

Taphonomy or signal sensitivity in palaeoecological investigations of Norse *landnám* in Vatnahverfi, southern Greenland?

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Anthrosols (cf. plaggen soils) are commonly found across the homefields of Norse farms, yet the extent to which these taphonomically-complex and heterogeneous deposits provide reliable archives of environmental change and vegetation history has rarely been investigated. This paper compares the palynological signature contained within an anthrosol located beside Norse farm ruins in the Eastern Settlement of Greenland, with that from a mire situated ~400 m from the nearest archaeological remains. The investigation covers a period of ~1000 years leading into, through, and beyond the Greenlandic *landnám* of AD 985. The results demonstrate that, as anticipated, the anthrosol contains a strong signal for human impact associated with settlement and occupation, although changes in both pollen percentages and accumulation rates (influx) through the profile appear smooth, not erratic, and radiocarbon dates are conformable. Thus the palynological signature contained in the anthrosol is broadly comparable to the patterns characteristic of stratified natural contexts (e.g. mires) with small pollen source areas that are located in close proximity to former Norse structures. Nevertheless, it is also demonstrated that secondary microfossils are a major component of the pollen assemblages within the anthrosol, and pollen influx is notably an order of magnitude higher when compared against the peat core taken from the mire. It is suggested

that this may result from the addition of pollen contained in animal dung, augmenting that accumulating through the natural accretion of pollen derived from the surrounding vegetation and landing on the surface of the anthrosol. While this complicates any palynological interpretation, by adopting a cautious approach we argue that anthrosols can be used to extract useful information about vegetation history at a local scale, as well as providing indirect evidence of landscape impacts and resource use around farmsteads.

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The colonisation of Greenland by Norse settlers from Iceland is considered to have begun in AD 985 (Seaver 2010). Pastoral farming, centred on cow, sheep and goat husbandry, was established in two principal regions – the Western (~64.4°N, 50.5°W) and Eastern (~60.9°N, 45.5°W) Settlements – located between the west coast and the inland ice (Fig. 1). The Western Settlement was probably abandoned around AD 1350 (Barlow *et al.* 1997), while occupation in the Eastern Settlement may have persisted until the mid-15th century (Seaver 2010). The landscape impacts of this *c.* 400 year ‘experiment’ in farming within a sub-arctic environment, a period characterised by significant climatic change, and the ultimate causes of its failure, are much debated. Some see evidence for a society that brought about its own collapse through pursuing an unsustainable farming system in a fragile landscape (e.g. Diamond 2005). Others argue that the Norse adapted quickly to the challenges that Greenland posed and were well adjusted custodians of their new environment, instead succumbing to the vagaries of historical, economic and climatic change (Dugmore *et al.* 2012).

This paper is concerned with the Eastern Settlement, where Fredskild (1973) was the first to address the topic of impacts on vegetation arising from Norse colonisation (*landnám*; ‘land-taking’). In a series of pollen profiles from the Qassiarsuk area (Fig. 1), Fredskild (1973, 1978, 1988) identified the key features of settlement as being the clearance of scrub and woodland and their replacement with improved grasslands along with the accidental introduction of selected plants such as *Rumex acetosella* (sheep’s sorrel). In recent years, high-resolution palaeoecological data has confirmed and developed such findings (Edwards *et al.* 2008, 2011a; Schofield *et al.* 2008, 2013; Schofield & Edwards 2011). Typically, although not exclusively (cf. Gauthier *et al.* 2010; Edwards *et al.* 2011b), these studies are from minerotrophic mires with small relevant source areas for pollen (RSAPs; cf. Sugita 1994; Bunting *et al.* 2013) that are located close (often <100 m) to archaeological ruins in order to maximise the palaeoecological signal of human impact. In addition to confirming

previously established landscape-scale trends, these local-scale studies have allowed a greater appreciation of Norse resource use (Schofield & Edwards 2011) and, through the application of high resolution age-depth modelling, have established precise individual farm chronologies (Edwards *et al.* 2008; Ledger *et al.* 2013; Ledger *et al.* 2014b).

Yet studies of small minerotrophic mires in Greenland are not without their difficulties. Sometimes they can fail to produce reliable palaeoenvironmental records (e.g. Ledger 2013) or simply do not occur in close proximity to ruin groups. Problems with radiocarbon dating (Edwards *et al.* 2008, 2011b) and hiatuses within the sediment column (Schofield *et al.* 2010; Schofield & Edwards 2011) have also been encountered.

Anthropogenically-enhanced soils (anthrosols or plaggens) may offer an alternative medium for palynological study in locations where mires are absent. Anthrosols are commonly found across the former homefields of Norse farms (e.g. Adderley & Simpson 2005; Simpson *et al.* 2005; Buckland *et al.* 2009; Golding *et al.* 2011). Although the palynological taphonomy of soils is more complex than that of peat or lacustrine muds (Dimbleby 1985), such fossiliferous media do receive pollen and cultural additions in the form of plant materials and animal dung that may provide insights into landscape processes around farming locations (cf. Behre 1976, 1993; Vuorela 1978; Edwards 1993; Whittington & Edwards 1999; Buckland *et al.* 2009).

This paper presents two palaeoenvironmental case studies from the coastal reaches of Vatnahverfi, a district of the Eastern Settlement; one based upon an anthrosol and the other upon a peat core taken from a small mire. Whilst these contexts offer the best available organic profiles for palynological study of *landnám* in both locations, they might otherwise be considered as sub-optimal for any investigation of past human impact on vegetation; the anthrosol due its taphonomic complexities, and the peat core due to its distance (~400 m) from the nearest archaeological structures, which may potentially make it an insensitive

archive for recording environmental impacts arising directly from activity at the nearest farm. In addition to presenting new palaeoecological data on Norse *landnám* from southern Greenland, we use these studies to explore several important methodological questions: (i) do anthrosols contain a stratified palynological signal for *landnám* that is comparable to vegetation records established using peat cores, or does the deposit simply reflect waste streams added to the soil as fertilizer?; (ii) how sensitive are small mires to vegetation changes associated with *landnám* when located at some distance from the nearest archaeological structures?; (iii) are ('on-site') anthrosols sometimes preferable to ('off-site') natural contexts in studies of human impact in Greenland, despite the probable taphonomic trade-offs?

The study locations

The sites of Nimerialik and Atikilleq lie in the sub-arctic, sub-oceanic climate belt of southern Greenland (Feilberg 1984). Mean summer (July) temperature is 10.3°C and annual precipitation is 615 mm (data for Narsarsuaq (Fig.1) over the period 1961-90; Cappelen *et al.* 2001). Basement geology is uncomplicated and dominated by granites of the Ketilidian Mobile Belt (*c.* 1.7-1.8 Ga) which are overlain by glaciofluvial deposits of Quaternary age (Feilberg 1984).

Nimerialik is in the south of Vatnahverfi and is a medium-sized body of water measuring ~300 x 200 m. Two streams flow into the lake from the east and north with an outflow into Equaluit (Hafgrimsfjord) to the south. The lake is fringed by a mire which spreads along the bank of the inflowing stream to the east. Topography to the east and south is undulating whilst to the north and west the terrain rises sharply to ~200 m. Vegetation consists variously of grazed grasslands, mires, and *Betula glandulosa*-*Salix glauca* scrub (plant nomenclature follows Böcher *et al.* 1968). Two Norse ruin groups are located within 1

km of Nimerialik (Fig. 1D); Ø196, ~80 m west of the lake, is a small group of structures that may have been a shieling, whilst Ø78a was a medium sized farm ~800 m southeast of the lake (Fig. 2). A further farm ruin (Ø78) is located approximately 2 km to the east.

Atikilleq is located on a coastal plain in northwest Vatnahverfi which, to the north, south and west, gradually shelves into the fjord, and to the east rises sharply to ~200 m a.s.l. The vegetation of the plain comprises grassland with patches of *Salix glauca*-*Betula glandulosa* scrub that has been heavily grazed by sheep. There are five Norse buildings on the site and a single 20th century structure 100 m to the northeast. The ruin group has not been excavated but was registered as Ø65 by Bruun (1896) who noted poorly-preserved overgrown ruins and exposed deposits of ash, bone and stone along the coast. Today the ruins are highly visible (Fig. 2), probably a result of grazing by animals from nearby sheep farms.

Methods

Fieldwork and sediment sampling

Fieldwork was undertaken in May 2006 and July 2010. At Nimerialik, shallow peat deposits were identified beneath the *Sphagnum-Eriophorum* mire abutting the eastern edge of the lake (~60° 46.115'N, 45° 34.961'W). Three overlapping cores were extracted to a depth of 145 cm using a 50 x 8 cm Russian corer, approximately 400 m east of Ø196 (Fig. 1). The core sections were protected in plastic guttering and wrapped in polythene before being placed in cold storage (4°C). The soil profile at Atikilleq (~60° 51.831'N, 45° 26.138'W) is exposed in a coastal section approximately 25 m south of the main ruin and was sampled using two (18.5 x 10 cm) monolith tins (Tin 1, 7.5-26.0 cm; Tin 2, 21.0-39.5 cm).

Sedimentary analyses

Contiguous 1 cm sub-sampling of each profile was undertaken in the laboratory with loss-on-ignition (LOI) measured following 3 h combustion at 550°C. The stratigraphies were described using the Troels-Smith (1955) system.

Pollen analysis

Samples were prepared for pollen analysis following standard 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 and influx data. Following processing, samples were suspended in silicone oil, mounted on slides and examined under a light microscope and counted until a sum of 500 total land pollen (TLP) had been achieved. Pollen and spore identifications were confirmed through reference to modern material and aided by the key in Moore *et al.* (1991). Nomenclature follows Bennett *et al.* (1994) and Bennett (2014a), with taxa absent from these lists following Moore *et al.* (1991) and informed by Böcher *et al.* (1968). *Betula* pollen was separated into tree (*Betula pubescens*) and shrub (*Betula glandulosa*) varieties using grain size diameter measurements (cf. Fredskild 1973; Schofield & Edwards 2011) with grains <20 µm classified as *B. glandulosa*. Some pollen may well have been mis-categorized in following this convention, but this is not regarded as having serious consequences for the overall interpretation. Poaceae grain size measurements reported by Andersen (1978) were used to discriminate between cereal-type and large wild Poaceae pollen grains. Pollen preservation data (cf. Havinga 1964) was also recorded at Nimerialik and local pollen preservation zonation was explored (Tweddle & Edwards 2010). The area covered by microscopic charcoal in pollen residues was measured using a microscope eyepiece graticule at a magnification of ×400; both charcoal influx and charcoal to pollen ratios (C:P) were calculated (cf. Swain 1978; Patterson *et al.* 1987). Coprophilous fungal spores, derived from fungi that grow on animal dung, were

identified with reference to van Geel *et al.* (2003). Pollen percentage, influx and preservation diagrams were constructed using TILIA and TGView software (Grimm 1993, 2013) with percentages based upon the TLP sum.

Numerical analysis

CONISS (Grimm 1987) was used to assist with biostratigraphic zonation of both the pollen preservation and conventional percentage diagrams. The analysis was stratigraphically constrained and undertaken following square root transformation of percentage data with Edwards and Cavalli-Sforza's chord distance used as the dissimilarity measure. Rarefaction analysis was performed in *psimpoll* (Bennett 2014b). This was used to determine the palynological richness, and hence floristic diversity, of samples (Birks & Line 1992), although it should be noted that increased pollen productivity can act to depress these values (Meltsov, 2011). Ordination of the pollen samples was performed using CANOCO 4.5. An initial exploration of the datasets was undertaken using detrended correspondence analysis (DCA). This generated gradient lengths of 1.252 (Nimerialik) and 1.457 (Atikilleq) for the primary axes, indicating a linear rather than unimodal response in the dataset (Lepš & Šmilauer, 2003), thereby suggesting that principal components analysis (PCA) was a more preferable approach (ter Braak & Šmilauer 2002). In both instances scaling was focused on inter-species scores, species scores were divided by the standard deviation, and species vectors centred by species. In addition to undertaking independent ordinations, a common analysis of both the Nimerialik and Atikilleq pollen datasets was also undertaken. PCA for Nimerialik was undertaken as described above with Atikilleq included as passive (supplementary) samples in order to explore the relationship between on-site (Nimerialik) and off-site (Atikilleq) assemblages.

Radiocarbon dating and age-depth modelling

Samples were gently disaggregated in weak NaOH and washed through a 125 µm sieve. Residues were examined under a binocular microscope and – in the case of Nimerialik – cleaned to remove roots of Ericaceae, Cyperaceae and fungal mycelium. The remaining macrofossils – predominantly bryophyte leaves and branches – were stored in distilled water containing a drop of HCl, and sent to SUERC, East Kilbride, for AMS ¹⁴C dating. Similar plant macrofossils were absent from the Atikilleq profile, and fragments of charcoal and *Betula* bark were selected for radiocarbon dating. Calibration of ¹⁴C dates was undertaken using the IntCal13 calibration curve (Reimer *et al.* 2013) and CALIB v7.0. Techniques involving classical (Clam; Blaauw 2010) and Bayesian (Bacon; Blaauw & Christen 2011) approaches were explored to generate age-depth models (discussed below).

Results and discussion

Nimerialik

Lithology. – The Nimerialik core can be broadly divided into deposits representing lacustrine (145-117 cm) and peat (117-35 cm) environments (Table 1). Further key divisions within the terrestrial part of the sequence are at 108 cm, above which the peat becomes more humified, and at 97 cm where there is an increase in minerogenic influx as the peat becomes sandy. Above 78 cm the peat is less minerogenic and more fibrous.

Chronology. – Seven radiocarbon dates make up the chronology from Nimerialik for which the basal date extends to *c.* 2500-2700 cal. a BP (Table 2, Fig. 3). An initial inspection suggests both Clam and Bacon provide plausible age-depth models, and indicate either

gradual (Clam) or sharper (Bacon) changes in the accumulation rate between ~115-100 cm. This is consistent with the lithostratigraphic change from fibrous to humified peat. The main differences between the two models are found within the settlement period. Clam produces a model that by-passes the bulk of the calibrated distribution for two radiocarbon dates in this period (SUERC-33435 and SUERC-36607) while Bacon produces a model that intercepts both of these age determinations.. Therefore the Bacon model appears preferable and is used to assign dates to events recorded in the core.

Numerical analysis. – PCA (Fig. 4) indicates reasonable separation of samples within the dataset. Axis 1 accounts for 51.8% of the total variance and reflects a gradient related to human impact with Poaceae, microscopic charcoal and spores of the coprophilous fungi *Sporormiella*-type (HdV-113) assigned positive scores and Cyperaceae (indicative of mire and steppe communities) given a negative score. Axis 2 accounts for 24.3% of the variance. The environmental gradient leading to separation along this axis may relate to the degree of landscape openness. Scrub and woodland taxa such as *Betula pubescens* and *Salix* respond positively while herbaceous taxa such as Cyperaceae and Poaceae display negative values.

Palynology. – Local pollen assemblage zone (LPAZ) NIM-1 opens between 175 BC and AD 650 and contains a record of the pre-*landnám* environment. High frequencies of Cyperaceae (~40-50% TLP) imply a local sedge-dominated mire with cushions of *Sphagnum* (~5-8% TLP). *Myriophyllum alterniflorum* (~3-6%), *Hippuris vulgaris* and *Potamogeton* pollen (traces, <1%) probably derive from plants growing in pools of standing water on the mire surface, or in the lake itself. Away from the mire, a reasonably open landscape is indicated with scrub and dwarf-shrub heath accounting for 25-32% of the assemblages. *Salix* is the most common shrub and probably formed *S. glauca* scrub or dwarf-shrub heath with

Betula glandulosa. *Betula pubescens* is reasonably well represented and perhaps suggests birch woodland in sheltered locations. The rarefaction index is between 22-26 throughout the zone and is suggestive of reasonable diversity. Poaceae registers at ~18-22% and steady contributions from Gentianaceae, *Campanula gieseckiana*, *Cerastium*-type and Brassicaceae may reflect herbs growing in local grassland or herbslope communities (Böcher *et al.* 1968).

NIM-2a is characterised by a decline in pollen from taxa common in woodland, scrub and dwarf-shrub heath, with a percentage and influx rise in Poaceae pointing to the expansion of grasslands and establishment of hayfields. Microscopic charcoal increases and the Norse introductions *Rumex acetosella* and *Polygonum aviculare* are recorded. The arrival of domesticated herbivores is also suggested by increases in spores of the coprophilous fungi *Sordaria*-type (HdV-55A) and *Sporormiella*-type, although there is no obvious evidence for soil erosion generated by grazing as LOI rises to a peak of 61%. These developments clearly represent *landnám*, yet their muted nature is suggestive of a regional as opposed to a local signal, and may therefore reflect the establishment of farming ~2 km to the southeast at ruin group Ø78. Age-depth modelling indicates the opening of NIM-2a dates to AD 775-1015. This embraces the accepted date for *landnám* (AD 985) in Greenland; the possibility of an earlier Norse presence is unsupported by historical evidence. The modelled age range illustrates the uncertainty within the age modelling procedure while the ¹⁴C date positioned on the NIM-1/2a boundary (SUERC-36607; 1085±35) provides a narrower span for the same event of AD 892-1017 (2σ).

A slight intensification of land use is inferred from NIM-2b, beginning AD 935-1125. Poaceae pollen increases in both influx and percentage terms, implying the spread of grasslands, but evidence for further scrub clearance is limited with *Betula* and *Salix* collectively comprising ~20% TLP. The rarefaction index peaks at 26 and remains above 20 reflecting the consistent representation of apophytes such as Brassicaceae, *Cerastium*-type,

Montia fontana and *Rumex acetosella*. LOI declines and is associated with the lithological change from humified to sandy peat (Fig. 5). Pteropsida (monolete) indet. spores – which are highly resistant to erosion and are over-represented in soils in southern Greenland (Schofield *et al.* 2007) – also increase, a pattern which could be linked to the inwash of catchment soils (Edwards *et al.* 2008). Preservation data may support this conclusion (Fig. 6). NIM-2b corresponds with local pollen preservation zone (LPPZ) NIMP-2b in which there are elevated levels of degraded pollen, and a peak in corroded microfossils. These are patterns which have been linked with the inwash of re-worked soils (Birks, 1970). However, poor preservation of pollen can also be an indicator of the post-depositional biasing of assemblages, whereby pollen grains less resistant to biodegradation are selectively destroyed (Cushing, 1964; Havinga 1984). This seems unlikely to be the case here; the rarefaction index indicates no dramatic reduction in pollen diversity and there is no obvious enrichment of pollen types with thick exines (such as Lactuceae) that are considered to be particularly resistant to degradation (Bunting and Tipping, 2000). Indeed, a concomitant increase in total pollen influx (Fig. 7) may reflect the increased deposition of secondary corroded and degraded microfossils eroded from re-worked soils in the catchment (cf. Birks 1970). Nevertheless, it should be noted that increased pollen influx could also in part be attributed to increased productivity of local plant communities (such as hay fields in managed homefield areas).

LPAZ NIM-3 (beginning AD 1115-1300) is characterised by falling levels of microscopic charcoal, implying less human activity, while a significant decrease in *Sporormiella*-type spores is indicative of reduced grazing intensity. Lower contributions from Norse apophytes and Poaceae, and an expansion of Cyperaceae, all probably signal the gradual abandonment of the area with grasslands and hayfields falling into disuse and becoming colonised by sedges. Declining rarefaction values may also indicate that much of the increase in Cyperaceae reflects the localised spread of mire and an associated reduction in

floristic diversity. Both *Betula glandulosa* and *B. pubescens* decline, implying a decrease in the coverage of scrub and dwarf-shrub heath and woodland. This could suggest continued scrub and woodland clearance in the area, although this seems unlikely considering other indicators point towards declining human impact. A more probable scenario is that *Betula* pollen production was suppressed by the deteriorating climate (Dugmore *et al.* 2007a, b) that characterised this period. Using data from Iceland, Erlendsson & Edwards (2009) have demonstrated that *B. pubescens* influx values (pollen accumulation rates) – and inferred flowering – can be influenced by changes in temperature. The onset of NIM-3 is typified by not only a decline in pollen influx of *Betula* spp., but a sharp fall in the influx of all taxa.

Consistent with the interpretation of abandonment, LOI initially rises in NIM-3 implying the stabilisation of catchment soils and decreasing erosion – yet by the middle of the zone, LOI begins to fall once more, suggesting a further period of minerogenic input to the mire. There is no increase in Pteropsida (monolete) indet. spores (Fig. 5) and there is a shift towards well preserved assemblages (Fig. 6). Taken together, these changes may be evidence for the increased deposition of windblown sediment (loess) on the mire surface. Based on evidence from marine and terrestrial sedimentary records, Kuijpers & Mikkelsen (2009) suggest that wind strength in south Greenland increased after AD 1000, reaching a peak around AD 1300, and that this resulted in the accumulation of the aeolian sands that eventually buried several Norse ruins in the area (e.g. Ø64 a and c, Fig. 1). Alternatively, the variable LOI could reflect water-level fluctuations involving episodic flooding of the mire surface.

The opening of NIM-4 dates from AD 1430-1570 and is likely to reflect the period following the Norse abandonment of Greenland. Microscopic charcoal is much reduced but not wholly absent, with the traces still recorded probably signifying inputs from long distance transport. Coprophilous fungi are occasionally present and may indicate the return of caribou

or the activity of other smaller mammals (cf. Gill *et al.* 2013). Poaceae percentages continue to decline and Norse apophytes are generally absent, pointing to the continued retreat and loss of managed grasslands and hayfields. An increase in *Salix* may denote the expansion of *S. arctophila* on the mire surface and/or a recovery of *S. glauca* scrub and dwarf-shrub heath. Some woodland regeneration may also be indicated by rising frequencies of cf. *Betula pubescens* pollen.

Atikilleq

Lithology. – The stratigraphy of the sampled section (Table 3) comprises natural soil (brown sandy loam containing occasional pebbles) from 40-36.5 cm, and between 15 cm and the modern surface. Intercalated between these is an organic-rich sandy soil containing cultural material (charcoal and charred bone fragments) that we interpret to be an anthrosol. This unit could be traced in open sections at the back of the beach over a distance of ~20 m.

Chronology. – Four radiocarbon dates were measured on material from Atikilleq, three on charcoal and one on *Betula* bark (Table 1). The dates are conformable with no age inversions. A sharp reduction in the sediment accumulation rate is evident towards the top of the profile. This coincides with the lithological change at 15 cm, above which charcoal and small fragments of bone are absent reflecting the end of anthropogenic input to the deposit. Radiocarbon dates are significantly different immediately above and below 15 cm; SUERC-120141 at 18-17 cm returned an age-estimate of 750 ± 35 a BP, whilst SUERC-36606 contains post-bomb carbon. This indicates a probable hiatus in the profile. Owing to the small number of ^{14}C dates available from Atikilleq, Bayesian modelling with Bacon was not feasible, and

linear interpolation in Clam was used to produce an age-depth model incorporating a hiatus at 15 cm (Fig. 8).

Numerical analysis. – PCA (Fig. 4) indicates good separation of the samples within the dataset. Axis 1 (45.1% of the variance) is characterised by positive scores for woody taxa such as *Betula pubescens* and *B. glandulosa*, and pteridophytes (*Lycopodium annotinum* and *Selaginella selaginoides*) which are common in scrub and heath in Greenland (Böcher *et al.* 1968). The largest negative loadings on axis 1 are for *Ranunculus acris*-type *Rumex acetosa* and *Apiaceae*, which do not suggest an obvious ecological gradient. Therefore this axis may reflect the degree to which the pollen assemblages have been biased by secondary pollen arriving either through erosion or in materials added to the anthrosol. Axis 2, accounting for 29.9% of the variance, is more clear and seems to be related to human impact. Apophytes and introduced taxa (e.g. *Polygonum aviculare*, *Cerastium*-type, Brassicaceae and *Montia fontana*) respond negatively while taxa more typical of natural vegetation communities (such as Cyperaceae and *Salix*) record positive scores.

Palynology. – Soils are far from ideal sediments for the preservation of pollen and are often severely affected by post-depositional biasing of fossil assemblages (Bryant & Hall 1993). To ascertain the extent of such biases, Bunting & Tipping (2000) propose eight tests (Table 4). The Atikilleq assemblage passes all but one of these, failing on the percentage of resistant taxa. This is not considered significant as the resistant taxa in this case (*Cerastium*-type, Brassicaceae, *Polygonum aviculare*, *Vicia*-type, Lactuceae and Caryophyllaceae) reflect ‘weeds’ frequent in Norse age pollen assemblages (cf. Fredskild 1978). The Atikilleq profile therefore does not appear to have been affected by differential preservation of pollen.

LPAZ AT-1 suggests an open landscape dominated by the herbaceous pollen types Cyperaceae and Poaceae. Shrubs such as *Salix* and *Betula glandulosa* are infrequent, as is *B. pubescens* (Fig. 9). This implies that grassy heath and/or sub-arctic steppe (grass or sedge communities growing on dry mineral soil; *sensu* Bocher *et al.* 1968) were common across the Atikilleq plain, which is unsurprising given the substrate (a sandy soil) and the exposed coastal aspect of the site. Low frequencies of *Sporormiella*-type (1-2%) fungal spores may indicate that wild herbivores played a role in maintaining a relatively open landscape (Fredskild & Holt 1993). The base of the zone dates to AD 870-1015. A pre-*landnám* age (i.e. prior to AD 985) seems the most reasonable for this LPAZ on the basis of pollen assemblages that show no sign of human impact, except for a single grain of *Rumex acetosella* at 37 cm, which could have percolated down the soil profile (cf. Dimbleby 1985). The presence of small amounts of microscopic charcoal may also imply similar processes.

The AT-1/2a boundary (AD 975-1095) marks Norse *landnám*. The clearest evidence for this is the appearance of charred bone fragments in the stratigraphy. Associated with this is an increase in macroscopic charcoal and a sharp rise in the C:P ratio, which may include airborne microscopic charcoal from local domestic fires (cf. Edwards *et al.* 2008). Increases in *Sporormiella*-type and *Sordaria*-type spores are likely to signify domesticated animals grazing in the vicinity and/or the addition of animal dung to the soil as a fertilizer (cf. Buckland *et al.* 2009). A brief decline in the LOI from 24.2% to 18.7% is associated with a peak (12%) in Pteropsida (monolete) indet. spores across the AT-1/2a zone boundary. This is suggestive of a period of soil erosion, a common occurrence at *landnám* (Edwards *et al.* 2008; Schofield & Edwards 2011) that may result from turf cutting for house construction (Fredskild 1973; Edwards *et al.* 2008). Pollen-analytical evidence also points to vegetational changes consistent with *landnám*. Weeds introduced by the Norse appear for the first time (e.g. *Polygonum aviculare*) and pollen from Brassicaceae, *Cerastium*-type and Lactuceae

becomes more frequent. The appearance of these ruderal types may be related to the downward migration of pollen, frequently found in soil profiles (cf. Dimbleby, 1985), but this seems unlikely given the associated changes in charcoal and LOI. Rather, it is probable that these pollen types imply an expansion of broken ground, probably around buildings and pathways, or the growth of the plants directly on the deposit. Scrub taxa also decline while Poaceae increases threefold to ~50-62% indicating the clearance of the scrub and heath and the establishment of hayfields.

The opening of AT-2b dates to AD 1090-1195 and marks a subtle shift in pollen assemblages characterised by an increase in *Ranunculus acris*-type. *Rumex acetosella*, *Polygonum aviculare*, *Cerastium*-type and Lactuceae persist and there is a decline in LOI. This may reflect increased soil erosion and the influx of minerogenic material into the deposit, or a reduction in the addition of organic materials such as manure. Declining *Sporormiella*-type frequencies support the latter explanation as does the fall in Pteropsida (monolete) indet. spores which suggest minimal soil erosion.

LPAZ AT-2c begins during the interval AD 1160-1240 and shows a reduction in Poaceae and an increase in Cyperaceae. There is a further increase in the pollen from *Ranunculus acris*-type, in this context most likely to represent the meadow buttercup (*R. acris*). In conjunction with the decline in Poaceae and rise in Cyperaceae, this may reflect an impoverishment of hayfield areas, as *R. acris* is common in ageing, poorly-managed hayfields (Grime *et al.* 1988). A similar pattern is not uncommon in Norse age pollen sequences, having been noted at both Qorlortup Itinnera (Schofield *et al.* 2008) and Sissarluttoq (Edwards *et al.* 2011b), and it probably reflects a cooling climate and the spread of sub-arctic steppe. The appearance of grazing-sensitive Apiaceae (Edwards *et al.* 2005) approaching ~2% towards the end of the zone, and a decrease in *Sporormiella*-type, may be evidence for a reduction in the number of domesticated livestock.

The contact separating the anthrosol from the overlying brown sandy-loam is estimated as dating AD 1235-1320, whilst a post-bomb radiocarbon date (SUERC-36606; $F^{14}C = 1.2804 \pm 0.0048$) immediately above the boundary between the two soil units demonstrates a probable hiatus, the position of which seems likely to correspond with the stratigraphic change at 15 cm.. A sample above the hiatus contains much reduced frequencies of microscopic charcoal and coprophilous fungal spores, although otherwise it is palynologically similar to the assemblages preceding it within AT-2c. Relatively high-frequencies of Poaceae (~37%) and Cyperaceae (~25%) pollen are recorded throughout the zone and indicate open sub-arctic steppe and grassy heath. Pollen from Norse apophytes is much reduced (Brassicaceae and Lactuceae) or rare (*Polygonum aviculare*, *Rumex acetosella* and *Cerastium*-type). It is therefore unclear whether the hiatus indicates the abandonment of the site, the end of soil management (augmentation), or both. Alternatively the hiatus may reflect an erosional contact that has subsequently been buried by material eroding from within the catchment, perhaps as a consequence of the re-introduction of sheep farming to the area during the 20th century.

Discussion

Although the pollen diagrams presented here represent contrasting contexts, the timing and environmental impact of *landnám* is broadly comparable. At Nimerialik palynological indications of human activity date to AD 775-1015 while anthropogenic soil formation at Atikilleq dates to AD 975-1095, suggesting farm establishment in the coastal reaches of Vatnahverfi was probably contemporaneous with elsewhere in the Eastern Settlement. At both sites *landnám* is characterised by rising levels of microscopic charcoal, a decline in LOI and an increase in coprophilous fungal spores. In addition, increases in Poaceae and apophytes are recorded alongside falling contributions from woodland and scrub pollen; patterns that

compare favourably with those from other sites (e.g. Edwards *et al.* 2008; Ledger *et al.* 2014a).

Despite their similarities, the intensity of the signature for Norse settlement differs substantially. This is visible in the combined PCA (Fig. 10) where Norse age pollen samples from Atikilleq plot separately from those of Nimerialik as a cluster with highly positive scores along axis 1. The anthrosol contains a strong signal for human impact characterised by high frequencies of Poaceae, with pollen from apophytes such as *Polygonum aviculare*, Lactuceae, Brassicaceae and *Cerastium*-type often exceeding 1%. This is comparable to other profiles in Vatnahverfi which are located in similarly close proximity (<100 m) to Norse ruins (Ledger *et al.* 2013, 2014a). The same patterns are broadly apparent in the mire profile but are less pronounced (Fig. 10). This probably reflects the distance between the sampling location and the nearest ruin group (~400 m), which would result in a dilution of the palynological signature for human impact specific to that site. Alternatively, the disparity in the strength of the palynological signals for human activity at Nimerialik and Atikilleq may reflect real differences in the intensity of human activity on and around both sites.

Interpretational problems associated with soil pollen profiles that arise from their complex taphonomy are well documented (Dimbleby 1985; Whittington & Edwards 1999; Donaldson *et al.* 2009). Although such misgivings result in them being understudied for landscape-scale analysis relative to pollen profiles from lakes and mires, the method has been widely exploited on archaeological sites (Greig 1981; Dimbleby 1985; Hall 1985; Segerström 1991; Kelso 1994; Tipping *et al.* 2009). Indeed the palynological analysis of 'non-conventional' pollen profiles has been attempted (with varying degrees of success) from a wide spectrum of deposits. These range from 'true' archaeological contexts (e.g. middens, house floors, etc.; Golding *et al.* 2011) through to palaeosols (Whittington & Edwards 1999;

Bunting *et al.* 2001) – soils which have become buried either through human or geomorphological processes.

Between these two extremes are plaggen soils and anthrosols (like Atikilleq) which are essentially anthropogenic in nature and accrue through the continued addition of waste materials to existing soils (Behre 1976, 1993; Waateringe 1992). Palynological analyses have revealed that low concentrations and extremely poor preservation of palynomorphs, typical of natural soil profiles, are less of a concern in plaggen deposits, owing to their lower pH and higher moisture content (Waateringe 1992; Donaldson *et al.* 2009). Despite receiving pollen input from the atmosphere, anthrosols are liable to be heavily influenced by secondary pollen from the addition of a mixture of cultural material (e.g. dung, floor waste, hearth sweepings, etc.; Panagiotakopulu & Buckland *et al.* 2012). The extent to which such potentially heterogeneous deposits contain stratified archives of environmental change is therefore an important question, especially given that these soils might also be expected to suffer from regular disturbance (e.g. trampling). Yet pollen assemblages through the anthrosol – LPAZs AT-2a to -2c – present neither a static signal nor erratic changes. Rather there are smooth changes (both in percentages and influx) that are comparable to the patterns one might expect from a palynological investigation of a natural context such as a mire. Radiocarbon dates from the base and top of the anthrosol also returned results that are in agreement with their relative stratigraphic positions, and provide additional confidence that the deposit contains a record of changes over time rather than simply a homogenised ‘snapshot’ of Norse settlement.

The most striking aspect of the influx diagram (Fig. 11) from Atikilleq is the inferred total pollen influx which peaks at ~ 70000 grains $\text{cm}^{-2} \text{a}^{-1}$. This is more than two orders of magnitude higher than typical anemophilous deposition in southern Greenland (348-407 grains $\text{cm}^{-2} \text{a}^{-1}$; Fredskild 1973) and an order of magnitude greater than that recorded in

natural fossil contexts in both Greenland (cf. Fredskild 1973; Pennington 1980; Schofield & Edwards 2011) and Iceland (Caseldine *et al.* 2003; Lawson *et al.* 2007) suggesting a high secondary pollen input. Indeed, total *Betula* pollen influx reaches a peak value of ~3000 grains $\text{cm}^{-2} \text{a}^{-1}$, which, if applying the pollen influx thresholds of Hicks & Sunari (2005), could be interpreted as evidence for the presence of dense woodland in the immediate vicinity. Clearly such an interpretation would be unsound given the absence of evidence for woodland prior to *landnám* and the exposed coastal aspect of this site which would inhibit woodland development (cf. Böcher *et al.* 1968). High *Betula* influx therefore appears to confirm a substantial input of secondary pollen into the Atikilleq profile. The source of this pollen is uncertain although it may have been incorporated in animal dung that was added to fields as fertilizer. High *Betula* pollen influx could therefore reflect leaf and twig foddering of livestock in the byre, a practice that is well documented across the North Atlantic region (Austad 1988; Buckland 2000).

Considering the evidence for secondary pollen input into the Atikilleq profile, it is likely the *Hordeum*-type pollen identified in AT-2a (Figs 9 and 12) were deposited in a similar manner. Although there is evidence emerging that Norse Greenlanders attempted to grow, or at least had access to cereals (Henriksen 2012), it seems unlikely that this would have been undertaken at Atikilleq. The site is located on a narrow plain protruding into Igaliku Fjord and is backed by steeply rising mountains which results in it being exposed to the desiccating winds blowing from the fjord; a setting that would not be conducive to arable agriculture. It is more likely that the *Hordeum*-type pollen derives from imported grain, or grain grown elsewhere in the Eastern Settlement, that was incorporated into the anthrosol with waste materials.

At Nimerialik there is also strong evidence for biasing of the assemblage through the deposition of secondary pollen. The total influx of pollen at this site increases at *landnám* and

remains high through the settlement period (Fig. 7). Enhanced influx is a common pattern in pollen records from Norse farmsteads in Greenland and appears linked to the increased productivity that results from the creation and management of hayfields (cf. Ledger *et al.* 2013), yet there is also a concurrent increase in both the number of corroded and degraded palynomorphs (Fig. 6) and Pteropsida (monolete) indet. spores (Fig. 5). Taken together with a sharp decline in LOI these changes are indicative of soil erosion and the inwash of secondary pollen from catchment soils. In this context, the substantially increased influx of both *Betula* and *Salix* pollen is unlikely to reflect actual changes in the woodland and scrub cover, highlighting the fact that natural palaeoecological profiles in Greenland – at least in this instance – can also be heavily influenced by variable taphonomic processes.

Conclusions

Anthrosols may typically be regarded as sub-optimal for palaeoenvironmental investigation in situations where organic profiles from natural contexts (e.g. mires and lakes) are also available. Unfortunately, the latter are not always present within the immediate vicinity of former Norse farms in southern Greenland. In other situations, natural contexts offering potential for palynological studies may exist but are present some distance from the nearest direct (archaeological) evidence for human settlement. In each circumstance, questions arise about the character, representation, strength and sensitivity of signals for human impact contained in the pollen record. This paper has attempted to address these issues by presenting palynological data from an ('off-site') peat sequence located ~400 m from the nearest visible structural ruins, and an ('on-site') anthrosol at a Norse farm.

Examination of the two profiles indicates similar pollen-analytical signatures for *landnám* and comparable dates for the arrival of settlers. The evidence for human impact in the anthrosol from Atikilleq is more pronounced than that recorded in the mire from

Nimerialik, and resembles that described for other natural sequences in Greenland that are located in similarly close proximity to the ruins of former Norse farms. This suggests that the anthrosol, at least in part, reflects real changes in vegetation communities around the farmed area rather than simply a record of the additions of waste to the soil. It also appears to be more sensitive to the impacts of Norse settlement than the mire at Nimerialik.

Despite the apparent advantages exhibited by the anthrosol, there are still some taphonomic problems to contend with. The record is heavily influenced by the deposition of secondary pollen, as would be expected. Birch pollen influx is unusually high and suggests the probable addition of birch pollen to the soil in animal dung, thus providing persuasive evidence for the stalling of livestock on twig and leaf fodder. Indeed, augmentation of the soil with waste from the dwelling and/or byre may also be responsible for the inclusion of two possible *Hordeum* (cf. barley) pollen grains in the anthrosol, rather than indicating that cereals were necessarily being grown on the site.

This paper has demonstrated that with a cautious interpretation of the data, anthrosols may provide valuable records of palaeovegetational change around farmed areas in Norse Greenland, and also provide unexpected insights into landscape management and resource use. Given that many similar contexts can be found throughout the North Atlantic region, the potential exists to extend the palynological study of these deposits into other Norse-settled regions with the aim of testing the repeatability of the results presented here and also improving our understanding of vegetational changes specific to individual farms. This may particularly be the case in those situations where more conventional contexts for palynological investigation (e.g. mires) are unavailable.

Acknowledgements. – We thank The Leverhulme Trust for financial support, Gordon Cook for the provision of radiocarbon dates and Andy McMullen for botanical identifications and

assistance in the field. Jane Bunting, Jan Piotrowski and an anonymous reviewer provided helpful comments which improved the manuscript.

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Table 1 Lithostratigraphy of the Nimerialik core.

Depth (cm)	Unit description and Troels-Smith formula
78-35	Brown slightly sandy moderately humified peat rich in bryophytes and containing abundant herbaceous rootlets and occasional sedge rhizomes. Th2-32 Tb21 Gmin1 As++ Nig 3 Sicc 3 Strf 0 Elas 0 Lim n/a
94-78	Light brown sandy and fibrous peat containing frequent herbaceous rootlets and sedge rhizomes. Th2-32 Sh1 Gmin1 As++ Nig 2+ Sicc 3 Strf 0 Elas 0 Lim 0
108-94	Brown slightly-sandy and well-humified peat containing a trace of clay, herbaceous rootlets and sedge rhizomes. Sh2 Th31 Gmin1 As++ Nig 3 Sicc 3 Strf 0 Elas 1 Lim 0
117-108	Dark brown poorly-humified and fibrous peat containing abundant sedge rhizomes, rootlets and bryophytes. Th13 Tb21 Ag+ Gmin+ Nig 3+ Sicc 2 Strf 0 Elas + Lim 0
145-117	Light brown slightly-sandy gyttja containing occasional moderately-humified herbaceous rootlets. Ld33 Gmin1 Th3++ Nig 2 Sicc 3 Strf 0 Elas + Lim 0

Table 2 Radiocarbon dates for the Atikilleq and Nimerialik profiles. Asterisk indicates a post-bomb date with the result reported as a fraction modern carbon ($F^{14}C$).

Site	Depth (cm)	Lab. code	Material	^{14}C a BP ($\pm 1\sigma$)	Cal. a BC/AD ($\pm 2\sigma$)	$\delta^{13}C$ (‰)
Atikilleq	14.5-13.5	SUERC-36606	<i>Betula</i> bark	*1.2804±0.0048	Modern	-29.0
	18-17	SUERC-12041	Charcoal	750±35	AD 1218-1291	-27.2
	35-34	SUERC-12045	Charcoal	965±35	AD 1016-1158	-25.8
	39-38	SUERC-36605	Charcoal	1090±35	AD 889-1017	-26.5
Nimerialik	43-42	SUERC-33434	<i>Sphagnum</i> sect <i>Acutifolia</i> leaves and branches	290±30	AD 1493-1662	-24.0
	59-58	SUERC-12051	<i>Sphagnum</i> sect <i>Acutifolia</i> leaves	265±35	AD 1494-1950	-25.4
	76-74	SUERC-33435	Bryophyte leaves and branches	910±30	AD 1033-1204	-27.0
	93-92	SUERC-12055	Bryophyte leaves and branches	955±35	AD 1020-1158	-25.7
	101-100	SUERC-36607	Bryophyte leaves and branches	1085±35	AD 892-1017	-28.1
	116-115	SUERC-33436	Bryophyte leaves and branches	2345±30	BC 509-371	-26.9
	143-141	SUERC-33440	Bryophyte leaves and branches and <i>Vaccinium uliginosum</i> leaves	2505±30	BC 787-540	-26.1

Table 3 Lithostratigraphy of the Atikilleq profile.

Depth (cm)	Unit description
7.5-0	Modern turf
94-78	Light brown and very sandy soil containing fine gravels and rootlets Gmin 4 Ag ++ Th2+ Nig 3 Sicc 3 Elas + Lim 0
108-94	Dark brown sandy silty soil with occasional gravels. Charcoal fragments up to 5 x 5mm are frequent as are bone fragments. Gmin 3Ag 1 Anthr++ Th2+ Nig 3-4 Sicc 3 Elas + Lim 0
145-117	Brown organic-rich, dry sand and gravel containing numerous rootlets Gmin 2 Gmaj 2 Th2++ Nig 3 Sicc 3 Strf 0 Elas 0 Lim 0

Table 4 Test for post-depositional bias in the Atikilleq dataset based upon threshold criteria outlined in Bunting & Tipping (2000). All values reflect the lowest value recorded in the analysed profile. Asterisk resistant taxa category includes all grains from Caryophyllaceae, Brassicaceae, *Polygonum aviculare*, *Cerastium*-type and Lactuceae.

Measure	Threshold	Atikilleq values	Pass/Fail
Total land pollen sum	<300	500	Pass
Pollen concentration	<3000 grains cm ⁻³	96200 grains cm ⁻³	Pass
Number of main sum taxa	<10	14	Pass
Percentage indeterminable	>30%	23%	Pass
*Percentage resistant taxa	>6%	20%	Fail
Percentage Pteropsida (monolete) indet.	>40%	12%	Pass
Spore : pollen concentration ratio	>0.66	0.12	Pass
Spore : pollen taxa ratio	>0.66	0.17	Pass

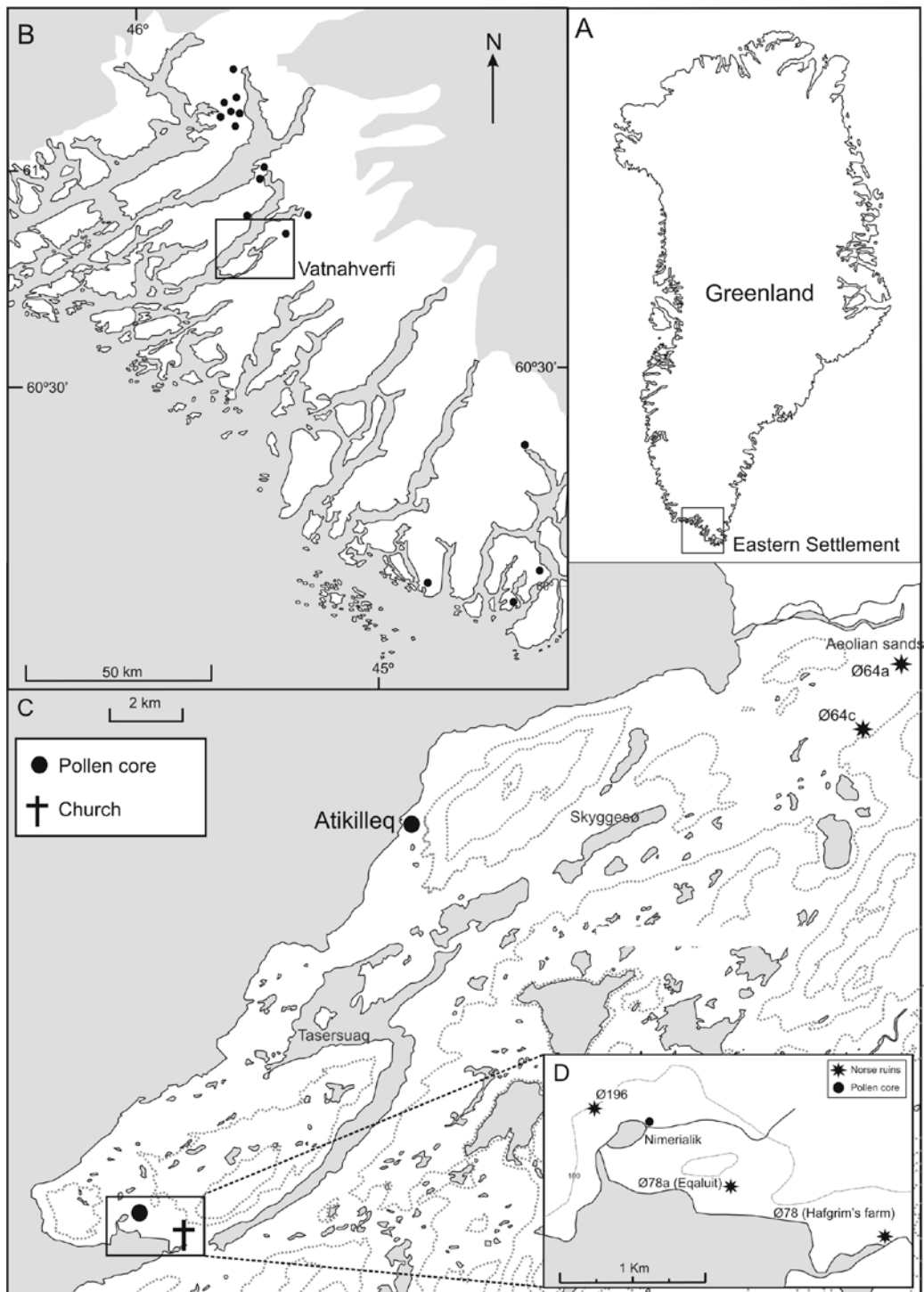


Figure 1. A. The Norse Eastern Settlement in Greenland (boxed). B. Sites (black dots) in the Eastern Settlement of Greenland for which palynological data are currently available (excludes this study). C. Places within Vatnahverfi that are featured or discussed in the text. D. Positions of Norse farm ruins in relation to the coring site at Nimerialik.

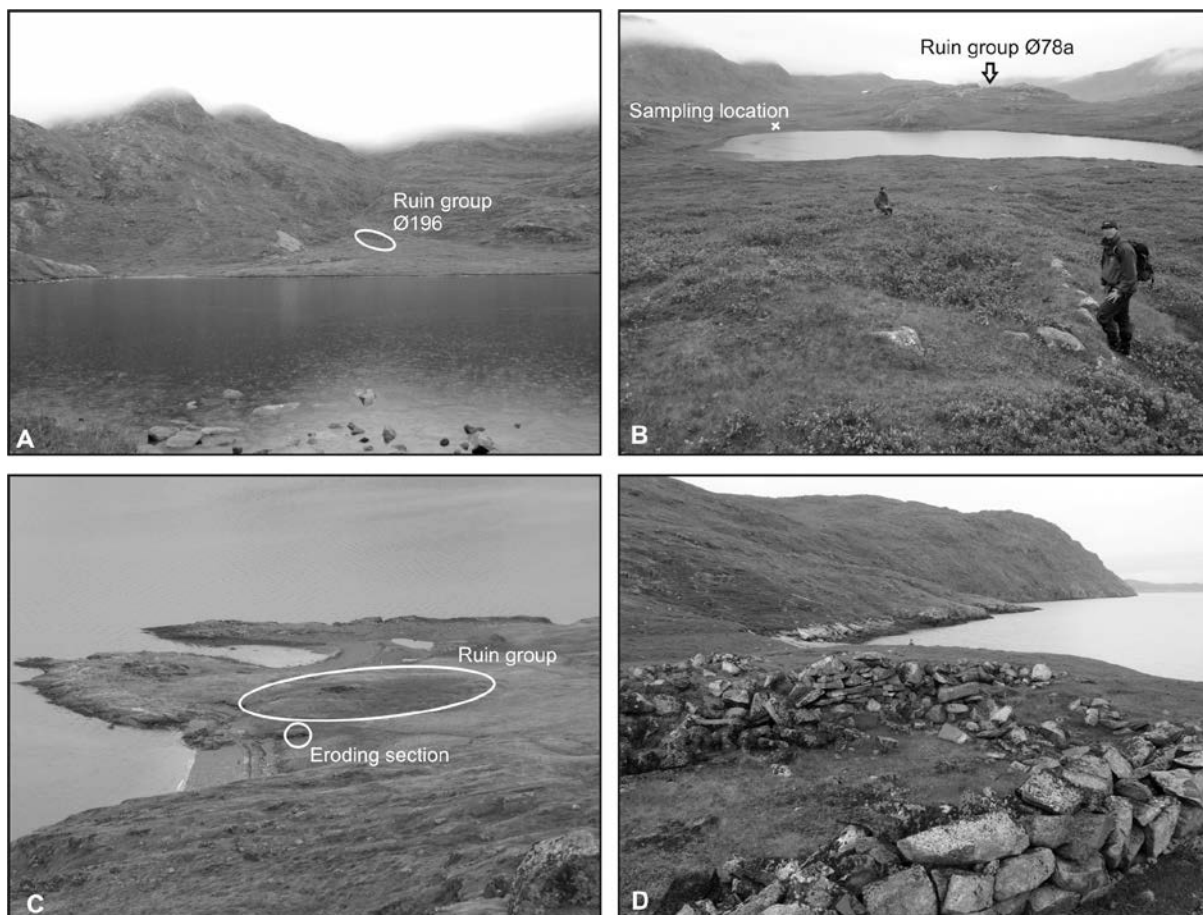


Figure 2. Photographs of the study sites. A. View northeast across the lake towards ruin group Ø196 at Nimerialik (Photo: P. M. Ledger, July 2010). B. Looking southeast over ruin group Ø196 towards the sampling location (Photo: K. J. Edwards, July 2010). C. View north across Ø65 at Atikilleq; the ruins and sampling location are circled (Photo: J. E. Schofield, May 2006). D. Main farm building at Ø65, looking southeast towards Igaliku Fjord (Photo K. J. Edwards, July 2010).

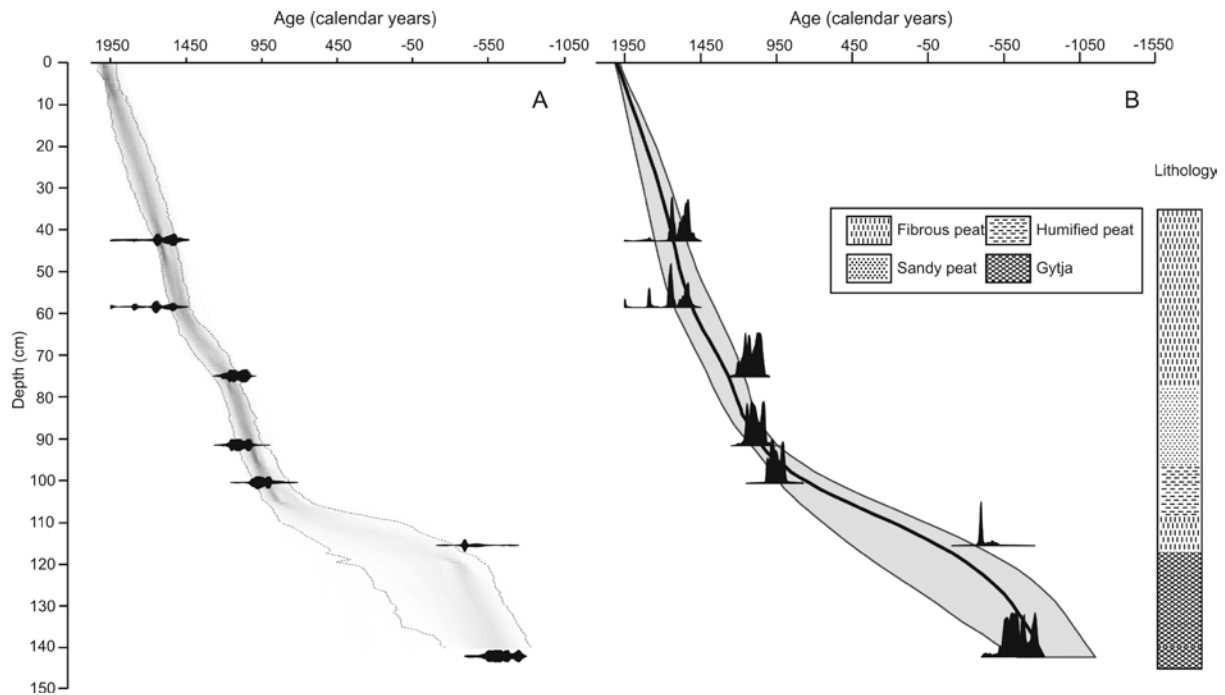


Figure 3. Age-depth models generated for the Nimerialik profile. A. Model generated using Bacon. Deposition time was set at 12 a cm^{-1} on the basis of mean accumulation rates for peatlands elsewhere in southern Greenland. Although there are no age-depth reversals there are indications of a sharp decline in accumulation rate between 116-100 cm where there is a *c.* 1000 cal. a difference between the two AMS dates. Memory strength and mean priors – which govern the flexibility of accumulation rates – were therefore set at 50 and 0.5 respectively to allow the model the flexibility to adjust for variation in the trajectory of accumulation. The shaded area indicates all possible age-depth models and the dotted lines show the 2σ age range; darker areas indicate increased certainty. B. Clam model generated using a smoothed spline. The grey envelope indicates the 95% confidence limits on the model, whilst the solid black line represents the ‘best estimate’.

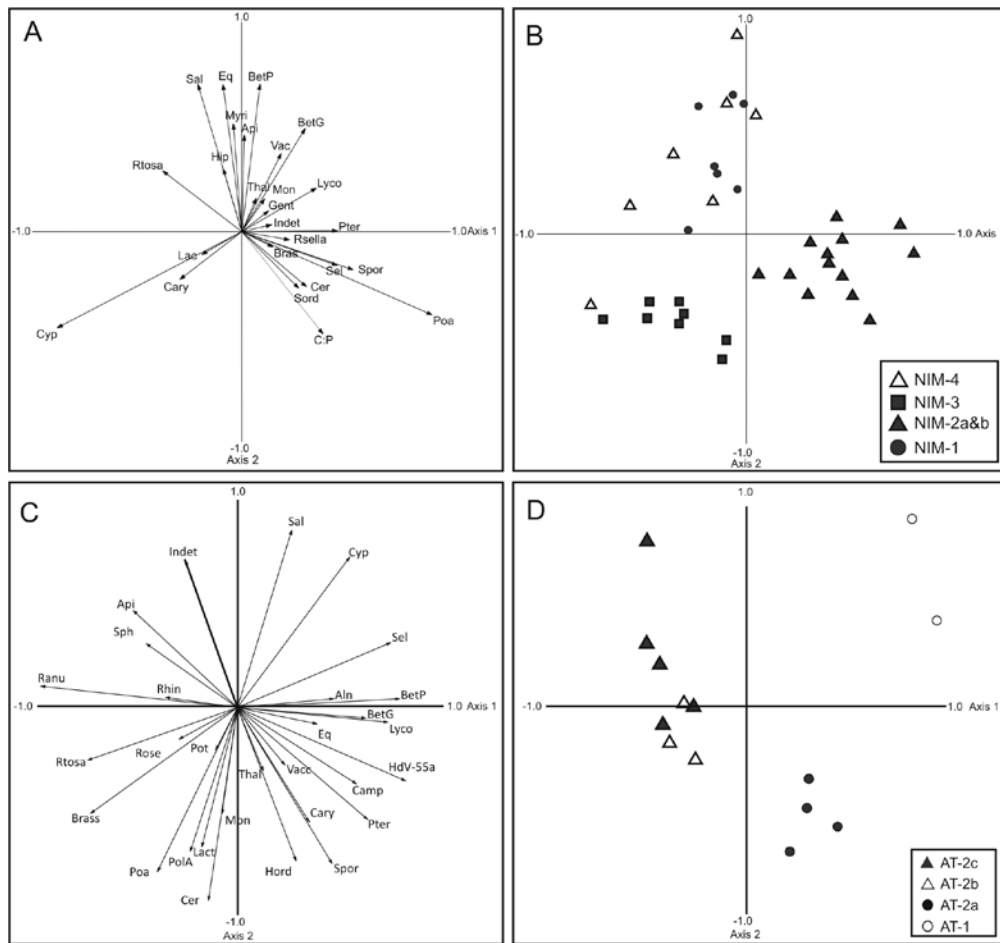


Figure 4. PCA plots of pollen for the two profiles. A. Pollen types and associated proxies from Nimerialik (selected taxa only). B. Sample scores for the Nimerialik pollen and spore dataset. C. Pollen types and associated proxies from Atikilleq. D. Sample scores for the Atikilleq pollen and spore dataset. Key to abbreviations: Aln = *Alnus*; Api = Apiaceae; BetG = *Betula glandulosa*; BetP = *Betula pubescens*; Brass = Brassicaceae; Camp = *Campanula gieseckiana*; Cary = Caryophyllaceae; Cer = *Cerastium*-type; C:P = charcoal to pollen ratio; Cyp = Cyperaceae; Eq = Equisetum; HdV-55a = *Sordaria*-type; Hip = *Hippuris vulgaris*; Hord = *Hordeum*-type; Indet = unknown and indeterminable; Lact = Lactuceae; Lyco = *Lycopodium annotinum*; Mon = *Montia fontana*; Myri = *Myriophyllum alterniflorum*; Poa = Poaceae; PolA = *Polygonum aviculare*; Pot = *Potentilla*-type; Ptero = Pteropsida (monoete) indet.; Ranu = *Ranunculus acris*-type; Rhin = *Rhinanthus*-type; Rose = Roseaceae; Rsell = *Rumex acetosella*; Riosa = *Rumex acetosa*; Sal = Salix; Sel = Selaginella selaginoides; Sord = *Sordaria*-type; Sph = Sphagnum; Spor = *Sporormiella*-type; Thal = *Thalictrum alpinum*; Vacc = *Vaccinium*-type. The aquatic pollen types *Myriophyllum alterniflorum* and *Hippuris vulgaris* were included as supplementary (passive) species in the ordination analysis in order to examine their behaviour relative to terrestrial pollen types.

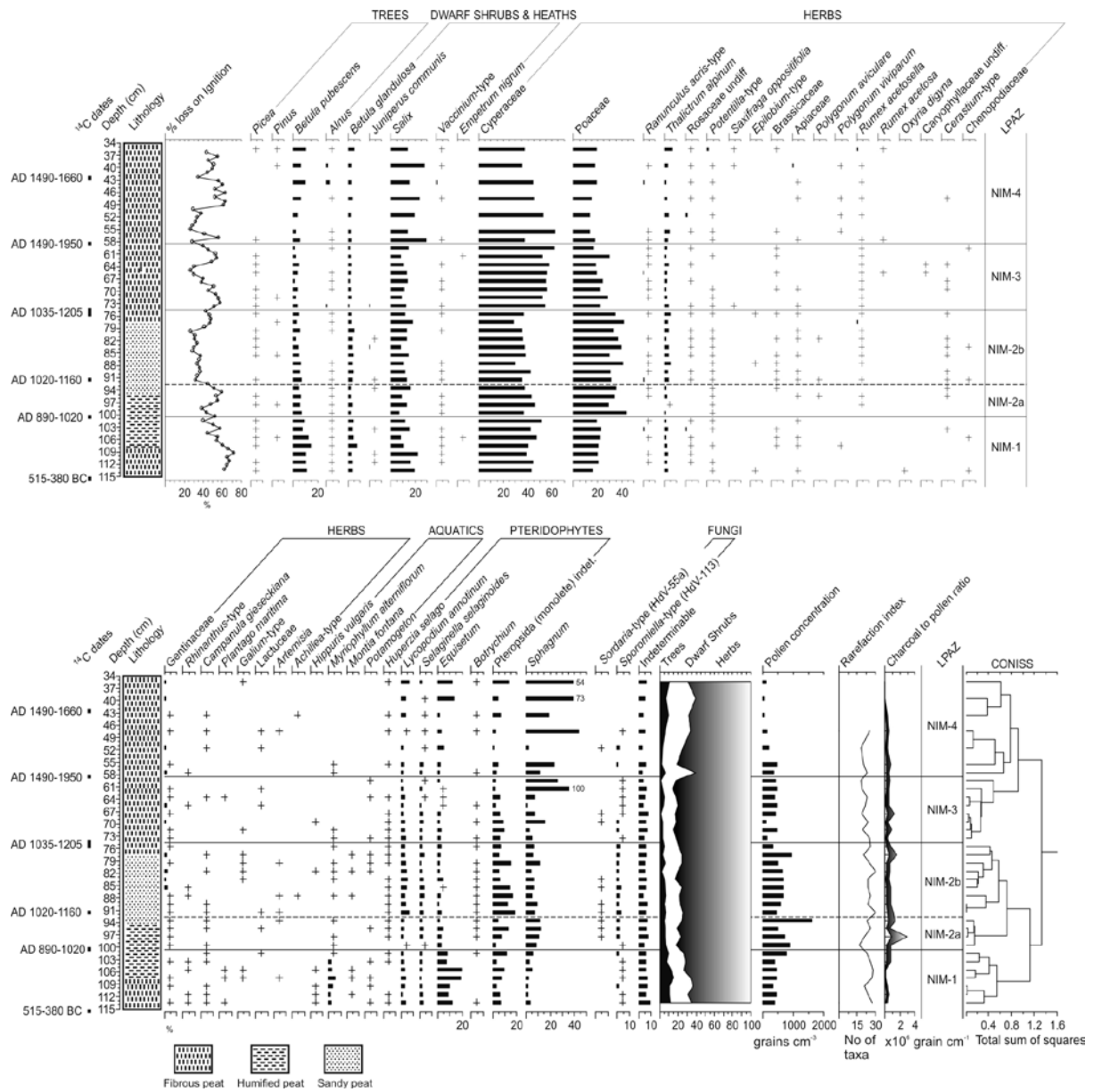


Figure 5. Percentage pollen and spore diagram for Nimerialik displaying selected taxa (minimum sum = 500 TLP). Also shown are the calibrated ^{14}C dates (2σ range), lithology, loss-on-ignition, microscopic charcoal, total pollen concentration and the rarefaction index. + indicates $<1\%$ TLP.

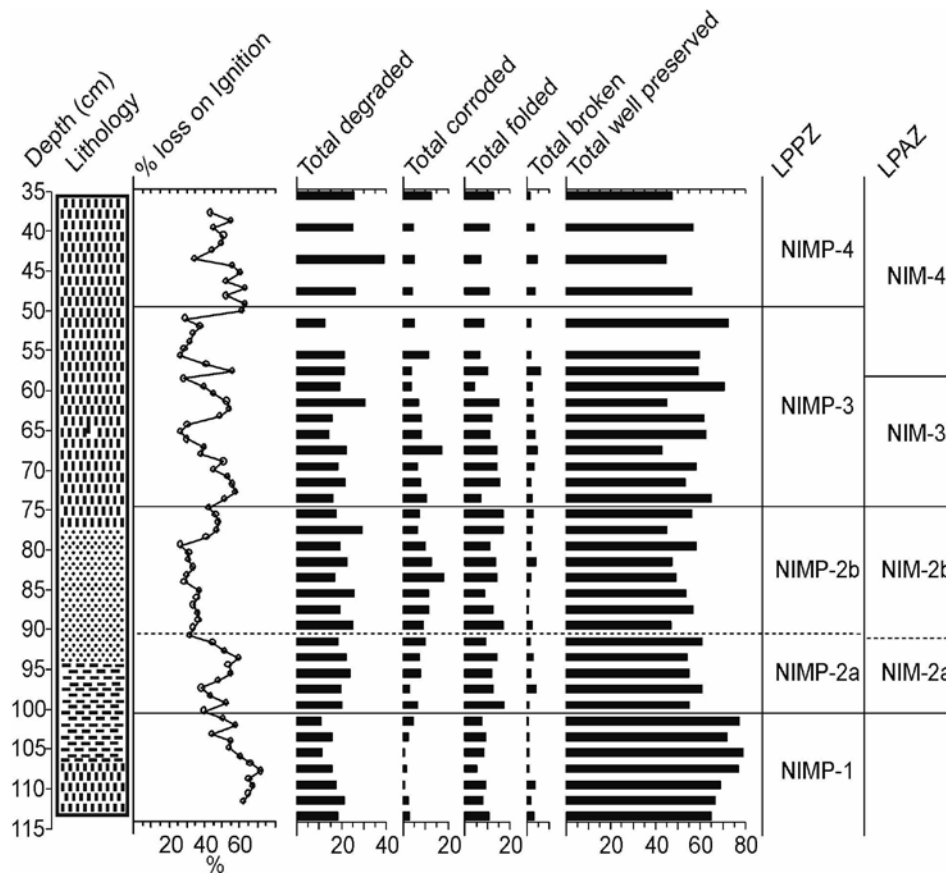


Figure 6. Pollen preservation diagram for Nimerialik illustrating the fluctuating percentages of the five main categories of preservation. Local pollen preservation zones (LPPZs) were designated with reference to CONISS (displayed). LPAZs are also indicated.

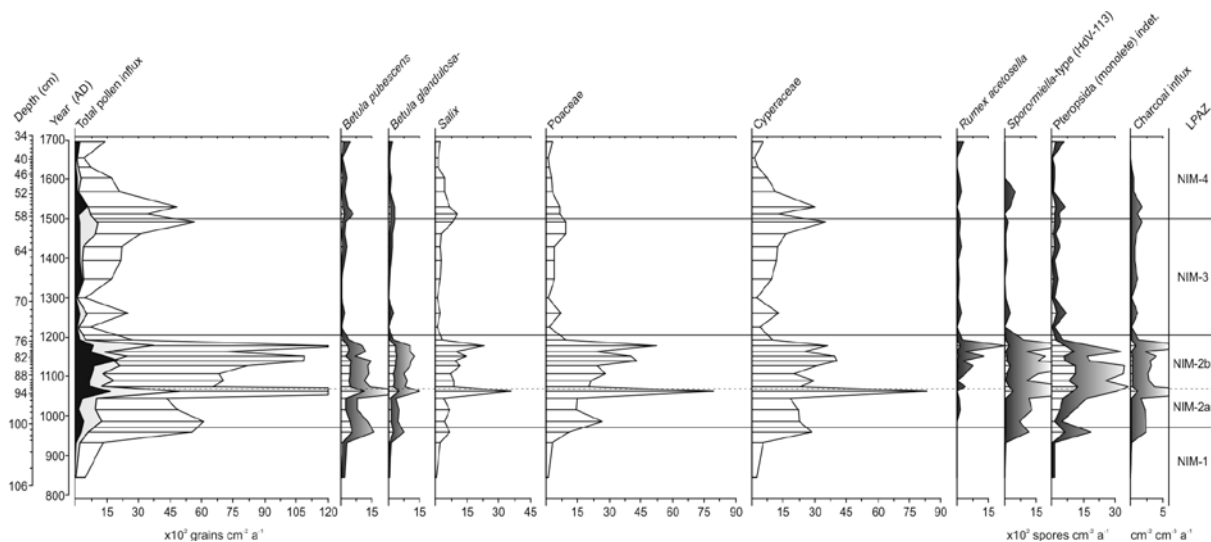


Figure 7.

Pollen influx diagram for Nimerialik showing total pollen influx, selected pollen types, spores and charcoal plotted against the maximum *a posterior* probability (MAP) from the Bacon model. Exaggeration curves, where present, are x15 with the exception of *Betula pubescens* and *B. glandulosa* which are x3. Influx of corroded (black) and degraded (grey) pollen are overlain on the total pollen influx curve.

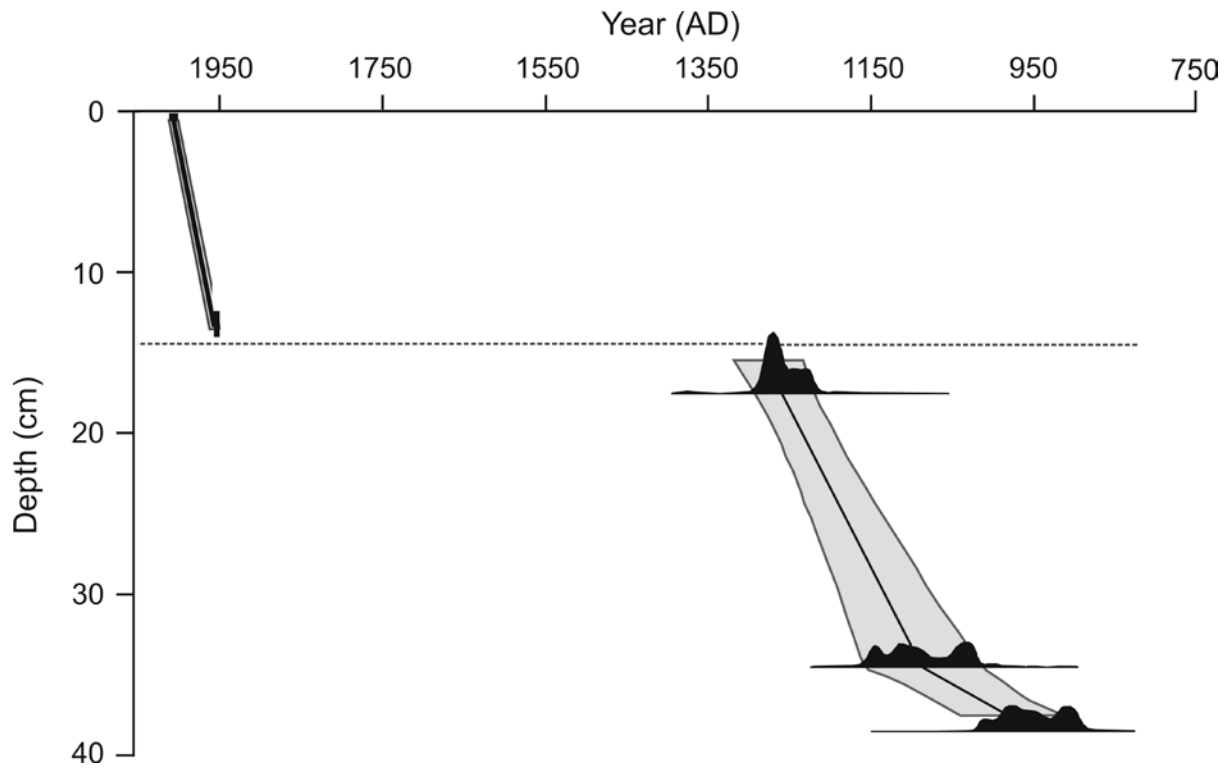


Figure 8. Clam model for the Atikilleq profile with the dashed line indicating the position where cultural inputs into the deposit appear to have ceased.

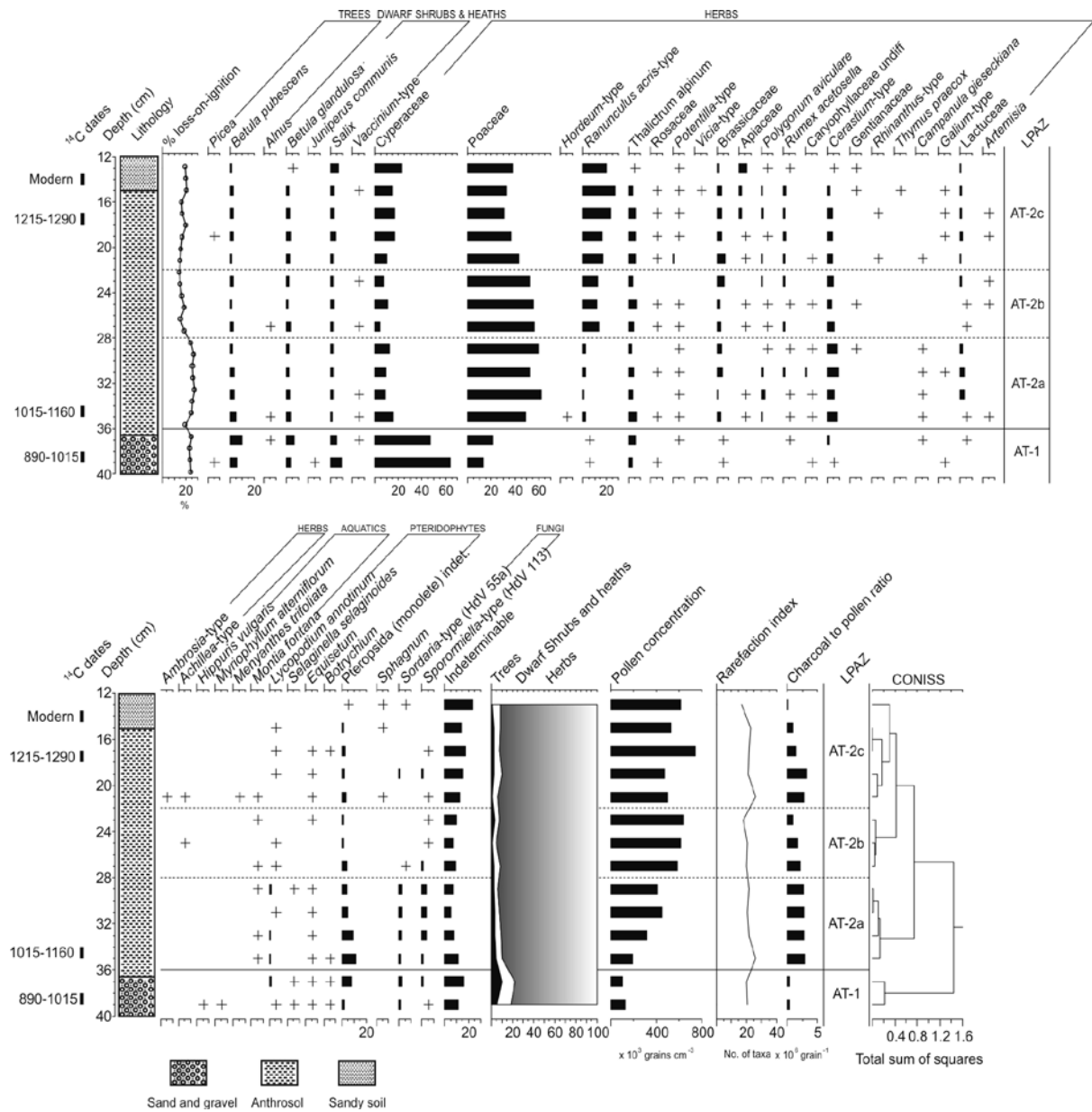


Figure 9. Percentage pollen and spore diagram for Atikilleq displaying selected taxa (minimum sum = 500 TLP). Also shown are the calibrated ¹⁴C dates, lithology, loss-on-ignition, microscopic charcoal, total pollen concentrations and the rarefaction index. + indicates <1% TLP.

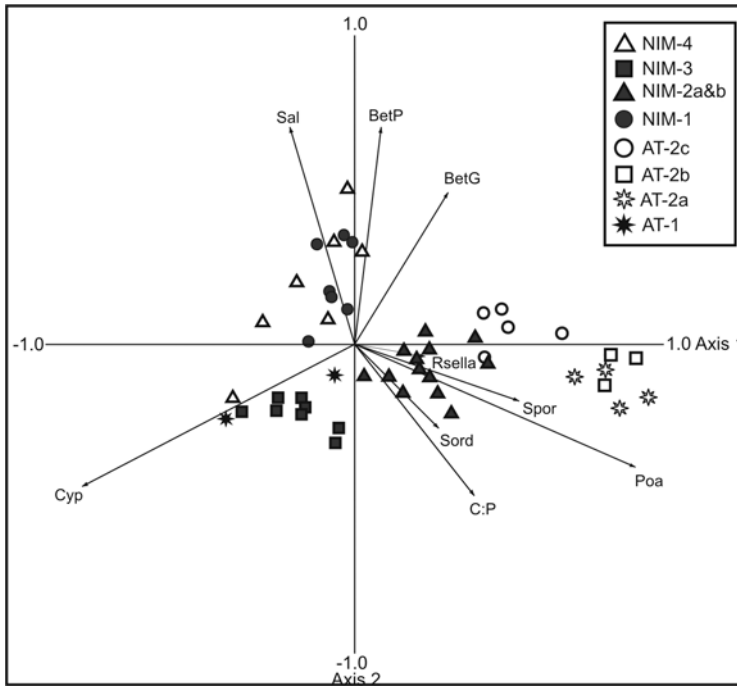


Figure 10. PCA comparing samples from Nimerialik and Atikilleq. Samples from Atikilleq were treated as supplementary objects in the ordination of Nimerialik data in order to observe relationships between the samples. Selected species are presented in the ordination and the abbreviations follow those in Figure 4.

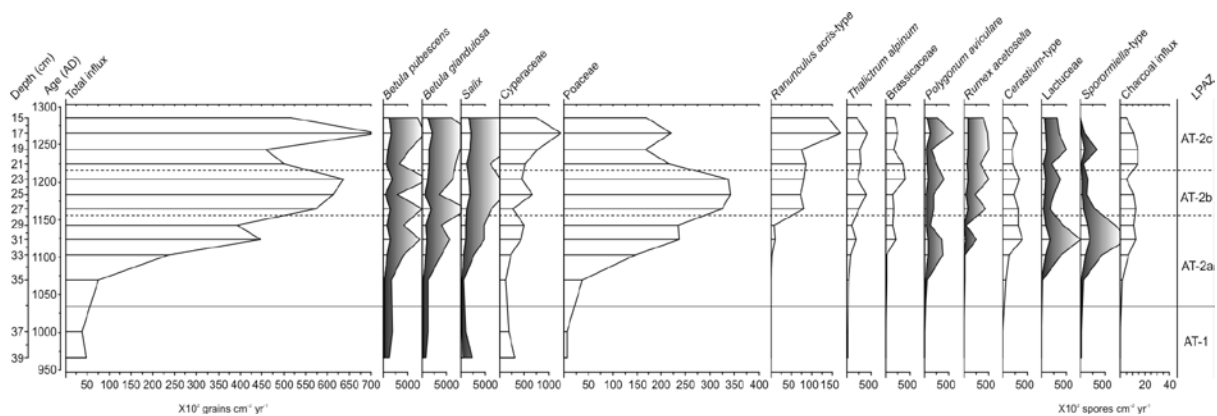


Figure 11. Influx diagram for Atikilleq showing total pollen influx, selected pollen types, *Sporormiella*-type and microscopic charcoal plotted against the best estimate from the *Clam* model (exaggeration curves where present are x5). Pollen influx was calculated only for the LPAZs below the hiatus.

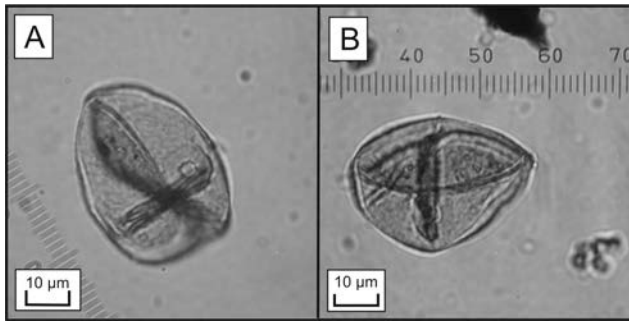


Figure 12. *Hordeum*-type pollen grains found at a depth of 35 cm in the Atikilleq profile.

Note the strong surface sculpturing of the grains, distinct annuli and relatively small size of the pores in relation to the annuli. These are characteristics more typical of *Hordeum* (barley) than that of *Elymus arenarius* (lyme-grass), a native plant which produces morphologically-similar pollen grains (Ledger 2014b). Grain A is a mean size of 38.6 µm with an annulus diameter of 9.96 µm. Grain B is 37.35 µm with an annulus of 8.30 µm. Both grains are highly folded and as such these measurements reflect the minimum size of the grains.