The Late Neolithic timescape of Orkney: islands of history

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[ABSTRACT]

Orkney is internationally recognised for its exceptionally well-preserved Neolithic archaeology. The chronology of the Orcadian Neolithic is, however, relatively poorly defined. We analysed a large body of radiocarbon and luminescence dates, formally modelled in a Bayesian framework, to address the timescape of the Orkney Late Neolithic. The resultant chronology for the period suggests differences in the trajectory of social change between the 'core' (defined broadly as the World Heritage site) and the 'periphery' beyond. Activity in the core appears to have declined markedly from c. 2800 cal BC, which, we suggest, resulted from unsustainable local political tensions and social concerns.

Keywords: Orkney; Late Neolithic; settlement; Bayesian modelling

Late Neolithic Orkney

Orkney is rightly famed for the exceptional quality and preservation of its Neolithic archaeology. House walls can stand above head-height, and chambers in tombs display outstanding masonry skill. The diversity of evidence is also striking, from settlements to chambered tombs, to stone circles and their quarries. There is varied material culture, especially in the Late Neolithic, with the presence of Grooved Ware pottery and a wide array of stone objects, including stone balls and maceheads. New discoveries continue, not only on small, outlying islands neglected in previous research, such as of the settlement of Braes of

Ha'Breck, on Wyre (Thomas & Lee 2012), but also in areas long explored, such as the settlement complexes of Barnhouse, Ness of Brodgar, and Bookan in western Mainland (Richards 2005; Card *et al*. 2017; Christopher Gee *pers. comm*.). The Ness of Brodgar has further enriched the archaeological record with its abundance of impressive buildings, wealth of interior fittings and incised and painted decoration (Card & Thomas 2012). Thus, the 'Heart of Neolithic Orkney' was granted World Heritage status in 1999 for very good reasons (Downes *et al*. 2013).

The stone houses grouped in settlements, and the monuments, which together define the Orcadian Neolithic, also provide opportunities to follow trajectories of change at the local and even household level of social interaction. Previous research charted the gradual development of a process of settlement nucleation beginning with small-scale dispersed settlements, with round-based pottery, in the mid fourth millennium cal BC. By the later fourth and into the third millennia cal BC, larger conglomerated settlements with Grooved Ware appear; towards the end of the Neolithic sequence, these are juxtaposed larger houses, later Grooved Ware, and in some cases Beaker pottery (Richards & Jones 2016a). Chambered tombs reached their peak of architectural sophistication and spatial complexity with Maeshowe passage graves (Davidson & Henshall 1989). Stone circles in the form of the Stones of Stenness and Ring of Brodgar appear to be innovations of the earlier and mid third millennium cal BC (Richards 2013).

Grooved Ware pottery emerged in the Late Neolithic, its flat-based forms supplanting a round-based repertoire (Cleal & MacSween 1999). One interpretation of the trajectory of social change was that the Late Neolithic saw the development of chiefdoms, following earlier segmentary societies (Renfrew 1979). Other accounts have stressed the complexity and diversity of the evidence, and have posited different models of social change at other scales with, among other features, an emphasis on community and great houses (Sharples 1985; Richards 2005, 2013; Richards & Jones 2016a).

Through all this run fundamental questions of chronology, especially timings, durations and tempo: for how long were the Neolithic settlements inhabited and was this settlement continuous? Can we date the different stages of settlement conglomeration through the Neolithic? Is there any consistency or concurrence in this process between settlements? Did the monumentality exemplified by Barnhouse and the Ness of Brodgar co-exist? When did Grooved Ware pottery emerge, and did its adoption coincide with the ending of previous bowl traditions? How quickly did it develop and change? When were Maeshowe passage graves built, and how do they relate to the temporal trajectory of stalled chambered cairns?

When were the Orkney stone circles erected? Was the initiation of all these changes simultaneous, and what was the tempo of change through this period? Before we can address such questions concerning the nature of social formations and the appearance of monuments in Late Neolithic Orkney, we need critically to consider the nature of dwelling, as represented by settlement histories, and that provides the focus of this article. The quantity and range of evidence now available offer the possibility to unravelling a more complicated sequence, specific site histories, and the changing social circumstances they exemplify.

Scientific dating and Bayesian chronological modelling on Orkney

When Colin Renfrew started excavation of the chambered cairn at Quanterness in 1972, there were no radiocarbon dates for Orkney Neolithic sites (Renfrew *et al*. 1976: 194). This situation quickly changed: by the mid-1980s, over 80 radiocarbon measurements relating to Neolithic activity on 11 sites across the islands could be listed and interpreted on a calibrated calendar timescale (Clark 1975; Renfrew & Buteux 1985).

Although only small numbers of additional radiocarbon dates were obtained over the following 15 years, by 2000 Patrick Ashmore was able to muster a total of 119 radiocarbon dates from 18 sites in his synthesis of the chronology of Neolithic Orkney. This study relied on the visual inspection of calibrated radiocarbon dates and summed probability distributions of groups of related calibrated dates from phases of activity at particular sites. The limitations of both approaches for inferring accurate chronologies of past activity have since become appreciated (Bayliss *et al.* 2007), although Ashmore's (1999) requirement for radiocarbon results on short-lived, single-entity samples and his emphasis on a critical assessment of the archaeological provenance of the dated material have substantially improved the utility of the dates obtained over the succeeding decades.

The 14 radiocarbon dates from the phase I and phase II settlements (Trench 1) at Skara Brae (Renfrew & Buteux 1985) formed the basis of one of the first case studies for the application of a Bayesian approach to interpreting chronology in archaeology (Buck *et al.* 1991). This approach combines calibrated radiocarbon dates, or other forms of scientific dating, with knowledge of the archaeological contexts from which they are derived, to produce a series of formal, probabilistic date estimates. Stringent demands are made of both the radiocarbon dates and our archaeological understanding of stratigraphy, associations, sample taphonomy, and context in general. Thus, the combined chronology should be both more reliable and more precise than its individual components, since it is reliant on multiple strands of reinforcing evidence (Bayliss & Whittle 2015).

Bayesian chronological modelling was not widely adopted for the Orcadian Neolithic at this time due to a perception that Bayesian analysis could only provide refined chronologies where there was a deep sequence of direct stratigraphic relationships (Ashmore 1998: 142–45). Furthermore, in considering the chronology of Grooved Ware in Scotland, Ashmore (1998: 142) asserted that there was limited potential for refining the dating of its first occurrence, as the shape of the radiocarbon calibration curve means that results on short-lived samples actually dating to between 3300 BC and 3100 BC would calibrate to "somewhere in the period 3400 to 3000 (or even 2900) cal BC."

Technical developments in both radiocarbon dating and the statistical modelling of dates over recent decades can now be used to challenge this view. Not only have the quoted errors on radiocarbon measurements approximately halved since Ashmore (1998), but it has now become possible to date calcined bone (Lanting *et al*. 2001). The potential for Bayesian statistics to provide refined chronologies on a routine basis, even in situations where stratigraphic sequences are limited, has also become clearly apparent (Bayliss 2009). This increased precision means that what previously was a undifferentiated plateau in the calibration curve for the late fourth millennium cal BC now resolves into a series of micro-wiggles which can be employed as the basis for much more constrained chronologies (Reimer *et al*. 2013).

The potential of these techniques to refine narratives for Neolithic Orkney is now being exploited. Major programmes of new dating and analysis have, for example, been undertaken on the stalled cairn at the Holm of Papa Westray North and the chambered cairn at Quanterness (Ritchie 2009: 59–66; Schulting *et al.* 2010). Recent research has also seen chronological modelling of Grooved Ware settlement sites at Pool, Sanday , Barnhouse and Skara Brae, Mainland, and preliminary models for Ness of Brodgar, Mainland and the Links of Noltland, Westray, where excavation is continuing (MacSween *et al*. 2015; Richards *et al*. 2016a; Clarke & Shepherd forthcoming; Richards *et al*. 2016a; Clarke & Shepherd forthcoming; Card *et al*. 2017; Clarke *et al*. in press). Further radiocarbon dates have also been obtained on samples of Orkney vole (*Microtus arvalis*) from a range of Neolithic sites (Martínková *et al.* 2013).

This article is based on a review of 613 radiocarbon measurements and 79 luminescence ages from 31 sites (Table 1; Figure 1). This analysis builds upon the work of Griffiths (2016), who provides a synthesis of the chronology of activity in the fourth millennium cal BC. The original intention was to confine our analysis to Late Neolithic activity associated with Grooved Ware, but it soon became apparent that round-based pottery

(as found at Isbister chambered tomb) and Grooved Ware (as found at Barnhouse) were almost certainly in contemporary use during the thirty-first century cal BC, at the very least (Figure S1; Richards *et al.* 2016a: figs. 6–8). We therefore consider all the dating evidence associated with Grooved Ware sites and with sites of the later fourth millennium, although our analysis centres on the centuries between *c.* 3300 and 2300 cal BC.

All the chronological modelling discussed here was undertaken using the OxCal v4.2 program (Bronk Ramsey 2009) and the atmospheric calibration curve for the northern hemisphere published by Reimer *et al.* (2013). The chronological models for each site are described in the online supplementary material, and are defined exactly by the brackets and OxCal CQL2 keywords on the left-hand side of the technical graphs (http://c14.arch.ox.ac.uk/). The posterior density estimates output by the model are shown in black, with the unconstrained calibrated radiocarbon dates shown in outline. The other distributions correspond to aspects of the model. For example, *start_isbister_primary* is the estimated date when burial in the chambered tomb at Isbister began (Figure S1). In the text and tables, the Highest Posterior Density intervals of the posterior density estimates produced by the models are given *in italics*, followed by a reference to the relevant parameter name and the figures in which the model which produced it is defined. Key parameters for the chronology of Late Neolithic Orkney are listed in Tables S4 and S5.

The Late Neolithic timescape of Orkney

Formal modelling not only enables more precise chronologies for individual sites, but allows us to characterise the timing and duration of different types of phenomena, and then to combine these into a much more differentiated narrative than previously available. First, we set out some of what we consider to be key elements in the Late Neolithic narrative (referring the reader to the Supplementary Material for site details).

Chambered cairns

Figure 2 shows models for the use of stalled cairns and Maeshowe passage graves on Orkney. Sites with more than two radiocarbon dates are represented by the estimated dates for the start and end of activity taken from the site-based model. We have taken the radiocarbon dates on human remains from within the primary chamber deposits to indicate the period when the tombs were used for burial. Although it is possible that these may represent secondary burials, the number of dated individuals across the period of burial at, for example, Quanterness (Figure S6), suggests that this is unlikely. The single date from the Knowe of

Lairo (SUERC-45833) is not included in either model, as this tomb underwent a series of modifications and it not clear from which phase of activity the dated sample derives. We have interpreted the dated human remains at the Point of Cott to relate to the use of the stalled cairn (Figure S16).

It is clear that both stalled cairns and Maeshowe passage graves (Figure 3, g and h) were first constructed in the middle centuries of the fourth millennium cal BC, although with current evidence it is not possible to say which came first. Human remains may have been deposited in Maeshowe passage graves into the middle centuries of the third millennium, whereas the primary deposition of human remains in stalled cairns appears to have ended in the first quarter of the millennium. Although a number of dated tombs became horned cairns in later phases, only two dates associated with this type of monument are available (Table 2). These suggest that the example at Vestra Fiold, at least, was constructed in the second quarter of the third millennium cal BC (Figure 2).

In particular chambered cairns, the deposition of animal remains occurred after that of human remains, although deposition sometimes overlapped. A model for the currency of this activity is also shown in Figure 2. Animal remains were clearly deposited in some tombs, whilst human remains were deposited in others.

The Orkney vole

The common vole (*Microtus arvalis*) is significant to the discussion of Neolithic Orkney, as it is found today on Orkney and on the European continent, but not in mainland Britain. Since the species cannot have survived the Last Glacial Maximum on the archipelago, it was probably introduced via direct long-distance sea travel between Orkney and the continent. Recent studies of dental morphology and mitochondrial DNA have been undertaken to identify the probable origins of the Orkney vole population (Martínková *et al*. 2013; but see Sheridan & Pétrequin 2014 for a critique). This work has been supplemented by a programme of direct AMS radiocarbon dating of vole remains from Neolithic sites on Orkney. Two existing measurements from the Links of Noltland (OxA-1081–1; Table S3) were performed in the early years of AMS dating, and fall outside the span of the measurements undertaken more recently (Figure 4). Given the significant refinements in bone pre-treatment protocols for radiocarbon dating that have occurred in the intervening period (e.g. Brown *et al*. 1988), we chose to exclude these measurements from the model shown in Figure 4. This model suggests that the common vole first appeared on Orkney in *3455–3100 cal BC* (*95% probability*; *start Orkney voles*; Figure 4), probably in *3315–3135 cal BC* (*68% probability*).

Late Neolithic settlement

Figure 5 summarises the estimated dates for the occurrence of different activities in later fourth and third millennium Orkney. The horizontal bars represent the probability that a particular site or monument-type was in use in a particular 25-year period (light shading is less probable, darker shading more probable). For the settlements and stone circles, distributions have been taken from the site-based models defined or referenced in the Supplementary Online Materials. Distributions for the chambered cairns derive from the model shown in Figure 2, and those for the appearance of the Orkney vole from the model defined in Figure 4.

House architecture

Figure 6 summarises the model for the currency of timber and stone houses on Orkney (Figures S19–S24). The first houses were timber (*57.3% probable*), in use from *3560–3360 cal BC* (*95% probability*; *start_timber_houses*; Figure 6), probably *3445–3370 cal BC* (*68% probability*). The first stone houses were linear in form (*63.1% probable*), being in use from *3490–3300 cal BC* (*95% probability*; *start_linear*; Figure 6), probably *3410–3330 cal BC* (*68% probability*). Timber and stone houses were, therefore, both concurrently in use during the second half of the fourth millennium cal BC.

Settlement intensity

Figure 7 provides an estimate for the intensity of settlement activity in 'core' and 'peripheral' areas across Orkney from 3500–2200 cal BC, derived from estimates of the number of structures in use on individual sites in 25-year periods (see Richards *et al.* 2016a: fig. 14). The intensity of activity in the core (defined as the concentration of sites and monuments in the Stenness–Brodgar area) from *c.* 3125–2850 cal BC (Figure 7) occurs in tandem with the start of a general decline in the periphery (simply defined as the rest of the archipelago), with a clear lull in settlement intensity apparent in the 28th century cal BC. Although settlement in the periphery appears to recover to its early intensity levels during the mid-third millennium BC, the core shows no similar recovery; peripheral settlement intensity goes into a second major decline in the later part of the third millennium BC.

Discussion

The emergent chronology set out above and in the Supplementary Online Material appears to present a more complex picture of extensive and overlapping activities, concurrences and discontinuities occurring at different sites throughout Orkney during the fourth and third millennia cal BC. This prompts a radical reassessment of this period.

First, there is now broader evidence to support the contemporaneity of early stalled chambered cairns and timber houses (Richards & Jones 2016b). The linear stone houses divided by upright stone slabs previously considered to characterise the Early Neolithic (e.g. Knap of Howar), are now revealed to be a later development *c*. 3300 cal BC (Figures 6 and 3, a-b). Round-based pottery was in use within the early timber settlements. From this point onwards, a very complex picture is revealed of round-based bowls and Grooved Ware vessels overlapping in use between various forms of house architecture at different sites across the archipelago, particularly during the 32nd–30th centuries cal BC (Figure 3a-f). Stalled cairns and Maeshowe passage graves (Figure 3g-h) seem to have been initially employed as places for human burial, and later as places where animal remains were deposited. This later phase of activity may coincide with the addition of horn-works to some stalled cairns to create large long mounds, or in the case of Vestra Fiold, an entirely new mound (Richards 2013: 152–176). On the basis of dating of human bone from Quanterness, it can be argued that passage grave architecture began in Orkney around 3400 cal BC. On current evidence, this would make Orcadian passage graves the earliest examples of this architecture in Britain and Ireland, accepting that Carrowmore is of an entirely different architectural form (*contra* Hensey 2015).

Secondly, we are now able to trace in some detail the development of fourth millennium cal BC settlement and identify the tendency towards nucleation. This trend continued into the third millennium cal BC, culminating at sites such as Skara Brae, which has substantial conjoined stone-houses, and encircling casing walls containing thick 'midden'. Between 3200 and 3000 cal BC two main occurrences transform the appearance of the settlements into large mounds: superimposed or recurrent nucleated houses, and the deposition of substantial midden material.

This phenomenon occurs throughout Orkney at sites as distant as Stonehall, Mainland, and Pool, Sanday (Hunter 2007; Richards *et al*. 2016b). With more detailed chronological analysis, settlement histories provide a more punctuated narrative of dwelling. The complex sequence at Pool reveals discrete superimposed phases of occupation respectively associated with early and late forms of house architecture and Grooved Ware (MacSween *et al*. 2015). A similar, but undated, division is observable in the nearby

settlement at the Bay of Stove, Sanday. Here, a nucleated Neolithic settlement is eroding from a small cliff and a massive Neolithic settlement mound lies *c*. 200m metres inland. Incised Grooved Ware has been recovered from the eroding settlement, while test pits into the large mound produced plastic ornamented Grooved Ware (Bond *et al.* 1995). At these two Sanday sites, a disjunction is evident in settlement between *c*. 2800 and 2600 cal BC. A similar scenario occurred at Skara Brae, where an earlier nucleated settlement with recessed house architecture founded in the centuries around 2900 cal BC may have been abandoned after a relatively short period of habitation, and re-occupied in the 28th century cal BC (Figure 5).

In the Stenness-Brodgar area of western Mainland, a similar situation has become apparent, with incised Grooved Ware and recessed house architecture appearing with the foundation of the nucleated Barnhouse settlement in the late 32nd century cal BC. From the outset, however, monumental architecture (House 2) is a dominant component of Barnhouse, a feature that becomes exaggerated with the subsequent construction of the massive Structure 8 (Figure 3f). Although the earliest settlement evidence is yet to be found, the Ness of Brodgar seems to share a similar trajectory to Barnhouse, with monumental structures dating to the first centuries of the third millennium cal BC (e.g. Figure 3e).

Thus, across Orkney (including the Stenness–Brodgar area of western Mainland) between the late 32nd–29th centuries cal BC, settlement nucleation accelerates alongside the deposition of substantial midden deposits to create identifiable 'villages'. At the majority of these villages a disjuncture occurred *c*. 2800 cal BC, involving abandonment and a spatial shift in settlement. Then, in the 27th–26th centuries cal BC, a process of reoccupation emerged that continues until a final abandonment of villages in the 24th century cal BC. This phase of occupation involved different house architecture, larger houses and differently made and decorated Grooved Ware. This temporal and spatial sequence is not, however, universal, and at the Bay of Stove, Sanday, the original village was never reoccupied and a massive settlement mound accrued a few hundred metres away. Equally, at Tofts Ness on Sanday, occupation appears to have continued to the end of the third millennium cal BC.

The later part of this narrative does not include settlements in the Stenness-Brodgar area, because something very different happened here. The founding of Barnhouse and Ness of Brodgar coincided with developments occurring in other parts of Mainland and the outer isles. Monumental construction in and around them significantly drew on the architecture of 'big houses' (Figure 3, e-f) and may have materialised links and relations beyond Orkney (see Richards 2013: 74–8). Unlike many of the other villages, however, these sites were

never reoccupied. Instead, from the 28th century cal BC, the Stenness-Brodgar area appears to have no longer served as a significant place of human dwelling. The later history of Ness of Brodgar involved extensive 'middening', and then an episode of large-scale feasting around the remains of the monumental Structure 10 (Card *et al*. 2017); construction of the Ring of Brodgar may have occurred towards the mid-third millennium BC (Supplementary Material; Figures S7–8).

Provisional conclusions

Instead of uninterrupted continuity, a much more complex and differentiated sequence emerges. At the island scale, this appears to be a history of interaction between households and relatively small communities. Because of the constant and rapid changes, it is plausible that this was a competitive situation, with rivalries played out in monument construction, forms of material culture and the social space of houses. There is good reason to view the innovations of both passage graves and Grooved Ware as part of local social strategies of differentiation (cf. Sheridan 2004). The foundation of new settlements in areas previously little occupied, such as Barnhouse (Richards *et al*. 2016a), and the constant development of the form and interior spaces of houses (Figures 6 & 3a-d), can be considered along the same lines. Perhaps local political tensions and social concerns driving the trajectory towards closer settlement nucleation could not be sustained, despite people investing time and labour in monuments relating to deities, ancestors and origins that stretched well beyond the shores of Late Neolithic Orkney.

The Orkney story is also one of connections throughout, as suggested above for passage graves and stone circles. Whether a consequence of local identities constituted through far-reaching contacts or relationships forged within imagined communities (that is, socially constructed communities imagined by the people who perceive themselves as part of those groupings), the late Neolithic world was clearly expansive in nature (Thomas 2010; Richards *et al.* 2016a; Sheridan *et al.* in prep). If there is a case for placing the origin of Grooved Ware in Orkney, does the coincidental appearance of the Orkney vole allow us to visualise the direct exchange of ideas or the movement of people from regions where flat-based pottery was already common in the later fourth millennium cal BC (e.g. from northern France to the Alpine foreland)? With the decline of Late Neolithic settlement in Orkney, it is perhaps no coincidence that previous connections and networks also lapsed, as evidenced by the sparse Beaker presence in the archipelago. History had moved elsewhere.

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References

ASHMORE, P.J. 1998. Radiocarbon dates for settlements, tombs and ceremonial sites with Grooved Ware in Scotland, in D.A. Simpson & A.M. Gibson (ed.) *Prehistoric ritual and religion*: 139–47. Stroud: Sutton.

– 1999. Radiocarbon dating: avoiding errors by avoiding mixed samples. *Antiquity* 73: 124–30.

– 2000. Dating the Neolithic in Orkney, in A. Ritchie (ed.) *Neolithic Orkney in its European context*: 299–308. Cambridge: McDonald Institute for Archaeological Research.

BAYLISS, A. 2009. Rolling out revolution: using radiocarbon dating in archaeology. *Radiocarbon* 51: 123–47.

BAYLISS, A. & A. WHITTLE. 2015 Uncertain on principle: combining lines of archaeological evidence to create chronologies, in A. Wylie & R. Chapman (ed.) *Material culture as evidence: learning from archaeological practice*: 213–42. London: Routledge.

BAYLISS, A., C. BRONK RAMSEY, J. VAN DER PLICHT & A. WHITTLE. 2007. Bradshaw and Bayes: towards a timetable for the Neolithic. *Cambridge Archaeological Journal* 17(1) (supplement): 1–28.

BOND, J.M., A.R. BRABY, S.J. DOCKRILL, J. DOWNES & C. RICHARDS. 1995. Stove Bay, a new Orcadian grooved ware settlement. *Scottish Archaeological Review* 9/10: 125–30.

BRONK RAMSEY, C. 2009. Bayesian analysis of radiocarbon dates. *Radiocarbon* 51: 337–60.

BROWN, T.A., D.E. NELSON, J.S. VOGEL & J.R. SOUTHON. 1988. Improved collagen extraction by modified Longin method. *Radiocarbon* 30: 171–77.

BUCK, C.E., J.B. KENWORTHY, C.D. LITTON & A.F.M. SMITH. 1991. Combining archaeological and radiocarbon information: a Bayesian approach to calibration. *Journal of Archaeological Science* 65: 808–21.

CARD, N. & A. THOMAS. 2012. Painting a picture of Neolithic Orkney: decorated stonework from the Ness of Brodgar, in A. Cochrane & A.M. Jones (ed.) *Visualising the Neolithic: abstraction, figuration, performance, representation*: 111–24. Oxford: Oxbow.

CARD, N., I. MAINLAND, S. TIMPANY, C. BATT, C. BRONK RAMSEY, E. DUNBAR, P.J. REIMER, A. BAYLISS, P. MARSHALL & A. WHITTLE. 2017. Formal chronological modelling for the Late Neolithic site of Ness of Brodgar, Orkney. *European Journal of Archaeology* 1–47. doi:10.1017/eaa.2016.29.

CLARK, R.M. 1975. A calibration curve for radiocarbon dates. *Antiquity* 49: 251–66.

CLARKE, D.V. & A. SHEPHERD. Forthcoming. *Skara Brae. A full compendium of the site*. Edinburgh: Historic Scotland.

CLARKE, D.V., N. SHARPLES, A. SHEPHERD, A. SHERIDAN, M. ARMOUR-CHELU, C. BRONK RAMSEY, E. DUNBAR, P.J. REIMER, P. MARSHALL & A. WHITTLE. In press. 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. *Proceedings of the Society of Antiquaries of Scotland* 146 (2016).

CLEAL, R. & A. MACSWEEN (ed.). 1999. *Grooved Ware in Britain and Ireland*. Oxford: Oxbow.

DAVIDSON, J.L. & A.S. HENSHALL. 1989. *The chambered cairns of Orkney: an inventory of the structures and their contents*. Edinburgh: Edinburgh University Press.

DOWNES, J. & J. GIBSON with S.J. GIBBS & A. MITCHELL. 2013. *Heart of Neolithic Orkney World Heritage Site: research strategy 2013–2018*. Edinburgh: Historic Scotland.

GRIFFITHS, S. 2016. Beside the ocean of time: a chronology of Neolithic burial monuments and houses in Orkney, in C. Richards & R. Jones (ed.) *The development of Neolithic house societies in Orkney*: 254– 302. Oxford: Windgather.

HENSEY, R. 2015. *First light: the origins of Newgrange*. Oxford: Oxbow.

HUNTER, J. 2007. *Investigations in Sanday, Orkney. Vol 1: excavations at Pool, Sanday. A multi-period settlement from Neolithic to Late Norse times.* Kirkwall: The Orcadian Ltd in association with Historic Scotland.

HUXTABLE, J. & M. AITKEN. 1979. Thermoluminescence dating, in C. Renfrew (ed.) *Investigations in Orkney*: 73–74. London: Thames & Hudson.

LANTING, J.N., A.T. AERTS-BIJMA & J. VAN DER PLICHT. 2001. Dating of cremated bone. *Radiocarbon* 43: 249–54.

MACSWEEN, A., J. HUNTER, A. SHERIDAN, J. BOND, C. BRONK RAMSEY, P.J. REIMER, A. BAYLISS, S. GRIFFITHS & A. WHITTLE. 2015. Refining the chronology of the Neolithic settlement at Pool, Sanday, Orkney. *Proceedings of the Prehistoric Society* 81: 283–310.

MARTINKOVÁ, N., R. BARNETT, T. CUCCHI, R. STRUCHEN, M. PASCAL, M. PASCAL, M.C. FISCHER, T. HIGHAM, S. BRACE, S.Y. HO, J.P. QUERE, P. O'HIGGINS, L. EXCOFFIER, G.

HECKEL, A.R. HOELZEL, K.M. DOBNEY & J.B. SEARLE. 2013. Divergent evolutionary processes associated with colonization of offshore islands. *Molecular Ecology* 22: 5205–20.
REIMER, P.J., E. BARD, A. BAYLISS, J.W. BECK, P.G. BLACKWELL, C. BRONK RAMSEY, C.E. BUCK, H. CHENG, R.L. EDWARDS, M. FRIEDRICH, P.M. GROOTES, T.P. GUILDERSON, H. HAFLIDASON, I. HAJDAS, C. HATTÉ, T.J. HEATON, D.L. HOFFMANN, A.G. HOGG, K.A. HUGHEN, K.F. KAISER, B. KROMER, S.W. MANNING, M. NIU, R.W. REIMER, D.A. RICHARDS, E.M. SCOTT, J.R. SOUTHON, R.A. STAFF, C.S.M. TURNEY & J. VAN DER PLICHT. 2013. IntCal13 and Marine13 radiocarbon age calibration curves 0–50,000 years cal BP. *Radiocarbon* 55: 1869–87. http://dx.doi.org/10.2458/azu_js_rc.55.16947
RENFREW, C. 1979. *Investigations in Orkney*. London: Thames & Hudson.
RENFREW, C. & S. BUTEUX. 1985. Radiocarbon dates from Orkney, in C. Renfrew (ed.) *The prehistory of Orkney*: 263–74. Edinburgh: Edinburgh University Press.
RENFREW, C., D. HARKNESS & S R. WITSUR. 1976. Quanterness, radiocarbon and the Orkney cairns. *Antiquity* 50: 194–204.
RICHARDS, C. 2005. *Dwelling among the monuments: the Neolithic village of Barnhouse, Maes Howe passage grave and surrounding monuments at Stenness*. Cambridge: McDonald Institute for Archaeological Research.
– 2013. *Building the great stone circles of the north.* Oxford: Windgather.
RICHARDS, C. & A.M. JONES. 2016b. Houses of the dead: the transition from wood to stone architecture at Wideford Hill, in C. Richards & R. Jones (ed.) *The development of Neolithic house societies in Orkney*: 16–40. Oxford: Windgather.
RICHARDS, C. & R. JONES (ed.). 2016a. *The development of Neolithic house societies in Orkney*. Oxford: Windgather.
RICHARDS, C., A.M. JONES, A. SHERIDAN, E. DUNBAR, P.J. REIMER, A. BAYLISS, S. GRIFFITHS & A. WHITTLE. 2016a. Settlement duration and materiality: formal chronological models for the development of Barnhouse, a Grooved Ware settlement in Orkney. *Proceedings of the Prehistoric Society* 82: 193–225.
RICHARDS, C., R. JONES, A. CHALLANDS, S. JEFFREY, A.M. JONES, S. JONES & T. MUIR. 2016b. At Stonehall Farm, Late Neolithic life is rubbish, in C. Richards & R. Jones (ed.) *The development of Neolithic house societies in Orkney*: 128–59. Oxford: Windgather.
RITCHIE, A. 2009. *On the fringe of Neolithic Europe: excavations of a chambered cairn on the Holm of Papa Westray, Orkney*. Edinburgh: Society of Antiquaries of Scotland.

SCHULTING, R.J., A. SHERIDAN, R. CROZIER & E. MURPHY. 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.

SHARPLES, N. 1985. Individual and community: the changing role of megaliths in the Orcadian Neolithic. *Proceedings of the Prehistoric Society* 51: 59–76.

SHEPHERD, A.N. 2016. Skara Brae life studies: overlaying the embedded images, in F. Hunter & J.A. Sheridan (ed.) *Ancient lives: object, people and place in early Scotland. Essays for David V. Clarke on his 70th birthday*: 213–32. Leiden: Sidestone.

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 (ed.) *From megaliths to metal: essays in honour of George Eogan*: 26–37. Oxford: Oxbow.

SHERIDAN, J.A. & P. PÉTREQUIN. 2014. Constructing a narrative for the Neolithisation of Britain and Ireland: the use of 'hard science' and archaeological reasoning, in A. Whittle & P. Bickle (ed.) *Early farmers: the view from archaeology and science* (Proceedings of the British Academy 199): 369–90. London: British Academy.

SHERIDAN, J.A., A. MACSWEEN, R. TOWERS, A. BAYLISS, P. MARSHALL & A. WHITTLE. In preparation. Grooved Ware in Orkney: towards an overall narrative. *Proceedings of the Prehistoric Society.*

SPENCER, J.Q.G. & D.C.W. SANDERSON. 2012. Decline in firing technology or poorer fuel resources? High-temperature thermoluminescence (HTTL) archaeothermometry of Neolithic ceramics from Pool, Sanday, Orkney. *Journal of Archaeological Science* 39: 3542–52.

STUIVER, M. & P.J. REIMER. 1993. Extended ^{14}C data base and revised CALIB 3.0 ^{14}C age calibration program. *Radiocarbon* 35: 215–30.

THOMAS, A. & D. LEE. 2012. Orkney's first farmers: early Neolithic settlement on Wyre. *Current Archaeology* 268: 12–19.

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): 1–15.

Figure captions

Figure 1. Map showing the location of sites considered in this review.

Figure 2. Probability distributions of dates from chambered cairns on Orkney. Each distribution represents the relative probability that an event occurred at a particular time. Two distributions have been plotted for each of the dates: one in outline, which is the result

of simple radiocarbon calibration, and a solid one based on the chronological model used. Distributions other than those relating to particular samples have been taken from models defined in Figures S1 (Isbister), S3 (Cuween), S6 (Quanterness), S13 (Knowe of Rowiegar), S16 (Point of Cott) and S18 (Holm of Papa Westray North), and MacSween et al. *(2015: fig. 13) (Quoyness). Other distributions are based on the chronological model defined here, and shown in black. For example, the distribution 'start stalled cairns' is the estimated date when human burial began in these cairns. The large square brackets down the left-hand side of the figure, along with the OxCal keywords, define the model exactly.*

Figure 3. Architectural range of Neolithic stone house structures: a) Knap of Howar; b) Stonehall Knoll House 3; c) Barnhouse House 6; d) Skara Brae Hut 1; e) Ness of Brodgar Structure 8; f) Barnhouse Structure 8, and chambered cairns: g) Knowe of Yarso stalled cairn; h) Wideford Hill passage grave.

Figure 4. Probability distributions of dates from specimens of Orkney vole from Neolithic sites. The format is identical to that of Figure S1. Measurements followed by a question mark and shown in outline have been excluded from the model for reasons explained in the text, and are simple calibrated dates (Stuiver & Reimer 1993).The large square brackets down the left-hand side of the figure, along with the OxCal keywords, define the model exactly.

Figure 5. Schematic diagram showing the periods of use of dated Neolithic settlements in Orkney in the later fourth and third millennia cal BC (mauve: associated with round-based pottery; green: associated with flat-based pottery; Green is left black as the ceramic association of this unpublished site is uncertain). The periods of human burial in stalled cairns and passage graves are also shown, along with the period when animal remains were deposited within them. The dates of construction for the Stones of Stenness and the Ring of Brodgar, and the date of the appearance of Orkney vole are also shown.

Figure 6. Probability distributions for beginnings and endings of use of Neolithic timber and stone houses on Orkney. The format is identical to that of Figure S1, although the tails on some distributions have been shortened. The distributions are derived from the model shown in Figures S19–S24.

Figure 7. Number of dated Neolithic houses in use in Orkney during the later fourth and third millennia cal BC. The 'core' area contains the settlements at Barnhouse and the Ness of Brodgar, the 'periphery' all other settlements.

Table 1. Summary of scientific dating evidence considered in this review.

Site	No. of ^{14}C results	No. of ^{14}C results (excluded)	No. of ^{14}C results (TPQ)	No. of ^{14}C results (TAQ)	No. of luminescence ages	No. of luminescence ages (excluded)	References
South Ronaldsay							
Isbister	32	2	–		–	–	Table S1
Mainland							
Barnhouse	74	4	13		–	–	Richards *et al.* 2016a: tab. 1
Crossiecrown	7	1	–		–	–	Table S1
Cuween	4	–	–		–	–	Table S1
Knowes of Trotty	9		2				Table S1
Maes Howe	10	6	1	3	–	–	Renfrew 1979
Ness of Brodgar	65	8	5		–	–	Card *et al.* 2017: tabs 1–2
Quanterness	30	2	–		5	5	Schulting *et al.* 2010: tabs 2–3 and fn 4; Huxtable & Aitken 1979: tab. 5
Ring of Brodgar	2	2	–		15	1	Tables S1–S2
Skara Brae	150	63	1		–	–	Clarke & Shepherd forthcoming: tabs 2.4.3/1–6
Smerquoy	7						Griffiths 2016: tab. 10.1
Stonehall	17	2	–		–	–	Table S1
Stones of Stenness	10	2	1		–	–	Table S1
Vestra Fiold	2						Table 2
Wideford Hill	9						Table S1
Wyre							
Ha'Breck	12	1					Table S1
Rousay							
Knowe of Ramsay	3	–	–		–	–	Renfrew *et al.* 1976: tab. A
Knowe of Rowiegar	26	–	–		–	–	Table S1
Knowe of Lairo	1	–	–		–	–	Table S1
Knowe of Yarso	2	–	–		–	–	Table S1
Midhowe	2	–	–		–	–	Table S1
Rinyo	1	–	–		–	–	Renfrew *et al.* 1976: tab. A
Eday							
Green	4						Table S1
Sanday							
Pool	26	1	2		59	59	MacSween *et al.* 2015: tab. 1;

						Spencer & Sanderson 2012: tab. A1
Quoyness	3	–	–	–	–	MacSween *et al.* 2015: tab. 2
Tofts Ness	11	–	–	–	–	MacSween *et al.* 2015: tab. 2
Westray						
Links of Noltland	33	5	5			Clarke *et al.* in press: tabs 1–5
Pierowall Quarry	10	2				Table S1
Point of Cott	18	–	1			Table S1
Papa Westray						
Knap of Howar	19	2	–			Table S1
Holm of Papa Westray						
Holm of Papa Westray North	14	–	1			A. Ritchie 2009: tab. 17

Table 2. Radiocarbon measurements and associated stable isotopic values from Vestra Fiold, Mainland.

Laboratory number	Sample description	Radiocarbon age (BP)	$\delta^{13}C$ (‰)	$\delta^{15}N$ (‰)	C:N ratio
SUERC-30971	Red deer metatarsal from among the pitched flagstones in the body of the primary cairn	4065±30	−21.8±0.2	5.9±0.3	3.3
SUERC-30972	Cattle metatarsal from among the pitched flagstones in the body of the primary cairn	4090±35	−21.6±0.2	5.4±0.3	3.3