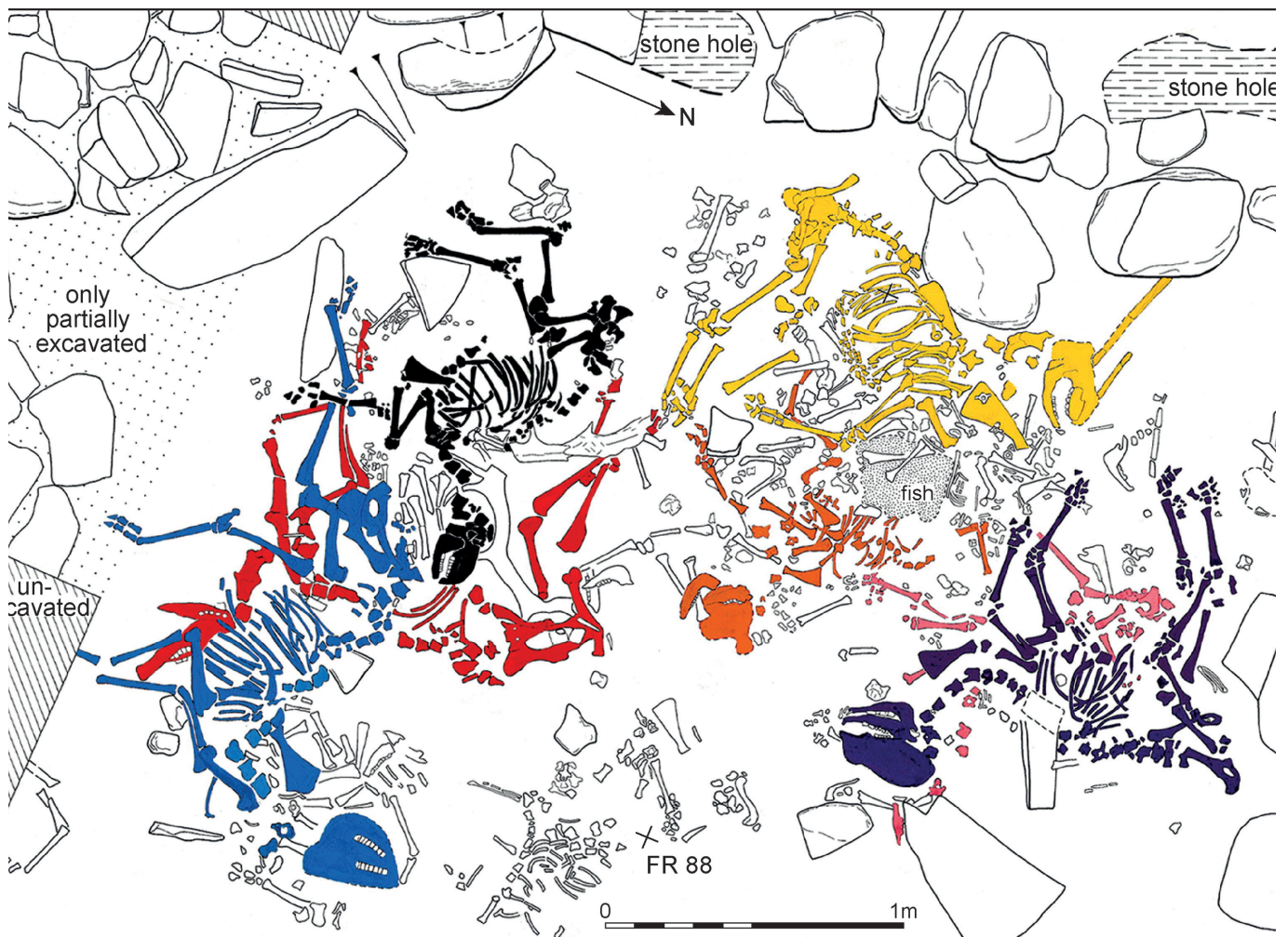




Links of Noltland, Westray, Orkney Radiocarbon Dating & Chronological Modelling

Peter Marshall, David Clarke, Alison Sheridan, Alexandra Shepherd, Niall Sharples, Miranda Armour-Chelu, Laura Hamlet, Christopher Bronk Ramsey, Elaine Dunbar, Paula Reimer, and Alasdair Whittle

Discovery, Innovation and Science in the Historic Environment



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WESTRAY
ORKNEY

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MODELLING

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SUMMARY

This report contains details of all the publically available radiocarbon determinations obtained on samples dated from the Links of Noltland up to the end of 2016. The chronological modelling of these radiocarbon dates was undertaken as part of *The Times of Their Lives Project* (European Research Council Advanced Investigator grant 295412). The archaeological significance of the modelled chronology is described in an accompanying publication (Clarke *et al* 2017).

CONTRIBUTORS

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INTRODUCTION

This document is a technical archive report on the dating of the Late Neolithic site at Links of Noltland, Westray Orkney and has been produced as part of *The Times of Their Lives* (ToTL) project, funded by the European Research Council (Advanced Investigator Grant 295412). This enabled new programmes of radiocarbon dating and chronological modelling to be undertaken on a series of Grooved Ware settlements on Orkney. We were able to provide new dating for fully published sites at Barnhouse, Mainland (Richards 2005; Richards *et al* 2016a) and Pool, Sanday (Hunter 2007; MacSween *et al* 2015), and to contribute to ongoing post-excavation analysis for Skara Brae, Mainland (Clarke and Shepherd forthcoming). At the Ness of Brodgar, Mainland, where excavation is ongoing we were able to produce a preliminary chronology for the site (Card *et al* in press).

An accompanying paper (Clarke *et al* 2017) incorporates the results from this report in a wider discussion of the Late Neolithic archaeology of the Links of Noltland and should be consulted for further information on the site.

Objectives

Refining the chronology of the sequence from Trench D at the Links of Noltland within the ToTL project aimed to:

- provide formal estimates of the date and duration of activity in this part of the site;
- provide a precise date for the deposition of the red deer heap;
- situate the activities in Trench D within a broader chronology of third millennium cal BC activity on the Links; and
- understand better the Marine Reservoir Effect for Late Neolithic Orkney, utilising the ‘perfect pair’ provided by the articulated cod found on the deer heap.

A further aim was to determine the date of the pottery, enabling its place within the broader typo-chronology of Grooved Ware within Orkney to be established more precisely. The results of that part of the study will be discussed in another paper (Sheridan *et al* forthcoming).

RADIOCARBON DATING AND CHRONOLOGICAL MODELLING

The radiocarbon dating programme for Trench D was conceived within the framework of Bayesian chronological modelling (Buck *et al* 1996). This allows the combination of calibrated radiocarbon dates, or other scientific dates, with archaeological prior information using a formal statistical methodology. In

Trench D, a number of stratigraphic relationships between contexts were available to constrain the radiocarbon dates (Clarke *et al* 2017).

Given the formation history of the excavated deposits in Trench D, it was not unexpected that material suitable for radiocarbon dating was not evenly distributed: for example, it was relatively scarce in cultivation deposits, but, not surprisingly, somewhat more common among the deposits of domestic refuse. Unfortunately all the sherds had been treated with chemical consolidant as part of the on-site conservation and therefore any carbonised residues that had been present will have been contaminated. The only material in the archive that was suitable for dating was the animal bone. Articulated bones had probably been incorporated into the deposit from which they were recovered while still fleshed and therefore there should be no significant time interval between the date of the context and the death of the animal concerned.

Nine radiocarbon determinations, all on unburnt mammal bone, had been obtained for Trench D during the 1980s (Table 1). A further nine radiocarbon measurements, from seven samples (six unburnt mammal bones and one fish bone, with two of the mammal bones being dated by two different laboratories (Table 1), were obtained as part of the TOTL Project.

The radiocarbon measurements that had been obtained for Trench D during the 1980s were part of a suite of dates obtained for material excavated by Clarke's team; the eight dates from his other trenches are presented in Tables 2–4. Six of these determinations (GU-1428–33) on samples from the 1980 excavation season were measured in 1981 (Clarke 1981) and a subsequent eight samples submitted in 1983 were dated (GU-1690–97) in 1984. Three radiocarbon dates (Hedges *et al* 1987) were obtained on otter and vole bones as part of doctoral research undertaken on part of the faunal assemblage from the 1978–1981 excavations by Miranda Armour-Chelu (1992). The otter also formed part of a suite of samples designed to explore the chronology of species introduction on Orkney (Hedges *et al* 1987).

From the more recent excavations by EASE Archaeology, seven radiocarbon results have been published (Moore and Wilson 2011, 38) and a further 38 have been obtained but are not yet in the public domain (Richard Strachan, pers comm). These samples, from both the Late Neolithic settlement and the Bronze Age cemetery and settlement (Table 5 and unpublished), were dated as part of post-excavation assessment, and submission of further samples as part of a more in-depth scientific dating programme is planned (Derek Hamilton, pers comm).

Radiocarbon results

Details of the 33 publicly available radiocarbon dates for the Links of Noltland, including the nine new determinations for Trench D, are given in Tables 1–5. All are conventional radiocarbon ages (Stuiver and Polach 1977). The human bone dates relating to a Bronze Age phase of activity are not included in the modelling presented here.

Samples of animal and fish bone were measured by Accelerator Mass Spectrometry (AMS) at the Oxford Radiocarbon Accelerator Unit (ORAU) in 1987 and 2015. The animal bone samples processed in 1987 were pre-treated as outlined in Gillespie *et al* (1984) and dated by AMS as described by Gillespie *et al* (1985). In 2015 the gelatinisation and ultrafiltration of animal and fish bone followed the methods described in Brock *et al* (2010), after which the samples were combusted, graphitised (Dee and Bronk Ramsey 2000; Brock *et al* 2010) and dated by AMS (Bronk Ramsey *et al* 2004).

The unburnt bone samples dated at the Scottish Universities Environmental Research Centre (SUERC) in East Kilbride in 2010 and 2015 were processed and dated by AMS using the methods described in Dunbar *et al* (2016).

At the Glasgow University Radiocarbon Dating Laboratory (the forerunner of SUERC), the animal bone samples dated in 1981 and 1984 were pretreated as described by Stenhouse and Baxter (1983), and converted to benzene for liquid scintillation counting (LSC) as outlined by Campbell and Baxter (1979).

Quality assurance

Both laboratories (Oxford and East Kilbride) from which measurements have been obtained since 2010 maintain continual programmes of quality assurance procedures, in addition to participation in international inter-laboratory comparisons (Scott *et al* 2007; 2010). These tests indicate no laboratory offsets and demonstrate the validity of the precision quoted.

In the early 1980s the first steps to formalise procedures for quality assurance in radiocarbon dating began with a collaborative study undertaken by 20 international radiocarbon laboratories and designed by the Glasgow University laboratory. The results of this first international intercomparison (International Study Group 1982) demonstrated that Glasgow produced results which were in good agreement with those of the other participating laboratories.

Bayesian modelling

The chronological modelling described in this section has been undertaken using OxCal 4.2 (Bronk Ramsey 1995; 2009) and the internationally agreed calibration curve for the northern hemisphere (IntCal13: Reimer et al 2013). The model is defined by the OxCal CQL2 keywords and by the brackets on the left-hand side of Figures 1–3. In the diagrams, calibrated radiocarbon dates are shown in outline and the posterior density estimates produced by the chronological modelling are shown in solid black. The Highest Posterior Density intervals which describe the posterior distributions are given in italics.

The chronological model

The overall form of the chronological model for activity at the Links of Noltland is shown in Figure 1, with the component relating to the western area (Trenches D and E) being shown in Figure 2 and that relating to the central and eastern areas (Trenches C, Grobust, and EASE Area 5) being shown in Figure 3.

Trench D

Eighteen radiocarbon measurements from sixteen samples are now available from Trench D. A summary of the stratigraphy in Trench D is provided by Clarke *et al* (2017, illus 5).

The earliest dated material derives from the cultivation with refuse deposition/incorporation at the end of Phase I. In FQ83 a bulked sample of *Bos* bones (GU-1696) from context [32], a thin sediment that covered the silted-up ditch [29] that had possibly housed a seaweed fence/barrier, provides a *terminus ante quem* for this feature and for the initial episodes of cultivation. Two samples from the part of ploughsoil [33] in the main part of Trench D that underlay context [32] were also dated, although the model does not incorporate this stratigraphic relationship as the dated samples from [32] and [33] are not from contiguous squares. Replicate measurements (SUERC-62079 and OxA-32613) on a cattle phalanx with refitting unfused proximal epiphysis are statistically consistent ($T'=0.2$; $T'5\%=3.8$; $v=1$; Ward and Wilson 1978), and a weighted mean (FR87 [33]; 4237 ± 25 BP) has been calculated as providing the best estimate of the age of the sample. The determination on a sample of bulked *Bos* bone (GU-1697) from [33] is statistically consistent ($T'=0.9$; $T'5\%=3.8$; $v=1$) with this weighted mean, and so both samples may accurately reflect the age of this deposit.

During the second phase of cultivation (Phase II), represented by ploughsoil ([25] and [26]), episodes of ingress by wind-blown sand occurred. Four samples have been dated from context [25] (Table 1). The dated vole (OxA-

1081), however, is clearly too old for its stratigraphic position and is also much earlier than any other dated material from the site or any other radiocarbon dates on vole bones from across Orkney (Martínková *et al* 2013; Bayliss *et al* in press). This measurement is therefore probably inaccurate and has therefore been excluded from the chronological modelling. Replicate measurements on a cattle phalanx with refitting unfused epiphysis (SUERC-62073 and UBA-29887) are statistically consistent ($T^{\circ}=0.1$; $T^{\circ}5\%=3.8$; $v=1$) and their weighted mean (FQ88 [25]; 4126 ± 26 BP) provides the best estimate for its age. This result (FQ88 [25]) is statistically consistent ($T^{\circ}=1.6$; $T^{\circ}5\%=6.0$; $v=2$) with two measurements on bulked *Bos* bones (GU-1428 and GU-1429), indicating that the material could all be of the same date.

Cultivation ceased and deposition/accumulation of much greater amounts of refuse took place during Phase III. A bulk sample of *Ovicaprid* bones (GU-1694) from a patch of refuse material [21] in FQ83 is stratigraphically earlier than the extensive refuse-laden deposits [20] that went on to accumulate over much of the excavated area in this part of the site. The two determinations from context [20] are not, however, statistically consistent ($T^{\circ}=21.4$; $T^{\circ}5\%=3.8$; $v=1$), with the AMS measurement on articulating sheep phalanges (SUERC-61770) being considerably older than the bulked sample of *Bos* bones (GU-1430). These deposits [20] are from the top of the sequence in FQ83 and, given the depth of material that accumulated in this area, it is entirely plausible that these seemingly divergent dates are actually accurate representations of the time-depth of this deposit.

Unfortunately, there are no samples relating to the construction of the wall ([15]–[17]). This event, however, is constrained by the stratigraphically-earlier samples (GU-1430 and SUERC-61770) from the Phase III deposits and by the stratigraphically-later Phase V deer heap near the top of [13]. Whether the deposition of cattle bone lower down in [13] – the event dated by GU-1431 – also post-dated the construction of the wall is a moot point (Clarke *et al* 2017). We have interpreted it as later for the purposes of the chronological modelling, and this relationship is included as a constraint in the model presented. The radiocarbon age of the bulked sample of *Bos* bone (GU-1431) is not statistically consistent with those from the three dated deer (SUERC-62077–8, and UBA-29886) at 95% confidence ($T^{\circ}=9.3$; $T^{\circ}5\%=7.8$; $v=2$) but it is at 99% confidence. There is no *a priori* reason for assuming that the deposition of the cattle remains and that of the deer carcasses in [13] are connected at all; the former appears to be part of continued dumping of waste material. The three determinations on separate deer from the deer heap (SUERC-62077–8 and UBA-29886) are statistically consistent ($T^{\circ}=1.8$; $T^{\circ}5\%=6.0$; $v=2$) and have been combined using the Combine function in OxCal since, although they almost certainly died at the same time, the measurements are not from the same organism.

The large articulated cod that lay on top of the red deer heap was dated as part of a ‘perfect pair’ of contemporary terrestrial and marine samples to assess the marine reservoir effect for Late Neolithic Orkney, rather than to contribute to understanding the chronology of activity in Trench D. The result has not therefore been included in the model, but is discussed further below.

The stratigraphically latest sample from Trench D — a vole bone (OxA-1080) — came from the final phase of cultivation activity (Phase VIII): a ploughsoil with ard marks (context [8]).

Trench D in its wider Links of Noltland context

Western Area

In addition to the dated samples from Trench D, there is one further measurement relating to the Western Area, obtained from a sample of bulked *Bos* and *Ovicaprid* bones (GU-1691) relating to the latest activity in Trench E (Table 2). This has been included only as providing a *terminus post quem* for its context as it could contain material of different ages.

Central Area

Three radiocarbon dates are available from Trench C — an area that, like Trench D, had produced remains of several deer, this time apparently butchered (Table 3). A sample of mixed *Bos* and *Cervus* bones (GU-1693) from context [15] provides a *terminus post quem* for the construction of a dry-stone wall that has been interpreted as a field boundary (Clarke 1991; Sheridan 1999, 114). A sample of bulked *Cervus elaphus* bone (GU-1432) from a light brown sand layer [7] comes from the ‘butchery area’ that post-dates the construction of the wall. A sample of bulked *Cervus elaphus* bone from a partial skeleton (GU-1690) from a layer with incorporated refuse, context [2], overlying the collapsed wall, provides a *terminus ante quem* for the disuse of the wall and for the butchery area.

Eastern Area (Grobust)

Four radiocarbon dates (Table 4) are available from material deposited within areas of the ‘Grobust’ building (Structure 18), excavated in Trench A. Parts of this structure are interpreted as having been deliberately infilled as an act of closure (Clarke 1991). Two samples of bulked animal bones (*Bos*, *Cervus elaphus*, *Ovicaprid* and *Sus*; GU-1433 and GU-1692) from the northern ‘passage’ probably at best provide *termini post quos* for the overlying contexts, as does a sample from an articulated skeleton of *Lutra lutra* (OxA-1082) from a cell leading off from the southern, inner chamber. This sample may have both a

marine and freshwater reservoir offset. The lack of stable isotope measurements means we cannot determine what proportion of the otter's diet was derived from marine and freshwater sources, and therefore correct its radiocarbon age, which will certainly be much earlier than its actual age. (See Clarke 1991, 48–9 on the taphonomy of the otter remains.)

A bulk sample of *Cervus elaphus* bones (GU-1695) from deposits lying over a pathway leading into the northernmost part of the structure may accurately date its context and provide some indication of when final occupation was taking place in at least this part of the structure.

EASE excavations: Area 5 'Midden'/Structure 8(10)

Five published radiocarbon results are available on samples from the EASE excavations of extensive, finds-rich deposits, termed 'midden' (see Clarke *et al* 2017, note 1 on the definition of that term), that post-dated the abandonment of the very substantial stone building, Structure 8(10), in Area 5 (Table 5; Moore and Wilson 2011, 20–1).

A sheep metapodial (SUERC-27904) from a concentration of sheep bones in one of the Structure 8(10) infill deposits (context 9011) is extremely late for its stratigraphic position, and has therefore been excluded from the model. As the sample was not found articulated, or found to articulate during post-excavation, it could simply represent intrusive material relating to activities on the Links around the end of the third millennium.

Due to ambiguities in the stratigraphic description of the way in which samples from the Area 5 deposits [7302] and a structure described as a 'kiln' [9009]/'flue' [9016] relate to each other (Moore and Wilson 2011, 21 and 38), these have been included in the model without any relative stratigraphic sequence.

The two samples (SUERC-27899–27900) from context [7302], part of the extensive Area 5 deposits, are statistically consistent ($T=3.1$; $T'5\%=3.8$; $v=1$) and could be of the same actual age. But those from the 'flue' (SUERC-27902) and 'kiln' (SUERC-27903) are not statistically consistent ($T=7.4$; $T'5\%=3.8$; $v=1$) and are of different ages. Given that components of the 'kiln'/'flue' feature could have been infilled at different times this is not necessarily unexpected.

Assessment of the dated samples

Taphonomy of bulked animal bones

The 14 samples of animal bone dated at Glasgow University during the 1980s (Tables 1– 4) inevitably comprised multiple skeletal elements, and in four cases multiple faunal species (GU-1433, GU-1691–3), given the requirements of a minimum of approximately 300g of bone for dating by liquid scintillation counting at the time. The four samples comprising material from different faunal species have been included in the model as providing *termini post quos* for their contexts, given that we cannot be sure that they comprise material of the same actual age.

The remaining ten samples consisted of multiple skeletal elements of single species: *Bos* (six samples), *Cervus elaphus* (three), and *Ovicaprid* (one). Only the red deer bone that was dated by GU-1690 is known to have been articulated when deposited.

In order to determine the reliability of the samples dated at Glasgow University in the 1980s for dating their contexts accurately, the ToTL project attempted to identify articulating material from Trench D contexts that had previously provided bulk samples for dating. Three contexts, [20], [25], and [33], were found to contain samples of articulating animal bone that had already been dated using bulked skeletal elements of single species, thus offering an opportunity to evaluate the potential taphonomy of previous dated samples.

The two determinations (GU-1430 and SUERC-61770) from context [20] in Square FQ 83 of Trench D are not statistically consistent ($T'=21.4$; $T'5\%=3.8$; $v=1$), with the articulating sheep phalanx (SUERC-61770) being considerably older than the sample of *Bos* bones (GU-1430). The samples do derive, however, from refuse-bearing deposits of considerable thickness which may have accumulated over a considerable period of time.

The two measurements on bulked *Bos* bones (GU-1428 and GU-1429) from the Phase II ploughsoil [25] in Trench D are statistically consistent ($T'=1.6$; $T'5\%=6.0$; $v=2$) with the weighted mean (4126 ± 26 BP; FQ 88 [25]) of replicate determinations (SUERC-62073 and UBA-29887; Table 1) on a cattle phalanx with refitting unfused epiphysis from the same context. The material could therefore all be of the same actual age. Results on samples from ploughsoil [33] (GU-1697 and FR 87 [33]; Table 1) are similarly statistically consistent ($T'=0.9$; $T'5\%=3.8$; $v=1$).

The four results from layer [13] (GU-1431, SUERC-62077–8, and UBA-29886) are not statistically consistent at 95% confidence ($T'=9.3$; $T'5\%=7.8$; $v=3$) but

are at 99% confidence ($T^* = 9.3$; $T^*1\% = 11.3$; $v = 3$). Given that bulk sample of *Bos* bones comes from the base of the context and the deer are from near the top, this simply suggests that layer [13] probably took a short period of time to form.

These results therefore suggest that the samples dated at Glasgow do not contain material of significantly different ages (such as different skeletal elements from the same faunal species) compared to other articulating material in the same context and that the originally reported ages are accurate estimates of the ages of the samples. We have therefore included the following ten radiocarbon ages from samples dated at Glasgow University (GU-1428–32; GU-1694–97) as providing accurate estimates for the dates of their contexts in the model and have also elected to use the original quoted errors for measurements with laboratory codes earlier than GU-1500 (*contra* Ashmore *et al* 2000).

Radiocarbon offsets

Radiocarbon offsets can occur if samples (such as animals) have taken up carbon from a reservoir not in equilibrium with the terrestrial biosphere (Lanting and van der Plicht 1998). Dietary stable isotope measurements from domestic animals (Tables 1 and 5; Jones and Mulville 2016) confirm that offsets from freshwater or marine reservoirs are not found among the sampled domestic faunal remains from the site.

This will not have been the case with the otter and the cod. The diet of otters consists very largely of fish caught in freshwater habitats or along sea coasts (Mason and Macdonald 1986; Chanin 1991), and hence the diet of the dated otter can be expected to have been obtained primarily from marine sources. However, without stable isotope measurements ($\delta^{13}\text{C}$ and $\delta^{15}\text{N}$) it is not possible to determine the proportions of marine and freshwater contributions to the diet of the otter and thus correct the radiocarbon age. The radiocarbon age therefore provides a maximum age for the death of the animal.

The cod was dated to provide additional information to understand better the Marine Reservoir Effect for Late Neolithic Orkney (see The Marine Reservoir Effect (MRE) - below).

Dates used in the model

Of the 33 available radiocarbon determinations from the Links of Noltland, five have been excluded from the model presented here: SUERC-20908 and SUERC-20912 (Table 5), as these samples of human bone found in the Scheduled Area in 2009 were interred during the mid-second millennium cal BC and do not contribute to understanding the third millennium chronology of the site; OxA-

1081, as the determination is clearly anomalous compared to other dates on Orkney voles (Bayliss *et al* in press) and samples from the site in general; SUERC-27904, since for the reasons outlined above this sample is probably intrusive; and OxA-32612, as the cod was dated to help with quantifying the Marine Reservoir Effect for Neolithic Orkney.

The model thus includes 28 determinations on 26 samples. Four samples that could contain potentially residual material (as they comprised bulked animal bone of different species) are included as only providing *termini post quos* for overlying deposits (GU-1433, GU-1691–3), while the radiocarbon determination for the otter (OxA-1082), although from an articulated individual, provides a *terminus post quem* for its death and context given an unknown offset (from marine and potentially freshwater reservoirs). Therefore 21 samples are believed to provide accurate ages for the deposits from which they were recovered.

In assessing the reliability of the model for the Links of Noltland we need to reflect on the number of dated samples available from different parts of the site. The Eastern Area (Grobust) has four dated samples, the Central Area (Trench C) three, the Western Area (Trenches D and E) 16, and the EASE excavations (Structure 8(10)) four. We clearly have far fewer dated samples than is sufficient to provide a meaningful chronology for the site as a whole, but for Trench D we have sufficient samples to provide a broad indication of activity in this part of the site. Clearly, the full post-excavation analysis of the areas currently under excavation and additional radiocarbon dates on the associated materials will substantially refine the chronology of the Links of Noltland presented here.

A CHRONOLOGICAL NARRATIVE

The model shown in Figures 1–3, based on the available radiocarbon dates, interprets the activity in the Eastern, Western and Central Areas and from the EASE excavations as a single continuous phase (Buck *et al* 1992). It has good overall agreement (Amodel: 83) between the radiocarbon dates and the prior information about their stratigraphic relationships outlined above.

The model estimates that the dated activity at the Links of Noltland began in *3160–2870 cal BC (95% probability; start_LoN; Fig 1)*. The earliest dated activity is from Trench D and it provides a *terminus ante quem* for the initial cultivation in this part of the site at the beginning of Phase I and for the construction of the putative seaweed fence/barrier [30] of *3060–2865 cal BC (93% probability; first_Trench_D; Fig 2)*, or *2810–2780 cal BC (2% probability)*. This first phase of cultivation in the Western Area, Trench D, and its continuation during one or more periods of sand ingress (Phases I and II), took place for a minimum of *55–330 years (95% probability; distribution not shown)*, ending in *2850–2640 cal BC (95% probability; last_Phase_II; Fig 2)*.

Deposition of considerable quantities of refuse (Phase III) began immediately after the end of cultivation in Phase II in 2830–2805 cal BC (3% probability; *first_Phase_III*; illus 11), or 2795–2600 cal BC (92% probability) and continued until 2570–2520 cal BC (9% probability; *last_Phase_III*; Fig 2) or 2500–2300 cal BC (86% probability). To judge from the date from a deposit of *Bos* bones in context [13] (GU-1431), the practice of depositing household waste — albeit not with the same intensity, given the smaller amounts of material found and the high sand content of context [13] — seems to have continued at least until the construction of the wall [16] in 2500–2225 cal BC (95% probability; *build_wall_[16]*; Fig 2). This estimated date for the wall’s construction is based on the assumption that all the material from context [13] post-dates construction of the wall.

Whether the low-level deposition of household waste persisted until the heap of deer carcasses was deposited beside the wall [16] in 2280–2245 (9% probability; *Red_deer*; Fig 2), or 2230–2130 (86% probability) (Phase V) remains unclear. Renewed agricultural activity at the top of Trench D (Phase VII) is attested at the end of the third millennium cal BC; the latest dated material (ie vole remains) for this trench is estimated to have been incorporated into the ploughsoil in 2200–1930 cal BC (95% probability; *last_Trench_D*; Fig 2), probably in 2150–2000 cal BC (68% probability). As noted above, this was not the last activity in this area: a later wall (Phase VIII) was subsequently erected; but that activity is not dated.

Other activity across the Links of Noltland

The end of the primary cultivation activity and the start of extensive refuse deposition in Trench D (Phase III) occurs slightly later than the start of the infilling of the abandoned massive Structure 8(10) in Area 5 (Fig 3). Dating indicates that the accumulation of occupation deposits in Area 5 had probably finished by the 26th or the first half of the 25th century cal BC (Fig 3), with the Phase III refuse accumulation in Trench D continuing for a little longer (Fig 2).

Activity in the Central Area (Trench C) is only dated by three samples (Table 3), with the earliest relating to the development of sediments incorporating domestic waste prior to the building of a wall; the second relating to the deposition of animal remains (predominantly of deer) in a ‘butchery area’ beside the wall; and the third deriving from deer bone within a thin, clay-rich layer overlying the collapsed remains of the wall. A later period of refuse-bearing sediment accumulation, which included an incised sherd with possible affinities to the Food Vessel tradition, was not dated, although if the ceramic attribution is correct, a date early in the second millennium (or around the turn of the millennium) might be assumed. According to the model (Figs 1–3), all three of the radiocarbon-dated phases of activity — not just the ‘butchery area’ activity —

could be broadly contemporary with Phase V (the deposition of the red deer heap) in Trench D, although a somewhat longer overall sequence cannot be ruled out. The wall in Trench C was probably constructed at some point between the 25th and the 23rd centuries cal BC (*build_wall*; Fig 3) — that is, around the same time as the Trench D Phase IV wall was probably being built — and the butchered animals were deposited beside it during the last quarter of the third millennium cal BC (Fig 2), around the same time as the Trench D deer heap was being deposited. The latest date for Trench C (GU-1690, Table 3) comes from deer bones found in the deposits overlying the collapsed wall and is virtually indistinguishable from the date for the ‘butchery area’ deer bone (GU-1432). If the bones in question (GU-1690) are not residual from a midden deposit — and their probable articulation suggests that they were not — then this date may also apply to the two Beaker pots whose sherds were found in that context [2]. This post-wall accumulation also contained a sherd from a hard-to-categorise pot, possibly within the Grooved Ware tradition, that conjoined with a sherd from the Grobust structure over 40m away. The latter was found among collapsed walling that ran across the northern chamber and belongs to a late stage in the life of this structure.

Placing the construction and use of the Grobust structure into this preliminary chronology of activity at the Links of Noltland on the basis of the four currently-available radiocarbon dates is difficult, and here further dates obtained from the EASE excavations should help to clarify matters. The two samples derived from sediments infilling the northern section of the structure at the end of its use are included in the model as only providing potential *termini post quos*; and the otter bone from the fill of the southern cell could be simply be intrusive, as well as undoubtedly having an unknown reservoir effect. Therefore, given the available data, the last-dated material from the infill could conceivably provide *a terminus ante quem* for the use of the structure; the model provides an estimate for the infilling of parts of the structure in the second half of the third millennium cal BC (Fig 3).

THE MARINE RESERVOIR EFFECT

The Marine Reservoir Effect (MRE) is a ^{14}C age offset between contemporaneous marine and terrestrial-derived carbon in Northern Hemisphere surface waters (Stuiver *et al* 1986; Russell *et al* 2015). Due to differences in the upwelling of different water masses and the exchange rate of CO_2 between the ocean and atmosphere, ^{14}C concentrations are non-uniform (Gordon and Harkness 1992) and therefore the MRE offset varies spatially and temporally. Thus accurately calibration radiocarbon ages from samples that contained marine derived carbon can be challenging (Ascough *et al* 2004).

‘Perfect pairs’ of contemporary terrestrial and marine samples are rare as most MRE research is based on the radiocarbon dating of ‘paired samples’ of mollusc

shells and carbonised grain from the same archaeological context; an exception is the research of Russell *et al* (2011), who used cod from contexts that had previously had paired measurements on dated carbonised grain and mollusc shell (Ascough *et al* 2009). In order to overcome the potential taphonomic problems inherent in such an approach, multiple 'pairs' are dated to try and demonstrate that the terrestrial and marine samples are 'contemporary'. This maximises the chance that all samples were formed and died at approximately the same point in time if they are found to be statistically consistent. A ΔR value is then calculated from the difference in ^{14}C ages between each marine and terrestrial sample pair and from this, a single mean value and representative error is determined (Ascough *et al* 2005).

Marine Reservoir Effect values (Table 6) were calculated using the methodology outlined in Soulet (2015) and the weighted mean MRE value is consistent with the limited number of other values for later prehistoric Neolithic Orkney (Fig 4).

APPENDIX 1

Point of Buckquoy – Cuttings 5 and 6

Excavated between 1978 and 1979 the sites known as Cuttings 5 and 6 lie towards the west tip on the Point of Buckquoy, on the north part of the Birsay Bay (Morris 1989, 91). Radiometric dating of two samples (GU-1222 and GU-1556; Table 7) from the midden deposit that sealed the walls of a structure (XE) took place following the excavations. The 200+ carbonised cereal grains that were dated (GU-1222) appear to represent a ‘single event’ deposit while the mixed deposit of animal bone (GU-1556), from the midden, ZAC in Cutting 5 and XF in Cutting 6, at best provides a *terminus post quem* for the midden deposits given the sample could contain material of different ages.

In the mid-2000s eight samples from the midden deposit, XF in Cutting 6, were dated by AMS as part of research into the marine reservoir effect (Ascough *et al* 2007; Table 7). The four measurements on marine molluscs (SUERC-221–224) have not been included in the model.

The model shown in Figure 5 that treats all the samples from the midden deposit as deriving from a uniform phase of activity (Buck *et al* 1992) has good overall agreement ($A_{\text{model}}=99$) and suggests the deposit formed from the late third to mid second millennium cal BC.

Skaill Bay

Erosion of sand dunes during the winter of 1992–3 in the bay of Skaill, close to the Neolithic site at Skara Brae, exposed a spread of faunal remains and stone tools representing a Late Neolithic butchery site separated by a wall from a deposit of articulated red deer (Richards *et al* 2016b). Measurements on samples from different deer (Table 8) have been combined (Fig 6) and provide an estimate for the deposit of 2300–2140 cal BC (95% probability; Skaill Bay; Fig 6).

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FIGURES

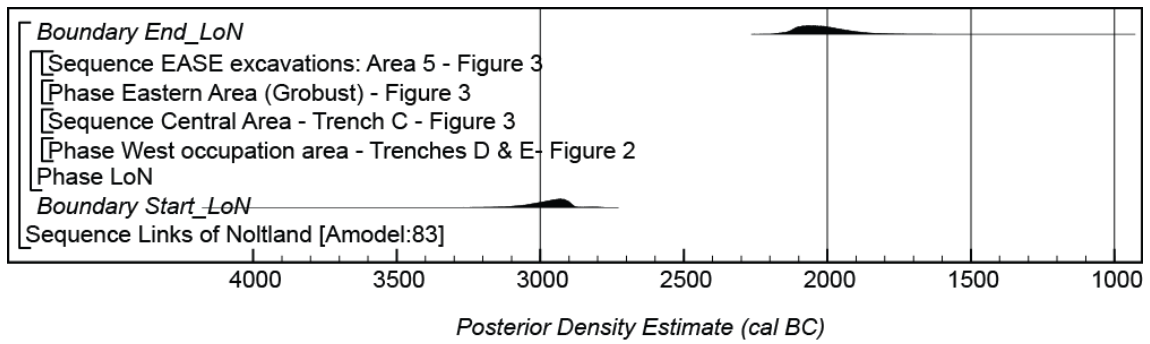


Figure 1: Overall structure for the chronology of third millennium cal BC activity at the Links of Noltland. The component sections of this model are shown in detail in Figures 1 and 2. The large square brackets down the left-hand side along with the OxCal keywords define the model exactly

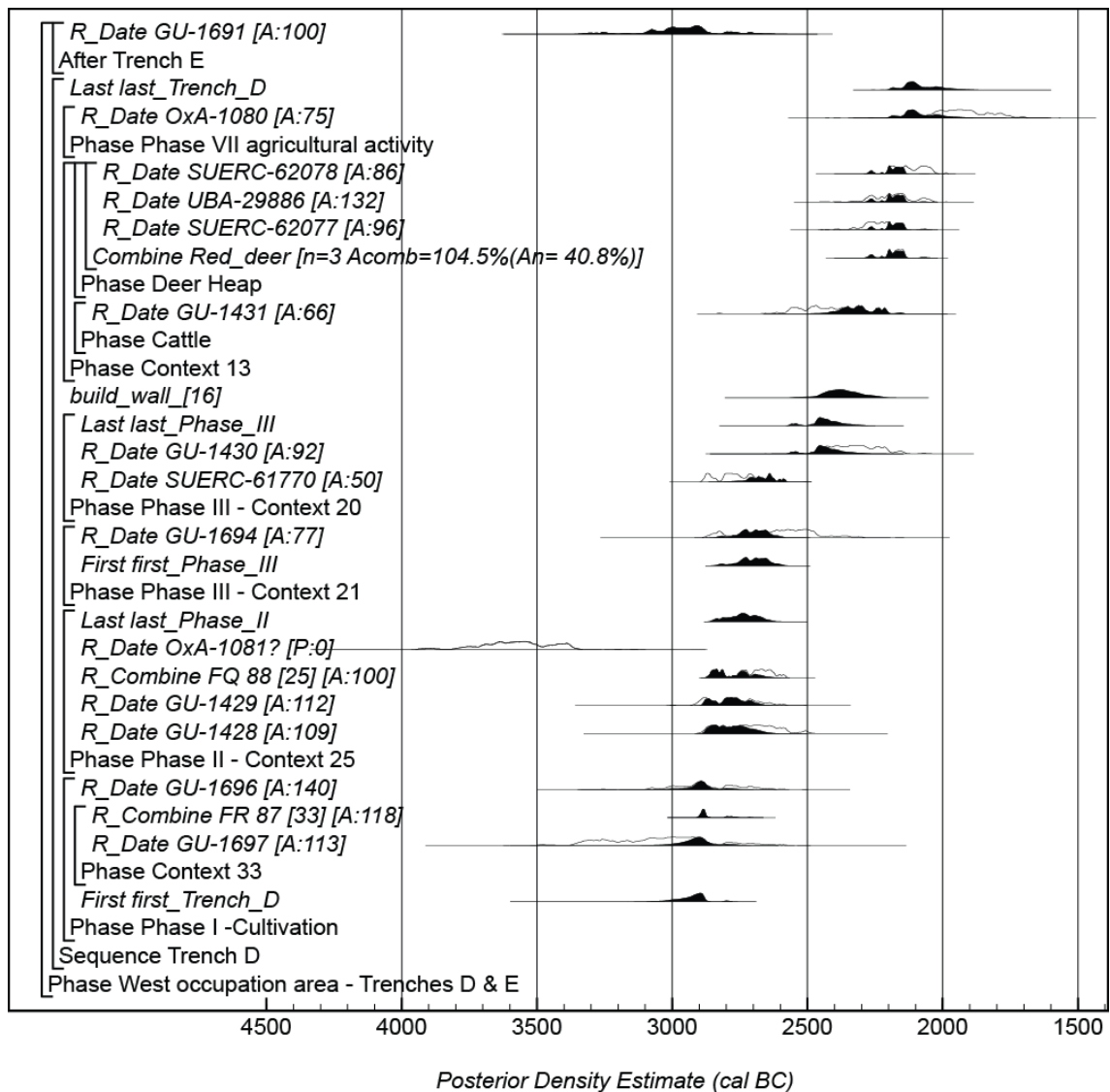


Figure 2: Probability distributions of dates from the Western Area, Trenches D and E. Each distribution represents the relative probability that an event occurs at a particular time. For each radiocarbon date, two distributions have been plotted: one in outline which is the result of simple radiocarbon calibration, and a solid one based on the chronological model used. The other distributions correspond to aspects of the model. For example, the distribution 'last_Phase_II' is the estimate for when the primary cultivation in Trench D ended

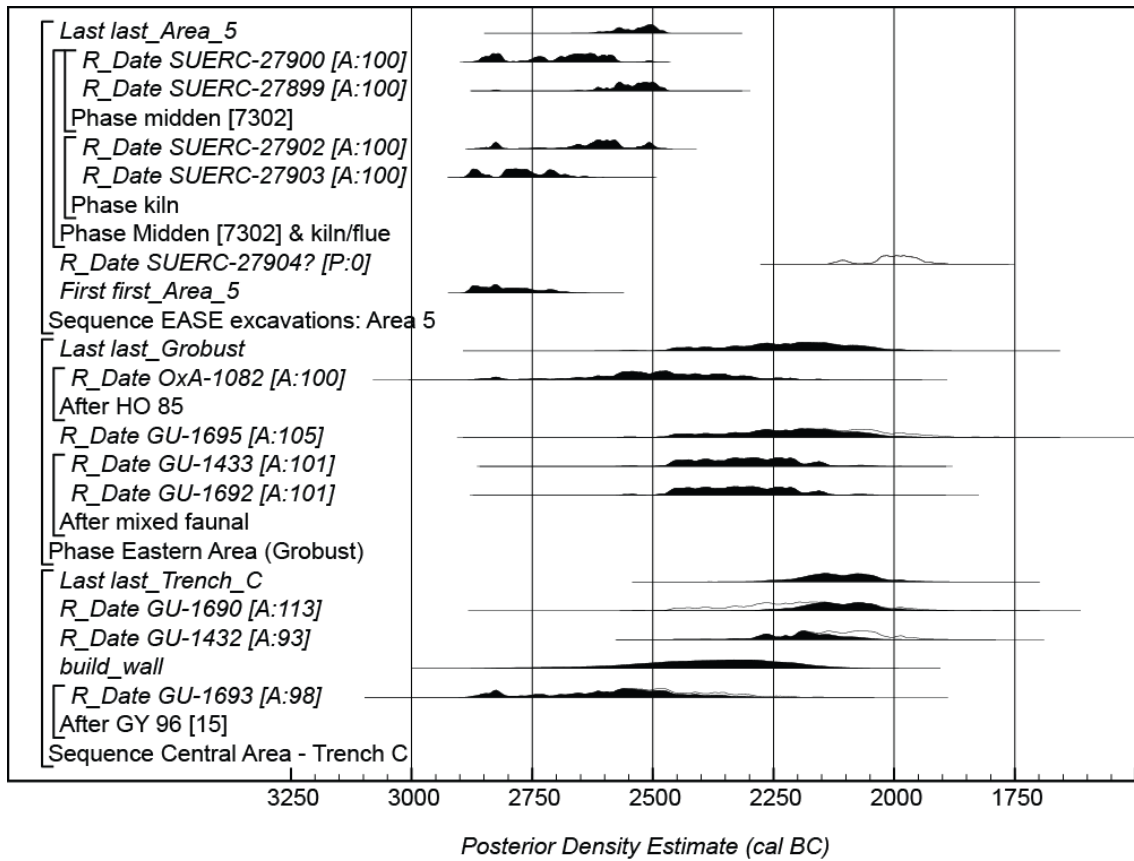


Figure 3: Probability distributions of dates from the Central Area, Eastern Area (Grobust) and EASE excavations: Area 5. The date followed by a question mark has been calibrated (Stuiver and Reimer, 1993), but not included in the chronological model for the reason outlined in the text. The format is identical to that shown in Figure 2

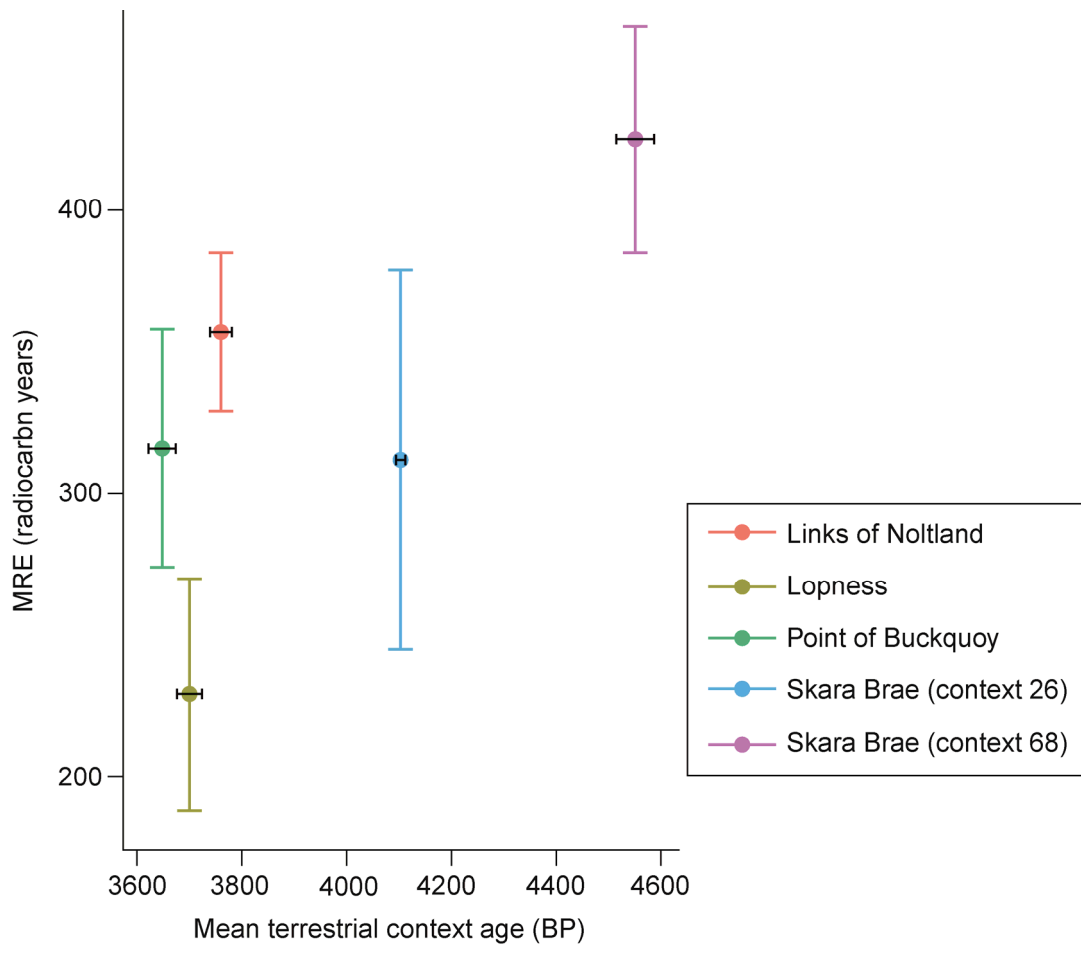


Figure 4: MRE (radiocarbon years) vs mean terrestrial context age (radiocarbon years BP) for the Links of Noltland and other prehistoric Orcadian sites – Lopness, Point of Buckquoy, and Skara Brae. Data from Russell et al (2015, table 1)

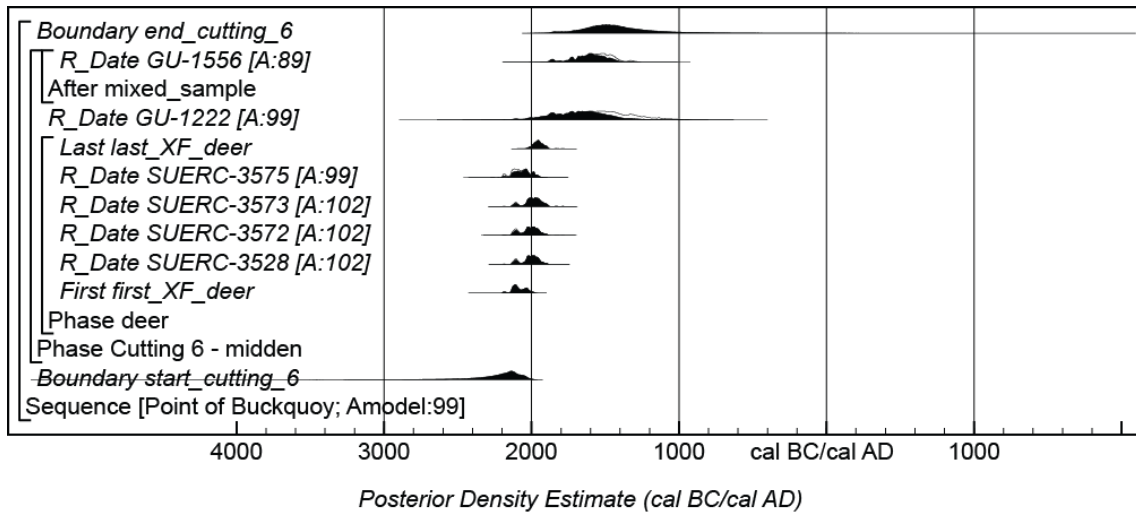


Figure 5: Probability distributions of dates from the Point of Buckquoy, Cuttings 5 and 6. The format is identical to that shown in Figure 2

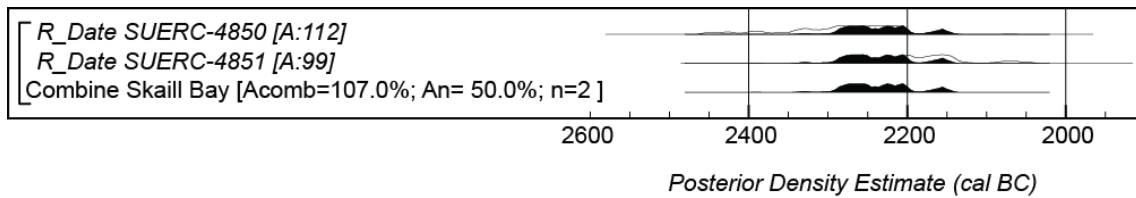


Figure 6: Combined probability distribution estimating the date of the butchery deposit at Skail Bay if it is interpreted as representing a single event

TABLES

Table 1: Links of Noltland: Western area, Trench D, radiocarbon and stable isotope results

Laboratory number *	Sample number**	Sample and context description	$\delta^{13}\text{C}$ (‰)	$\delta^{15}\text{N}$ (‰)	C:N	Radiocarbon Age (BP)	Posterior Density Estimate – cal BC (95% probability)
Phase I - Cultivation							
GU-1697	FR 87 [33](6)	Animal bone, <i>Bos</i> humerus, radius, metacarpal + limb bone (M. Armour-Chelu), 254g, from context [33], a brown sand layer (ploughsoil)	-22.3			4360±125	3045–2755
SUERC-62079	FR 87 [33](6) - sample A	Animal bone, cattle second phalanx with refitting unfused proximal epiphysis (S. Fraser) - context as GU-1697	-21.8±0.2	6.0±0.3	3.2	4250±38	
OxA-32613	FR 87 [33](6) - sample B	As SUERC-62079: duplicate sample	-21.6±0.2	5.8±0.3	3.4	4228±31	
	FR 87 [33]	Weighted mean ($T^*=0.2$; $v=1$; $T^*(5\%)=3.8$; (Ward and Wilson 1978)				4237±25	2910–2860 (90%) or 2805–2775 (5%)
GU-1696	FQ 83 [32](18)	Animal bone, <i>Bos</i> (M. Armour-Chelu), 280g, from context [32], a dark brown clay layer comprising domestic refuse deposited in the west half of the trench	-22.8			4270±75	3015–2830 (86%) or 2815–2755 (9%)
Phase II – Cultivation during wind-blown sand accumulation							
GU-1428	FQ 89 [25]	Animal bone, <i>Bos</i> (L. Barneston), c 250g, from context [25], a ploughsoil comprising a series of discontinuous lenses of yellow to brown sand	-20.7			4140±65	2880–2665
GU-1429	FR 88 [25]	Animal bone, <i>Bos</i> (L. Barneston), c 300g – context as GU-1428	-21.4			4215±65	2890–2675
OxA-1081	FQ 83 [25]	Animal bone, <i>Microtus arvalis</i> (G. Corbet) – context as GU-1428				4800±120	-

Laboratory number *	Sample number**	Sample and context description	$\delta^{13}\text{C}$ (‰)	$\delta^{15}\text{N}$ (‰)	C:N	Radiocarbon Age (BP)	Posterior Density Estimate – cal BC (95% probability)
SUERC-62073	FQ 88 [25] (7) - sample A	Animal bone, cattle second phalanx with refitting unfused proximal epiphysis (S Fraser) – context as GU-1428	-21.2±0.2	6.4±0.3	3.2	4127±37	
UBA-29887	FQ 88 [25] (7) - sample B	As SUERC-62073: duplicate sample	-21.1±0.22	6.1±0.15	3.2	4126±35	
	FQ88 [25]	Weighted mean ($T'=0.0$; $v=1$; $T'(5\%)=3.8$;))				4126±26	2875–2655
Phase III – Deposition of domestic refuse							
GU-1694	FQ 83 [21](7)	Animal bone, <i>Ovicaprid</i> (L. Barneston), 200g, from context [21], a red brown clay layer found only in FQ 83, part of an extensive deposit of domestic refuse	-21.2			4040±80	2830–2805 (3%) or 2795–2600 (92%)
GU-1430	FQ 83 [20](2)	Animal bone, <i>Bos</i> (L. Barneston), 240g, from context [20], a dark brown layer of domestic refuse containing large quantities of artefacts and bones	-19.9			3860±60	2570–2520 (9%) or 2500–2300 (86%)
SUERC-61770	FQ 83 [20](2)	Animal bone, articulating sheep first and second phalanges (S Fraser) – context as GU-1430	-20.6±0.2	6.7±0.3	3.2	4182±34	2760–2575
Possibly continuation of Phase III; before Phase V– Continuation of deposition of domestic refuse amid accumulation of sand							
GU-1431	FR 89 [13](3)	Animal bone, <i>Bos</i> (L. Barneston), c 255g, from context [13], a dark brown sand becoming almost clayey in places, restricted to the area east of wall 16 and containing just below its top the red deer heap	-21.2			3950±65	2440–2195 (94%) or 2170–2150 (1%)
Phase V – Red deer heap							
SUERC-62077	FQ 88 [13] – purple deer	Animal bone, red deer, right femur (S. Fraser). The deer bones were concentrated in squares FQ 87, FP 87 and FQ 88, in context [13]. The deer occurred to the east of a wall. The purple deer is also known as D and the sampled bone is Bone No 159	-21.4±0.2	6.9±0.3	3.3	3796±37	2280–2245 (12%) or 2230–2130 (83%)

Laboratory number *	Sample number**	Sample and context description	$\delta^{13}\text{C}$ (‰)	$\delta^{15}\text{N}$ (‰)	C:N	Radiocarbon Age (BP)	Posterior Density Estimate – cal BC (95% probability)
UBA-29886	FR 87 [13](6) Black deer	Animal bone, red deer, rear left metatarsal (S. Fraser). As SUERC-62077. The black deer is also known as L and the sample comes from Bone No 160	-20.8±0.22	7.6±0.15	3.2	3768±41	2280–2245 (12%) or 2230–2130 (83%)
SUERC-62078	FR 87 [13](6) Blue deer	Animal bone, red deer, right radius (S. Fraser). As SUERC-62077. The blue deer is also known as C.	-21.3±0.2	6.8±0.3	3.2	3727±37	2280–2245 (12%) or 2230–2130 (83%)
OxA-32612	FQ 88 [13]	Fish bone, single thoracic vertebra, cod (<i>Gadus morhua</i>), (Sarah M. Colley), part of a virtually complete fish skeleton from context [13]. The fish, together with a large set of antlers, a gannet's wing and part of a greater black-headed gull, had been placed on the top of the heap of articulated red deer skeletons directly in front of a wall. The sample comes from bone No 219	-12.0±0.2	15.4±0.3	3.3	4118±32	-
Phase VII – Agricultural activity							
OxA-1080	FQ 88 [8](5)	Animal bone, <i>Microtus arvalis</i> (G. Corbet), from context [8], a ploughsoil on the surface of which there were clear signs of ard cultivation				3590±80	2200–1930

* The laboratory numbers in **bold** indicate the dates that were obtained as part of *The Times of their Lives* project

** Note that the numbers in round brackets are original, square-specific context numbers; those in square brackets are the final, consolidated context numbers applicable across the excavated area and it is the latter that are cited throughout this report and in Clarke *et al* (2017)

Table 2: Links of Noltland: Western area, Trench E, radiocarbon results

Laboratory number	Sample no	Sample and Context description	$\delta^{13}\text{C}$ (‰)	Radiocarbon Age (BP)	Posterior Density Estimate – cal BC (95% probability)
GU-1691	FE 87 [25]	Animal bone, <i>Bos</i> and <i>Ovicaprid</i> (J. Jewell [J Clutton-Brock]), >300g, from context [25], an occupation deposit of domestic waste comprising peat ash, animal bones, shells and pottery, contemporary with or pre-dating a stone structure, hearth and oven	-22.0	4315±80	3330–3215 (7%) or 3180–3155 (1%) or 3125–2835 (76%) or 2815–2675 (11%)

Table 3. Links of Noltland: Central area, Trench C, radiocarbon results

Laboratory number	Sample no	Sample and Context description	$\delta^{13}\text{C}$ (‰)	Radiocarbon Age (BP)	Posterior Density Estimate – cal BC (95% probability)
GU-1693	GY 69 [15]	Animal bone, <i>Bos/Cervus?</i> lumbar vertebra, <i>Cervus</i> vertebra, and <i>Bos</i> rib (M. Armour-Chelu), c 250g from a scatter of bone among features pre-dating a wall, probably a field wall	-21.5	3990±85	2875–2800 (12%) or 2780–2340 (83%)
GU-1690	GX 69 [2]	Animal bone, <i>Cervus elaphus</i> radius and other bones from partial skeleton (J. Jewell [J Clutton-Brock]), 200g, from dark brown clay-rich layer containing domestic refuse, including Beaker sherds. This layer seals an area of butchering (context [7]) and the wall. Related to deposits in northern section of Grobust structure (Trench A) by conjoining potsherd of a pot that is hard to classify: if it is Grooved Ware, it is unusual	-21.8	3760±85	2265–1975
GU-1432	GZ 69 [7]	Animal bone, <i>Cervus elaphus</i> (L. Barneston), from spread of animal bone to the south of the wall constituting a probable butchery area, with the animal remains dominated by red deer.	-21.4	3722±60	2340–2035

Table 4. Links of Noltland: Eastern Area, Trench A (Grobust), radiocarbon results

Laboratory number	Sample no	Sample and Context description	$\delta^{13}\text{C}$ (‰)	Radiocarbon Age (BP)	Posterior Density Estimate – cal BC (95% probability)
GU-1692	HQ 89/90 (204)	Animal bone, <i>Ovicaprid</i> , <i>Bos</i> , <i>Sus</i> and <i>Cervus elaphus</i> (L. Barneston) from the material filling the northern most passage at Grobust	-20.0	3850±65	2480–2135
GU-1433	HP90 (29)	Animal bone, <i>Ovicaprid</i> , <i>Bos</i> , <i>Sus</i> and <i>Cervus elaphus</i> (L. Barneston) - - context as GU-1692	-20.6	3840±60	2470–2140
GU-1695	HN 89 (165)	Animal bone, <i>Cervus elaphus</i> (J. Jewell), 240g, from material overlying a pathway entering the northern chamber of the structure at Grobust	-22.9	3750±100	2470–2005
OxA-1082	HO 85	Animal bone, <i>Lutra lutra</i> , from material filling a cell at the southern end of the structure	-	3970±80	2855–2810 (2%) or 2745–2725 (1%) or 2695–2270 (89%) or 2260–2205 (3%)

Table 5. Links of Noltland: EASE excavations, radiocarbon and stable isotope results

Laboratory number	Sample and Context description	$\delta^{13}\text{C}$ (‰)	$\delta^{15}\text{N}$ (‰)	C:N	Radiocarbon Age (BP)	Posterior Density Estimate – cal BC (95% probability)
Area 5 ‘Midden’						
SUERC-27899	Animal bone, articulated cattle phalange (Moore and Wilson 2011, 21) from context 7302	-22.0±0.2	6.4±0.3	3.8	4030±30	2625–2470
SUERC-27900	Animal bone, articulated sheep vertebrae (Moore and Wilson 2011, 21) from context 7302	-19.6±0.2	4.6±0.3	2.9	4105±30	2865–2805 (23%) or 2760–2570 (72%)
SUERC-27902	Animal bone, articulated cattle calcaneus (Moore and Wilson 2011, 21) from context 9016, infill within the kiln/flue feature directly under the ‘midden’	-21.7±0.2	4.7±0.3	3.1	4070±30	2855–2810 (12%) or 2745–2725 (1%) or 2695–2490 (82%)
SUERC-27903	Animal bone, articulated sheep vertebrae (Moore and Wilson 2011, 21) from context 9009, rubble and clay infilling the kiln	-18.2±0.2	7.0±0.3	3.2	4185±30	2890–2835 (22%) or 2820–2665 (73%)
SUERC-27904	Animal bone, sheep metapodial from a concentration of sheep bone, context 9011 (Moore and Wilson 2011, 21) from Structure 8 infill	-20.5±0.2	7.3±0.3	3.4	3635±30	-
Scheduled Area 2009						
SUERC-27901	Human bone, adult ?male femur, from context 9053, a partial burial comprising both articulated and disarticulated remains (Moore and Wilson 2011, 28)	-19.4±0.2	12.0±0.3	3.9	3280±30	-
SUERC-27908	Human bone, female (35–45 years) femur, from context 9054, a crouched inhumation (Moore and Wilson 2011, 28)	-19.4±0.2	9.7±0.3	3.2	3315±30	-

Table 6: Marine Reservoir Effect (MRE) values for the Links of Noltland

Laboratory number	Terrestrial age (BP)	Laboratory number	Marine age (BP)	MRE (BP)
SUERC-62075	3727±32	OxA-36212	4118±32	391±45
UBA-29886	3768±41	OxA-36212	4118±32	350±52
SUERC-62077	3796±37	OxA-36212	4118±32	322±49

Table 7: Point of Buckquoy: Cuttings 5 and 6 radiocarbon results

Laboratory number	Sample and context description	$\delta^{13}\text{C}$ (‰)	Radiocarbon Age (BP)	Posterior Density Estimate – cal BC (95% probability)	Reference
GU-1556	Animal bone, mixed collection, mainly red deer + unidentifiable fragments (?red deer) from midden deposits A and B, ZAC in cutting 5 and XF in cutting 6	-20	3260±90	1885–1795 (6%) or 1780–1405 (88%)	Morris 1989
GU-1222	Carbonised barley grains (approx. 7g) from midden deposit A, XF in cutting 6	-25	3260±180	2045–1290	Morris 1989
SUERC-3588	Animal bone, red deer from midden deposit A, XF in cutting 6	-22.0	3640±35	2135–2075 (14%) or 2065–1910 (81%)	Ascough <i>et al</i> 2007
SUERC-3572	Animal bone, red deer from midden deposit A, XF in cutting 6	-22.4	3645±40	2135–1910	Ascough <i>et al</i> 2007
SUERC-3573	Animal bone, red deer from midden deposit A, XF in cutting 6	-22.5	3625±40	2130–2080 (9%) or 2060–1885 (86%)	Ascough <i>et al</i> 2007
SUERC-3575	Animal bone, red deer from midden deposit A, XF in cutting 6	-22.1	3685±40	2195–2175 (2%) or 2150–1945 (93%)	Ascough <i>et al</i> 2007

Table 7: *Skail Bay radiocarbon results*

Laboratory No*	Sample and context description	$\delta^{13}\text{C}$ (‰)	Radiocarbon Age (BP)	Posterior Density Estimate – cal BC (95% probability)	Reference
SUERC-4850	Antler, red deer (sample SB/Ant 2/1)	-21.1	3825±35	2300–2140	Ashmore 2005; Richards <i>et al</i> 2016b
SUERC-4851	Antler, red deer (sample SB/Ant 2/4)	-20.8	3775±35	2300–2140	Ashmore 2005; Richards <i>et al</i> 2016b



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