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To cut a long story short: formal chronological modelling for the Late Neolithic site of Ness of Brodgar, Orkney --Manuscript Draft--

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	<p>neighbour of Barnhouse, in use from the later 32nd to the earlier 29th century cal BC, and the Stones of Stenness, probably constructed by the 30th century cal BC. The Ness, including Structure 10, appears to have outlasted Barnhouse, but probably did not endure in its primary form for as long as previously envisaged. The decay and decommissioning of the Ness might coincide with the further development of the sacred landscape around it; but precise chronologies for both the Ring of Brodgar and Maeshowe are urgently required. The spectacular feasting remains deposited above Structure 10 may belong to a radically changing world, coinciding (in Model 2) with the appearance of Beakers nationally, but it was arguably the by now mythic status of that building which drew people back to it.</p>	
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To cut a long story short: formal chronological modelling for the Late Neolithic site of Ness of Brodgar, Orkney

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In the context of unanswered questions about the nature and development of the Late Neolithic in Orkney, a summary is given of research up to 2015 on the major site at the Ness of Brodgar, Mainland, concentrating on the impressive buildings. Finding sufficient samples for radiocarbon dating was a considerable challenge. There are indications from both features and finds of activity predating the main set of buildings exposed so far by excavation. Forty-six dates on 39 samples are presented and are interpreted in a formal chronological framework. Two models are presented, reflecting different possible readings of the sequence. Both indicate that piered architecture was in use by the 30th century cal BC and that the massive Structure 10, not the first building in the sequence, was also in existence by the 30th century cal BC. Activity associated with piered architecture came to an end (in Model 2) c. 2800 cal BC. Midden and rubble infill followed. After an appreciable interval, the hearth at the centre of Structure 10 was last used c. 2500 cal BC, perhaps the only activity in an otherwise abandoned site. The remains of some 400 or more cattle were deposited over the ruins of Structure 10: in Model 2, in the mid-25th century cal BC, but in Model 1 in the late 24th or 23rd century cal BC. The chronologies invite comparison with the near-neighbour of Barnhouse, in use from the later 32nd to the earlier 29th century cal BC, and the Stones of Stenness, probably constructed by the 30th century cal BC. The Ness, including Structure 10, appears to have outlasted Barnhouse, but probably did not endure in its primary form for as long as previously envisaged. The decay and decommissioning of the Ness might coincide with the further development of the sacred landscape around it; but precise chronologies for other sites in the surrounding landscape are urgently required. Spectacular feasting remains deposited above Structure 10 may belong to a radically changing world, coinciding (in Model 2) with the appearance of Beakers nationally, but it was arguably the by now mythic status of that building which drew people back to it.

Questions for Late Neolithic Orkney

A series of striking changes in practice from the late fourth to the mid-third millennia cal BC characterise what can be defined as the Late Neolithic in Orkney. Although continuing survey and excavation are revealing more settlements from earlier stages of the Neolithic and thereby a long established insular tradition of constructing houses in timber and later on in stone (Richards & Jones, 2016), it appears that Late Neolithic settlements became more numerous, and in some instances, much larger than their predecessors. Their greater archaeological visibility was the outcome of a shift to the regularity with which substantial, well-made, stone-walled houses were built, often in concentrated or nucleated layouts. There were some monumental structures, such as the Maeshowe passage tomb, and much skill in building with stone was displayed. This has been claimed as a time when the house, as social fact and pervasive metaphor, dominated social strategy (Richards, 2013; Richards & Jones, 2016). The idea of chambered cairns persisted into this period, but now, in contrast to earlier styles of simple-chambered and stalled cairns, these probably principally took the form of the passage grave, of ‘Maeshowe’ type (Henshall, 1972), seen in the construction of monuments such as Quanterness, Quoyness and Maeshowe itself (Renfrew, 1979; Davidson & Henshall, 1989; Schulting et al., 2010; Griffiths & Richards, 2013; MacSween et al., 2015; Griffiths, 2016). Their elaborate architecture, with marked separation of the interior from the exterior, controlled access via passages, and gradation among internal chambers, may have derived from or been part of active connections with the apogee of the passage tomb tradition in eastern Ireland (Sheridan, 2004; Schulting et al., 2010; Hensey, 2015).

Another innovation was the stone circle, as manifest in the form of the Stones of Stenness, probably constructed by the 30th century cal BC (Ritchie, 1976; Griffiths & Richards, 2013), and even more spectacularly in the shape of the Ring of Brodgar, possibly (but far from certainly) in the middle part of the third millennium cal BC (Downes et al., 2013). Whether this was an invention of people in Orkney (Sheridan, 2004; 2012) or the outcome of more widely distributed social connections (Griffiths & Richards, 2013: 286) remains open to debate. That such links to further afield existed and probably intensified in the Late Neolithic is seen in the range of other places from which materials or practices present in Orkney originated, including pitchstone from Arran, flint from mainland Scotland and possibly beyond, tuff from the central Fells of Cumbria (Mark Edmonds, *pers. comm.*) and passage grave decorative motifs from eastern Ireland (Sheridan, 2004; Card & Thomas, 2012). Stone maceheads and balls add to the picture of material elaboration (Simpson & Ransom, 1992; Sheridan, 2014).

Finally, the novel style of Grooved Ware, replacing an earlier tradition featuring the use of Unstan bowls and associated decorated and plain round-based pottery, appeared in Orkney, from at least the later 32nd century cal BC at Barnhouse (Richards, et al., 2016). Flat-based, bucket-like forms in a wide range of sizes, with varying incised and applied decoration, characterise the new ceramic assemblages. Some of those in Orkney have close similarities to others much further away in other parts of Britain (Wainwright & Longworth, 1971; MacSween et al., 2015; Richards et al., 2016). Whether the new style originated exclusively in Orkney, where the biggest assemblages have been found so far, or in more widely dispersed social networks has again been the subject of debate (Sheridan, 2004; Thomas, 2010; Richards, 2013; Sheridan, et al., in prep.). There is no doubt, however, that Late Neolithic Orkney was a place where the combination of changes was extensive, and the pace of change probably intense, even though we cannot claim that all the innovations listed above came in at the same time. That uncertainty defines the first of a whole series of unanswered questions. How quickly did change happen, and what was the timing and tempo of subsequent development? What kind of communities and worldviews are we dealing with? What role did the outside world play in the initiation and maintenance of Late Neolithic Orkney society and material practice? What were the circumstances in which the Late Neolithic ended in Orkney, and when?

Ness of Brodgar: the story so far, 2003–15

The Ness of Brodgar (Fig. 1) sits on the SE tip of the Brodgar isthmus separating the Loch of Harray to the east, and the Loch of Stenness to the west, at the centre of the large natural bowl of hills of the West Mainland of Orkney. From it the Ring of Brodgar (0.75 km to the NW), the Stones of Stenness (0.5 km to the SE) and Maeshowe (1.5 km to the E) are clearly visible. On the south side of the Bridge of Brodgar, barely 300 m distant, is the Neolithic settlement of Barnhouse (Richards, 2005).

The site is in the middle of the ‘Heart of Neolithic Orkney’ World Heritage Site (Historic Scotland, 1998). That designation was awarded in 1999, before the discovery of the Ness. In 2002 the area was geophysically surveyed as the pilot study for the Heart of Neolithic Orkney Geophysics Programme (GSB 2002; Card et al., forthcoming), the results unexpectedly revealing a mass of anomalies covering the peninsula. Their nature and character started to be realised the following year when investigations of a large notched slab discovered during ploughing revealed architecture similar in form to House 2 at nearby Barnhouse (Ballin Smith, 2003). Between 2004

and 2008 trial trenching to investigate the nature of the mound and the threat from agricultural practices gave indications that this massive mound (c. 250 m by 100 m, lying NW–SE, and over 4 m high), previously considered a natural feature of the landscape, was mainly artificial and consisted of a sequence of Neolithic buildings, middens and midden-enhanced soils.ⁱ Since 2008, area excavation (though still less than 10% of site) has been carried out (Fig. 2). This has revealed a complex sequence of monumental buildings contained within a massive walled enclosure. In its latter phases the site is dominated by several large buildings which, judging by their scale and architectural finesse, would appear to be outside the norm for the domestic sphere. This is also reflected in the artefactual assemblage and over 700 examples of decorated stone (Card & Thomas, 2012).

Due to the depth and complexity of the stratigraphy, and the exceptional preservation of the architecture, only the later phases of the site have so far been investigated in detail. Although in several cases construction levels have yet to be reached and cross-site stratigraphic relationships fully determined, a preliminary phasing of the site is possible. Selective sondages between buildings have revealed definitive relationships between several buildings, while other more obvious relationships are discernible where a clear sequence of construction is visible (Fig. 3).

The earliest physical evidence of activity are a few sherds of Modified Carinated Bowl, discovered in 2014 in a sondage sitting on the natural boulder clay under a robbed-out wall of Structure 14. Presumed structural remains associated with this pot have yet to be found.

Other activity pre-dating the construction of the large pierced buildings is represented by several lengths of walling revealed between, under, and in some cases incorporated into, the buildings presently under investigation. Other earlier buildings are also implied by the subsidence, collapse and the undulating nature of wall lines of later buildings. These earlier buildings, where revealed, utilise orthostats partially built into wall lines to define internal space similar to stalled tombs and early Neolithic houses. It is presumed that the surrounding walled enclosure was first constructed during these earlier phases.

In the later phases, orthostats are replaced by the use of opposed stone-built piers to create recesses along internal wall faces as in Structures 1, 8, 12, 14 and 21, each of which saw several phases of reuse and remodelling. These buildings (which are the present focus of excavation) can be seen as exaggerated or elongated versions of Neolithic houses of the kind seen, for instance,

in the early phase of Skara Brae (Clarke, 1976). A paved area with a standing stone is central to the whole of the walled enclosure at this stage.

The last major construction so far identified, Structure 10 (Fig. 4), is a departure in style and scale from earlier building styles. It partially overlies the collapsed remains of the piered Structure 8. Its internal square chamber with rounded corners bears close comparison with Structure 8 at Barnhouse (Richards, 2005), as does its scale (some 20 by 19 m externally), which mirrors a general trend to monumentality in the Late Neolithic of Orkney. As with the piered structures at the Ness which mirror other house plans but on an exaggerated scale, so too does Structure 10 reflect later house styles, such as House 1 at Skara Brae (Clarke, 1976). Although the foundations of Structure 10 show the overall monumentality of its build, as with the majority of other late structures at the Ness it suffered from subsidence. That may have been the cause of the collapse of its SW corner. It was rebuilt with extensive remodelling of the interior into a cruciform plan with the addition of new wall faces and corner buttressing.

At the end of these monumental phases, the buildings at the Ness were partly demolished and infilled with layers of midden and rubble. The placing of a structured deposit of mainly cattle bone around Structure 10 has been seen as part of this decommissioning process (Mainland et al., 2014). This has been suggested as ‘a single depositional event’ or ‘at the least a series of events occurring over a fairly short period of time’ (Mainland et al., 2014: 875). Later, some of the walls of the structures were systematically robbed of stone. Ephemeral activity continued, but on a much reduced scale.

Outside the walled enclosure at the very tip of the peninsula a large partially quarried mound previously considered to be a broch has been shown to be an integral part of the development of the Ness. The preliminary geophysical survey of this mound revealed concentric anomalies encircling the mound which were interpreted as revetments, as present at various Maeshowe-type tombs. Initial investigations in 2013 showed that these were revetments but related to a remodelling of the mound, probably in the Iron Age, as a revetted, rubble-filled ditch around its summit produced pottery of this date. The vast majority of the mound consists of a monumental Neolithic midden heap over 70 m in diameter and in excess of 4 m high. In 2015, near the bottom edge of the mound, and predating the deposition of the midden, structural remains have been partially revealed that may represent a robbed-out chambered cairn. The structural elements revealed so far have parallels with the tomb of Bookan that lies 2 km to the NW (Card, 2006).

Apart from Grooved Ware being present in both the main trenches there is no direct stratigraphic relationship between the two areas. It is presumed, however, that the midden utilised in the creation of this monumental mound was a result of activity associated with the structures revealed elsewhere at the Ness.

A large assemblage of Grooved Ware in Trench P, dominated by sherds from overlying midden deposits, was characterised by applied cordons, both plain and incised (Towers & Card, 2015). By contrast, Grooved Ware pottery from Trench J is mainly shell-tempered and is from fairly large and thin-walled vessels with flat bases and flat, simple rounded and interior bevelled rims principally with incised decoration (MacSween, 2008). The assemblage as a whole will be assessed in subsequent synthesis (Sheridan et al., in prep.) for the project, *The Times of Their Lives* (ToTL: see Acknowledgments), within which the current paper is offered.

The exceptional architecture, the diversity of structures (Fig. 5), and the evident size and spatial complexity of the Ness of Brodgar all emphasise its special character. Even the newly discovered external midden mound may speak to themes of conspicuous consumption, status and affluence. The discovery and present investigation of the site add to the list of research questions noted at the start of this paper. Could the Ness of Brodgar have acted as a focus for communities not only locally but across the Orkney archipelago and possibly beyond? If so, who pulled the strings and made decisions? How was the site articulated into its local setting, in relation to other known sites such as Barnhouse, or monuments such as Maeshowe, the Stones of Stenness and the Ring of Brodgar? How quickly did the site come into being, how long did it last, and did it retain the same character over the course of its life? That puts basic questions of chronology centre-stage.

Aims of the Ness of Brodgar dating project

The dating presented here has been within the Orkney component of the ToTL project, which seeks to refine our understanding of the development of Late Neolithic settlement and Grooved Ware pottery, by formal chronological modelling of scientific dates. The project has investigated Pool (MacSween et al., 2015), Barnhouse (Richards et al., 2016) and the Links of Noltland (Clarke et al., in prep.). It is also contributing to a new formal chronology for Skara Brae.

A number of specific objectives relating to the site sequence at the Ness of Brodgar were identified:

- to provide formal estimates of the date and duration of activity

- to provide a precise date for the deposition of the cattle as part of the late history of Structure 10
- to help in the construction of an archaeomagnetic calibration curve for the Late Neolithic period.

Radiocarbon dating and chronological modelling

The radiocarbon dating programme for the Ness of Brodgar 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. At the Ness of Brodgar a number of stratigraphic relationships between stone-walled structures and the surrounding midden layers were available to constrain the radiocarbon dates (Fig. 6).

A limited number of radiocarbon dates had been obtained as part of doctoral studies into aspects of the geoarchaeology of the site (Cluett, 2008) and dietary reconstruction of the Neolithic-Bronze Age transition in Orkney (Chelsea Budd, *pers. comm.*). The dating of three charcoal samples from below the southern boundary wall was funded by the BBC for an episode of *A History of Ancient Britain*.

Material suitable for radiocarbon dating was scarce. Unburnt bone did not survive particularly well, the exception being the mass of cattle bones associated with the near-final act at Structure 10 (Mainland et al., 2014) and charred plant remains were scarce. Sherds were scanned for the presence of charred residues which might represent carbonised organic material, although in many cases what appeared to be ‘residue’ was covered by a thin layer of ‘midden’ material that precluded sampling. Fragments of calcined bone were available from hand-collection and bulk environmental samples. The amount of burnt bone recovered suggests a scale of burning beyond that which might be expected from the routine burning of domestic waste (Richards, 2005; Card, 2010), and there is evidence for spatial variation in both the intensity of burning and the species and elements represented.

Rarely was there a choice of material for sampling, and with the exception of carbonised residues from refitting sherds, only one of the samples was ‘articulated’. Thus a high proportion of the samples have the potential to be residual in the context from which they were recovered. Some samples have a plausible functional relationship with their parent contexts (such as calcined bone

in hearth deposits) and in some cases the state of preservation of large and unabraded sherds may suggest that they are not reworked, but in other cases the taphonomy of the dated material is much more uncertain (such as most of the single sherds from midden deposits).

In addition to some of the issues outlined above, the nature of the buildings, with stone-built foundations and walls, means that potential samples suitable for radiocarbon dating and functionally related to the archaeological ‘event’ — stone wall construction — are extremely rare. This contrasts with much Late Neolithic monumental construction, particularly from southern Britain, which is based on the digging out of ditches, stoneholes and postholes, and the raising of banks and mounds, where tools used in their construction such as antler picks and scapula shovels are regularly found. An architecture based on stone foundations does not in itself produce samples for dating, unlike the wooden-built structures associated with the digging of postholes.

The Ness of Brodgar therefore offers a challenging opportunity to determine how we build chronologies for such settlement and monument complexes built of stone. The paucity of contexts with potential samples for scientific dating related to key ‘archaeological events’ — the building and abandonment of structures — contrasts with the potentially huge pool of samples from the ‘residues’ of activity taking place in the structures which will have ended up on the midden heap and midden deposits used on the site, which are yet to be fully explored.

Radiocarbon results

A total of 65 radiocarbon measurements are now available from the Ness of Brodgar (Tables 1–2). All are conventional radiocarbon ages (Stuiver & Polach, 1977).

Samples of animal bone, carbonised residue, charred plant remains, and calcined bone were measured by Accelerator Mass Spectrometry (AMS) at the Oxford Radiocarbon Accelerator Unit (ORAU). The samples were pretreated and combusted as described in Brock et al. (2010), graphitised (Dee & Bronk Ramsey, 2000) and dated (Bronk Ramsey et al. 2004).

The Scottish Universities Environmental Research Centre (SUERC) processed samples of bulk soil, charcoal, charred plant material, charred residues, and calcined and non-calcined bone, which were dated by AMS using the methods described in Dunbar et al. (2016).

The ¹⁴CHRONO Centre, The Queen's University, Belfast processed 16 samples using methods described by Reimer et al. (2015). Charred residues were pretreated using an acid wash; charred plant remains were prepared using an acid-base-acid protocol; and samples of calcined bone were pretreated as described by Lanting et al. (2001). All samples were graphitised using zinc reduction (Slota et al., 1987), except for UBA-26534, -29335–6, -29752 and -29754, which were subject to hydrogen reduction (Vogel et al., 1984).

Quality assurance

All three laboratories maintain continuous programs of internal quality control in addition to participation in international inter-comparisons (Scott et al., 2007; 2010). These tests indicate no laboratory offset and demonstrate the validity of the precision quoted.

Two pairs of replicate and two sets of triplicate measurements are available on samples that were divided and submitted for dating to different laboratories. In all cases the measurements are statistically consistent at 95% confidence (Table 1; Ward & Wilson, 1978). These measurements on the same samples have therefore been combined by taking a weighted mean before calibration and inclusion in the chronological models.

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 models are defined by the OxCal CQL2 keywords and by the brackets on the left-hand side of Figs 7 and 9. 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 radiocarbon samples dated as part of a PhD thesis on soils and sediments in the World Heritage Site buffer zones (Cluett, 2008) were selected to provide a chronology for soils and sediment-based cultural records. The excavated trenches were deliberately located away from the main structural features and cannot be directly related to the excavated archaeological evidence. Although sample selection was based on sound principles — single entity, short-lived fragments of charcoal and single fragments of calcined bone — the utility of the results in contributing

anything beyond the fact that Late Neolithic material exists in the soils surrounding the site is such that we have not included them in the chronological modelling.

A series of earlier structures are indicated by walling encountered under Structure 8 (Structures 17 and 18), Structure 10 (Structure 20), Structure 12 (Structures 23 and 24) and Structure 5, which was excavated in Trench J adjacent to the northern boundary wall. It is perhaps during this stage of development that the massive stone enclosure was built to contain all these buildings. The three samples from under the southern boundary wall provide *termini post quos* for its construction (Fig. 7). Whether the *Pinus sylvestris* charcoal represent trees growing on the island at this time (Farrell, 2015) or driftwood (Dickson, 1992) is open to debate. However, the three measurements are statistically consistent ($T^*=0.5$; $T^*5\%=6.0$; $v=2$) and could be of the same actual age (Fig. 7).

Trench P

The construction and primary use of Structures 1, 8, 12, 14, 16 and 21 (plus several others revealed by the geophysical surveys) probably occurred over a relatively restricted period of time. Similarities in architecture of the main buildings (the use of pairs of opposed stone piers to define internal space) and their spatial respect for each other are taken, for the present, to imply their contemporaneity. This would appear to be borne out by the proven stratigraphic relationships between Structures 1 and 14, and 1 and 21.

Five samples have been dated from the secondary phase of Structure 1 (Fig. 7). The latest use of the sub-square hearth [3603] from its 'secondary' phase is dated by calcined bone fragments (SUERC-55462 and UBA-26531) from hearth fill [3603] that is stratigraphically below [3247], a silt layer, dated by calcined bone fragments SUERC-55465 and UBA-26536. For both contexts the pairs of measurements on single fragments of calcined bone are statistically consistent ($T^*=2.0$; $T^*5\%=3.8$; $v=1$) and could be of the same actual age. Carbonised residue (SUERC-55466) from SF 7423, a single sherd of a Grooved Ware vessel from a levelling deposit [2114], which may have been part of the initial backfilling of the structure at the end of its tertiary phase, is stratigraphically later than the hearth, but appears to be a residual sample and is thus incorporated into the model as a *terminus post quem*.

Two calcined animal bone fragments (SUERC-55463 and UBA-26532) from the lowest use fill of hearth [2679] are statistically consistent ($T^*=2.1$; $T^*5\%=3.8$; $v=1$) and represent the primary

episode of burning in the feature in the centre of Structure 7 (Fig. 7). Structure 7 is stratigraphically later than Structure 8 and its use is therefore likely to have been contemporary with the use of Structure 10.

Two samples have been dated from Structure 8 (Fig. 7). A single calcined bone (UBA-26335) from the lowest hearth deposit [3806] provides a date for its initial use, and a carbonised residue (SUERC-60417) from a large, thick Grooved Ware body sherd provides a date for its infilling with midden deposits prior to the construction of Structure 10.

Seven samples have been dated from the secondary use of Structure 12 and its annex (Fig. 7). Four measurements (calcined bone, UBA-26533, and three single barley grains, OxA-32069, SUERC-60419 and UBA-29335) from the black charcoal 'hearth' layer [4509] are not statistically consistent ($T^*=89.1$; $T^*5\%=7.8$; $v=3$), but measurements on the three grains are ($T^*=1.5$; $T^*5\%=6.0$; $v=2$). The calcined bone fragment (UBA-26533) is considerably older than the grains and has been included in the model as a *terminus post quem*; it could either be residual or have a fuel-derived offset (see below). Measurements on sherds from two Grooved Ware vessels, SF 20850 and SF 21623, from [5337] are statistically consistent ($T^*=0.2$; $T^*5\%=3.8$; $v=1$). Part of [4508], the large spread of fragmented ceramics [5337], may have formed as the result of the roof of Structure 12 collapsing on to pots standing upright on the floor just to the east of the hearth. Carbonised residue adhering to the interior of Grooved Ware sherds from a very large pottery deposit between the northerly hearth and the interior entrance to the annex of Structure 12 and sealed by the lowest midden infill deposits ([2278] and [2287]) provides a date for the end of use of the annex.

Two samples, single grains of carbonised barley from the west [4662] and east hearths [4613], were dated from Structure 14 (Fig. 7). The two determinations are statistically consistent ($T^*=0.1$; $T^*5\%=3.8$; $v=1$).

Following subsidence and the roof collapse of Structure 8, Structure 11 was built against its southern end, while similarly Structure 19 was built against the west wall of Structure 8 (Fig. 3). At this time the start of midden dumping within Structure 8 and the central midden area began, although no samples deriving from this activity could be identified for dating.

The primary phase of Structure 10 necessitated the removal or clearing of the south-east section of the collapsed Structure 8, and was built with a square central chamber with rounded corners and extensive use of dressed stone. The monumental foundation slabs of Structure 10 may in part be an (ultimately unsuccessful) attempt to counteract the subsidence evident elsewhere on the site (as in Structure 8). The construction of the Structure 10 annex area (slightly later than the original build) at its east end incorporates at least one standing stone. After potential partial collapse of its primary build a thick, very mixed clayey levelling or floor deposit was laid, particularly over the north side where subsidence is most evident, and new internal walls and corner buttresses were built to create a cruciform central chamber. Dressers and orthostatic arrangements were also inserted, but compared to the original build this secondary phase is rather shoddily constructed.

Measurements on carbonised residues adhering to sherds of different vessels (UBA-26529 and OxA-30950) from a foundation deposit [4381] associated with the remodelling of Structure 10 are statistically consistent ($T'=0.9$; $T'5\%=3.8$; $v=1$) and provide *termini post quos* for its rebuilding (Fig. 7). A sequence of samples from the central hearth in Structure 10 were dated. At the base of this sequence, SUERC-55458 was measured on a fragment of calcined cow humerus, from [3490], an *in situ* burning deposit that underlies [3482], a ?midden-enhanced soil rather than a true hearth deposit. Measurements on two fragments of cremated animal bone from [3482] are statistically different ($T'=29.0$; $T'5\%=3.8$; $v=1$), although those from overlying [3488], the uppermost fill of the hearth, are statistically consistent ($T'=2.4$; $T'5\%=3.8$; $v=1$).

The end of the formal use of Structure 10 as a building sees it being demolished and infilled with a sequence of middens and rubble deposits, as are Structures 8, 12, 14 and 16 but with apparent intervals between various episodes of deposition and ephemeral reuse of the structures. Further deposition of large amounts of midden in the 'Central Midden Area' perhaps originates from tertiary phases of activity.

The late history of Structure 10 sees it reused with an elaborately pecked stone placed next to an upturned cattle skull in the central hearth and the surrounding pathway backfilled, the uppermost fill [1403] of which contained a monumental amount of mainly cattle bone (Mainland et al., 2014). Radiocarbon determinations on eight samples from the cattle deposit [1403] are statistically consistent ($T'=12.3$; $T'5\%=12.3$; $v=7$). The bones dated from the cattle bone deposit as part of the ToTL project were chosen to maximise the likelihood that separate individuals

were being sampled. Five tibiae were sampled (SF 72, SF139, SF213, SF98, SF32), all of which are from different animals, on the basis of body side and fragmentation. The remaining sample from this deposit, a cattle mandible (SF147), could, however, derive from one of these five individuals, as could the two unidentified skeletal elements (CBNB1 and 2; OxA-25032 and OxA-25033).

Finally, the remains of articulated red deer skeletons were deposited over part of the Structure 10 bone layer and one of these (SUERC-55468) provides a *terminus ante quem* for deposition of the cattle remains.

Trench T

Two samples from Trench T (Fig. 2 and Fig. 7), on the 70-m diameter mound located on the south-eastern portion of the low ridge occupying the Brodgar peninsula, were dated to provide an indication of when a very large animal, perhaps an auroch, died and whether the midden surrounding it could be contemporary with this. The two measurements (SUERC-61360 and SUERC-61343) are statistically consistent ($T^*=3.1$; $T^*5\%=3.8$; $v=1$) and could therefore be of the same actual age.

Trench J

A series of stratigraphically related samples from a number of hearth deposits overlying Structure 5 in Trench J were submitted to provide an idea of the length of activity in this part of the site, in which the Grooved Ware was markedly thinner-walled than the Grooved Ware elsewhere at the Ness and was also dominated by shell filler (Ann MacSween, *pers. comm.*), and therefore probably of different date from the majority of activity in Trench P. The radiocarbon dates, although on samples with a plausible functional relationship to their contexts (charcoal and calcined bone from hearths) do not, however, form a coherent chronological sequence (Fig. 8) and must represent the incorporation of residual material from activity that significantly predates the main phase of activity at the site. As such they have been excluded from the chronological modelling, but at the same time they provide a tantalising glimpse of the time-depth to the history of the Ness of Brodgar as a place of human activity.

Assessment

Of the 65 radiocarbon determinations from the Ness of Brodgar, 13 have been excluded from the analysis, seven because they are not from trenches excavated as part of the main

archaeological investigations (Table 2) and six from Trench J as deposits here seem to contain material deriving from earlier activity. The model thus includes 46 determinations on 39 samples. Five samples that are potentially residual are included as only providing *termini post quos* for overlying deposits (UBA-26533, SUERC-35999–36000, SUERC-36004 and SUERC-55466), and therefore 34 samples are believed to provide accurate ages for the deposits from which they were recovered.

In assessing the reliability of the model for the Ness of Brodgar we need to reflect on the number of dated samples available from different parts of the site. Structure 1 has five dated samples, Structure 7 two, Structure 8 two, Structure 10 sixteen, Structure 12 and its annex seven, Structure 14 two, Trench R three, and Trench T two. We clearly have fewer dated samples than would be ideal from structures and it is disappointing that no samples could be found from a number of Structures (9, 11, 16, 19, 21 and 22). Our model quite clearly therefore under-samples activity at the site and as such can only provide an imprecise picture of the chronology.

The confidence we have placed on samples of calcined bone (13 out of 39) is a further consideration in assessment of the reliability of the model. Fuel used in the cremation process, in the case of the Ness of Brodgar this being represented by the large hearths, has been shown in experimental work (Snoeck et al., 2014) to contribute to the carbon in calcined bone apatite along with components from the atmosphere and the dated individual. This could be an issue at the Ness of Brodgar, as for the one hearth ([4509] in Structure 12) where it was possible to find samples of calcined bone and charred material (barley grains), the calcined bone (UBA-26533) is considerably older in age (327 ± 36 yrs BP older than a weighted mean of the three charred barley grains: SUERC-60419, UBA-29335, and OxA-32069).

The possibility of fuel offsets has to be taken into account but these may not be substantial. The absence of cramp (Photos-Jones et al., 2007) indicates that seaweed was not used as a fuel and therefore we have no reason to believe there any of the calcined bone dated from the site has a marine offset. Ongoing analysis of the fuels used at the Ness of Brodgar indicates a significant utilisation of turf for burning, with heather and seeds indicative of such practices being identified from hearth features. Wood fuel has also been identified but to a lesser extent than turf and so far shows a varied assemblage of approximately ten different arboreal taxa. The tree types attested from the charcoal record indicate a landscape dominated by scrub woodland largely of birch, with some hazel. Areas of wetland woodland are also shown by the presence of alder and

willow, while there is some evidence of stands of deciduous woodland from the presence of smaller numbers of oak, Pomoideae and pine, together with other coniferous charcoal. The occurrence of larch/spruce is likely to represent the use of driftwood and this has also been suggested for the pine, although pollen evidence (Farrell, 2015) has indicated that pine was probably present in the woodlands of Orkney. For the most part, the short-lived species indicated support the conclusion that any inbuilt age offset in the cremated bones is likely to be minimal.

Finally, radiocarbon offsets can occur if samples (such as animals or carbonised residues) have taken up carbon from a reservoir not in equilibrium with the terrestrial biosphere (Lanting & van der Plicht, 1998). Dietary stable isotope measurements from animals (Table 1; Jones & Mulville, 2015), together with lipid analysis of cooking vessels (Cramp et al., 2014), confirm that offsets from freshwater or marine reservoirs are not found at this site.

Interpretations

Two models for the chronology of activity at the Ness of Brodgar are presented in detail. The first of these (Model 1) is based on the assumption that the dated material from Trenches P and T derives from a single continuous phase of activity (Buck et al., 1992). The second (Model 2) incorporates an alternative reading of the archaeological evidence relating to the later use of Structure 10, and in particular to the relationship of the large hearth in the remodelled structure to the main phase of activity associated with the distinctive piered architecture. In this alternative reading, outlined in detail below, the hearth in the remodelled Structure 10 and the deposition of the cattle remains are interpreted as being a separate phase of activity from that associated with the stratigraphically earlier piered architecture. The activity is thus modelled in terms of separate, but successive, periods of continuous activity with an interval of unknown duration between them.

Model 1

Model 1, shown in Fig. 7, interpreting the activity in Trench P and Trench T as a single continuous phase, has good overall agreement (Amodel: 86) between the radiocarbon dates and this reading of the archaeological evidence. The model estimates that the main dated phase of activity at the Ness of Brodgar began in *3060–2950 cal BC (95% probability; start NoB; Fig. 7)*. There is, however, earlier activity at the site which has yet to be excavated fully, such as the structures discovered under the southern boundary wall of the site, and the primary phases of

Structures 1, 12 and 10. The sherds of round-based Modified Carinated Bowl discovered embedded into the natural substrate under Structure 14 further support the view of earlier, pre-Grooved Ware Neolithic activity at the Ness. Thus, although the dating programme has provided an estimate for the primary use of Structure 8, and secondary use of Structures 1, 12 and 14, this is only a *terminus ante quem* for the beginning of the monumental building activity.

The earliest dated material from Structures 1, 8, 12 and 14 suggests that they were in use during the 31st to the 30th centuries cal BC, although for Structures 1, 12, and 14 samples from hearth deposits do not derive from their primary use.

Providing formal estimates for the end of use of the structures is extremely challenging, due to the difficulty in finding samples associated with such events. However, for Structure 12, the roof collapse that resulted in the smashing of pots near the hearth occurred in 2855–2835 cal BC (2% probability; *last_st_12*; Fig. 7) or 2820–2585 cal BC (93% probability). The replacement of Structure 8 by Structure 10 is estimated to have occurred in 2990–2895 cal BC (95% probability; *end_st8_start_st10*; Fig. 7). Thus, compared to other structures on the site, Structure 8 would therefore have been standing for a relatively short period of time, although providing a robust estimate for this is problematic given that only a single dated sample relates directly to its use.

Structures 7 and 10 were both built later than Structure 8. Although no samples were dated from the first phase of use of Structure 10, it is estimated to have been constructed in 2990–2895 cal BC (95% probability; *end_st8_start_st10*; Fig. 7), with its remodelling estimated to have taken place shortly after 2915–2885 cal BC (95% probability; *st10_secondary_build*; Fig. 7), when a significant quantity of pottery was deliberately deposited prior to rebuilding.

Midden above the clay capping sealing the earliest phase of midden deposition in Trench T started to accumulate in the 29th to 27th centuries cal BC (Fig. 7).

Construction of the large hearth in the remodelled Structure 10 must have begun just prior to the deposition of one of its first fills around the very end of the 29th century cal BC. Although the hearth contains no obvious evidence for a hiatus, it was last used in 2550–2460 cal BC (95% probability; *central_hearth_st10*; Fig. 7). This would suggest that either the hearth was partially cleaned on a regular basis over its apparently centuries-long lifespan, or that a break in its use is

not visible. During the lifespan of the remodelled Structure 10, many of the other structures were backfilled with ‘midden’ material.

The final use of what at that time may have simply been the foundations of Structure 10 began with the placement of a vast number of predominantly cattle remains that took place an estimated *135–320 years (95% probability; distribution not shown)* after the last use of the hearth, in *2340–2200 cal BC (95% probability; structure_10_cattle; Fig. 7)*. The final act in the history of Structure 10 occurred with the deposition of a red deer skeleton in *2290–2125 cal BC (95% probability; SUERC-55468; Fig. 7)*.

Model 2

Model 2 (Fig. 9) presents an alternative reading of the archaeological evidence for activity at the Ness of Brodgar. The model interprets the activity associated with the construction and use of the piered structures (dated by samples from Structures 1, 7, 8, 10, 12, 14 and the Trench T midden) as a single continuous phase (Buck et al., 1992) that is followed by a hiatus (after the deposition of layers of midden and rubble) before the final phase of activity in what by that time may have only been the remains of Structure 10.

The key components that differentiate Model 2 from Model 1 are, first, that two phases of coherent activity (piered architecture and the last use of Structure 10) are separated by a hiatus. Secondly, the dated calcined bone (SF bone 1524) from the basal hearth deposit [3482] is interpreted as residual; it is significantly earlier than another dated single fragment of calcined bone (SUERC-55457) from the same context, and earlier than samples from the last use of the hearth. The visible, horizontally bedded, layers within the hearth suggest only a continuous, short period of use, with no evidence for cleaning out, recutting or hiatus (Fig. 10). Thirdly, the cattle deposited in Structure 10 are seen as having probably all died at the same time, since ‘the faunal assemblage together with a comparable stratigraphic record in each excavated area is indicative of a single depositional event’ (Mainland et al., 2014, 875). Hence the probability distributions of the calibrated dates obtained from the cattle can be combined (using the OxCal function Combine), as they are not from the same organism, to produce an estimate for the date of this event. Fourthly, the deer placed on top of the cattle spread is not interpreted as part of that phase of activity, but is seen as a later isolated act.

The chronological model shown in Fig. 9 has good overall agreement ($A_{\text{model}}: 92$), suggesting that the radiocarbon dates do not contradict the reading of the archaeological sequence outlined above (Model 2). This model suggests that the first dated activity associated with the use of structures characterised by piers architecture took place in 3020–2920 cal BC (95% probability; *start_NoB*; Fig. 9). The ending of the activity in the dated piers structures is estimated to have occurred in 2855–2665 cal BC (95% probability; *end NoB*; Fig. 9). On this reading, the monumental structures were therefore in use for between 70 and 305 years (95% probability; *piers_architecture*; Fig. 11).

Following the end of activity associated with the piers structures a period of disuse ensued, lasting for 30–335 years (95% probability; *gap_1*; Fig. 11). Following this potentially considerable gap, activity in what were by then probably only the remains of Structure 10 is estimated to have resumed in 2720–2480 cal BC (95% probability; *start_st10_last_use*; Fig. 9). The final use of the hearth in Structure 10 took place in 2545–2460 cal BC (95% probability; *central_hearth_st10*; Fig. 9). The eight dates on cattle from the enormous deposit of animal bone that filled the pathway running around the building are consistent ($A_{\text{comb}}=44.5\%$ ($A_n=25.0$; $n=8$)) with the interpretation suggested by faunal analysis that they represent a ‘single-event’ deposit (Mainland et al. 2014, 875), and the model estimates that the cattle died in 2565–2360 cal BC (95% probability; *st10_cattle*; Fig. 9), with deposition taking place very quickly after this. The deposition of the animal bone took place very shortly after the last use of the hearth, an interval estimated to have been between 1–135 years (95% probability; distribution not shown).

Following a considerable gap lasting 115–420 years (95% probability; *gap_2*; Fig. 11), an articulated deer skeleton (SUERC-55468) was placed on top of the animal bone deposit in the last quarter of the third millennium cal BC.

Archaeomagnetic dating

Precise and reliable magnetic directions have been obtained from a number of sampled hearth features (Batt & Outram, 2014). Although no archaeomagnetic calibration curve currently exists for the Late Neolithic in Britain, estimates from this scientific dating programme will provide some initial calibration data points, as the magnetic directions obtained (Fig. 12) reflect temporal differences in the use of Structures. The magnetic directions for the primary use of the Structure 8 hearth are very different to those measured from secondary hearths in Structures 1, 12, 14 and 16.

The two magnetic directions produced from the secondary hearth in Structure 1 do not overlap, suggesting that some period of time elapsed between the different phases of use (Batt & Outram, 2014, 18), a picture confirmed by radiocarbon dating.

Discussion

Robust dating of a site of the character of the Ness of Brodgar throws up considerable challenges, and the models presented above are both unavoidably provisional, because excavation continues, and incomplete, since neither includes any estimate for the start of Grooved Ware activity at the site. A precise chronology for the Ness of Brodgar simply derived from scientific dates is unlikely to materialise given some of the challenges outlined above, but integrating architectural sequence and chronological modelling has given us the opportunity to construct provisional narratives for the chronology of activity which are different from what has been previously suggested. This raises many implications. The discussion here focuses on the Ness and its immediate setting, in relation to the chronological questions set out at the start of the paper. Wider considerations will be followed in subsequent synthesis to draw together all the strands of the ToTL project in Orkney.

It had previously been tempting to think of a very long span of more or less continuous use of the Ness, on the basis of preliminary radiocarbon dates and on the assumption that a large site of this kind was likely to have been in use for a long period of time (Card, 2012). Now, although neither model provides a start date for Late Neolithic activity on the site, both indicate a broadly similar *terminus ante quem*, 3065–2950 cal BC (95% probability; *start_NoB*; Fig. 7; Model 1; Table 3), and 3020–2920 cal BC (95% probability; *start_NoB*; Fig. 9; Model 2; Table 3). It is not possible to say how much earlier the first Late Neolithic activity may have occurred, though both the presence of the underlying structures noted above and the different character of the Grooved Ware in Trench J allow the possibility of some time depth.

Models 1 and 2 both provide comparable estimates for both the primary (Structures 7, 8, 10 and 14) and secondary (Structures 1 and 12) use of the distinctive piered buildings (Fig. 13). Model 1 suggests a concentration of activity in the first quarter of the third millennium cal BC (Fig. 13), with the primary use of Structures 7, 8, 10 and 14 (Fig. 7) clearly occurring during the 30th century cal BC. Model 2, however, provides a formal estimate which places this activity between 3020–2920 cal BC (95% probability; *start_NoB*; Fig. 9) and 2855–2665 cal BC (95% probability;

end_NoB_piered; Fig. 9; Table 3). The phase of piered architecture at Ness of Brodgar therefore lasted, on this reading, 70–305 years (95% probability; *piered_architecture*; Fig. 11).

How long this set of buildings, including Structure 10, went on in active and continuous use is hard to define from Model 1. We can say with some confidence that there were no further new constructions in Trench P. A series of modifications to various of the buildings were made (Structure 8 having gone out of use with the construction of Structure 10). Structure 1 had its interior area much reduced by the insertion of a large curving wall and the creation of a new side entrance; Structure 12 was deconstructed (due to subsidence) and then rebuilt with the addition of a new entrance with an annex, and two of its earlier entrances blocked; and Structure 14 had many of its orthostatic divisions removed and its entrances remodelled. Model 1 suggests that the last use of hearths in Structure 12 (2755–2565 cal BC (94% probability; *last_hearth_st12*; Fig. 13; Table 3) or 2515–2500 cal BC (1% probability) and Structure 1 (2770–2570 cal BC (95% probability; *last_hearth_st1*; Fig. 13; Table 3) was relatively late. It is not possible to follow this part of the Ness story in detail in Model 1. Model 2, however, does suggest that this activity came to an end c. 2800 cal BC, after a minimum duration of a couple of centuries.

As had been the case with Structure 8 at neighbouring Barnhouse (Richards et al., 2016), the most monumental of all the buildings at the Ness, Structure 10, was not the first to be set up. It does seem to have appeared early on in the sequence of piered architecture, however, with both models agreeing that it was probably constructed during the 30th century cal BC. Model 1 estimates a date of 2990–2895 cal BC (95% probability; *end_st8_start_st10*; Fig. 13; Model 1; Table 3), and Model 2 estimates a date of 2965–2895 cal BC (95% probability; *end_st8_start_st10*; Fig. 13; Model 2; Table 3).

How are pre-eminent structures of this kind to be characterised? In some of the preliminary and popularising accounts, labels such as ‘temple’ and ‘cathedral’ have been used (Card, 2010), but even more modest terms such as ‘shrine’ or ‘meeting house’ can carry significant charge (Waterson, 1990; Gell, 1998). Whatever the role of Structure 10 was, the models raise the question of the circumstances in which such a remarkable construction came into being. Did it need predecessors, and a previous history which it could trump? Or did it come out of conditions of competition among the users of the other buildings, be they purely local householders or, say, kin groupings, or representatives of wider communities from further afield across Orkney (cf. Downes et al., 2013, 116; Card, 2012; Colin Richards, *pers. comm.*)?

The models now available (Fig. 14) indicate that the Ness of Brodgar and Barnhouse were certainly in contemporaneous use. In Model 1, this was for a minimum of *75–195 years (95% probability; distribution not shown)*, and in Model 2 for a minimum of *45–155 years (95% probability; distribution not shown)*. Barnhouse was abandoned in the earlier 29th century cal BC. It is not possible to envisage which of the two sites might prove to be the older. Barnhouse appears to have been a fresh foundation, but the indications, noted above, are that there had been earlier activity on the Ness of Brodgar.

These overlapping histories raise further questions about relationships. Were these rival sites, on either side of the narrows that separated them, one claiming seniority and precedence and the other challenging for equal or better position? We can say that the construction of Structure 8 at Barnhouse (Richards et al., 2016: fig. 7) was earlier (*94.8% probable; Model 1; 98.9% probable; Model 2*) than that of Structure 10 at the Ness (Fig. 14), and it would be plausible to envisage the builders of the latter setting out to emulate and surpass the scale of the former. But we have also to be mindful of the language of ‘site’ so often used. Were these separate communities? Did they start as such but became part of a wider complex in which, on grounds of scale, Barnhouse could be seen as some kind of satellite to the Ness? From this perspective, it is interesting to remember the estimate placing the construction of the Stones of Stenness probably in the 30th century cal BC (Schulting et al., 2010; Griffiths & Richards, 2013: 284–5), and thus squarely within the period of certain overlap between these two ‘neighbours’. Although the samples dated from the Stones of Stenness do not have a direct relationship to its construction and thus only give an indication of the chronology of activity taking place at the stone circle, the available models would indicate that this monument was erected at about the same time as Structure 10 at the Ness (Fig. 14). This puts our interpretive powers on the spot, since in most other settings in Britain and Ireland as a whole monuments are not directly accompanied by such a wealth of settlement remains (and it is a moot point in any case whether we label Ness of Brodgar as simply a settlement). These models certainly set difficult questions about ownership and the constituency of users of monuments. Finally, given the earlier 29th century cal BC as the date when Barnhouse was abandoned, this was probably, on the reading built into Model 2, the time when the character of the Ness of Brodgar began to change too. Activity at the Ness associated with piers architecture probably continued for *10–210 years (95% probability; Model 2; distribution not shown)*, or *20–120 years (68% probability)* after Barnhouse finished.

Model 1 does not provide a precise estimate for the duration of the use of piered architecture at the Ness; Model 2 suggests this was not less than a century or two (Fig. 11). Barnhouse was in use for *165–205 years (9% probability; use Barnhouse; Richards et al., 2016: fig. 13)* or *210–295 years (89% probability)*. It is entirely possible that the primary Late Neolithic phase at the Ness lasted for longer — but not for several centuries, and that should give us pause for thought. It may also provide a valuable clue to the nature of social relations, both at the site and in the networks beyond in which it both participated and perhaps even had a controlling interest. There must have been both risks and costs in first constructing and then maintaining a site of the size and potential complexity of the Ness. Labour had to be mobilised, and people fed, even if some of the users of the site might only have been there some of the time. As well as a place of renown and even awe, the site could have encouraged rivalries and engendered jealousies. Early Mesa Verde villages in the south-western United States have been called ‘social tinderboxes’, which rarely lasted beyond 30–70 years or one to three generations, their duration being established precisely through dendrochronology (Wilshusen & Potter, 2010: 178). A possible scenario for the Ness is that the effort of keeping it all going was not maintained for more than a few generations (our estimates being unavoidably imprecise). Buildings began to be modified and in some instances were reduced in size; if there was a degree of social differentiation behind the emergence and initial development of the Ness, that did not become institutionalised enough to keep the complex going in an unaltered state forever. Conversely, one could use the analogy to turn the perspective here right round; perhaps some settlements and complexes in Late Neolithic Orkney *were* able to maintain social cohesion for considerable periods of time, and the Ness could be the pre-eminent candidate for this kind of role. But defining duration with greater precision becomes of key importance.

At various points in the sequences of individual buildings, and over the site as a whole probably by at least *c.* 2600 cal BC (Fig. 7; Model 1), or by *c.* 2800 cal BC (Fig. 9; Model 2), there began extensive middening. In Colin Richards’ terms, we might think of this as ‘wrapping’ of the site; whether for concealment, protection, containment or other purposes (Richards, 2013: 17), this certainly marks a further shift in the character of the site.

Following this, after an appreciable interval (even in the less precise Model 1), there were the final modifications to the hearth in the centre of the once great Structure 10, *c.* 2500 cal BC (Model 2) or a little later, *2550–2460 cal BC (95% probability; central_hearth_st10; Fig. 13; Model 1; Table 3)*. Again it seems no accident that by this date this is the one visible and so far dated locus

of activity on the site, the massive and special building still being able to attract attention presumably by the enduring power of social memory.

At this point in the sequence, our two models strongly diverge. Model 1 suggests another significant interval following the last use of the hearth in Structure 10 before the last major event associated with it (*135–320 years (95% probability)*; distribution not shown): the prodigious cattle deposit dated in the model to *2340–2200 cal BC (95% probability; structure_10_cattle*; Fig. 13; Table 3). There has been previous discussion of this as a ‘decommissioning’ of Structure 10 (Mainland et al., 2014: 869), but following Model 1 it would be more plausible to apply that concept to the final deposition in the central hearth around or slightly later than 2500 cal BC.

Model 2 indicates that a significant gap occurred before the reuse of Structure 10 following the end of the primary phase of Late Neolithic activity (*30–335 years (95% probability; gap_1*; Fig. 11)). In contrast to Model 1, use of the hearth and the placing of the animal bone deposit were part of a short-lived phase of activity, which was over by *2465–2360 cal BC (95% probability; st10_cattle*; Fig. 13; Table 3). In this reading, the animal bone deposit does indeed constitute a major decommissioning of Structure 10 (Mainland et al., 2014: 869).

The stupendous scale of this depositional event marks it out as something completely different from other acts of deposition on the site: as much a new beginning as an ending. Once again, it was Structure 10 which was chosen for the extraordinary deposition of cattle and other remains, plausibly a final testament to its now arguably mythic status. Presumably we should look to the circumstances of a wider world which now had Beaker-related practices in it, which can be dated nationally from *2475–2360 cal BC (95% probability; Parker Pearson et al., 2016, fig. 2)*, even though we know rather little about the Beaker presence in Orkney (cf. Sheridan, 2013), and there is only one incised sherd in the deposit which could be compared with Beaker or Beaker-related pottery elsewhere. It is striking that the Model 2 estimate for the animal bone deposit so closely overlaps that for the appearance of Beakers nationally. The lack of Beaker material might suggest some kind of insular resistance to the spread of Beaker-related practices, as has been argued also in the case of Silbury Hill, finished in the late 24th or early 23 centuries cal BC (Marshall et al., 2013, 111): at a slightly later date following Model 1, but at the point of initial Beaker spread following Model 2. The Beaker funerals marked by extravagant deposition of cattle remains at Irthlingborough and Gayhurst in southern Britain also spring to mind (Davis & Payne, 1993; Chapman, 2007), but these are significantly later in the Beaker sequence.

After the deposition of the cattle spread, the interior of Structure 10 was infilled in a very structured manner with alternating layers of midden and rubble (Mainland et al., 2014: 869).

Looking beyond the Ness of Brodgar, there may be significant hints elsewhere in Orkney of similar chronological patterning. Barnhouse went out of use in the earlier 29th century cal BC. There was a pronounced hiatus in the occupation of Pool, Sanday, between the 28th and 26th century cal BC (MacSween et al., 2015) (Fig. 14), at more or less the same time as at the Ness (in Model 2). So we should not assume that Grooved Ware settlements went on forever, right across the archipelago. What, if anything, could have occurred locally to the Ness of Brodgar in the phase of reduced or absent activity before the final events connected to Structure 10? Is it coincidence that one estimate, claimed as ‘reasonable’, for the date of the digging of the Ring of Brodgar ditch is 2600–2400 BC, based on very imprecise OSL dating (to which we will return critically in subsequent synthesis) (Downes et al., 2013: 113)? Was the Ness now mainly a place of ghosts and memories, closed off (as it were) by a great new sacred ring close by? Or does the construction of the Ring of Brodgar — and perhaps also that of Maeshowe — better belong to the floruit of the Ness of Brodgar, Barnhouse and the Stones of Stenness, when we know that substantial numbers of people must have been concentrated, at least at intervals, in the local landscape?

Finally, the provisional formal chronologies for the Ness of Brodgar presented here already define the goals of future research. Deeper levels need to be uncovered, and across the sequence the search is on for more short-life samples of known taphonomy: no easy task in a context of this kind. The emergent chronologies for the Ness also demand more certain dating for both the Ring of Brodgar and Maeshowe (Griffiths & Richards, 2013), in line with the declared research strategy for the World Heritage Site (Downes and Gibson, 2013: 25: objectives 266 and 270). Robust formal modelling can help fundamentally to change our understanding of the major research questions, and such a remarkable landscape requires a committed and continuing response.

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Bibliography

Ballin Smith, B. 2003. *A New Late Neolithic House at Brodgar Farm, Stenness, Orkney*. Unpublished report for GUARD, Project 1506. Glasgow.

Batt, C.M. & Outram, Z. 2014. *Telling the Time in Neolithic Orkney: Archaeomagnetic Studies of Features from the Ness of Brodgar, Orkney 2012–2013*. Unpublished report, University of Bradford.

Buck, C.E., Cavanagh, W.G. & Litton, C.D. 1996. *Bayesian Approach to Interpreting Archaeological Data*. Chichester: Wiley.

Buck, C.E., Litton, C.D. & Smith, A.F.M. 1992. Calibration of radiocarbon results pertaining to related archaeological events. *Journal of Archaeological Science*, 19: 497–512.

Brock, F., Higham, T., Ditchfield, P. & Bronk Ramsey, C. 2010. Current Pretreatment Methods for AMS Radiocarbon Dating at the Oxford Radiocarbon Accelerator Unit (ORAU). *Radiocarbon*, 52: 103–12.

Bronk Ramsey, C. 1995. Radiocarbon Calibration and Analysis of Stratigraphy: the OxCal Program. *Radiocarbon*, 36: 425–30.

Bronk Ramsey, C. 2009. Bayesian Analysis of Radiocarbon Dates. *Radiocarbon*, 51: 37–60.

Bronk Ramsey, C., Higham, T., & Leach, P. 2004. Towards High Precision AMS: Progress and Limitations. *Radiocarbon*, 46:17–24.

Card, N. 2006. Excavations at Bookan Chambered Cairn. *Proceedings of the Society of Antiquaries of Scotland*, 135 (2005): 163–90.

Card, N. 2010. Neolithic Temples of the Northern Isles. *Current Archaeology*, 241: 12–19.

Card, N. 2012. The Ness of Brodgar. *British Archaeology*, 128: 14–21.

Card, N., Downes, J. & Edmonds, M. (eds) forthcoming. *Landscapes Revealed: Remote Sensing Around the Heart of Neolithic Orkney World Heritage Site*. Oxford: Windgather Press.

Card, N. & Thomas, N. 2012. Painting a Picture of Neolithic Orkney: Decorated Stonework from the Ness of Brodgar. In A. Cochrane and A.M. Jones, eds. *Visualising the Neolithic: abstraction, figuration, performance, representation*. Oxford: Oxbow Books, pp. 111–24.

Chapman, A. 2007. A Bronze Age Barrow Cemetery and Later Boundaries, Pit Alignments and Enclosures at Gayhurst Quarry, Newport Pagnell, Buckinghamshire. *Records of Buckinghamshire*, 47: 83–211.

Clarke, D.V. 1976. *The Neolithic Village at Skara Brae, Orkney: 1972–73 Excavations*. Edinburgh: Department of the Environment and Her Majesty's Stationery Office.

Clarke, D., Sheridan, J.A., Shepherd, A., Sharples, N., MacSween, A., Armour-Chelu, M., Hamlet, L., Bronk Ramsey, C., Dunbar, E., Reimer, P., Marshall, P. & Whittle, A. in preparation. The End of the World, or Just Goodbye to All That? Contextualising the Late Third Millennium cal BC Deer Heap at Links of Noltland, Westray, Orkney.

Cluett, J.P. 2008. *Soil and Sediment-based Cultural Records and The Heart of Orkney World Heritage Site Buffer Zones*. Unpublished PhD thesis, University of Stirling.

Cramp, L.J., Jones, J., Sheridan, J.A., Smyth, J., Whelton, H., Mulville, J., Sharples, N. & Evershed, R.P. 2014. Immediate Replacement of Fishing with Dairying by the Earliest Farmers of the Northeast Atlantic Archipelagos. *Proceedings of the Royal Society B Biological Sciences*, 281: 1–8.

Davidson, J.L. & Henshall, A.S. 1989. *The Chambered Cairns of Orkney: an Inventory of the Structures and their Contents*. Edinburgh: Edinburgh University Press.

Davis, S. & Payne, S. 1993. A Barrow Full of Cattle Skulls. *Antiquity*, 67: 12–22.

Dee, M., & Bronk Ramsey, C. 2000. Refinement of the Graphite Target Production at ORAU, *Nuclear Instruments and Methods in Physics Research B*, 172, 449–53.

Dickson, J.H. 1992. North American Driftwood, especially *Picea* (Spruce), from Archaeological Sites in the Hebrides and Northern Isles of Scotland. *Review of Palaeobotany and Palynology*, 73: 49–56.

Downes, J. & Gibson, J., with Gibbs, S.J. & Mitchell, A. eds. 2013. *Heart of Neolithic Orkney World Heritage Site: Research Strategy 2013–2018*. Edinburgh: Historic Scotland.

Downes, J., Richards, C., Brown, J., Cresswell, A.J., Ellen, R., Davies, A.D., Hall, A., McCulloch, R., Sanderson D.C.W. & Simpson, I.A. 2013. Investigating the Great Ring of Brodgar, Orkney. In: C. Richards, ed. *Building the Great Stone Circles of the North*. Oxford: Windgather Press, pp. 90–118.

Dunbar, E., Cook, G.T., Naysmith, P., Tripney, B.G. & Xu, S. 2016. AMS ^{14}C Dating at the Scottish Universities Environmental Research Centre (SUERC) Radiocarbon Dating Laboratory. *Radiocarbon*, 58. Available at CJO 2016 doi:10.1017/RDC.2015.2

Farrell, M. 2015. Later Prehistoric Vegetation Dynamics and Bronze Age Agriculture at Hobbister, Orkney, Scotland. *Vegetation History and Archaeobotany*, 24: 467–86.

Gell, A. 1998. *Art and Agency: an Anthropological Theory*. Oxford: Clarendon.

Griffiths, S. 2016. Beside the Ocean of Time: a Chronology of Neolithic Burial Monuments and Houses in Orkney. In: C. Richards and R. Jones, eds. *The Development of Neolithic House Societies in Orkney*. Oxford: Windgather Press, pp. 254–302.

Griffiths, S. & Richards, C. 2013. A Time for Stone Circles, a Time for New People. In: C. Richards, ed. *Building the Great Stone Circles of the North*. Oxford: Windgather Press, pp. 281–91.

GSB Prospection 2002. *Orkney World Heritage Site, Geophysical Report, Phase 1* (GSB Report 2002/61). Bradford.

Hensey, R. 2015. *First Light: the Origins of Newgrange*. Oxford: Oxbow Books.

Henshall, A. 1972. *The Chambered tombs of Scotland: Volume Two*. Edinburgh: Edinburgh University Press.

Historic Scotland 1998. *Nomination of the Heart of Neolithic Orkney for Inclusion in the World Heritage List*. Document submitted to UNESCO. Edinburgh.

Jones, J.R. & Mulville J. 2015. Isotopic and Zooarchaeological Approaches Towards Understanding Aquatic Resource Use in Human Economies and Animal Management in the Prehistoric Scottish North Atlantic Islands. *Journal of Archaeological Science Reports*.
<http://dx.doi.org/10.1016/j.jasrep.2015.08.019>

Lanting, J.N., Aerts-Bijma, A.T. & van der Plicht, J. 2001. Dating of Cremated Bones. *Radiocarbon*, 43: 249–54.

Lanting, J.N. & van der Plicht, J. 1998. Reservoir Effects and Apparent ¹⁴C Ages. *Journal of Irish Archaeology*, 9: 151–65.

MacSween, A. 2008. *Ness of Brodgar: Report on the Pottery*. Unpublished pottery report, University of the Highlands and Islands, Archaeology Institute. Kirkwall.

MacSween, A., Hunter, J., Sheridan, J.A., Bond, J., Bronk Ramsey, C., Reimer, P., Bayliss, A., Griffiths, S. & Whittle, A. 2015. Refining the Chronology of the Neolithic settlement at Pool, Sanday, Orkney. *Proceedings of the Prehistoric Society*, 81: 283–310.

Mainland, I., Card, N., Saunders, M.K., Webster, C., Isaksen, L., Downes, J. & Littlewood, M. 2014. ‘SmartFauna’: a Microscale GIS-based Multi-dimensional Approach to the Faunal Deposition at the Ness of Brodgar, Orkney. *Journal of Archaeological Science*, 41: 868–78.

Marshall, P., Bayliss, A., Leary, J., Campbell, G., Worley, F., Bronk Ramsey, C. & Cook, G. 2013. The Silbury Chronology. In: J. Leary, D. Field and G. Campbell, eds. *Silbury Hill: The Largest Prehistoric Mound in Europe*. Swindon: English Heritage, pp. 97–116.

Parker Pearson, M., Richards, M., Chamberlain, A., Jay, M., Curtis, N., Evans, J., Gibson, A., Mahoney, P., Marshall, P., Montgomery, J., Needham, S., Pelligrini, M., Sheridan, J.A., Wilkin, N., Chiu, L., Deter, C., Hutchison, M., Johns, S., Nehlich, O., Nystrom, P., Schmidt, C., Thomas, S. & Towers, J. 2016. Bell Beaker People in Britain: Migration, Mobility and Diet. *Antiquity* 90, 620–37.

Photos-Jones, E., Hall, A.J., Ballin Smith, B. & Jones, R.E. 2007. On the Intent to Make Cramp: An Interpretation of Vitreous Seaweed Cremation ‘Waste’ From Prehistoric Burial Sites in Orkney, Scotland. *Oxford Journal of Archaeology*, 26: 1–23.

Reimer, P.J., Bard, E., Bayliss, A., Beck, J.W., Blackwell, P.G., Bronk Ramsey, C., Buck, C.E., Cheng, H., Edwards, R.L., Friedrich, M., Grootes, P.M., Guilderson, T.P., Haffidason, H., Hajdas, I., Hatté, C., Heaton, T.J., Hoffmann, D.L., Hogg, A.G., Hughen, K.A., Kaiser, K.F., Kromer, B., Manning, S.W., Niu, M., Reimer, R.W., Richards, D.A., Scott, E.M., Southon, J.R., Staff, R.A., Turney, C.S.M. & van der Plicht, J. 2013. Intcal 13 and Marine13 Radiocarbon Age Calibration Curves 0–50,000 Years cal BP. *Radiocarbon*, 55: 1869–87.

Reimer, P., Hoper, S., McDonald, J., Reimer, R. & Thompson, M. 2015. *Laboratory Protocols Used for AMS Radiocarbon Dating at the ¹⁴CHRONO Centre, The Queen’s University, Belfast*. English Heritage Research Report. Portsmouth: English Heritage.

Renfrew, C. 1979. *Investigations in Orkney*. London: Society of Antiquaries.

Richards, C. ed. 2005. *Dwelling Among the Monuments: the Neolithic Village of Barnhouse, Maeshowe Passage Grave and Surrounding Monuments at Stenness, Orkney*. Cambridge: McDonald Institute for Archaeological Research.

Richards, C. ed. 2013. *Building the Great Stone Circles of the North*. Oxford: Windgather Press.

Richards, C. & Jones, R. eds. 2016. *The Development of Neolithic House Societies in Orkney*. Oxford: Windgather Press.

- Richards, C., Jones, A.M., MacSween, A., Sheridan, J.A., Dunbar, E., Reimer, P., Bayliss, A., Griffiths, S. & Whittle, A. 2016. Settlement Duration and Materiality: Formal Chronological Models for the Development of Barnhouse, a Grooved Ware Settlement in Orkney. *Proceedings of the Prehistoric Society*, 81: 283–310
- Ritchie, J.N.G. 1976. The Stones of Stenness, Orkney. *Proceedings of the Society of Antiquaries of Scotland*, 107: 1–60.
- Schulting, R., Sheridan, J.A., Crozier, R. & Murphy, E. 2010. Revisiting Quanterness: New AMS Dates and Stable Isotope Data from an Orcadian Chamber Tomb. *Proceedings of the Society of Antiquaries of Scotland*, 140: 1–50.
- Scott, E.M., Cook, G.T., Naysmith, P., Bryant, C. & O'Donnell, D. 2007. A Report on Phase 1 of the 5th International Radiocarbon Intercomparison (VIRI). *Radiocarbon*, 49: 409–26.
- Scott, E.M., Cook, G.T. & Naysmith, P. 2010. A Report on Phase 2 of the Fifth International Radiocarbon Intercomparison (VIRI). *Radiocarbon*, 52: 846–58.
- Shepherd, A.N. 2016. Skara Brae Life Studies: Overlaying the Embedded Images. In: F. Hunter & A. Sheridan, eds. *Ancient Lives: Object, People and Place in Early Scotland. Essays for David V. Clarke on his 70th Birthday*. Leiden: Sidestone Press, pp. 213–32.
- Sheridan, J.A. 1999. Grooved Ware from the Links of Noltland, Westray, Orkney. In: R. Cleal & A. MacSween, eds. *Grooved Ware in Britain and Ireland*. Oxford: Oxbow Books, pp. 112–24.
- Sheridan, J.A. 2004. Going Round in Circles? Understanding the Irish Grooved Ware ‘Complex’ in its Wider Context. In: H. Roche, E. Grogan, J. Bradley, J. Coles & B. Raftery, eds. *From Megaliths to Metal: Essays in Honour of George Eogan*. Oxford: Oxbow Books, pp. 26–37.
- Sheridan, J.A. 2012. Contextualising Kilmartin: Building a Narrative for Developments in Western Scotland and Beyond, from the Early Neolithic to the Late Bronze Age. In: A.M. Jones, J. Pollard, M.J. Allen & J. Gardiner, eds. *Image, Memory and Monumentality: Archaeological Engagements with the Material World*. Oxford: Oxbow Books, pp. 163–183.

Sheridan, J.A. 2013. Plus Ça Change...? Developments in Shetland, c 2500–1800 BC. In: D.L. Mahler, ed. *The Border of Farming. Shetland and Scandinavia: Neolithic and Bronze Age Farming*. Copenhagen: The National Museum of Denmark, pp. 47–72.

Sheridan, J.A. 2014. Little and Large: the Miniature ‘Carved Stone Ball’ Beads from the Eastern Tomb at Knowth, Ireland, and their Broader Significance. In: In R.-M. Arbogast & A. Greffier-Richard (eds), *Entre Archéologie et Écologie, une Préhistoire de Tous les Milieux. Mélanges Offerts à Pierre Pétrequin*. Besançon: Presses Universitaires de Franche-Comté, pp. 303–314.

Sheridan, J.A., MacSween, A., Towers, R., Bayliss, A., Marshall, P. & Whittle, A. in prep. Grooved Ware in Orkney: towards an overall narrative.

Simpson, D. & Ransom, R. 1992. Maceheads and the Orcadian Neolithic. In: N. Sharples & J.A. Sheridan, eds. *Vessels for the Ancestors: Essays on the Neolithic of Britain and Ireland in Honour of Audrey Henshall*. Edinburgh: Edinburgh University Press, pp. 221–43.

Slota, P.J. Jr, Jull, A.J.T., Linick, T.W. & Toolin, L.J. 1987. Preparation of small samples for ^{14}C accelerator targets by catalytic reduction of CO. *Radiocarbon* 29, 303–6.

Snoeck, C., Brock, F. & Schulting, R.J. 2014. Carbon Exchanges between Bone Apatite and Fuels During Cremation: Impact on Radiocarbon Dates. *Radiocarbon*, 56: 591–602.

Stuiver, M. & Polach, H.A. 1977. Reporting of ^{14}C Data. *Radiocarbon*, 19: 355–63.

Thomas, J. 2010. The Return of the Rinyo-Clacton Folk? The Cultural Significance of the Grooved ware Complex in Later Neolithic Britain. *Cambridge Archaeological Journal*, 20: 1–15.

Towers, R. & Card, N. 2015. Technological Adaptation in Grooved Ware Pottery from the Ness of Brodgar, Orkney, or How to Make Your Cordons Stick. *Scottish Archaeological Journal*, 36-37: 51–63.

Vogel, J.S., Southon, J.R., Nelson, D.E. & Brown, T.A. 1984. Performance of Catalytically Condensed Carbon for Use in Accelerator Mass Spectrometry. *Nuclear Instruments and Methods in Physics Research B*, 233: 289–93.

Wainwright, G.J. & Longworth, I.H. 1971. *Durrington Walls: Excavations 1966–1968*. London: Society of Antiquaries.

Ward, G.K. & Wilson, S.R. 1978. Procedures for Comparing and Combining Radiocarbon Age Determinations: a Critique. *Archaeometry*, 20: 19–31.

Waterson, R. 1990. *The Living House: an Anthropology of Architecture in South-east Asia*. Oxford: Oxford University Press.

Wilshusen, R.H. & Potter, J.M. 2010. The Emergence of Villages in the American Southwest: Cultural Issues and Historical Perspectives. In: M.S. Bandy & J.R. Fox, eds. *Becoming Villagers: Comparing Early Village Societies*. Tucson: University of Arizona Press, pp. 165–83.

NOTE

¹We use midden as a general term, aware of the complexities of its diverse character and formation (Shepherd 2016).

Table 1. Ness of Brodgar: radiocarbon and stable isotope results.

[illegible]

Laboratory code	Sample ref	Material & context	$\delta^{13}\text{C}$ (‰) - diet	$\delta^{13}\text{C}$ (‰) - AMS	$\delta^{15}\text{N}$ (‰)	C: N	Radiocarbon age (BP)	<i>Posterior Density Estimate, cal BC (95% probability) Model 1</i>	<i>Posterior Density Estimate, cal BC (95% probability) Model 2</i>
SUERC-55463	SF bone 2017, context [2680] – sample A	Calcined animal bone, large ungulate long bone from within the central hearth in Structure 7. The lowest use fill of the hearth 2679 (80mm thick) was completely sealed by layer 2670 and consisted of ash rich light orange/pinkish brown clay silt with occasional charcoal and burnt bone fragments. This appears to represent the primary episode of burning and sealed a lower levelling layer [2680] up to 0.15m thick in the base of the hearth setting.	-26.1±0.2				4294±30	2940–2875	2925–2880
UBA-26532	SF bone 2017, context [2680] – sample B	Calcined animal bone, cow tibia, as SUERC-55463		-19.6			4379±50	2990–2890	2965–2885
Structure 8									
SUERC-60417	[2213] SF 5299	Carbonised residue [163mg] adhering to the interior of a large, thick (16mm) heavily rock-tempered Grooved Ware body sherd. From [2213], a dark yellowish grey clayey silt, which was overlain by [2212], a mid orangey brown silty clay, which was in turn overlain by [2208], a mid greyish brown silty clay. The midden in the central part of Structure 8.	-28.7±0.2				4350±35	3015–2920	2990–2910
UBA-26535	SF bone 12851, context [3806]	Calcined animal bone, large ungulate rib from within Structure 8: [3806] is the lowest hearth deposit and seals [3807].		-21.5			4380±34	3030–2930	3005–2915
Structure 10									
SUERC-55457	SF bone 1524, context [3482] – sample A	Calcined animal bone, red deer antler from the central hearth area within Structure 10: 3463=3468=3482=3489 an orangey brown friable peat-ashy silt with occasional burnt bone and charcoal flecks, (which may be a midden-enhanced soil rather than a ‘true’ hearth deposit).	-18.0±0.2				4019±30	2625–2490	2620–2610 (1%) or 2600–2475 (94%)
UBA-26530	SF bone 1524, context [3482] – sample B	Calcined animal bone, large ungulate long bone, as SUERC-55457		-23.6			4278±39		
SUERC-60627	SF bone 1524, context [3482] – sample C	Calcined animal bone, large ungulate long bone, replicate of UBA-26530	-25.2±0.2				4200±31		

Laboratory code	Sample ref	Material & context	$\delta^{13}\text{C}$ (‰) - diet	$\delta^{13}\text{C}$ (‰) - AMS	$\delta^{15}\text{N}$ (‰)	C: N	Radiocarbon age (BP)	<i>Posterior Density Estimate, cal BC (95% probability) Model 1</i>	<i>Posterior Density Estimate, cal BC (95% probability) Model 2</i>
	SF bone 1524, context [3482], large ungulate	Weighted mean ($T^*=2.5$; $v=1$; $T^*(5\%)=3.8$)					4230 \pm 25	2900–2860 (60%) or 2810–2755 (32%) or 2720–2705 (3%)	2905–2860 (64%) or 2810–2755 (29%) or 2720–2705 (3%)
SUERC-55458	SF bone 1560, context [3490]	Calcined animal bone, cow humerus (right), from the central hearth area within Structure 10: 3466=3469=3483= 3490 , was a mottled grey brown to black ashy silt, the product of <i>in situ</i> burning that underlay 3463=3468=3482=3489 (which may be a midden-enhanced soil rather than a ‘true’ hearth deposit).	-26.3 ± 0.2				4350 \pm 30	2910–2880	2935–2885
SUERC-55464	SF bone 10823, context [3488] – sample A	Calcined animal bone, cow femur, left from the central hearth area within Structure 10: [3461], [3481] and [3488]. The uppermost fill, a 30-140mm-deep light orangey brown silt 3461=3467=3188=3481= 3488 contained occasional charcoal and bone, and appears to be an interface layer between 2526 and the underlying hearth fills. The NE quadrant of this layer, i.e. 3488 , contained a significant amount of animal in comparison to the other quadrants The sample is stratigraphically later than the two samples from hearth fill = [3463], [3468] and [3489]	-19.6 ± 0.2				4020 \pm 30	2570–2470	2560–2465
UBA-26534	SF bone 10823, context [3488] – sample B	Calcined animal bone, large ungulate long bone, as SUERC-55464		-21.5			3915 \pm 32		
OxA-32032	SF bone 10823, context [3488] – sample C	Calcined animal bone, large ungulate long bone, as SUERC-55464, (replicate of UBA-26534)	-20.7 ± 0.2				4012 \pm 33		
OxA-32447	SF bone 10823, context [3488] – sample C	Calcined animal bone, large ungulate long bone, as SUERC-55464, (replicate of OxA-32032 and UBA-26534)	-20.8 ± 0.2				4009 \pm 38		
SF bone 10823		Weighted mean ($T^*=5.6$; $v=2$; $T^*(5\%)=6.0$)					3975 \pm 20	2565–2515 (34%) or	2565–2515 (21%) or

Laboratory code	Sample ref	Material & context	$\delta^{13}\text{C}$ (‰) - diet	$\delta^{13}\text{C}$ (‰) - AMS	$\delta^{15}\text{N}$ (‰)	C: N	Radiocarbon age (BP)	<i>Posterior Density Estimate, cal BC (95% probability) Model 1</i>	<i>Posterior Density Estimate, cal BC (95% probability) Model 2</i>
								2500–2460 (61%)	2500–2460 (74%)
SUERC-55468	SF bone 38E, context [1403]	Animal bone, red deer, mtc proximal + shaft, left-hand side. Structure 10 was decommissioned and infilled with a sequence of middens and rubble deposits. This included infilling the outer paved area with deposits, [1403], including a large bone assemblage consisting almost entirely of cattle tibia representing 100's of cattle. The articulated red deer skeleton overlay the main Structure 10 bone spread and provides a constraint for the deposition of the bone assemblage.	-21.6 ± 0.2		8.0 ± 0.3	3.4	3720 ± 32	2295–2125	2205–2025
SUERC-55472	SF bone 32, context [1403]	Animal bone, cattle tibia distal + shaft, left-hand side. Structure 10 was decommissioned and infilled with a sequence of middens and rubble deposits. This included infilling the outer paved area with deposits, [1403], including a large bone assemblage consisting almost entirely of cattle tibia representing 100's of cattle.	-21.4 ± 0.2		5.0 ± 0.3	3.3	3946 ± 33	2570–2515 (16%) or 2500–2335 (79%)	2465–2360
SUERC-55473	SF bone 72, context [1403]	Animal bone, cow tibia, left-hand-side, distal + shaft. As SUERC-55472	-21.6 ± 0.2		5.4 ± 0.3	3.4	3832 ± 33	2460–2200	2465–2360
SUERC-55474	SF bone 98, context [1403]	Animal bone, cow tibia, left proximal + shaft. As SUERC-55472	-21.9 ± 0.2		5.4 ± 0.3	3.5	3900 ± 30	2470–2295	2465–2360
OxA-30798	SF bone 139, context [1403]	Animal bone, cow tibia, left-hand-side, distal. As SUERC-55472	-21 ± 0.2		4.5 ± 0.3	3.2	3901 ± 33	2470–2290	2465–2360
OxA-30799	SF bone 147, context [1403]	Animal bone, cow mandible, right-hand-side. As SUERC-55472	-21.1 ± 0.2		5.2 ± 0.3	3.1	3912 ± 34	2480–2290	2465–2360
OxA-30800	SF bone 213, context [1403]	Animal bone, cow tibia, left-hand-side, distal + shaft. As SUERC-55472	-21.2 ± 0.2		5.5 ± 0.3	3.1	3915 ± 33	2480–2290	2465–2360
GU35059	SF 7161, context [2510]	Carbonised residue (59mg) adhering to the interior of Grooved Ware sherd. From within Structure 10: context [2510] from the loose fill of pot SF 7161 within 2441 (cut containing 2442 [E-W orthostat on 2441] and 2443 [N-S orthostat in 2441]).					Failed due to insufficient carbon		
UBA-26529	SF 18080, context [4381]	Carbonised residue (60mg) adhering to the interior of Grooved Ware sherd. From within Structure 10: context [4381] is a levelling surface beneath context [4374]. This sherd is from a find spot	-26.4 ± 0.2				4271 ± 42	2935–2885	2930–2855 (91%) or 2810–2775 (4%)

Laboratory code	Sample ref	Material & context	$\delta^{13}\text{C}$ (‰) - diet	$\delta^{13}\text{C}$ (‰) - AMS	$\delta^{15}\text{N}$ (‰)	C: N	Radiocarbon age (BP)	Posterior Density Estimate, cal BC (95% probability) Model 1	Posterior Density Estimate, cal BC (95% probability) Model 2
		[4382] close to SF 16858, however, the sherd is from a separate vessel to SF 16858 and is the “upper pot”.							
OxA-30950	SF 16858, context [4381]	Carbonised residue (60mg) adhering to the interior of a Grooved Ware body sherd, from large sections of a pot. The base is flat with almost vertical walls while the walls are 9mm thick and the vessel height is c. 150mm. From within Structure 10: context [4381] is a levelling surface beneath context [4374]. This sherd is associated with an incised stone.	-24.0±0.2				4231±37	2920–2885	2915–2840 (77%) or 2815–2755 (18%)
OxA-25032	CBNB 1	Animal bone, <i>Bos</i> (M. Lillie), from the bone deposit forming the upper fill of the paved pathway around Structure 10 that marked its decommissioning	-20.9±0.2				3878±26	2465–2290	2465–2360
OxA-25033	CBNB 2	Animal bone, <i>Bos</i> (M. Lillie), from the bone deposit forming the upper fill of the paved pathway around Structure 10 that marked its decommissioning	-21.2±0.2				3829±27	2455–2375 (13%) or 2350–2200 (83%)	2465–2360
Structure 12 and annex									
UBA-26533	SF bone 2340, context [4509]	Calcined animal bone, large ungulate long bone from within Structure 12: [4509] is a black charcoal 'hearth' layer with animal bones, ? <i>in situ</i> burning, sealed by [4053].		-25.3			4447±31	3335–3210 (39%) or 3195–3150 (7%) or 3140–3005 (46%) or 2985–2935 (3%)	3335–3210 (39%) or 3195–3150 (7%) or 3140–3005 (46%) or 2995–2935 (3%)
SUERC-60419	[4509] <2360> sample A	Carbonised grain, <i>Hordeum vulgare</i> (S. Timpany), from black charcoal 'hearth' layer [4509] with animal bones, <i>in situ</i> burning sealed by [4053] in Structure 12	-25.2±0.2				4100±28	2860–2805 (22%) or 2760–2715 (9%) or 2705–2570 (63%) or 2515–2500 (1%)	2875–2800 (90%) or 2760–2720 (5%)

Laboratory code	Sample ref	Material & context	$\delta^{13}\text{C}$ (‰) - diet	$\delta^{13}\text{C}$ (‰) - AMS	$\delta^{15}\text{N}$ (‰)	C: N	Radiocarbon age (BP)	Posterior Density Estimate, cal BC (95% probability) Model 1	Posterior Density Estimate, cal BC (95% probability) Model 2
UBA-29335	[4509] <2360> sample B	Carbonised grain, <i>Hordeum vulgare</i> (S. Timpany), from black charcoal 'hearth' layer [4509] with animal bones, <i>in situ</i> burning sealed by [4053] in Structure 12	-22.0±0.22				4149±30	2880–2625	2885–2725
OxA-32069	[4509] <2360> sample C	Carbonised grain, <i>Hordeum vulgare</i> (S. Timpany), from black charcoal 'hearth' layer [4509] with animal bones, <i>in situ</i> burning sealed by [4053] in Structure 12	-27.4±0.2				4114±30	2865–2800 (25%) or 2775–2575 (70%)	2880–2720
SUERC-55467	SF 10100, context [2306] sample A	Carbonised residue (119mg) adhering to the interior of Grooved Ware sherd. From within Structure 12 (annex): Finds deposit [2306] was located in the junction between wall 2832 and orthostat 2848. It consisted of a large spread of Grooved Ware pottery, which measured 1.15m WNW to ESE by 0.3m wide. Context [2306] was recorded in four horizons, during excavation each successive pottery horizon was lifted, revealing more pottery below.	-26.2±0.2				4197±30		
UBA-26528	SF 10100, context [2306] sample B	Carbonised residue (114mg) adhering to the interior of Grooved Ware sherd. From within Structure 12 (annex): Finds deposit [2306] was located in the junction between wall 2832 and orthostat 2848. It consisted of a large spread of Grooved Ware pottery, which measured 1.15m WNW to ESE by 0.3m wide. Context [2306] was recorded in four horizons, during excavation each successive pottery horizon was lifted, revealing more pottery below.	-26.4±0.2				4246±39		
	SF 10100, context [2306]	Weighted mean ($T^*=1.0$; $V=1$; $T^*(5\%)=3.8$)					4215±24	2900–2855 (42%) or 2810–2750 (45%) or 2725–2695 (8%)	2900–2855 (72%) or 2810–2755 (23%)
GU37544	[5337] SF 21623 sample A	Carbonised residue [210mg] adhering to the interior of Grooved Ware sherd from Structure 12, context [5337] SF 21623.					Failed due to insufficient carbon		

Laboratory code	Sample ref	Material & context	$\delta^{13}\text{C}$ (‰) - diet	$\delta^{13}\text{C}$ (‰) - AMS	$\delta^{15}\text{N}$ (‰)	C: N	Radiocarbon age (BP)	Posterior Density Estimate, cal BC (95% probability) Model 1	Posterior Density Estimate, cal BC (95% probability) Model 2
UBA-29338	[5337] SF 21623 sample B	Carbonised residue [194mg] adhering to the interior of Grooved Ware sherd from Structure 12, context [5337] SF 21623.	-27.2±0.22				4148±35	2880–2620	2885–2730
SUERC-60626	[5337] SF 20850, sample A	Carbonised residue [390mg] adhering to the interior of Grooved Ware sherd from Structure 12, context [5337] SF 20850.	-27.4±0.2				4155±31		
UBA-29337	[5337] SF 20850, sample B	Carbonised residue [283mg] adhering to the interior of Grooved Ware sherd from Structure 12, context [5337] SF 20850.	-26.8±0.22				4145±37		
OxA-32310	[5337] SF 20850, sample C	Carbonised residue [210mg] adhering to the interior of Grooved Ware sherd from Structure 12, context [5337] SF 20850.	-27.1±0.2				4187±29		
	SF 20850	Weighted mean (T'=1.0; v=2; T'(5%)=6.0)					4165±19	2880–2835 (18%) or 2815–2670 (77%)	2880–2830 (63%) or 2820–2740 (31%) or 2725–2710 (1%)
Structure 14									
SUERC-60418	[4662] <2499>	Carbonised grain, <i>Hordeum vulgare</i> (S. Timpany), from [4662], west hearth, red silt clay, burning sealed by [4665] in Structure 14	-23.8±0.2				4369±25	3015–2910	2985–2905
GU37541	[4613] <2424> sample A	Carbonised grain, <i>Hordeum vulgare</i> (S. Timpany), from east hearth, ashy deposit of rake out [4613] sealed by [4612] in Structure 14					Failed insufficient carbon		
GU37925	[4613] <2424> sample A - replacement	As GU37541					Failed insufficient carbon		
UBA-29336	[4613] <2424> sample B	Carbonised grain, <i>Hordeum vulgare</i> (S. Timpany), from east hearth, ashy deposit of rake out [4613] sealed by [4612] in Structure 14	-23.5±0.22				4386±41	3025–2905	2985–2900
GU37543	[5074] SF 19116	Carbonised residue [163mg] adhering to the interior of pot under Structure 14, context [5074] SF 19116.					Failed due to insufficient carbon		
Trench J – Structure 5									
OxA-X-2633-41	[410] <240>	Calcined animal bone, unidentified (I. Mainland), from [410], a fine peat ash deposit, stratigraphically earlier than [448]	-27.5±0.2				5432±38		

Laboratory code	Sample ref	Material & context	$\delta^{13}\text{C}$ (‰) - diet	$\delta^{13}\text{C}$ (‰) - AMS	$\delta^{15}\text{N}$ (‰)	C: N	Radiocarbon age (BP)	Posterior Density Estimate, cal BC (95% probability) Model 1	Posterior Density Estimate, cal BC (95% probability) Model 2
P38996	[460] <247>	Calcined animal bone, unidentified (I. Mainland), from [460], a silty ash deposit, interpreted as a fire-spot it is stratigraphically earlier than [456] and later than [461]	Failed insufficient carbon				±		
SUERC-61344	[458] <251>	Charcoal, <i>Betula</i> sp. (S. Timpany), from [458] a charcoal-rich ashy silt interpreted as a fire-spot, it is stratigraphically earlier than [457]	-25.0 (assumed)				4608±30		
GU-37924	[461] <248>	Carbonised single grain <i>Hordeum vulgare</i> var nudum (S. Timpany), from [461] a raked ash deposit probably from fire-spot [460], stratigraphically earlier than [460] and later [462]	Failed insufficient carbon						
SUERC-61637	[461] <248>	As GU-37924	-23.5±0.2				4337±29		
UBA-29752	[441] <257>	Carbonised single grain <i>Hordeum vulgare</i> var nudum (S. Timpany), from the primary fill of the hearth cut below the cist, stratigraphically earlier than [440] and later [443]	-25.5±0.22				4384±30		
UBA-29753	[456] <243>	Calcined animal bone, unidentified (I. Mainland), from [456] a ?hearth deposit stratigraphically earlier than [458] and later [460]		-28.0			6042±36		
UBA-29754	[462] <249>	Calcined animal bone, unidentified (I. Mainland), from [462], is a ?hearth deposit in Trench J [Structure 5], stratigraphically earlier than [461] and later [457]		-20.5			5212±35		
Trench R									
SUERC-35999	7741	Charcoal, <i>Pinus sylvestris</i> , from [3029] a greyish brown midden	-25.6±0.2				4450±30	3335–3210 (44%) or 3190–3150 (7%) or 3135–3015 (44%)	3335–3210 (19%) or 3195–3150 (2%) or 3140–3010 (74%)
SUERC-36000	1263	Charcoal, <i>Pinus sylvestris</i> , from [3029] a greyish brown midden	-25.1±0.2				4420±30	3330–3215 (19%) or 3175–3155 (2%) or 3120–2990 (75%)	3325–3230 (14%) or 3120–2940 (81%)
SUERC-36004	1263	Charcoal, <i>Betula</i> , from [3029] a greyish brown midden	-25.6±0.2				4430±30	3330–3215 (28%) or	3330–3215 (23%) or

Laboratory code	Sample ref	Material & context	$\delta^{13}\text{C}$ (‰) - diet	$\delta^{13}\text{C}$ (‰) - AMS	$\delta^{15}\text{N}$ (‰)	C: N	Radiocarbon age (BP)	<i>Posterior Density Estimate, cal BC (95% probability) Model 1</i>	<i>Posterior Density Estimate, cal BC (95% probability) Model 2</i>
								3180–3155 (3%) or 3125–3005 (64%)	3175–3155 (2%) or 3125–2945 (70%)
Trench T									
SUERC-61360	[5816] SF 22469	Calcined animal bone, cattle phalange II (I Mainland), from [5816], a midden layer above the clay capping sealing the earliest phase of midden deposition	-22.6±0.2				4219±27	2905–2855 (44%) or 2810–2745 (43%) or 2725–2695 (8%)	2905–2855 (74%) or 2810–2755 (21%)
SUERC-61343	[5822] SF 22497	Animal bone, cattle (<i>Auroch</i>) skull (I Mainland), from [5822], a midden layer above the clay capping sealing the earliest phase of midden deposition	-22.5±0.2		5.0±0.3	3.2	4146±31	2875–2620	2885–2725

Table 2. Ness of Brodgar: radiocarbon results obtained as part of a PhD thesis on soils and sediments in the World Heritage Site buffer zones (Cluett, 2008)

Laboratory code	Material & context	$\delta^{13}\text{C}$ (‰)	Radiocarbon age (BP)	Calibrated date (95% confidence) cal BC
SUERC-6191	Charcoal, <i>Ericales</i> (S. Ramsay, GUARD), from NOB E 047	-25.0±0.2	4280±35	2930–1870
SUERC-6684	Bulk soil, humic acid from NOB E 047	-27.2±0.2	3160±40	1510–1300
SUERC-6762	Animal bone, cremated (C. Smith, SUAT), from NOB E 047	-22.4±0.2	4225±40	2910–2690
SUERC-6764	Charcoal, <i>Betula</i> sp. (S. Ramsay, GUARD), from NOB C 075	-26.0±0.2	4320±40	3030–2880
SUERC-6685	Bulk soil, humic acid from NOB C 075	-27.4±0.2	4085±40	2870–2490
SUERC-6761	Animal bone, calcined (C. Smith, SUAT), from NOB C 86	-27.0±0.2	4185±45	2900–2620
SUERC-9542	Animal bone, calcined (C. Smith, SUAT), from NOB E 003	-20.4±0.2	4285±35	2930–2870

Table 3. Highest posterior density intervals from key parameters from Ness of Brodgar, derived from the models defined in fig. 7 (model 1) and fig. 9 (model 2)

<i>Parameter name</i>		Model 1 (see Fig. 7 for definition of the model)		Model 2 (see Fig. 9 for definition of the model)	
		<i>Posterior Density Estimate (95% probability unless otherwise stated)</i>	<i>Posterior Density Estimate (68% probability unless otherwise stated)</i>	<i>Posterior Density Estimate (95% probability unless otherwise stated)</i>	<i>Posterior Density Estimate (68% probability unless otherwise stated)</i>
<i>start_NoB</i>	Boundary parameter estimating the start of the dated late Neolithic activity and providing a <i>terminus ante quem</i> for the start of activity	3065–2950 <i>cal BC</i>	3035–2980 <i>cal BC</i>	3020–2920 <i>cal BC</i>	2975–2925 <i>cal BC</i>
<i>last_hearth_st1</i>	Last parameter estimating the last dated event in the Structure 1 hearth	2770–2570 <i>cal BC</i>	2705–2585 <i>cal BC</i>	2865–2695 <i>cal BC</i>	2860–2875 <i>cal BC</i>
<i>last_hearth_st7</i>	Last parameter estimating the last dated event in the Structure 7 hearth	2930–2875 <i>cal BC</i>	2915–2890 <i>cal BC</i>	2925–2880 <i>cal BC</i>	2915–2890 <i>cal BC</i>
<i>last_hearth_st12</i>	Last parameter estimating the last dated event in the Structure 12 hearth	2755–2565 (94%) or 2515–2500 (1%) <i>cal BC</i>	2670–2575 <i>cal BC</i>	2860–2715 (94%) or 2705–22685 (1%) <i>cal BC</i>	2855–2800 <i>cal BC</i>
<i>last_st12</i>	Last parameter estimating the dated event in Structure 12 when the roof collapse resulted in the smashing of pots near the hearth	2855–2835 (2%) or 2820–2585 (93%) <i>cal BC</i>	2775–2660 (65%) or 2645–2634 (3%)	2875–2710 <i>cal BC</i>	2870–2830 (46%) or 2820–2780 (22%) <i>cal BC</i>
<i>last_st14</i>	Last parameter estimating the last dated event in the Structure 14	2995–2905 <i>cal BC</i>	2960–2915 <i>cal BC</i>	2970–2900 <i>cal BC</i>	2940–2910 <i>cal BC</i>
<i>end_st8_start_st10</i>	Date parameter estimating the end of activity associated with Structure 8 and the start of activity associated with the construction of Structure 10	2990–2895 <i>cal BC</i>	2955–2905 <i>cal BC</i>	2965–2895 <i>cal BC</i>	2935–2905 <i>cal BC</i>
<i>st10_secondary_build</i>	Last parameter estimating the last dated event associated with the primary use of Structure 10 prior to its remodelling	2920–2885 <i>cal BC</i>	2910–2890 <i>cal BC</i>	2910–2840 (73%) or 2815–2755 (22%) <i>cal BC</i>	2900–2860 (66%) or 2800–2795 (2%)
<i>end_NoB_piered</i>	Boundary parameter estimating the end of the dated activity associated with piered architecture	-	-	2855–2665 <i>cal BC</i>	2850–2755 <i>cal BC</i>

<i>start_st10_last_use</i>	Boundary parameter estimating the start of the dated activity associated with last use of Structure 10	-	-	<i>2720–2480 cal BC</i>	<i>2620–2500 cal BC</i>
<i>central_hearth_st10</i>	Last parameter estimating the last dated event in the Structure 10 hearth	<i>2550–2460 cal BC</i>	<i>2500–2465 cal BC</i>	<i>2545–2460 cal BC</i>	<i>2495–2465 cal BC</i>
<i>structure_10_cattle</i>	Last parameter estimating the last dated event in the Structure 10 animal deposit	<i>2340–2200 cal BC</i>	<i>2315–2265 (50%) or 2250–2205 (18%) cal BC</i>	<i>2465–2360 cal BC</i>	<i>2460–2420 cal BC</i>
<i>end_st10_last_use</i>	Boundary parameter estimating the end of the dated activity associated with Structure 10	-	-	<i>2460–2270 cal BC</i>	<i>2455–2380 cal BC</i>
<i>end_NoB</i>	Boundary parameter estimating the end of the dated activity	<i>2285–2100 cal BC</i>	<i>2275–2230 (36%) or 2200–2150 (32%)</i>	-	-

Formal chronological modelling for the Late Neolithic site of Ness of Brodgar, Orkney

Figure list

FIGURE 1 Location map.

FIGURE 2 Overall plan showing location of trenches.

FIGURE 3 Plan showing Trench P structures.

FIGURE 4 Aerial view of Structure 10 (Photo: Hugo Anderson-Whymark).

FIGURE 5 The structures in Trench P as seen in the 2015 season (Photo: Hugo Anderson-Whymark). Orientation is given in Fig. 3.

FIGURE 6 Schematic representation of stratigraphic relationships between structures, middens and other features that define prior information incorporated into the chronological models for Ness of Brodgar.

FIGURE 7 Ness of Brodgar. Probability distributions of dates (Model 1). 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_hearth_st1*' is the estimate for when the hearth in Structure 1 was last used.

FIGURE 8. Ness of Brodgar: Calibrated dates from radiocarbon determinations obtained from Trench J (Stuiver & Reimer, 1993).

FIGURE 9 Ness of Brodgar. Probability distributions of dates (Model 2). The date followed by question mark has been calibrated (Stuiver & Reimer, 1993), but not included in the chronological model for the reason outlined in the text. The overall structure is identical to Figure 9.

FIGURE 10 Sections through the central hearth of Structure 10.

FIGURE 11 Ness of Brodgar. Durations of the dated phase of activity associated with structures built using piered architecture and for the interval between the end of activity associated with structures built using piered architecture and the later use of Structure 10 (*gap_1*) and from the last use of structure 10 and deposition of the articulated deer skeleton (*gap_2*), derived from the model defined in Fig. 11.

FIGURE 12 Ness of Brodgar. Mean magnetic directions, after removal of outliers (Batt & Outram, 2013) with errors at 95% confidence.

FIGURE 13 Ness of Brodgar. Probability distributions of key archaeological events derived from the models shown in Figs 9 and 11.

FIGURE 14 Probability distributions for key parameters from Barnhouse (Richards et al., 2016), Ness of Brodgar (Figs 7 and 9), Pool (MacSween et al., 2015) and the Stones of Stenness (Bayliss et al., in prep.).

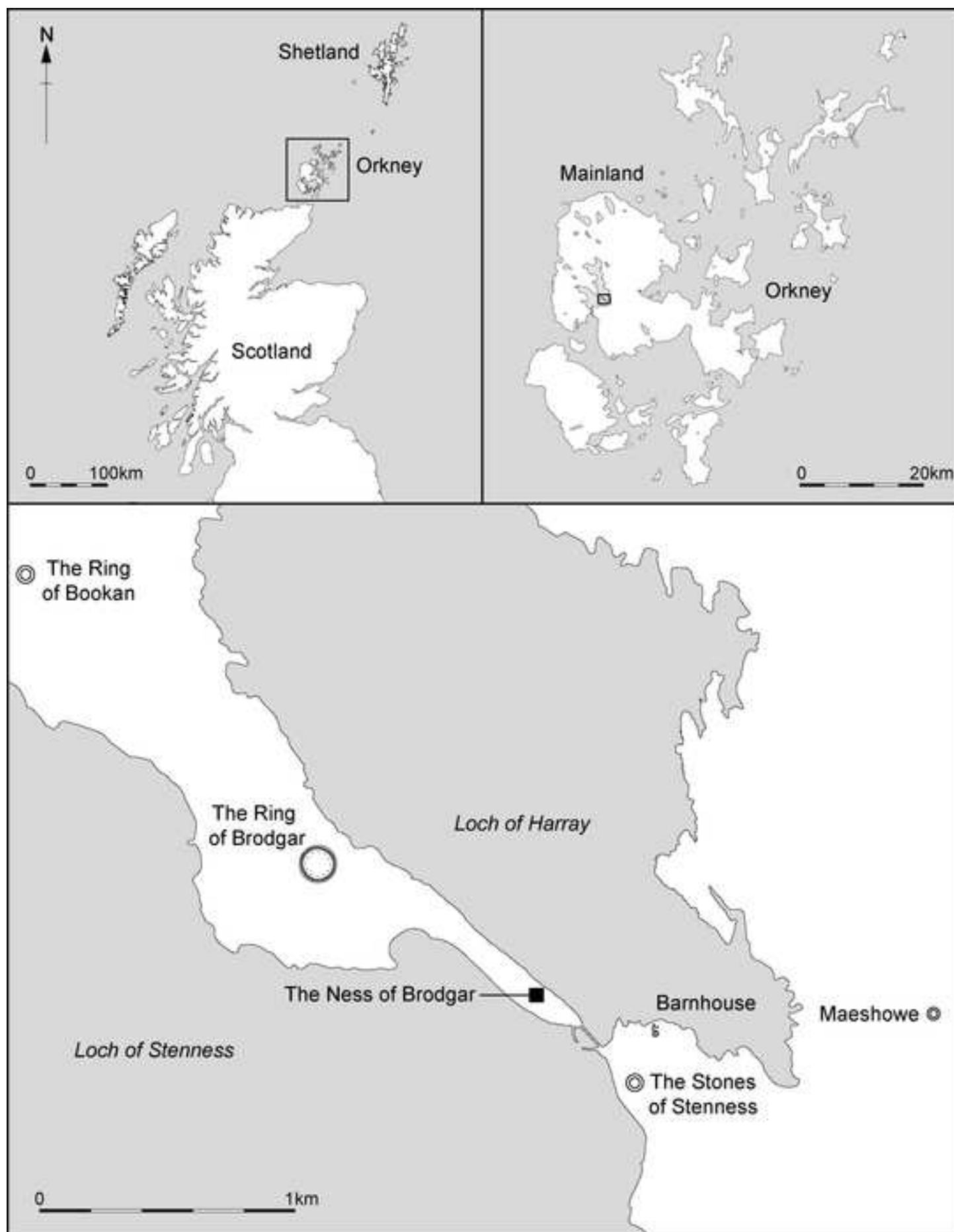


Fig 2

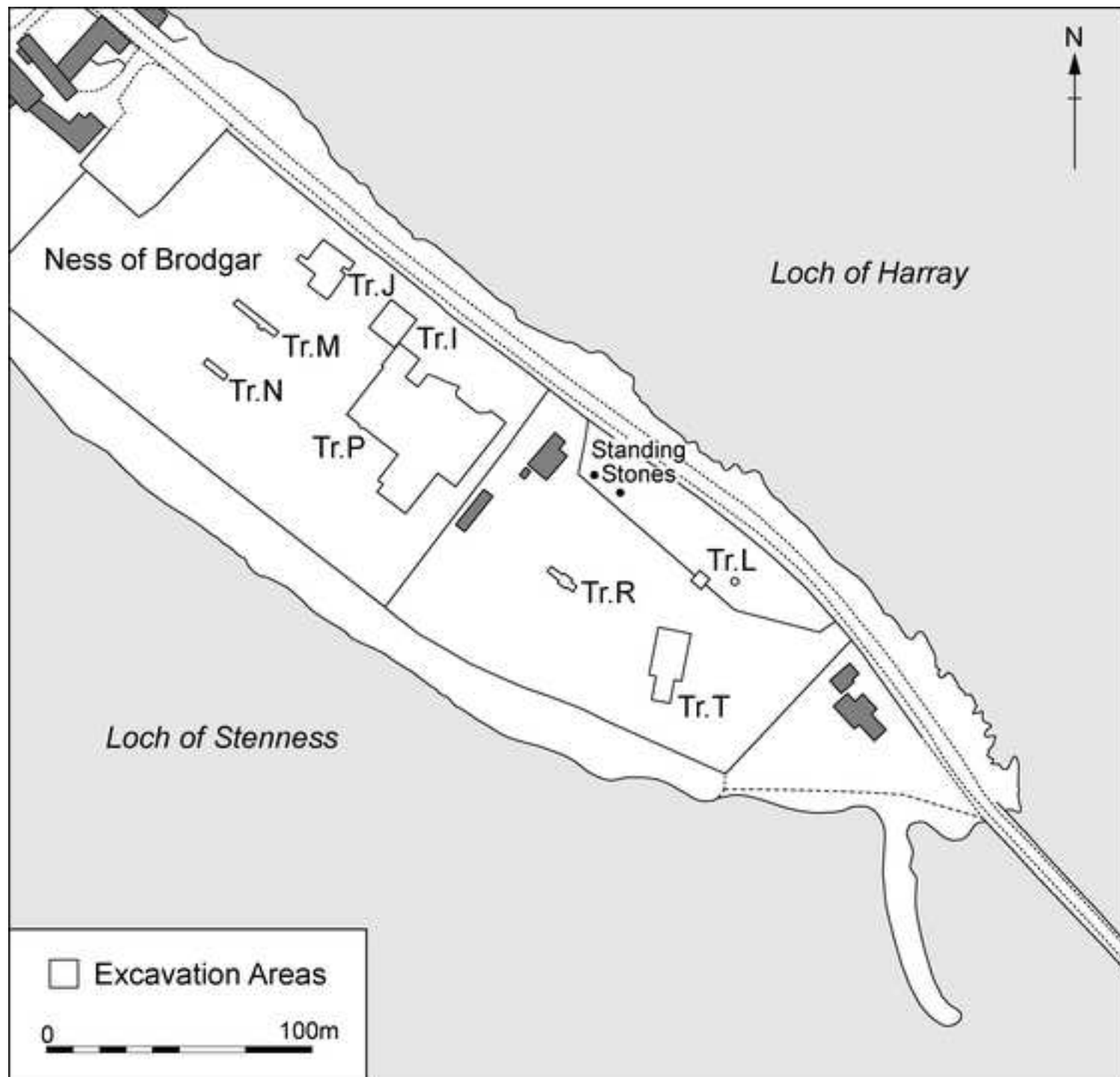


Fig 3

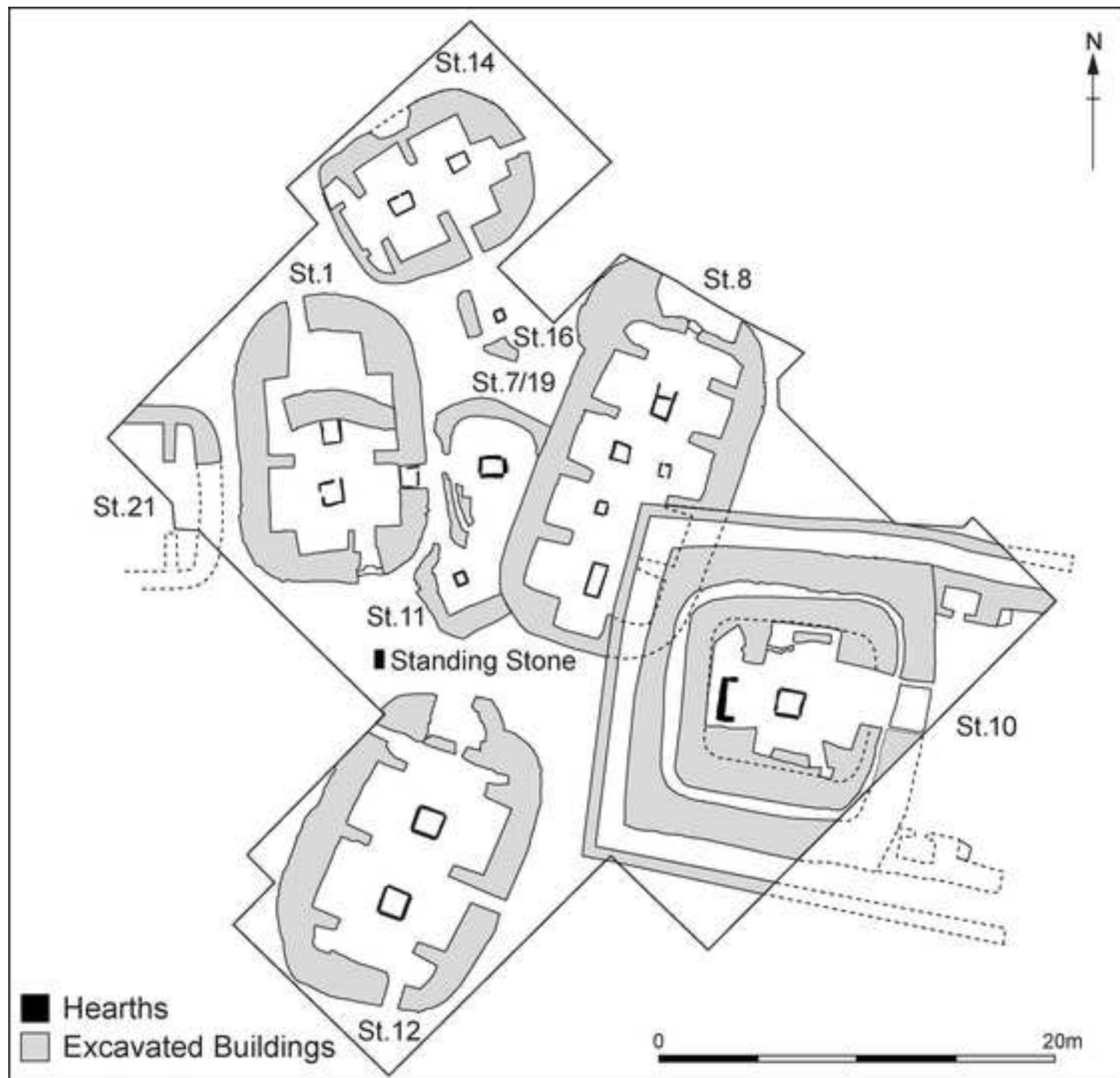
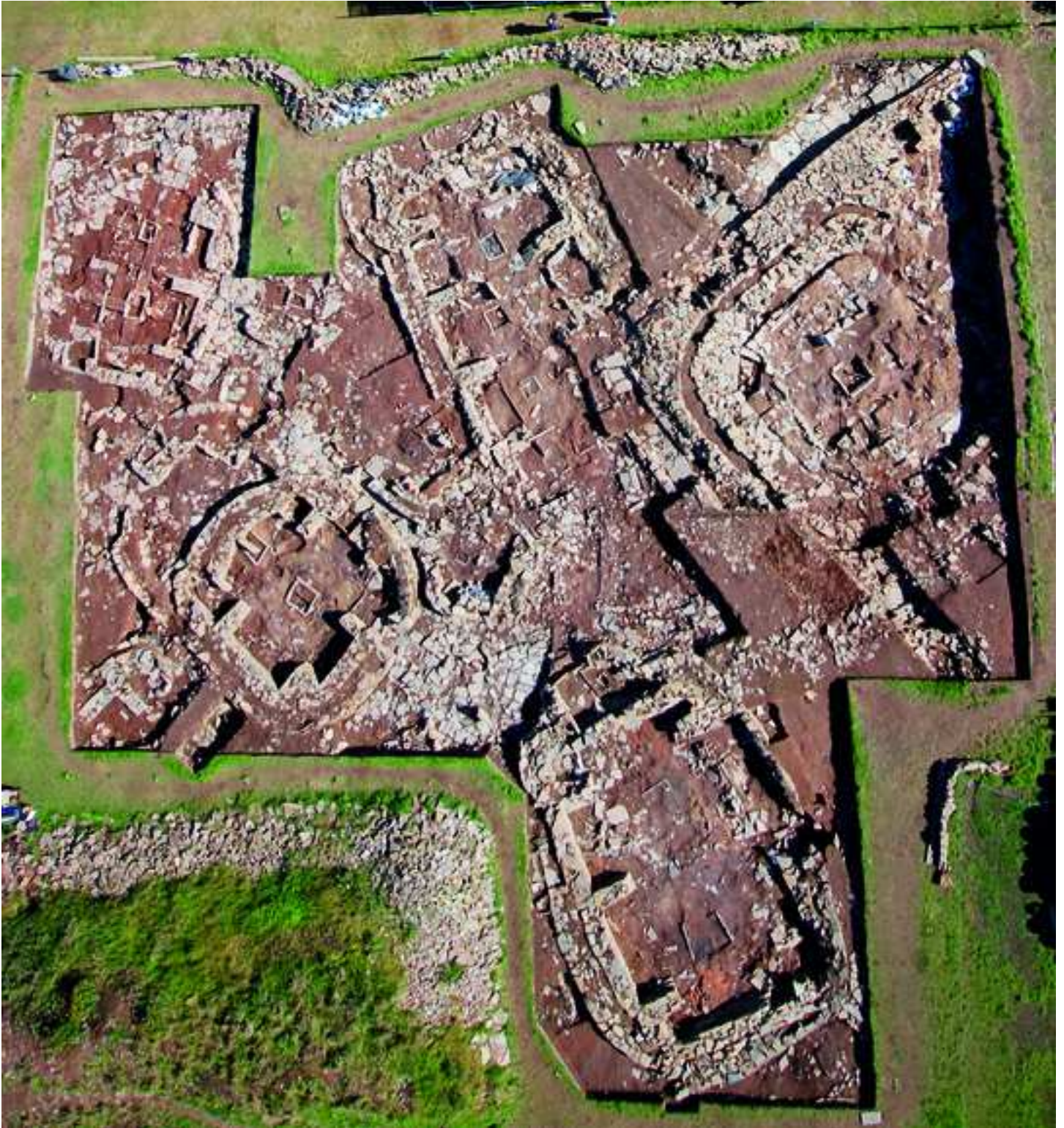
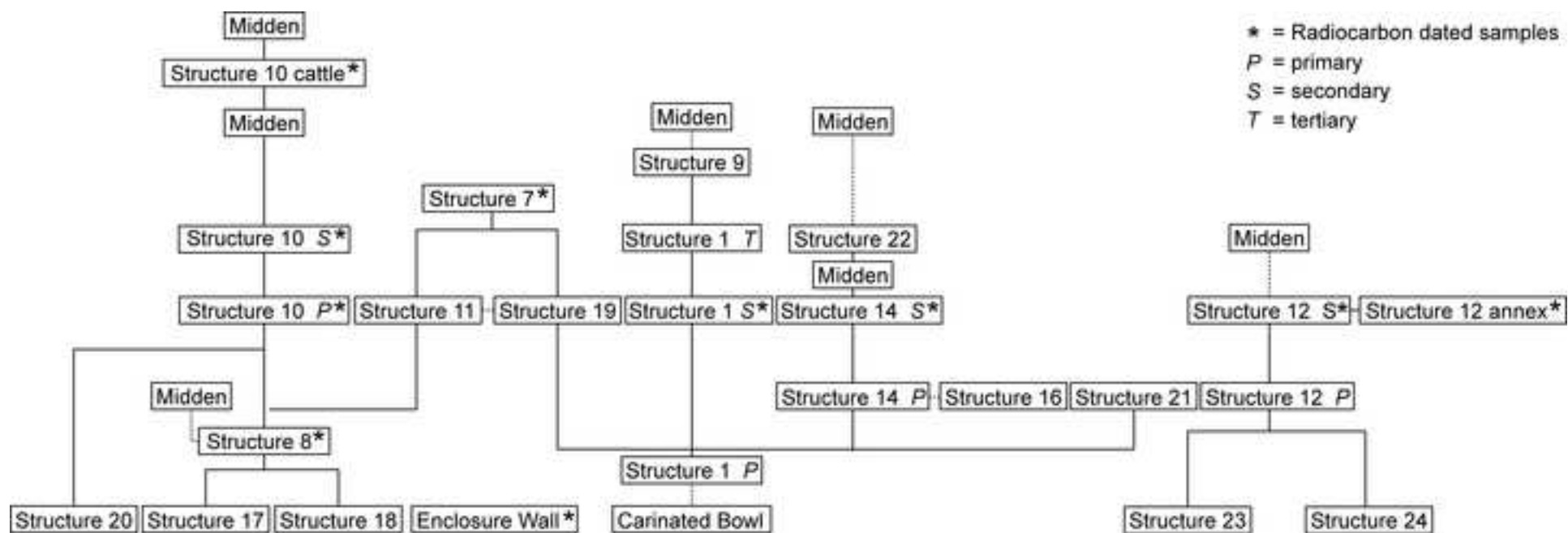


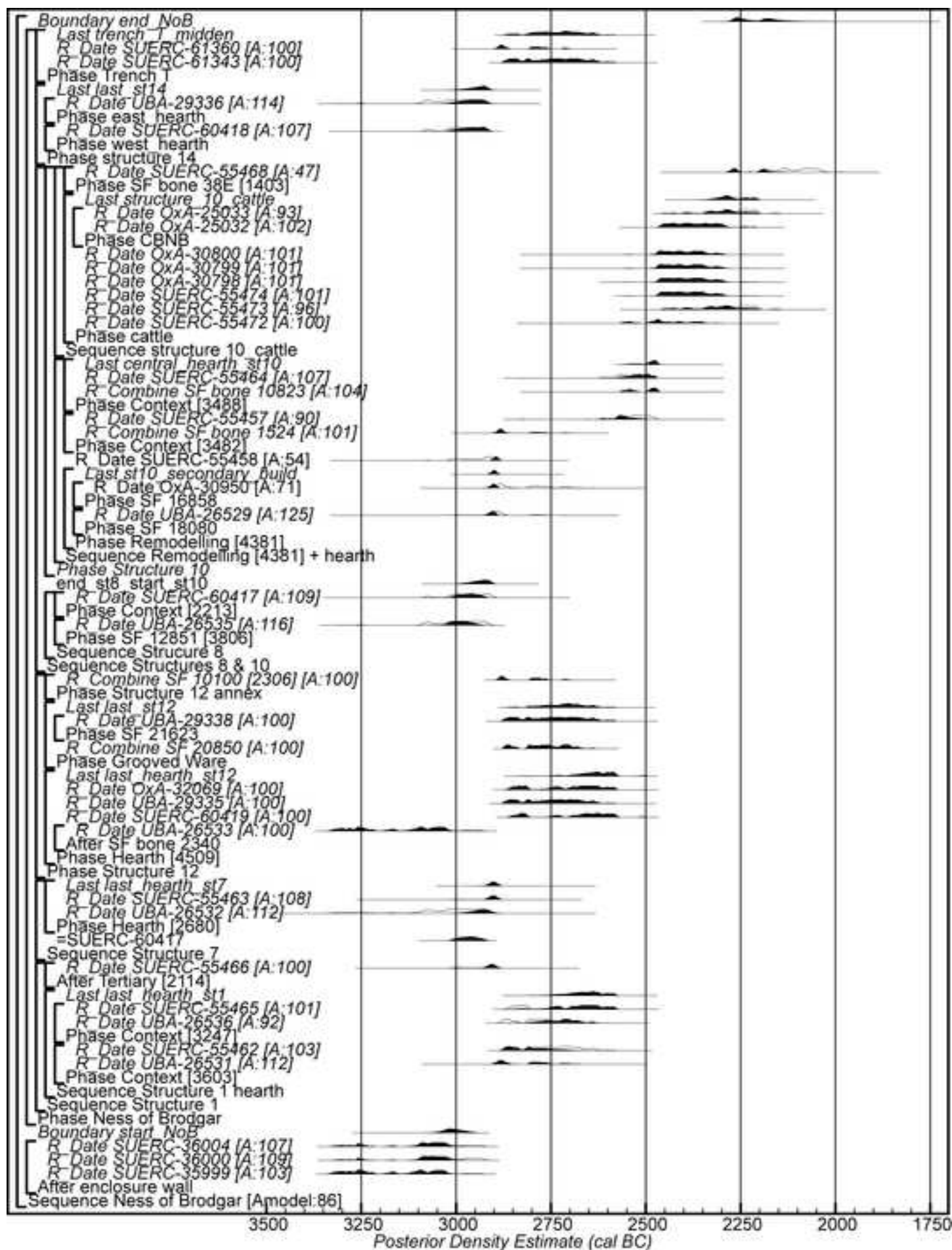
Fig 4

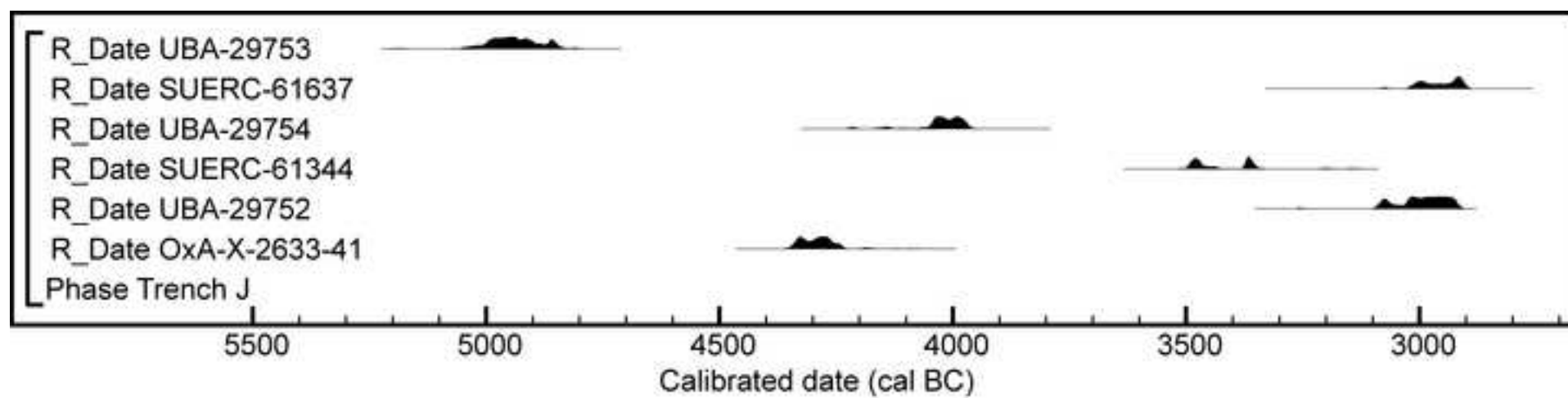
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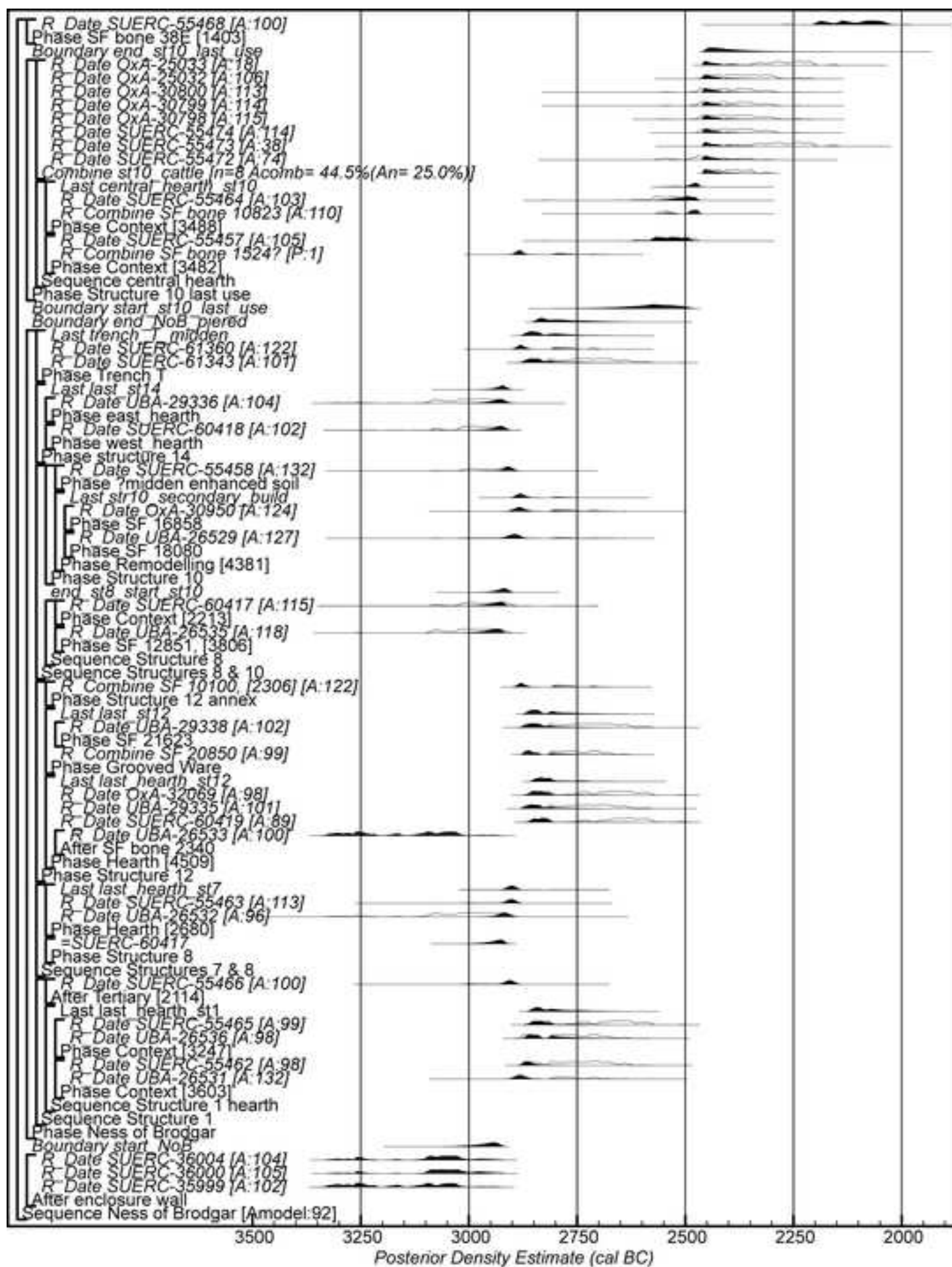
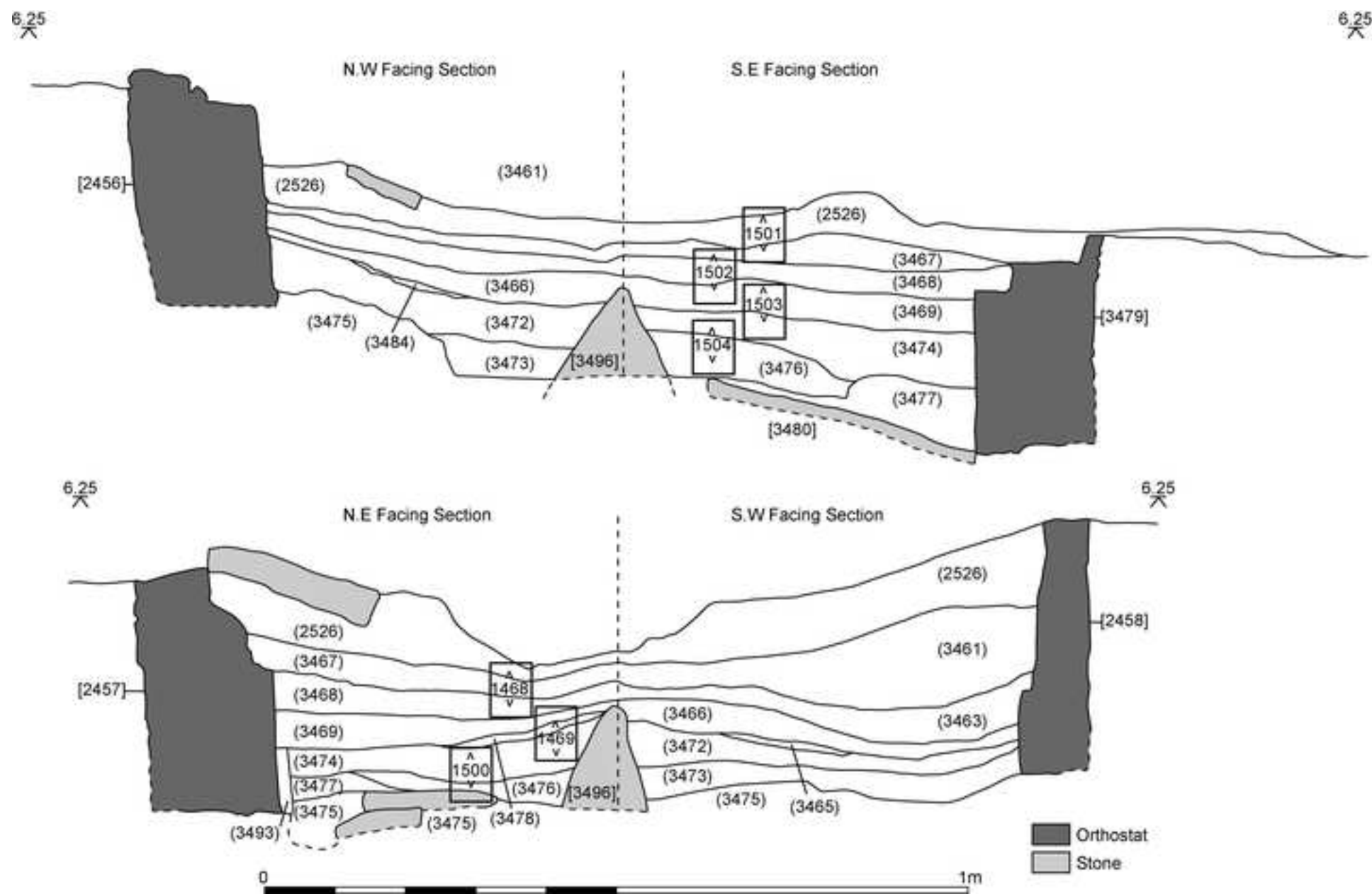


Fig 10



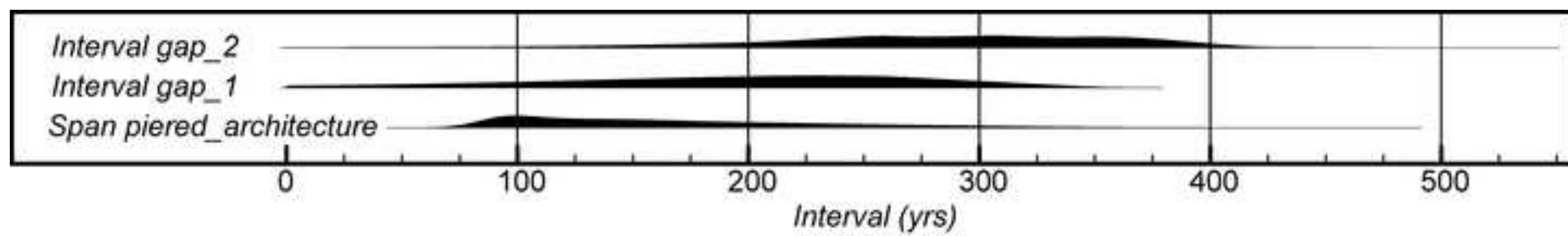
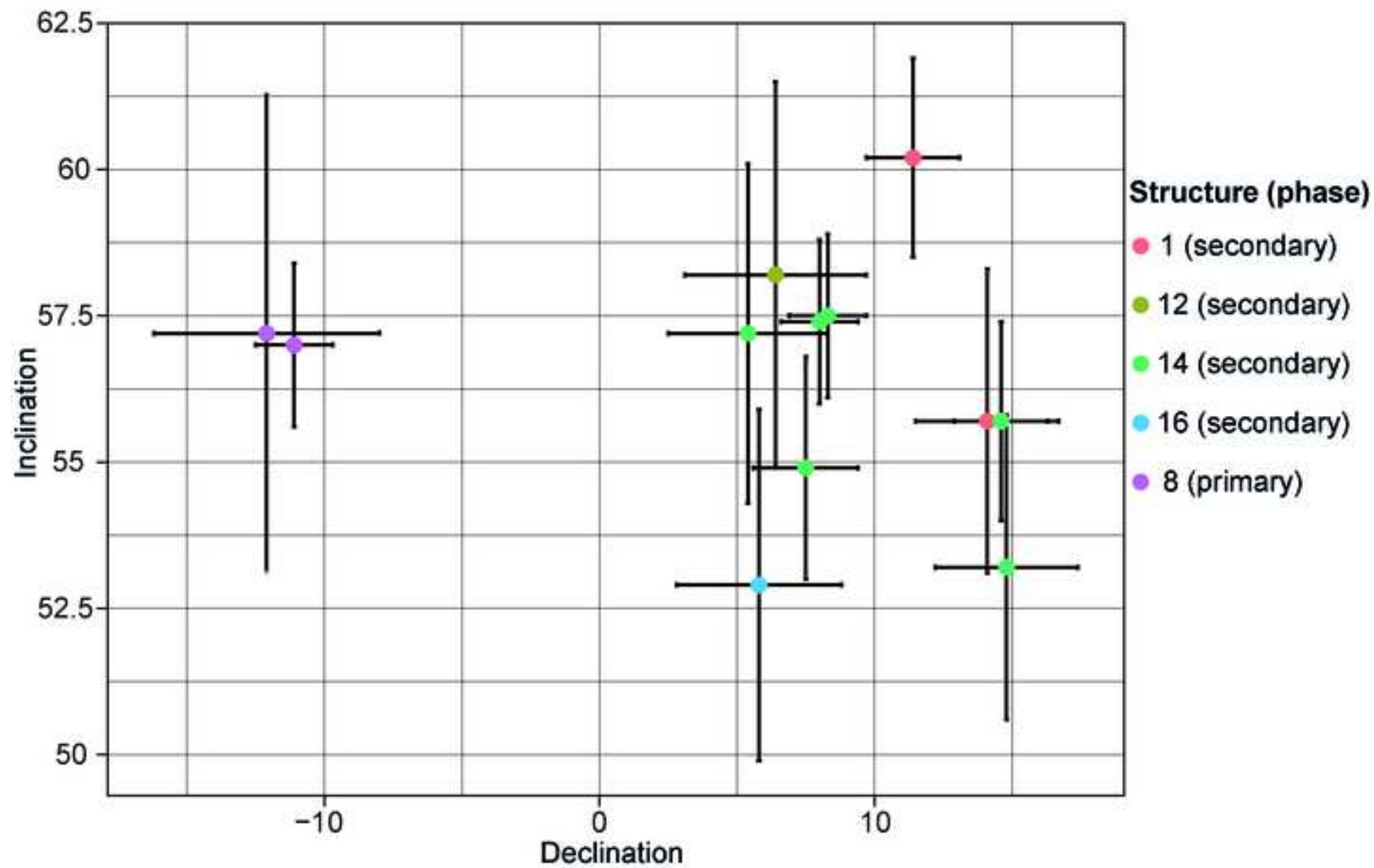
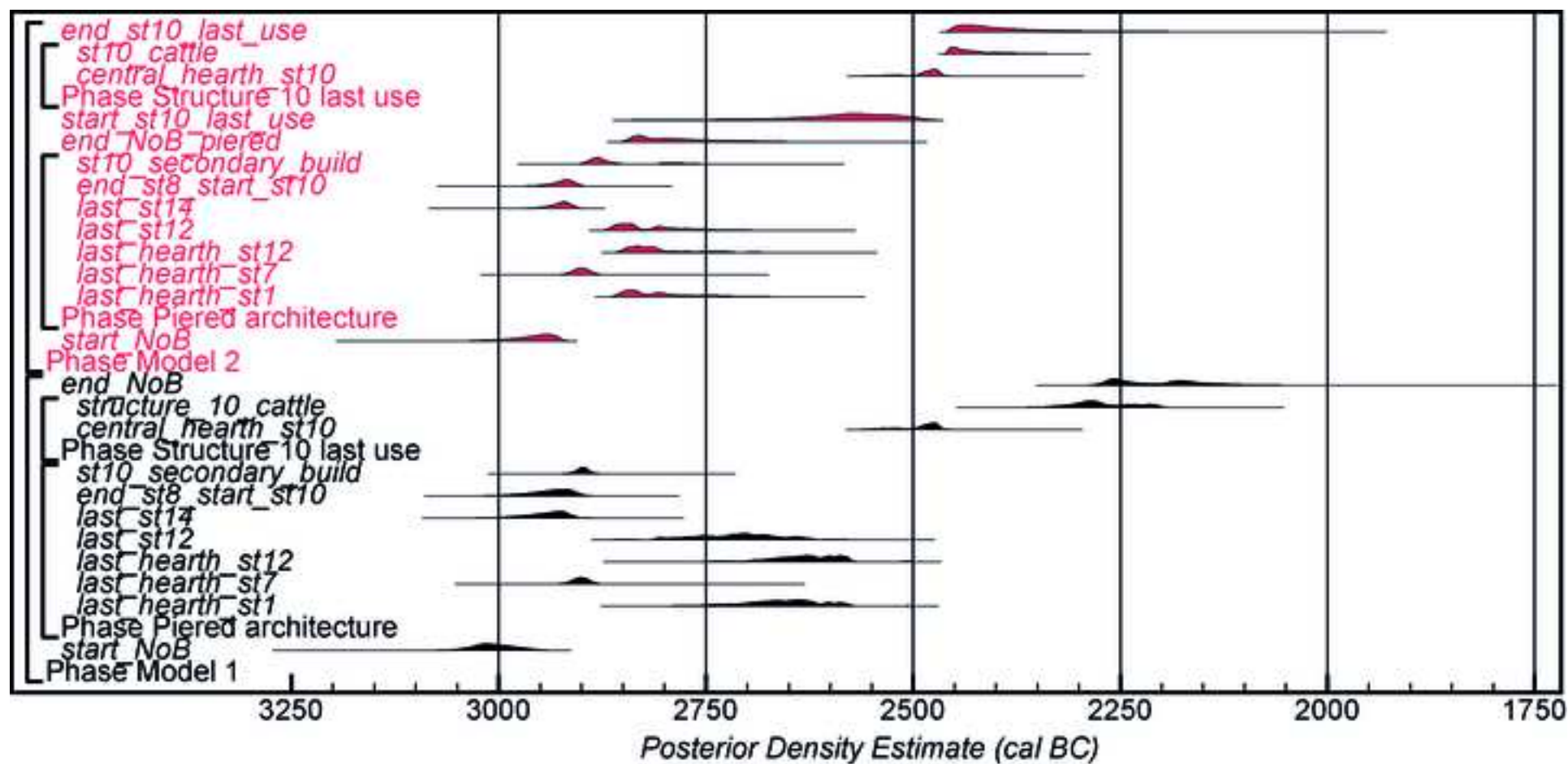
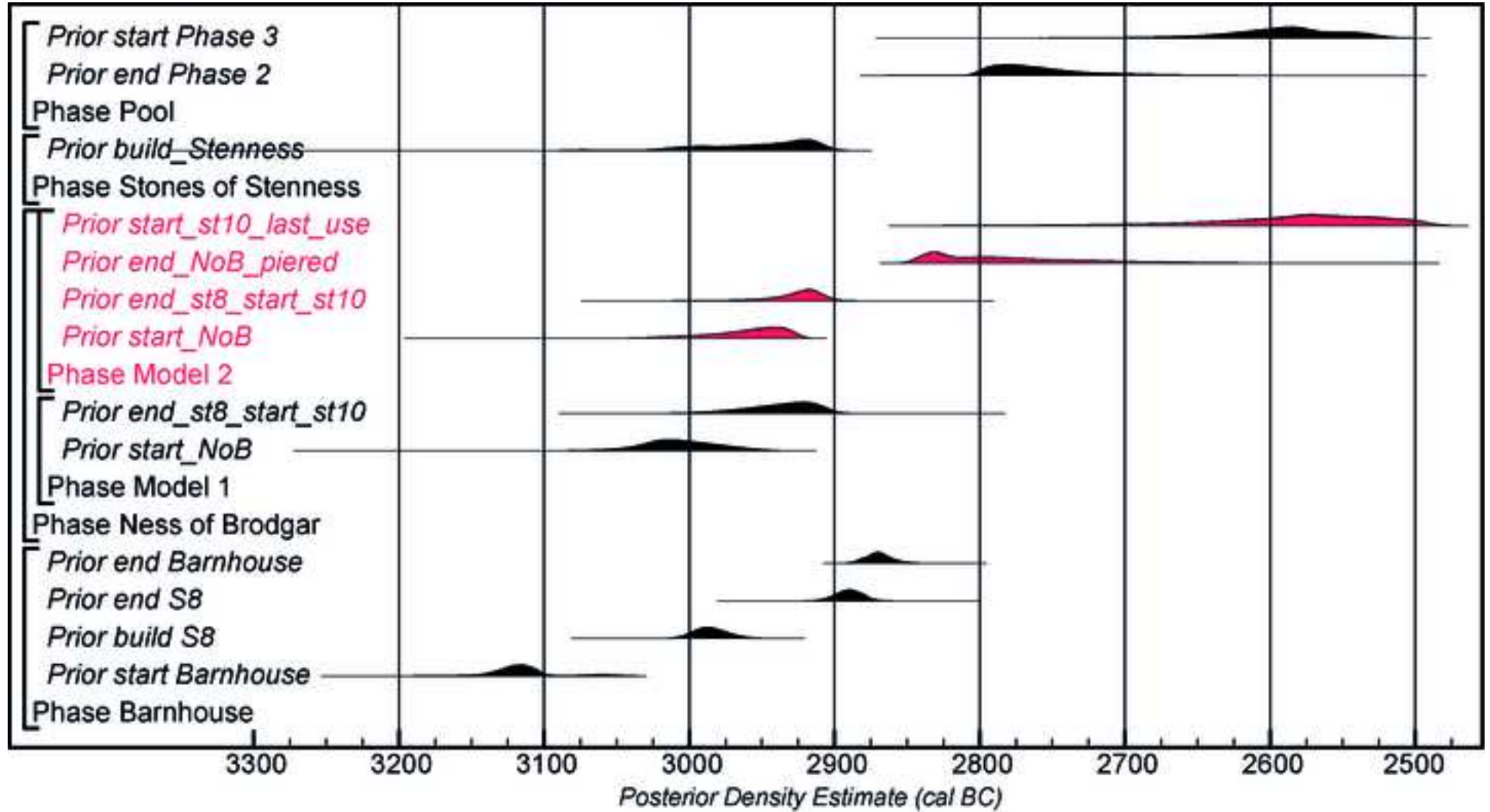


Fig 12







Nick Card et al., To cut a long story short: formal chronological modelling for the Late Neolithic site of Ness of Brodgar, Orkney

Response to the three referees, by Alasdair Whittle, corresponding author

We thank all three referees for their comments. Responding to the specific comments of Referees 1 and 2 has helped to improve the paper. The point of Referee 3 is well taken by the excavation team, and further efforts are planned; this paper is at least a start.

We have acted on many of the comments of Referees 1 and 2, but we have not responded to every suggestion made by Referee 2, because we disagree on aspects of terminology, phrasing and interpretation. Most of the points are minor. We note here, however, that we are sticking with the term Carinated Bowl on page 5 (Modified CB) and Fig 6, and that the issues raised at page 24 are complex, and would require a very substantial addition properly to deal with them in full; we are covering all this in another ToTL paper on Grooved Ware in Orkney (to be offered to PPS: first author, a certain Alison Sheridan!), and so judge that it is best to leave things as they are in the text. We must also keep the archaeomagnetic section (and see Referee 3!).

We are resubmitting tweaked versions of Figs 6 and 13.

Referee 2 made the sensible suggestion that Figs 7 and 9 might be more easily legible if set landscape.

29 August 2016