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**Article:**

Swindles, GT, Outram, Z, Batt, CM et al. (2019) Vikings, peat formation and settlement abandonment: a multi-method chronological approach from Shetland. *Quaternary Science Reviews*, 210. pp. 211-225. ISSN: 0277-3791

<https://doi.org/10.1016/j.quascirev.2019.02.026>

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1 **Vikings, peat formation and settlement abandonment: a multi-method**  
2 **chronological approach from Shetland**  
3

4 Graeme T. Swindles<sup>1,2\*</sup>, Zoe Outram<sup>3</sup>, Catherine M. Batt<sup>4</sup>, W. Derek Hamilton<sup>5</sup>, Mike J. Church<sup>6</sup>,  
5 Julie M. Bond<sup>3</sup>, Elizabeth J. Watson<sup>1</sup>, Gordon T. Cook<sup>5</sup>, Thomas G. Sim<sup>1</sup>, Anthony J. Newton<sup>7</sup> &  
6 Andrew J. Dugmore<sup>7</sup>.

7

8 <sup>1</sup>School of Geography, University of Leeds, Leeds, LS2 9JT, UK

9 <sup>2</sup>Ottawa-Carleton Geoscience Centre and Department of Earth Sciences, Carleton University,  
10 Ottawa, K1S 5B6, Canada

11 <sup>3</sup>Historic England, Brooklands Avenue, Cambridge, CB2 8BU, UK

12 <sup>4</sup>Archaeological and Forensic Sciences, University of Bradford, Bradford, BD7 1DP

13 <sup>5</sup>Scottish Universities Environmental Research Centre, Radiocarbon Dating Laboratory, Scottish  
14 Enterprise Technology Park, East Kilbride, G75 0QF, UK

15 <sup>6</sup>Department of Archaeology, Durham University, South Road, Durham, DH1 3LE, UK

16 <sup>7</sup>School of GeoSciences, University of Edinburgh, Edinburgh, EH9 3FE, UK

17

18 \*Corresponding author

19 Tel. +44 (0)1133 439127; Email address: [g.t.swindles@leeds.ac.uk](mailto:g.t.swindles@leeds.ac.uk)

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21 **Keywords:** Radiocarbon; Tephrochronology; Archaeomagnetism; Norse; Viking; Peat; Unst;  
22 Shetland

23

24 Manuscript for *Quaternary Science Reviews*

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27

28 **Abstract**

29 Understanding the chronology of Norse settlement is crucial for deciphering the archaeology of  
30 many sites across the North Atlantic region and developing a timeline of human-environment  
31 interactions. There is ambiguity in the chronology of settlements in areas such as the Northern Isles  
32 of Scotland, arising from the lack of published sites that have been scientifically dated, the presence  
33 of plateaus in the radiocarbon calibration curve, and the use of inappropriate samples for dating.  
34 This novel study uses four absolute dating techniques (AMS radiocarbon, tephrochronology,  
35 spheroidal carbonaceous particles and archaeomagnetism) to date a Norse house (the “Upper  
36 House”), Underhoull, Unst, Shetland Isles and to interpret the chronology of settlement and peat  
37 which envelops the site. Dates were produced from hearths, activity surfaces within the structure,  
38 and peat accumulations adjacent to and above the structure. Stratigraphic evidence was used to  
39 assess sequences of dates within a Bayesian framework, constraining the chronology for the site as  
40 well as providing modelled estimates for key events in its life, namely the use, modification and  
41 abandonment of the settlement. The majority of the absolute dating methods produced consistent  
42 and coherent datasets. The overall results show that occupation at the site was not a short, single  
43 phase, as suggested initially from the excavated remains, but instead a settlement that continued  
44 throughout the Norse period. The occupants of the site built the longhouse in a location adjacent to  
45 an active peatland, and continued to live there despite the encroachment of peat onto its margins.  
46 We estimate that the Underhoull longhouse was constructed in the period *cal. AD 805–1050* (95%  
47 probability), and probably in *cal. AD 880–1000* (68% probability). Activity within the house ceased  
48 in the period *cal. AD 1230–1495* (95% probability), and most probably in *cal. AD 1260–1380* (68%  
49 probability). The Upper House at Underhoull provides important context to the expansion and  
50 abandonment of Norse settlement across the wider North Atlantic region.

51

52

53

54 **1. Introduction**

55 The overall aim of this paper is to establish a multi-method chronology of settlement and  
56 environment changes at the site of Underhoull in Unst, Shetland Isles. This is important for both  
57 Quaternary science and global environmental change research because it typifies the challenges of  
58 dating the Viking Age-Medieval Scandinavian colonisation of the North Atlantic islands. The term  
59 ‘Viking’ usually refers to raiding activity and the initial territorial expansion of Scandinavian  
60 peoples from the last decades of 8<sup>th</sup> century to the 11<sup>th</sup> century, whereas ‘Norse’ covers the whole  
61 cultural period from first settlement to the mid-15th century in the Northern Isles when the islands  
62 were ceded to the Scottish crown (Batey and Sheehan, 2000). This movement of people involved  
63 the migration into, and enduring occupation of, both long settled-lands in Atlantic Scotland and  
64 mid-oceanic islands that were some of the last places on Earth to be colonised by people. The  
65 former provide instructive cases of culture contact, the latter provide recent case studies of the  
66 impact of people on pristine environments with clear pre-human environmental baselines. Both  
67 provide ‘completed experiments’ of human interactions with the environment during the Medieval  
68 Climate Anomaly (a time of warm climate lasting from ~AD 950 to AD 1250) in NW Europe  
69 (Goosse et al., 2012) that are relevant to contemporary debates about global change that include  
70 societal resilience, the basis of sustainability over multi-century time scales, causes of human  
71 insecurity, climate change adaptation and the limits to adaptation (e.g. Nelson et al., 2016).

72

73 Increasing attention has been paid to the study of Norse sites across the North Atlantic and the  
74 Distributed Long-Term Observing Network of the Past (DONOP) that they provide (Hambrecht et  
75 al., 2018). The investigation of DONOP has involved archaeological excavation and related multi-  
76 proxy environmental studies which can be used to address Grand Challenges in archaeology,  
77 including questions of 1) societal resilience, persistence and collapse; 2) the movement, mobility  
78 and migration of people, and 3) human environment interactions (Kintigh et al., 2014). The drivers  
79 of the Scandinavian migrations and the expansion of the Viking Age settlements across this region

80 have been attributed to a variety of factors, such as stresses of population change (Fossier, 1999),  
81 climate (Dugmore et al., 2007), economic factors and political tension (Frei et al., 2015; Pálsson  
82 and Edwards 1981; Sawyer, 2003), while similar theories have been postulated for the abandonment  
83 of Norse settlements in Greenland (Dugmore et al., 2012). An accurate and precise chronology is  
84 essential for the assessment of specific Norse sites and their utilisation as DONOP to allow the  
85 archaeological evidence to be directly compared and understood across this vast geographical area,  
86 and be mobilised to address Grand Challenges (Kintigh et al., 2014, Nelson et al., 2016).

87

88 Over the last 30 years, the chronological assessment of Norse sites across the North Atlantic realm  
89 have made widespread use of radiocarbon or in the case of Iceland, radiocarbon and the use of  
90 visible tephra layers (e.g. Barrett et al., 2000; Dugmore et al., 2005; Arge et al., 2005; Lawson et al.,  
91 2005; Church et al., 2005; 2007; Schmid et al., 2017). However, many existing chronological  
92 frameworks have significant limitations due to a primary reliance on artefact and structural  
93 typologies (e.g. Hamilton, 1956; Small, 1966; Stummann Hansen, 2000) or on scientific dating  
94 approaches that utilise inappropriate materials, including non-native species such as Spruce (*Picea*)  
95 or mixtures of materials. In Iceland, classic tephrochronology, based on the identification and  
96 correlation of layers of volcanic ash (tephra), is a very powerful dating tool for establishing a robust  
97 chronology for the Viking Age settlement. The utility and accuracy of classic tephrochronology  
98 stems from the very widespread distribution of the Landnám tephra as a visible layer, and the  
99 extensive occurrence of a series of other visible tephra layers within the 10<sup>th</sup> century, such as the  
100 Katla c. AD 920 tephra and the Eldgjá tephra from AD 939 (Schmid et al., 2017). The great  
101 precision of classic tephrochronology in Viking Age Iceland is because two of these crucial layers-  
102 the Landnám tephra and the Eldgjá tephra- have been traced to Greenland and dated in ice core  
103 records (Grönvold et al., 1995; Zielinski et al., 1995, 1997; Sigl et al., 2015; Schmid et al., 2017).  
104 While the use of visible tephra layers is routine in Icelandic archaeology, the use of cryptotephra in  
105 archaeological sites elsewhere in the North Atlantic is not, despite their discovery in terrestrial

106 Scottish peat deposits 30 years ago (Dugmore 1989, Dugmore et al., 1995a; 1995b). This represents  
107 significant opportunity for archaeology, because of the continental scale dispersal of the tephras as  
108 crypto deposits, and their very precise dating- either through connections with ice cores, or through  
109 contemporary written sources, such as the dating of Hekla eruptions to AD 1104 and AD 1158.

110

111 Cryptotephrochronology is making vital contributions to the precise correlation of long-term proxy  
112 records of Quaternary environments (e.g. Davies, 2015; Lane et al., 2012). The great potential for  
113 the use of cryptotephras in archaeology and correlating archaeological DONOP (e.g. Lane et al.,  
114 2014) is largely untapped. As its potential is realised, an effective integration of  
115 cryptotephrochronology with other Quaternary dating techniques presents particularly interesting  
116 opportunities. Thus, we present an integrated chronology for the establishment, use and  
117 abandonment of a peat-covered Norse longhouse at the site of Underhoull, Shetland, UK  
118 (60.71888°N, 0.94735°W) using the novel combination of radiocarbon, cryptotephra, spheroidal  
119 carbonaceous particles and archaeomagnetic dating. We critically assess and compare these  
120 techniques within a Bayesian framework in order to produce a robust chronology for the site. We  
121 address the following research questions: 1. When was the site occupied and then subsequently  
122 abandoned? 2. What is the chronostratigraphic relationship between the longhouse and peat  
123 accumulation? The answers to these questions contribute significantly to evaluation of Norse  
124 settlement in Shetland and demonstrate methodologies applicable across Northwest Europe and  
125 North America.

126

## 127 **2. Study site selection and context**

128 Archaeological sites in Shetland, such as Old Scatness (Dockrill et al., 2010), Norwick (Ballin  
129 Smith, 2007), Hamar and Underhoull (Bond et al., 2013) form a DONOP and provide a window  
130 into the culturally turbulent Viking Age, set within the equable conditions of the Medieval Climate  
131 Anomaly.

132 The site of Underhoull is located on Unst, the most northerly of the Shetland Isles, and of Britain  
133 (Figure 1). Unst is particularly significant because it may have played an important role in the  
134 westwards expansion of the Viking/Norse populations, acting as a staging post between Norway,  
135 Britain and the islands further west (Ritchie, 1996; Graham-Campbell and Batey, 1998). Recent  
136 discoveries have produced early dates for Scandinavian settlement in the Northern Isles (Orkney  
137 and Shetland), which have important implications for understanding the timing, pace and nature of  
138 the westward migrations of the Viking Age. The site of Norwick, for example, now has evidence  
139 for an early phase of Scandinavian settlement in the 7<sup>th</sup>–9<sup>th</sup> centuries AD (Ballin Smith, 2007). If  
140 the pattern from Norwick is replicated elsewhere, it would stretch the chronology of westward  
141 Norse expansion earlier, and modify ideas of its development and consequences.

142

143 A large number of Norse longhouses have been recorded on Unst, with Dyer et al. (2013)  
144 identifying some 30 individual sites, together with another 20 possible longhouses. This implies  
145 that the island played a very significant role in the westwards expansion of the Norse. Despite this  
146 significance, only a small number of Norse sites have been investigated to date, including Sandwick  
147 (Bigelow, 1985), Underhoull (Small, 1966), Norwick (Ballin Smith, 2007), Hamar (Bond et al.,  
148 2013) and Belmont (Larsen et al., 2013). At Underhoull, Small (1966) recorded a Norse structure  
149 that sealed an Iron Age roundhouse and souterrain, demonstrating one of many Shetlandic examples  
150 of site continuity linked to transformative cultural changes (Figure 2). A 10<sup>th</sup> century date was  
151 assigned to the Norse site following Small's work based on the artefact evidence, although a later  
152 date has been suggested by a reassessment of the structural and artefact typologies (Graham-  
153 Campbell and Batey, 1998). Radiometric dating evidence has been produced for the sites of  
154 Sandwick, Norwick, Hamar and Belmont (Figure 1), although only the sites of Hamar and Belmont  
155 have been fully published to date. The remaining published site chronologies in Shetland, such as  
156 the iconic site of Jarlshof (Hamilton, 1956), are largely based on artefact typologies. While these  
157 traditional approaches provide a general framework, they have limited precision. More rigorous

158 chronologies based on a wider range of approaches and scientific methodologies will provide an  
159 enhanced understanding of the pattern and timing of Norse occupation of Shetland, the longevity of  
160 settlement and its wider significance within the Norse diaspora.

161

### 162 **3. Establishing chronology: The sampled contexts**

163 The site discussed within this paper is located upslope from the excavations carried out by Small  
164 (1966), and so to avoid confusion with this earlier work it will be referred to as the “Upper House”,  
165 Underhoull. The Upper House site (Figure 2) consists of a longhouse with two associated annexes.  
166 The addition of annexes to longhouses has been considered a characteristic feature of Late Norse  
167 longhouses, recorded on sites such as Underhoull, Hamar and Belmont (Graham-Campbell and  
168 Batey, 1998; Bond et al., 2013; Larsen et al., 2013), which suggests that the surviving structure at  
169 Underhoull dates to the late 10<sup>th</sup> century at the earliest. Several features were recorded within the  
170 structure including a paved area in the western end of the main structure and three hearths, one in  
171 each of the annexes and a third in the eastern part of the main structure. An area of paving (context  
172 [029]) was also identified to the south of the main structure overlying the peat, and has been  
173 interpreted as an attempt by the occupants to maintain a dry area around the longhouse despite the  
174 close proximity to the peat accumulations.

175

176 Understanding the formation processes is crucial in the selection of appropriate samples, as well as  
177 the interpretation of the results, so the formation processes of the anthropogenic deposits are  
178 summarised under the heading ‘depositional context’. A classification of deposits in terms of  
179 chronological significance is derived from the work of Schiffer (1987) and Dockrill et al. (2006),  
180 and is summarised in Table 1. The peat dates were not categorised using this approach due to the  
181 potential mobility of the different fractions. The materials finally selected for dating formed two  
182 groups: the deposits associated with the occupation of the structure, and the peat located in the

183 south-west area of the site. The dates have been summarised in Table 2 (radiocarbon), Table 3  
184 (archaeomagnetic) and Table 4 (tephra).

185

186 The deposits located within the structure were dated by AMS radiocarbon and archaeomagnetic  
187 dating techniques, including occupation surfaces (contexts [189] & [185]), hearths (contexts [166],  
188 [214] and [201]), a surface interpreted as a yard to the north of the main structure (context [170]),  
189 and a possible industrial deposit (context [093]). The peat accumulations adjacent to the longhouse  
190 were sampled for cryptotephra and for AMS radiocarbon dating; the flagged surface (context [029])  
191 associated with the structural remains effectively acted as a horizon dividing the peat layers into  
192 those that pre- and post-dated the construction of the longhouse (Figure 3). The dating evidence  
193 produced from these deposits therefore brackets this event, providing an opportunity to investigate  
194 when the occupation of the Upper House commenced relative to the peat and the impact that the  
195 peat development had on the occupation of Underhoull. The date of the paved surface [029] is also  
196 important as it provides the upper limit for the construction of the longhouse, as well as dating an  
197 attempt by the occupants to maintain the site.

198

#### 199 **4. Materials and methods**

200 Three dating methods (AMS radiocarbon, archaeomagnetic dating and cryptotephrochronology)  
201 were employed in addition to the conventional archaeological methods of stratigraphy and  
202 typology. In addition to these approaches, spheroidal carbonaceous particles (SCPs) within the peat  
203 were used to infer a post 19th-century date for the top of the sampled sequences (e.g. Swindles,  
204 2010). All of the dates presented here are quoted at 2 sigma ( $\sigma$ )/95.4% confidence levels with the  
205 exception of the SCPs (post-AD1850 markers) and the tephra isochrones dated to the 12<sup>th</sup> century  
206 AD based on historical observation and documentary evidence. The Hekla-Selsund tephra (also  
207 referred to as the Kebister tephra by Dugmore et al., 1995b) has been previously wiggle-match <sup>14</sup>C  
208 dated (Wastegård et al., 2008).

209 **4.1 AMS Radiocarbon dating**

210 AMS radiocarbon determinations (Table 2) were produced by the Scottish Universities  
211 Environmental Research Centre (SUERC), and the Natural Environment Research Council (NERC)  
212 Radiocarbon Facility, East Kilbride, and calibrated using OxCal v4.3 (Bronk Ramsey, 2012), with  
213 IntCal13 (Reimer et al., 2013).

214

215 The materials selected for dating included charred grains of barley (*Hordeum* sp.) and *Sphagnum*  
216 remains extracted from the peat (although *Sphagnum* was only found in a 5-cm horizon in one of  
217 the peat monoliths), as these represent chronologically coherent entities that did not require a  
218 marine correction (Harris, 1987). Barley grains represent a single entity produced in a single  
219 season's growth, removing some of the problems of 'old' carbon being incorporated (Ashmore,  
220 1999), and were selected from discrete contexts such as hearths, floor surfaces and a yard area. Both  
221 the barley grains and *Sphagnum* leaves and stems were hand-picked from samples using tweezers  
222 under a low-power binocular microscope. Above-ground macrofossils (e.g. *Sphagnum* remains)  
223 were mostly not present or in low abundance in the peats, therefore the humin and humic acid  
224 fractions of humified peats were extracted from discrete samples for dating.

225

226 The composition of peat varies depending on the plant communities, the accumulation rate, the  
227 water-table level, bioturbation, root penetration, and the incorporation of residual material, as well  
228 as any anthropogenic activity in the area (Rydin and Jeglum, 2008). It can therefore be argued that  
229 no two accumulations of peat are the same, making it difficult to state with confidence which of the  
230 fractions would represent the 'true' age of peat accumulation as all of these factors are site specific  
231 (Tonneijck et al., 2006; Wüst et al., 2008; Brock et al., 2011). A number of radiocarbon dates were  
232 produced for this study using both the humic and humin fractions from the same sample, allowing  
233 these processes to be evaluated.

234

235 The charred barley grains and *Sphagnum* remains were pre-treated using the standard acid-base-acid  
236 procedure for removal of carbonates and organic acids (Ascough et al., 2007). The peat humin  
237 fraction was extracted through the digestion of the peat in 2M HCl (80°C, 8 hours) followed by 1M  
238 KOH (80°C, 2 hours) until no further humic material was extracted. The residue was then rinsed  
239 free of alkali, before being immersed in 1M HCl (80°C, 2 hours), rinsed free of acid, dried and then  
240 homogenised. The peat humic acid fraction was extracted using a similar approach, but the filtrate  
241 was retained and the humic fraction precipitated following the addition of 2M H<sub>2</sub>SO<sub>4</sub>. The  
242 precipitate was recovered, rinsed free of acid, dried and homogenised (Gulliver, 2011). The pre-  
243 treated remains were then converted to graphite for subsequent AMS analysis using standard  
244 methods defined by Slota et al. (1987). The  $\delta^{13}\text{C}$  value of the sample CO<sub>2</sub> was determined on a VG  
245 SIRA 10 stable isotope mass spectrometer using NBS standards 22 (oil) and 19 (marble) to  
246 determine the 45/44 and 46/44 mass ratios, from which a sample  $\delta^{13}\text{C}$  value could be calculated  
247 (Ascough et al., 2007). The  $\delta^{13}\text{C}$  ratios were used to correct the sample <sup>14</sup>C activities for  
248 fractionation by normalisation to -25‰.

249

250 The potential problem of post-depositional movement of the barley grains or the mobility of the  
251 different fractions of peat was investigated through the production of multiple dates analysed in  
252 stratigraphic order, a comparison of paired dates produced on different fractions and by a  
253 comparison between different methods.

254

#### 255 **4.2 Archaeomagnetic dating**

256 Archaeomagnetic dating can yield significant chronological information as the dated event relates to  
257 the last use of the features which usually corresponds to anthropogenic activity (Clark et al., 1988;  
258 Batt et al., 2017). Three features were sampled for archaeomagnetic dating from Underhoull:  
259 hearths located in each of the two annexes (contexts [166] and [214]) and a possible industrial  
260 feature (context [093]) located to the North of the site (Table 3). A fourth hearth was identified

261 within the main structure (context [201]), but it did not contain sufficient material for  
262 archaeomagnetic dating. Plastic tubes were inserted into the fired material using the methodology  
263 defined by Clark et al. (1988). A magnetic compass was used to record the orientation of the  
264 samples; this method can be problematic as the feature itself may deflect the compass, introducing  
265 errors into the sampling procedure. A sun compass can be used, but due to the variable nature of the  
266 sun in Shetland, a magnetic compass was deemed more reliable. All of the features sampled were  
267 assessed in the field prior to the use of the magnetic compass and it was concluded that no distortion  
268 was present (Meng and Noel, 1989; Lange and Murphy, 1990).

269

270 The direction of remanent magnetisation of the samples was measured using a Molspin spinner  
271 magnetometer. The stability of this magnetisation was then determined by step-wise alternating  
272 field demagnetisation of pilot samples to allow removal of any less stable magnetisations acquired  
273 after the firing event, leaving the magnetisation of archaeological interest, known as the  
274 characteristic remanent magnetisation (ChRM).

275

276 Pilot samples were selected as they represented the range of characteristics displayed by the  
277 assemblage. The demagnetisation data were assessed using methods defined by Tarling and Symons  
278 (1967), Kirschvink (1980) and Sagnotti (2013) and principal component analysis (PCA) was used  
279 to investigate the linearity of the magnetic vector throughout the demagnetisation process and to  
280 select the field used to remove the unstable component of the magnetisation, leaving the  
281 magnetisation of archaeological interest. Values of less than 2° were taken as evidence that the plots  
282 were acceptably linear between the selected vector, and that the magnetisation was likely to be  
283 stable (Linford, 2006). It was noted that a field of 5mT was suitable to remove the less stable  
284 component for all of the samples investigated.

285

286 The magnetic directions of the samples collected from a feature were combined to give a mean  
287 direction, the precision of which is defined using Fisherian statistics (Fisher, 1953). The alpha-95  
288 ( $\alpha_{95}$ ) value represents a 95% probability that the true direction lies within that cone of confidence  
289 around the observed mean direction, and should be less than 5° for dating purposes (Tarling and  
290 Dobson, 1995). A value larger than this indicates that the magnetic directions of the samples are  
291 scattered and therefore do not all record the same magnetic field, making the material undatable.  
292 Outlier samples were statistically defined using the approaches defined by Beck (1983) and  
293 McElhinny and McFadden (2000); if the values failed these tests they were statistically classified as  
294 lying significantly from the mean and therefore removed from the analysis.

295

296 Context [166] was sampled twice as a portion of the sampled feature lay underneath an unexcavated  
297 area of the site. When the area of excavation was extended the remaining part of the feature was  
298 exposed and sampled (AM150). The mean directions were shown to be statistically  
299 indistinguishable (McFadden and Lowes, 1981) and so they were combined to give a single  
300 magnetic direction.

301

### 302 *4.3 Cryptotephrochronology*

303 Tephrochronology is based on the identification and correlation of tephra layers (Thórarinnsson,  
304 1944). The recognition and correlation of cryptotephra deposits (those hidden from view) has  
305 extended the precision of tephrochronological correlations to continental scales (Dugmore, 1989;  
306 Dugmore et al., 1995a; Swindles et al., 2010; Watson et al., 2017). Calendar dates for the various  
307 tephra layers have been obtained through the use of written records (e.g. Thórarinnsson, 1967),  
308 correlation to precise timescales such as those provided by ice cores (e.g. Zielinski et al., 1995;  
309 1997; Sigl et al., 2015), or complementary dating techniques such as radiocarbon (Dugmore et al.,  
310 1995a; 1995b; Wastegård et al., 2008; Swindles et al., 2011). The precision of the associated  
311 radiocarbon dates have been greatly improved in recent years through the application of both

312 radiocarbon wiggle-matching and sophisticated age-depth models, including Bayesian approaches,  
313 and for some tephra layers this exceeds the available precision associated with a single radiocarbon  
314 determination for the same period of time (Hall and Pilcher, 2002; Wastegård et al., 2003).

315

316 Despite the potential of tephrochronology for both chronological and palaeoenvironmental studies,  
317 only limited work has been carried out in Shetland (Dugmore 1991; Bennett et al., 1992; Swindles  
318 et al., 2013). A number of cryptotephra layers may have been deposited on Shetland during the  
319 periods that pre- and post-date the settlements at Underhoull (Dugmore et al., 1995b; Hall and  
320 Pilcher, 2002; Swindles et al., 2011). These aid the chronological constraint of the sites, as well as  
321 allowing the evidence recorded at Underhoull to be unambiguously linked to sites across the North  
322 Atlantic and major paleoclimate archives.

323

324 Monolith samples were extracted from peat faces at the site using box guttering (de Vleeschouwer  
325 et al., 2010). A series of three cores were collected from the accumulations of peat under- and over-  
326 lying the archaeology in the south-west area of the site (Figures 3 and 4): ‘SF238/239’, ‘SCHO’,  
327 and ‘UHM’. The peat cores were stored at 4°C prior to sub-sampling at contiguous 1-cm intervals.  
328 Tephra layers in each profile were determined using the conventional ashing and extraction  
329 technique (following Swindles et al., 2010). As the samples contained some minerogenic material,  
330 LST Fastfloat ( $2.3\text{--}2.5\text{ g cm}^{-3}$ ) was used to concentrate the shards. The total number of tephra  
331 shards within a  $1\text{ cm}^3$  sample was counted under light microscopy at  $100\times$  magnification. No  
332 basaltic shards were encountered in the samples.

333

334 Peat samples from depths of peak shard concentration were selected for subsequent geochemical  
335 analysis. Approximately  $5\text{ cm}^3$  of peat was acid digested ( $\text{H}_2\text{SO}_4$  and  $\text{HNO}_3$ ) following standard  
336 procedures (Dugmore et al., 1992, Pilcher and Hall, 1992) and density separation was undertaken as  
337 before. The samples were sieved through a  $10\mu\text{m}$  mesh and washed with deionised water, before

338 being centrifuged to concentrate the tephra shards. The tephra were then mounted onto glass slides,  
339 which were polished using 0.25- $\mu\text{m}$  diamond paste, before being carbon coated (Swindles et al.,  
340 2010).

341

342 Geochemical analysis was carried out at the NERC Tephra Analytical Unit at the University of  
343 Edinburgh. A CAMECA SX100 electron microprobe with a beam current of 2nA and diameter of  
344 5 $\mu\text{m}$  was used. The microprobe was calibrated using Lipari obsidian and synthetic oxides with X-  
345 PHI correction, undertaken on PeakSight version 4.0 software. Energy-dispersive spectroscopy  
346 (EDS) using the Princeton Gamma Tech Spirit EDS system was used to aid in the detection of  
347 tephra shards. Once a shard was located, the beam was moved to a flat section of the shard  
348 (avoiding vesicles) for wavelength-dispersive spectroscopy and all analyses with a value of >95  
349 wt% were logged.

350

351 It has been suggested that acid digestion can alter the geochemistry of tephra shards (Blockley et al.,  
352 2005). However, the use of this method allows ‘like-with-like’ comparisons with type data which  
353 have been prepared in this way (e.g. Dugmore et al., 1992). The case for chemical alteration by acid  
354 digestion has also been refuted in subsequent studies (Roland et al., 2015; Watson et al., 2016).  
355 Biplots were used to compare our data to those on TephraBase (Newton et al., 2007), with the  
356 identified tephra layers summarised in Table 4.

357

#### 358 **4.4 Spheroidal carbonaceous particles**

359 Spheroidal carbonaceous particles (SCPs) are formed following the high-temperature combustion of  
360 fossil fuels and are predominately composed of elemental carbon. SCPs are associated with  
361 industrial activities that occurred from the mid-19<sup>th</sup> century onwards, and so the presence of SCPs  
362 within a deposit can therefore be used to indicate a post-AD1850 date for the layer (Rose, 1994;

363 Swindles, 2010; Swindles et al., 2015). The SCPs were extracted from the peat cores using the  
364 methodology defined by Swindles (2010).

365

#### 366 **4.5. Data analysis**

367 The chronological information from the Upper House, Underhull was investigated within a  
368 Bayesian framework, which utilises prior information to interrogate and refine the scientific dates  
369 (Buck et al., 1991; 1994). All the chronological modelling was undertaken using OxCal v4.3  
370 (Bronk Ramsey, 2012). The samples selected have been discussed above, and were recovered from  
371 a number of discrete and secure contexts. Primary contexts were prioritised, such as hearth deposits,  
372 with short-lived species of charred and waterlogged plant remains preferred so as to avoid the ‘old-  
373 wood-effect’. Radiocarbon ages were all calibrated using the international agreed northern  
374 hemisphere calibration curve (IntCal13) of Reimer et al. (2013). Archaeomagnetic dates were  
375 incorporated into the model as prior probabilities, which were derived from their individual  
376 calibrations using the Rendate software and the UK secular variation calibration dataset (Batt et al.,  
377 2017). The dates of tephra layers were incorporated as normal probability distributions using a  
378 mean and standard deviation with the C\_Date parameter in OxCal.

379

380 Inclusion of stratigraphic information can refine the resulting age ranges through the production of  
381 posterior density estimates but it is important to note that the resulting age ranges are the result of a  
382 statistical model imposed on the data and the interpretation of the stratigraphy within the field. Any  
383 new information, such as additional dating evidence or a different model being imposed on the data,  
384 will produce different posterior density estimates. The *modelled estimates* are given in *italics* when  
385 discussed within the text to differentiate them from the raw calibrated age ranges.

386

387

388

389 **5. Results**

390 The dates produced for the Upper House site have been summarised in Tables 2-4. A summary of  
391 each of the results of the dating programme are provided in this section before the chronology of the  
392 site is discussed.

393

394 **5.1 <sup>14</sup>C dating**

395 A total of 22 AMS radiocarbon dates were produced for the Upper House, Underhoull, with the  
396 majority sampling either the humin or humic acid fractions extracted from the peat (owing to lack  
397 of suitable macrofossils). An assessment of the dates obtained from the peat demonstrated that  
398 several of the radiocarbon dates (humin fractions) were not in chronological order and appeared to  
399 be too old for their stratigraphic position when compared to the tephra dates (Table 2; Figure 4).

400

401 Two radiocarbon dates were produced on the same sample of peat: SUERC-33130 and SUERC-  
402 34106 sampled the humic acid fraction and humin fractions respectively, which allowed the dates  
403 produced on different fractions of the same sample to be directly compared. It was clear that  
404 SUERC-34106 (humin fraction) gave an older age estimate than SUERC-33130 (humic acid  
405 fraction; see Table 2), which may be due to the peat formation processes (Brock et al., 2011). The  
406 discrepancy noted between the fractions radiocarbon dated may relate to the microscopic charcoal  
407 present throughout the peat profiles of the 'SCHO' core (Edwards et al., 2013, Fig 4.6b) and the  
408 'UHM' core (Figure 5). The small size of the fragments of charcoal made it impossible to identify  
409 the species, which may have provided information about the origin of the material and whether the  
410 charcoal related to local species, bog- or drift wood. In situations where wood is scarce, such as the  
411 Northern Isles, the use of recycled wood, bog- or drift wood can result in 'old' material becoming  
412 incorporated into the archaeological record (Schiffer, 1986). It was therefore also possible that the  
413 discrepancy noted in the dates may have resulted from the presence of residual charcoal within the

414 humin fraction. The resulting radiocarbon age would therefore lie between the age of the charcoal  
415 present and the peat, rather than giving a date for the accumulation of the peat.

416

417 The presence of the peat accumulations so close to a domestic structure would have provided  
418 regular opportunities for burnt material to have become incorporated into the peat, for example,  
419 from the burning of bog- or drift wood or 'old' peat as a fuel source within the structure itself or in  
420 the industrial feature to the north of the site. In addition, burnt material may have been carried to  
421 site as hill-wash, or from the land clearance activities to create grazing land for sheep and cattle.

422

## 423 **5.2 Archaeomagnetic dating**

424 A total of three features were sampled for archaeomagnetic dating, two of which related to hearths  
425 located in the S and SW annexes (contexts [166] and [214 respectively) and one to a possible  
426 industrial feature (context [093]) to the north of the longhouse. Context [093] butted against the  
427 outer wall of the longhouse and was therefore created at a later stage. All of the sampled features  
428 recorded remanent magnetisation that was considered stable, with the directions being generally  
429 well grouped, as demonstrated by small alpha-95 values (Table 3). An assessment of the samples  
430 demonstrated that the magnetisation was stable, but there were a small number of outliers. These  
431 samples may have been disturbed in antiquity: all of the anomalous samples were on the edge of the  
432 features, the area that is vulnerable to slumping or being trampled on by activity within the  
433 structure.

434

435 The calibrated archaeomagnetic dates (Batt et al., 2017) suggest two different phases of activity.  
436 The feature sampled in the SW Annexe represented the earliest area of burning sampled at  
437 Underhoull, with a date of AD 800–1080 (AM151). The calibrated date is broad due to slow  
438 changes in the geomagnetic field between AD 900–1100, limiting the precision available within this  
439 period. A radiocarbon date on material interpreted as the occupation deposits associated with the

440 hearth (SUERC-34111), produced a calibrated date of *cal.* AD 1045-1265, which suggests that the  
441 latter part of the archaeomagnetic range may better represent the ‘true’ age of the feature, and  
442 placing the last use to the 11<sup>th</sup> century AD at the earliest.

443

444 The feature sampled by AM149/AM150 gave a later date than AM151, AD 1240–1310, suggesting  
445 that the activity in the S Annexe continued after the SW Annexe went out of use. This date is  
446 supported by a radiocarbon date (SUERC-34108) of *cal.* AD 1045–1260 produced on charred  
447 grains recovered from the hearth. A comparison of these two dates suggests that the later part of the  
448 radiocarbon range may represent the ‘true’ age of the feature, indicating that the hearth in the S  
449 Annexe was in use in the 13<sup>th</sup> century, but potentially earlier if the full range of the radiocarbon date  
450 is considered.

451

452 The archaeomagnetic date for the industrial feature (AM148), AD 1280–1430, indicates that it  
453 could have been in use at the same time as the hearth in the S Annexe but it is likely to represent the  
454 last area of burning on the site. This is supported by the archaeological evidence which suggests  
455 that activity at the Upper House may have continued as late as the early 16<sup>th</sup> century, to the very end  
456 of the Late Norse period and in to the Medieval period.

457

### 458 **5.3 Tephra and SCPs**

459 Several cryptotephra layers were identified in the peat profiles (Figure 6, Supplementary file 1). The  
460 identification of tephra layers, through analysis of major element oxides, is illustrated through  
461 biplots shown in Figure 7. The tephras discovered include the Hekla-Selsund (Kebister) tephra in  
462 the SCHO profile that has been dated to 1800–1750 *cal.* BC by Wastegård et al. (2008). In addition,  
463 the historically dated Hekla-1104 and Hekla-1158 tephras (Thórarinnsson, 1967) were identified in  
464 UHM and Hekla 1158 was identified in SF238-239. A mixed tephra layer was found between 32-42  
465 cm in the SCHO profile that could not be assigned to a specific eruption (see Swindles et al., 2013).

466 The Hekla-1158 tephra provides a precise way of correlating the UHM and SF238-239 peat  
467 sections, with the Hekla-Selsund tephra dating the start of peat formation at the site. SCPs were  
468 found in the uppermost 3 cm of the UHM and SCHO profiles indicating a post 19th-century date.

469

#### 470 *5.4 Underhoull longhouse chronological model*

471 A Bayesian approach was taken to the development of a chronological framework for the peat  
472 accumulations and longhouse settlement at Underhoull (Supplementary file 2). In addition to the  
473 stratigraphic relationships of the accumulations and the archaeological features, additional  
474 information, such as the pollen recorded with the peat deposits, was used to ‘tie’ the three peat  
475 sequences together. Edwards et al. (2013) have noted that the sediment accumulation rate may have  
476 varied over time. It could have been slower following the accumulation of context [055], and a  
477 change in land use (or putative phase of abandonment) between the Iron Age and Norse period, as  
478 indicated by the reduction in the grassland and the increase in heath between contexts [041] and  
479 [026] (Edwards et al., 2013).

480

481 A single chronological model was constructed that allowed for the evaluation and interpretation of  
482 both the longhouse settlement and its temporal relationship with the surrounding peatland. The  
483 broad chronological narrative sees a period of peat formation at the site (contexts [055] and [041]),  
484 with longhouse walls constructed overtop of [041]. Peat continued to accumulate (context [026]),  
485 eventually sealing the walls of the longhouse structure. At some point during the use of the  
486 longhouse, a paved surface was laid over context [026], which itself formed over a cleared area of  
487 bedrock. The chronological model is given in the form of a simplified Harris matrix (Figure 8),  
488 which can be related directly to the OxCal model and the description that follows.

489

490 The chronological model is separated into two main sequences. The first includes the peat  
491 formation prior to the longhouse construction (peat sequences SCHO and SF238/239), as well the

492 archaeological activity associated with the longhouse. The second sequence focuses on the  
493 beginning of the formation of the upper layers of peat (context [026]) that eventually cover the  
494 longhouse and the construction of the paved surface. Tephra deposits from the Hekla eruptions of  
495 AD 1104 and AD 1158 occur within context [026].

496

497 The first sequence begins with a date (SUERC-24946) on the humic acid fraction of a sample of  
498 peat from the base of context [055]. Within [055] and overlying this peat sample was a layer of  
499 tephra from the Hekla-Selsund eruption. The previous wiggle-match date of 1800–1750 cal. BC  
500 (Wastegård et al., 2008) is included in this model as a C\_Date of 1775 ±25 years BC. Above the  
501 tephra, and still within [055], a second radiocarbon result is available (SUERC-33130) on the humic  
502 acid fraction of a sample of peat. The two peat samples are separated by only approximately 2 cm  
503 within the SCHO sequence. [055] transitions into context [041] and the humic acid fraction was  
504 dated (SUERC-33129) on a sample of peat from near the base of the layer in sequence SCHO. A  
505 second sample of peat, from sequence SF238/239, had its humic acid fraction dated (SUERC-  
506 33131). Although the relative depths would suggest SUERC-33129 is earlier than SUERC-33131,  
507 because the two results are from different peat sequences they have been placed in an unordered  
508 group. The longhouse was constructed on top of [041], and since it is impossible to know what, if  
509 any, peat was removed during the construction, the model separates the pre-longhouse peat  
510 sequence from the dating associated with the longhouse activity, while respecting the relative order  
511 of the two groups of dates. None of the scientific dates from the structure are stratigraphically  
512 related to one another and are modelled as part of a single phase of activity that post-dates the  
513 underlying peat. There are five radiocarbon dates (SUERC-24945, -34108, and -34111–3) on  
514 individual charred barley grains recovered in various contexts from the main structure, the two  
515 annexes, and the yard. Furthermore, there are three archaeomagnetic dates from two hearths  
516 (AM149/150 and AM151) associated with the longhouse and an area of burning north of the house

517 (AM148). This portion of the model also includes a cross-reference to a date estimate for the laying  
518 of the paved surface derived from the dating in the second sequence.

519

520 The second sequence is derived primarily from peat sequence UHM, which comprises dating  
521 evidence from throughout context [026]. Although the humin fractions from the peat in [026] were  
522 deemed unreliable due to the potential inclusion of allochthonous carbon, a sample of identifiable  
523 *Sphagnum* leaves and stems (Figure 5) was collected and dated (SUERC-24946) from 8 cm above a  
524 paving stone. Two tephra dates are available from levels above this radiocarbon sample, from  
525 Hekla-1104 and Hekla-1158. It is important to note that the exceptional precision recorded for two  
526 of the tephra layers (Hekla-1104 and Hekla-1158) is due to the fact that both of these eruptions  
527 occurred within historical time periods and so the specific date of the eruption is known. At some  
528 point after [026] began forming, but before the Hekla-1104 eruption, stone paving [029] was laid,  
529 which butted against the outer wall face of the longhouse. As stated above, this sequence is linked  
530 to the primary longhouse sequence through the dating estimate for the laying of the stone paving.

531

532 The chronological model has good agreement between the different dating techniques and the  
533 observed stratigraphic relationships (Amodel=82). Although relatively imprecise, the dating  
534 evidence estimates that peat formation began by 2795–1770 *cal. BC* (95% probability; Figure 9;  
535 *start: peat formation*), and probably by 2135–1795 *cal. BC* (68% probability). The transition in the  
536 peat sequence from [055] to [041], which the pollen indicated shows a sharp change from heath to  
537 grazing land, occurred in 675 *cal. BC–cal. AD 235* (95% probability; Figure 9; *transition*  
538 *[055]/[041]*), and probably in 495 *cal. BC–cal. AD 130* (68% probability). A considerable amount  
539 of time passed between the start of agricultural improvement in the area and the construction of the  
540 longhouse, with the model estimating the span covering 670–1625 *years* (95% probability; Figure  
541 10; *span: start [041] and longhouse construction*), and probably 825–1425 *years* (68% probability).  
542 The Underhoull longhouse was constructed in *cal. AD 805–1050* (95% probability; Figure 9; *start:*

543 *Underhoull longhouse*), and probably in *cal. AD 880–1000* (68% probability). The longhouse was  
544 in use for *225–630 years* (95% probability; Figure 10; *span: Underhoull longhouse*), and probably  
545 *295–485 years* (68% probability). Activity within the house ended in *cal. AD 1230–1495* (95%  
546 probability; Figure 10; *end: Underhoull longhouse*), and probably in *cal. AD 1260–1380* (68%  
547 probability).

548

549 The modelling estimates the stone paving was laid in *cal. AD 1035–1105* (95% probability; Figure  
550 9; *Paved surface laid*), and probably in *cal. AD 1070–1105* (68% probability). This would indicate  
551 that *25–280 years* (95% probability; Figure 10; *span: longhouse construction and paving laid*), and  
552 probably *80–205 years* (68% probability), passed between the initial construction of the longhouse  
553 and the laying of the paved surface.

554

## 555 **6. Discussion**

556

### 557 **6.1 Before the Norse occupation of the site**

558 The dates show that peat began to accumulate in the early second millennium BC, or during the  
559 beginning of the Early-Middle Bronze Age. This peat initiation may have been triggered by climate  
560 change (e.g. Morris et al., 2018), but recent studies have warned against this interpretation. For  
561 example, Lawson et al. (2007) assessed the timing of peat formation in the Faroe Islands, which  
562 occurred before any known human settlement of the archipelago, and concluded that no strong  
563 evidence could be found to suggest that climate change influenced the timing of peat initiation. Peat  
564 formation in the Shetland Isles may be driven by similar processes to those in the Faroe Islands, but  
565 despite some similarities in terms of climate and biota, one crucial factor is the very different  
566 history of human settlement.

567

568 The dating evidence reported here for a discontinuity in the peat between contexts [055] and [041]  
569 is consistent with sharp changes in the pollen stratigraphy reported by Edwards et al. (2013)  
570 indicative of a change in the landscape from heath to pasture. This event probably occurred between  
571 *495 cal. BC–cal. AD 130* (68% probability; Figure 9), placing it firmly within the Iron Age. It is  
572 possible that the identified landscape changes identified around Underhoull may be relate to the  
573 construction and use of the nearby broch tower.

574

## 575 **6.2 The construction of the longhouse**

576 We estimate that the longhouse was constructed in *cal. AD 880-1000* (68% probability; Figure 9).  
577 This compares to the late 7<sup>th</sup> to late 9<sup>th</sup> century dates for the establishment of the early Viking  
578 occupation of Norwick (Ballin Smith, 2007) and the probable 9<sup>th</sup> to 10<sup>th</sup> century earliest phase of  
579 the longhouse at Belmont (Larsen et al., 2013). The 9<sup>th</sup> century dates for these longhouses are  
580 contemporaneous with the settlement of Iceland (Schmid et al., 2017) and while this is consistent  
581 with the possibility that Shetland could have played an important part in the westward expansion of  
582 the Norse, it also highlights the rapid extension of Norse settlement westwards from Norway in the  
583 9<sup>th</sup> -10<sup>th</sup> centuries.

584

## 585 **6.3 The occupation of the structure**

586 The end of the longhouse occupation at Underhoull occurred between *cal. AD 1260-1380* (68%  
587 probability; Figure 9). These dates also compare well with those produced for other longhouse sites  
588 in Unst, where the primary occupations of the longhouses at Hamar and Belmont were placed to the  
589 11<sup>th</sup>-13<sup>th</sup> centuries AD (Larsen et al., 2013; Bond et al., 2013). However, it is important to note that  
590 the chronological evidence from Hamar and Belmont has not yet been fully investigated and so  
591 greater resolution may be available in the future.

592

593 The dating evidence and modelled estimates produced from the Upper House structure appear to fit  
594 within a developing pattern in Shetland and the wider region of Atlantic Scotland, for extensive  
595 settlement late in 9<sup>th</sup> and through the 10<sup>th</sup> centuries AD. Conventionally, sites such as the Upper  
596 House, Underhoull and Hamar have been interpreted as representing short-lived, single-phase  
597 settlements based on a survey of the visible structural remains and surface features. However, now  
598 that a number of these structures been excavated, there is evidence the structures underwent several  
599 phases of use and modification over a prolonged time period. This included the division of the  
600 structures into separate rooms, the addition of annexes, and use through to the end of the Late Norse  
601 period (Bond et al., 2013; Larsen et al., 2013). Collectively, evidence produced from the Upper  
602 House, Underhoull combined with data from recently excavated sites of Hamar and Belmont  
603 indicates that established ideas about the nature and use of such sites needs reassessment, in the  
604 light of longer, more complex and nuanced stories of settlement.

605

#### 606 **6.4. The abandonment of the structure and peat development**

607 Following the production of posterior density estimates, dates associated with the use of the  
608 structure, place occupation within the *cal.* 10<sup>th</sup>-13<sup>th</sup> centuries AD. The youngest features recorded  
609 on the site relate to a possible industrial area associated with large quantities of fuel-ash slag and an  
610 area of burning (context [093]). An archaeomagnetic date of AD 1280-1430 (AM148) was  
611 produced on the area of burning. This suggests that activities at the site continued through the 13<sup>th</sup>-  
612 15<sup>th</sup> centuries, placing them between the very end of the Late Norse period and into the Medieval  
613 period. This correlates well with other examples of other well-dated Norse settlements in the  
614 Northern and Western Isles of Scotland, such as Bornais (Sharples, 2005), Cille Pheadair (Sharples  
615 et al., 2004), and Pool (Hunter, 2007). Unfortunately, no material suitable for dating was recovered  
616 from the final phase of occupation at Hamar (Phase 5), although an archaeomagnetic date of AD  
617 1100-1330 (AM154) produced for a hearth assigned to the Phase 3 occupation can be used to  
618 provide a *terminus post quem* for the final phase of activity (Bond et al., 2013). The dating evidence

619 from these sites may place their abandonment into a period of climate change, increased winter  
620 storminess (Dugmore et al., 2009), and “famine, war, and plague” that affected Atlantic Europe  
621 from the 14<sup>th</sup> century (McGovern, 2000; Dugmore et al., 2007). It is unclear at present why the  
622 Upper House site was abandoned and whether this related to environmental or economic factors that  
623 resulted in a change in the activities carried out in the area or a decline in the status of the site.

624

625 The excavation of the Upper House, Underhoull shows that the occupants built the longhouse in an  
626 area where peat was already accumulating, which raises the possibility that continued peat growth  
627 contributed to the abandonment of the site. The dates obtained for the construction of the paved  
628 surface over the peat (context [029]), could be interpreted as an attempt by the occupants to manage  
629 the site and maintain a dry and stable area around the longhouse despite the close proximity to the  
630 peat. A modelled estimate of *cal. AD 1070-1105* (68% probability; Figure 9) obtained for the paved  
631 surface, places its construction in the 11<sup>th</sup> century AD at the earliest, but possibly as late as the early  
632 12<sup>th</sup> century. When this is compared to the estimates obtained for the construction of the longhouse,  
633 it is possible to argue that the features were contemporary as the modelled estimates overlap, but it  
634 is also possible that the paving related to a later phase of activity. This uncertainty illustrates the  
635 challenges of site interpretation, even in the context of high resolution, multi-method chronology.

636

637 When the occupation of the structure is compared to the dates of peat accumulation two of the  
638 deposits sampled from within the structure (SUERC-24945 and SUERC-34113) and the possible  
639 industrial feature (AM148) are found to be younger than the Hekla-1158 tephra recorded in the peat  
640 located 7 cm above the paved surface to the south of the structure. Two of these dates (SUERC-  
641 24945 and AM148) sampled primary, *in situ* contexts and indicate that the occupation of the  
642 longhouse and the activity on the site continued even when the peat had encroached on the structure  
643 and paved surface. This was unexpected and suggests that the abandonment of the site cannot be  
644 attributed solely to the growth of peat on the site. This illustrates how well-constrained chronologies

645 demand more nuanced explanations for settlement change (e.g. Dugmore et al., 2012) than the  
646 mono-causal drivers that are often invoked.

647

## 648 **7. Conclusions**

649 The development of the chronology for the Upper House site at Underhoull demonstrates the  
650 strength of using a multi-method approach including cryptotephrochronology; the different dating  
651 techniques sampled different materials and targeted different dated events, which provided a more  
652 complete assessment of the chronology. It was noted that the dates produced on the peat humin  
653 fraction appeared to sample residual material. It can be concluded that the anthropogenic activity in  
654 the area adjacent to the peat has encouraged the incorporation of residual material, such as ‘old’  
655 wood or peat into the peat following their use as a fuel source on the site. This has complicated the  
656 determination of the chronology and acts as a warning to other studies that aim to produce dates on  
657 the humin fraction of peat sampled so close to settlement/activity sites. Hand-picked plant  
658 macrofossils (e.g. *Sphagnum* remains), when present, are best for reliable dates from peats from  
659 archaeological contexts. We found that <sup>14</sup>C dates on charred barley grains correlate well with  
660 archaeomagnetic dates on hearths as both reflect the latest use of the feature.

661

662 The accurate and precise dating of the Upper House site, Underhoull required the detailed  
663 consideration of the contexts, the stratigraphy, and the scientific dates. The integration of specialists  
664 (dating and environmental) both in the planning stages of the project, and in the field, aided the  
665 development of the chronology. In addition, the assessment of dates in sequence further enhanced  
666 the development of a robust chronology, combining the strengths of each method, compensating for  
667 their weaknesses and identifying any anomalous dates. One of the greatest advantages of this  
668 approach was the ability to produce modelled estimates for key events in the life of the site that  
669 could not be directly dated, such as the construction of the longhouse and the truncation events  
670 recorded within the peat that were indicative of the rearrangement of the landscape. The best results

671 were achieved when several dates from a sequence could be assessed, allowing the internal  
672 consistency of the dates from each context to be determined as well as using the stratigraphic  
673 relationships of the samples to refine the age ranges further.

674

675 The construction of the longhouse *c. cal. AD 880-1000* lies between the very first phases of the  
676 settlement of Iceland and the settlement of Greenland, indicating that the Norse were consolidating  
677 settlement in the eastern North Atlantic region while simultaneously extending westward. The  
678 abandonment of the site echoes the demise of Norse settlement in Greenland (e.g. Dugmore et al.,  
679 2012). This reinforces the idea that settlement contraction was not happening simply at the margins  
680 of European settlement, but instead was more widespread, for example in Atlantic Scotland and the  
681 more-marginal areas of Iceland (Vésteinsson et al., 2014). Multi-method chronologies combined in  
682 Bayesian analysis offer exciting opportunities to realise the potential of archaeology as Distributed  
683 Long-term Observing Networks of the Past (DONOP - Hambrecht et al., 2018), to tackle Grand  
684 Challenge agendas in archaeology (Kintigh et al., 2014), and also provide detailed and extensive  
685 data on the changing lived environment of wide relevance in Quaternary science.

686

## 687 **8. Acknowledgements**

688 This research was supported by research grants to GTS from the Natural Environmental Research  
689 Council UK for <sup>14</sup>C dating (Allocations: 1493.0910, 1466.0410) and geochemical analysis of  
690 tephtras at Edinburgh University (Allocation: TAU58/1109). We thank the Shetland Amenity Trust  
691 for funding the excavation and post-excavation phases of the work (HLF-funded Viking Unst  
692 Project). JB and MC acknowledge an IPY grant from the National Science Foundation (IPY 'Long  
693 Term Human Ecodynamics in the Norse North Atlantic: Cases of Sustainability, Survival and  
694 Collapse', Award number 0732327, PI Tom McGovern). CMB acknowledges a British Academy  
695 Mid-Career Fellowship (MD120020). EW acknowledges NERC Doctoral Training Grant  
696 NE/K500847/1. We thank Kevin Edwards and Ed Schofield for sampling one of the peat profiles.

697 We would like to thank John Craven and Chris Hayward (University of Edinburgh) for their advice  
698 on geochemical analysis of tephtras. We thank Daniel Bashford for assistance with cartography. We  
699 thank Stephen Dockrill for co-directing the excavation at Underholl and the excavation team from  
700 the University of Bradford, City University of New York, University of Glasgow, University of  
701 Groningen, and local volunteers from the Unst Heritage Group.

702

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979 **Figure captions:**

980 Figure 1: Location map of Shetland and the island of Unst, highlighting the Norse sites excavated to  
981 date. The Upper House site, Underhoull is located at 60.72°N, 0.95°W.

982

983 Figure 2: (a) The key archaeological sites located in the Westing area of Unst; (b) the Norse  
984 longhouse excavated at Underhoull as part of the Viking Unst Project, referred to as the ‘Upper  
985 House’.

986

987 Figure 3: Extent of peat accumulations recorded adjacent to the Upper House site, Underhoull.

988

989 Figure 4: The relative positions of the three cores used to sample the peat. The position of the  
990 material sampled for dating has been highlighted.

991

992 Figure 5: Summary of the concentration of charcoal present within the ‘UHM’ core following  
993 extraction using a 63 µm sieve. The presence of *Sphagnum* remains in the UHM core is also shown.

994

995 Figure 6: Tephrostratigraphy of the three peat profiles (number of tephra shards per cm<sup>3</sup>). The  
996 horizon representing the first appearance of SCPs (dated to c. AD 1850 or later) are also shown

997

998 Figure 7: Tephra geochemistry biplots. Type analyses from tephabase (Newton et al., 2007) are  
999 shown for comparison.

1000

1001 Figure 8: Simplified Harris matrix for the Upper House at Underhoull.

1002

1003 Figure 9. The chronological model for the Upper House at Underhoull.

1004

1005 Figure 10. Timing of key events associated with the Upper House at Underhoull.

1006

1007 **Table captions:**

1008 Table 1: The definition of the types of deposits recorded at the Upper House, Underhoull using the  
1009 methodology defined by Schiffer (1987) and Dockrill et al. (2006).

1010

1011 Table 2: Summary of the AMS radiocarbon dates, calibrated using IntCal13 (Reimer et al., 2013).

1012

1013 Table 3: Summary of the archaeomagnetic dates produced from the Upper House, Underhoull. All  
1014 of the sampled deposits represented primary deposits. The mean directions are the characteristic  
1015 remanent magnetisation directions at the site and have been calibrated using ARCH-UK.1 (Batt et  
1016 al., 2017).

1017

1018 Table 4: Summary of the tephra horizons recovered from the peat.

1019

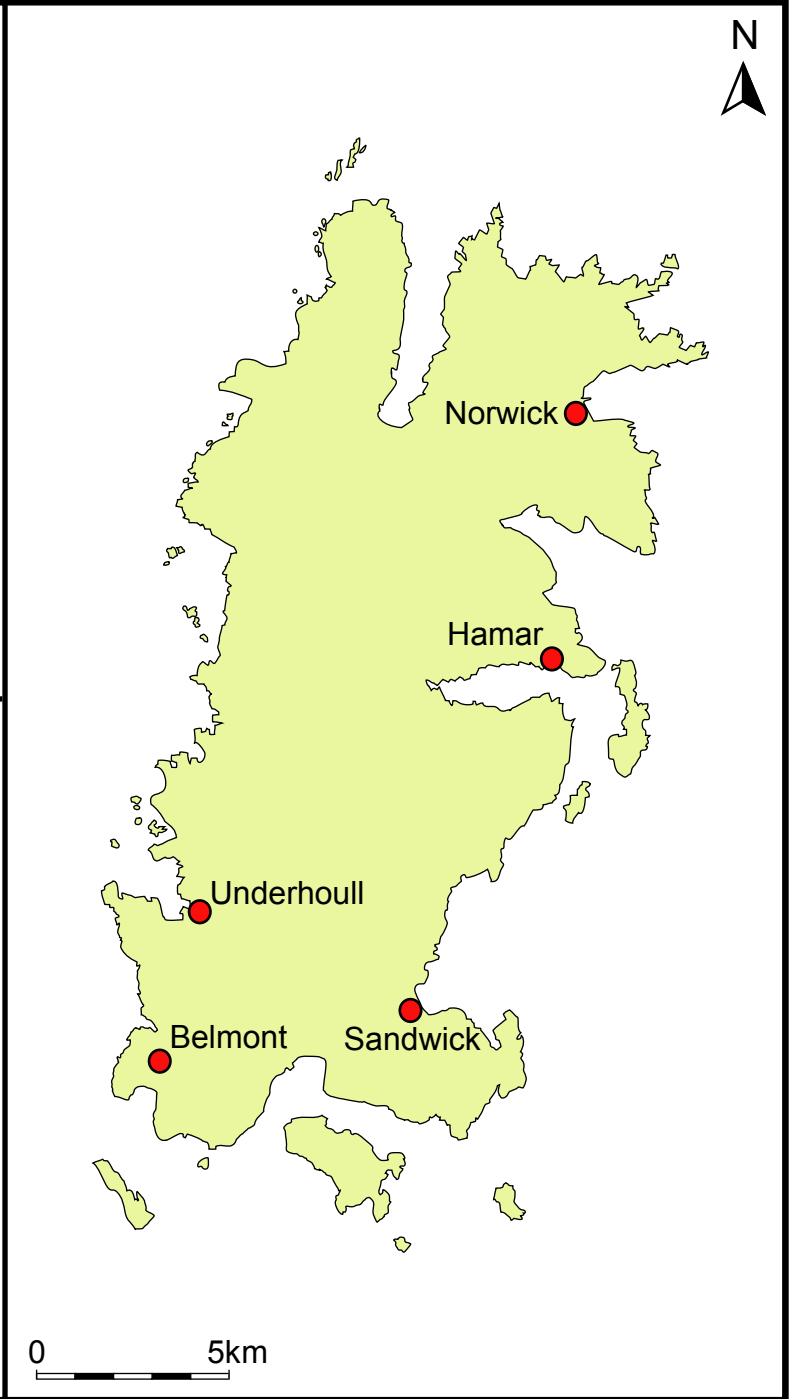
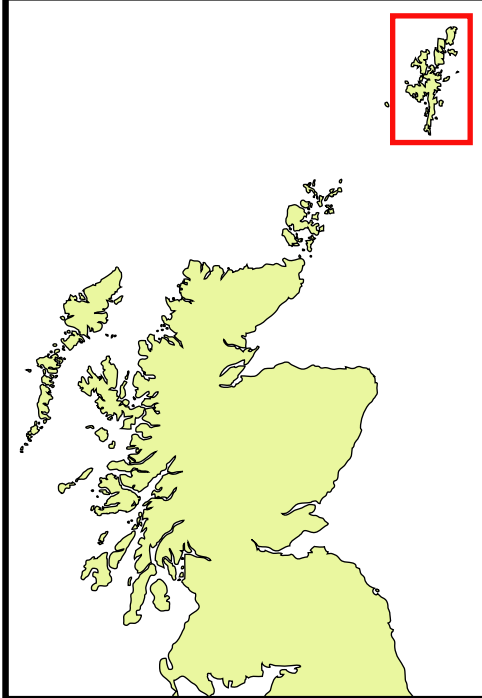
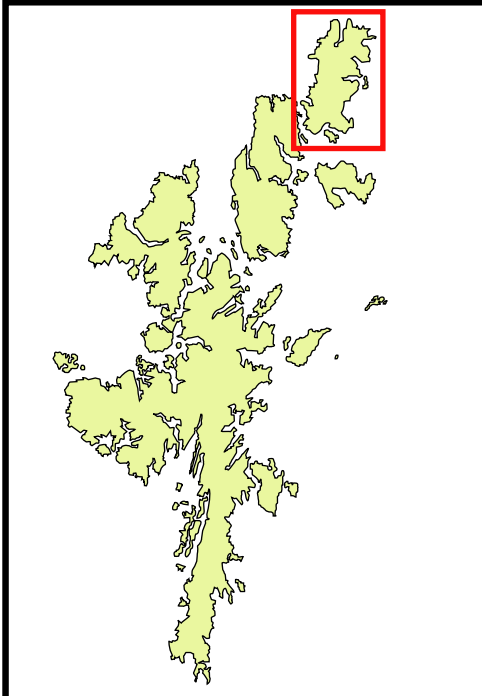
1020 **Supplementary files:**

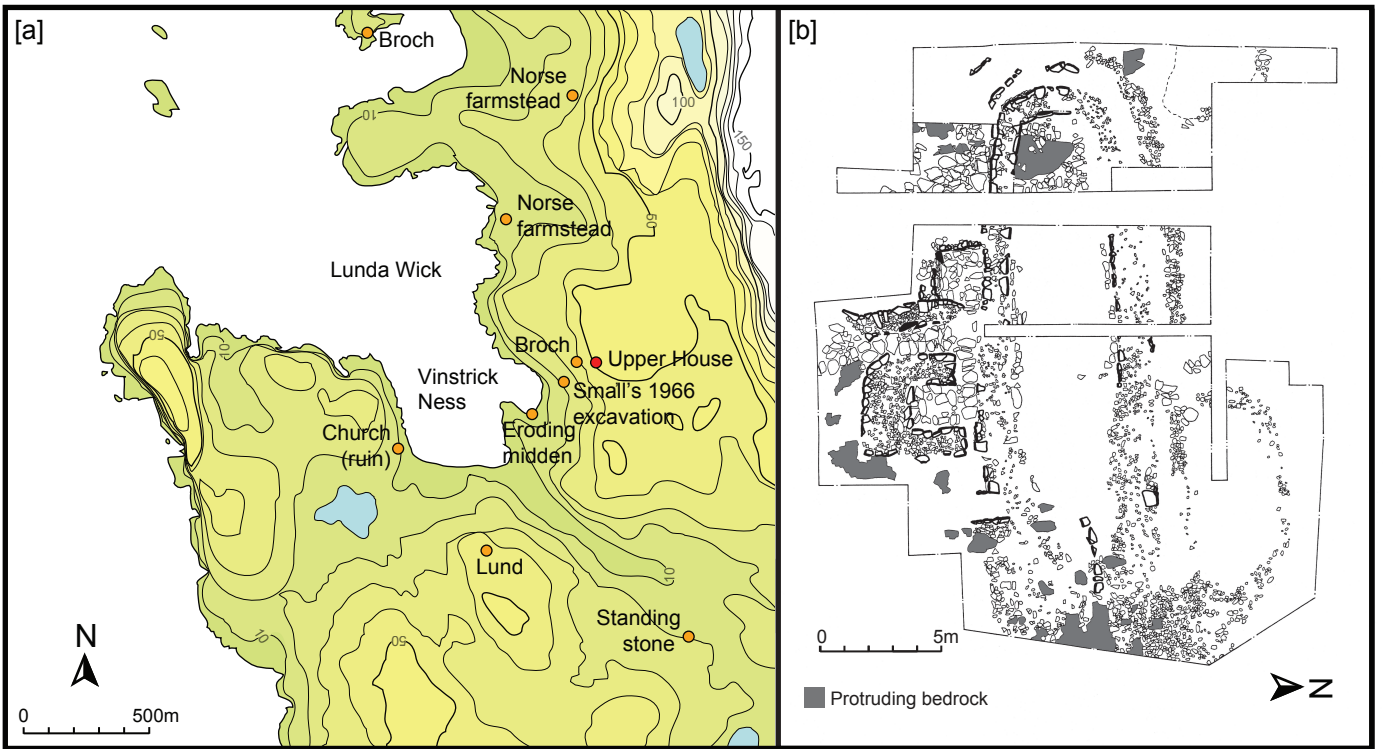
1021 Supplementary file 1: Tephra geochemical data.

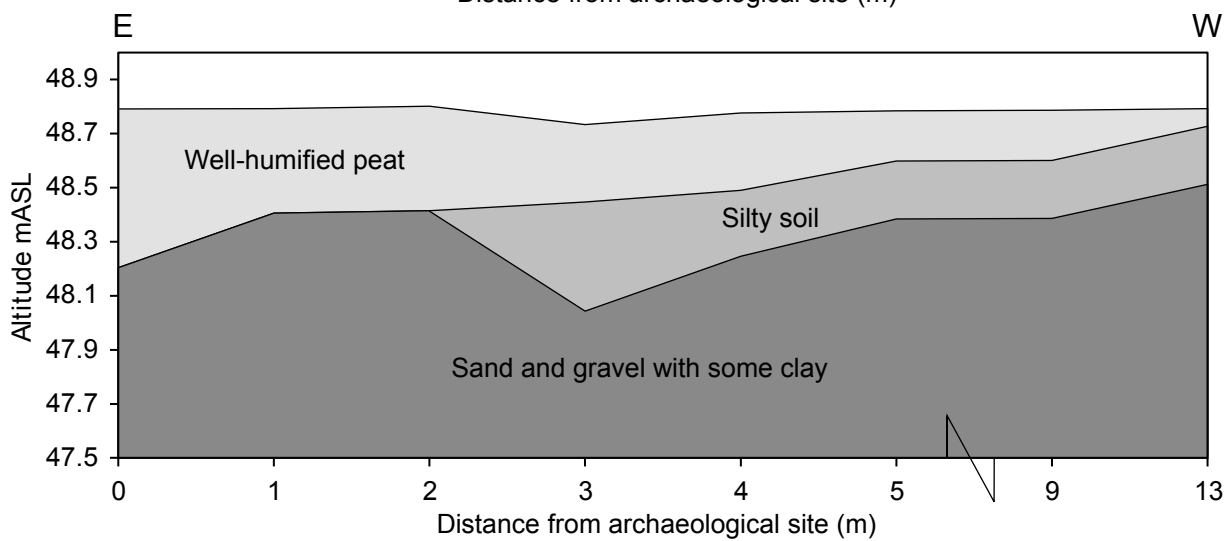
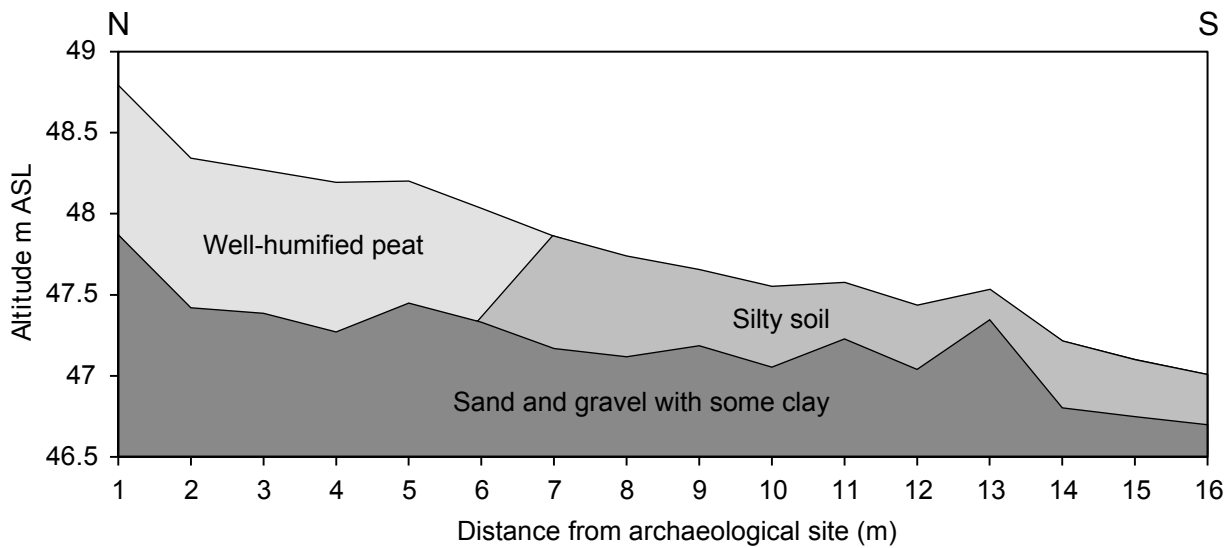
1022 Supplementary file 2: Bayesian model code and prior files for the archaeomagnetic dates.

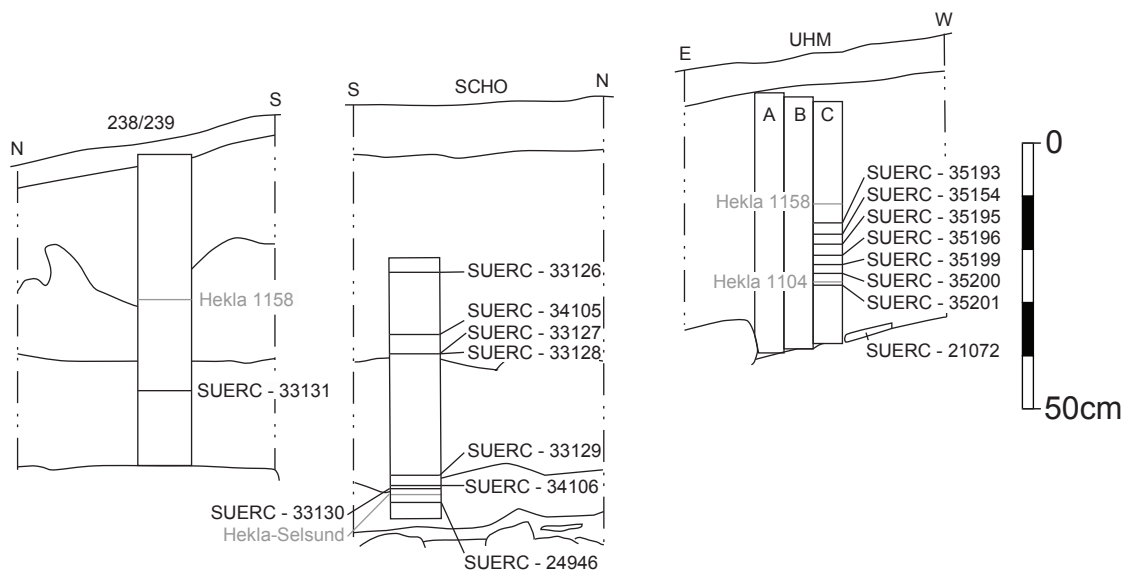
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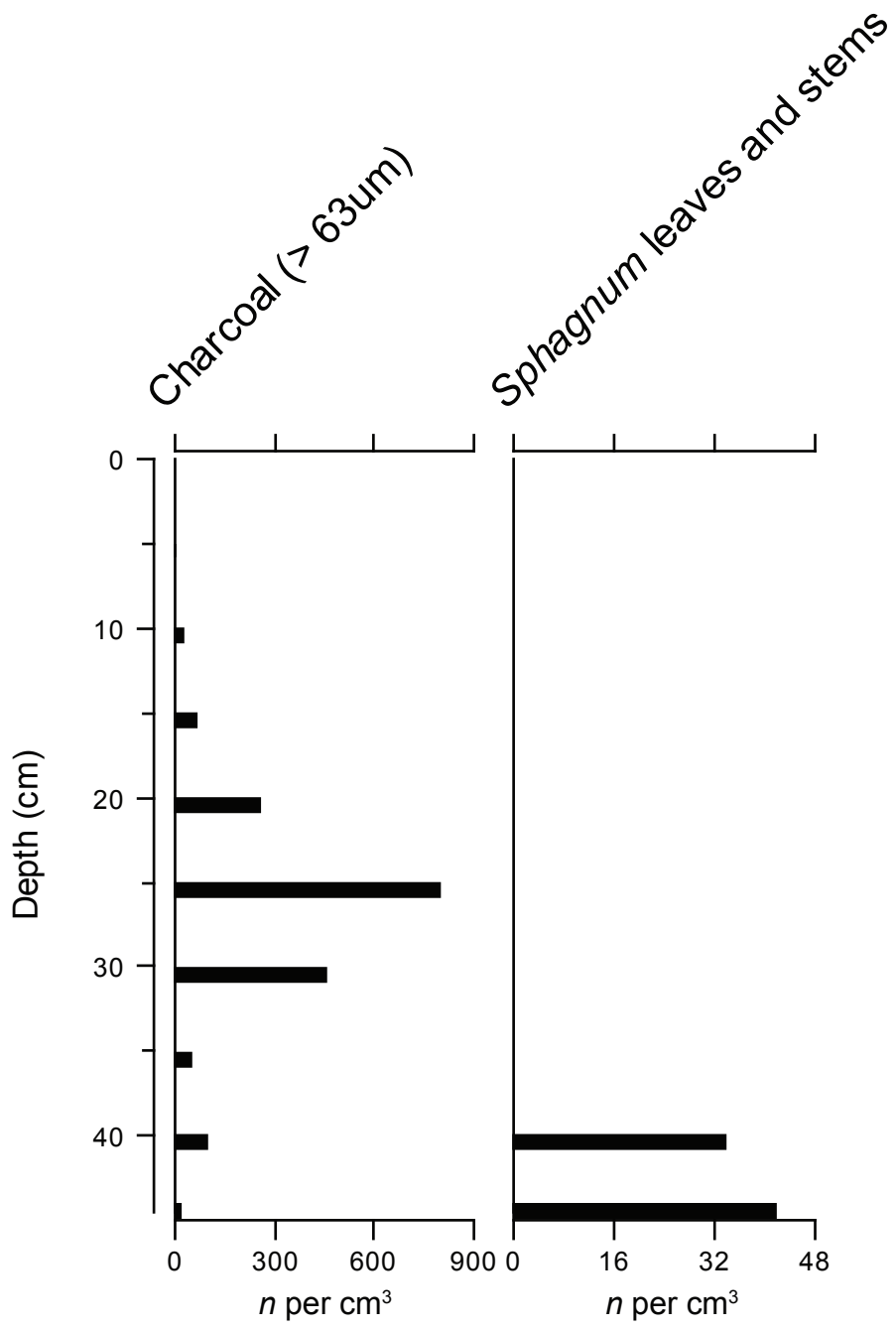
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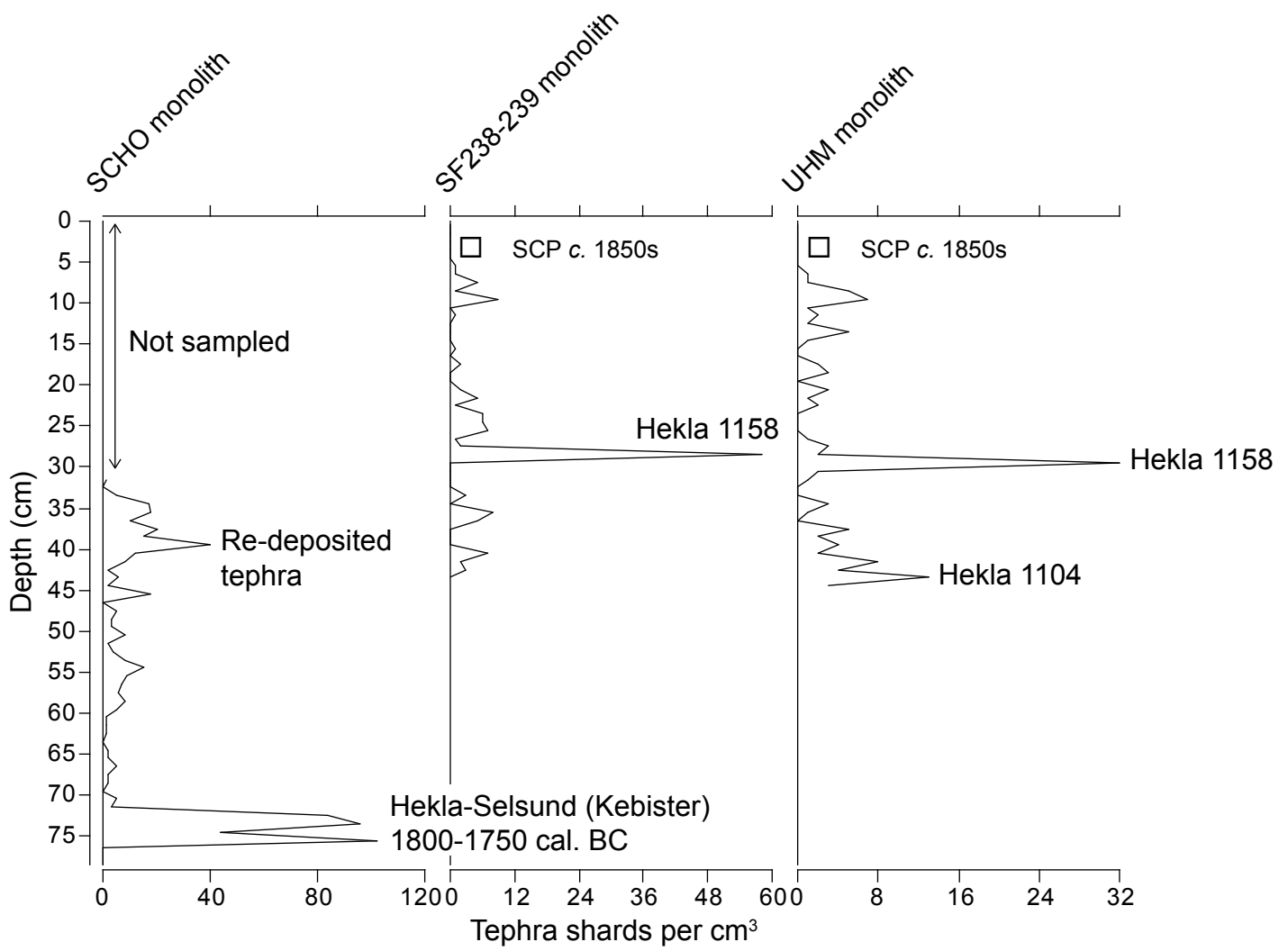


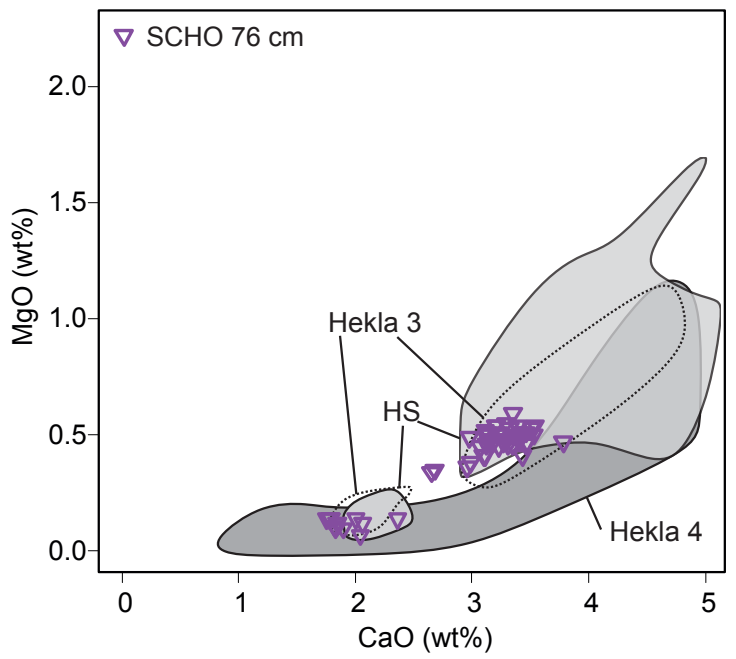
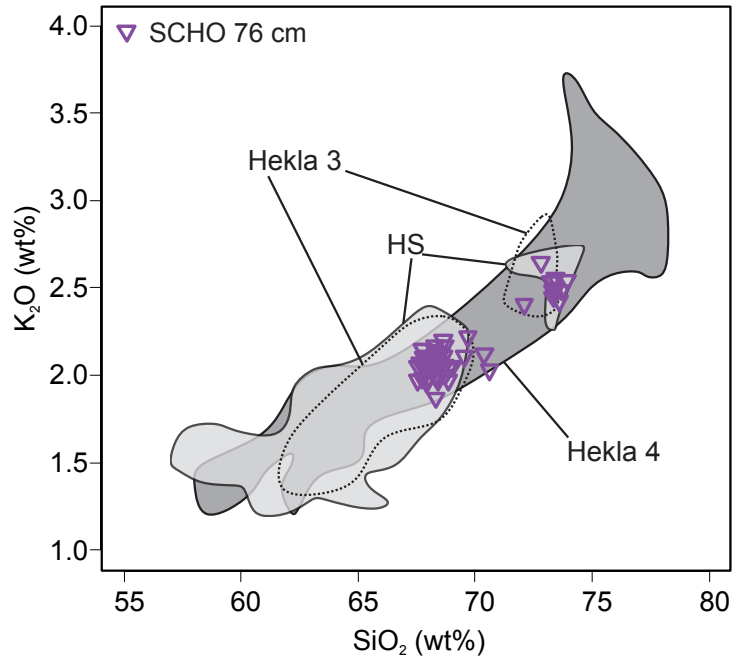
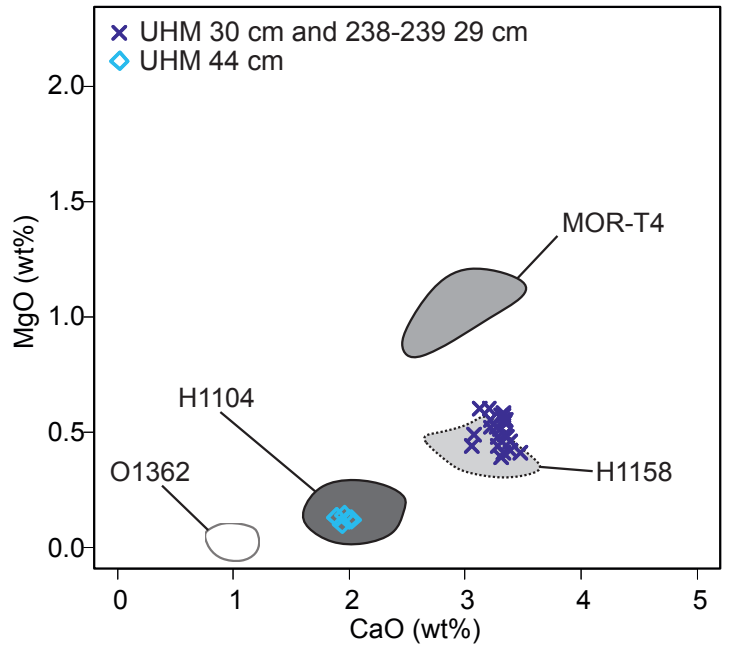
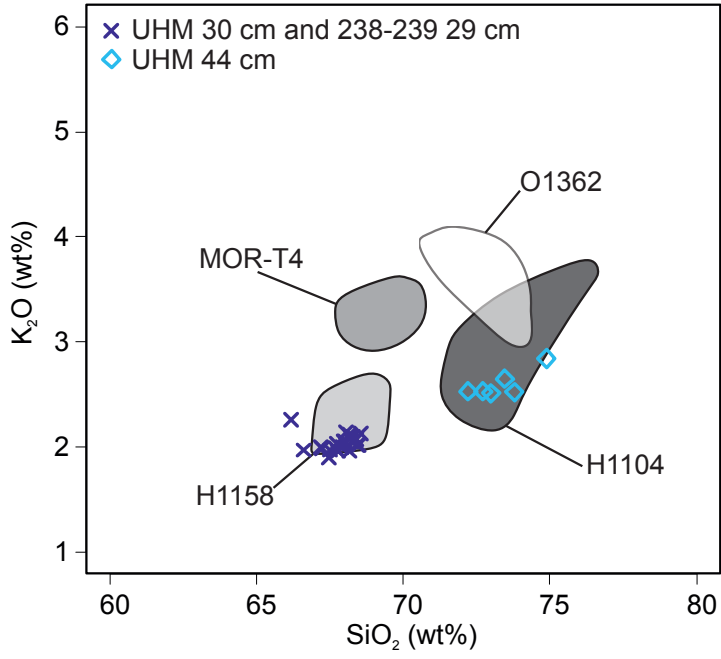




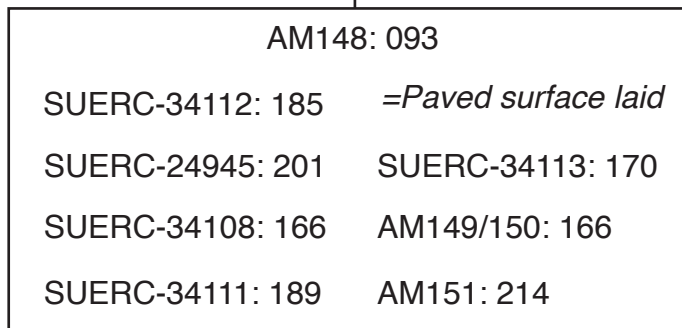






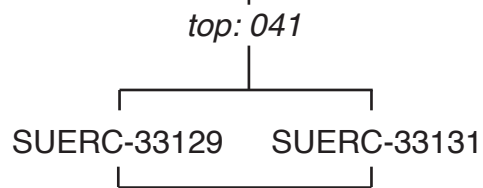


*end: Underhoull longhouse*



Longhouse  
features

*start: Underhoull longhouse*



041

*start: peat formation*

055

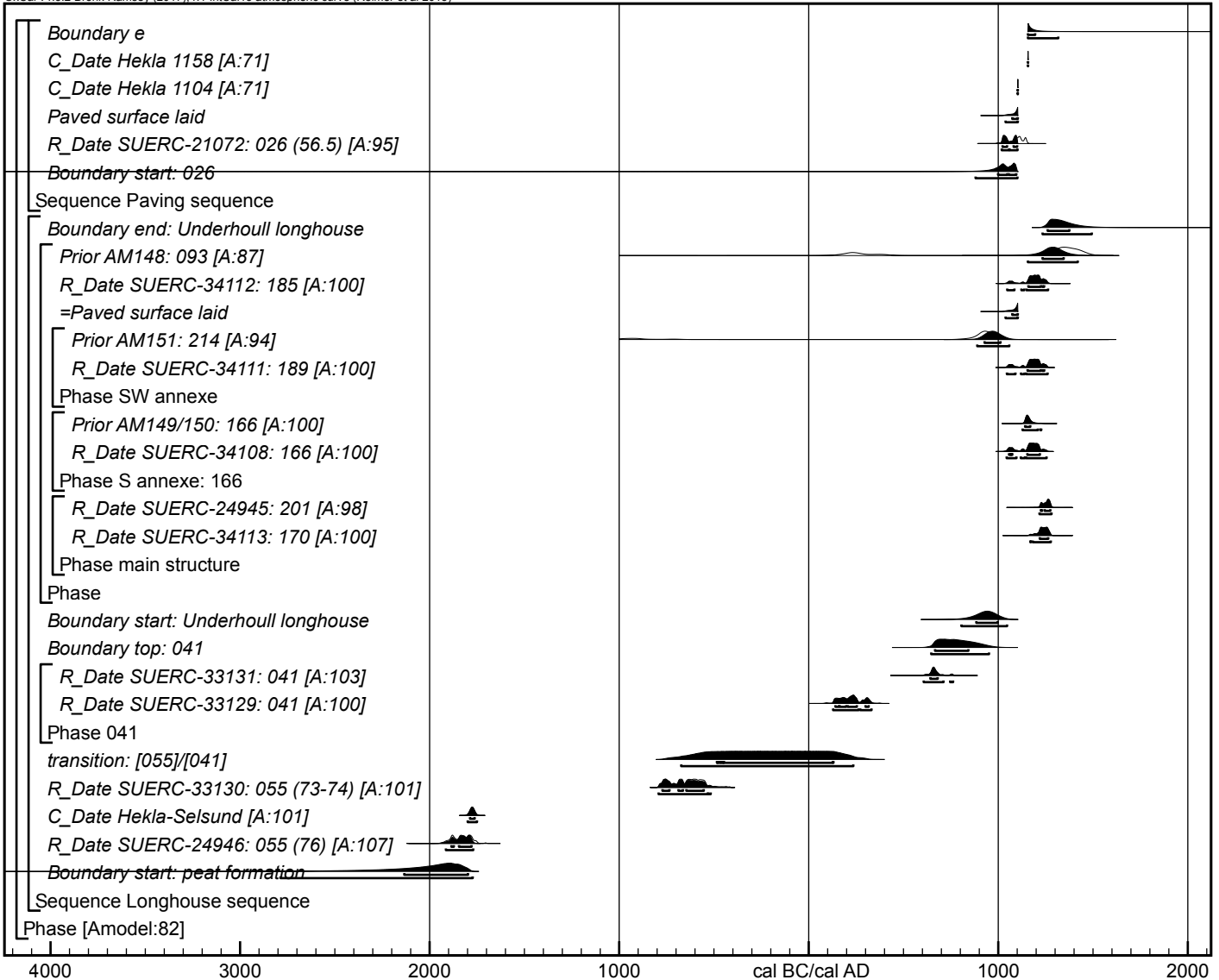
Hekla-1158

Hekla-1104

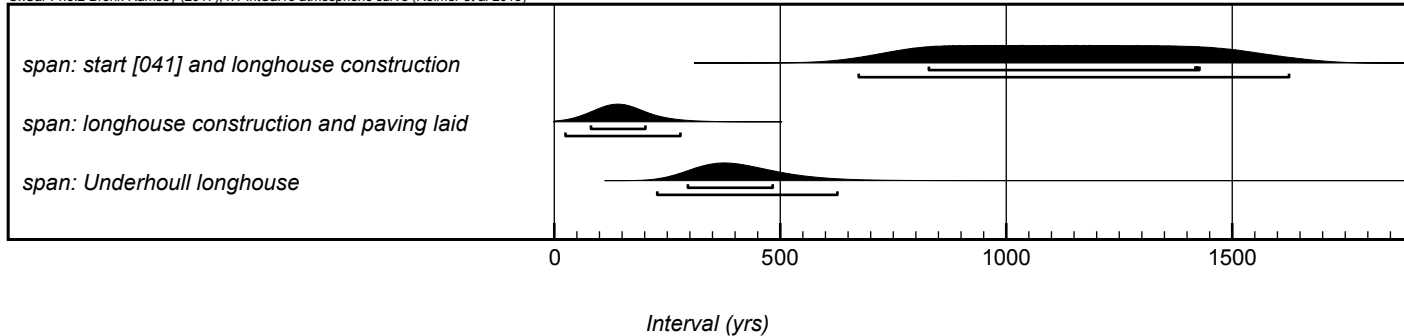
*Paved surface laid*

SUERC-21072

*start: 026*



Modelled date (cal BC/cal AD)



| <b>Deposit type</b> | <b>Min. number of times the material has been moved</b> | <b>Description and key features for identification</b>   | <b>Example</b>   | <b>Reference</b>                            |
|---------------------|---|--|--|---|
| <b>Primary</b>      | None  | An <i>in situ</i> deposit  | Hearth deposits, dedicatory deposits, Microrefuse trodden into a floor | Schiffer, 1987, p.58                        |
| <b>Secondary</b>    | Once  | The boundaries separating deposits would be clear and distinct                                   | A midden, the material raked out from a hearth                         | Schiffer, 1987, p.58; Dockrill et al., 2006 |
| <b>Tertiary</b>     | Twice   | The deposits would be homogenised. The boundaries separating deposits may be merging and diffuse | The use of a midden deposits to level an area                          | Dockrill et al., 2006                       |

|   | Context | Description  | Lab. Ref.<br>SUERC- | Material       | Monolith | Depth<br>from<br>surface<br>(cm) | Depositional<br>context | Uncalibrated<br>Years BP | Calibrated<br>95% confidence | $\delta^{13}\text{C}$<br>‰ |
|---|---------|--|---------------------|----------------|----------|----------------------------------|-------------------------|--------------------------|------------------------------|----------------------------|
| Deposits associated with the<br>structure | 201     | Dark red ashy material running down the edge of the interior, interpreted as a possible hearth | 24945               | Charred barley |          |                                  | Secondary               | 765±30                   | AD1220-1280                  | -26.5                      |
|   | 166     | Orange/red hard baked ash hearth within S annexe   | 34108               | Charred barley |          |                                  | Primary                 | 866±35                   | AD1045-1260                  | -24.8                      |
|   | 189     | Occupation deposit in the SW annexe  | 34111               | Charred barley |          |                                  | Secondary               | 856±37                   | AD1045-1265                  | -23.0                      |
|   | 185     | Occupation deposit in the centre of the structure  | 34112               | Charred barley |          |                                  | Secondary               | 849±37                   | AD1045-1265                  | -23.7                      |
|   | 170     | Steatite and charcoal rich deposit in the yard area to the N of the structure                  | 34113               | Charred barley |          |                                  | Secondary/Tertiary      | 792±35                   | AD1175-1280                  | -24.0                      |
| Peat                                      | 026     | Purple/black peat overlying the bedrock  | 35193               | Humin fraction | UHM      | 32.5                             | Primary                 | 1769±37                  | AD135-380                    | -28.6                      |
|   |         |  | 35154               | Humin fraction | UHM      | 34.5                             | Primary                 | 1434±35                  | AD565-660                    | -28.6                      |
|   |         |  | 35195               | Humin fraction | UHM      | 36.5                             | Primary                 | 1578±35                  | AD410-560                    | -29.0                      |
|   |         |  | 35196               | Humin fraction | UHM      | 38.5                             | Primary                 | 2314±37                  | 510-210BC                    | -29.3                      |
|   |         |  | 35199               | Humin fraction | UHM      | 40.5                             | Primary                 | 2158±37                  | 360-60BC                     | -30.1                      |
|   |         |  | 35200               | Humin fraction | UHM      | 42.5                             | Primary                 | 1558±37                  | AD420-580                    | -29.5                      |

|       |            |  |                |                         |       |                  |                  |             |             |       |
|-------|------------|--|----------------|-------------------------|-------|------------------|------------------|-------------|-------------|-------|
|       |            |  | 35201          | Humin fraction          | UHM   | 44.5             | Primary          | 1622±35     | AD345-540   | -29.0 |
|       |            |  | 21072          | Sphagnum leaves & stems | UHM   | 56.5             | Primary          | 970±30      | AD1015-1155 | -27.4 |
|       | <b>041</b> | Brown peat sealed by flagstones [029] and peat [026] | 33131          | Humic acid              | SF239 | 45-46            | Primary-Tertiary | 1358±37     | AD610-770   | -29.0 |
|       | <b>026</b> | Purple/black peat overlying the bedrock              | 33126          | Humic acid              | SCO   | 31-32            | Primary-Tertiary | 1688±37     | AD255-425   | -28.9 |
| 34105 |            |  | Humin fraction | SCO                     | 44-45 | Primary          | 1905±37          | AD20-220    | -29.8       |       |
| 33127 |            |  | Humic acid     | SCO                     | 44-45 | Primary-Tertiary | 1708±37          | AD250-410   | -29.4       |       |
| 33128 |            |  | Humic acid     | SCO                     | 47-48 | Primary-Tertiary | 1604±37          | AD385-550   | -29.3       |       |
|       | <b>041</b> | Brown peat sealed by flagstones [029] and peat [026] | 33129          | Humic acid              | SCO   | 71-72            | Primary-Tertiary | 1799±35     | AD130-335   | -29.4 |
|       | <b>055</b> | Dark peaty material sealed by [041]                  | 33130          | Humic acid              | SCO   | 73-74            | Primary-Tertiary | 2504±37     | 790-425BC   | -29.3 |
| 34106 |            |  | Humin fraction | SCO                     | 73-74 | Primary          | 2774±37          | 1010-830BC  | -30.1       |       |
| 24946 |            |  | Humic acid     | SCO                     | 76    | Primary-Tertiary | 3515±30          | 1920-1750BC | -29.0       |       |

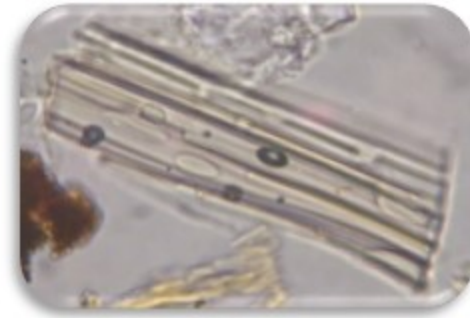
| Context | Description  | Lab. Ref.<br>(Bradford) | Number of<br>samples | Mean<br>Declination<br><i>Degrees</i> | Mean<br>Inclination<br><i>Degrees</i> | Alpha-95<br><i>Degrees</i> | Precision<br>parameter | Stability index    | Calibrated<br>age range<br><i>95%<br/>confidence</i> |
|---------|--|-------------------------|----------------------|---------------------------------------|---------------------------------------|----------------------------|------------------------|--------------------|--|
| 214     | Orange/red hard baked ash<br>hearth material within SW<br>annexe           | AM151                   | 14                   | 28.1                                  | 70.4                                  | 4.1                        | 115.5                  | Stable             | AD800-1080   |
| 166     | Orange/red hard baked ash<br>hearth within S annexe                        | AM149 &<br>AM150        | 51<br>(26 + 25)      | 10.2                                  | 58.1                                  | 1.9                        | 122.7                  | Stable-Very stable | AD1240-1310  |
| 093     | Large area of burning<br>associated with a possible<br>industrial activity | AM148                   | 20                   | -8.5                                  | 59.5                                  | 4.8                        | 63.5                   | Stable             | AD1280-1430  |

| Context | Description                             | Core | Depth from surface<br><i>cm</i> | Volcano         | Date                               |
|---------|---|------|---------------------------------|-----------------|------------------------------------|
| 026     | Purple/black peat overlying the bedrock | UHM  | 29.5                            | Hekla           | January 19 <sup>th</sup><br>AD1158 |
|         |   | 239  | 28.5                            | Hekla           | January 19 <sup>th</sup><br>AD1158 |
|         |   | UHM  | 42.5                            | Hekla           | October AD1104                     |
| 055     | Dark peaty material sealed by [041]     | SCO  | 74.5                            | Hekla (Selsund) | 1600-1650 cal.<br>BC               |

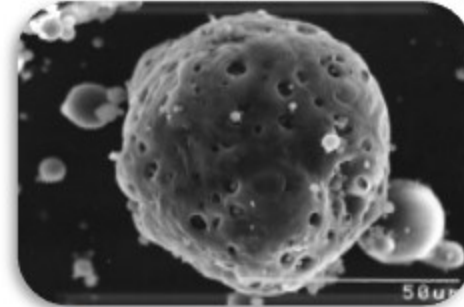
# Underhoull longhouse Shetland Isles, UK



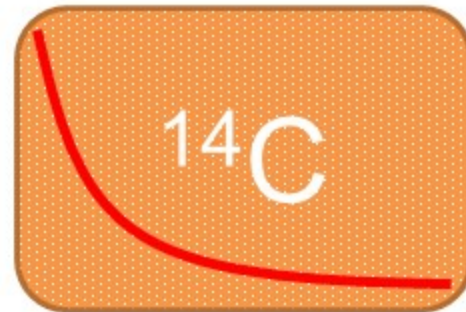
## Peat sampling



Tephra



SCPs



Radiocarbon



Archaeo-  
magnetism

1. We investigate the chronology of a Norse house in the Shetland Isles, UK.
2. A multi-method approach including  $^{14}\text{C}$ , tephra and archaeomagnetic dating is used.
3. The results have implications for Norse expansion across the North Atlantic.