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RESEARCH ARTICLE

A new time: Bayesian models of an Early Neolithic enclosure in North-Western Denmark

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ABSTRACT
The article presents the results of the first Bayesian model of a causewayed enclosure from Denmark. 21 samples were dated, some with multiple dates, giving a total of 41 dates. These dates are built into a model which includes archaeological priors in the form of stratigraphy. It is demonstrated that this enclosure can be dated to the same time as the majority of enclosures on the British Isles: the 37th century BC. Together with other early dates for enclosures, it illustrates that enclosure construction was introduced in South Scandinavia as part of a large European expansion of enclosures. With Bayesian modelling, we can provide better answers to more questions, both regarding intrasite chronologies and a wide range of chronological issues.

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Introduction

The Neolithisation of South Scandinavia clearly marks a great shift in society, but the following centuries offer additional great changes. One of these is related to the construction of monuments in the form of non-megalithic long barrows and causewayed enclosures. The start of a new time: The time of monuments. This article will focus on the introduction of causewayed enclosures into South Scandinavia, especially the date of this event. It has been convincingly demonstrated by the Gathering Time project that by using Bayesian modelling, we can get within generations of these shifts (Bayliss *et al*. 2011). This is a drastic improvement of previous methods. What is of further interest here is that the project revealed that the enclosures of the British Isles were built during a short period, starting in the later 38th century BC and booming in the 37th century BC (Whittle *et al*. 2011). This seems to be part of a European expansion of enclosure construction in the period (Klassen 2014, pp. 206–219). This begs the question: Did the South Scandinavian enclosures follow this trend, or were they several centuries younger? Traditionally, the enclosures in South Scandinavia have been seen as a phenomenon dating to the EN II, starting roughly at 3.500BC, but as suggested by Klassen, the majority of enclosures are poorly dated or not dated at all (Klassen 2014, pp. 199–206). Together with new results from northern Germany and southern Jutland, it will be argued that at least the Jutland peninsula experiences a more widespread construction of enclosures in the 37th century BC.

An important part of the argument made in this article relies on Bayesian modelling, thus this approach deserves a few words. This approach is named after Thomas Bayes' theorem (Bayes 1763). In archaeology, Bayesian modelling refers to an approach where our established knowledge, such as stratigraphy and typology or any other information available to us (called prior beliefs), are integrated with our knowledge provided by dates with probability estimates (such as radiocarbon dates) in a common model. Good introductions to the use of Bayes' theorem in this way can be found in Bayliss *et al*. (2007, 2011) and Bronk Ramsey (2009a). Today, Bayesian modelling is becoming standard within archaeology, with a high increase in the number of papers in the last years (Bayliss 2015). This is, however, not so within Scandinavian Neolithic research. Note that calibration of radiocarbon dates in some

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programs, such as OxCal, are Bayesian in nature (Bronk Ramsey 2009a), so all calibration using these programs is Bayesian. More complex models in addition to simple dating are rarely, if ever, applied in Scandinavian Neolithic research, and the Bayesian approach is limited to the use of OxCal and similar programs.

The use of Bayesian models in archaeology is not without problems. Several factors can lead to the models being inaccurate, such as problems with the samples (reservoir-effects, residual samples, etc.), but also with the defined prior information (e.g. the archaeology) and the understanding of the radiocarbon dates. Especially lack of information and/or poor implementation of these factors have been criticised (Bayliss 2015, Pettitt and Zilhão 2015). It must be noted that the issues raised in these papers apply to all use of radiocarbon dates, whether they are within a formal model or not (and several of the issues apply to all use of any sort of dating, whether typological or by other means). However, the more the dates are used in the argumentation and interpretation, the more important these issues become. Additionally, the more constraining priors of more complex models allow more erroneous answers, or false positive answers, if the models are not critically evaluated.

A more fundamental discussion of issues related to the Bayesian calibration is presented by Weninger *et al.*, where they demonstrate serious issues in the way the tree ring wiggle curve can interact with the calibration, producing problematic results (Weninger *et al.* 2015). Counter-intuitively, these problems are greater for very precise dates, which tend to produce erroneous peaks in large datasets (see also Contreras and Meadows 2014, Brown 2015). This calls for some caution in interpreting the results of the models. However, the strength of the models is the addition of archaeological priors (or other dating priors if such are available), which should mitigate the problems rather than enlarge them, as they are not dependent on the calibration curve.

If applied correctly, Bayesian models offer a powerful tool to build very precise chronologies, which in accuracy and precision go beyond what we can expect of the dates by themselves. However, the approach is fundamentally subjective as it, just as any other archaeological chronological approach, relies on our choices of elements to be analysed and an evaluation of these elements' relation to the events, features or artefacts we wish to date (Buck and Meson 2015). In this article, I have focused on clarifying my choices and discussing why these were made. The certainty of our archaeological interpretation is difficult to quantify, and the results of a Bayesian model is never more certain than the interpretation it relies on.

The site: Liselund

Liselund is located on the present day peninsula Thy in North Western Jutland (Figure 1). In the Neolithic, Thy would have been an island off the coast of Jutland. When built, the enclosure would have been located 4 km from the coast, but near where a small river runs into the now drained Sjørring Sø (Sjørring Lake). It is located on a small plateau, and in the Neolithic a small stream likely ran west of the enclosure, and possibly another south of the enclosure. The location at a place where two rivers/streams met is a typical one of South Scandinavian enclosures (Klassen 2014, p. 43, Table 2). The site is interesting in relation to Bayesian modelling of enclosures, as organic material has been retrieved from multiple layers in the ditches. This organic material was found in close relation to clear phases of the ditch cutting process, and in many cases in relation to datable artefacts. Such information has generally not been systemically selected for in Scandinavian excavations of enclosures. New excavations of other enclosures should focus on achieving this by careful retrieval of soil samples and radiocarbon dating of relevant contexts.

Several factors are included in the models: the overall layout of the enclosure, individual ditch-stratigraphy, as well as the pottery chronology. The site is known through several small-scale excavations: the first in 1989–1990 (Mikkelsen 1989), a small excavation focussed on an Iron Age settlement in 1993 (A. L. H. Olsen 1993), and excavations in 1996 and 1997 (Westphal 1996, 1997) with mainly Neolithic finds. These excavations uncovered several ditches in different parts of the enclosure, as well as pits, postholes, and cultural layers inside the enclosure related to a Neolithic settlement phase. As the excavations are small, orthophotography has been

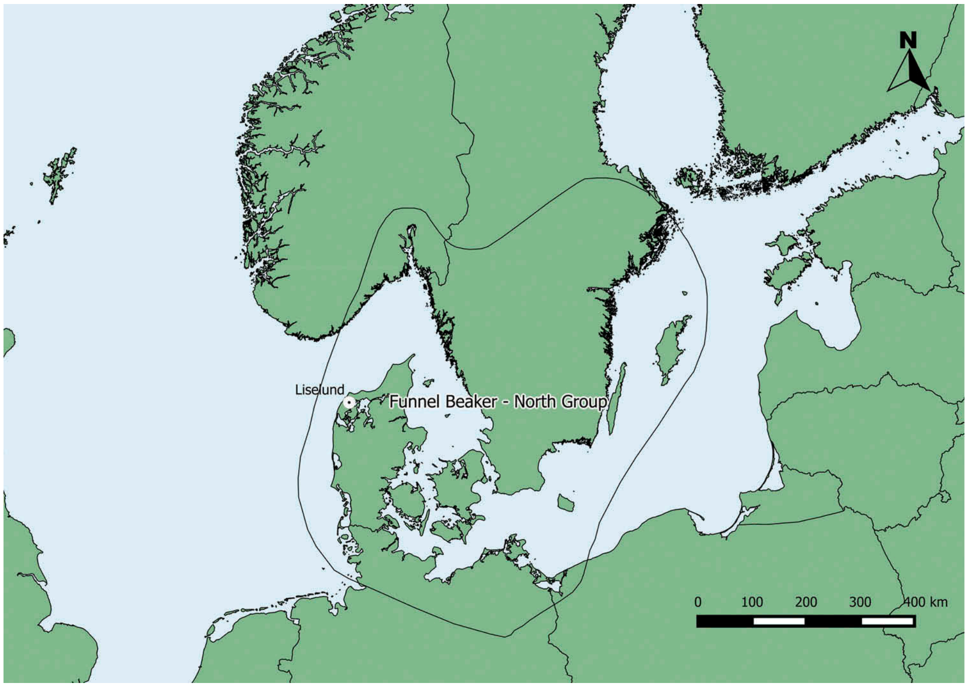

Figure 1. Geographical location of Liselund

used to improve the understanding of the enclosure (Westphal 2000), and in 2014 a geomagnetic survey was conducted on part of the area, only part of which gave a successful result, as the readings from the southern part was blurred by natural phenomena and Iron Age/Bronze Age activity.

Layout of the site

The enclosure is slightly triangular (Figure 2). The outer perimeter of the enclosure is marked by two rows of ditches and possibly a palisade. Internally, there are two rows of ditches that divide the area.

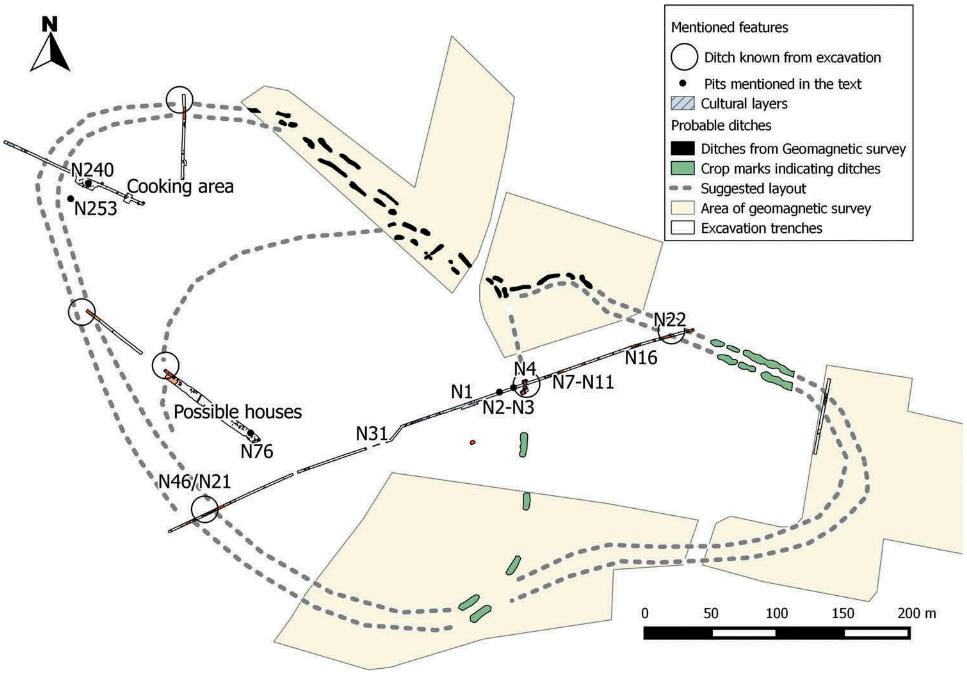

Figure 2. Reconstructed layout of the site

The ditches recorded in the geomagnetic survey and the outer ditch circuit recorded on photos indicate that the causeways between the ditches are between 2 m and 6 m wide, while the 'causeways' in the internal row are 25–35 m. As the inner rows connect to the outer circuit near a possible entrance to the enclosure to the north-east, it is likely that the inner rows have the purpose of separating the space of the inner surface in different compartments. The inner rows connect to the outer circuit, suggesting that the entire enclosure is one system and is made as one mental whole. It is, however, important to note that there are no excavations from where the ditches join but only a geomagnetic survey.

The clearest indications for settlement were found in the central part of the enclosure, in the form of a thick cultural layer and possible houses. The uneven distribution is possibly due to the small scale investigation, as less than 2% of the area has been excavated. Most artefacts come from a 20 cm thick cultural layer 35–50 m west of ditch N4. Several pits were found in relation to this layer, and two of these, N2 and N3, were dated (see Table 1). Around 65 m north east of N46/N24, at least 15 post holes, several pits, and two hearths were found, likely the remains of houses. From this concentration, pit N76 was dated. Both of these areas were within the two internal rows of ditches. The traces of settlement were fewer outside this central area, but a series of thin cultural layers (N7-N11 and N16) and a few pits were found in the eastern part between N4 and N22. South-east of N22, an Iron Age settlement was present. In the northern part many scattered pits, especially cooking pits, and a few post holes can be dated to the Neolithic, most importantly two pits containing cereal: N240 with around 800 cereal grains and N253 with estimated (on the basis of a 10% sample) 42.000–44.000 cereal grains (Westphal 2005). N253 has previously been dated and has been included in the models.

Stratigraphy

Three ditches have been included in the dating scheme, N4, N22 and N46/N24. N22 and N24/N46 are both from the outer circuit, while N4 is from the inner row. Only a 1.6–1.7 m wide cut across the ditches was excavated, but the ditches were excavated to the subsoil. Clear profiles were drawn and

Table 1. List of replica dates on single samples. Problematic T' values in bold

Context	Material	Lab number	Radiocarbon age (BP)	X^2 test	Replicate group
N2, pit	Hazelnut- shell	AAR21905	4643 ± 29	T' = 0.3; T' (5%) = 3.8	1
		KIA51018	4674 ± 45		
N3, pit	Hazelnut- shell	AAR22904 (ext)	4681 ± 29	**T' = 187**; T'(5%) = 11.1	2
		AAR22904	4689 ± 32		
		KIA50122a	5079 ± 26		
		KIA50122b	5082 ± 29		
		KIA50122c	4935 ± 22		
		KIA50122d	4923 ± 22		
N3, pit	Corylus	AAR21907	4761 ± 30	**T' = 4.5**; T' (5%) = 3.8	3
		KIA51020	4661 ± 36		
N4, layer c	Corylus	AAR21903	4562 ± 26	T' = 2.1; T' (5%) = 3.8	4
		KIA51017	4625 ± 26		
N4, layer c	Corylus	KIA50594a	4905 ± 35	**T' = 10.4**; T' (5%) = 3.8	5
		KIA50594a	4745 ± 35		
N4, Layer d	Corylus	AAR22905 (ext)	4677 ± 29	**T' = 56.4**; T' (5%) = 11.1	6
		AAR22905	4713 ± 31		
		KIA50123a	4859 ± 26		
		KIA50123b	4891 ± 23		
		KIA50123c	4864 ± 27		
		KIA50123d	4891 ± 27		
N4, layer d	Corylus	KIA50124a	4826 ± 22	**T' = 7.9**; T' (5%) = 7.8	7
		KIA50124b	4865 ± 22		
		KIA50124c	4875 ± 38		
		KIA50124d	4930 ± 30		
N22, layer k	Corylus	AAR21908	4711 ± 28	T' = 1.1; T' (5%) = 3.8	8
		KIA51020	4657 ± 42		
N22, layer k	Corylus	KIA50125a	4853 ± 27	T' = 0.5; T' (5%) = 6.0	9
		KIA50125b	4848 ± 32		
		KIA50125c	4874 ± 26		
N22, layer l	Corylus	KIA50126a	4935 ± 22	**T' = 4.7; T'** (5%) = 3.8	10
		KIA50126b	4866 ± 23		
N22, Layer l	Betula	KIA50127a	4840 ± 22	T' = 1.0; T' (5%) = 3.8	11
		KIA50127b	4774 ± 27		

soil samples and pollen samples taken from each layer. In most cases, the dated samples were found in connection with pottery, but in some cases no artefacts were found and the samples come from soil-samples taken during the excavation.

The ditch N4

The primary layer is layer e, which is formed of quickly backfilled material, with no growth layer at the bottom and no silting layers. On the bottom of this layer, two funnel beakers as well as sherds from a third vessel were found. Between the sherds of one of the vessels some charcoal fragments were found, which constitute the sample for dating from this layer. A large part of the vessel was recovered, and it seems to have been placed on the bottom of the ditch purposefully (Figure 3).

Layer d constitutes a re-cut of the ditch. As with layer e, the finds are from the bottom of the layer, which seems to have been re-filled quickly. Several large fragments of vessels were found as well as smaller sherds. Sherds from around 12 vessels and additionally 7–9 clay disks were present in the excavated part of the layer. The dated sample comes from charcoal at the bottom of the layer.

The final re-cut in the ditch is marked by layer c. At the bottom of the layer, a whole vessel was found, placed between some stones (Figure 4). This indicates continued ritual use at the time of layer c, but in contrast to layers e and d, more refuse material was present in the layer, indicating both flint and amber production. Parts of more than 20 different vessels were present, as well as at least 10 clay disks. It is doubtful whether the material was deposited due to normal settlement activity, as several large sherd fragments were found, which is not typical of the settlement debris at the nearby cultural layer.

Figure 4. Deposited vessel at the bottom of layer c in N4

The debris could be material created elsewhere and discarded at the ditch after the deposition of the whole vessels. Some sherds were in very bad preservation state, and some seemed very weathered, while the whole vessels were in a better state of preservation. Layer c is covered by layer b, which contained only a few sherds and a little flint, and layer a, which had almost no finds. Layer a consisted of clayish sand with small charcoal particles, making the layer almost black. A similar almost black top layer is known from the other excavated ditches at Liselund.

The ditch N22

The primary phase is layer l, which contained few artefacts and no pottery. A small sample of charcoal from the bottom of layer l was available for dating (Figure 5).

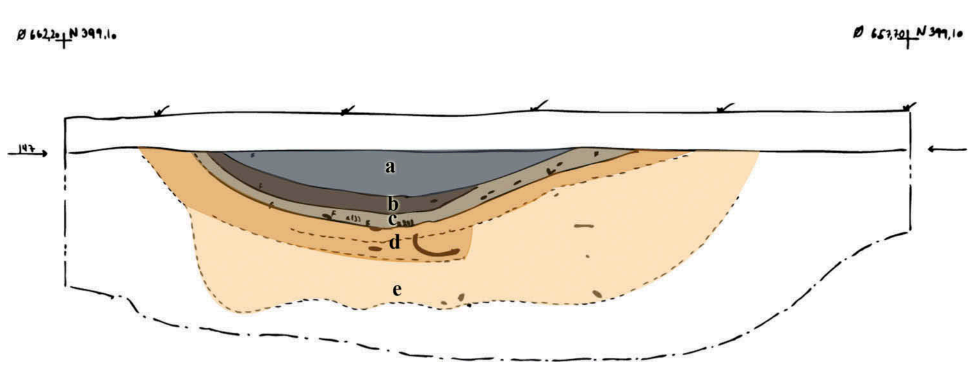

Figure 3. Profile of ditch N4

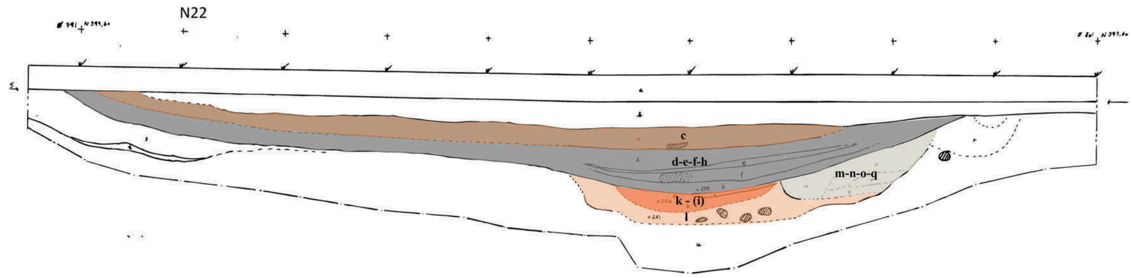

Figure 5. Profile of ditch N22

Layer k is a re-cut containing pottery, including several almost complete vessels. From this layer, another charcoal sample was available. To the east of layer k, another series of layers is present, likely another re-cut, which is later than layer l, but impossible to relate to layer k. No artefacts or charcoal was retrieved from these layers.

Above these re-cuts was a series of thin layers containing varied degrees of gravel and larger rocks. One of the layers, layer e, was almost black from charcoal particles, resembling layer a in N4. Above these layers, layer c is a homogeneous brown mix of sand and clay. In contrast to N4 and N46/N24, there is no large deposition layer near the top.

To the west of N22, another feature is also partly covered by layers d and c. This feature also ran across the excavation trench and could be part of another enclosure ditch or more likely a trench for supporting a palisade, see below for N46/N24.

The ditches N46 and N24

The ditch N46 is cut by N24. Layer p near the bottom is interpreted as the primary deposition layer. The primary cut is a few centimetres deeper, but the soil below layer p is likely to derive from loose soil deposited during digging of the ditch. There were no finds in layer p, and a few undiagnostic sherds higher in layer n makes up all the finds from N46. Layer p contained charcoal particles, and a few pieces were large enough to determine and date (Figure 6).

A re-cut of the ditch is moved slightly to the east, layer m, covered by refill in the form of layer l. No finds and no datable material.

The bottom of N24 is marked layer k, which contained no artefacts. Sherds and the butt end of a polished axe was found at the bottom of the superseding layer h. A soil sample from layer k contained charcoal, but the pieces were too small to identify and date.

The fill of layer h is slightly stratified, and several distinct layers could be observed. At least layer f, but likely also layer i and g are re-cuts of the ditch. This suggests a total of 4–6 re-cuttings happen after the first construction of N46. To these can be added layer d, which marks a deposition horizon with many artefacts, including large pottery fragments. Layer d is dated and included in the models.

Layer d is covered by the layer c, which contains charcoal particles and is likely related to layer b from N 4 and layer e from N22. Layer c also covers two features to the east of the ditches, both trenches running parallel to the ditches across the excavation trench. With the limited extent of the excavation, it

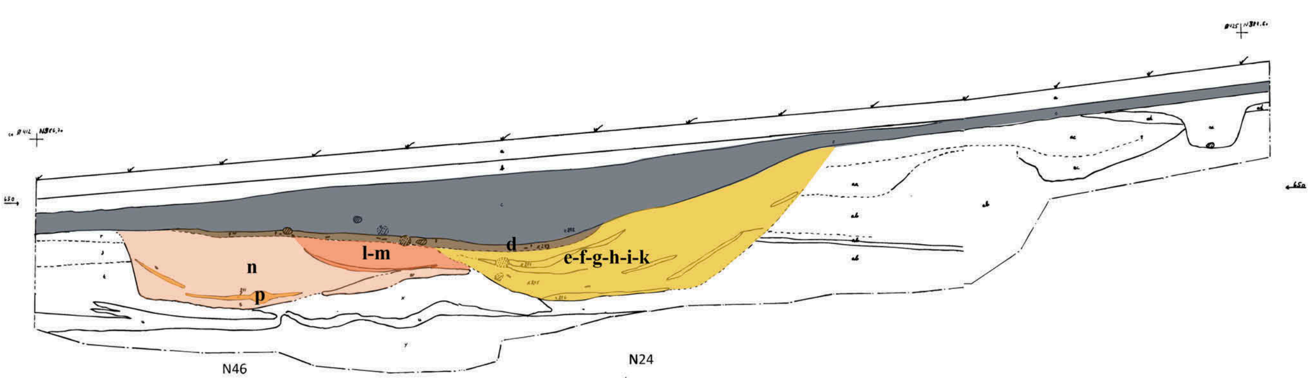

Figure 6. Profile of ditch N46 and ditch N24

is impossible to ascertain, but these features likely mark palisade trenches as at Sarup I (Andersen 1997, pp. 29–34). The double trench indicates that the palisade was renewed/replaced, perhaps at the same time as the digging of N24.

Relation between enclosure and settlement

No clear stratigraphic evidence is present. It is noteworthy that several culture layers (N1, N7-N11 and N31) and some settlement pits have the same black character as the thick sealing layer of the enclosure. Thus, it is likely that these charcoal layers are formed in relation to the settlement activity. This indicates that the settlement is later than the final depositions in the enclosure, which lie below these layers. Alternatively, the final layers of the ditches belong to the settlement phase, as indicated by the amount of waste.

Pottery

There is a difference in the pottery style between the lower layers, and the upper layers of the enclosure. The difference is especially clear on the lugged beakers: Lugged beakers with whipped cord occur in the final layers, while unornamented ceramics or ceramics ornamented with a toothed tool occur in the lower layers. Sherds with stab-and-drag are present at the lower layers at both N4 and N22. Stab-and-drag rarely occurs in the final layers, in spite of much larger pottery depositions in these layers. Stab-and-drag is common within the EN I (3950–3500calBC) Volling style, while whipped cord appears regularly in the EN II styles (3500–3350calBC) (Madsen and Petersen 1984), however the exact introduction is poorly dated. The observed change of deposition practice between the primary phases, with few but complete pots, and the final deposition, with both complete pots, single sherds, flint and amber waste, is together with the difference in style used to define the upper layers as one horizon.

Samples and dating

The first step was to select suitable samples. As there were no existing samples from the enclosure, the strategy was to date the primary phase of the three ditches. In addition to this, it was attempted to date as many subsequent layers of these ditches as possible. One date existed for the settlement from pit N253. In addition to this date, a series of new dates reflect the settlement activity of the site.

Selecting samples

In the second chapter of Gathering Time, Bayliss *et al.* discuss the taphonomic considerations of samples and order different sample types according to reliability (Bayliss *et al.* 2011, pp. 38–42). At Liselund, no bone or antler is preserved, and the only possible datable material was charcoal and carbonised residue, ‘food crusts’, on pottery. Carbonised residue on refitted pieces of pottery rank high (4 out of 12) in the reliability suggested by Bayliss *et al.*, however later they note some observed issues with the dating of carbonised residues (Bayliss *et al.* 2011, pp. 56–57). For this reason and due to the issue with freshwater reservoir effect, it was chosen not to date carbonised food residue (Fischer and Heinemeier 2003, J. Olsen *et al.* 2010, Philippsen *et al.* 2010, Philippsen 2013, Fernandes *et al.* 2013).

The dating thus relies on single entity plant remains, primarily charcoal from short-lived trees, in addition to dates on a few charred hazelnut shells and the existing date on cereal from a pit. Radiocarbon dates of small pieces of charred material are usually not considered very reliable, as they can be residual. There are good arguments against this being the case in the present project. Samples from three categories of contexts can be considered: pits, primary layers of the enclosure and secondary layers of the enclosure. The majority of samples from pits come from charred layers at the bottom of the pits, and thus likely relate to the primary function. Similarly, the cereal sample must be considered an intended deposition due to the amount of cereal. The primary layers of the ditches are all deliberately refilled within a short time. As there is no indication of any activity on the site prior to the enclosure, any material from the primary layer of the enclosure ditches must be considered as belonging to the primary phase. More problematic are dates from secondary layers. These can either be related to the re-cutting event, be residual from the first enclosure phase, or relate to activities in the central part of the enclosure. As the re-cuts in most cases respect the lower layers (with exception of N46/N24), the chance of residual material should be low. If the settlement is later, the chance of material from this entering the ditches should not be a major concern.

However, loose samples will never be as certain as samples functionally related to an event such as articulated bones in primary position, tools for digging found at the bottom of ditches or charcoal related to function. To establish the reliability of the dates, it was attempted to date multiple samples from each context. In some cases, the same species was used, and it is uncertain whether they are two separate entities or two pieces from the same tree found apart. In other cases, separate species were dated and they are thus definitely separate entities.

Another possible issue is the old wood effect, where the organic material has grown over a long time-frame and thus contains carbon that already has a significant age at the time of burning and deposition. In the primary layers, charcoal from acer (maple) and betula (birch) were common, with minor inclusions of corylus (hazel). In the secondary layers, only corylus and a few cases of prunus (cherry-family) and alnus (alder) is recorded, though not all charcoal pieces were analysed. From the pits corylus, betula, and quercus (oak) are determined and only corylus dated. As charcoal from corylus was common, and it can be considered short-lived, it was generally preferred. In the primary layers, hazel was not as dominant as in the secondary layers, and the amount of charcoal pieces large enough for determination generally low. Therefore, betula and acer were also frequently dated. Both trees as well as the dated alnus can be older than corylus, so some consideration must be given to this. The only acer native to the area around the enclosure is acer platanoides, both this tree, alnus and betula can be considered trees with a lifetime of middle length.

Dating

Overall, 21 samples were selected and dated. Some samples have been dated more than once, thus the number of dates/measurements is 41. Seven samples are from pits located in the interior, while 14 are from the enclosure ditches.

In the dating scheme, two laboratories were used. A series of dates were dated in the Leibniz-Labor in Kiel (code KIA). The remainder were dated in the Aarhus AMS Centre (code AAR). During this period, the dates from Aarhus were dated in Seattle, but the samples were extracted in Aarhus. All new dates were dated in the period 2014–2015. The single previous date, AAR-7205, was dated in 2001. All calibration and modelling has been done in OXCal 4.2, using IntCal13 curve (Bronk Ramsey 1995, 2009a, Reimer *et al.* 2013).

Testing replicate radiocarbon measurements

To investigate reliability of the measurements, multiple measurements were done on individual dates. The samples dated at different labs were selected from large pieces of charcoal or nutshell, which were broken into pieces and pre-treated separately. Multiple dates from KIA, marked with a, b, c, d, are multiple measurements, sometimes on the same pre-treated sample and sometimes dates on new extractions of the same sample to test reliability of previous dates. All dates were combined before calibration using the R_combine function in OxCal (Bronk Ramsey 2009a, 2009b).

Six out of 11 samples fail at the 5% level, thus much above the expected (Table 1). A clear explanation is not easy. Replicate groups 3, 7 and 10 are only slightly above the threshold that 95% of samples should be below. The T'-value (the chi-squared value calculated by OxCal) of these groups fall within the 1% level. The error of these groups could relate to the reported uncertainty of the samples. An increase of the uncertainties of the measurements with additional 5 years give T' values below the threshold. Thus these dates can perhaps be considered correct. Replicate groups 2, 5 and 6 are more problematic, as all dates from these cannot be correct.

In two cases (group 2 and 6), there is a difference between laboratories, in both cases with KIA dates significantly older. The Kiel dates are from a group of dates (KIA50122-KIA50129) measured in February 2014 with additional dates on new extractions of the samples done in June 2014. The multiple measurements from Kiel are consistent for each sample, and this suggests the Kiel results are accurate. This is contradicted by other dates from N3: replicate group 3 is also from this pit, both KIA and AAR dates from this group are consistent with the AAR date from group 2. Another date from N3, AAR21906 is also consistent with the younger date (see full list of dates). These dates were all measured in 2015. We could then expect that KIA50122 is erroneous, or the sample residual *and* the AAR-measurement wrong. The chance of a residual sample is unlikely, as it comes from a layer of charcoal and charred nuts at the bottom of the pit. This leads to considerations regarding the accuracy of the KIA dates, since the Kiel lab experienced issues in the period 2009–2012 (Meadows *et al.* 2015). In four cases, the dates from Kiel and Aarhus fit well (group 1, 3, 4 and 8), in some cases the Aarhus date is even slightly older (group 3 and 8). The Kiel dates consistent with AAR dates are all from 2015, while the dates not consistent with AAR are from the measurements in 2014. Replicate group 5 is likewise dated in 2014. It is difficult to explain how the dates from the series KIA50122-KIA50129 could be wrong, but so consistently so, even when two extractions were taken separately and measured in February and June, respectively, the last dates according to the new stricter procedure introduced at this time and together with material with a known age which didn't show any issues. To test the significance on the results, a model where all Kiel dates from 2014 have been removed is presented alongside a model where they are included (see Figure 11 below). In the model without KIA 2014 dates, an AAR date is the oldest and any issue from the Kiel lab does not determine the start date. Both models show the same pattern, and it is thus possible that the Kiel dates from 2014 are correct (except KIA50122, which was still excluded, and KIA50594, which is considered an outlier). If this is true, it is difficult to determine the reason for the high rate of inconsistent replicate groups (6 out of 11, with 3 being very divergent), at least without further analysis of the dates, including new samples.

Evaluation of the effect of the old wood effect

As discussed, some considerations are needed in relation to the possibility of old wood effect. Since betula and acer are only dated in the primary layers, and since there were few corylus dates from these layers, the old wood effect could push the start date of the enclosure too far back in time. Three methods were considered to counter this possible old wood age.

The first method is using the charcoal dates only as a *terminus post quem* (TPQ) by using the *After* function in OxCal. This method is useful in many situations, but it is questionable if it adds any value to this question, since it is doubtful whether the *After* function puts enough weight on the possibility that the dates could in fact be contemporary with the event they should date. Testing has shown that the result is often imprecise when dealing with datasets consisting only or mainly of charcoal dates (Dee and Bronk Ramsey 2014).

The second method is running a charcoal outlier model (Bronk Ramsey 2009b, Dee and Bronk Ramsey 2014). Such a model can allow for outliers due to old wood effect, but still allow the dates to be included in the analysis. The drawback is that the model considers all charcoal samples equally.

The third option is adding a uniform distribution as an extra uncertainty (Valzolgher *et al.* 2012, p. 492). It adds a probability that the wood is between 0 and a fixed number of years old, depending of the expected maximum age of the tree. It has the advantage over the *After* function that it includes our knowledge of how much older the wood is likely to be. In the models, the hazel has been assumed to be 20 years or less, while acer, betula and alnus have been assumed to be 100 years or less.

The difference of assumption between the outlier model and the approach of adding a uniform distribution is that the outlier model expects the dates to be exponentially distributed with most of the charcoal samples only slightly older than the event, but with a long tail of older dates (Bronk Ramsey 2009b). Which assumption is correct will vary according to the situation. In hearths and fire-pits, we might assume that many branches and young trees are burnt along with fewer larger pieces, favouring a dominance of short-lived samples. When dealing with wood used in constructions, less short-lived material is included, and a more uniform distribution can perhaps be assumed, even though the volume of the outer tree rings (youngest) is larger than that of the inner tree rings (oldest), favouring a non-uniform distribution of charcoal ages. If the last few years are lost due to dressing the wood for use, we would see a non-uniform distribution starting at the outermost preserved tree ring. The charcoal outlier analysis suggested by Bronk Ramsey also assumes that dates can be very much older (1.000 years). This is especially true for very old trees, but it also accounts for residual samples. The uniform distribution model is the one favoured here, since it adjusts for our prior beliefs about the maximum age of the individual trees and since residual samples are considered unlikely, at least in the primary phases of the enclosure. The final end of the entire sequence is also supported by dates on hazelnut shells and cereal, which is generally of the same age as the charcoal from the same layers. Again, some caution of using charcoal is warranted, but with multiple samples of relatively short-lived material in clear stratigraphic position the results are relatively robust.

Models

The model includes the prior beliefs from archaeology, in this case both the layout of the enclosure, the stratigraphy of the ditches and the pottery chronology. Above, it was argued that the enclosure forms one system. This leads to the belief that a common start boundary for the enclosure can be assumed. The start boundary is followed by a phase including dates from the ditches with individual stratigraphic sequences of re-cuts. Before the last use of the enclosure, there is a shift in the style of the lugged beakers and a change in the deposition behaviour. This is seen in N4, layer c and in N24, layer d. These two layers are believed to represent the same horizon. To estimate the time of this shift, a cross-referenced date is inserted, with the *Date* function in OxCal, just before layer d from N4 and layer d from N24, and after layer k in ditch N22. The inclusion of the date in the sequence of N22 is due to considerations of the stratigraphy and the pottery chronology. There are undated layers stratigraphically above layer k, and the pottery of layer k is older than that of the final layers of the other ditches. It is further suggested that the enclosure predates the settlement, thus a boundary marks this transition (start settlement). Finally, the settlement phase ends in a final end boundary. (Figures 7 and 8).

An alternative interpretation, where the settlement is contemporary with the final phase of the enclosure, is also presented (Figures 9 and 10). N4 layer c and N24 layer d have been included in the settlement phase. The alternative model offers a slightly different chronological interpretation. It would mean that depositions of pottery in the ditches (see Figure 4) occurred at the time of the settlement. It also means that we have fewer discrete events dated, allowing the start date of the settlement to move back in time. It is important to point out

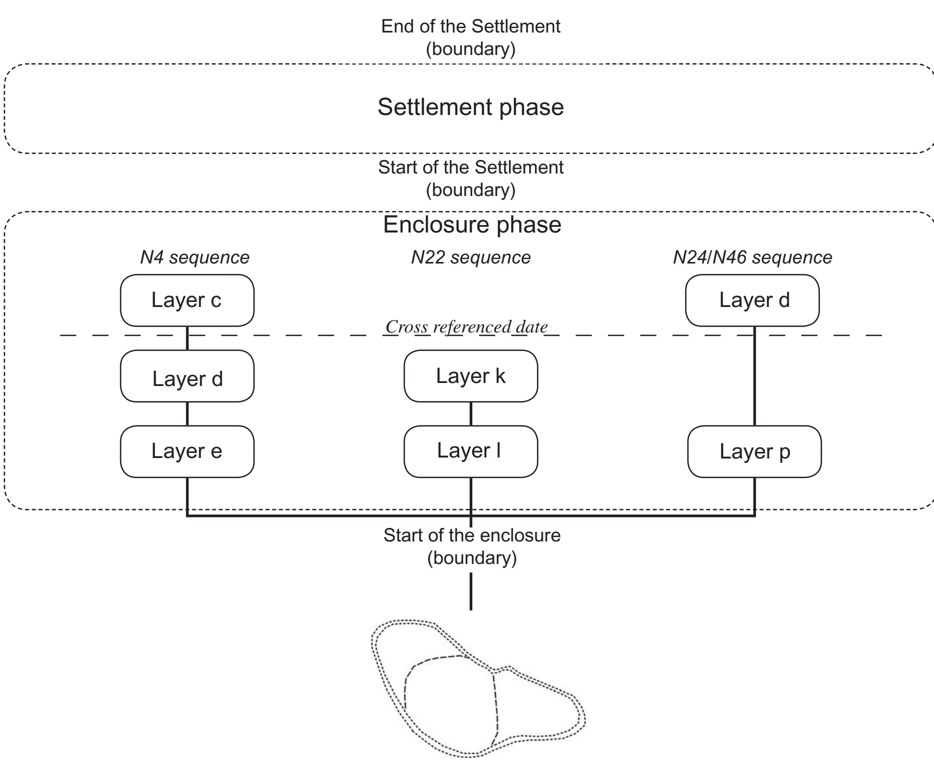

Figure 7. Schematic model of Liselund where the settlement is later than the enclosure (model 1 and 2)

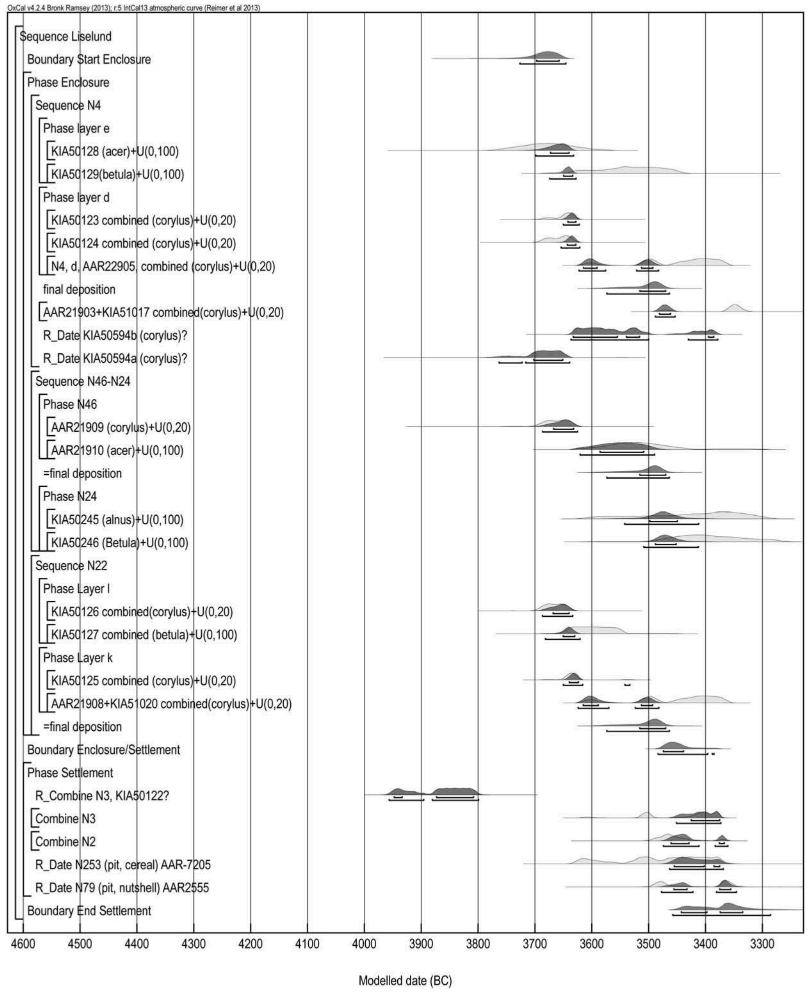

Figure 8. The OxCal implementation of model 2, presented in Figure 7

that the N46/N24 has at least four undated re-cuts between N46 layer p phase and N24 layer d. N22 has at least one undated re-cut before the undated sealing layers.

Results and discussion

In all models, the enclosure is most likely to start in the early 37th century (Figure 11). The models where Kiel 2014 dates are included produce results comparable to those without (with the exception of a bimodal start boundary on model 1, and a more undefined start boundary in model 1 and 3). This could be taken as an indication that the results including the Kiel 2014 dates are correct. In the further discussion, this is taken to be the case. The main conclusion that Liselund was built in the EN I period (e.g. before 3500calBC) is true in all four models (see Figure 11).

The favoured model suggests a start of enclosure activity between 3700–3660BC at 68.2% (3730–3645BC at 95.4%). After a final deposition, the site becomes a settlement around 3475–3445BC 68.2% (3485–3405BC at 95.4%). The settlement is abandoned before 3460–3275BC at 95.4%. This shows that the enclosure is contemporary with the EN Ib phase (3700–3500BC) and the settlement with the EN II phase (3500–3350BC). The model in which the last layers of the ditches belong to the settlement have comparable start and end boundaries, but have an earlier and slightly bimodal boundary between the enclosure and the settlement (see Figure 11, in dates 3615–3485BC at 68.2% or 3620–3470BC at 95.4%).

OxCal allows for estimating the probable duration of defined 'boxes' such as phases, using the *Span* command. When applied to Liselund (Figure 12),

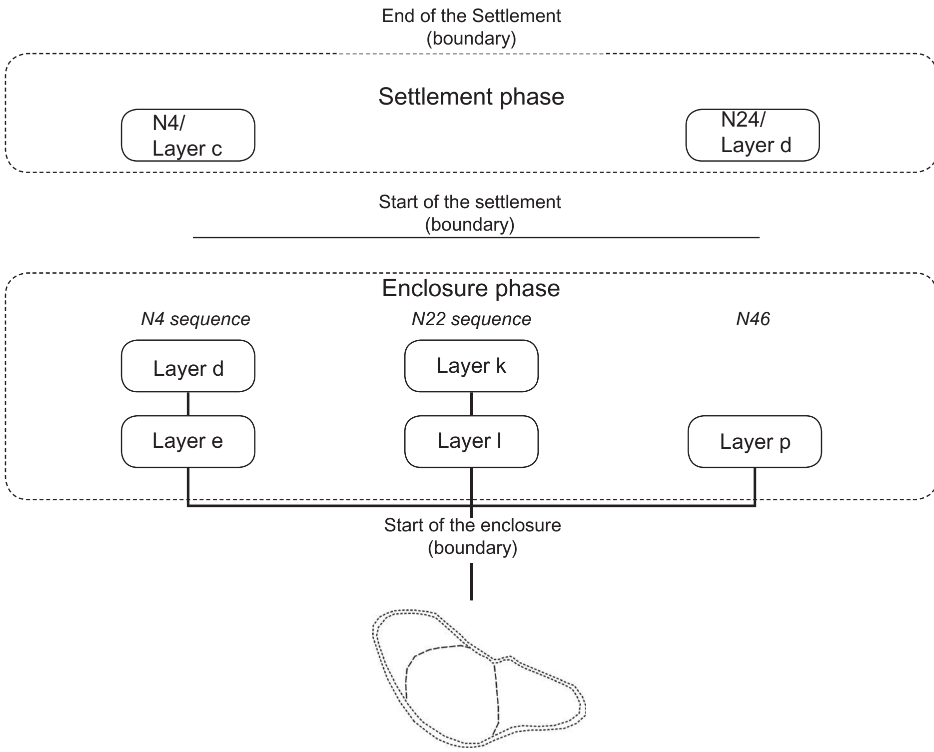

Figure 9. Schematic model of Liselund where the settlement is contemporary with the final layers in the enclosure (model 3 and 4)

the enclosure phase is between 166–253 years (95.4%), and the settlement between 0–98 (95.4%) years in model 2. In the alternative model (model 4), the enclosure is in use for 23–198 years (95.4%), and the settlement for 14–230 years (95.4%). In N46/ N24, the layers p, m, k and f are certain 'enclosure events', with possibly also g, i and d, indicating at least four uses in the maximum 166–253 years of the enclosure. If equally distributed in time, it would result in one re-cut every 40–60 years, or approximately every generation to every other generation.

The start date of the enclosure in the 37th century BC is earlier than the traditional expectations of enclosures, but is comparable to new dates from enclosures in Southern Jutland and North Germany (Lützau Pedersen 2010, Lützau Pedersen and Witte 2012, Hage 2015). It could be pointed out that some enclosures or enclosure related sites could be added to these (Skousen 2008, p. 169; Madsen 2009, Klassen 2014, pp. 182–188). In addition, there is the Hamremoen site in Southern Norway (Glørstad and Sundström 2014, Glørstad and Solheim 2015). This site is atypical and has a very early start date, modelled to be between 3990–3820, and a long use time of 200–370 years, both estimates at 68.2% (Glørstad and Solheim 2015). The dated material is from a cultural layer inside the ditch, and the exact date of the ditch remains unknown. It is worth noting that Büdelsdorf in Northern Germany has a similarly early date (Hage 2015).

Little work has been done so far to precisely date the more than 40 enclosures from South Scandinavia (Klassen 2014, pp. 199–204), but when new dating schemes are implemented, it can be demonstrated that the enclosure phenomenon starts with a few very early sites such as Büdelsdorf and perhaps Hamremoen, but with the major construction phase of new enclosures after 3700BC. Interestingly, the start dates of the enclosures follow the pattern gained from England (Whittle *et al.* 2011). Here enclosures began in the end of the 38th century BC, and in many regions had its height in the 37th century BC. This indicates that the British explosion in enclosure construction is mirrored in South Scandinavia and Northern Germany, at least on the Jutland peninsula.

Recently, a population boom has been suggested at this time (Collard *et al.* 2010, Hinz *et al.* 2012, Shennan *et al.* 2013, Timpson *et al.* 2014). This can be explained as either a population explosion or migration from older farming communities, and it could be considered as an underlying reason for the

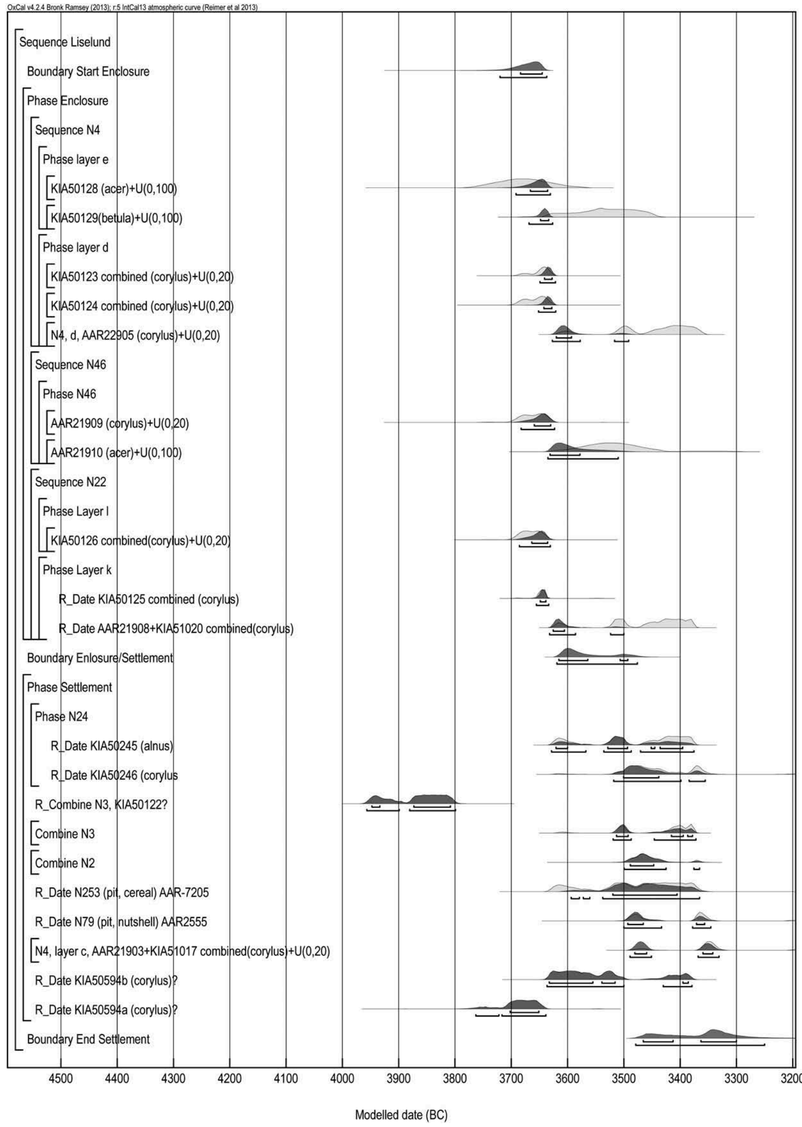

Figure 10. The OxCal implementation of model 4, presented in Figure 9

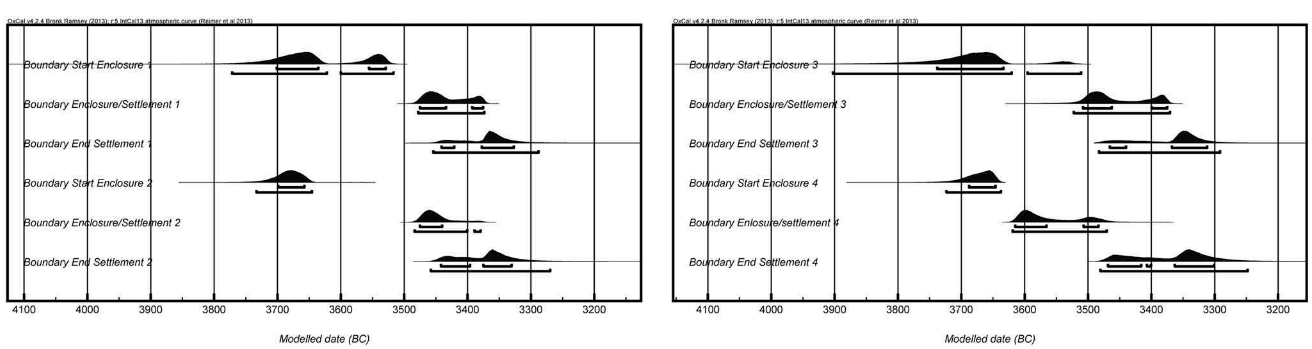

Figure 11. Left: the boundaries arrived at with the primary suggested model with the settlement later than the enclosure. Above model 1 (Amodel 64.7) without dates from Kiel 2014, and below model 2 (Amodel 67.1) including them. Right: a model where the settlement is contemporary with the last layer in the ditches. Above model 3 (Amodel 98.5) without KIA 2014 dates, and below model 4 (Amodel 78.4), which included them

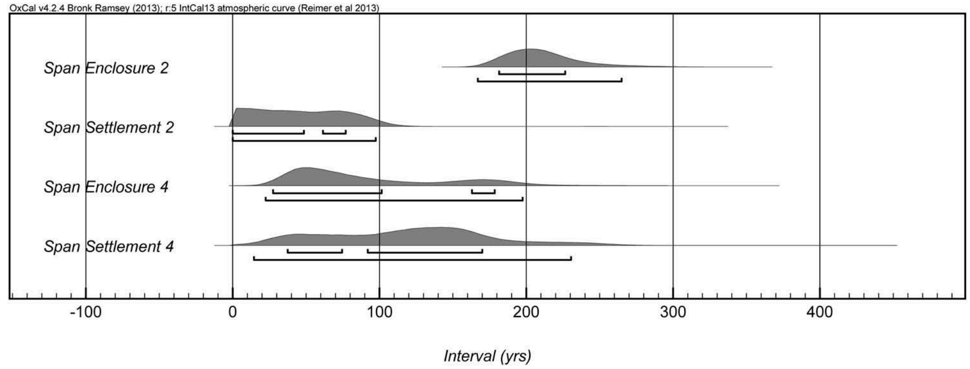

Figure 12. Comparison of the estimated span (use time) of the enclosure and settlement in model 2 and 4

boom in enclosure construction. However, not only are the population booms problematic from a modelling perspective (Contreras and Meadows 2014, Brown 2015, Weninger *et al.* 2015), it can also be demonstrated that the majority of dates forming these peaks are from continued use of Mesolithic shell midden sites and related to differences in research activity and preservation (Torfing 2015a, 2015b). The settlement record of this time is one of small scattered settlements, and the population have a continued use of wild resources. In the archaeological record, there is a lack of evidence for a population boom at this time. Population pressure would be more in line with the traditional date of the enclosures to the EN II-MN I (3.500–3200calBC), where an expansion of the settled area takes place (Madsen 1982, Andersen 1999, pp. 296–302; Klassen 2014, pp. 135–146). Instead, the enclosure construction in South Scandinavia is probably better understood as a step towards an increasingly Neolithic self-identification and increased contact with other societies due to wider exchange networks.

Conclusion

With the aid of Bayesian modelling, it can be shown that the enclosure at Liselund was in all likelihood constructed in the very late 38th century, or more likely the 37th century. Along with other early dates for enclosures, the result forces us to re-evaluate the introduction of enclosures in South Scandinavia. It can no longer be regarded as a phenomenon of the EN II, but must be something that already starts in the middle of the EN I. It requires us to rethink the development of society in the course of the Early Neolithic, and the way enclosures were introduced and why. With the new dates, the Scandinavian and North German enclosures become an integrated part of a larger explosion of enclosures from the 38th century BC to the 36th century BC. This could be the result of changes in the underlying social construction of the newly neolithizised communities and/or changes in the wider networks of contact. However, most Scandinavian enclosures remain poorly dated, and a new effort to date them will likely prove useful in discussing the development and changes during the Early Neolithic of Northern Europe. Radiocarbon dates revolutionised archaeology when first discovered. Bayesian models can take us a step further, as they integrate the dates further in our archaeological processes and data and so offer better answers for more questions.

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