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Constructing chronologies in Viking Age Iceland: Increasing dating resolution using Bayesian approaches

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Abstract

Precise chronologies underpin all aspects of archaeological interpretation and, in addition to improvements in scientific dating methods themselves, one of the most exciting recent developments has been the use of Bayesian statistical analysis to reinterpret existing information. Such approaches allow the integration of scientific dates, stratigraphy and typological data to provide chronologies with improved precision. Settlement period sites in Iceland offer excellent opportunities to explore this approach, as many benefit from dated tephra layers and AMS radiocarbon dates. Whilst tephrochronology is widely used and can provide excellent chronological control, this method has limitations; the time span between tephra layers can be large and they are not always present. In order to investigate the improved precision available by integrating the scientific dates with the associated archaeological stratigraphy within a Bayesian framework, this research reanalyses the dating evidence from three recent large scale excavations of key Viking Age and medieval sites in Iceland; Aðalstræti, Hofstaðir and Sveigakot. The approach provides improved chronological precision for the dating of significant events within these sites, allowing a more nuanced understanding of occupation and abandonment. It also demonstrates the potential of incorporating dated typologies into chronological models and the use of models to propose sequences of activities where stratigraphic relationships are missing. Such outcomes have considerable potential in interpreting the archaeology of Iceland and can be applied more widely to sites with similar chronological constraints.

Keywords: Iceland, Viking Age, Chronology, Radiocarbon dating, Bayesian statistics, Tephra

1. Introduction

Recent developments in the understanding of scientific dating methods and their use in the construction of archaeological chronologies offer exciting opportunities to reassess and reinterpret the dates obtained from excavations, improving precision and allowing more detailed archaeological questions to be addressed. In Iceland, prior to the 1990s, typology, tephrochronology and radiocarbon determinations rarely allowed more precise dating of early sites than to the ‘Viking Age’ typically accepted to be AD 800e1050 (Eldjarn, 2000; Grímsdottir, 1997; Vilhjalmsson, 1991) but the wealth of new data, coupled with methodological advances, now make it possible to aim for much higher dating resolution within the Viking Age. In particular, Bayesian analysis allows a chronological framework to be developed that combines stratigraphy, tephrochronology, typology, historical dates and multiple radiocarbon dates (Bronk Ramsey, 2009). Such an analysis allows the maximum information to be generated from limited archaeological resources and is particularly relevant in Iceland, where recent excavations provide chronological information from a variety of sources. Reinterpretation of the existing archaeological information has the potential to produce a refined chronology, enabling more precision in dating specific archaeological contexts and events, and allowing an objective assessment of dates that do not appear to fit their stratigraphic position. This in turn enhances understanding of settlement processes within Iceland, for example the speed and pattern of initial settlement.

In recent years a number of significant archaeological investigations in Iceland have illuminated many aspects of Viking Age settlement including the debate about first-peopling and colonization models (Vesteinsson and McGovern, 2012; Bolender et al., 2008, 2011); immigration patterns (Price and Gestsdottir, 2006; Vesteinsson and Gestsdottir, forthcoming); environmental reconstructions of the landscape (McGovern et al., 2007; Dugmore et al., 2007; Adderley et al., 2008) and activity within settlements (Milek, 2012; Milek and Roberts, 2013). Comprehensive open area excavations have been carried out (e.g. Hofstaðir: Lucas, 2009; Sveigakot: Vesteinsson, 2010; Vatnsfj€orður: Milek, 2010, 2011 and Hrísbrú: Zori et al., 2013; Zori and Byock, 2014) and intensive surveys have been employed to locate burials and settlements (Friðriksson, 2009; Friðriksson and Vesteinsson, 2011). Increasingly the archaeological interpretations are supported by a framework of scientific dates, predominantly using radiocarbon dating of charred barley seeds and bone, and tephrochronology.

The aim of this research was to ascertain the potential of reanalysis of existing dating evidence from recent, well-documented, large scale excavations and, in particular, the extent to which combining radiocarbon, tephra, stratigraphy and typological evidence within a Bayesian framework can aid in site-specific and broader interpretations. Three sites were selected as excellent examples of recent excavations of key Viking Age and medieval sites in Iceland e Aðalstræti, Hofstaðir and Sveigakot (Fig. 1). These excavations took place before Bayesian statistical analysis was a consideration in sampling strategies; this research allows discussion of the extent to which these developments might inform future sampling strategies.

We begin with a review of the archaeological record in this period and the data available, and then give an overview of the analytical approach employed. The techniques are applied to the selected sites and the implications discussed.

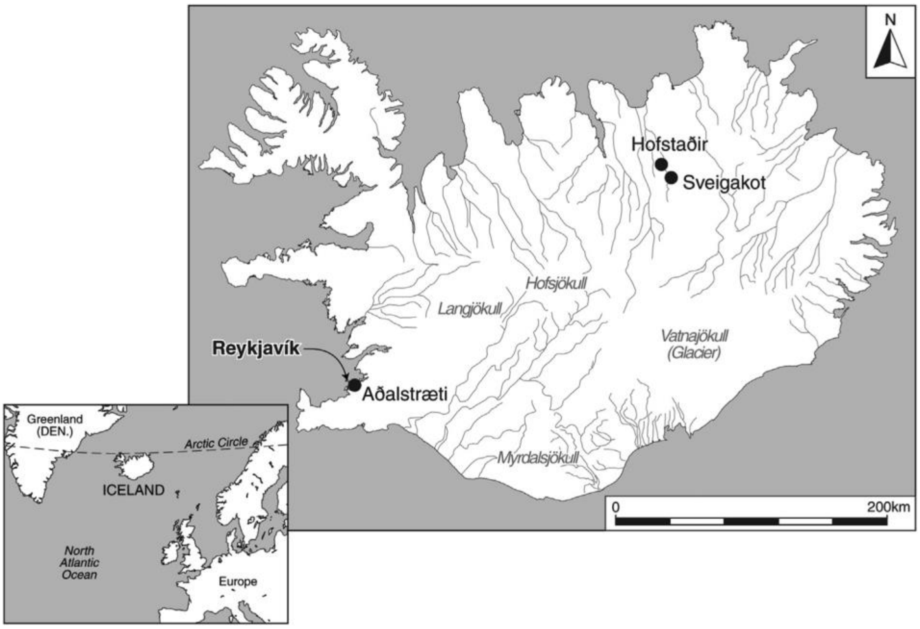


Fig. 1. Map of Iceland showing sites discussed in text.

2. Materials and methods

2.1. Archaeological context

Eldjarn (1958, 2000) laid the foundations for modern research into Viking Age material culture in Iceland. His research was based on artefact typology from pre-Christian burials, which suggested tenth century dates for the majority of early finds. Hermanns-Auðardottir (1989, 1991) criticized this conclusion and claimed a seventh century colonization of Iceland, based on a number of apparently early radiocarbon dates. The charcoal samples yielding early dates all came from just above a tephra layer which underlies the earliest archaeological deposits in two-thirds of the island. The ensuing debate essentially hinged on the age of this layer, known as the *Landnam* tephra. Its dating to AD 871 ± 2 (Gr€onvold et al., 1995) or AD 877 ± 4 (Zielinski et al., 1997) by reference to annual snowmelt in the Greenland icecap effectively demolished the early settlement hypothesis.

Although there are pollen records suggesting earlier human presence and two sites with structural remains below the *Landnam* tephra, there are more than 100 sites with archaeological deposits just above the tephra (Schmid, forthcoming), suggesting that while people may have been present in Iceland for much of the ninth century, large scale settlement only commenced after AD 870. With increasing chronological clarity about the inception of settlement in Iceland, interest has shifted towards trying to refine understanding of developments during and after the colonization (Vesteinsson et al., 2002; Vesteinsson and McGovern, 2012).

Recently, site specific chronologies of Viking age farmsteads have been attempted (e.g. Lucas, 2009: 57). Iceland is ideal for constructing regional chronologies, with an abundance of dated in situ tephra layers below and above cultural remains, providing secure relative chronological frameworks. Tephrochronology has a major impact on temporal interpretation of settlement history; however the challenge remains of providing precise dates for events between tephra layers, or where tephra are absent. The chronological frameworks can be enhanced by multiple radiocarbon dates of short-lived material, but these are restricted by the precision of calibrated radiocarbon dates. Combining these dates using archaeological stratigraphy and typology allows the information to be used to its full potential.

Three sites in Iceland were selected in order to investigate the potential of this approach to provide greater chronological precision. All have stratigraphic sequences from recent well-recorded excavations, in situ tephra layers and radiocarbon dates from accelerator mass spectrometry (AMS). Additional information, such as typological data, was also used where applicable. One site in west Iceland was selected, Aðalstræti, a well-preserved hall in Reykjavík, and two sites in the north of Iceland in the vicinity of Lake Mývatn were also investigated; Hofstaðir, a high status site with the largest hall in Iceland, associated with an early church, and Sveigakot, a low-status farm which was already settled by the end of the ninth century. All three sites have a wealth of datable samples and can be used to address key questions of the date of first settlement, site development and abandonment.

2.2. Tephrochronology

A key feature of all the sites selected is the presence of dated tephra layers within the archaeological stratigraphy. Tephra layers are referred to by a letter denoting their volcanic origin, followed by the calendar year (AD) of the eruption; for instance H-1104 is tephra from the eruption of Hekla in AD 1104. In cases where the date of the eruption can only be estimated, the ~symbol is used and for dates that have a quantifiable error value, the ±symbol is used. The volcanic systems are E: Eldgja, H: Hekla, K: Katla, R: Reykjaneshryggur, V: Veiðiv€otn. The following tephra layers are most frequently used in dating Viking and Medieval Age deposits in Iceland:

V-871 ± 2 AD (Grönvold et al., 1995) and V-877 ± 4 AD (Zielinski et al., 1997).

K ~ 920 AD (Hafliðason et al., 1992).

E-934 ± 2 AD (Hammer et al., 1980) and E-938 ± 4 (Zielinski et al., 1995).

V ~ 930-940 AD (Sigurgeirsson et al., 2013).

H-1104 AD (þorarinsson, 1967).

H-1158 AD (þorarinsson, 1967).

R-1226 AD (Sigurgeirsson, 1995).

K-1500 AD (Hafliðason et al., 1992).

The presence of well-dated tephra within the archaeological stratigraphy is a major asset when building site chronologies. The tephras have different distributions, with the V-871 ± 2, H-1104 and K-1500 covering substantial parts of the country and appearing frequently at archaeological sites, while the others have a more limited distribution.

2.3. Radiocarbon dating and reservoir considerations

The selection of suitable material for radiocarbon dating is clearly crucial to the chronological interpretation. In the future it is hoped that Bayesian models will be used to inform sample selection (Bayliss, 2009) but in this case we had to rely on previously dated material. All radiocarbon dates considered were produced by AMS and obtained from known archaeological contexts within the stratigraphic sequence. Where possible, we prioritised short-lived, single-entity materials, such as single barley grains or human and animal bones, to avoid the possibility of mixed samples or the 'old wood' problem (Schiffer, 1986). There has been active debate about the validity of radiocarbon dates from birch charcoal, which has been shown to give consistently earlier dates than charred barley from the same context (Sveinbjörnsdottir et al., 2004). Given the uncertainties involved in interpreting dates from charcoal, this material was not used.

Dates from human and animal bone need particular consideration. It is well known that diet can affect the resulting radiocarbon determinations (e.g. Arneborg et al., 1999; Barrett et al., 2000). Carbon in the marine environment is depleted in radiocarbon, relative to that in the contemporaneous terrestrial environment, because of the extended residence time in the ocean while separated from atmospheric contact, during which ^{14}C undergoes radioactive decay. Hence, organisms in marine environments, such as marine fish, mammals and shellfish, will have an older apparent radiocarbon age. Inclusion of this material in human or animal diets can cause bones to appear several hundred years older than their true age. The extent of this effect can be assessed by using measurements of $\delta^{13}C$ as an indication of the percentage of marine contribution in the diet, having established values that would be expected for 100% terrestrial diet and 100% marine diet and performing linear interpolation between the two extreme values. The end points can be arrived at by either using measurements of local flora and fauna, taking appropriate account of fractionation, or by values directly measured from human/animal collagen from skeletons within the study area with extreme diets (Dewar and Pfeiffer, 2010). This study calculated the percentage of non-terrestrial carbon within the bone samples using the linear regression calculation of Ascough et al., 2012 (y ¼ 270.67 + 13.333x where x is δ^{13}C value and y is % marine contribution to diet). Which is based on δ^{13}C values of 20.3 to 22.1‰ for cattle bone collagen and values of 20.8-22.0‰ for caprines as the terrestrial samples and 12.4 to 14.7‰ for marine material (fish and seal bone) from sites in northern Iceland, with an adjustment of + 1‰ for tropic level shift (Ascough et al., 2012). The uncertainties arising in this data are discussed in Ascough et al., 2012.

When calibrating radiocarbon determinations where there has been a significant contribution from marine carbon, it is necessary to consider both the global average reservoir effect and site-specific deviations from it. The global average is provided by the calibration curve, in this case Marine13 (Reimer et al., 2013) and delta-R quantifies the site-specific deviations (Reimer et al., 2002). Delta-R has been shown to vary both spatially and temporally (Ascough et al., 2006; Russell et al., 2010). This study used a delta-R value of 111 ± 10^{14}C/year (Ascough et al., 2007) obtained from multiple paired measurements on terrestrial mammals and marine molluscs from Norse period archaeological deposits in northern Iceland. Both the selection of endpoints for marine and terrestrial diets and the value of delta-R are estimates made from the best available data, but further site-specific characterisation of these factors would be helpful. A further area of uncertainty in radiocarbon dating concerns the effects of freshwater reservoirs on bone collagen. It has been shown (Ascough et al., 2012) that human bone collagen can contain freshwater diet-derived carbon and that the freshwater radiocarbon reservoir effect in Iceland, partly arising from upwelling of geological age carbon from volcanic activity into freshwater lakes, can be both significant and variable (Ascough et al., 2011). It is not possible to correct for this effect with the data available at present, but it is important to recognise the potential complication.

Radiocarbon determinations were calibrated using OxCal Version 4.2.4 (Bronk Ramsey, 2009), with the calibration data sets Intcal13 and Marine13 (Reimer et al., 2013). Calibrated dates were rounded outwards to the nearest 5 years to avoid the impression of spurious precision.

2.4. The Bayesian approach

Bayesian analysis of radiocarbon dates from archaeological sites is becoming a routine tool (e.g. Bayliss et al., 2007; Whittle et al., 2011) and offers a powerful method of interpreting site chronologies. The principles are discussed in a number of detailed publications (e.g. Buck et al., 1991; Buck et al., 1994) and the reader is referred to these for further details. Bayesian statistical analysis derives posterior information by combining prior information, a likelihood function and the available data (Buck and Millard, 2004). In practical terms for most archaeological applications, this involves combining the probability distribution of radiocarbon determinations with archaeological information about their stratigraphic relationships or diagnostic artefacts to give more precise dates (Bayliss and Bronk Ramsey, 2004).

There are clear advantages to a statistical approach that combines archaeological and scientific dating evidence, both in interpreting existing data and in planning sampling strategies. Whilst concerns have been expressed about the use of prior information (Steier and Rom, 2000), in the applications described here the process simply formalises the existing archaeological information in a format that allows a variety of models and interpretations to be tested. For this study, the models were constructed using the Bayesian statistical tools available in OxCal v4.2.4 with the prior knowledge relating to the stratigraphic information established from site reports and discussions with the excavators. All of the dates and modelled estimates are presented at the 95.4% confidence level. The reader is referred to the OxCal supporting documentation for detailed discussion of the functions available. Within this investigation the most widely used models are a Phase, or unordered group, which was used to refer to multiple dates from the same archaeological context or from contexts that were stratigraphically equivalent. Sequence, or ordered group, was used to model archaeological contexts that had clear stratigraphic relationships. The OxCal program allows the user to develop different models that take into account factors such as the rate of deposition of a deposit (Bronk Ramsey, 2008). However, in the cases discussed here, anthropogenic activity is highly likely to have altered the rate of accumulation and so the more conservative 'Sequence' function was used to assess the dates with no assumptions made about rates of deposition.

The radiocarbon dates were incorporated into the models as RDates in their uncalibrated form. The tephra and, where relevant, artefact typological dates were introduced as calendar dates (CDates) with uncertainties as appropriate, plotted as a normally distributed range with a mean value and assessment of the error, cited at the 68% confidence level (1s) (Bronk Ramsey, 2012). Each Sequence was bracketed by a 'Boundary', which has often been cited as the most complicated aspect of Bayesian analysis, as the results are very sensitive to the assumed priors used for a Sequence (Steier and Rom, 2000; Steier et al., 2001; Bronk Ramsey, 2000). A conservative approach was employed with the use of Boundaries at points in the stratigraphy where the archaeological evidence suggested a hiatus in deposition, as discussed on a case by case basis. As suggested by Bronk Ramsey (2000) a number of Sequences were assessed for each dataset with a series of different Boundaries being applied in order to determine the potential sensitivity of a Sequence. If the results of the sensitivity analysis were similar for the different Sequences, it was concluded that the Sequences were robust. The assessment of the dates in Sequence resulted in a probability distribution that demonstrated how the age ranges were affected by the inclusion of the stratigraphic information; the resulting probability distribution is referred to as a posterior density estimate. The modelled estimates have been given in italics when discussed within the text to differentiate them from the raw calibrated age ranges. The 'agreement index' value (A-values) quantifies the degree to which the data support the proposed model and are calculated for the posterior distributions of each date in the model and for the overall model itself (Bronk Ramsey, 2000). The critical value defined for the agreement indices is set at 60%: values below this level were indicative of problems within the Sequence and may indicate the presence of residual or intrusive material or errors in the stratigraphic interpretation (Bronk Ramsey, 2012). If dates were highlighted as being anomalous, the security of the material and the context were reassessed using the site records.

Inclusion of stratigraphic information can refine the resulting age ranges through the production of posterior density estimates, but it is important to note that the resulting age ranges are the result of a statistical model imposed on the data and the interpretation of the stratigraphy. They present one particular view of the past; any new information, such as additional dating evidence or changes in the interpretation of the stratigraphic record will produce different outcomes.

3. Results

3.1. Aðalstræti

Archaeological excavations were carried out between 1971 and 1975 in the centre of Reykjavik (Nordahl, 1988). They revealed the remains of a number of structures, dating both to the settlement period and to the 18the19th centuries. The area was reinvestigated in 2001 and 2003 with improved excavation methods (Roberts et al., 2001, 2003; Snæsdottir, 2007). The new investigations uncovered exceptionally well-preserved remains of a Viking period hall, which was altered with an annexed hall to the south-west and with a porch on the eastern side of its northern end (Fig. 2a). Approximately four meters to the north-east of the hall, a fragmentary wall was found, abutted by the *Landnam* tephra in situ, representing the earliest known archaeological remains in Iceland. The dating of the construction and abandonment of this key early structure is significant in understanding the first settlement of Reykjavik and the specific research objective was to obtain precise dates for these events.

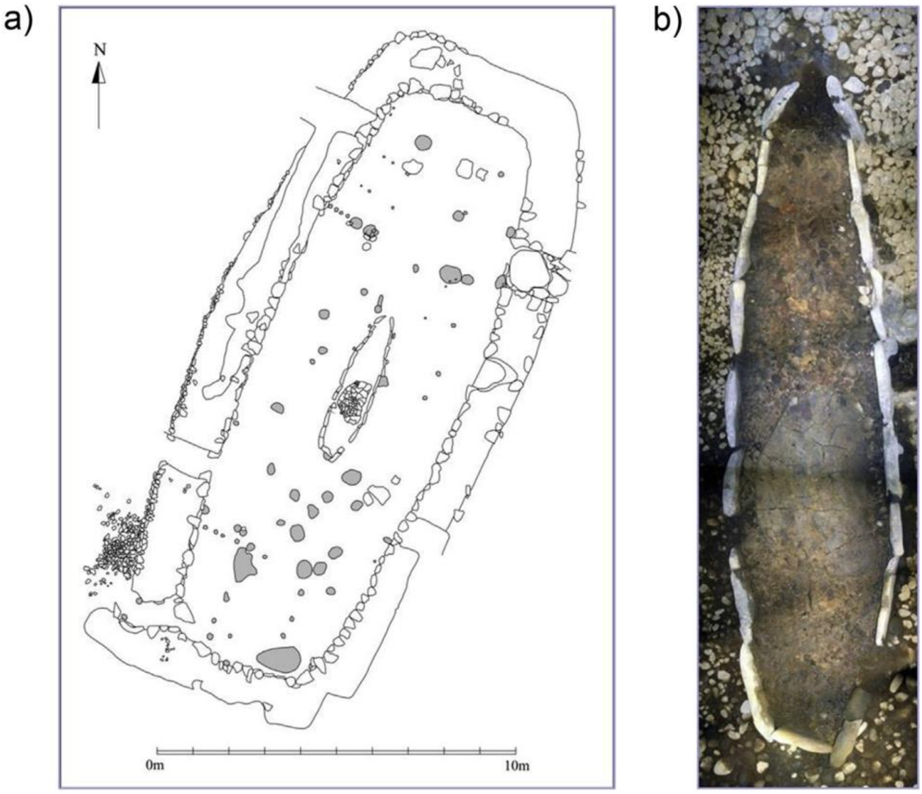


Fig. 2. (a) Plan of Aðalstræti Hall after Roberts et al., 2003 and (b) photograph of central hearth from archive of FSI, Institute of Archaeology, Reykjavík.

The stratigraphy of the site is straightforward. The bottom layer consists of an old sea-bed made of pebbles. The *Landnam* tephra is in situ overlying the pebbles, followed by a thin (1e8 cm) accumulation of soil, underlying the foundation of the hall. A sequence of three distinct floor layers are preserved in the middle of the hall and four deposits within the central hearth (Fig. 2b), all of which have provided samples for radiocarbon dating. Turf from the walls and roof are collapsed on top of the floor layers, followed by a ~57 cm thick fluvial/aeolian accumulation, which is sealed by the K-1500 tephra in situ. There are no traces of repair found within the hall; the only clear constructional phases are the later addition of the porch and annexed hall (Milek and Roberts, 2013). Since secure radiocarbon dates have not been obtained from the added structures, nor from the fragmentary wall that is stratigraphically below the *Landnam* tephra, it is not possible to consider these elements.

The accumulation of deposits below and above the cultural remains at Aðalstræti was measured by Roberts and Schmid in 2013 in order to date the occupation and abandonment of the site more precisely. The soil accumulation between the *Landnam* tephra in situ and foundations of the hall is between 1 and 3 cm on the eastern side and between 3 and 8 cm on the western side. The accumulation varies because the hall, facing NE, was constructed at the bottom of a steep slope starting on the western side of the hall; thus, the soil was deposited through fluvial processes and accumulated at a faster rate than aeolian deposits would do. In total 78 cm of soil was deposited between the *Landnam* and K-1500 tephra in situ. If we assume that soil accumulated at a constant rate, we have an average of 1.24 mm/year, suggesting that the time elapsed between the *Landnam* tephra and the construction of the hall could have been between 12 and 99 years with an average of 37 years. However, the gap between the two tephra layers is large and we cannot assume that soil accumulated at a constant rate. Calculation of accumulation rates would be more easily justified if a tenth century tephra had been identified but unfortunately hardly any tenth century tephras survive in the Reykjavík area. Sediment accumulation rates have been calculated for sediments in the pond in Reykjavík centre, where Hallsdottir (1987) claims a yearly deposit of 1.3 mm, very similar to the rate obtained in this study.

It has been suggested by Roberts that the use of the hall dates between the late ninth and the end of the tenth centuries, based on house typology and radiocarbon dates (Roberts et al., 2003). Focussing on the soil accumulation rates, especially the contrast with the meagre pre-871 accumulation, Vesteinsson has argued for a start of occupation around or after AD 930 (2014: 86e87). Artefactual evidence discussed by Milek and Roberts (2013) suggests a tenth century occupation of the hall, in particular based on datable artefacts from the floor of the house, including a polychrome glass bead (Callmer Type B610; Callmer, 1977) and a possible glass vessel fragment with ‘grape’ decoration, which have a late ninth to tenth century date range.

The chronological model for Aðalstræti is based on seven AMS radiocarbon dates for barley seeds and the *Landnam* tephra (Table 1). The tephra provides a terminus post quem for the site and the main event of interest (Boundary Start occupation) occurs between this tephra and the floor and hearth sequences. Four stratigraphically related horizons within the long fire and three stratigraphically related floor layers form two Sequences above the tephra (Fig. 3). The exact relationship between the hearth and floor layers is not known; therefore the Sequences are placed into the same Phase. The K-1500 tephra is not incorporated in the model because it occurs significantly later than the other dated events, following major sediment deposition, and its inclusion does not affect the model outcomes. The model (Fig. 4a) appears consistent with the archaeological evidence, with an overall agreement index of 103% for the proposed model and all individual dates have agreement indices >60%. The modelled date for earliest occupation of the hall (Boundary Start occupation) is AD 865-890. The modelled date for the top of the Sequence (Boundary End occupation stage) is AD 890-1020.

Archaeological structure/deposit & context	Context number	Context description	Sample number	Sample material	Conventional ^{14}C age (BP)	δ^{13}C Prior 2-σ cal range	Modelled 2-σ cal range
Hall, long fire	793	Upper fill	AAR-7611	Barley	1092 ± 39	-25.63 780e1025	890e990
Hall, long fire	795	Lower-upper fill	AAR-7612	Barley	1150 ± 36	-23.94 775e975	885e965
Hall, long fire	802	Upper-lower fill	AAR-7613	Barley	σ1087 ± 35	-25 890e1020	875e950
Hall, long fire	831	Bottom fill	AAR-7614	Barley	1218 ± 40	-25.90 680e895	865e935
Hall, floor layer	858	Floor deposit north of long fire	AAR-7615	Barley	1153 ± 36	-25.21 775e975	885e975
Hall, floor layer	864	Upper floor deposit west of long fire	AAR-7616	Barley	1129 ± 35	-24.32 775e990	875e955
Hall, floor layer	873	Lower floor deposit west of long fire	AAR-7617	Barley	1152 ± 36	-23.42 775e975	870e935

Table 1 - Radiocarbon dates from Aðalstræti floor and hearth sequence.

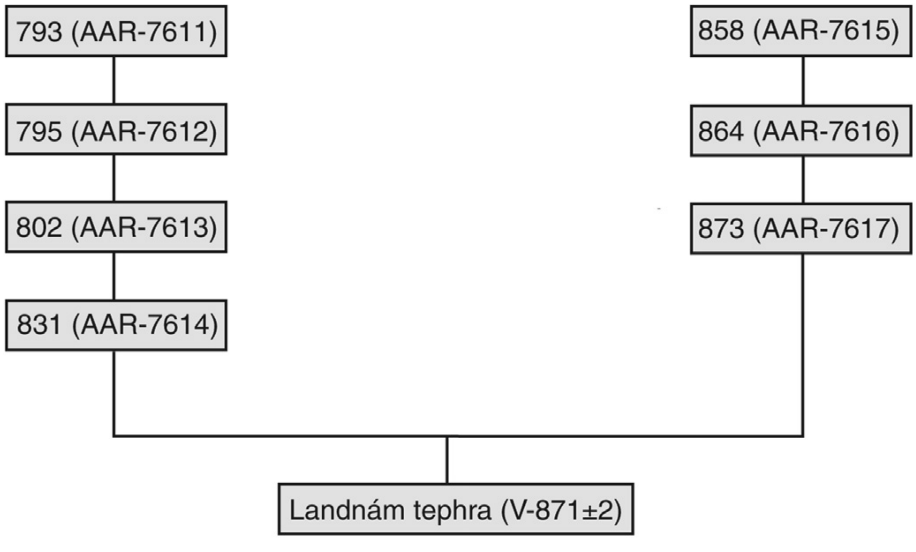


Fig. 3. Sequence of deposits at Aðalstræti Hall showing relationship of AMS ^{14}C samples.

The constrained dates of the model propose that the hall was occupied by AD 890, indicating that construction was within a few years of the deposition of the Landnam tephra, making this hall one of the earliest dwelling sites in south-west Iceland. This would lend support to Roberts' early date for the first occupation (Roberts et al., 2003) and would suggest a rapid (c. 20 year) accumulation of soil between the Landnam tephra and the first occupation. Radiocarbon dates from within the soil accumulation would allow more detailed modelling of the rate of accumulation, as demonstrated in Eyjafjallahreppur, southern Iceland by Church et al. (2007).

The abandonment of the site is more difficult to establish. If the uppermost dated archaeological horizons represent the last occupation of the site, this would suggest that the site was abandoned by AD 1020. This would also concur with the timescale proposed by Roberts (et al., 2003). However, caution must be exercised with this archaeological interpretation, as the radiocarbon samples are restricted to hearths and floor surfaces. It has been suggested by Milek that therewere steady accumulations of floor deposits within the house and therefore that floors were continuously shovelled out, leaving behind discontinuous floor sequences that cannot be used to infer the intensity or duration of the occupation of a building (Milek, 2012: 133). Thus, the radiocarbon dates may not capture the earliest deposits or the final phases of use. Conversely, context 831 might represent an early hearth deposit that had not been cleared out, with the later deposits coming from the final occupation. To capture the full lifetime of the building further radiocarbon samples are needed, particularly from the underlying soil accumulation and the porch and annexe. The constrained radiocarbon dates of the floor and hearth deposits at Aðalstræti suggest that the hall was in use for no more than 150 years and possibly considerably less.

Bayesian models can also either incorporate established artefact typologies or be used to test them. At Aðalstræti there is a typologically distinctive polychrome glass bead (Callmer Type B610) in context 864, traditionally dated to AD 860- AD 950 AD (Callmer, 1977). This can be incorporated into the model as a C-Date (Fig. 4b). The date of the bead is in good agreement with the radiocarbon date from the same context (AAR-7616) and yields a slightly reduced date for the context of AD 875e950. The inclusion of the bead on this occasion makes a slight improvement to the precision of the date of the first occupation; if the typological dates were more precise, or the other dating evidence was less constrained, the information provided by the bead would be more significant. It should be stressed that bead typology is problematic; there are no independent scientific dates and the typology is based on the co-occurrence of objects such as oval brooches decorated in Viking Age animal styles and datable coins. These dates provide a terminus post quem, however there is often no clear link between the date obtained and the bead in question and assumptions must be made about the period of possible circulation. Given these difficulties the fact that the typological date fits well within the chronological model is extremely interesting and lends some support to the reliability of the typological date. There is clear potential for the further investigation of bead typologies using these methods.

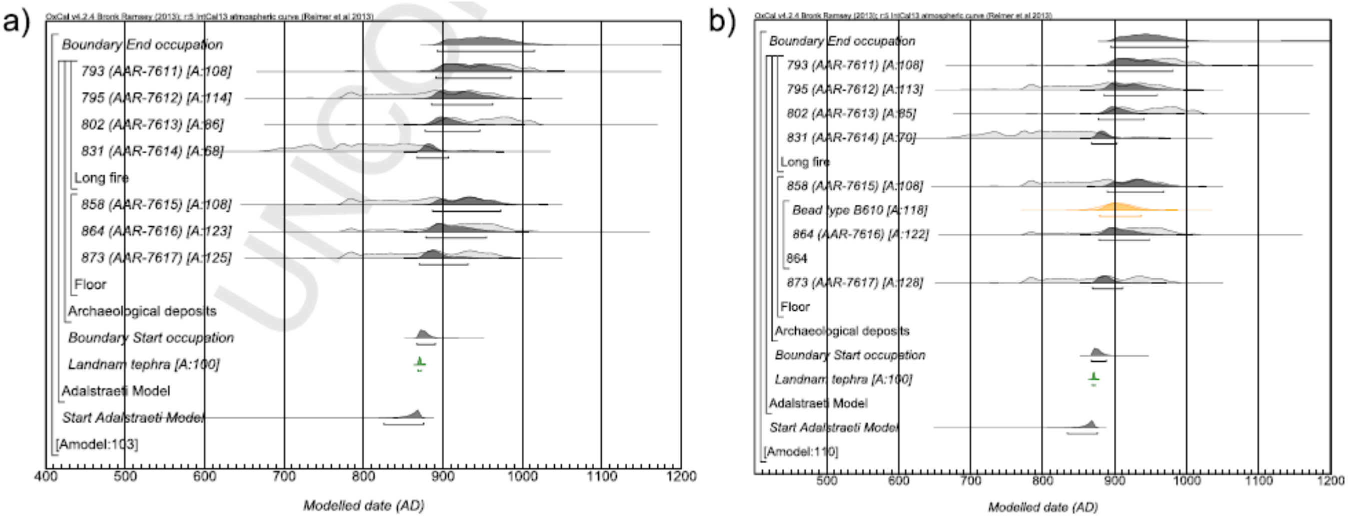


Fig. 4. a Modelled calibrated dates from deposits within Aðalstræti Hall. Radiocarbon dates in black, tephra dates in green. b Modelled calibrated dates from deposits within Aðalstræti Hall including typologically dated bead. Radiocarbon dates in black, tephra dates in green, bead date in orange. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

3.2. Hofstaðir

The site of Hofstaðir lies in the Laxa valley in the district of Mývatn in northern Iceland (Fig. 1). Comprehensive large-scale excavations were carried out between 1991 and 2002 (Lucas, 2009). A series of structures are dated to the Viking period (Fig. 5); a hall [AB] with a porch and three annexes [A2, C2 and D1], a pit house [G], two sunken floored buildings [A4, A5] and a latrine [E2]. Little activity in this part of the site is documented in the medieval and later periods. The stratigraphy at the site is complex; however, the dates are constrained as many of the cultural layers are located between two tephra layers: the recently dated V~930-940 (Sigurgeirsson et al., 2013) and H-1104 (þorarinsson, 1967). The hall has at least two structural phases; the construction of the hall itself and the later addition of three annexes and a porch. It is suggested by Lucas (2009: 57) that the site can be divided into three phases of Viking age structures. The first phase includes the pit house [G], the hall [AB] and one sunken feature [A5]; the second phase includes the enlargement of the hall, its annexes [A2, C2, D1], another sunken feature [A4] and latrine [E2]; the third phase includes the collapse of the structures and some reuse as hay storage. Lucas's interpretation of the site development (Lucas, 2009: 57) suggests that the pit house [G] was abandoned before the hall and its annexes, and he dates the abandonment of the site between AD 1030 and 1070 (Lucas, 2009: 57, 165). One key challenge to understanding the chronology of this site is that there are large, open spaces between most of the structures, and connecting layers are thin or discontinuous, particularly between the hall and pit house, making it difficult to establish a secure overall site stratigraphy.

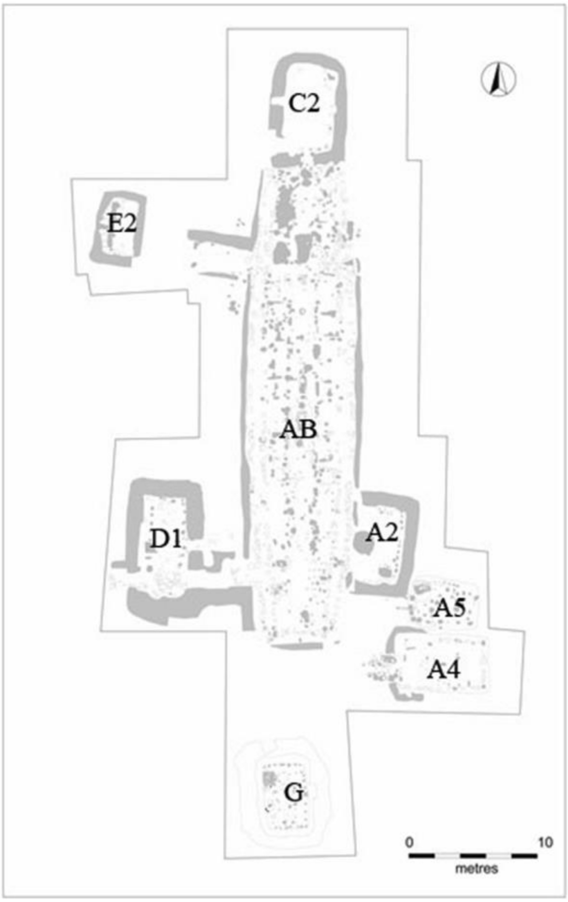


Fig. 5. Site plan of Hofstaðir showing structures and deposits discussed in text. After Lucas and McGovern, 2008; based on original drawing produced by Gavin Lucas/For-nleifafstofnun Islands.

Hofstaðir represents a much more complex archaeological example than Aðalstræti, with several phases of activity. It has the advantage of multiple radiocarbon dates, but the drawback of complex and sometimes unresolved stratigraphic relationships. Given these considerations, the analysis in this study focussed on two particular groups of dates; those associated with the abandonment of the pit house [G] (Table 2a) and those associated with the abandonment of the hall [AB] and its annexe [A2] (Table 2b). Areas D1 and E2 could not be stratigraphically related and were excluded from the analysis.

The chronological models for Hofstaðir are based on 23 AMS radiocarbon dates from animal bone collagen (Tables 2a and 2b) and the two tephra layers. Two of the radiocarbon dates (SUERC-3431 and SUERC-8352) appear to show reservoir effects based on measurements of δ^{13}C and appropriate corrections were applied as discussed above. Given that the dates were obtained from cattle and sheep/goat such values seem unusual, particularly the value of -15.7‰ for SUERC-8352. This may indicate a marine input into the animals' diet (Balasse et al., 2005). Although the site is far from the sea, isotopic work (Sayle et al., 2013) suggests that domestic animals from Mývatn may have been grazing on the coast. It is unlikely that the values are due to neonatal dietary effect, as such effects are usually much smaller but future measurements of nitrogen isotope values might clarify the situation further.

The V ~ 930-940 tephra provides a terminus post quem of the pit house Sequence (Fig. 6a). A single date from a cattle bone (Beta-149404) is associated with the collapse of the pit house, overlain by a series of stratigraphically related midden accumulations (contexts 7a, 6n, 6g, 6d and 4). The stratigraphy provides a Sequence for the Bayesian model; multiple radiocarbon determinations within a single archaeological context were modelled as a Phase (Fig. 7a). There is one radiocarbon determination (SUERC-3431) which has a poor agreement with the proposed model, in the late midden deposit. This may represent later intrusive material, but it should be noted that this was one of the samples with an unusual $\delta^{13}C$ value, which leads to uncertainty about the reliability of the determination. If this radiocarbon determination is omitted from analysis, the model is consistent with the archaeological evidence, with an overall agreement of 71%. SUERC-3433 and Beta-124004, both have individual agreement indices slightly <60%; however, repeating the model without them makes little difference to the overall outcomes. The variation may reflect the mixed nature of material within midden deposits. The specific event of interest is the abandonment of the pit house (context 8) and the date for this is constrained by the model to AD 925-945. The Bayesian model thus suggests that the pit house was only in use for a short time, between AD 930 (the earliest date for the underlying tephra) and AD 945 (the latest date for the overlying turf collapse). This is consistent with the archaeological evidence, but it should be noted that there is only one sample directly taken from the turf collapse. The model also shows that the early and late midden layers on top of the turf collapse accumulated before AD 1030 (Boundary End pit house infilling). Unfortunately there is no overlying tephra on this part of the site to constrain the later dates further.

The stratigraphic sequence for hall AB is also underlain by the V ~ 930-940 tephra (Fig. 6b). Three radiocarbon dates are associated with the floor layers and a pit infill within hall AB (Table 2b). These have no stratigraphic relationship to each other and therefore comprise a Phase in the model. The hall was altered with an annexe [A2] added at a later stage and two dates derive from the immediate backfill of that annexe, overlain by a stratigraphically related sequence of peat and ash dumps. The H-1104 overlies the entire Sequence and a Boundary is inserted between the dates for the peat and ash dumps and this tephra, to allow for the possibility of a hiatus in deposition. There are two radiocarbon determinations that show poor agreement with the proposed model (Fig. 7b). SUERC-8352 presents a similar case to SUERC-3431 discussed above and may be later intrusive material but also has an unusual $\delta^{13}C$ value. SUERC-6397, a cattle bone, appears to be too early for its position within the stratigraphic sequence. This bone (along with SUERC-6398 and 6399) was within the turf collapse of A2 and could be residual; the same context [0159] contained both parts of an articulated sheep and weathered cattle skulls which are thought to have hung on the outside of the building, and the latter may have already been old when they were deposited in the abandoned building, possibly as a part of an abandonment ritual (Lucas, 2009: 236-52). If SUERC-8352 and SUERC-6397 are omitted from the model, the model agreement is excellent, 117%. The archaeological event of interest in this case is the end of the abandonment of the complex (Boundary Abandonment) and this sequence of dates suggests that both the hall and annexe were abandoned by AD 1015-1095, in agreement with Lucas's proposed dates for abandonment of the site between AD 1030 and 1070 (Lucas, 2009: 57, 165). The constrained dates allow for the possibility of abandonment of the hall as early as AD 1015 but other interpretations are possible. The latest date for the turf collapse of the annex A2 (context 159) is AD 1005 suggesting it was abandoned before the hall, supporting Lucas's interpretation of the site development (Lucas, 2009: 57).

Table 2a

Radiocarbon dates from Hofstaðir pit house G. Calibrated radiocarbon dates differ from those in Lucas (2009) as a more recent calibration curve is used and the full 95.4% confidence range is included.

Archaeological structure/ deposit & context	Context number	Context description	Sample number	Sample material	Conventional ^{14}C age (BP)	δ^{13}C	% Marine contribution to diet	Prior 2-σ cal range	Modelled 2-σ cal range
Pit house G, midden	4	Late infill	Beta-149403	Cow bone	1120 ± 40	-21.7	NA	775-1015	945-1015
Pit house G, midden	6d	Late infill	SUERC-3431	Cow bone (neonatal)	1045 ± 35	-18.8	20.1	990-1215	Omitted
Pit house G, midden	6d	Late infill	SUERC-3432	Pig bone (adult)	1040 ± 40	-21.5	NA	890-1120	940-1010
Pit house G, midden	6g	Late infill	SUERC-3433	Cow bone	1030 ± 35	-21.1	NA	895-1150	940-1005
Pit house G, midden	6n	Early infill	SUERC-8624	Cow bone (adult)	1080 ± 35	-21.2	NA	890-1020	935-990
Pit house G, midden	6n	Early infill	SUERC-8618	Cow bone (adult)	1110 ± 40	-21.0	NA	775-1020	935-985
Pit house G, midden	6n	Early infill	SUERC-8619	Cow bone (adult)	1110 ± 30	-20.9	NA	875-1015	935-985
Pit house G, midden	6n	Early infill	SUERC-8623	Cow bone (adult)	1130 ± 35	-21.1	NA	775-990	935-980
Pit house G, midden	6n	Early infill	Beta-124004	Cow bone	1170 ± 40	-21.4	NA	730-975	935-980
Pit house G, midden	7a	Early infill	SUERC-3429	Cow bone (neonatal)	1160 ± 35	-21.2	NA	770-970	930-960
Pit house G, midden	7a	Early infill	SUERC-3430	Pig bone (adult)	1170 ± 40	-20.8	NA	730-975	930-960
Pit house G, collapse	8	Primary collapse of pit house	Beta-149404	Cow bone	1130 ± 40	-21.5	NA	775-990	925-945

The modelled dates are very similar to the archaeologically proposed ranges, so they offer support but little additional insight into the abandonment of the site. They do suggest a much tighter and decidedly early date for the abandonment of pit house [G]. For additional precision it would be helpful to be able to stratigraphically relate dated contexts from other parts of the site. It would also be useful to obtain dates for plant material within the middens to further explore issues of residuality and gain insight into the reservoir effects that may be affecting the dating of some animal bone.

3.3. Sveigakot

The farm at Sveigakot is close to Hofstaðir and Lake Mývatn in northern Iceland (Fig. 1). Comprehensive large scale excavations were carried out between 1998 and 2006 (Vesteinsson, 2010). The farm is divided into several areas: M, P, S, T and intersections MT and MP (Fig. 8). There is one central midden area [M] with several structures to the north [P1-3, MP 1e3] and south-west [MT1-2, T]. Another midden deposit [T] accumulated within the abandoned pit house [T1]. North of the structures P1-3 is a byre [S7] with associated pavements [N] and [SP]. North of and above S7 a hall was built [S4] with an associated outdoor activity area [S6]. The site was briefly abandoned and then a smaller hall [S1] with annexes [S3, S5] was constructed above [S4].

Table 2b

Radiocarbon dates from Hofstaðir Hall AB and Annexe A2.

Archaeological structure/deposit & context	Context number	Context description	Sample number	Sample material	Conventional ^{14}C age (BP)	δ^{13}C	% Marine contribution to diet	Prior 2-σ cal range	Modelled 2-σ cal range
Hall, annexe A2, collapse	159	Turf collapse	SUERC-6399	Cow bone	1015 ± 35	-21.2	NA	900-1155	1000-1050
Hall, annexe A2, collapse	159	Turf collapse	SUERC-6398	Cow bone	1035 ± 35	-21.2	NA	895-1120	1000-1040
Hall, annexe A2, collapse	159	Turf collapse	SUERC-6397	Cow bone	1110 ± 35	-21.0	NA	775-1020	Omitted
Hall, annexe A2, midden	170	Peat and ash dump	SUERC-8360	Sheep/caprine bone	1050 ± 35	-21.4	NA	895-1035	995-1030
Hall, annexe A2, midden	213	Peat and ash dump	SUERC-8352	Sheep/caprine bone	1035 ± 35	-15.7	61.4	1170-1395	Omitted
Hall, annexe A2, midden	233	Peat and ash dump	SUERC-8353	Sheep/caprine bone (adult)	990 ± 35	-21.6	NA	985-1155	990-1025
Hall, annexe A2, infill	254	Backfill of barrel pit	SUERC-8354	Sheep/caprine bone (adult)	1035 ± 35	-21.4	NA	895-1120	980-1020
Hall, annexe A2, infill	254	Backfill of barrel pit	SUERC-8356	Sheep bone (adult)	1040 ± 35	-21.8	NA	895-1040	975-1020
Hall AB, infill	2428	Pit infill	SUERC-11541	Caprine bone (adult)	1030 ± 35	-21.3	NA	895-1150	945-1010
Hall AB, floor	448	Lower floor layer	SUERC-11542	Sheep bone (adult)	1040 ± 35	-20.8	NA	895-1040	940-1005
Hall AB, floor	1480	Lower floor layer	SUERC-11546	Sheep bone (adult)	1075 ± 35	-20.9	NA	890-1020	935-1000

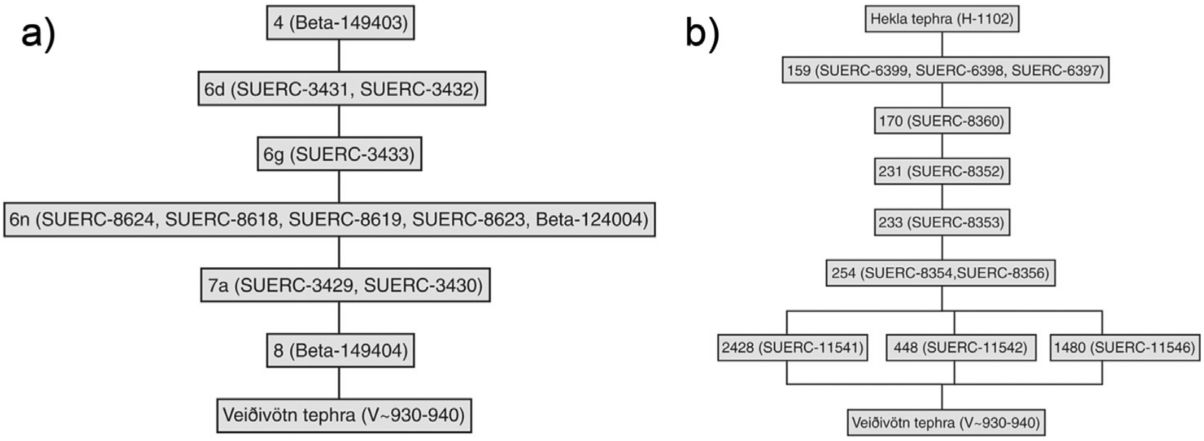


Fig. 6. a Sequence of deposits at pit house G at Hofstaðir showing relationship of AMS ^{14}C samples. b Sequence of deposits for Hall AB and Annexe A2 at Hofstaðir showing relationship of AMS ^{14}C samples.

The stratigraphy at the site is complex and discontinuous, due to erosion of the substrata. This means that there are no overall linking deposits and it is not possible to create a site-wide stratigraphic sequence, despite comprehensive excavation. Tephra layers are the prime connection between different areas of the site and key to interpretation of the stratigraphy. There are two tephra layers in situ: the *Landnam* tephra and V ~ 930-940 tephra, no other tephra layers have been detected and even these two tephra are not present in every sequence. In area M, midden has accumulated below and above the in situ tenth century tephra. The *Landnam* tephra and V ~ 930e940 tephra lie in situ under the turf wall on the south side of S4 giving the structure its terminus post quem (Vesteinsson, 2003: 18e19). After a brief period of abandonment and the partial collapse of the hall S4, a new hall S1 was built in its ruins, making use of some elements of the earlier building. S5 and S3 are interpreted as annexes to S1 but the stratigraphic relationships are ambiguous. Some structures (P1 and S7 in particular) are clearly built and abandoned before the deposition of the V ~ 930-940 tephra. Because of the relatively tight dating provided by the tephras these structures were not prioritized for selection of radiocarbon samples. Vesteinsson (2010; also Vesteinsson and McGovern, 2012: 211e212) has proposed that the site was occupied shortly after the deposition of the *Landnam* tephra, probably in the AD 880s; it was briefly abandoned in the eleventh century and, following possibly intermittent use as a shieling, the site was reoccupied for a while, possibly to as late as around AD1200.

The discontinuous nature of the stratigraphic record makes it necessary to construct four short sequences (Fig. 9aed), reflecting the different areas of the site. As with the example of Hofstaðir, the complexity of the site stratigraphy makes it necessary to focus on specific questions. In this case focus is placed on the first occupation of the site and the date of the proposed brief period of abandonment associated with the disuse of the hall S4.

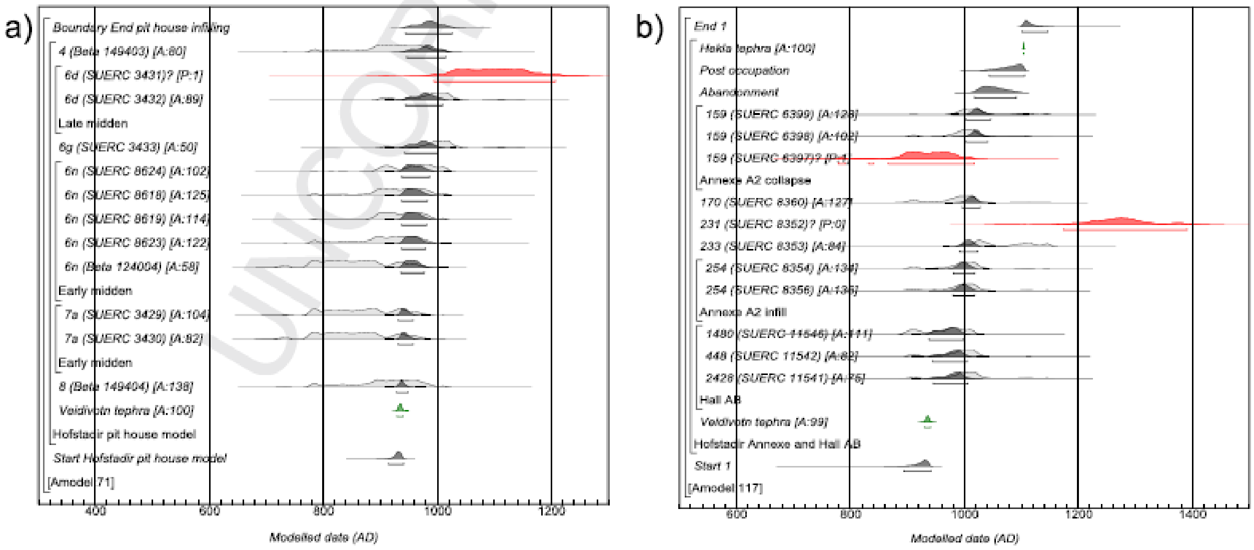


Fig. 7. a Modelled calibrated dates from deposits associated with pit house G at Hofstaðir. Radiocarbon dates in black, tephra dates in green, anomalous result indicted in red. b Modelled calibrated dates from deposits associated with Hall AB and Annexe A2 at Hofstaðir. Radiocarbon dates in black, tephra dates in green, anomalous results indicted in red. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

There are 21 relevant radiocarbon determinations, predominantly from animal bone (Table 3). In one case (Beta-134145) the d13C value of a sheep bone suggested a marine input into the diet and an appropriate correction was made for samples. Seven dates from three stratigraphically related structures (MT, T1 and T2) are shown in Fig. 10a, a short sequence of three dates from the midden deposits (area M) with two associated tephra are given in Fig. 10b. Five dates from MP1 and MP3 are shown in Fig. 10c and six dates from structures S1, S4 and S5 are given in Fig. 10d. In all cases there is good agreement with the archaeological model but, because these are all short sequences with a small number of dates, the impact on calibrated date ranges is limited.

The model including structures MT, T1 and T2 shows excellent agreement for all samples (Fig. 10a). This model indicates that the key date of the final infilling of the pit house T1 (Boundary End 1) is AD 990e1080 with the start of T1 (Context 889) at AD 945-995 indicating a short period of occupation. The area M midden sequence (Fig. 10b) also fits the model well, including the reservoir-corrected sheep bone, giving confidence in the correction protocol. The middens date to between AD 875 and AD 1095. The boundary at the bottom of the sequence indicates that the earliest date for occupation of the site is AD 875, which matches well with the date proposed by Vesteinsson (2010). The sequence including MP1 and MP3 (Fig. 10c) shows good overall agreement. There is one date with a low agreement index (SUERC-28652) but, given that the deposit is a mixed fill which might contain material from a number of sources, all the data were retained within the model. Boundary End 1 indicates that structure MP1 was out of use by AD 900-1045. Fig. 10d shows the modelled dates for structures S1, S4 and S5 and the earliest date in the sequence, the occupation of S4 (Context 989) is constrained to AD 940-1020, with the end of the occupation sequence being AD 1065-1355, which again matches well with the last occupation suggested by Vesteinsson (2010). There would appear to be a hiatus in occupation around AD 1020, again supporting the archaeological inferences of Vesteinsson. S1 and S5 would appear to be occupied contemporaneously, within the precision of the available dates. Unfortunately there are no radiocarbon dates from S3, making it impossible to incorporate it into the model.

The sequences discussed provide some improved precision to the archaeological dating but their impact is reduced by the fact that the sequences are short and therefore the number of dates is small. However, rather than using the stratigraphic information to constrain the dates, it is also possible to postulate a number of models and use the statistical analysis to indicate which is the most likely sequence of events. For example, a key archaeological question is the relationship between the sequences in MP, the midden in T and the MT sequence. The radiocarbon dates suggest that MP1 (which is later than MP3) predates MT and T. When this possibility is modelled (Fig. 10e) the agreement with the model is excellent (108%), whereas if MP1 is modelled as coming after MT and T the agreement is very poor (5%), indicating that this is very unlikely. Hence, the model can be used to suggest that MP1 predates T and MT. If this model is correct then the levelling layer for pit house MT (Context 1602) dates to AD 915-970 rather than AD 900-995, as suggested by Fig. 10c. This would support the proposition that pit house MT was in use when the V~930-940 tephra fell, explaining why the tephra was only found around the structure but not on top or below the deposits associated with it. The similarity of the archaeological dates means that the midden in T cannot be temporally separated from the midden inMor structures S1, S4 and S5. It is also not possible to identify which parts of the MP and MT sequences are contemporary with the upper and lower midden as the dates are too close. The dates suggest that the upper midden is contemporary with S4 and the last use of MT, within the precision of the dates available.

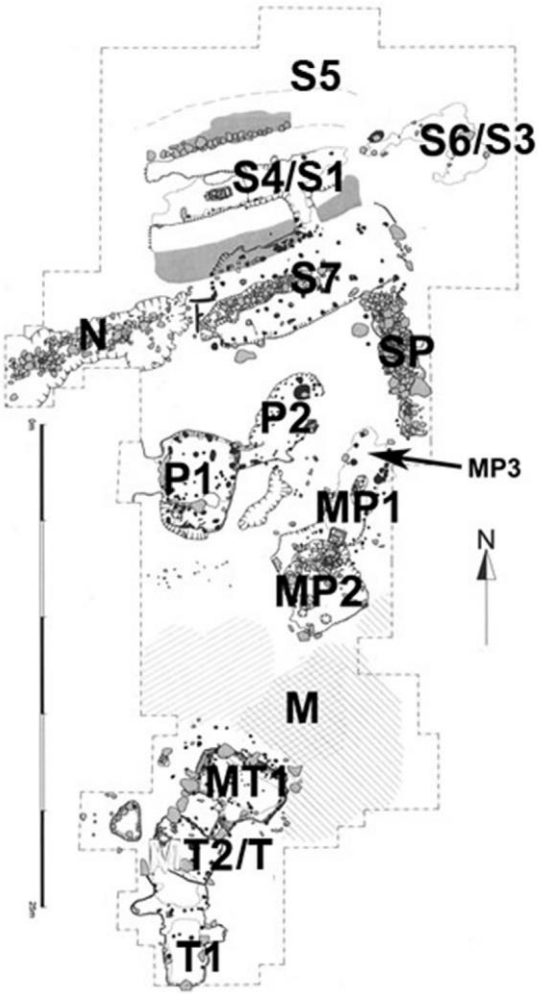


Fig. 8. Site plan of Sveigakot showing structures and deposits discussed in text.

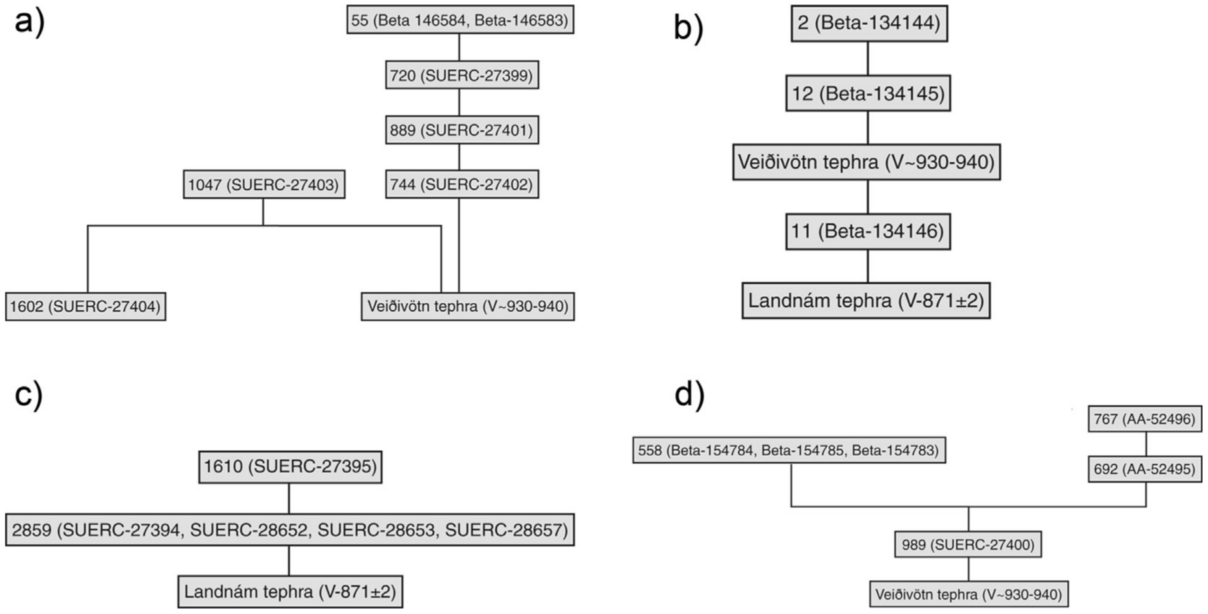


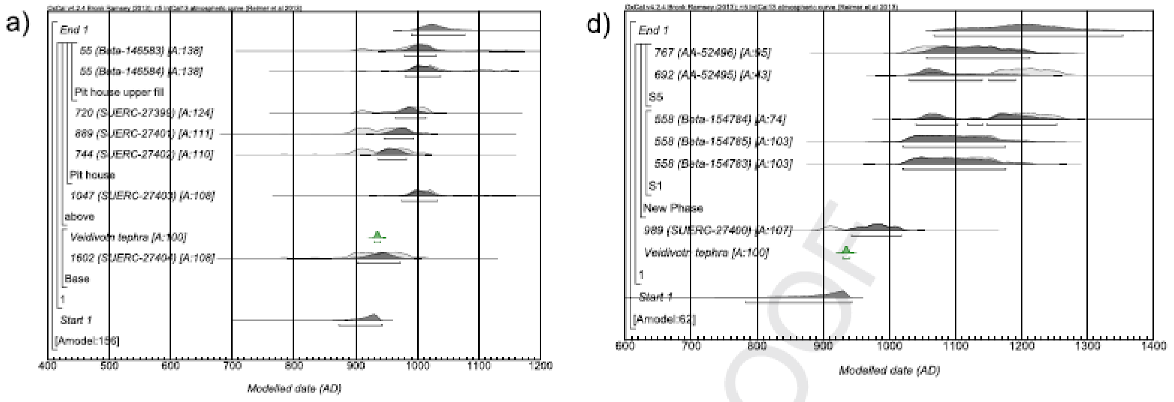
Fig. 9. a Sequence of deposits associated with MT, T1 and T2 at Sveigakot showing relationship of AMS ^{14}C samples. b Sequence of deposits associated with area M midden at Sveigakot showing relationship of AMS ^{14}C samples. c Sequence of deposits associated with MP1 and MP3 at Sveigakot showing relationship of AMS ^{14}C samples. d Sequence of deposits associated with S1, S4 and S5 at Sveigakot showing relationship of AMS ^{14}C samples.

Archaeological structure/deposit & context	Context number	Context description	Sample number	Sample material	Conventional ^{14}C age (BP)	δ^{13}C	% Marine contribution to diet	Prior 2-σ cal range	Modelled 2-σ cal range
Pit house T, midden	55	Upper fill of pit house	Beta 146583	Cow bone	1040 ± 40	-22.7	NA	890-1120	975-1030
Pit house T, midden	55	Upper fill of pit house	Beta 146584	Cow bone	1010 ± 40	-21.5	NA	900-1155	980-1040
Pit house T	720	End of house I	SUERC 27399	Cow bone	1060 ± 30	-20.8	NA	895-1025	960-1015
Pit house T	889	Start of house I	SUERC 27401	Sheep bone	1100 ± 30	-21.2	NA	885-1015	945-995
Pit house T	744	Layer outside house II	SUERC 27402	Cow bone	1095 ± 30	-21.1	NA	890-1015	935-985
Area M/T	1047	Wall of house II	SUERC 27403	Caprine?	1015 ± 30	-20.9	NA	970-1150	970-1035
Area M/T	1602	Levelling layer	SUERC 27404	Cow bone?	1110 ± 30	-21.2	NA	875-1015	900-975
Midden M	2	Upper midden	Beta 134144	Cow bone	1120 ± 40	-21.0	NA	775-1015	935-1010
Midden M	12	Upper midden	Beta 134145	Sheep bone	1090 ± 40	-19.3	13.4	885-1160	930-990
Midden M	11	Lower midden	Beta 134146	Cow bone	1110 ± 40	-21.0	NA	775-1020	875-940
Structure MP1, floor	1610	Floor layer	SUERC 27395	Cow bone	1105 ± 30	-21.0	NA	880-1015	895-995
Structure MP3, infill	2859	Fill of structure	SUERC 28657	Burnt bark	1105 ± 35	-27.9	NA	775-1020	875-970
Structure MP3, infill	2859	Fill of structure	SUERC 27394	Pig bone	1210 ± 35	-20.1	NA	685-940	865-945
Structure MP3, infill	2859	Fill of structure	SUERC 28652	Cow bone	1050 ± 35	-21.8	NA	895-1035	885-985
Structure MP3, infill	2859	Fill of structure	SUERC 28653	Sheep bone	1090 ± 35	-21.3	NA	885-1020	880-975
Structure S5, midden	767	Upper midden fill	AA 52496	Cow bone	920 ± 40	-21.5	NA	1025-1210	1055-1215
Structure S5, midden	692	Upper midden fill	AA 52495	Cow bone	840 ± 45	-20.7	NA	1045-1275	1030-1190
Structure S1, floor	558	Upper floor layer	Beta 154784	Cow bone	840 ± 40	-21.1	NA	1045-1270	1040-1255
Structure S1, floor	558	Upper floor layer	Beta 154785	Caprine bone	930 ± 40	-21.4	NA	1020-1190	1020-1175
Structure S1, floor	558	Upper floor layer	Beta 154783	Cow bone	930 ± 40	-21.4	NA	1020-1190	1020-1180
Structure S4	989	Occupation deposit, southern doorway	SUERC 27400	Cow bone	1075 ± 30	-21.1	NA	890-1020	940-1020

4. Discussion

Integration of the stratigraphic data with existing AMS radiocarbon dates has allowed further detailed insights into the chronology of settlement in Iceland and the pattern of occupation and abandonment of three key sites. It has been particularly successful at Aðalstræti where the model has suggested that the earliest excavated hall in Iceland was occupied by AD 890, very shortly after the *Landnam* tephra deposition of AD 871 ± 2. The model also indicated that the hall was abandoned by AD 1020. This adds detail and precision to the timescale proposed by Roberts et al. (2003). Although secure initial floor deposits are missing, the date of the earliest occupation is constrained by the underlying tephra. The proposed length of occupation is around 150 years maximum, and although there could be later hearth deposits that have been cleared out and therefore not sampled, this is unlikely given the lack of repairs. It was also possible to test the incorporation of typologically dated artefacts into the chronological sequence, which provided improved precision of dates.

The approach was also informative when applied to Hofstaðir, a site with a much more complex stratigraphy. On the evidence available it was not possible to reliably estimate the date of first occupation of the site but it was possible to propose a date for the use of the early pit house between AD 930 and AD 945, a much more precise date than previously obtained. It was also possible to identify that the site had been abandoned by AD 1015-1095, which concurs with the existing archaeological interpretation (cf. Lucas, 2009: 67, Table 3.1). Sveigakot presented a more challenging example as the archaeological record comprised a series of sequences which could not be stratigraphically related. Despite these limitations the models provided improved precision of the dating of key archaeological events. In addition the approach was used to investigate possible stratigraphic relationships and to identify which was most likely sequence of events, aiding the interpretation of the site.



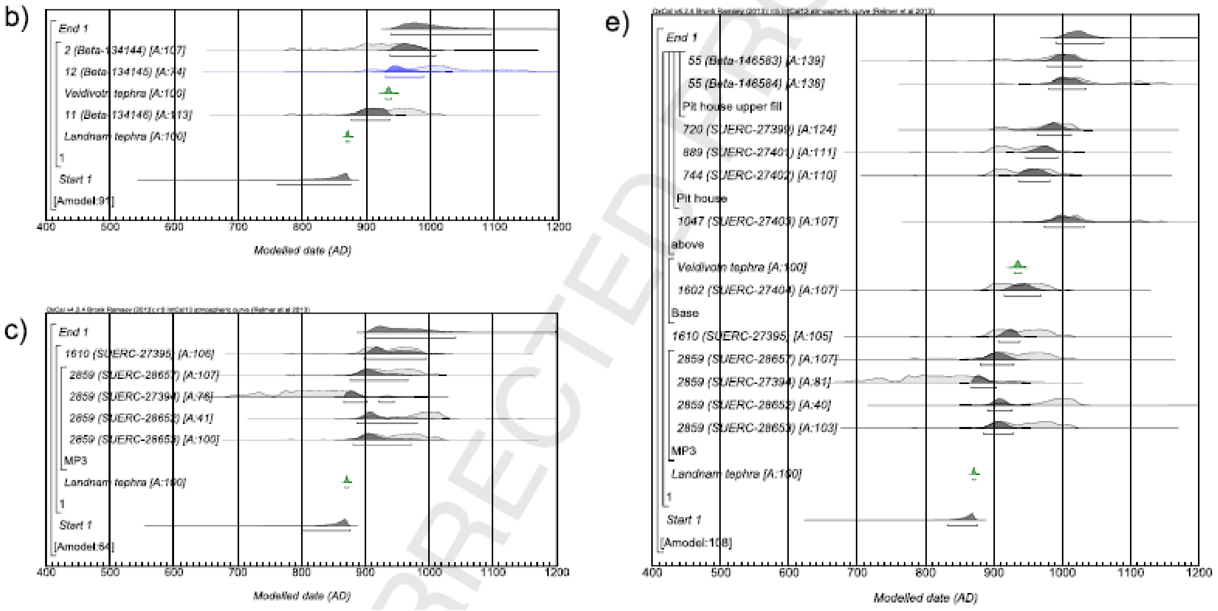


Fig. 10. a Modelled calibrated dates from deposits associated with MT, T1 and T2 at Sveigakot. Radiocarbon dates in black, tephra dates in green. b Modelled calibrated dates from deposits associated with area M midden at Sveigakot. Radiocarbon dates in black, reservoir corrected dates in blue, tephra dates in green. c Modelled calibrated dates from deposits associated with MP1 and MP3 at Sveigakot. Radiocarbon dates in black, tephra dates in green. d Modelled calibrated dates from deposits associated with S1, S4 and S5 at Sveigakot. Radiocarbon dates in black, tephra dates in green. e Modelled calibrated dates from deposits associated with MP1, MP3, MT and T at Sveigakot. Radiocarbon dates in black, tephra dates in green. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

The adjustments made for reservoir effects were largely successful in the sense that most changes produced calibrated dates that were in accordance with other dated material from the same context. However, there remain some examples where the adjustments based on the d13C values still give radiocarbon dates that are apparently anomalous when compared with samples from the same context, particularly two dates on cattle bones from Hofstaðir. A wider study of reservoir effects, ideally on paired plant and animal tissues, is needed to ascertain whether the discrepancy is caused by unquantified reservoir effects, mixing within the archaeological record or ambiguities within the archaeological stratigraphy.

5. Conclusions

Archaeologists in Iceland already have excellent chronological control provided by dated tephra layers but the approach outlined has been shown to have the potential to provide greater precision for dates between the tephras or where they are absent. It has been shown to refine key aspects of the previous chronologies at Aðalstræti, Hofstaðir and Sveigakot, and been particularly valuable in determining the lifespan of significant structures. The methods used also allowed the incorporation of typologically dated material into chronological models and the evaluation of possible relationships where stratigraphic evidence is absent. The approach is most informative where there are high-quality AMS radiocarbon dates and tephra within a well-established stratigraphy, but still yielded valuable insights where the archaeological information was less ideal. There remains uncertainty about the interpretation of marine and freshwater reservoir effects, and the extent to which the proposed corrections are applicable in all situations. As awareness of the potential of such approaches increases, models can be produced in advance of dating programmes, to inform the selection of samples within the known stratigraphy, thus ensuring the most informative outcome within the resources available. Future application of these approaches would be greatly enhanced by selection of short-lived material with no reservoir effects for radiocarbon dating, modelling of possible outcomes before deciding which material to date and producing more scientific dates from throughout site sequences, even where there are tepra layers.

The approaches taken here are particularly successful due to the precision provided by tephrochronology. However, their applicability is not restricted to sites with such controls; the same approaches can provide improved precision with combinations of stratigraphy, scientific dates, historical sources and typologies. The use of these analyses to reinterpret typological sequences shows great potential for systematic re-evaluation of typologically dated material and for the evaluation of chronological models in the absence of stratigraphic information.

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