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Environmental impacts around the time of Norse *landnám* in the Qorlortoq valley, Eastern Settlement, Greenland

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Abstract

Palynology, radiocarbon dating, and open-section stratigraphies from archaeological trenches are used to examine the impact of human activity around the time of Norse *landnám* on vegetation and landscape associated with a small farm (Ø34) in the Qorlortoq valley, Eastern Settlement, Greenland (61° N 45° W). Peat deposits from a mire abutting the Norse ruins revealed a discontinuous palaeoenvironmental record containing a possible hiatus from ca. AD 410–1020. Palaeovegetational data were recovered either side of this period. Pollen assemblages suggest that open *Salix* scrub dominated the landscape during the pre-settlement phase. The later phases of *landnám* resulted in the creation of hay fields and heavily-grazed grassy heath. Site abandonment is reflected by a re-expansion of *Salix*. This occurs shortly before the onset of deposition of a *Sphagnum* peat, dated to cal AD 1420–1630 (2σ) and reflecting an increase in mire surface wetness, probably in response to a deteriorating climate. Radiocarbon dates were obtained on peat and plant macrofossils sampled from either side of the proposed hiatus at two different but closely-spaced (<20 m) locations across the mire. These produced significantly different dates for the cessation of peat formation in the pre-*landnám* period (cal BC 2130–1770 and cal AD 240–410 respectively), but near-synchronous dates for the recommencement of peat growth (cal AD 890–1150 for peat and a probably more reliable interval of cal AD 1020–1190 based on plant macrofossils). It is suggested that this hiatus may represent the first direct evidence for peat cutting in Norse Greenland.

Keywords: Greenland; Norse Eastern Settlement; *Landnám*; Pollen analysis; Radiocarbon dating; Peat cutting

1. Introduction

From the 9th century AD onwards, the Norse *landnám* (Old Norse, 'land taking') had a significant environmental impact upon the biota and landscape of the North Atlantic islands. This was particularly the case in some of the larger and more westerly islands, such as Greenland (Fig. 1a), where the subarctic character of the climate placed the European-style farming systems favoured by the Norse colonists very close to their physical limits (Dugmore et al., 2005). Pollen diagrams from the Eastern Settlement (Fredskild, 1973, 1978, 1988;Edwards et al., in press) reveal that the arrival of the Norse settlers coincided with a reduction in woodland and scrub and an expansion in grassland, open-ground pioneers and ruderal plant communities. Alien plant taxa, most notably sheep's sorrel (*Rumex acetosella*), were introduced to the native flora, and soil erosion intensified (Jakobsen, 1991; Sandgren and Fredskild, 1991) as the fragile equilibrium between climate, vegetation, and soils was disturbed. Environmental degradation was perhaps important in leading to the ultimate failure of the Norse colonies in Greenland (e.g. Amorosi et al., 1997), although other factors, most notably climate change, purportedly played key, if contested, roles in the collapse of these societies (cf. Barlow et al., 1997; Diamond, 2005; Panagiotakopulu et al., 2007).

Our understanding of *landnám*-age environmental impacts in Greenland is still heavily reliant upon data from a relatively small number of sites (Fredskild, 1978) concentrated in the area around the posited ruins of Erik the Red's farm,

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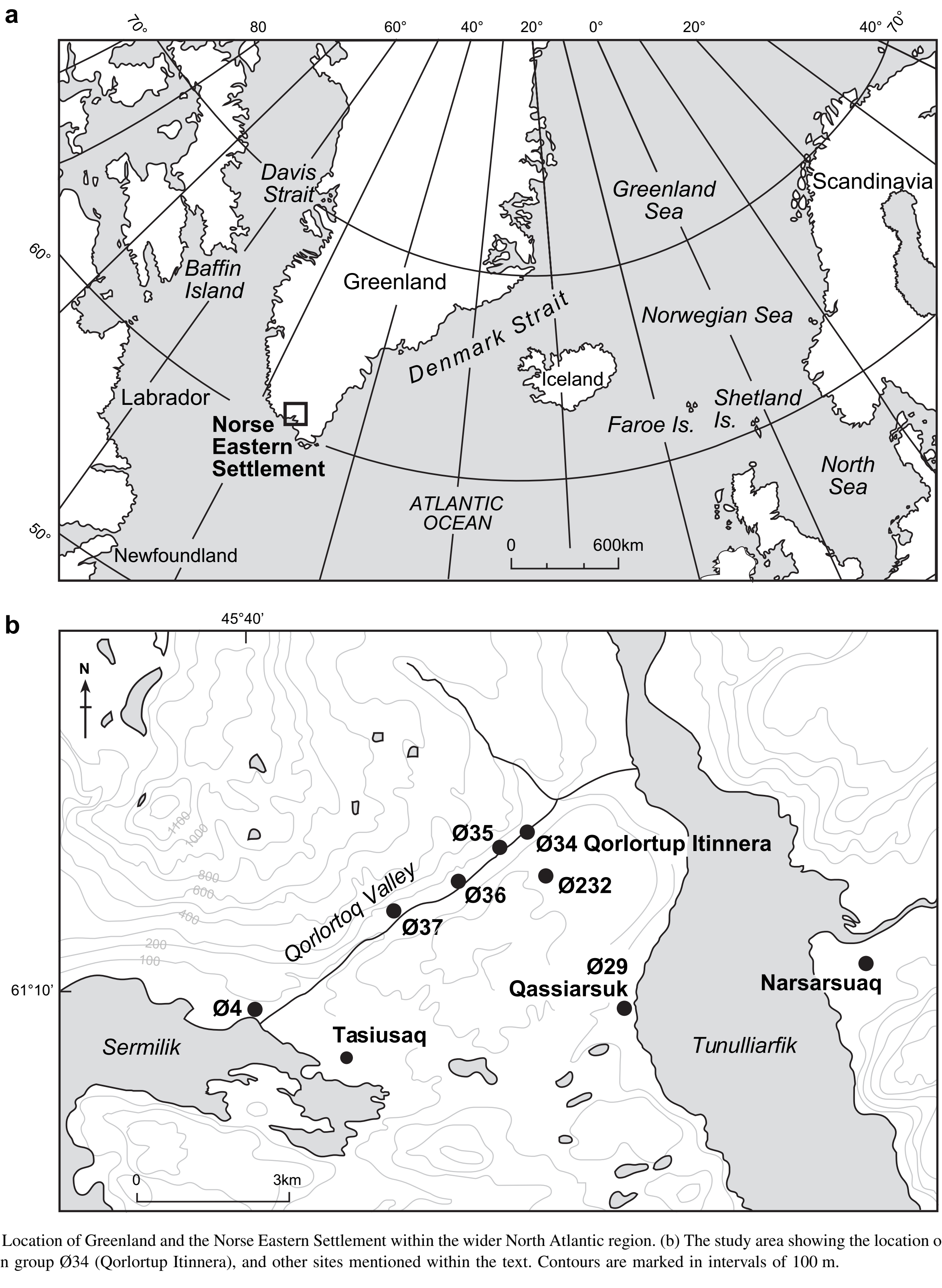

Fig. 1. (a) Location of Greenland and the Norse Eastern Settlement within the wider North Atlantic region. (b) The study area showing the location of the Qorlortoq valley, ruin group Ø34 (Qorlortup Itinnera), and other sites mentioned within the text. Contours are marked in intervals of 100 m.

Brattahlið, which is today occupied by the modern sheep farming village of Qassiarsuk (Fig. 1b). In addition, very few radiocarbon dates are available to accompany pollen profiles and, therefore, chronologies covering the period of Norse settlement are, at best, of low-resolution. As a result many uncertainties still surround the timing and rate of vegetation changes initiated at *landnám*, and it is still largely unproven as to whether patterns produced at Qassiarsuk are characteristic of the wider landscape.

Amongst the objectives set out by the project of which the current study is part (Edwards et al., 2004) were palaeoenvironmental investigations designed to improve the spatial coverage and temporal resolution of palaeovegetational data in Norse-age landscapes across the North Atlantic region. The research presented here falls under this rationale. This paper contains results from a palaeoenvironmental investigation of a small Norse farmstead in the Qorlortoq valley, designated as ruin group Ø34 (Qorlortup Itinnera) in archaeological surveys of the Eastern Settlement (Holm, 1883; Bruun, 1895; Guldager et al., 2002). Pollen analysis of a peat profile located within 50 m of the ruins is used to reconstruct the local vegetational changes associated with *landnám*. This term is used here to denote the initial signs of 'land taking' together with subsequent environmental changes associated with early Norse settlement. For the site under investigation, the onset of *landnám* is actually considered to be absent (see below), although the pollen and related data enable a discussion of the pre-settlement environment, the development of Norse land use within decades of the initial *landnám*, and the environment after abandonment. A high-resolution chronology is provided by AMS radiocarbon dating of closely-spaced plant macrofossil samples. Analyses from core samples are complemented by conventional radiocarbon dating of bulk peat and stratigraphic descriptions of open-sections recorded during an earlier archaeological survey of the site. Of great interest is an apparent hiatus recorded in the stratigraphy of mire deposits abutting the ruins. Competing hypotheses are proposed to explain this phenomenon. These emphasise the potential utilisation of peat by the Norse settlers as a source of fuel and/or building material, yet also consider possible evidence that the mire could have been dug-out to create a reservoir for an artificial irrigation scheme serving the valley bottom.

2. Background

2.1. Archaeology

Ruin group Ø34 (listed as Norse site 525 in the Grønlands Landsmuseum catalogue [cf. Berglund, 1986; Guldager et al., 2002]) is located in the Qorlortoq valley at an altitude of ca. 125 m a.s.l. and ca. 3 km southwest and inland of the Tunulliarfik fjord (Fig. 1b). The ruins rest on moraine-like features elevated slightly above the general level of the valley floor (Fig. 2). The group (17 ruins in total) contains a small dwelling and a byre of modest size. Investigation of a refuse layer situated next to the farmstead (the 'midden' of Guldager et al. (2002), shown in Fig. 3) resulted in the collection of a large sample of animal bones (9000 fragments) comprising mostly seal (46%), cattle (21%), sheep and goat (28%), and five fragments belonging to at least two individuals identified as domestic cat, representing the first finds of this animal from Norse Greenland (Nyegaard, 1996). A number of well-preserved Norse artefacts made from wood, bone, tooth, antler and steatite were also recovered, together with some textiles and a few artefacts of chalcedony (including a blade-like object with a hint of a tang) belonging to the Dorset culture (Nyegaard, 1996). A farm of similar size (Ø35/RG 529), and with an associated church, is located just a few hundred metres up the valley. A shieling in the mountains at Sammisoq Timaa (Ø232/RG 527) (Fig. 1b) may also have belonged to Ø34 (Guldager et al., 2002). Dykes from supposed Norse irrigation systems—used to divert water from the mountains down to the edge of the homefields, where the hay crop required for over-wintering livestock was grown—have also been reported at some farms in the Qorlortoq valley (Ø4, Ø36 and Ø37; Arneborg, 2005).

Fig. 2. The Norse ruins at Ø34 (photograph by J.E. Schofield, August 2004).

2.2. Physical geography

The study area is situated in the subcontinental, subarctic climatic and vegetational zone of southern Greenland (Feilberg, 1984). Mean monthly temperatures range between 9.3 °C and −6.3 °C (Box, 2002) with mean annual precipitation of 696 mm (Feilberg, 1984). Local basement geology comprises gneisses, granites and metamorphosed supracrustal rocks of

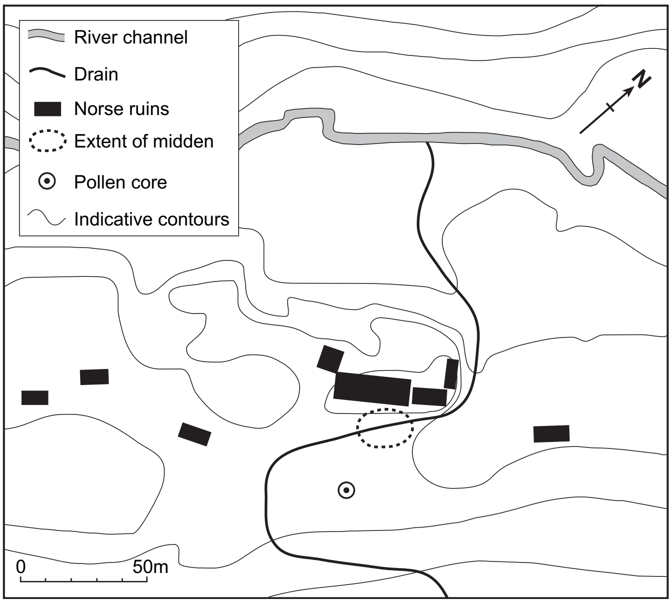

Fig. 3. General plan of ruin group Ø34 (based upon Guldager et al., 2002, Fig. 58). Contours are indicative of the relief with altitude ranging from ∼125 m a.s.l. (in the valley bottom beside the river) to ∼150 m a.s.l.

the Ketilidian mobile belt (Allaart, 1976). The ruins at Ø34 are overlooked by steep slopes to the northwest and southeast, upon which grows dense *Salix glauca* (grey willow) scrub containing smaller patches dominated variously by *Betula glandulosa* (dwarf birch), *Juniperus communis* (juniper), *Vaccinium uliginosum* (bog bilberry) and *Empetrum nigrum* (crowberry) (plant nomenclature follows Böcher et al., 1968). The valley bottom is predominantly a managed agricultural landscape dedicated to the cultivation of hay and grazing. *Carex rariflora* (loose-flower alpine sedge) mire supporting *Salix arctophila* (arctic willow) and bryophytes (principally *Aulacomnium palustre* and *Helodium blandowii*) occupies a narrow stretch of the valley bottom (no more than 50–100 m wide) between the ruins and the base of the southeastern slope (Fig. 4). Consequently the presumed pollen catchment area for the mire is assumed to be small, with the majority of the pollen rain deriving from valley bottom and adjacent slope vegetation (local and extra-local sources *sensu* Jacobson and Bradshaw [1981]). The mire surface is also rather uneven, is dissected by a field drain, and rises to the west, where small pools of open water are also present.

3. Methodology

3.1. Archaeological excavation and open section sampling

Archaeological investigations began after field drainage revealed apparent midden material within peat. Excavations in 1997, 1998 and 2001 were carried out by Qaqortoq Museum assisted by the National and Zoological Museums of Denmark. Excavation sections were located east of the drainage ditch other than for a single trench to the west which ran close to the ruins. Four test pits were also made within the mire area. Well-preserved waste inferred to come from the farm was incorporated within the peat, and consisted of animal bone, wooden artefacts and tools, wood waste, twigs (probably from the house and byre), and burnt stones. Open faces within these trenches were cleaned and the stratigraphies were recorded (Troels-Smith, 1955; there were many minor stratigraphic changes visible within the profiles and full details may be obtained from CC). Monolith samples were collected, sealed in bags, and returned to Denmark for processing.

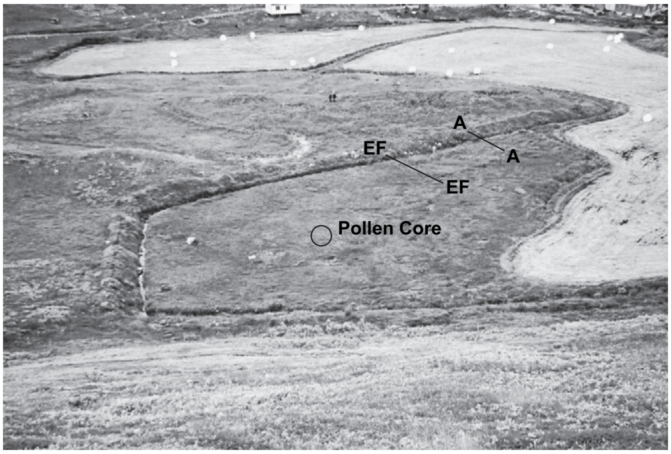

Fig. 4. View northward across the eastern area of the mire basin at Ø34. The Norse ruins are visible on the raised relief behind the mire (note the people standing amongst the ruins for scale). The coring location is circled and the approximate positions of the open sections (A and EF) are marked. (Photograph by K.J. Edwards, August 2004).

3.2. Collection of core samples and sedimentary analysis

Core sampling was undertaken in 2004 from the eastern mire basin (Figs. 3 and 4) immediately southeast (<50 m) of the ruins (N 61° 11.506′ W 45° 33.075′; 126 m a.s.l.) using a Russian corer (Jowsey, 1966). Positional and altitudinal data for the coring location were recorded using a portable Garmin GPS. A vegetation survey was also undertaken, the full results of which are available in Schofield et al. (2007).

Core sections were protected in plastic guttering, wrapped in polythene, and returned to the University of Aberdeen where they were placed in cold storage (4 °C). Sub-sampling for pollen analysis and Troels-Smith (1955) recording of the lithostratigraphy was undertaken in the laboratory. The organic content of samples was measured by loss-on-ignition (LOI) following 3 h combustion in a furnace at 550 °C (Bengtsson and Enell, 1986).

3.3. Pollen analysis

Samples for pollen analysis were prepared using standard NaOH, HF and acetolysis procedures (Moore et al., 1991) with *Lycopodium* tablets (Stockmarr, 1971) added to each sample to allow the calculation of concentration data. Microfossils were suspended unstained in silicone oil of 12,500 cSt viscosity and in most cases samples were counted until a sum in excess of 500 TLP (total land pollen) grains had been surpassed, although low pollen concentrations (<10,000 grains cm^{-3}) at the top of the core resulted in a smaller pollen sum of 300 TLP being accepted for four samples. Scanning of pollen samples for non-pollen palynomorphs (NPPs) was also undertaken (results courtesy of B. van Geel, pers. commun.) but these microfossils were not assessed quantitatively. Pollen and spore identifications were made in consultation with the key in Moore et al. (1991) and modern reference material held at the University of Aberdeen. Pollen nomenclature largely follows Bennett et al. (1994) and Bennett (2007b). Nomenclature for taxa not appearing in this catalogue follows Moore et al. (1991). Separation of *Betula* (birch) pollen into tree (*Betula pubescens*) and shrub (*Betula glandulosa*) categories was achieved on the basis of grain size, with grains <20 μm diameter classified as *B. glandulosa* (cf. Fredskild, 1973). Grain diameter was measured as the length from the pore tip to the outer surface of the opposite wall (cf. Mäkelä and Hyvärinen, 1998).

Pollen percentage, concentration and influx diagrams were constructed using TILIA and TGView software (Grimm, 1991, 2007). Unless stated otherwise, cited pollen percentage data are based on the total land pollen (TLP) sum. High numbers of Cyperaceae (sedge) pollen were recorded in all samples.

Sedges are common in both dryland and wetland environments in Greenland (Böcher et al., 1968) and most of the sedge pollen recorded at this site is likely to be locally-derived from the *Carex*-dominated mire surface vegetation, resulting in this pollen type being heavily over-represented in the pollen rain. A percentage diagram with Cyperaceae excluded from the pollen sum (TLP – Cyperaceae) was therefore also constructed in order to correct for the proportional effects of variations in Cyperaceae upon all other taxa. Although this results in a sometimes low effective pollen sum, it is considered that the benefits of depicting data in this fashion are still instructive. Stratigraphically constrained cluster analysis following square root transformation of the percentage data (Grimm, 1987) was used as an aid to biostratigraphic zonation of diagrams. Rarefaction analysis as an index of pollen richness (Birks and Line, 1992) was performed using psimpoll (Bennett, 2007a).

3.4. Charcoal

The size of microscopic charcoal particles in pollen residues was measured using a microscope eyepiece graticule at a magnification of ×400. Owing to the high concentrations of charcoal in most of the samples, only the first 50 fragments encountered larger than 50 μm^2 were included in these analyses. Techniques employed in determining pollen concentrations and influx were used to calculate charcoal concentration (expressed in units of $cm^2\ cm^{-3}$) and charcoal influx ($cm^2\ cm^{-2}\ yr^{-1}$) (cf. Swain, 1978). Charcoal to pollen concentration ratios (C:P) were also calculated (expressed in units of $cm^2\ grain^{-1}$) to check whether charcoal abundance was independent or a consequence of sedimentary changes affecting all particles (Patterson et al., 1987). Charcoal data are displayed on the pollen diagrams.

3.5. Radiocarbon dating and chronological models

Accelerator mass spectrometry (AMS) radiocarbon measurements were undertaken on both plant macrofossils (bryophytes) and the humic acid fraction of small ($1\ cm^3$) peat samples from the pollen core. Plant macrofossils selected for AMS were disaggregated from the sediment matrix by gently heating the sample for 20 min in 10% NaOH then washing through a 125 μm sieve mesh using distilled water. Sieve residues were examined under a binocular microscope at low magnification (×8–30) and plant tissues (moss stems, branches and leaves) picked for dating. Bryophytes were identified using the key and diagrams in Smith (1978). AMS samples were processed and measured at the SUERC Radiocarbon Laboratory, East Kilbride.

The chronology of open section EF is based on the conventional radiocarbon dating of six bulk peat samples, 1–2 cm in thickness. The samples were extracted from a peat monolith (the basal 3 samples) or cut directly from the cleaned face of the field section (the uppermost 3 samples) so as to follow variations within the peat strata. Coarse plant macrofossils and cultural remains visible within the peat matrix were removed from samples prior to submission. A conventional radiocarbon date on wood (*Betula* and *Salix* twigs with bark intact) was also taken from open section A. Bulk peat samples were dated at the former Radiocarbon Laboratory of the National Museum of Denmark, Copenhagen.

Calibration of radiocarbon dates was performed using the IntCal04 calibration curve (Reimer et al., 2004) and OxCal (Bronk Ramsey, 1995, 2001, 2005). Unless stated otherwise all calendar dates in the text are expressed at the 2σ confidence level and are rounded to the nearest 10 years.

An age–depth model for the pollen core was produced using the five AMS radiocarbon dates on plant macrofossils. These were calibrated using Bayesian procedures (BCal [Buck et al., 1996, 1999, 2003] which forces chronological ordering of dates) and the results were exported to psimpoll where a calendar age–depth graph was constructed using the method of linear interpolation between the weighted averages of the calibrated dates (cf. Yeloff et al., 2006). Weighted averages were preferred to modal values as the former produces more conservative age-estimates. This approach can provide calendar dates for non-radiocarbon-dated levels, although for lower and upper sections of the core the data generated are less precise. The model extrapolates between the two lowermost macrofossil dates (52–51 cm and 55–54 cm) to the base of the pollen-analysed profile. This results in the widening of confidence intervals over this section because of the lack of an absolute date from the base of the core. The model interpolates over the section between the youngest radiocarbon date (28–27 cm) and the modern ground surface (0 cm). This produces narrower confidence intervals as the model assumes that the surface equates with AD 1950.

4. Results

4.1. Lithostratigraphy

Open sections (Figs. 5 and 6) and the pollen core (Table 1) reveal a two-part stratigraphy to the mire. At the base of each profile is a medium-to-dark brown, well-humified peat containing occasional large stones. This peat was proven to a depth of at least 1.5 m below the modern ground surface (the limit of the excavation) in open section EF. Overlaying this is a lighter brown, more poorly-humified peat composed primarily of a mat of fine herbaceous rootlets (hereafter referred to as *turfa* peat, following Troels-Smith, 1955) and containing fragments of monocotyledon stems, bryophytes, and occasional cultural remains. The depth of the contact between the humified peat and the *turfa* peat is quite variable. In section EF it was observed 90–100 cm below the modern ground surface, with the same contact recorded at a depth of 65–90 cm in section A, and at 54 cm in the pollen core. The midden-like deposit containing burnt stone and animal bone (including whalebone and a cat cranium identified by Georg Nyegaard) was revealed in section A. This midden rests upon a base of two large stones and also, in part, upon the humified peat layer. The midden is separated from the *turfa* peat across a diffuse (>1 cm) boundary.

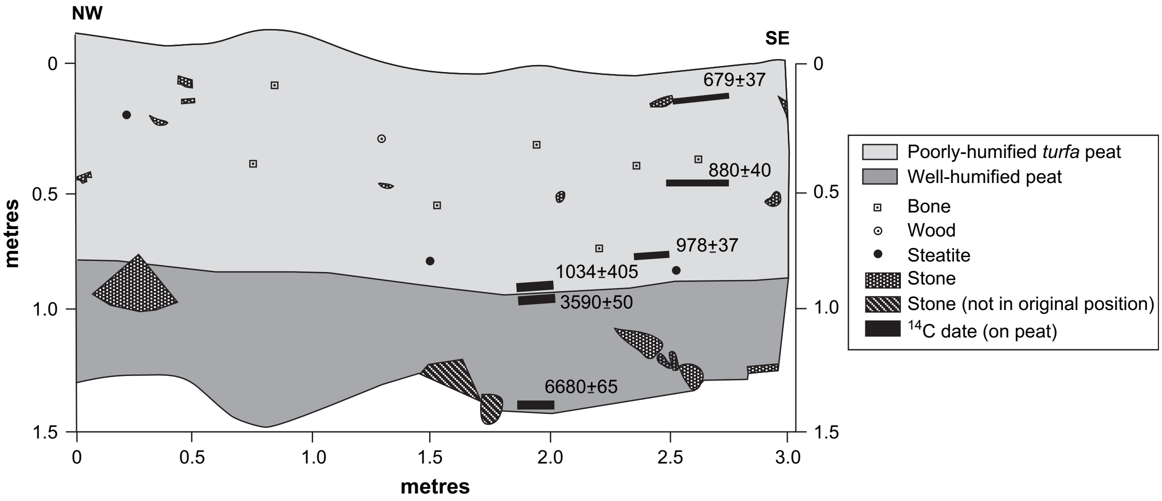

Fig. 5. Stratigraphy of open section EF. Depth (*y*-axis) is measured against an arbitrary datum.

4.2. Biostratigraphy

Four local pollen assemblage zones (prefixed QOR-) can be recognised in the pollen diagrams (Figs. 7–9). The defining characteristics of these pollen zones are summarised in Table 2. The pollen influx diagram (Fig. 9b) corresponds approximately with the period of Norse settlement (QOR-2 and QOR-3). No attempt has been made to calculate pollen influx for assemblage zones without a secure absolute chronology (QOR-1 and QOR-4).

4.3. Radiocarbon dates

Radiocarbon dates are presented in Table 3 and displayed as a scatterplot (Fig. 10). Towards the top of the pollen core (above 50 cm) dates are in stratigraphic order. Further down the profile (below 50 cm) AMS dates on plant macrofossils (in this case the bryophytes *Sphagnum*, *Calliergon*, and *Plagiomnium* spp.) are much younger than the measurements on the humic acid fraction of peat.

The dates on plant macrofossils appear to provide a more accurate reflection of the 'true' age of events within the palaeoenvironmental record. This argument is supported and most clearly illustrated by a comparison of the measurement on *Calliergon giganteum* branches (leaves and stems) (665 ± 35 BP, cal AD 1020–1190) at 52–51 cm with the date obtained from the humic acid fraction of the peat (1385 ± 35 BP, cal AD 590–690) at the same depth. On the basis of pollen assemblages from this horizon—which contain pollen from Norse introductions and apophytes—both these samples should post-date the documented calendar date for first arrival of the Norse in Greenland (ca. AD 985). Yet this is clearly not the case for the measurement on humic acid, which provides a calendar date which appears to be 300–400 cal. years too old.

Possible explanations as to why the AMS dates on humic acid appear too old are contamination of peat deposits through the redeposition of 'old carbon' eroding from soils or sediments elsewhere within the site catchment (cf. Pilcher, 1991), disturbance of the peat surface (possibly by human activity), or the net upward transport of water soluble organics through the sediment column, which can result from shifts

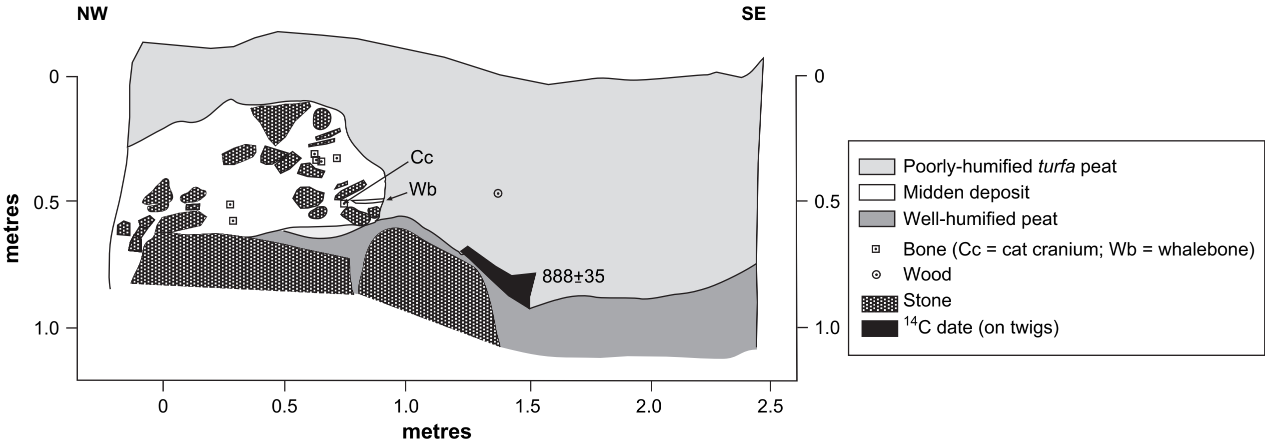

Fig. 6. Stratigraphy of open section A. Depth (*y*-axis) is measured against an arbitrary datum.

Table 1
Lithostratigraphy of the pollen core

Depth (cm)	Unit description and Troels-Smith formula
17–12	Black (oxidised) fibrous peat composed primarily of fine herbaceous rootlets (many modern) Th^{0}3 Sh1 As+ Nig 4 Sicc 3 Strf 0 Elas+ Lim 0
23–17	Pale yellow-brown silt-rich peat containing abundant fine herbaceous rootlets and a trace of sand Th^{1}2 Ag2 Sh+ Ga+ Nig 2 Sicc 3 Strf 0 Elas 0 Lim 0
27–23	Yellow-brown poorly-humified fibrous peat composed primarily of fine herbaceous rootlets Th^{2}4 Sh+ Dl+ Gs+ Tb^2+ Nig 3 Sicc 3 Strf 0 Elas 2 Lim 0
35–27	Poorly-humified *Sphagnum* peat containing occasional herbaceous rootlets TSphag^{1}4 Sh+ Th^1+ Nig 3 Sicc 3 Strf 0 Elas 2 Lim 0
54–35	Yellow-brown poorly-humified fibrous peat composed primarily of fine herbaceous rootlets Th^{2}4 Sh+ Dl+ Gs+ Tb^2+ Nig 3 Sicc 3 Strf 0 Elas 2 Lim 0
64–54	Medium brown well-humified peat composed primarily of fine herbaceous rootlets and monocot stems Th^{4}2 Sh2 As+ Gs+ Nig 3 Sicc 3 Strf 0 Elas 0 Lim 0

in the height of the watertable (cf. Shore et al., 1995). Similar patterns to those recorded here have been demonstrated with the radiocarbon dating programme undertaken during a recent palaeoenvironmental investigation at Tasiusaq, ca. 8 km southwest of Qorlortup (Edwards et al., in press). This suggests that radiocarbon dating of the humic acid fraction of peat samples may be subject to error throughout this region (cf. Sandgren and Fredskild, 1991) and it would be wise to exercise caution when dating similar contexts. In the discussion that follows the rate and timing of vegetational changes inferred from pollen samples are based upon an age–depth model (Fig. 11) which was constructed using only the results from the dating of plant macrofossils.

Radiocarbon dating at Ø34 also reveals the likely presence of a sedimentary hiatus between the end of formation of the humified peat and the onset of formation of the (overlying) *turfa* peat. AMS dates taken from the pollen core at either side of this sedimentary contact (both plant macrofossils and peat samples) indicate this proposed hiatus covers a period of some 700–800 radiocarbon years. Conventional dates on peat from open section EF (K-7047 and -7046), however, indicate a significantly longer duration for the hiatus of approximately 2500 ^{14}C yr. A significant change in the rate of sediment accumulation is apparent either side of the hiatus, with a rise in the sediment accumulation rate (to ca. 0.06 cm yr^{-1}) following the recommencement of peat formation. This pattern is also clearly reflected in the calendar age–depth graph for the site (Fig. 11).

5. Discussion

5.1. Vegetation history

Assemblage zone QOR-1 covers the period from ca. 2000 BC to shortly after cal AD 240–410 (1720 ± 35 BP, SUERC-8908) and provides evidence for baseline environmental conditions prior to Norse *landnám*. The environment appears to have been very similar to that recorded at Qassiarsuk before *landnám* (Fredskild, 1973, 1978). High Cyperaceae pollen frequencies and moderate amounts of Poaceae (grass), *Salix* and *Thalictrum alpinum* (alpine meadow-rue) pollen indicate a local sedge-dominated mire community surrounded by open willow scrub. Low pollen frequencies for *Betula* spp., which are highly over-represented in pollen diagrams from this environment (Schofield et al., 2007), are also suggestive of an open landscape supporting very little woodland. The low and variable organic content of the peat throughout this assemblage zone indicates regular inputs of clastic sediment to the mire surface, illustrating that catchment soils were far from stable even in the apparent absence of human activity. Low levels of microscopic charcoal are recorded in QOR-1. These may come from a variety of sources, for instance, natural heathland fires caused by lightning strike, the possible presence of palaeo-Eskimo camps in nearby coastal areas (cf. Böcher and Fredskild, 1993; Grønnow and Sørensen, 2006), or from North American fires derived either naturally or anthropogenically.

The QOR-1/2 boundary corresponds with the probable hiatus in the profile and the sedimentary change from well-humified peat to poorly-humified *turfa* peat. Pollen assemblages (and therefore inferred vegetation communities) reveal subtle rather than major changes across this boundary. A small increase in floristic diversity (indicated by the rarefaction curve) and the appearance of a Norse ‘footprint’ in pollen assemblages are apparent from the base of QOR-2. Most notable is the appearance and increase in pollen from plants introduced through, or favoured by, Norse activity, such as *Rumex acetosella* (sheep’s sorrel), *Rumex acetosa* (common sorrel), and *Ranunculus acris* (meadow buttercup) (cf. Porsild, 1932; Pedersen, 1972; Fredskild, 1973; Feilberg, 1984).

Assemblage zone QOR-2 covers the period from immediately before cal AD 1020–1190 (930 ± 35 BP, SUERC-8907) to ca. AD 1400. Palynological data indicates that *landnám* was probably already underway before the opening of the zone. Elevated Poaceae, *Rumex acetosella* and *Ranunculus acris* pollen percentages are likely to reflect both the establishment of hay fields and an expansion in the area covered by open grassy heath. Although clear, the expansion in grasses is not dramatic and it could be that Poaceae representation is diminished as a result of over-grazing (cf. Groenman-van Waateringe, 1993; Whittington and Edwards, 1993), or perhaps more extensive grasslands were being utilised in shieling areas. Trace values (<1%) of ruderal pollen types such as *Polygonum aviculare* (knotgrass), *Cerastium*-type (mouse-ears), and *Rumex acetosa* are also frequently recorded, indicating increased disturbance of vegetation communities and the likely presence of patches of bare ground. Grazing by livestock around the site during this period appears to have been considerable, with ascospores of *Sporormiella* frequently observed in pollen residues (B. van Geel, pers. commun.). Most species of these fungi are coprophilous and their presence can be used to indicate increased animal populations (van Geel et al., 2003). It is unclear from the palynological evidence alone whether animal dung (or any other

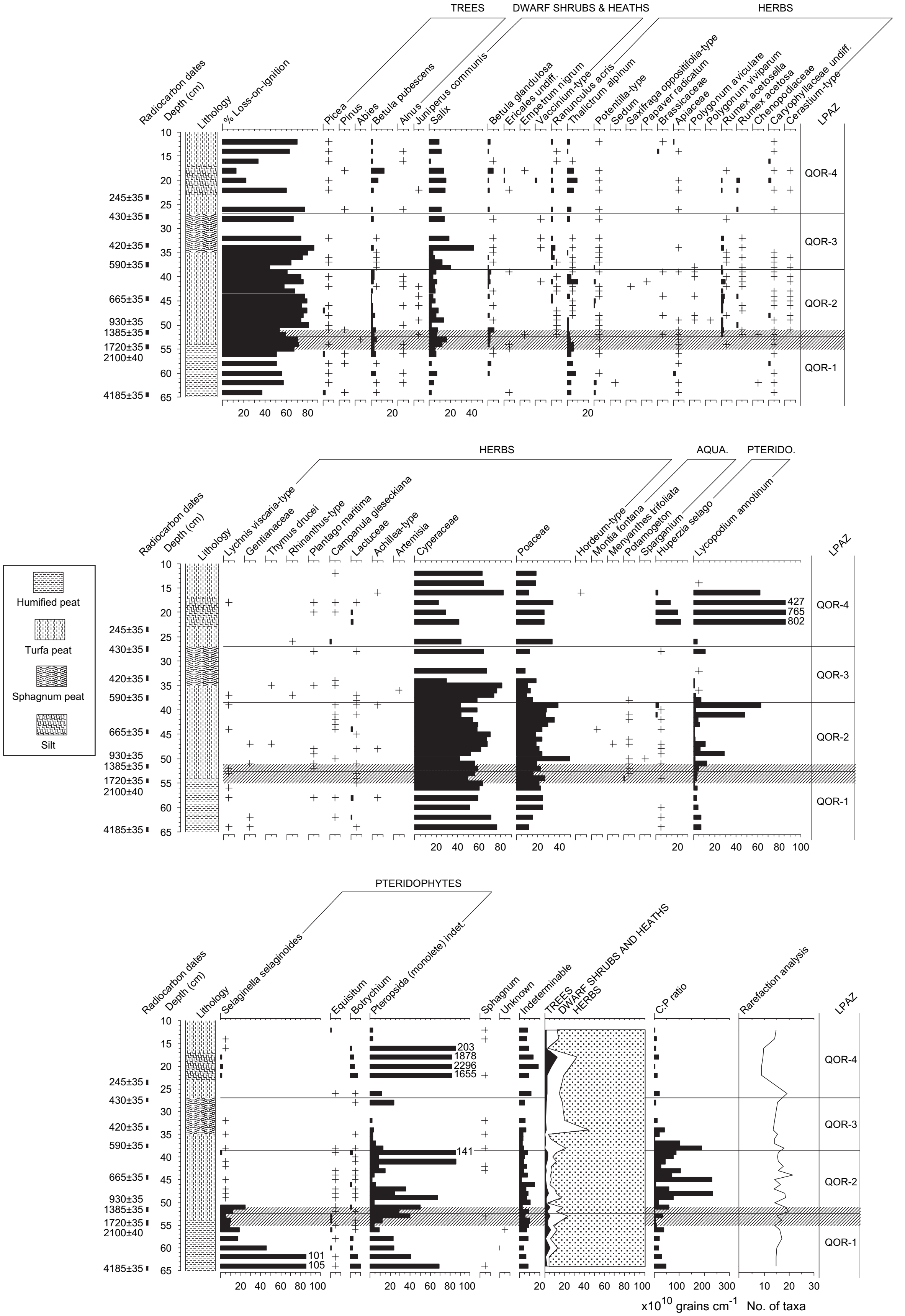

Fig. 7. Diagram of percentage pollen and spores, LOI, C:P and rarefaction analysis. + indicates <1% TLP. The shaded area shows the interval within which the proposed hiatus is located.

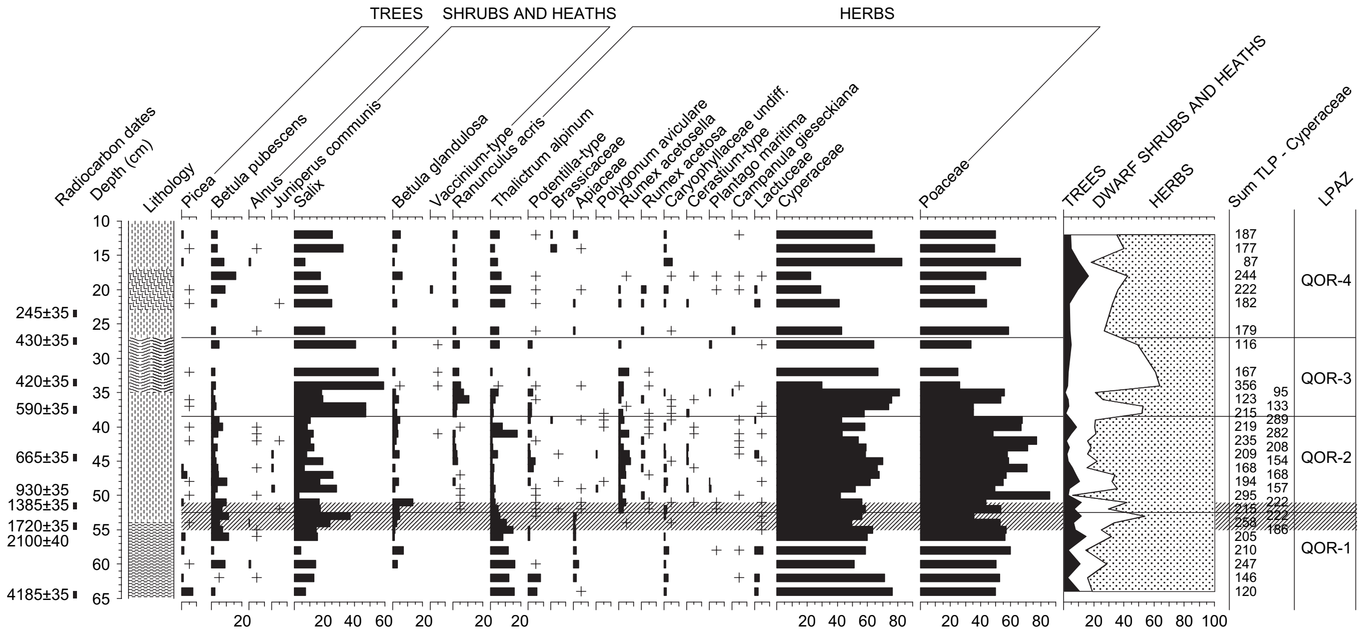

Fig. 8. Percentage diagram for selected taxa based upon a TLP – Cyperaceae pollen sum. Cyperaceae percentages are calculated on a TLP + taxon basis. + indicates <1% TLP. See Fig. 7 for key to lithology. The shaded area shows the interval within which the proposed hiatus is located.

farm waste) was deliberately spread across the infield area to act as a fertiliser, a practice proposed for several other farms in the Qorlortoq valley (cf. Commisso and Nelson, 2006, 2008).

Although LOI values remain high (70–80%) throughout this pollen zone, instability of catchment soils continues to be indicated by high frequencies of undifferentiated fern spores in pollen assemblages. These can be regarded as a proxy for soil erosion in this environment (Schofield et al., 2007). Elevated C:P ratios (concentrations only peak mid-zone) are also recorded. The marked rise in C:P values may largely represent domestic fires associated with cooking and heating around the farm as there is no obvious change in the representation of tree and shrub pollen that might result from burning of the wider landscape in order to extend the area available for hay production or grazing.

Falling C:P ratios and declining Poaceae pollen percentages, concentrations and influx in QOR-3 correspond with an increase in *Salix* pollen and the disappearance of *Sporormiella* ascospores, indicating the regeneration of willow-scrub at the expense of grassy heath, most likely as a response to reduced grazing intensity. Herbaceous pollen from annual 'weeds' (e.g. *Cerastium*-type, *Polygonum aviculare*) indicative of disturbed ground are rarely recorded in this assemblage zone, although perennials characteristic of meadows and pasture (e.g. *Ranunculus acris*, *Rumex acetosella*) do appear to hold their ground to some extent. Soils gradually became stabilised during this period, as indicated by the low mineral content of the sediment (LOI rises from the opening of the zone) and reduced frequencies of Pteropsida (monolete) indet. spores.

QOR-3 thus appears to reflect abandonment of the farm. Radiocarbon dates and age–depth modelling suggests that the timing of abandonment (the QOR-2/3 boundary) dates to the early 15th century AD. This date is consistent with the final documented evidence for Norse activity in the Eastern Settlement—a reference to a marriage at Hvalsey church in 1408 (Krogh, 1967; Seaver, 1996)—although it is generally accepted that the Norse may have remained in Greenland beyond this date and probably to the mid 15th century AD (Berglund, 1986; McGhee, 2003). Abundant remains of *Sphagnum* spp. (cf. *S. girgensohnii* and *S. capillifolium*) in the stratigraphy at the top of QOR-3 provide clear evidence for the development of increasingly wet mire surface conditions at this time. The onset of formation of the *Sphagnum* peat is dated to cal AD 1420–1630 (420 ± 35 BP, SUERC-8905). This coincides approximately with evidence for the onset of the 'Little Ice Age', reflected *inter alia* in terms of falling temperatures in the northern hemisphere (e.g. Moberg et al., 2005), and increased sea-ice and storminess across the North Atlantic (e.g. Dugmore et al., 2007). Birch pollen (*Betula pubescens* and *Betula glandulosa*) is reduced to minimum values in QOR-3, suggesting this decline is perhaps a result of climatic deterioration rather than human activity.

Assemblage zone QOR-4 post-dates cal AD 1410–1620 (430 ± 35 BP, SUERC-8901) and may the span the period up to approximately AD 1750. Palaeoenvironmental data continue to illustrate the dynamic nature of the landscape around Ø34 even in the probable absence of a significant human presence. The band of fine silt observed in the pollen core at 23–17 cm exhibits extremely high frequencies of pteridophyte spores and damaged/indeterminable pollen grains, and reduced taxonomic diversity (note the fall in the rarefaction curve). This may result from localised slope disturbance or is conceivably an aeolian deposit derived from the deflation of unprotected (bare) surfaces at the ice front.

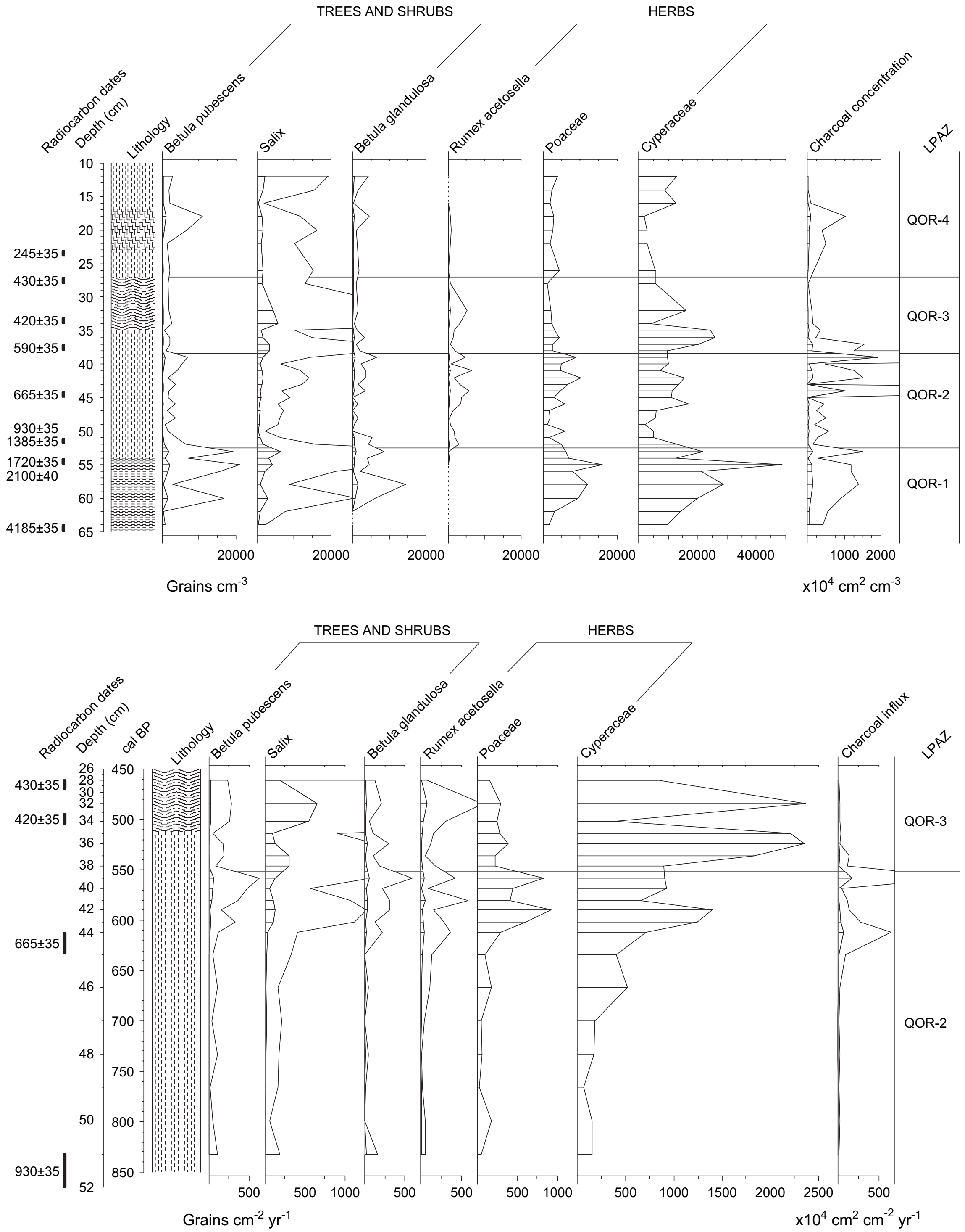

Fig. 9. Concentration (upper) and influx (lower) diagrams for selected pollen types and microscopic charcoal particles. Exaggeration curves, where shown, are ×10. See Fig. 7 for key to lithology.

5.2. Explaining the hiatus: possible evidence for peat cutting or irrigation?

Perhaps the simplest explanation for the presence of a putative hiatus within the peat column at Qorlortup would be a standstill in peat growth (i.e. zero net sediment accumulation). Put in simple terms, if peat growth is to proceed, the production of organic matter must exceed its rate of decay. Decay rate is primarily a function of site moisture status, with secondary influences from temperature and water chemistry (Charman, 2002). Factors which act to disturb the balance of these controlling variables, whether these are the result of autogenic processes or external forcing, will often lead to changes in the rate of peat accumulation and may even halt peat growth altogether.

Table 2
Diagnostic pollen, spore, charcoal, and loss-on-ignition characteristics of the local pollen assemblage zones

LPAZ	Depth (cm)	Diagnostic pollen and spore characteristics	Charcoal	LOI
QOR-4	27.0–12.0	Increase in Poaceae (30%), *Betula* spp. (10%), and *Thalictrum* (5%); decline in *Rumex acetosella* (<2%); *Salix* prominent (10%); extremely high numbers of pteridophyte spores (>2000%); increased frequencies of damaged/indeterminable grains	Low C:P and concentrations (<0.15 cm^2 cm^{-3})	Decline to minimum (20%) followed by recovery
QOR-3	38.5–27.0	Decline in Poaceae (10%); increase in *Salix* (20–40%); sustained high frequencies (5%) of *Rumex acetosella* and *Ranunculus acris*; minimum values for *Betula* spp.; pteridophyte spores decline to trace values	Declining C:P and concentrations (to < 0.15 cm^2 cm^{-3})	High and relatively stable (60–80%)
QOR-2	52.5–38.5	Rise in Poaceae (20–40%); sustained rise in *Rumex acetosella* (5%) and regular trace occurrences of 'agricultural weeds' (e.g. *Polygonum aviculare*, *Cerastium*-type, *Ranunculus acris*, *Rumex acetosa*); erratic fluctuations in pteridophyte spores; increase in palynological richness (15–20 taxa per sample); significantly lower pollen concentrations (<30,000 grains cm^{-3})	Peak C:P (200×10^{-10} cm^2 grain^{-1}), concentrations (2 cm^2 cm^{-3}) and influx (0.175 cm^2 cm^2 yr^{-1})	High and relatively stable (65–80%)
QOR-1	64.0–52.5	Cyperaceae dominant (60–80%); Poaceae sub-dominant (10–20%); lesser amounts of *Salix* (5–10%), *Betula* spp. (*B. pubescens* and *B. glandulosa* combined [5%]) and *Thalictrum alpinum* (5%); pteridophyte spores declining; palynological richness low and stable (approximately 15 taxa per sample)	Low C:P and concentrations (<0.15 cm^2 cm^{-3})	Rising from 40% to 60%

Pollen percentages are based upon the TLP sum.

For small mires, such as Qorlortup, peat growth at closely-spaced points across the mire surface might reasonably be expected to respond near-synchronously to changes such as those described above. Yet this does not appear to be the case. Radiocarbon dates of 3590 ± 50 BP (cal BC 2130–1770, K-7046) returned from open section EF, and 1720 ± 35 BP (cal AD 240–410, SUERC-8908) obtained from the pollen core, provide significantly different maximum

Table 3
Radiocarbon dates

Depth (cm)	Lab code	Material	^{14}C yr BP	Error ($\pm 1\sigma$)	cal BC/AD ($\pm 2\sigma$)	δ^{13}C (‰)
Pollen core (AMS on peat)						
24–23	SUERC-4305	Peat (humic acid fraction)	245	35	AD 1520–1960	−27.7
38–37	SUERC-6391	Peat (humic acid fraction)	590	35	AD 1290–1420	−28.3
52–51	SUERC-6390	Peat (humic acid fraction)	1385	35	AD 590–690	−28.5
55–54	SUERC-4309	Peat (humic acid fraction)	2100	40	BC 350–1	−27.2
65–64	SUERC-6389	Peat (humic acid fraction)	4185	35	BC 2890–2630	−27.8
Pollen core (AMS on plant macrofossils)						
28–27	SUERC-8901	*Sphagnum* cf. *capillifolium* leaves	430	35	AD 1410–1620	−24.9
34–33	SUERC-8905	*Sphagnum* cf. *girgensohnii* leaves	420	35	AD 1420–1630	−24.8
45–44	SUERC-8906	*Calliergon giganteum* branches	665	35	AD 1270–1400	−24.8
52–51	SUERC-8907	*Calliergon giganteum* branches	930	35	AD 1020–1190	−24.1
55–54	SUERC-8908	*Sphagnum* cf. *girgensohnii* leaf buds and *Plagiomnium* cf. *ellipticum* branch	1720	35	AD 240–410	−23.3
Open Section EF						
14–10	K-7050	Bulk peat	679	37	AD 1260–1400	−26.3
46–44	K-7049	Bulk peat	880	40	AD 1030–1220	−27.3
75–73	K-7162	Bulk peat	978	37	AD 990–1160	−24.8
92–90	K-7047	Bulk peat	1030	40	AD 890–1150	−26.2
95–93	K-7046	Bulk peat	3590	50	BC 2130–1770	−27.7
139–136	K-7045	Bulk peat	6680	65	BC 5710–5490	−29.4
Open Section A						
95–75	K-7051	Twigs (cf. *Betula* and *Salix*)	888	35	AD 1030–1220	−26.8

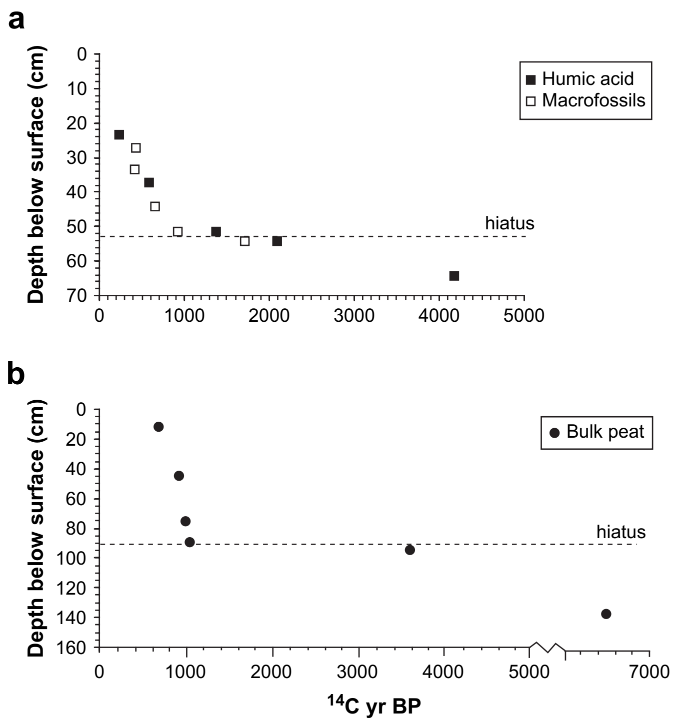

Fig. 10. (a) Scatterplot of AMS radiocarbon dates on the humic acid fraction of peat and plant macrofossils sampled from the pollen core. (b) Scatterplot of conventional radiocarbon dates on bulk peat sampled from section EF. In both cases the vertical sampling resolution and the laboratory errors associated with radiocarbon dates are contained within the symbols on the diagrams. Source data are available in Table 3.

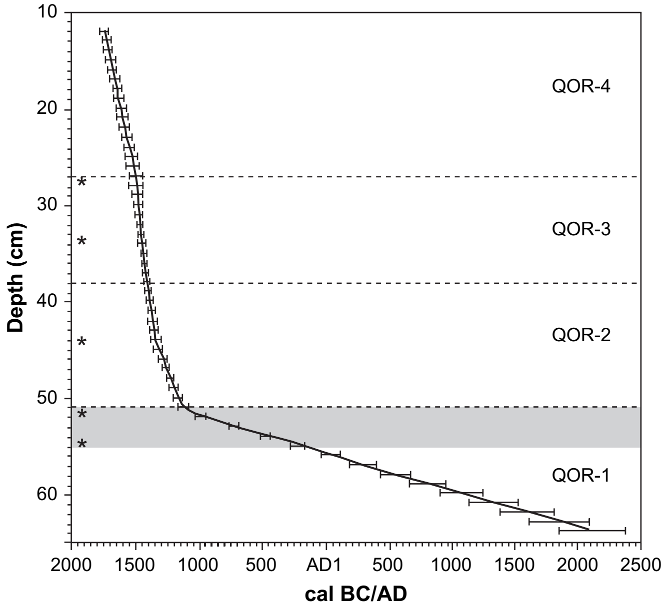

Fig. 11. Calendar age–depth model for the pollen core. *X*-axis error bars denote 2σ confidence limits on weighted averages. Asterisks represent the positions of radiocarbon dates used in model construction. Dashed lines represent the boundaries of local pollen assemblage zones (prefixed QOR-). The proposed hiatus occurs somewhere within the shaded area.

dates for the top of the humified peat despite the locations being separated by less than 20 m. Recommencement of peat formation at both locations, however, appears to have occurred at approximately the same time. Radiocarbon dates of 1030 ± 40 BP (cal AD 890–1150, K-7047) from open section EF, and 930 ± 35 BP (cal AD 1020–1190, SUERC-8907) from the pollen core, provide overlapping 2σ ranges from the base of the *turfa* peat.

Diachronous dates for the onset of a hiatus at different but closely-spaced locations, and near-synchronous dates for renewed basin infilling subsequent to Norse *landnám*, are inconsistent with hypotheses that seek to explain changes in peat accumulation as a response to natural factors which act evenly across the mire surface. Another explanation must be sought to explain this enigmatic pattern. A strong possibility is the cutting of peat and this may be reflected in the irregular but relatively sharp form of the junction between the humified peat and the *turfa* peat (Fig. 6).

The exploitation of peat has a long tradition in northern Europe. Peat use is known from Neolithic contexts in Shetland (Calder, 1956; Whittle et al., 1986). The oldest direct evidence for deep peat cutting and stack construction, from the Isle of Barra in the Outer Hebrides of Scotland (Branigan et al., 2002), possibly dates to the Bronze Age, whilst Iron Age peat digging tools have been recovered and peat extraction pits have been identified at archaeological sites across Denmark (Christensen and Fiedel, 2003). Kaland (1986) reports that peat cutting across the coastal heaths in Norway dates back at least 1000 years before present, where 'peat mould' (dried, crumbled peat) was regularly used as bedding in byres due to its capacity to soak up the liquid part of the dung. The mix of peat and manure would subsequently be spread across fields as a plaggen-type fertiliser.

In areas with little or no woodland, peat would have been an extremely valuable resource, and preferred over turf as a fuel source due to its higher organic content (Fenton, 1986). Peat was commonly burnt for domestic purposes (heating and cooking), whilst 'peat coal' (produced through the charring of peat) is also considered to have made an extremely suitable fuel for iron smelting and forging (Christensen and Feidel, 2003). Simpson et al. (2004) have identified peat ash residues in Norse-age soils from Mývatnssveit, northwest Iceland, that indicate the combustion of peat at high temperatures (800 °C) during what is described as 'industrial activity'.

In open North Atlantic landscapes where timber was in short supply, if peat was available then this was also used in the construction of Norse buildings. There are several references to the cutting of long sods (*strengur* in Iceland; often over a metre long and 7–10 cm thick) and thicker rectangular, wedge-shaped and diamond-shaped blocks of turf (*hnaus*) for use in house walls and roofs (e.g. Roussell, 1941; Jansen, 1972; Albrethsen and Ólafsson, 1998; Ólafsson and Ágústsson, 2006). Turves appear to have been cut from both dry and wet areas. For example, at L'Anse aux Meadows in Newfoundland, Wallace (2006) notes that sedge peat sods (presumably cut from one or both of the two bogs close to the settlement) formed a large proportion of the building materials used at the site. "Sedge peat sod cut into strips was the very best building material" and, "when dried, the sedge peat becomes as solid and sturdy as mud bricks and, unlike the latter, they can withstand heavy rain simply by absorbing it'' (Wallace, 2006, p.50). It seems likely that peat was also used in the preparation of Norse house floors. Palaeoentomological data from Sandnes (V51) in the Western Settlement indicates that peat litter, together with wood chips and twigs, was purposefully spread across building floors as a carefully prepared layer designed to insulate against frozen or simply cold ground (Buckland et al., 1994).

The recommencement of peat formation at Qorlortup had begun by cal AD 1020–1190, although palynological evidence suggests continuing use of the site to a much later date (~AD 1400). This pattern could suggest that the peat resource was used primarily during the early stages of site establishment and occupation, and therefore probably as a construction material for farm buildings. It appears unlikely that the resource became exhausted, for a substantial depth of the humified peat remains below the level of the hiatus (the QOR-1/2 boundary in the pollen diagram). If peat sods were being used for construction work, then the deeper peat would perhaps have been of little use, lacking a matt of intertwined living roots to bind it together. It may also have become an increasingly difficult task to exploit this deeper peat, especially if the cutting became flooded. Renewed peat growth in a waterlogged cutting might account for the apparent increase in sediment accumulation above the QOR-1/2 boundary. If peat was still in demand during the later stages of settlement, sites elsewhere in the Qorlortoq valley or in plateau areas may have been preferred.

The removal of peat for the construction of a pond or reservoir—to be used as part of an irrigation system serving the farm and/or as a supply of drinking water—might potentially also explain the possible hiatus revealed by the stratigraphic and radiocarbon data. Soil chemical, physical and hydraulic properties and palaeoclimatic data indicate the frequent requirement for irrigation throughout the period of Norse settlement in Greenland with, on average, 11–16% of years experiencing conditions of drought (Adderley and Simpson, 2006). Archaeological evidence has already been proposed for irrigation schemes comprising a series of man-made dykes, dams, and reservoirs at a number of sites in the Eastern Settlement (Ingstad, 1966; Krogh, 1967; Guldager et al., 2002; Arneborg, 2005). These include irrigation schemes at the high-status farms at *Brattahlið*/Qassiarsuk and *Garðar*/Igaliku, and also at a number of middle-sized farms including two in the Qorlortoq valley (Ø36 and Ø37). There is still some debate as to whether the dykes present at Ø37 were cut for purposes of irrigation or drainage, since they are located in relatively flat but fertile areas of the valley bottom which today appear to be poorly-drained (Arneborg, 2005).

The construction of a reservoir at Ø34 would surely have resulted in a successional reversal in which mire taxa growing at, or slightly above, the level of the water table were replaced by more overtly-aquatic plants. Some pollen from aquatic plants, principally *Potamogeton* (pondweeds), does appear in pollen assemblages immediately above the hiatus (QOR-2), suggesting an increase in mire surface wetness. Only very low frequencies (typically <1%) are registered, however, and pollen from submerged aquatics characteristic of Greenlandic lakes and ponds (e.g. *Myriophyllum* spp. [water-milfoils]) is notably absent. Although there are small reductions in pollen from taxa characteristic of drier mire surfaces (e.g. Cyperaceae, *Salix*) immediately above the hiatus, these changes are indistinguishable from other fluctuations associated with these pollen curves. Furthermore, if a reservoir or pond were present we might reasonably also anticipate the deposition of a layer of lake mud (gyttja) in the stratigraphy, yet this is not the case. On balance, therefore, it appears more likely that the increase in *Potamogeton* pollen witnessed above the hiatus may be explained as a result of very localised changes in the patterning of vegetation across the mire surface or, if peat removal did take place, the advent of groundwater in peat cuttings.

6. Conclusions

The vegetational changes apparent in pollen diagrams from Ø34 following Norse *landnám* appear subtle, possibly as a result of the open and unstable nature of the landscape in this area during the period prior to settlement. Nevertheless, the arrival of the Norse did have a perceptible impact upon the Qorlortoq valley, notably in the expansion of the area of grassland for stock grazing and probably also for hay production, an increase in numbers of agricultural 'weeds', and the expansion of plant species previously absent from the native local flora (e.g. *Rumex acetosella, Ranunculus acris*). The site possibly also provides the first direct evidence for peat cutting in Norse Greenland, with the void created by peat removal subsequently being infilled through a renewed episode of peat growth, and partly also through the dumping of domestic refuse from the farm.

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