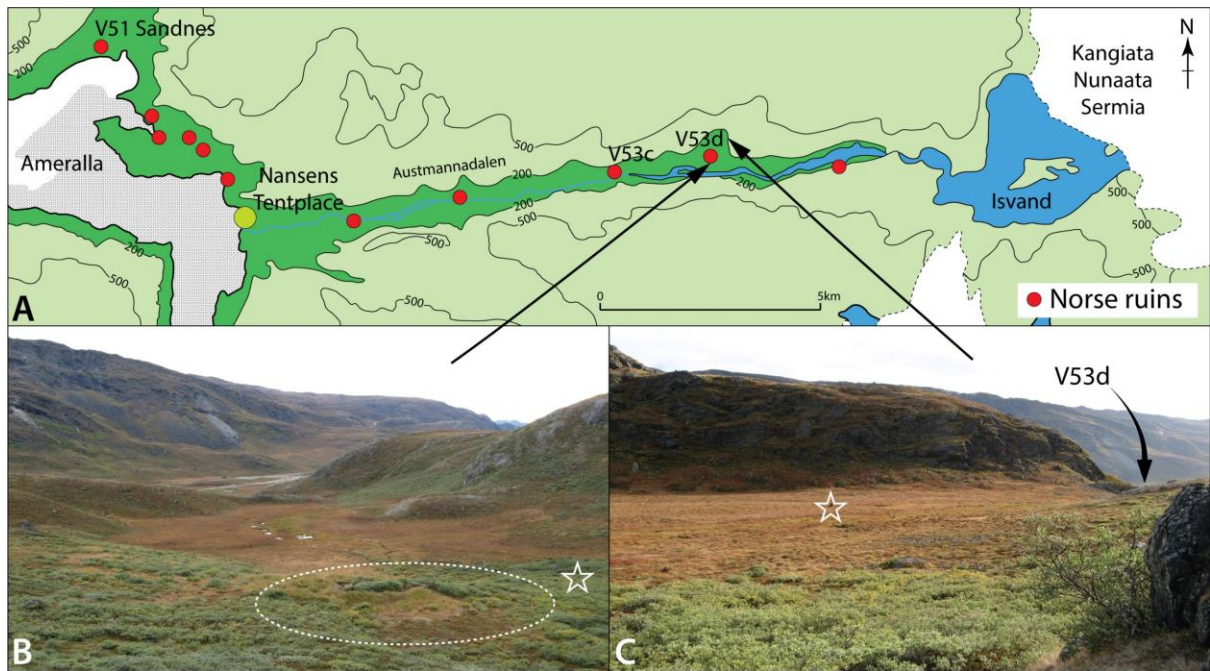


**Figure 1**

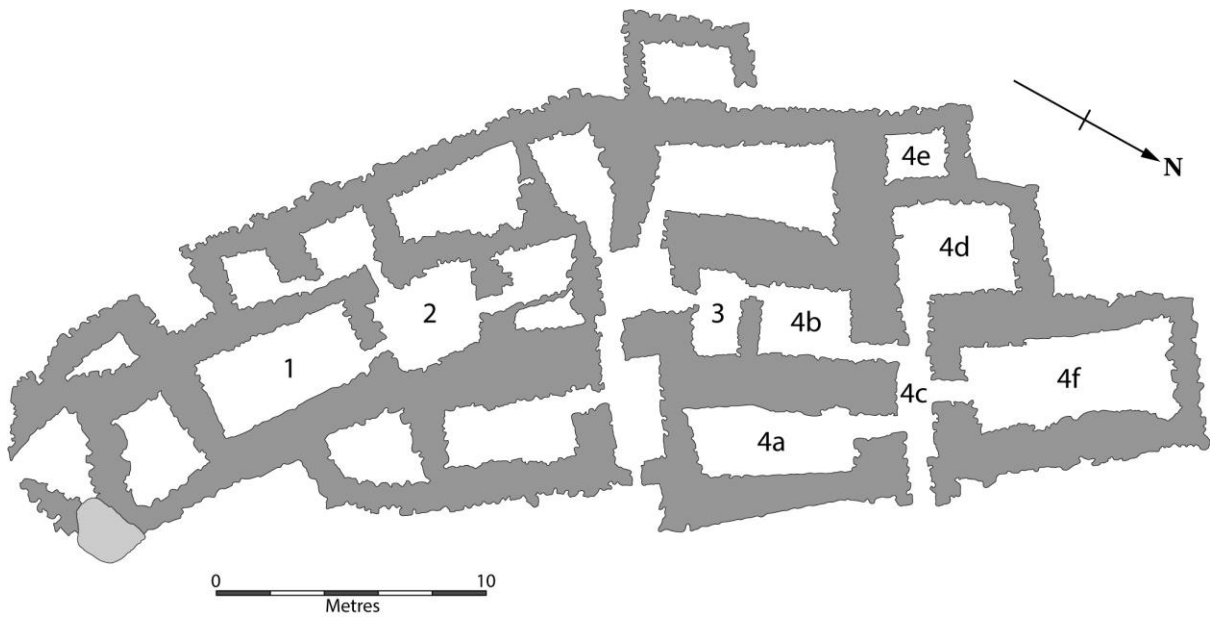


**Figure 2**

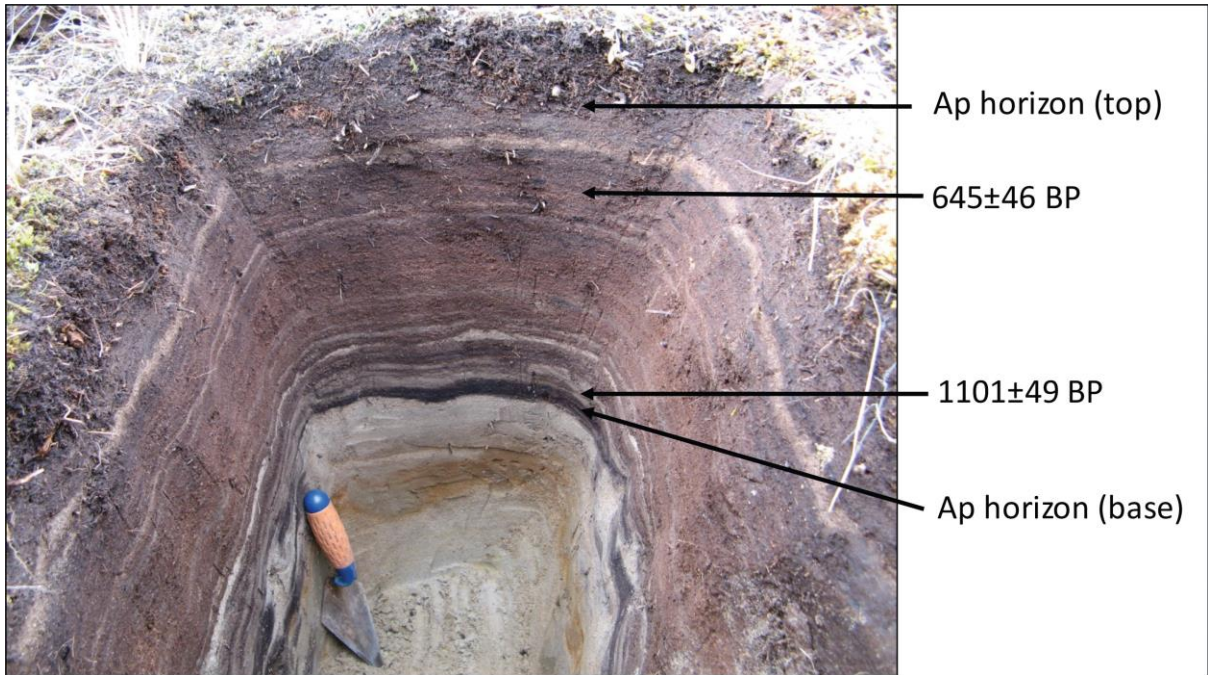




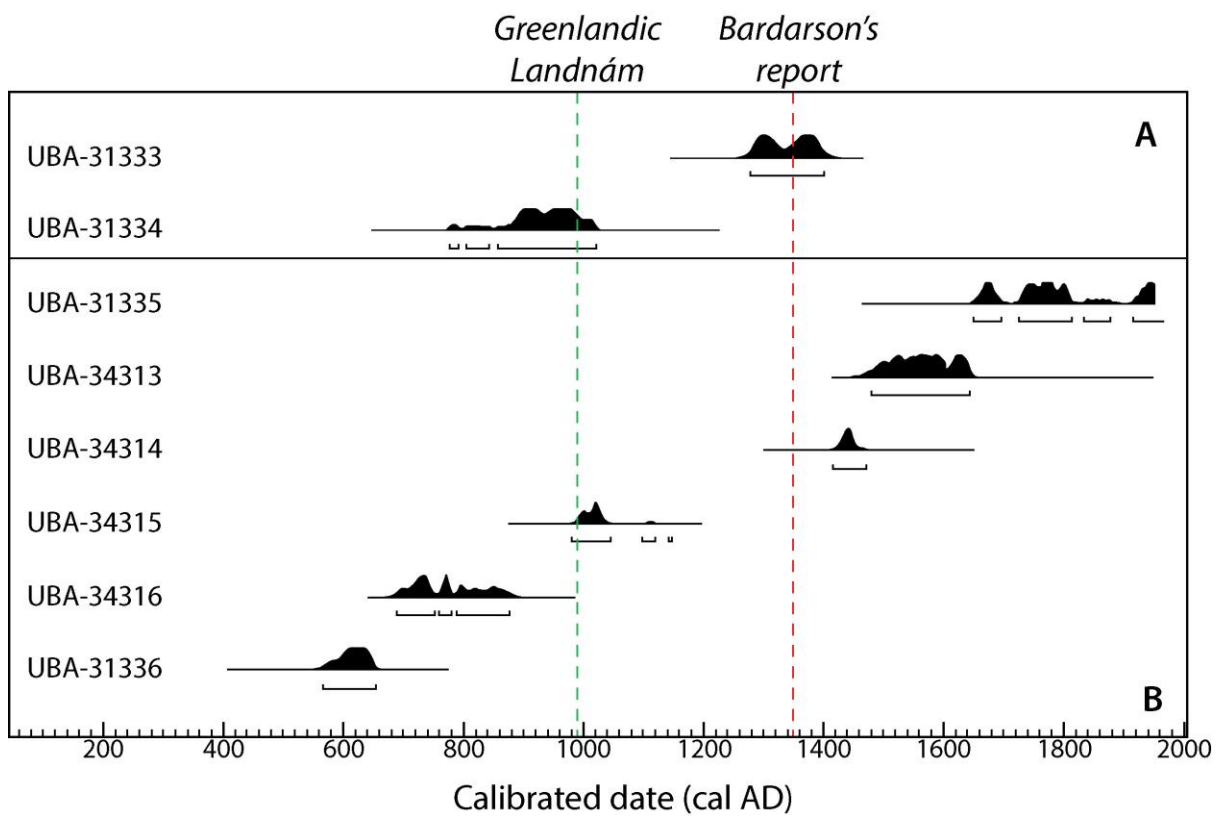
**Figure 3**



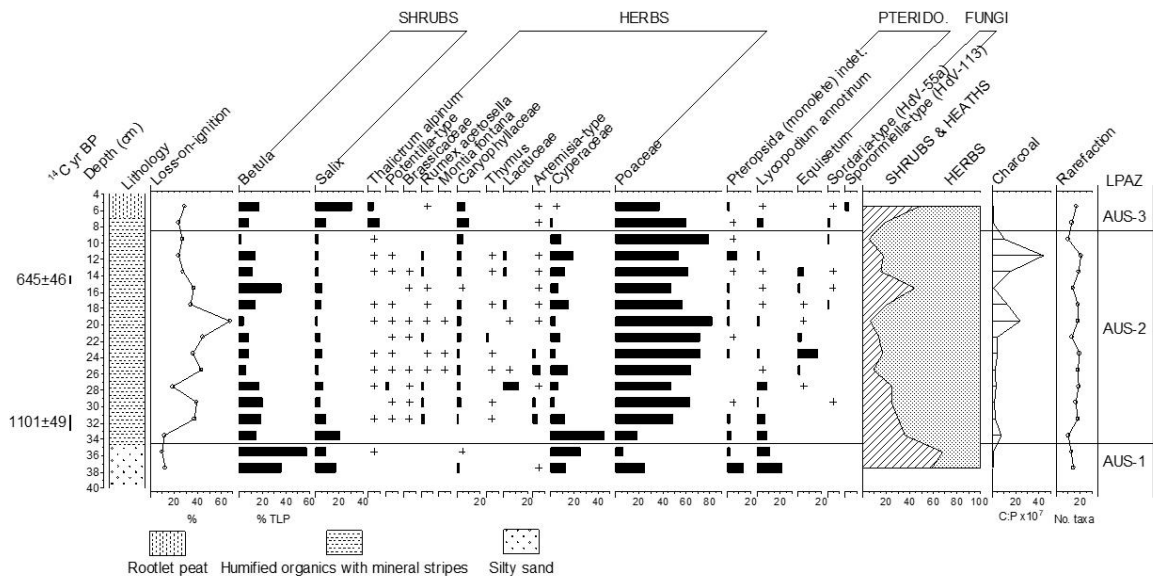
**Figure 4**



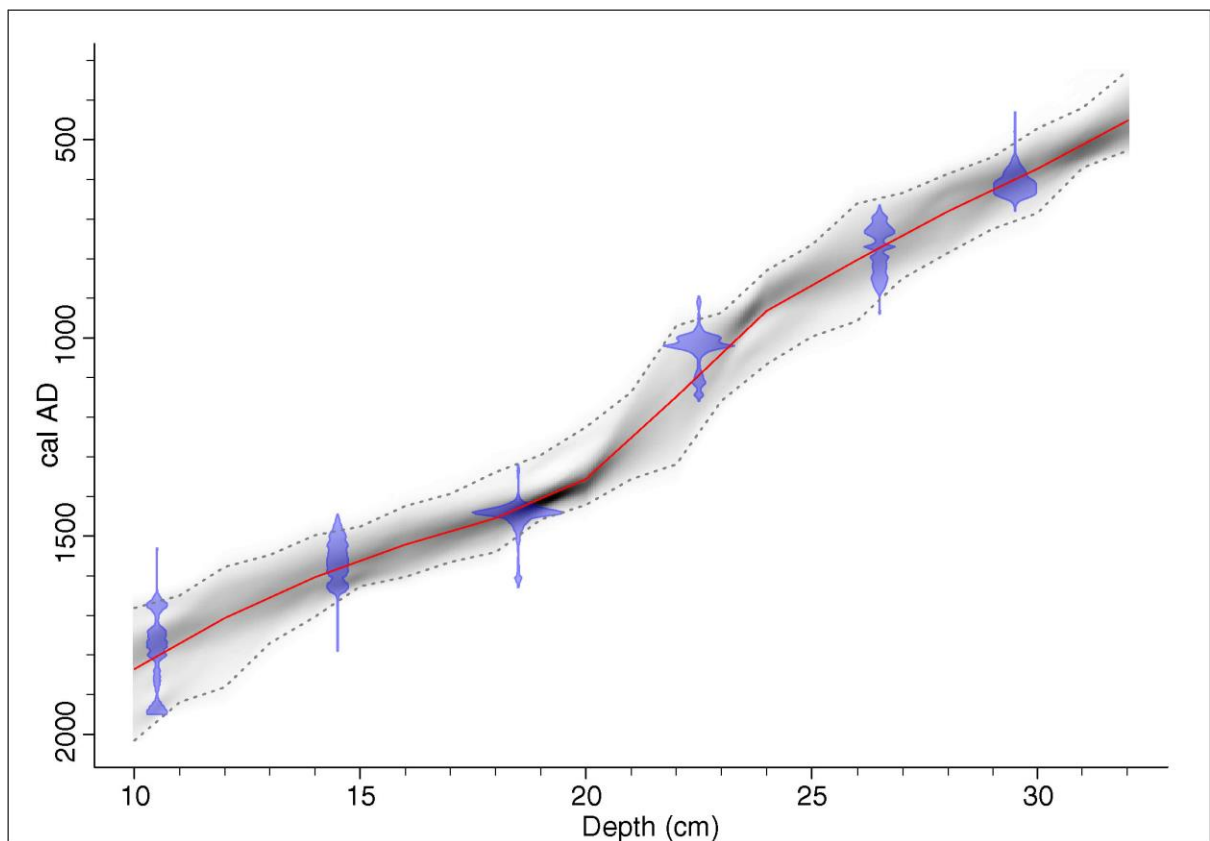
**Figure 5**



**Figure 6**



**Figure 7**



**Figure 8**

