Abhandlung

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Reconsidering the Pitted Ware chronology

A temporal fixation of the Scandinavian Neolithic hunters, fishers and gatherers

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Zusammenfassung: Die Grübchenkeramische Kultur (Pitted Ware culture, PWC) fasziniert seit langem die Fachwelt. Chronologisch gehört sie zum Neolithikum, bricht aber mit traditionellen Vorstellungen von kultureller und sozialer Entwicklung, da sie eine Rückkehr zu – oder Weiterführung von – längst aufgegebenen Jäger-Sammler-Lebensweisen darstellt. Ein Schlüssel zum Verständnis der PWC ist ihre Chronologie. Wann und wo entstand sie, wie breitete sie sich aus, und warum endete sie? Zur Klärung dieser Fragen präsentiert dieser Artikel die bisher größte Zusammenstellung von alten und neu gemessenen Radiokarbondatierungen von grübchenkeramischen Fundplätzen aus ganz Skandinavien. Über 900 Datierungen wurden kritisch begutachtet, neu kalibriert und korrigiert. Die große Zahl von Datierungen ermöglicht einen Blick auf die Gesamtheit der PWC, der nicht durch Probleme mit individuellen Datierungen von einzelnen Fundplätzen getrübt wird. Unser Modell schlägt vor, dass sich die PWC schnell von einem vermuteten Zentrum in zentralen Ostschweden (um 3400 v. Chr.) in weite Teile Skandinaviens und Nordostdänemarks ausbreitete. Die rasche Ausbreitung in vorwiegend küstennahen Gebieten kann durch das Engagement der PWC in weitreichenden Feuerstein-Handelsnetzen verstanden werden. Das Ende der PWC (um 2200 v. Chr.) kann als Konsequenz der landwirtschaftlichen Intensivierung und Ausbreitung nach Norden im Spätneolithikum verstanden werden.

Schlüsselworte: Grübchenkeramische Kultur, Skandinavien, Neolithikum, Radiokarbondatierungen, Chronologie; 4.–3. Jahrtausend v. Chr., big data

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Résumé: La culture de la céramique perforée (Pitted Ware culture, PWC) continue d'attirer l'attention des scientifiques. Appartenant à la période néolithique définie par l'avènement de l'agriculture, le phénomène PWC rompt avec notre conception traditionnelle de l'évolution culturelle et sociale, en incarnant le retour ou la continuation du mode de vie des chasseurs-cueilleurs. Pour comprendre cette apparente anomalie, il est essentiel de pouvoir restituer la chronologie de la PWC: Quand et où ce phénomène a-t-il émergé pour la première fois? Comment s'est-il répandu? Quand et pourquoi s'est-il éteint? Afin de clarifier ces questions, le présent article décrit le plus grand échantillonnage jamais assemblé de sites PWC, localisés à travers toute la Scandinavie et bénéficiant de datations radiocarbones recalibrées et corrigées. Sur plus de 900 datations ^{14}C collectées, nous fument en mesure de surmonter les nombreux obstacles engendrés par la limitation de dates individuelles obtenues sur des sites uniques, qui entravent bien trop souvent l'interprétation et empêchent toute vision d'ensemble. En conséquence, nous sommes maintenant en mesure de présenter un modèle montrant la propagation rapide de la PWC, depuis une origine supposée située dans le centre-est de la Suède (env. 3400 av. J.-C.) vers les vastes zones essentiellement côtières de la péninsule scandinave et du nord-est du Danemark. Cette propagation rapide peut être expliquée par l'intégration de la PWC dans les réseaux d'échange de silex à longue distance. La fin du phénomène PWC, datée aux environs de 2200 cal av. J.-C.) peut être considérée comme une conséquence de l'intensification de l'agriculture et de son expansion vers le nord durant le néolithique tardif.

Mots-clés: culture de la céramique perforée, Scandinavie; Néolithique, datations radiocarbones, chronologie, 4ème–3ème millénaire av. J.-C., big data

Abstract: The Pitted Ware culture continues to attract attention from scholars. Being chronologically situated in the Neolithic, the Pitted Ware phenomenon breaks with our traditional view on cultural and social evolution by representing a return to, or continuation of, an otherwise abandoned hunter-gatherer lifestyle. One of the key issues for trying to understand the Pitted Ware Culture is its chronology – when and where did this phenomenon emerge for the first time, how did it spread and when and why did it end? In order to clarify these issues this paper presents the hitherto largest sample of new as well as old recalibrated and error corrected radiocarbon dates from Pitted Ware sites all over Scandinavia. From more than 900 radiocarbon dates, we are able to look through the many obstacles that often hamper the interpretation of the limited numbers of individual dates obtained from single sites. Furthermore, we are able to present a model showing a rapid spread of the "Pitted Ware Culture" or "Pitted Ware phenomenon" from a supposed origin in central eastern Sweden (c. 3400 cal BC) to vast, mostly coastal, areas on the Scandinavian Peninsula and northeastern Denmark. The rapid spread can be explained by Pitted Ware engagement in far-reaching flint exchange networks. The end of the Pitted Ware phenomenon (c. 2200 cal BC) can be seen as a consequence of the agricultural intensification and expansion northwards during the Late Neolithic.

Keywords: Pitted Ware culture, Scandinavia, Neolithic, radiocarbon dates, chronology, 4th–3rd millennium BC, big data

Introduction

The chronology of the Scandinavian hunter-, fisher- and gatherer-based Pitted Ware culture (PWC) is an old and so far unsolved problem in Scandinavian archaeology. This is primarily due to the lack of secure contact finds from sealed undisturbed contexts relating the Pitted Ware culture to other co-existing archaeologically defined cultural groups such as the late Funnel Beaker culture (TRB), the Danish Single Grave culture (SGC) or the Swedish/Norwegian Battle Axe culture (BAC). Many sites contain culture layers with several occupation phases spanning a number of periods and cultural groups. However, due to older and non-specialist led excavations as well as post-depositional formation processes such as soil erosion, transportation and transgressions, it has often turned out to be difficult to relate datable material to the different cultural occupation phases. To this must be added the possibility of re-cutting and backfilling of features in the Neolithic as known from various causewayed enclosures.

Furthermore, many of the older conventional radiocarbon dates often made on charcoal might be affected by the 'old wood effect' as they required quite large samples almost certainly including heartwood and therefore, implicitly, a high sample age. Direct dates of the Pitted Ware culture can be obtained from food crust from the Pitted Ware vessels, however, due to the marine orientation of the Pitted Ware culture these will usually be influenced by the marine reservoir effect. Therefore, they must be corrected dependent on their $\delta^{13}C$ isotope values, which are not always available.

Not all of these obstacles do of course affect all sites and some can even been dealt with when analysing individual sites and resampling old material. However, in order to obtain an overall picture of the chronology and spread of the Pitted Ware phenomenon we need another approach. Based on the hitherto largest collection of radiocarbon dates from the entire Pitted Ware area this article presents a re-evaluation of the Pitted Ware chronology as regards where and when it begins and ends. By modelling more than 900 radiocarbon dates, representing more than 80 different sites (Figure 1) we are able to identify the outliers caused by the various sources of error that will otherwise distort the case value from individual sites. The collected radiocarbon dates come from a range of different sources and have all been critically evaluated, corrected and recalibrated (cf. Appendix). In addition, 66 new dates have been processed as a part of the international research project CONTACT. The Pitted Ware Phenomenon in Djursland and Maritime Relations across the Kattegat in the Middle Neolithic[1].

An overview of the Pitted Ware horizon in Scandinavia and its subdivision

The Pitted Ware culture was already defined in the early 1900s in eastern central Sweden as the 'East Swedish settlement culture' due to Oscar Almgren's excavations at Åloppe in Uppland[2]. Based on later investigations of some very large and find rich sites, such as Säter and Fagervik, a Pitted Ware pottery chronology was established showing origins in the Early Neolithic Funnel Beaker culture[3]. It was the characteristic pit-decorated pottery that from early on defined, and later on also named, the Pitted Ware culture.

The duration of the Pitted Ware horizon in eastern Sweden has been, and still is, a disputed topic, as it is in southern Scandinavia. In particular some very early dates (early 4th millennium BC) have been questioned because of

1 Klassen 2020.
2 Almgren 1906.
3 Bagge 1952.

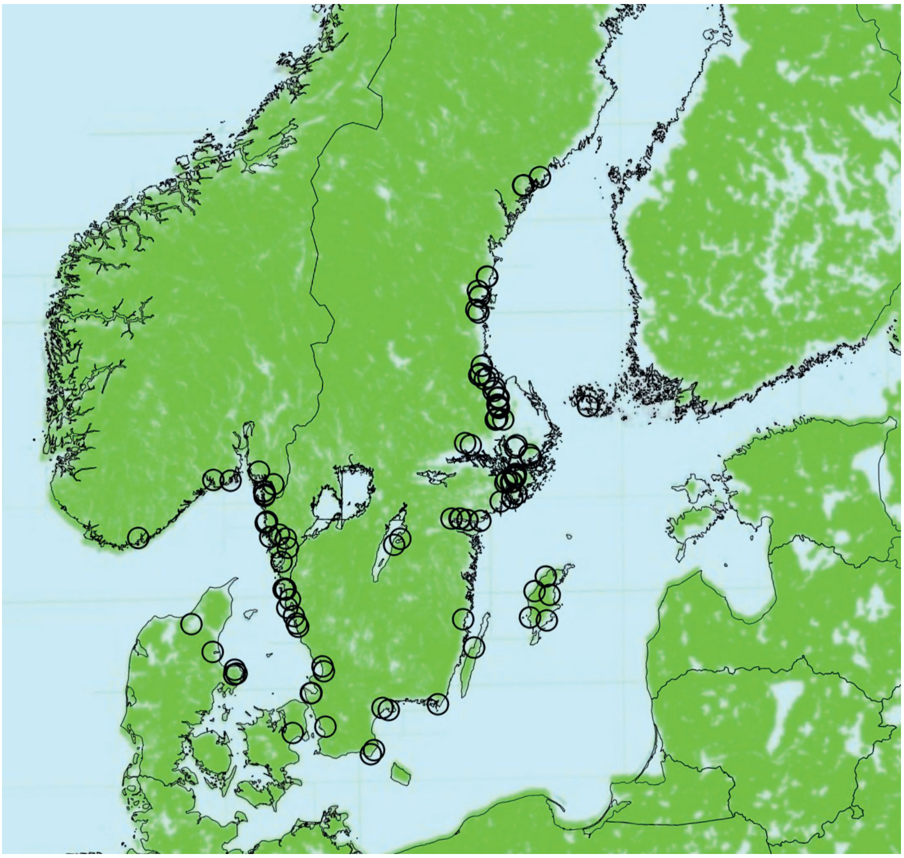

Fig. 1: Map showing the distribution of Pitted Ware sites radiocarbon dated in the present study (black circles). The modern shoreline is marked with a black line whereas the prehistoric landmass around 3000 cal BC is marked with green colour. Drawn by Per Persson, shorelines after Geological Survey of Sweden (SGU) map generator: http://apps.sgu.se/kartgenerator/maporder_en.html

the potential influence of the marine reservoir effect and because Early Neolithic Funnel Beaker pottery (the Fagervik I stage) has been included in the Pitted Ware horizon. At the other end of the chronological sequence, the Fagervik IV stage seems to end the Pitted Ware horizon no later than c. 2400/2300 cal BC, however, significantly later dates (until c. 2150 cal BC) are sometimes stated reaching well into the Late Neolithic. Leaving single outliers and uncertain dates out of account, the Pitted Ware culture in eastern central Sweden must be dated to the period c. 3600/3400–2400/2300 cal BC, corresponding to the late Early Neolithic and Middle Neolithic in South Scandinavia[4].

In western Sweden and southern Norway, Pitted Ware sites are mainly found along the cost, but sites have also been recorded further inland. Sites are predominantly located via the presence of tanged flint arrowheads and cylindrical flint cores but also slate arrowheads are known as is Pitted Ware pottery. Sites with preserved organic remains that could provide us with material for radiocarbon dating are, however, few but include sites such as Ånneröd, Dafter, Sandhem, Rörvik and Auve[5].

The definition of distinct Pitted Ware sites in western Sweden and southern Norway is not as straightforward as in southern Scandinavia, as defining elements such as tanged flint arrowheads and cylindrical flint cores by all means were introduced into western Sweden as early as the Early Neolithic (c. 4000–3300 cal BC). This happened under influence from southern Norway, where tanged arrowheads are known from Mesolithic contexts and seem to have been used throughout the Neolithic[6].

4 Edenmo *et al.* 1997, 182–185; Persson 1999, 32–33; Segerberg 1999, 127–129, fig. 89; M. Larsson 2006, 21–22; Å. M. Larsson 2009, 57–58, 407–412 with references; Hallgren 2011, 32–33; M. Larsson *et al.* 2014, 89.

5 Bakka 1973; Kaelas 1973; Edenmo *et al.* 1997, 152–168; Hernek 2007; Østmo 2008.

6 Indrelid 1994, 187–188; Bergsvik 2006, 41.

The early occurrence of this, otherwise typical Pitted Ware assemblage, is apparently confirmed by a few radiocarbon dates made on food-crust on Pitted Ware vessels. However, these dates derive from one site only; Olas in Halland, and as in eastern central Sweden such early dates can been questioned. Of the five food crust dates from Olas only the three youngest have measured $\delta^{13}C$ values showing a marine content. Their reservoir-corrected age distribution is between c. 3400 and 3000 cal BC. The two other food crust dates are older, but here we lack the $\delta^{13}C$ values. Thus, we cannot exclude the possibility of a reservoir effect and these dates should therefore be treated with caution[7]. The wider accumulation of dates made on food crusts and bones from western Sweden and southern Norway all group within the Middle Neolithic, ranging between c. 3300–2500 cal BC and thus seem to agree with the reservoir-corrected dates from Olas[8].

With Oskar Lidén's investigations of the Jonstorp settlements in northwestern Scania a few decades after Almgren's initial discoveries at Åloppe, the Pitted Ware culture was also recognized in southern Scandinavia[9]. Ten years after Lidén's publication of the Jonstorp sites, Carl Johan Becker published evidence for the existence of the Pitted Ware culture in northeastern Denmark. The overall characteristics were the tanged flint arrowheads (types A, B and C), bipolar cylindrical flint cores and Pitted Ware pottery (Figure 2). Attempts have been made to subdivide the south Scandinavian Pitted Ware culture based on the tanged arrowheads, which have been seen as representing a typo-chronological sequence with type A-arrowheads as the earliest type and type C-arrowheads as the latest[10]. This typology builds on Sophus Müller's old deduction that simple arrowheads (type A) were succeeded by more elaborate types (type B and then C)[11].

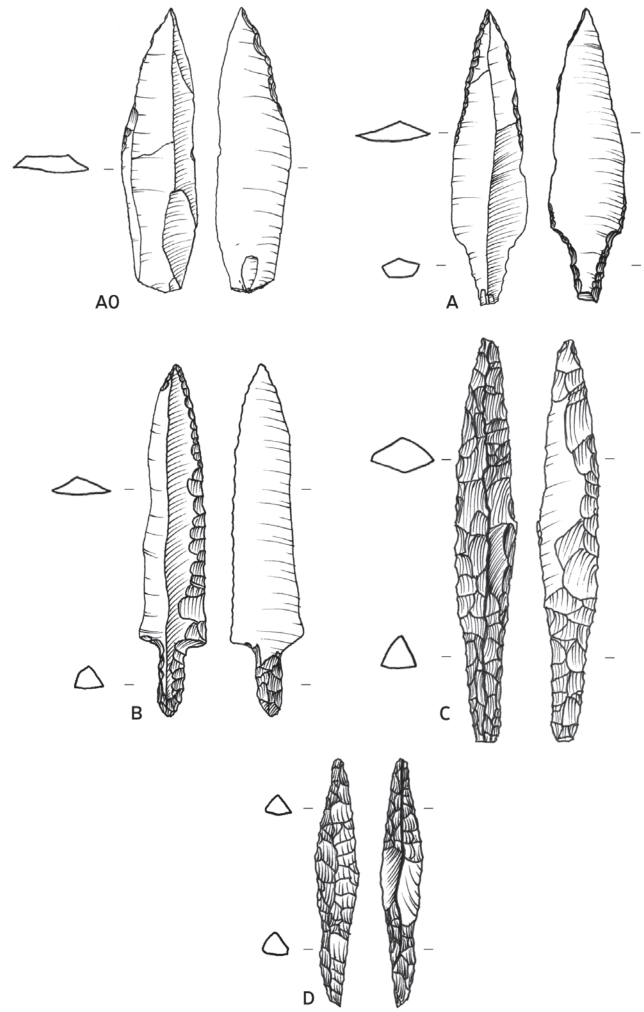

Fig. 2a: Tanged arrowheads. Types A, B and C (Pitted Ware culture), type D (Single Grave and Battle Axe cultures). Drawn by Timm Christensen. After Iversen 2015.

The division of the Pitted Ware horizon in phases A, B and C, roughly corresponding to the respective arrowhead types, is primarily based on the Scanian Jonstorp sites, which have been distinguished chronologically based on their topography and location in relation to the changing shoreline. According to this shoreline chronology, the overall settlement sequence is as follows: M, H, RÄ, M2 and M3. The earliest Jonstorp sites M and H are dominated by A-points, a phase parallel to Fagervik III in the East Swedish chronology. With some reservation, a middle phase has been separated which is made up by late type A arrowheads (the A3 sub-type) as well as type B arrowheads. Jonstorp M2 represents this phase. Type C-arrowheads define the youngest phase represented by Jonstorp M3, whereas Jonstorp RÄ is regarded as contemporary with both the Jonstorp MH stage and early M2-M3 stage even though only type A arrowheads have been found. Radiocarbon dates from Jonstorp M2 and M3 fall between c. 2900 and 2500 cal BC[12].

The causewayed enclosure site at Stävie, Scania, contains a mixture of late Funnel Beaker and Pitted Ware finds. While the pottery clearly resembles the Store Valby tradition, the flint material clearly relates to the Pitted Ware

7 See Appendix: Halland; Strinnholm 2001, 107, fig. 50.
8 Edenmo *et al.* 1997, 159–162; Strinnholm 2001, 105–112, figs. 49–50; Østmo 2008, 159–166; 2010: 50–57.
9 Kjær 1920, 36–40; Lidén 1940; Malmer 1969.
10 Becker 1951, 188–195, 221–222; 1955a, 83–85 fig. 36; 1982, 24–26.
11 Müller 1888, nos. 174–176.
12 Lidén 1940, 7–36; Becker 1951, 193–195; 1955a, 127 fig. 36; 1982, 24–25 fig. 6; Malmer 1969, 1–6; 45–50; 78–86; 2002, 123; Carlie 1986, 160; Edenmo *et al.* 1997, 144 fig. 5,6; M. Larsson 2006, 73–75.

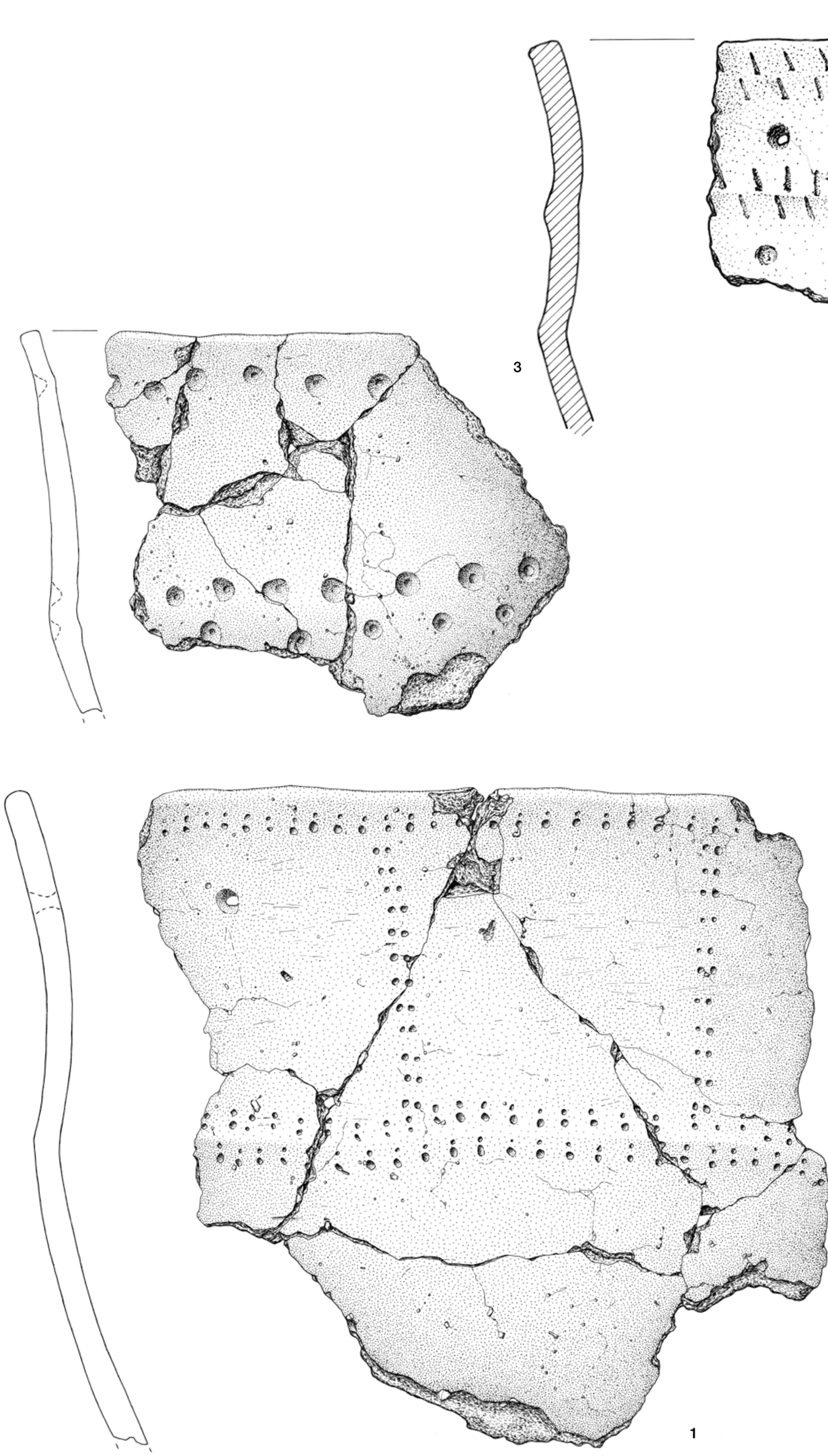

Fig. 2b: Pitted Ware pottery from Kainsbakke, Djursland. Drawn by Freerk Oldenburger (1, 3) and Jack Bacher. After Wincentz 2020.

culture and includes cylindrical flint cores and tanged arrowheads types A and B. Radiocarbon dates range from c. 2850 to 2300 cal BC[13].

Some Pitted Ware sites from northeastern Scania and Blekinge such as Nymölla I, Sirestorp and Björkärr have revealed somewhat older dates covering the time span c. 3500 to 2200 cal BC. These dates are comparable with those known from western and central eastern Sweden and indicate the presence of Pitted Ware sites in southeastern Sweden already in MN I (Middle Neolithic I, the Troldebjerg and Klintebakke phases, c. 3300–3100 cal BC)[14]. However, these samples span quite a long period and can be questioned for several reasons. Those from Nymölla I are all charcoal samples dating from c. 3500 to 2300 cal BC and might be influenced by the 'old wood effect'. Furthermore, the samples are not directly associated with the Pitted Ware occupation on the site and could derive from both earlier and later phases. At Björkärr, dated c. 3500–2650 cal BC[15], the oldest sample was only treated with hydrochloric acid and no bases. Therefore, (potentially older) humic substances from the soil could have remained in the sample, which makes this date problematic. The two other dates from this site were made on fully pre-treated material and both fall after 3000 cal BC.

The discovery and partial excavation of the Kainsbakke and Kirial Bro sites on Djursland in the 1980s contributed with new and important information on the Danish Pitted Ware culture thanks to, among other things, the presence of preserved faunal material and the possibility for producing new radiocarbon dates. These range from c. 2900–2550 cal BC[16]. Type A arrowheads predominate on both Kainsbakke (in particular subtype A3) and Kirial Bro. Therefore, the two sites have been considered belonging to an early phase of the Pitted Ware horizon. On the basis of the new evidence from Kainsbakke and Kirial Bro compared with other sites predominated by certain arrowhead types such as Smedegårde (mainly subtype A3) and Livø (mainly type C) in the Limfjord area, the Pitted Ware chronology was subsequently simplified.

Thus, Lisbeth Wincentz Rasmussen argues for a bipartition of the horizon of which A-arrowheads, primarily A3, define the older phase while B- and C-arrowheads define the younger phase. The older phase is linked to pottery from Jonstorp H-RÄ and thick-butted flint axes of type A, while the younger is related to Jonstorp M2-M3 and thick-butted B-axes[17].

As already argued elsewhere, the internal Pitted Ware chronology can no longer be sustained as type A-, B- and C-arrowheads are contemporary[18]. In addition to Kainsbakke and Kirial Bro, different sites with settlement contexts holding type A and/or B arrowheads have provided identical radiocarbon dates ranging from c. 2900–2550 cal BC. These sites include Ajstrup Krat at Mariager Fjord, Aldersro I in eastern Jutland and the palisaded enclosure at Helgeshøj (pit x 454) in eastern Zealand. On Aldersro, however, the Pitted Ware finds derive from a MN V (Store Valby phase) Funnel Beaker layer, which means that one cannot assume that the radiocarbon dates necessarily represent the Pitted Ware finds[19].

New important excavations carried out at the Helgeshøj palisaded enclosure have revealed more than 150 tanged arrowheads of which several show impact fractures. The tanged arrowheads come from different features but mainly relate to a secondary deposited culture layer overlaying the palisade. However, the principal excavator sees the layer as contemporary with the palisade. The arrowheads are mainly type B (61 %) of which the ferociously looking type B2 with coarsely toothed edges forms quite a large share (44 % of the B-arrowheads). Type C constitutes 30 %, whereas type A only makes 9 %. All three main arrowhead types (A, B and C) are present in the same culture layer (x 34)[20].

Type C arrowheads, which according to the old typologically based chronology should represent a younger phase, are present in altogether four Jutland Single Grave culture interments. These cover phase 1a, 1b and 1c (i. e. the entire Under Grave period[21]) equal to the timespan c. 2850–2600 cal BC according to Eva Hübner's chronology of the Single Grave culture. The graves are Skærbæk, Fragdrup, Sejbæk and Gedsted Hedgård[22].

Furthermore, type C arrowheads have been found in two late Funnel Beaker (MN V) stone-packing graves at Vrou Hede I and Kappelhage in northwestern Jutland.

13 L. Larsson 1982; M. Larsson 2006, 73.

14 Bagge/Kjellmark 1939; Wyszomirska 1975, 69; 1986a; 1986b; Edenmo *et al.* 1997, 144–145, fig. 5,6; M. Larsson 2006, 53–58.

15 Edenmo *et al.* 1997, 145.

16 L. W. Rasmussen 1984; 1986a; 1991; 1993; 2000; Tauber 1986.

17 L. W. Rasmussen 1986a, 166–167; see also Hübner 2005, 681–683 fig. 496.

18 Iversen 2010, 6–7; 2016.

19 U. L. Rasmussen 2000; Giersing 2004, 24–25; Skousen 2008, 211–212, appendix 1.

20 Information about the site was kindly provided by Lotte Sparrevohn, Kroppedal Museum, 1 February 2017. Helgeshøj-området 2, archive no. TAK 1726. Typological classification of the arrowheads by Rune Iversen.

21 Cf. Glob 1945.

22 Becker 1951, 224–228 fig. 20; 1974, 179 fig. 46; Ebbesen 1975, 254 figs. 181–182; Davidsen 1978, 166 fig. 81; Malmros 1980, 63; Hübner 2005, 680–681 fig. 477.

The C-arrowhead from Vrou Hede was not recovered from a sealed context but does by all accounts come from the disturbed rectangular feature (the so-called 'mortuary house')[23]. At Kappelhage, a C-arrowhead was recovered from one of the oblong graves that are usually placed in front of the 'mortuary house'[24]. As the final Funnel Beaker phase (MN V) was rather long, probably spanning the period c. 3000–2600 cal BC[25], the two stone-packing graves do not give a narrow date of the C-arrowheads. However, the two stone-packing graves underline the fact that type A and C arrowheads occur in the exact same period and therefore must be contemporary.

Somewhat similar conclusions have been made on the basis of the west Swedish arrowheads but type A is generally considered to be the earliest to occur[26]. Also in southern Norway the tanged arrowheads seem to have been used contemporarily as indicated by the rich Auve site in the archipelago on the western side of the outer Oslo Fjord. However, type A occurs more frequently in the earlier phases whereas type B and C become more common in the later phases on the site[27].

Yet another tanged arrowhead type (type D) belongs to the later Single Grave and Battle Axe cultures, both part of the larger Corded Ware phenomenon. Type D is well dated due to its presence in the late Jutland single graves covering phases 2b, 3a and 3b (i. e. the late Ground Grave period and the Upper Grave period) equal to the timespan c. 2525–2250 cal BC. Because of morphological similarities relating type D to type C and the presence of hybrid forms, it is reasonable to consider type D as derived from type C somewhere around the transition between period 2b and 3a, at c. 2450 cal BC, whereupon type D became absolute[28].

A logical consequence of the contemporaneity of the Pitted Ware arrowhead types (A, B and C) is of course that a subdivision of the Pitted Ware horizon in two (or even three) phases cannot be sustained. Instead, the applied flint knapping technique can explain the different arrowhead types. The tanged arrowheads were struck from bipolar cylindrical cores. The significant cylindrical shape of these cores with a platform in each end is a consequence of the flint knapping technique, by which the core is regularly turned 180° in order to produce long and straight blades. In the beginning of the production sequence, wide and flat blades are produced; these are used for the A-arrowheads. As more blades are removed the flint core obtains an increasingly multifaceted cylindrical form. The diameter of the platforms are gradually reduced and the angles between the flake scars get more or less acute. Consequently, blades get slender with a three-sided cross section. Such blades could be used for the C-arrowheads[29].

The different types of blades that came out of this production sequence were not only a logical outcome of the flint knapping technique but probably also instigated by the flint knapper in order to produce arrowheads with different properties. Thus, the Pitted Ware arrowhead types had different functions. The simple and relatively flat and wide type A represents hunting arrowheads whereas the slender type C with a triangular cross section probably functioned as specialized war arrowheads. Type B represents a multifunctional group of arrowheads that mixes features from type A and C. However, subtype B2 might be affiliated with the group of war arrowheads due to its coarsely toothed edges[30].

Notes on the South Scandinavian Middle Neolithic chronology

According to the general South Scandinavian chronology, the Pitted Ware culture falls within the Middle Neolithic (c. 3300–2350 cal BC). However, due to the cultural diversity that characterises most of the 3rd millennium BC, the Middle Neolithic as such, as well as its subdivision, has been debated thoroughly. It is not our intention to refer the entire debate here, but merely to provide a short research historical background to the used terminology.

In 1944 Therkel Mathiassen redefined and renamed Sophus Müller's old chronology covering the 'Passage grave period' of the Megalithic culture (i. e. the Funnel Beaker culture). Müller's classification was based on a series of stylistic phases defined from the pottery found in the passage graves: the Grand Style, the Beautiful Style, Closing Florescence, the First Declining Period, Continued Decline and the Last Ornamentation[31]. Based on a series of excavated settlement sites Mathiassen proposed a five-phase chronology for the Passage grave period: I. Troldebjerg, II. Blandebjerg, III. Trelleborg, IV. Bundsø and V. Lindø[32]. In 1947 Becker introduced the present terminology, Early, Middle and Late Neolithic equal to the former

23 Jørgensen 1977, 61–63; 184; 207–208.
24 Damm 1989; Fabricius/Becker 1996, 229.
25 Iversen 2015, 21–24.
26 Hernek 1995, 32; Edenmo *et al.* 1997, 161; Persson 1998, 66–72; Toreld 2003, 34–35; Munkenberg 2007, 107.
27 Østmo 2008, 83; 156–158 fig. 73.
28 Hübner 2005, 439; Iversen 2010, 7–9.
29 See also Thorsberg 2007.
30 Iversen 2016.
31 Müller 1918.
32 Mathiassen 1944.

Dolmen period, Passage grave period and Dagger/Stone cist period. At the same time Becker dismissed the old term 'Megalithic culture' in favour of the 'Funnel Beaker culture'[33].

By the mid-1950s Becker had modified Mathiassen's Middle Neolithic chronology and added the Store Valby pottery phase, marking the end of the Funnel Beaker culture. Accordingly, the Troldebjerg style represents MN Ia, Klintebakke MN Ib, Blandebjerg (Trelleborg) MN II, Bundsø MN III, Lindø MN IV and Store Valby MN V. Later on, Poul Otto Nielsen merged the Bundsø and Lindø phases into a combined MN III/IV phase as the Lindø style is weakly defined with no new finds in recent decades[34]. Becker placed the Single Grave culture and the Pitted Ware culture parallel with the Middle Neolithic Funnel Beaker phases of MN III–V, at which point the Late Neolithic began[35].

Thanks to an increasing number of radiocarbon dates obtained from the 1970s and 1980s it seems clear that the Single Grave culture generally succeeded the Funnel Beaker culture chronologically[36]. However, the early phase overlaps with the Store Valby phase (MN V) that seems to continue in eastern Denmark for a couple of hundred years, probably until c. 2600 cal BC[37]. The recognition that the Single Grave culture appeared on the Jutland Peninsula around 2850 cal BC at the expense of the Funnel Beaker culture has led to a discussion of the Middle Neolithic terminology. The period ranging from the occurrence of the first single graves in Jutland to the beginning of the Late Neolithic (c. 2850–2350 cal BC) has been labelled: the Battle-Axe period, the Younger Neolithic/YN, the Single Grave period (in Jutland) or the Middle Neolithic B/MN B (for the Danish islands). The preceding Middle Neolithic Funnel Beaker phases (I–V) are sometimes referred to as the Middle Neolithic or Middle Neolithic A/MN A (for southern Scandinavia in general)[38].

As pointed out elsewhere[39], the Middle Neolithic chronology suffers from an unfortunate merging of cultural groups and chronological periods. Thus, the late Funnel Beaker culture has become synonymous with the Middle Neolithic or MN A, whereas the Younger Neolithic, Battle-Axe period or MN B represents the Jutland Single Grave culture and the time after the end of the Funnel Beaker culture on the Danish islands. This correlation between archaeologically defined cultures and chronological periods causes serious problems when the various cultural groups coexist for a longer period. This is exactly the case with the late Funnel Beaker culture that continued in the eastern parts of southern Scandinavia while being replaced by the early Single Grave culture in central and western Jutland. Thus, MN AV and the presumably succeeding period MN BI[40] will be convergent on the Danish islands.

The most obvious way to escape the unfortunate implied association between culture and chronological period is to adopt a 'culture neutral' terminology such as early and late Middle Neolithic and keep the chronological subdivisions to the archaeologically defined cultural groups on the basis of which they are defined[41]. Consequently, MN I–V only describes a subdivision of the later Funnel Beaker culture whereas the Under, Ground and Upper Grave periods describe the chronological sequence of the Single Grave culture (Figure 3).

Searching for the beginning of the Pitted Ware culture in Denmark – the archaeological evidence so far

As it appears form the overview presented above, placing the Pitted Ware culture in the complicated Middle Neolithic sequence has been a debated topic among scholars. One of the issues that formed the basis for the discussion was the general lack of finds from sealed contexts combining Pitted Ware types with characteristic artefacts from other Middle Neolithic groups[42]. However, thanks to the presence of type C arrowheads in four period 1 Single Graves, the morphological similarities between types C and D and the defined dates for type D arrowheads, the chronological relation between the Pitted Ware and Single Grave cultures should be firmly established as argued above.

In spite of the marked increase in the number of radiocarbon dates from Pitted Ware sites in southern Scandinavia, the number of sites is still rather limited and dates have primarily been provided by the rich material from Kainsbakke. Thus, we cannot be certain when exactly in the Pitted Ware horizon these dates fit; do they represent the first phase of Pitted Ware occupation or a later phase? In this respect, the relation between the Pitted Ware and

33 Becker 1947, 9.
34 Midgley 1992, 159–164; P. O. Nielsen 1993, 85–86.
35 Becker 1955a.
36 Tauber 1971; 1986; Malmros/Tauber 1977.
37 Iversen 2015, 21–24.
38 Cf. Malmer 1962; P. O. Nielsen 1979; Adamsen/Ebbesen 1986; L. Larsson 1989; Hübner 2005; Ebbesen 2006; Siemen 2009.
39 See Iversen 2015, Ch. 3.
40 See P. O. Nielsen 1979, 53 fig. 26.
41 Iversen 2015, 24–27.
42 Sterum 1978; S. Nielsen 1979, 28–34.

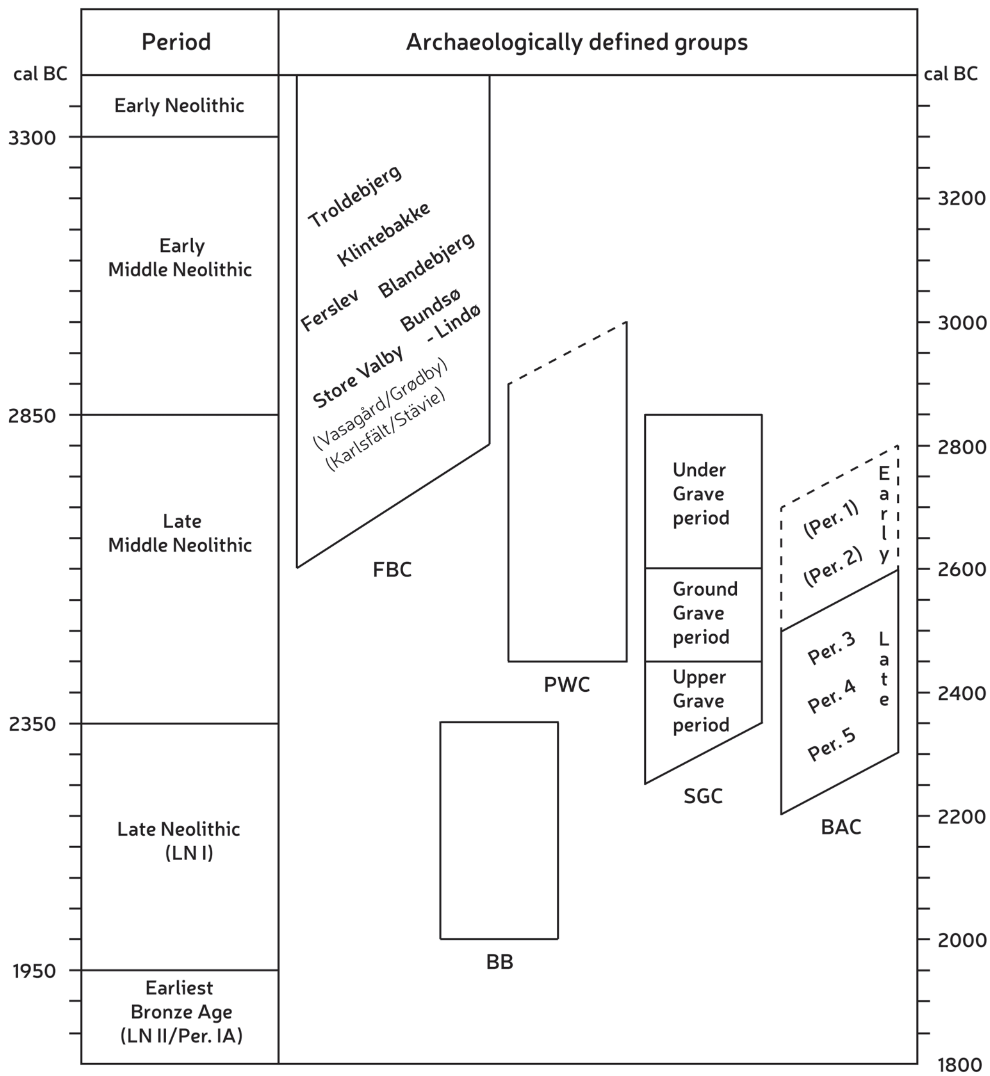

Fig. 3: Adjusted chronology for southern Scandinavia. FBC – Funnel Beaker culture, PWC – Pitted Ware culture, SGC – Single Grave culture, BAC – Battle Axe culture, BB – Bell Beaker culture. After Iversen 2015

the Funnel Beaker cultures becomes of central importance. According to the traditional chronological schemes[43], the Middle Neolithic Funnel Beaker phases form a successive sequence with each period lasting 100 years. We are therefore looking for contexts that contain datable Funnel Beaker pottery from phases prior to the period represented by the known Pitted Ware radiocarbon dates, e. g. MN I, II and III/IV.

A key site when it comes to the relationship between the Funnel Beaker and the Pitted Ware cultures is of course the Alvastra pile dwelling. Alvastra is located in Östergötland, central eastern Sweden. The pile dwelling site was used from c. 3350 to 2750 cal BC, equal to MN I–V, and contains Funnel Beaker as well as Pitted Ware occupations. An intensification of depositions and burial activities seems to have taken place at the beginning of MN III/IV, around c. 3000 cal BC, when Pitted Ware occupation succeeded the Funnel Beaker culture on the site[44]. Despite the many fascinating aspects of Funnel Beaker and Pitted Ware interactions on Alvastra, one should be extremely cautious not to draw direct parallels between central eastern Sweden and Denmark. This reservation is due to the different cultural situation in the two areas regarding the presence and character of the Pitted Ware culture. Denmark and Scania clearly represent the southernmost fringes of

43 Cf. P. O. Nielsen 1993, 85; Jensen 2001, 271; for Bornholm see P. O. Nielsen *et al.* 2014, 4; 88; 94.

44 Browall 2011, 411–413; 2016, 148–154.

the overall Pitted Ware phenomena. Also, when it comes to burial tradition (reuse of megalithic tombs) and subsistence economy, the Pitted Ware culture in southern Scandinavia is much more intermixed with the Funnel Beaker culture than was the case in eastern central Sweden[45].

In a Danish context, we have already discussed the presence of tanged arrowheads related to the late Funnel Beaker culture but as these date to MN V we are within the range given by the radiocarbon dates from Kainsbakke and Kirial Bro. However, some old and disputable finds scattered across Denmark hint at a somewhat earlier occurrence of the Pitted Ware culture.

Karsten Davidsen points at three Funnel Beaker settlement sites with culture layers containing Pitted Ware arrowheads: Lilleborg, Gammelborg and Rispebjerg on Bornholm. Lilleborg and Rispebjerg contain pottery that, according to Davidsen, dates no later than MN IV, which is indicative for the dating of the arrowheads[46].

On Rispebjerg, the Pitted Ware element consists of a type C arrowhead found in a culture layer[47]. However, later excavations on the site have shown that Rispebjerg contains a final Funnel Beaker palisade enclosure dated to c. 2900–2700 cal BC[48]. If the culture layer and the palisade enclosure are related features, the Pitted Ware arrowhead becomes less significant from a chronological point of view.

Lilleborg is a mediaeval castle ruin. Early excavations from the late 19th and early to mid-20th century recovered Middle Neolithic material in the form of MN III/IV Funnel Beaker pottery and type B and C arrowheads in addition to some Late Neolithic finds. Davidsen sees the tanged arrowheads as contemporary with the Middle Neolithic pottery[49] even though the finds are retrieved from a rather large area without defined contexts. In addition, two tanged arrowheads have been found on the castle mounds site of Gammelborg[50],[51].

In this connection, it is worth mentioning the Pitted Ware site of Livø, northern Jutland. The site contains Pitted Ware pottery, cylindrical flint cores and tanged arrowheads, predominantly type C in addition to a considerable amount of Funnel Beaker pottery and a single double-edged stone battle axe, type B3, dated to MN III/IV[52]. The site consists of an up to 20 cm thick culture layer with no visible stratigraphy. According to Oscar Marseen, who excavated the site, one must interpret the recovered finds with some reservations due to the possibility of admixture[53].

A few Pitted Ware finds consisting of one type B arrowhead and two cylindrical flint cores were recovered from the Sølager shell midden in northern Zealand. The Pitted Ware finds come from a stratigraphic context, layer IV, containing MN II Blandebjerg style pottery and a fragmented thin-butted flint axe. In addition, the layer held two thick-butted Lindø type flint axes dated to MN (IV)-V[54] as well as a few MN V pottery sherds[55]. Jørgen Skaarup sees the thick-butted flint axes as a part of a later Pitted Ware intrusion of layer IV. The existence of a later intrusion is furthermore confirmed by a radiocarbon date (K-1725) c. 2850–2450 cal BC (1σ)[56]. Furthermore, the location of the B-arrowhead in layer IV has been questioned[57].

An equally problematic context is found at another shell midden at Selbjerg, northern Jutland. Fragments of a MN II funnel-necked beaker were scattered across several square meters at the bottom of a Pitted Ware shell layer. The layer also contained cylindrical flint cores, fragments of tanged arrowheads, one type A3 arrowhead and sherds from a Pitted Ware vessel. Three type B arrowheads were found in an earlier unauthorized excavation in the midden. Oscar Marseen, who excavated the site in 1952, stated that the Funnel Beaker vessel must date the Pitted Ware occupation at Selbjerg[58]. Becker, on the other hand, argues that the Pitted Ware finds are later than the funnel-necked beaker, as the cylindrical cores and the Pitted Ware sherds were scattered throughout the layer, whereas the funnel-necked beaker was located at the bottom of the layer. Above the Pitted Ware layers is a partly preserved stone pavement, the upper culture layer on the site. Single Grave pottery was found in and above this layer together with Late Neolithic flint artefacts and Funnel Beaker sherds (presumably MN II–III)[59].

As also noted by Niels Sterum, it is doubtful whether the distribution of the artefacts within the Pitted Ware layer has any chronological significance as the scattering of shards from the Pitted Ware vessel throughout the

45 E.g. M. Larsson 2004; 2006; Iversen 2010.
46 Davidsen 1982, 39–40.
47 Davidsen 1978, 164–165 fig. 69n.
48 P. O. Nielsen *et al.* 2014, 107–118.
49 Davidsen 1977.
50 Ibid. 21.
51 Recent excavations (2013–17) on the causewayed enclosure Vasagård Vest, Bornholm, have also revealed tanged arrowheads from final Funnel Beaker layers deposited in the ditch segments.
52 Ebbesen 1975, 197; Marseen 1963; Iversen 2010, catalogue: no. 2.
53 Marseen 1963, 126–128.
54 As for the dating of the flint axes, see P. O. Nielsen 1979, 22; 39; Iversen 2015, 36–38.
55 See Davidsen 1975, 168.
56 Skaarup 1973, 98–104; 116.
57 Sterum 1978, 68.
58 Marseen 1953.
59 Becker 1955a, 85–89; 108.

layer clearly shows that contemporary artefacts can be found throughout the entire layer. Besides, cylindrical flint cores are also found at the bottom of the layer. Still, Sterum rightly questions the stratigraphic value of the find because of the disturbance from the aforementioned unauthorized diggings on the site, the clearly mixed nature of the stone pavement layer and the sporadic distribution of this layer. Furthermore, cylindrical cores have also been found above the stone pavement[60].

Kornerup, near Roskilde, holds a series of Neolithic pits, minor culture layers and a shell midden. The midden was excavated in 1897 and revealed Funnel Beaker pottery, presumably from MN III, as well as flint and bone artefacts including a cylindrical flint core[61]. Besides, a fragment of a tanged arrowhead (type A1) was recovered from a shallow pit together with Funnel Beaker sherds, which most likely date to MN III[62]. Becker had earlier questioned the validity of the find, as the arrowhead might be an accidental intermixture. However, he does not state any reason for his queries about the context[63].

The early 20th century excavations at the classical Lindø site on Langeland, which has named the MN IV Lindø pottery style, has additional to a rich late Funnel Beaker material revealed some Pitted Ware finds. The site constitutes a series of culture layers, pits, fireplaces and a few houses. Lindø mainly dates to MN IV but also contains a significant MN V occupation as well as finds from MN I–III and the Late Neolithic[64]. The bottom layer of a pit on Lindø, site 4, contained two cylindrical cores and one type A1 tanged arrowhead. The pit was rich in both MN IV and MN V pottery. Besides, cylindrical cores have been recovered together with MN IV–V artefacts on both Lindø site 2 and 9. Site 2 also contained a tanged arrowhead type A1. More arrowheads and cylindrical cores have been collected as stray finds on the Lindø sites[65].

Even though doubts can be, and rightfully have been, raised on each of the individual finds reviewed above, they all seem to point to the existence of the Pitted Ware culture in MN III/IV. Based on the traditional chronology, this means that we have indication that the Pitted Ware material culture appears around 3000–2900 cal BC, or if the Selbjerg find is to be trusted already from c. 3100–3000 cal BC (MN II). These dates predate the traditional beginning of the Pitted Ware horizon in Denmark by 100–200 years based on the earliest range of the old radiocarbon dates from Kainsbakke. According to these, the Pitted Ware horizon starts around 2900 cal BC corresponding to the final MN V Funnel Beaker phase[66]. Meanwhile, new radiocarbon dates have been obtained from Kainsbakke and other nearby sites, including Ginnerup, which seem to fit the early date indicated by the Selbjerg find (see below). However, it is reasonable to question the Middle Neolithic Funnel Beaker chronology as it rests on pottery styles from mixed settlements and megalithic tombs lacking sealed contexts.

As has already been noticed in the literature, the successive and generalising pottery based chronological sequence that describes the Middle Neolithic Funnel Beaker period is highly improbable. Instead, the individual styles should be viewed as overlapping and partly contemporary[67] (cf. Figure 3). Still, radiocarbon dates show an overall development where dates from MN I–II contexts cluster in the centuries prior to 3000 cal BC whereas the MN V dates fall in the centuries after 3000 cal BC. The couple of dates available from MN III/IV contexts seem to overlap with both clusters around 3000 cal BC[68].

Despite the significant overlap between the Middle Neolithic Funnel Beaker phases and the uncertainty that can be ascribed to the controversial contact finds referred above, the opportunity still exists that Pitted Ware material culture was introduced prior to or around 3000 cal BC. A beginning of the Pitted Ware culture before 3000 cal BC should not be particularly striking considering the early dates from western Sweden and northeastern Scania/Blekinge. However, the incorporation of a large dataset comprising more than 900 radiocarbon dates together with new dating evidence from Kainsbakke and other sites have given us the opportunity to answer the question on when the Pitted Ware phenomenon appeared in Scandinavia.

Radiocarbon dating the Pitted Ware phenomenon

In order to firmly settle the chronology of the Scandinavian Pitted Ware phenomenon, we collected 947 radiocarbon dates published in various reports, online databases, research papers, conference proceedings and books,

60 Sterum 1978, 66–67; for further discussion on the stratigraphy at the Selbjerg site, see Philippsen *et al.* 2020.

61 Madsen *et al.* 1900, 163–172; Becker 1955b, 180–182.

62 Ebbesen 1982, 55 fig. 4.

63 Becker 1951, 223 note 2.

64 Davidsen 1978, 51–2; Skaarup 1985, 45.

65 Winther 1926; 1928, 13–21; 40–49; Skaarup 1985, 370 note 579.

66 L. W. Rasmussen 1984; 1986b; Tauber 1986

67 e. g. Davidsen 1978; S. Nielsen 1979, 30–31; Gebauer 1988, 112–115; Midgley 1992, 170–171, 211–221; Dörfler 2008, 135–136 fig. 1; Iversen 2015, 25.

68 Iversen 2015, fig. 3,3.

corrected them for reservoir effects when possible, and made new calibrations. Furthermore, some dates had to be omitted because, after all, they proved not to be from the PWC. Out of the collected dates, 737 proved to be reliable (cf. Appendix). When $\delta^{13}C$ values of the samples were available, they were used e. g. to calculate the proportion of marine diet reflected in human bones. $\delta^{13}C$ values of local fauna samples were used to find the marine and terrestrial endpoints for these calculations. In cases where these had not been measured, standard values were used based on nearby sites. Ideally, the local reservoir age for marine samples would have been used for the corrections. However, as this is not known for most of the sites, different strategies were tested: the global model ocean with the calibration curve Marine13, or a Baltic calibration with the terrestrial calibration curve IntCal13[69] after subtracting a reservoir age of e. g. 300 or 400 radiocarbon years, or the local reservoir age, when such measurements were available in the literature.

The dates were calibrated and mapped with OxCal 4.3[70]. Short discussions and graphs of the calibrated ages for the different sites can be found in the Appendix and the overall results are presented in Figures 4 and 5 below. It should be noted that the maps only display sites with reliable radiocarbon dates, thus only a selection of all Pitted Ware sites in the study region.

New radiocarbon dates obtained within the CONTACT project

In total, 66 radiocarbon dates have been obtained for Pitted Ware sites within the CONTACT project. In addition to the radiocarbon dates themselves, stable isotope values of already dated pottery food crusts were measured. This enables us to re-evaluate those dates by applying corrections for the marine reservoir effect.

As already touched upon in the introduction, we face a general challenge when radiocarbon dating the Pitted Ware culture in Denmark as almost all sites are mixed, featuring earlier Mesolithic or Neolithic occupation[71]. This is because the Pitted Ware economy favored the same locations as the late Mesolithic Ertebølle culture and because Funnel Beaker sites were re-used. Pottery with datable food residues is scarce, which means that the dated material in many cases could belong to other culture groups. Below we present the new Pitted Ware radiocarbon dates from sites in western Sweden and Denmark. The list is ordered alphabetically after site name.

Ajstrup Krat

Five new radiocarbon dates were obtained for the site Ajstrup Krat at Mariager Fjord, eastern Jutland. The dates from the Pitted Ware contexts fall within the period 3000–2200 cal BC.

SID	AAR	Sample name	Archaeological Remarks	Description	^{14}C age	$\delta^{13}C$	Cal. Age (1σ range)	Cal. Age (2σrange)
24654	21751	ÅHM3642 X74	PWC hearth A5, lower shellheap (oyster)	Charred nut shell	4108±35	−24.58	2851–2582 BC	2867–2506 BC
24655	21752	ÅHM3642 X174	PWC hearth A18, upper shellheap (cardium)	Charred nut shell	3800±25	−24.75	2286–2201 BC	2333–2141 BC
24656	21753	ÅHM3642 X224	PWC hearth A27, culture layer (upper part) under shellmidden	Charred nut shell	4364±27	−27.16	3011–2920 BC	3084–2907 BC
24657	21754	ÅHM3642 X242	PWC hearth A27, culture layer (middel part) under shellmidden	Charcoal	3811±28	−25.86	2289–2204 BC	2397–2142 BC
24658	21755	ÅHM3642 X489	Deep deposit of shell layer in beach ridge under PWC midden	Charcoal	4854±29	−25.45	3691–3635 BC	3704–3537 BC

69 Reimer *et al.* 2013.

70 Bronk Ramsey 2009.

71 E.g. Becker 1951.

Anfasteröd

From Anfasteröd (Bohuslän, Sweden), three food crusts on pottery and one cremated human bone were dated. The food crusts were calibrated with a correction for the marine reservoir effect, after calculating %marine from the $\delta^{13}C$ values. Two of the sherds are from the first, the other one from the second half of the third millennium BC. The human bone is from c. 2850–2600 cal BC.

SID	AAR	Name	$\delta^{13}C$	$\delta^{15}N$	C:N	C% (TCD)	N% (TCD)	^{14}C age	Cal. Age (1σ range)	Cal. Age (2σ range)
29258	24677	220, F545 food crust *insol.*	−22.16	11.12	12.66	49.23	4.55	4379±25	2888–2770	2900–2700
		base-sol.	−23.32	8.54	12.64	52.10	4.81			
29259	24678	221, F553 food crust*insol.*	−25.92	14.65	15.15	25.48	1.92	3868±33	2452–2231	2461–2207
		base-sol. fraction lost								
29260	24679	222, F612 food crust *insol.*	−24.42	18.82	21.69	20.03	1.09	4332±49	2929–2760	3020–2693
		base-sol.	−22.66	9.66	10.13	45.45	5.25			
29261	24680	223 burnt bone, human						4117±27	2854–2623	2865–2578

Ginnerup

From Ginnerup on Djursland, eastern Jutland, one shell and six bone samples were dated. The shell sample was calibrated with the Danish Marine Calibration (reservoir age subtracted, calibrated with the terrestrial calibration curve). All samples have relatively old ages between 3300 and 2900 cal BC. However, the bones could reflect non-Pitted Ware activities at the site. The existence of an early Middle Neolithic Funnel Beaker occupation on the site has recently been confirmed by detailed analyses of the excavated material showing that the Ginnerup site most probably contains two consecutive phases. The earliest phase is represented by fragments of thin-butted flint axes and Funnel Beaker pottery dated to the Early Neolithic II/early Middle Neolithic. This phase corresponds to the radiocarbon dated interval c. 3300–3100 cal BC. The later phase represents the Pitted Ware occupation proven by pottery, bipolar cylindrical flint cores and radiocarbon dates ranging from c. 3100 to 2900 cal BC.[72] Thus, the Ginnerup site points at an early occurrence of the Pitted Ware phenomenon in Denmark before 3000 cal BC (MN II) as also indicated by the questionable contact find from Selbjerg (see above).

SID	AAR	Sample name	Description	^{14}C age	$\delta^{13}C$ (EA)	$\delta^{15}N$	Cal. Age (1σ range)	Cal. Age (2σ range)
29382	24733	A1 X133	Shell	4769±32			3014–2922	3090–2906
29383	24734	A1 X134	Bone, Metatarsus	4503±27	−21.38	6.43	3337–3107	3348–3098
29384	24735	A1 X617	Bone, Radius	4399±28	−20.95	3.17	3086–2931	3096–2919
29385	24736	A3 X209	Bone, Tibia	4500±31	−22.67	4.32	3336–3105	3348–3096
29386	24737	A3 X244	Bone, 1st phalanx	4511±28	−18.30	7.69	3342–3115	3351–3100
29387	24738	A4 X610	Bone, Vertebra	4431±31	−21.34	3.91	3308–2945	3327–2926
29388	24739	A4 X613	Bone, Centrotarsal	4472±29	−21.13	3.31	3327–3028	3330–3022

72 See Philippsen *et al.* 2020; U. L. Rasmussen 2020.

Hakeröd

Eleven charcoal samples, found in soil samples, were dated for the site Hakeröd (Bohuslän, Sweden). Furthermore, eight food crust samples were submitted for stable isotope analysis, and three of them were dated as well.

SID	AAR	Sample name	Description	^{14}C age	Cal. Age (1σ range)	Cal. Age (2σ range)
26790	22906	Hakerödprov 1c	Charcoal – *Pinus*	4176±31	2878–2697 BC	2886–2637 BC
26791	22907	Hakerödprov 3e/P1	Charcoal – *Tilia*	4183±52	2883–2680 BC	2898–2621 BC
26792	22908	Hakerödprov 3e/P2	Charcoal – *Pinus*	4222±31	2896–2762 BC	2906–2694 BC
26793	22909	Hakerödprov 5e	Charcoal – *Quercus* *(weighted mean of two dates)*	6394±36	5464–5323 BC	5470–5317 BC
29251	24670	213, y2 112 163-170	Charcoal from soil sample	4156±27	2869–2677 BC	2878–2633 BC
29252	24671	214, y2 113 170-240	Charcoal from soil sample	4113±39	2856–2586 BC	2872–2573 BC
29253	24672	215, y2 113 120-160	Charcoal from soil sample	4073±29	2833–2502 BC	2854–2492 BC
29254	24673	216, y2 113-85	Charcoal from soil sample	4183±31	2880–2699 BC	2889–2666 BC
29255	24674	217, y2 113 100-120	Charcoal from soil sample	4327±26	3009–2897 BC	3013–2895 BC
29256	24675	218, y2 113-115	Charcoal from soil sample	4163±36	2873–2680 BC	2881–2630 BC
29257	24676	219, y2 113-90	Charcoal from soil sample	4125±26	2856–2631 BC	2866–2581 BC

For every sherd, there are up to four measurements. On some sherds, both the interior (i) and exterior (e) crust were sampled. Samples originating from the same sherd are shaded in the same colour. Furthermore, stable isotopes were measured both before and after chemical pretreatment. For radiocarbon dating, the samples need to be pretreated in order to remove contamination that could influence the ^{14}C age. However, stable isotopes on food crusts are often measured without pretreatment. Therefore, our values would be easier to compare to literature values if we did not pretreat our samples. To test the effect of pretreatment, we therefore measured both before and after.

SampleID	Name	δ^{13}C (‰ VPDB)	δ^{15}N (‰ AIR)	C:N atomic ratio	Carbon fraction	Nitrogen fraction	"old" δ^{13}C value	^{14}C age
28295 (i)	165 SHM 20862 y2 112c	−23.94	15.87	12.713	51.725	4.745	−24.3	GrA-16554: 4340±60
	pretreated	−24.51	13.04	11.58	50.63	5.17		
28296 (e)	166 SHM 20862 å2 110c	−24.83		38.791	45.57	1.37	−25	GrA-16557: 4290±60
	pretreated	−24.63	14.96	28.02	57.48	1.95		
28297 (i)	167 SHM 20862 å2 110c	−24.28	15.17	12.954	33.625	3.03		
	pretreated	−24.25	12.22	11.05	42.78	4.51		AAR-24250: 4395± 35
28298 (e)	168 SHM 20862 x2 126ab	−24.45		46.414	38.59	0.97	−25.1	GrA-16551 : 4320±60
	pretreated	−24.08	15.72	45.70	52.40	1.67		
28299 (i)	169 SHM 20862 x2 126ab	−24.51	14.86	12.679	22.985	2.115		
	pretreated	−25.09	10.24	10.061	43.11	4.81		AAR-24251: 4005±38
28300 (i)	170 SHM 20862 y2 113c and x2 114c	−24.43	15.32	15.177	29.27	2.25	−26	GrA-16555: 4280±60
	pretreated	−24.50	11.12	14.52	41.44	3.78		
28301 (e)	171 SHM 20862 y2 113c and x2 114c	−24.35	16.36	28.099	32.86	1.365		
	pretreated	−24.39	15.55	21.29	49.01	2.69		AAR-24252: 4280±33
28302 (i)	172 SHM 20862 x2 124c	−21.85	15.74	8.78	35.93	4.77	−19.7	GrA-16553: 4360±60
	pretreated	−22.34	13.22	8.83	36.77	4.92		

In those cases where both the pretreated and the untreated food crusts were analysed, the $\delta^{15}N$ values decreased due to the pretreatment. Apparently, components with high $\delta^{15}N$ values were removed. We cannot tell yet whether this is due to the removal of e. g. marine mammal fat, or removal of contamination. There is no systematic shift in $\delta^{13}C$ values that could support either conclusion.

Hällorna/Flykärr and Skee 45

Five samples from these sites in Bohuslän (Sweden) were submitted for stable isotope analysis. They had already been radiocarbon dated previously and $\delta^{13}C$ values were available for the samples from Hällorna/Flykärr. As they were not dated, they do not have AAR numbers, only SampleIDs.

SampleID	Name	$\delta^{13}C$ (‰ VPDB)	$\delta^{15}N$ (‰ AIR)	C:N atomic ratio	Carbon fraction	Nitrogen fraction	"old" $\delta^{13}C$ value	"old" ^{14}C age
28307 *Skee 45*	177 A8, Fnr 374 *pretreated*	−23.15 −24.53	16.77 23.55	14.327 39.958	26.215 20.64	2.135 0.6	−24.53	Ua-3738: 4355±65
28308 *Skee 45*	178 A1, Fnr 347 *pretreated*	−23.16 −24.42	15.35 23.14	10.22 14.2	30.135 9.25	3.44 0.76	−24.42	Ua-3736: 4155±60
28309 (i) *Hällorna/ Flykärr*	179 R2022, L7:2 *pretreated*	−24.39 −24.28	--- 16.91	28.474 40.68	24.58 27.08	1.015 0.76	−25.8	Ua-8632: 4045±60
28310 *Hällorna/ Flykärr*	180 R1829, L16:1 *pretreated*	−24.39 −24.36	12.19 10.63	14.561 12.72	32.145 49.89	2.605 4.98	−25.1	Ua-8631: 4645±55
28311 *Hällorna/ Flykärr*	181 R2025, L16:1 *pretreated*	−24.57 −25.62	13.97 ---	14.955 ---	14.09 3.22	1.1 0.25	−25.3	Ua-8633: 4210±60

Kainsbakke

From the Kainsbakke site, Djursland, eastern Jutland, 18 conventional radiocarbon dates were obtained from bones and molluscs in the 1980s. The dates range from c. 4000 to 2300 cal BC, most falling into the period 3000–2500 cal BC. A further 18 dates had been obtained on grains, seeds and straw from A47 and yielded ages between c. 3300 cal BC and modern. As a part of the CONTACT project, 18 new dates were measured on samples from the site ranging from c. 3500–2900 cal BC, the only exception being the varnish which had been used to conserve the human bone, and which was dated to around 23500 cal BC. Compared with the older measurements, the dates recently obtained form quite a large chronological span and yield generally older dates. This might be due to the presence of old material from the TRB occupation of the site, which was mixed with younger material due to the PWC activities in pit A47. Interestingly, the pits A2, A6, A56 and A64 only contain material from c. 2900 to c. 2300 cal BC. It is therefore possible that these pits only contain PWC material.

The fact that entire large bones or several shells were needed for a conventional radiocarbon date is generally regarded as a disadvantage of this technique. However, the small samples of bone, shell, charcoal or grain, which are datable with AMS radiocarbon dating, bear a much larger risk of redeposition than the large bones used for conventional dating. Furthermore, when several shells had to be collected for one conventional radiocarbon date, a single too young or too old shell would make almost no difference to the dating result.

We do not know how the conventional bone and mollusk samples were pretreated prior to dating, and if the pretreatment really removed all contamination. Especially the bone samples could be contaminated with younger material. However, as the dates on both materials, bones and molluscs, are consistent, one might judge that the risk of contamination is small.

SID	AAR	Sample name	Description	^{14}C age	$\delta^{13}C$	$\delta^{15}N$	Cal. Age (1σ range)	Cal. Age (2σrange)
24321	21424	DJM 1900 x2649	Human bone (maxilla)	4464±28	−19,35	11,51	3326–3034 BC	3336–3024 BC
24321	21424	DJM 1900 x2649	Varnish from human bone	21170±150			23736–23401 BC	23872–23232 BC
26919	23038	DJM1900 x2908	Oyster shell, innermost layer	4822±36			3651–3536 BC	3694–3522 BC
26920	23039	DJM1900x2854	Oyster shell, innermost layer	4951±30			3651–3536 BC	3695–3522 BC
26921	23040	DJM1900x2847–2	Cattle bone	4430±38	−23.04	6.41	3309–2938 BC	3331–2922 BC
29786	25132	DJM1900x2908-B	Oyster shell, outermost layer	4625±28			3496–3362 BC	3511–3351 BC
29787	25133	DJM1900x2854-B	Oyster shell, outermost layer	4914±27			3702–3568 BC	3762–3644 BC
24572	21674	DJM 1900 X781	Charred wheat grain	4195±28	−25.93		2883–2706 BC	2891–2678 BC
24573	21675	DJM 1900 X1348	Charred barley grain	4228±35	−24.3		2899–2765 BC	2908–2698 BC
24574	21676	DJM 1900 X5481	Charred barley grain	4482±28	−24.67	5.89	3329–3098 BC	3341–3034 BC
24575	21677	DJM 1900 X5486	Charred barley grain	4324±31	−27.27		3010–2895 BC	3019–2891 BC
24576	21678	DJM 1900 X5492	Charred grain – emmer/spelt	4630±32	−22.32		3498–3363 BC	3516–3352 BC
24577	21679	DJM 1900966,5/ 465 fase VII	Charred wheat grain	2192±26	−22.85		354–202 BC	361–186 BC
29408	24757	DJM1900 X4693	Food crust, pit A47 phase III	4465±29	−24.01	13.55	3327–3036 BC	3337–3024 BC
29409	24758	DJM1900 X4696	Food crust, pitA47 phase III	4249±31	−24.34	5.80	2906–2874 BC	2916–2709 BC
29410	24759	DJM1900 X4725	Food crust, pitA47 phase III	3924±31	−23.22	10.25	2473–2348 BC	2488–2298 BC
29411	24760	DJM1900 X4735	Food crust, pit A47 phase IV	4260±29	−23.93	10.54	2904–2881 BC	2920–2765 BC
29412	24761	DJM1900 X5063	Food crust, pitA47 phase VI	4439±29	−21.80	10.65	3311–3019 BC	3330–2931 BC

Kirial Bro

Three new dates on charred cereal grains from Kirial Bro, on Djursland, were measured in the project.

SID	AAR	Sample name	Description	^{14}C age	$\delta^{13}C$	$\delta^{15}N$	Cal. Age (1σ range)	Cal. Age (2σ range)
24578	21680	DJM 1930 X989	Charred barley grain	4299±26	−24.53		2916–2893 BC	3010–2880 BC
24579	21681	DJM 1930 X1157A	Charred wheat grain	4363±28	−23.96		3011–2920 BC	3085–2907 BC
24580	21682	DJM 1930 X1157B	Charred barley grain	4319±27	−23.74	5.23	3005–2894 BC	3012–2891 BC

Lyse

Stable isotopes were measured on four food residues from Lyse (Bohuslän, Sweden). One of them was also dated.

SampleID	Name	δ13C (‰ VPDB)	δ15N (‰ AIR)	C:N atomic ratio	Carbon fraction	Nitrogen fraction	"old" δ13C value	14C age
28303 (i)	173 Lyse 13b, UM 28017	−24.61	16.12	12.73	18.795	1.725	−25.2	Ua-10636: 4140±70
	pretreated	−24.40	10.62	9.45	12.41	1.51		
28304 (e)	174 Lyse 13b, UM 28017	−24.21	16.9	15.31	28.825	2.195		
	pretreated	−23.89	12.52	12.23	19.12	1.83		AAR-24253: 4248±28
28305 (i)	175 Lyse 13c, UM 28018	−24.91	19.99	24.008	39.715	1.93	−24.6	Ua-10635: 4290±70
	pretreated	−24.63	16.51	20.25	45.54	2.55		
28306 (i)	176 Lyse 13d-s, UM 28019	−23.17	19.53	11.876	25.00	2.46	−22.9	Ua-10634: 4405±80
	pretreated	−22.90	17.18	11.65	32.81	3.67		

The δ13C values of these samples are terrestrial, some with a small marine influence. However, the δ15N values are very high and would indicate aquatic, in this case freshwater, food. The chemical pretreatment decreases the δ15N values of the food crusts. There is a tendency that δ13C values increase slightly, but the effect is not large enough to allow for any firm conclusions.

Olas (Halland) and Roligheda (Norway)

From each of these Pitted Ware sites, one additional sample was dated for the CONTACT project. However, the pine charcoal from Olas is much older than the Pitted Ware culture and was probably already present in the soil when the Pitted Ware occupation started. The antler from Roligheda was a surface find and is apparently not associated with the Pitted Ware culture either.

SID	AAR	Sample name	Description	14C age	Stdev14C age	Cal. Age (1σ range)	Cal. Age (2σ range)
26794	22910	Olas2, Halland, Sweden, djup 112 cm	Charcoal – *Pinus*	6728	39	5701–5618 BC	5717–5564 BC
26795	22911	C59635, Roligheda, Grimstad	Antler	225	38	AD 1644-…	AD 1525-…

Trönninge (Halland) and Fiskevik (Bohuslän)

From each of the sites Trönninge and Fiskevik, two food crust samples have been dated. Stable isotope analysis was performed both on the usual pretreated material, i. e. the base-insoluble fraction, and on the base-soluble fraction, to assess which substances are removed by the base.

SID	AAR	Name	δ13C (CF-CN)	δ15N (CF-CN)	C:N (TCD)	C% (TCD)	N% (TCD)	14C age
28314	**24148**	**HM 25000 F19-20 Tron 479**						
	base-insoluble, weighted mean		**–25.75**	**15.82**	**13.213**	**29.854**	**2.638**	4385±26
	base-soluble, weighted mean		**–24.99**	**7.79**	**10.356**	**44.475**	**4.995**	
28315	**24149**	**HM 25000 F63-64 tron 501**						
	base-insoluble, weighted mean		**–24.19**	**12.27**	**10.462**	**38.608**	**4.309**	4333±28
	base-soluble, weighted mean		**–24.25**	**10.85**	**9.288**	**42.87**	**5.37**	
28316	**24150**	**SHM 15104: A10: 1 FIS 429 1171702**						
	base-insoluble, weighted mean		**–25.55**	**12.96**	**17.143**	**42.366**	**2.883**	4377±27
	base-soluble, weighted mean		**–25.41**	**6.55**	**10.022**	**47.925**	**5.575**	4127±29
28317	**24151**	**Bo. Fiskevik 15104: K9 1171703 FIS 428**						
	base-insoluble, weighted mean		**–23.86**	**15.27**	**12.849**	**38.29**	**3.473**	4389±33
	base-soluble, weighted mean		**–21.32**	**11.49**	**10.497**	**46.99**	**5.215**	

Discussion and results

The radiocarbon dates from the Pitted Ware sites span quite a long period of time with outliers at both ends of the spectrum c. 4000–2000 cal BC clearly reflecting pre- and post-Pitted Ware activities on these sites (Figure 4). The colours of the data points on figure 4 indicate the median of the probability density function of the calibrated age. Secure dates, e. g. those on terrestrial material clearly associated with a Pitted Ware occupation, or dates on bones and food residues that are corrected for reservoir effects, are indicated by circles that scale with probability. The larger the circle on a time slice, the greater the probability of the calibrated age to fall within this period. Uncertain dates, e. g. uncorrected bone and food residue dates or charcoal not clearly associated with Pitted Ware activities, are indicated by crosses and are thus barely visible when compared with the solid circles. The bulk of dates fall within the early 3rd millennium BC, c. 3000–2500 cal BC with a concentration between c. 3000 and 2800 cal BC. However, from c. 3300 cal BC and lasting to c. 2300–2200 cal BC, we see the full distribution of Pitted Ware sites stretching from central eastern Sweden, Gotland, southern Sweden, western Sweden, south-eastern Norway and eastern Jutland.

In order to calculate the most likely dates for the beginning and ending of the Pitted Ware horizon in Scandinavia, we have modelled the 737 reliable radiocarbon dates in OxCal as one phase. In the model, we have specifically allowed for uncertainties such as old wood effect making charcoal samples too old and the possibility of the youngest dates being the result of intermixing of younger material. However, obvious outliers have been omitted (cf. Appendix). With these reservations included in the model, the Scandinavian Pitted Ware horizon can be dated to c. 3400–2200 cal BC. Figure 5 displays sum distributions for the different regions within the Pitted Ware area.

It is interesting to note that the radiocarbon dates do not show any clear gradual spread of the Pitted Ware phenomenon from one region to another. Although the very earliest Pitted Ware dates seem to derive from central eastern Sweden, dates appear almost equally early in eastern and western Sweden and Denmark. However, the earliest dates from Denmark seen on Figure 4 (represented by Ginnerup and Kainsbakke) clearly derive from

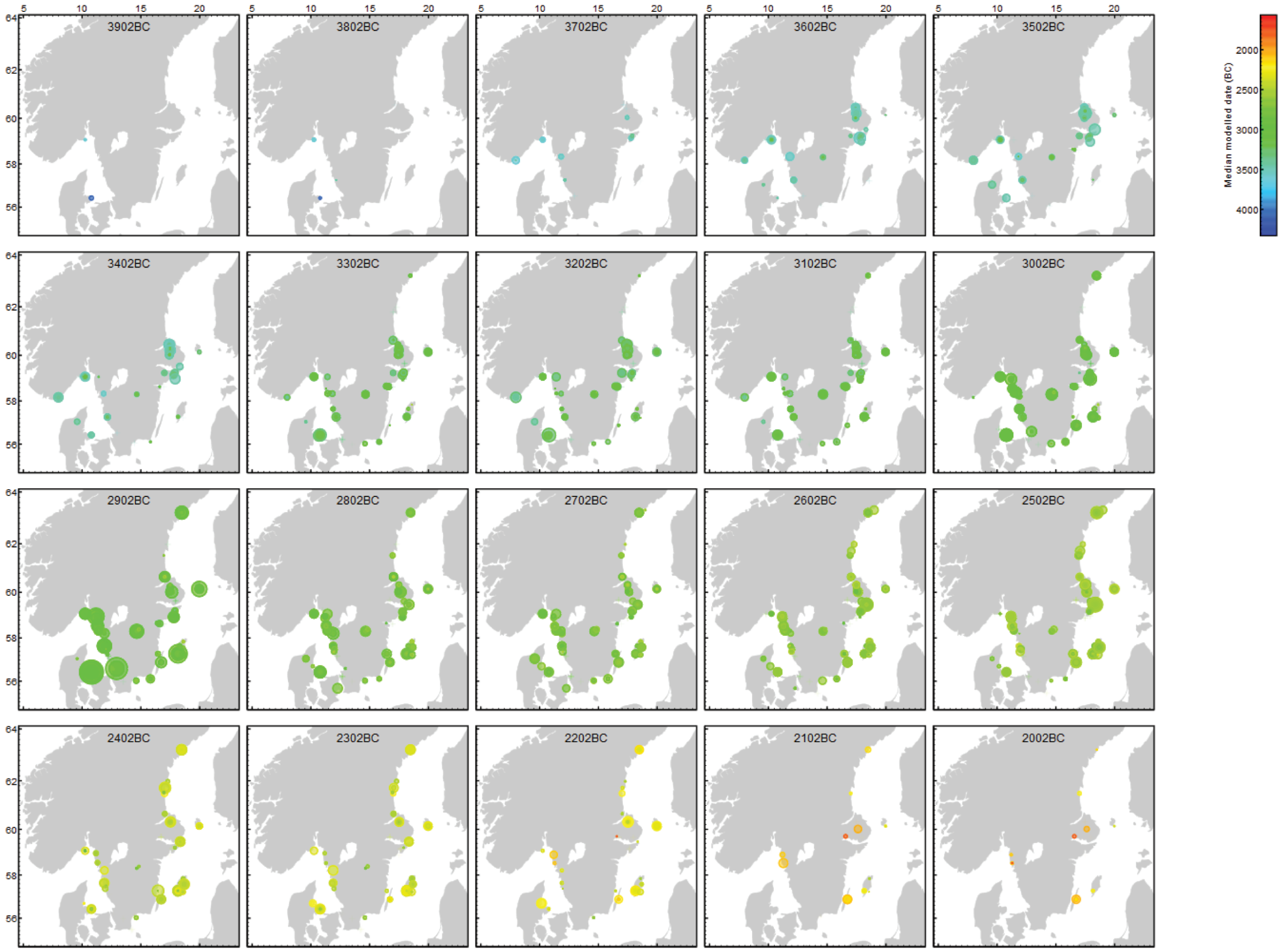

Fig. 4: Maps showing the calibrated radiocarbon dates of PWC sites for 100 yr – timeslices between 3900 cal BC and 2000 cal BC. The circles are coloured according to their median date. The entire probability distribution of the sites or individual dates can extend beyond the century of the median date. Therefore, different colours can appear on the same time slice. The circle size indicates the relative height of the probability distribution at a given time. The background map shows the present coastline. During the PWC, however, the sea level especially in the North was much higher, so that all but two of the Swedish sites had been coastal sites. The maps were made with OxCal 4.3 (Bronk Ramsey 2009). The dates were calibrated using the terrestrial calibration curve IntCal13, the marine calibration curve Marine13 (Reimer *et al.* 2013), or a combination of both in cases of mixed carbon sources, using the local DR whenever available from the literature

older Funnel Beaker phases on the two sites (cf. above). Still, the new Pitted Ware radiocarbon dates from Ginnerup support a relatively early occurrence of the phenomenon in Denmark from c. 3100 cal BC as also indicated by the otherwise questionable MN II contact find from Selbjerg.

The fact that Pitted Ware dates in Denmark appear to be nearly as early as those in eastern Sweden indicates a relatively rapid spread (estimated 300 years) of the Pitted Ware phenomenon. This picture could of course be seen as an indication that C. J. Becker was right in his old hypothesis that the occurrence of the Pitted Ware culture in north-eastern Denmark reflects short stays by Swedish Pitted Ware groups, who came to Denmark to exploit the rich flint deposits[73]. However, this idea has been rejected in a recent study[74].

Another possibility is that the Middle Neolithic contacts, and consequently the spread of ideas and people, were more intensive than hitherto recognised. This is supported by the rapid spread of the Pitted Ware phenomenon throughout Southern Scandinavia (Figure 5). We know that an intensive distribution of flint took place in the Late Neolithic (LN I, c. 2350–1950 cal BC) in the form of flint daggers. From the flint rich areas of southern Scandina-

73 Becker 1951, 243–244.
74 Klassen *et al.* 2020.

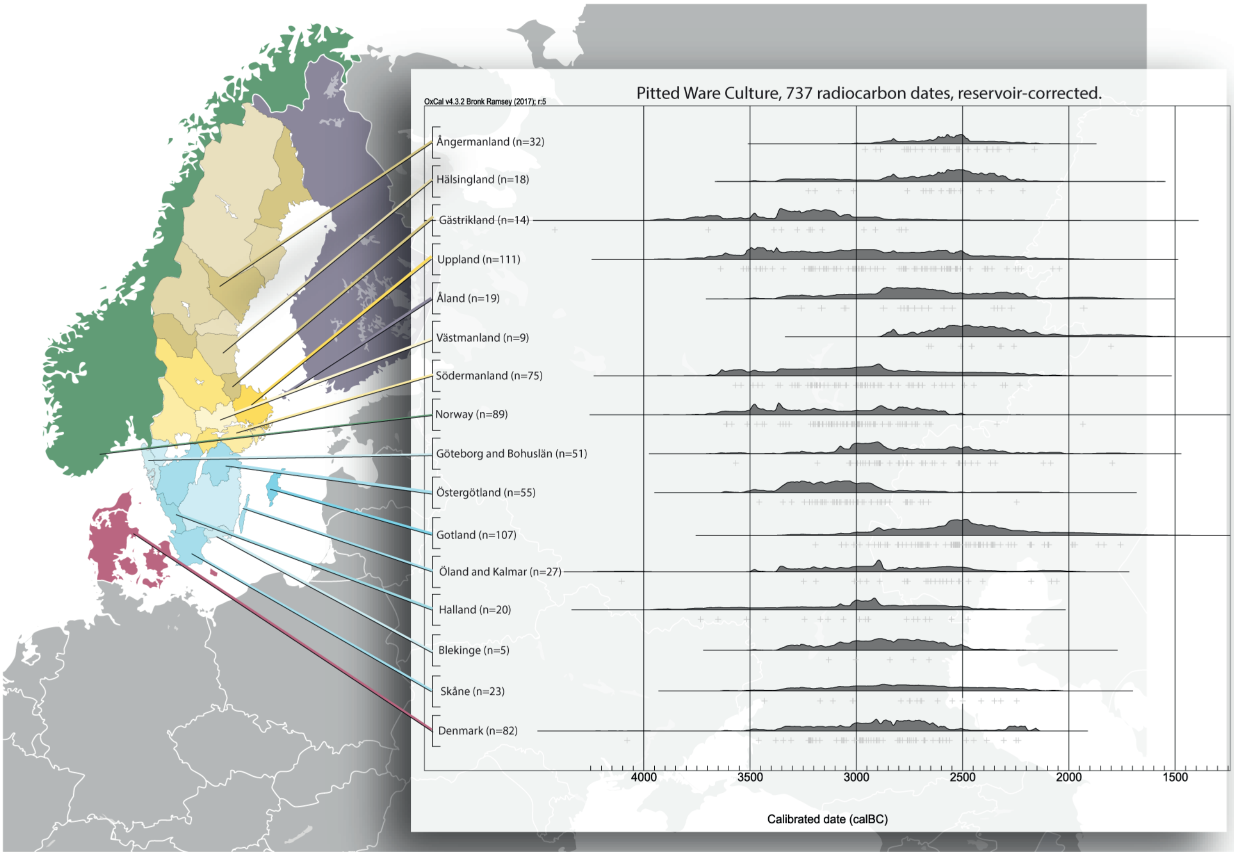

Fig. 5: Calibrated radiocarbon dates of Pitted Ware Culture sites. For every region, a sum distribution was calculated. Grey crosses under the sum distributions indicate the median values of the individual calibrated radiocarbon ages. The dates were calibrated with OxCal 4.3.2 (Bronk Ramsey 2017), using the terrestrial calibration curve IntCal13, the marine calibration curve Marine13, or an appropriate combination of the two (Reimer *et al.* 2013)

via, the core areas supposedly being northern Jutland, the Danish isles and southwestern Scania, flint was exported to eastern and western Sweden and Norway[75]. This export of good quality South Scandinavian flint to the northern parts of the Scandinavian Peninsula, which lack natural flint deposits, was not a new phenomenon in the Late Neolithic but rather part of a very long tradition stretching back to the Early Neolithic. The Early Neolithic point-butted flint axes and the Early Neolithic/early Middle Neolithic thin-butted flint axes are distributed throughout the Scandinavian Funnel Beaker area showing that wide distribution networks stretching up to 700 kilometres were established within the early Funnel Beaker North Group[76]. However, the far-reaching exchange networks also existed in the later Middle Neolithic after the cease of the Funnel Beaker culture. This is in particular evident from a number of large hoards containing up to 175 unpolished, semi-finished thick-butted adzes and chisels located along the coast of Norrland in the county of Västerbotten, northeastern Sweden. The large quantity of Zealand Senonian flint used in the production of the adzes indicates that they derive from eastern south Scandinavia, probably Stevns on eastern Zealand, as also indicated by new energy-dispersive x-ray fluorescence (EDXRF) analyses. Thus, the hoards are located 1500 kilometres from the natural flint deposits in southern Scandinavia[77].

It is very plausible that the northeastern Swedish hoards were the result of Pitted Ware contacts as proposed by Becker since tanged arrowheads (type C) and cylindrical blade cores are included in some hoards[78]. Besides, some tanged flint arrowheads (type B and C) and polished flint axes are present in Pitted Ware graves from Gotland[79].

75 Apel 2001.
76 E.g. Sundström 2003, 143–159; Sørensen 2014a, 162–169; 175–176 figs. V.05; V.44.
77 Becker 1953; Malmer 1962, 506–528; Olausson *et al.* 2012.
78 Becker 1953; Knutsson 1986.
79 Wennersten 1909; Stenberger 1943; Janzon 1974, 295 plate 24.

Furthermore, Pitted Ware flint arrowheads can sometimes occur in abundant numbers on sites in western Sweden and southern Norway[80].

From the short review of the flint exchange presented above, it becomes clear that long existing networks connected southern Scandinavia with eastern and western Sweden and southern Norway during the entire Neolithic. The distribution of the Pitted Ware phenomenon in southern Scandinavia is in overall means in accordance with the distribution of natural flint deposits. Thus, it is obvious to link the occurrence of the Pitted Ware in southern Scandinavia with wide-ranging flint exchange networks through which people and alternative 'sub-Neolithic' lifeways rapidly spread to Neolithic southern Scandinavia from eastern central Sweden[81].

As indicated by more aDNA studies, the east central Swedish Pitted Ware groups (samples mainly collected from inhumation burials on Gotland and Öland) differ genetically from the Funnel Beaker groups. Whereas the Pitted Ware people were genetically related to Mesolithic hunter-gatherers from Scandinavia (a mix of western and eastern hunter-gatherers), Funnel Beaker individuals show genetic affiliation with contemporaneous central European Middle Neolithic and Chalcolithic farmers and the preceding early Neolithic Linear Pottery Culture (LBK)[82].

Unfortunately, we do not have graves clearly related to the Pitted Ware phenomenon in southern Scandinavia and consequently we are lacking the genetic profile of the Pitted Ware people in this region[83]. However, it is highly unlikely that there should be any direct connection in southern Scandinavia between the local Mesolithic Ertebølle people and the up to 900 years younger Pitted Ware culture, even if there could have been a certain coexistence and admixture between Mesolithic hunter-gatherer groups and early farmers as shown in other parts of Neolithic Europe[84]. Considering the genetic profile of the East Swedish Pitted Ware, it is most reasonable to assume that the emergence of the phenomenon happened in areas where Mesolithic hunter-gatherer groups continued to exist right up to the emergence of the Pitted Ware horizon. This could have happened in western Sweden/southern Norway or, more likely, in central eastern Sweden where we see some of the earliest substantial concentrations of Pitted Ware radiocarbon dates (cf. Figure 4).

Based on the presented radiocarbon dates and the recent studies of Pitted Ware genetics, it seems plausible that we should expect an early emergence of the Pitted Ware culture in eastern central Sweden around 3400 cal BC. Then, the phenomenon spread via the well-established flint exchange routes to southern Scandinavia and western Sweden and southern Norway within a few centuries. Shortly thereafter, the coastal areas of central-northern Sweden, inland Sweden (Alvastra) as well as the island of Gotland were settled by Pitted Ware communities (Figure 4). The Pitted Ware hunters, fishers and gatherers presumably died out or were assimilated into the population that eventually lead to present-day Scandinavians[85]. This would most likely have happened during the early Late Neolithic around, or shortly after, 2200 cal BC. From this period, genetic data from Ölsund, northeastern Sweden, have provided evidence for the influence of both the early Neolithic and Late Neolithic/Early Bronze Age genomic expansions to have reached northern Sweden[86]. Thus, the beginning of the end of the Pitted Ware phenomenon could very likely have been the 're-Neolithization' of the Pitted Ware areas and the further expansion of agriculture northwards that took place on the Scandinavian Peninsula at the beginning of the Late Neolithic, c. 2350 cal BC (2600–2200 cal BC)[87].

Conclusion

This paper is based on the hitherto largest collection of radiocarbon dates from the Pitted Ware culture. More than 900 radiocarbon dates have been collected and reassessed from various Pitted Ware sites across Scandinavia and, when necessary and possible, corrected for error sources such as reservoir effects. By looking at all the reliable dates (737) we have been able to show that the Pitted Ware phenomenon occurred within a few centuries across Scandinavia during the later 4th millennium BC with a supposed beginning around 3400 cal BC. Supported by the recent year's research on the East Swedish Pitted Ware genetics showing clear affiliation with European Mesolithic hunter-gatherers, we propose that the Pitted Ware phenomenon emerged in eastern central Sweden at the northern fringes of the Funnel Beaker culture. The rapid

80 Persson 1998; Hernek 2007; Munkenberg 2007; Østmo 2008, 81–83; Iversen 2016.
81 Iversen 2010, 2011.
82 Malmström *et al.* 2009; Skoglund *et al.* 2012; Skoglund *et al.* 2014; Malmström *et al.* 2015; Mittnik *et al.* 2018; Fraser 2018; Malmström *et al.* 2019.
83 But see Philippsen *et al.* 2020.
84 E.g. Lipson *et al.* 2017; Jensen *et al.* 2019
85 Cf. Malmström *et al.* 2009; Malmström *et al.* 2015.
86 Mittnik *et al.* 2018.
87 E.g. Prescott 1996; 2009; 2014; Sørensen 2014b. See also Vanhanen *et al.* 2019 for local PWC adaption of agriculture.

spread of the Pitted Ware can be explained as a result of participation in well-established flint exchange networks connecting the flint-rich areas of southern Scandinavia with the flint-lacking areas on the Scandinavian Peninsula. At the beginning of the Late Neolithic, or shortly thereafter, probably c. 2200 cal BC, the Pitted Ware tradition ceased and was either outcompeted by, or assimilated into, the population that lead to the present-day Scandinavians as a result of the Late Neolithic agrarian expansion northwards.

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References

Adamsen/Ebbesen (Eds) 1986: C. Adamsen/K. Ebbesen, Stridsøksetid i Sydskandinavien. Beretning fra et symposium 28.–30.X.1985 i Vejle. Ark. Skr. 1 (København 1986).

Almgren 1906: O. Almgren, Uppländska stenåldersboplatser. Fornvännen 1, 1906, 1–19 and 101–118.

Amundsen 2000: Ø. M. Amundsen, Neolitikum i Agder og Telemark. En komparativ analyse av keramikk og flintøkser. Unpublished 'hovedfagsoppgave i nordisk arkeologi' Universitetet i Oslo (Oslo 2000).

Apel 2001: J. Apel, Daggers, Knowledge and Power. The Social Aspects of Flint-Dagger Technology in Scandinavia 2350–1500 cal BC. Coast to coast books 3 (Uppsala 2001).

– *et al.* 2018: –/P.Wallin/J. Storå/G. Possnert, Early Holocene human population events on the island of Gotland in the Baltic Sea (9200–3800 cal. BP). Quaternary International 465 Part B, 2018, 276–286.

Artursson 1996: M. Artursson (Ed.), Bollbacken. En sen gropkeramisk boplats och ett gravfält från äldre järnålder (1996).

Bagge 1952: A. Bagge, Fagervik. Ein Rückgrat für die Periodeneinteilung der Ostschwedischen Wohnplatz- und Bootaxtkulturen aus dem Mittelneolithikum. Acta Arch. XXII (1951), 1952, 57–118.

–/Kjellmark 1939: –/K. Kjellmark, Stenåldersboplatserna vid Siretorp i Blekinge (Stockholm 1939).

Bakka 1973: E. Bakka, Gropkeramisk kultur og gropkeramiske kulturelement i Sør-Noreg. In: P. Simonsen/G. S. Munch (Eds), Bonde – Veidemann. Bofast – ikke bofast i nordisk forhistorie. Tromsø Mus. Skr. XIV (Tromsø 1973) 74–82.

Becker 1947: C. J. Becker, Mosefundne Lerkar fra yngre Stenalder. Studier over Tragtbægerkulturen i Danmark. Aarb. Nord. Oldkynd. og Hist. 1947, 1–318.

– 1951: –, Den grubekeramiske kultur i Danmark. Aarb. Nord. Oldkynd. og Hist. (1950), 1951, 153–274.

– 1953: –, Die Nordschwedischen Flintdepots. Ein Beitrag zur Geschichte des Neolithischen Fernhandels in Skandinavien. Acta Arch. XXIII, 1952, 31–79.

– 1955a: –, Die Mittelneolithischen Kulturen in Südskandinavien. Acta Arch. XXV (1954), 1955, 49–150.

– 1955b: –, Stenalderbebyggelsen ved Store Valby i Vestsjælland. Problemer omkring tragtbægerkulturens ældste og yngste fase. Aarb. Nord. Oldkynd. og Hist. 1954, 127–204.

– 1974: –, Studien zu Neolithischen Flintbeilen. Methodische Probleme – Neue Formen und Varianten der Dicknackigen Beile innerhalb der Trichterbecherkultur – Chronologische Probleme. Acta Arch. XLIV (1973), 1974, 125–186.

– 1982: –, Om grubekeramisk kultur i Danmark. Korte bidrag til en lang diskussion (1950 – 1980). Aarb. Nord. Oldkynd. og Hist. 1980, 13–33.

Bengtsson 1998: L. Bengtsson/R. Hernek/G. Johansson, Timmerås och Hällorna/Flykärr: boplatsundersökningar i mellersta Bohuslän: arkeologiska undersökningar för motorvägen Lerbo-Torp, del 3, Arkeologiska resultat/UV Väst, 1104–8069; 1998/6 (Kungsbacka 1998).

Bergsvik 2006: K. A. Bergsvik, Ethnic Boundaries in Neolithic Norway. BAR Internat. Ser. 1554 (Oxford 2006).

Björck 2004: M. Björck, Måsta, Rislyck och Vithällan. Tre neolitiska kustboplatser 2005/3, Länsmuseet Gävleborgs rapportserie (Gävleborg 2004).

– *et al.* 2005: –/M. Persson/B. Ulfhielm, Södra Mårtsbo. En neolitisk kustboplats. Arkeologisk undersökning, RAÄ 397, Valbo socken, Gästrikland, 1993 2004/14, Rapport – Länsmuseet Gävleborg (2005).

Björck 1999: N. Björck, Gropkeramiska boplatser i norra Uppland: en inventering av neolitiska kustboplatser 1997 1999:11, Länsstyrelsens meddelandeserie (Uppsala Län 1999).

– 2000: –, Västeräng: arkeologisk undersökning Valbo socken, Gästrikland (Huddinge 2000).

– *et al.* 1998: –/C. Hällström/T. Sandstedt, Fräkenrönningen: en "by" för 5000 år sedan: en gropkeramisk boplats: arkeologisk undersökning, E4:an, RAÄ 399, Valbo socken, Gästrikland, Rapport – Länsmuseet i Gävleborgs län, 0281–3181; 1998/14 (Gävle 1998).

–/Hjärthner-Holdar 2008: –/E. Hjärthner-Holdar, Mellan hav och skog. Högmossen, en stenåldersmiljö vid en skimrande strand i norra Uppland 6, 6, Riksantikvarieämbetet (Uppsala 2008).

–/Larsson 2005: –/F. Larsson, Snåret. Aspekter på sten-, brons- och järnålder i Vendel. Väg E4, sträckan Uppsala–Mehedeby Uppland, Vendels socken, Fallsboda 1:2, Karby 29/5, RAÄ 291, Dnr 422-1399-2003 och 423-2325-2003 2005:14, UV GAL (Uppsala 2005).

Bjørkli 2005: B. Bjørkli, Den arktiske steinalder i sør. En studie av skiferfunn fra Sørøst-Norge, Oldsakssamlingens Museumsdistrikt (Diss. Universitetet i Bergen 2005).

Bramstång/Ortman 2006: C. Bramstång/O. Ortman, Stenålder och gropkeramik i Anfasteröd, Bohuslän. Bohuslän, Ljung socken, Anfasteröd 1:114, 1:115, 1:163 och 1:164, RAÄ 71 2006: 26, UV VÄST RAPPORT – ARKEOLOGISK UNDERSÖKNING (Mölndal 2006).

Bronk Ramsey 2009: C. Bronk Ramsey, Bayesian analysis of radiocarbon dates. Radiocarbon 51/1, 337–360.
– 2017: –, Methods for Summarizing Radiocarbon Datasets. Radiocarbon 59/2, 1809–1833.
Browall 1986: H. Browall, Alvastra pålbyggnad – social och ekonomisk bas 15, Theses and Papers in North-European Archaeology. Akad. avhandl. för filosof. doktoreks. 1986 (Stockholm 1986)
– 2011: –, Alvastra pålbyggnad. 1909–1930 års utgrävningar. Handlingar, Ant. Ser. 48 (Stockholm 2011).
– 2016: –, Alvastra pålbyggnad. 1976–1980 års utgrävningar. Västra schaktet. Handlingar, Ant. Ser. 52 (Stockholm 2016).
Carlie 1986: A. Carlie, Om gropkeramisk kultur i Skåne, speciellt Jonstorp. In: C. Adamsen/K. Ebbesen (Eds), Stridsøksetid i Sydskandinavien. Ark. Skr. 1 (København 1986) 156–164.
Claesson 2015: P. Claesson, En gropkeramisk boplats i norra Bohuslän. Arkeologisk undersökning, Skee 45, Ånneröd 2:8, Skee socken, Strömstads kommun, Uppdragsarkeologiska rapporter. Bohusläns mus. Rapport (Uddevalla 2015).
Damm 1989: C. B. Damm, Stendyngegrave i enkeltgravstid. In: L. Larsson (Ed.) Stridsyxekultur i Sydskandinavien. Report Ser. 36 (Lund 1989) 89–101.
Darmark *et al.* 2010: K. Darmark/M. Guinard/N. Stenbäck, Sofiedal 11 – En mellanneolitisk boplats i södra Gästrikland 2010:9, 2010:9, Societas Archaeologica Upsaliensis, http://www.sau.se/wp-content/uploads/2016/04/2010_9-sofiedal.pdf (Uppsala 2010).
Davidsen 1975: K. Davidsen, Tragtbægerkulturens slutfase. Nye C 14 dateringer. Kuml 1973–74, 165–178.
– 1977: –, Stenalderbopladsen på Lilleborg', Bornholmske Samlinger II/11,1975, 9–22.
– 1978: –, The Final TRB Culture in Denmark. A settlement Study. Ark. Stud. V (København 1978).
– 1982: –, Undergravstid på de danske øer, Aarb. Nord. Oldkynd. og Hist. 1980, 38–51.
Dörfler 2008: W. Dörfler, Des 3. Jahrtausend v. Chr. in hoch auflösenden Pollendiagrammen aus Norddeutschland. In: W. Dörfler/J. Müller (Eds), Umwelt – Wirtschaft – Siedlungen im dritten vorchristlichen Jahrtausend Mitteleuropas und Südskandinaviens. Offa-Bücher 84 (Neumünster 2008) 135–148.
Ebbesen 1975: K. Ebbesen, Die jüngere Trichterbecherkultur auf den dänischen Inseln. Ark. Stud. II (København 1975).
– 1982: –, Enkeltgravskulturen – 100 år efter opdagelsen, Aarb. Nord. Oldkynd. og Hist. 1980, 52–72.
– 2006: –, The Battle Axe Period (København 2006).
Edenmo *et al.* 1997: R. Edenmo/M. Larsson/B. Nordqvist/E. Olsson, Gropkeramikerna – fanns de? Materiell kultur och ideologisk förändring. In: M. Larsson/Olsson (Eds), Regionalt och inter-regionalt. Stenåldersundersökningar i Syd- och Mellansverige. Ark. Under. Skr. 23 (Stockholm 1997) 135–213.
Ekholm 1929: G. Ekholm, De uppländska boplatsfynden kring Bålinge mossar, Fornvännen 24, 1929, 1–18.
Eriksson 2004: G. Eriksson, Part-time farmers or hard-core sealers? Västerbjers studied by means of stabile isotope analysis. Journal Anthrop. Arch. 23, 2004, 135–162.
– *et al.* 2008–/A. Linderholm/E. Fornander/M. Kanstrup/P. Schoultz/H. Olofsson/K. Lidén, Same island, different diet: Cultural evolution of food practice on Öland, Sweden, from the Mesolithic to the Roman Period. Journal Anthrop. Arch. 27, 2008, 520–543.
Fabricius/Becker 1996: K. Fabricius/C. J. Becker, Stendyngegrave og Kulthuse. Studier over Tragtbægerkulturen i Nord- og Vestjylland. Ark. Stud. XI (København 1996).
Fornander *et al.* 2008: E. Fornander/G. Eriksson/K. Lidén, Wild at heart: Approaching Pitted Ware identity, economy and cosmology through stable isotopes in skeletal material from the Neolithic site Korsnäs in Eastern Central Sweden. Journal Anthrop. Arch. 27, 2008, 281–297.
Fraser 2018: M. Fraser, People of the Dolmens and Stone Cists. An archaeological investigation of megalithic graves from the Neolithic period on Gotland. AUN 47 (Uppsala 2018).
Färjare/Olsson 2000: A. Färjare/E. Olsson, Lill-Mosjön – boplat-slämningar och fångstgropar från neolitikum,äldre järnålder och historisk tid. Ångermanland, Grundsunda socken, Banafjäl 1:10 och 21:1, RAÄ 345:1–2 och 356 (Hägersten 2000).
Gebauer 1988: A. B. Gebauer, Stylistic variation in the pottery of the Funnel beaker Culture. In: T. Madsen (Ed.), Multivariate Archaeology. Numerical Approaches in Scandinavian Archaeology. Jutland Arch. Soc. Publ. XXI (Højbjerg 1988) 91–117.
Gheorghiu 2009: D. Gheorghiu, Early Farmers, Late Foragers, and Ceramic Traditions: On the Beginning of Pottery in the Near East and Europe (Cambridge 2009).
Giersing 2004: T. Giersing, Et mellemneolitisk palisadeanlæg ved Helgeshøj, Østsjælland. Aarb. Nord. Oldkynd. og Hist. 2001, 7–34.
Glob 1945: P. V. Glob, Studier over den jyske enkeltgravskultur. Aarb. Nord. Oldkynd. og Hist. 1944, 1–283.
Granath Zillén 2001: G. Granath Zillén, Besökt och återbesökt: stenålders- och bronsåldersplats vid Myrstugeberget: arkeologisk undersökning. väg 259 Södermanland, Huddinge socken, Masbo 1:8 och Myrstugeberget 2, RAÄ 331, Rapport/UV Mitt, 1403–9044; 2001/8 (Stockholm 2001).
Gustafsson *et al.* 2000: P. Gustafsson/T. Jakobsson Holback/P. Lindholm/H. Runesson, En gropkeramisk boplats och järnålderslämningar vid Lindskrog. Arlanda flygplats tredje landningsbanan, Riksantikvarieämbetet (2000).
Güthlein 1996: A. Güthlein, Neolitisk keramik i Hälsingland. En jämförande studie av keramikmate-rialet från RAÄ 127, 129 och 130 i Jättendal sn samt RAÄ 68 i Enånger sn (Hedningahällan). Neolithic pottery in Hälsingland. A comparative study of pottery from Raä 127, 129 and 130 in Jättendal parish and Raä 68 in Enånger parish (Hedningahällan). UMARC (Umeå 1996).
Hallgren 2004: F. Hallgren, Trössla, efterundersökning av en grustagen trattbägarboplats i östra Södermanland. Överåda 3:1, RAÄ nr 270, Trosa – Vagnhärad socken, Södermanland. Soc. Arch. Upsaliensis (Uppsala 2004).
– 2011: –, Om gropkeramik och dess relation till äldre keramikhant-verkstraditioner kring Östersjön. In: P. Bratt/R. Grönwall (Eds), Gropkeramikerna. Ark. i Stockholms län 6 (Stockholm 2011) 31–43.
Hedemark *et al.* 2000: Å. Hedemark/C. Samuelsson/N. Ytterberg, Stenåldersboplatsen vid Hemmor i ny belysning, Gotländskt arkiv 2000, 7–28.
Hennius 2011: A. Hennius, Sotmyra. Återbesök på en gropkeramisk boplats. Sotmyra 1:1, Raä 251:1, Skuttunge socken, Uppland. Upplandsmus. rapporter 2011.

Hernek 1995: R. Hernek, Två neolitiska fångstboplatser vid Viskafjordens mynning. Ark. resultat, UV Väst Rapport 1995/12 (Kungsbacka 1995).

– 2007: –, Sandhem. Presentation och tankar kring en nyfunnen kökkenmödding. In: M. Lönn/P. Claesson (Eds), Vistelser vid vatten. Gropkeramiska platser och kokgropar från bronsålder och järnålder. Riksantikvarieämbetet Ark. Unders. Skr. 69 (Uddevalla 2007) 179–230.

Holback *et al.* 2004: T. Holback/P. Lindholm/H. Runeson, Bjästamon – Ett kustbundet boplatskomplex från slutet av neolitikum. Bottniabanan, Västernorrland. Ångermanland, Nätra socken, Bjästa 55:1, Eriksgården 1:1m.fl.; RAÄ 307, RAÄ 318 och RAÄ 321Dnr 423-1944-2001, 423-1493-2002 (Hägersten 2004).

Holm 1997: L. Holm, Neolitisk keramik i södra Norrlands kustland – inte bara Hedningahällan. In: A. Åkerlund/S. Bergh/ J. Nordbladh/J. Taffinder (Eds), Til Gunborg. Ark. samtal (Stockholm 1997) 237–252.

– 2003: –, Contacts in the Bothnian region: the Neolithic site Hedningahällan in regional and interregional contexts, in: Uniting sea: Stone Age societies in the Baltic Sea region. Proceedings from the first Uniting Sea Workshop at Uppsala University, Sweden, January 26–27, 2002 (2003) 89–102.

Hübner 2005: E. Hübner, Jungneolithische Gräber auf der Jütischen Halbinsel. Typologische und chronologische Studien zur Einzelgrabkultur. Nordiske Fortidsminder, Ser. B 24 (København 2005).

Indrelid 1994: S. Indrelid, Fangstfolk og bønder i fjellet. Bidrag til Hardangerviddas førhistorie 8500–2500 år før nåtid. Univ. Oldsaksamlings Skr., Ny rekke 17 (Oslo 1994).

Ingstad 1970: A. S. Ingstad, Steinalderboplassen Rognlien i Eidanger. Et bidrag til belysning av yngre steinalder i Telemark 1967–1968, Universitetets Oldsaksamling. Årbok (1970).

Isaksson 2000: M. Isaksson, Forskning i Platons skuggvärld? Om kulturteori och variation i neolitiskt källmaterial utifrån analys av tidigare forskning och organiska beläggningar på gropkeramik från Jonstorp, Jonstorp sn, Skåne [CD-uppsats i laborativ arkeologi]. (Stockholm 2000).

Iversen 2010: R. Iversen, In a World of Worlds. The Pitted Ware Complex in a Large Scale Perspective. Acta Arch. 81, 2010, 5–43.

– 2011: –, Den grubekeramiske kontakt. In: L. Appel/K. Langsted (Eds), Ressourcer og Kulturkontakter. Arkæologi rundt om Skagerrak og Kattegat. Kulturhist. Skr. fra Nordsjælland 1 (Helsingør 2011) 9–18.

– 2015: –, The Transformation of Neolithic Societies. An Eastern Danish Perspective on the 3rd Millennium BC. Jutland Arch. Soc. Publ. 88 (Højbjerg 2015).

– 2016: –, Arrowheads as indicators of interpersonal violence and group identity among the Neolithic Pitted Ware hunters of southwestern Scandinavia. Journal Anthr. Arch. 44(A), 2016, 69–86.

Janzon 1974: G. O. Janzon, Gotlands Mellanneolitiska Gravar. Stud. in North-European Arch. 6 (Stockholm 1974).

Jensen 2001: J. Jensen, Stenalder 13.000–2.000 f. Kr. Danmarks Oldtid 1 (København 2001).

Jensen et al. 2019: T. Z. T. Jensen/J. Niemann/K. H. Iversen/ A. K. Fotakis/S. Gopalakrishnan/Å. J. Vågene/M. W. Pedersen/ M.-H. S. Sinding/M. R. Ellegaard/M. E. Allentoft/L. T. Lanigan/ A. J. Taurozzi/S. H. Nielsen/M. W. Dee, M. N. Mortensen/ M. C. Christensen/S. A. Sørensen/M. J. Collins/M. T. P. Gilbert/ M. Sikora/S. Rasmussen/H. Schroeder, A 5700 year-old human genome and oral microbiome from chewed birch pitch. Nature Communications 10 (5520), 2019, 1–10.

Johansson 2005: Å. Johansson, En gropkeramisk boplats och ett gravfält från äldre järnålder. Uppland, Norrsunda socken, Starrmossen 1/1, RAÄ 209 (Hägersten 2005).

Jørgensen 1977: E. Jørgensen, Hagebrogård – Vroue – Koldkur. Neolithische Gräberfelder aus Nordwest-Jutland. Ark. Stud. IV (København 1977).

Kaelas 1973: L. Kaelas, Den gropkeramiska kulturen vid den svenska västkusten – bofast eller ej. In: P. Simonsen/G. S. Munch (Eds), Bonde – Veidemann. Bofast – ikke bofast i nordisk forhistorie. Tromsø Mus.Skr. XIV (Tromsø 1973) 62–74.

Kihlstedt 2016: B. Kihlstedt, Tråsättra – en gropkeramisk boplats. Arkeologisk förundersökning. RAÄ Österåker 553, Tråsättra 1:14, Österåker socken och kommun, Stockholms län, Uppland (Västerås 2016).

Kihlstedt *et al.* 2007: B. Kihlstedt/H. Larsson/H. Runeson, Sittesta – en gropkeramisk boplats på Södertörn. Utbyggnad av Väg 73, delen Hammarbacken–Nyfors. Södermanland, Ösmo socken, Sittesta 1:17 och 1:6, RAÄ 68. Dnr 423-1874-2005 (Hägersten 2007).

Kihlstedt *et al.* 1997: B. Kihlstedt/M. Larsson/B. Nordqvist, Neolitiseringen i Syd-, Väst- och Mellansverige: ekonomisk och ideologisk förändring, in: E. O. M Larsson (Ed.), Regionalt och interregionalt: stenåldersundersökningar i Syd- och Mellansverige (Stockholm 1997) 85–134.

Kjær 1920: H. Kjær, Nordisk Archæologmøde i Kjøbenhavn 1919. Aarb. Nord. Oldkynd. og Hist. 1920, 1–62.

Klassen (Ed.) 2020: L. Klassen, The Pitted Ware Culture on Djursland: Supra-regional significance and contacts in the Middle Neolithic of southern Scandinavia. East Jutland Mus. Publ. 5 (Aarhus 2020).

Klassen *et al.* 2020: L. Klassen/R. Iversen/N. N. Johannsen/ O. Poulsen/U. L. Rasmussen, The Pitted Ware culture on Djursland in the Neolithic world. In: L. Klassen (Ed.), The Pitted Ware Culture on Djursland: Supra-regional significance and contacts in the Middle Neolithic of southern Scandinavia. East Jutland Mus. Publ. 5 (Aarhus 2020).

Knutsson 1986: K. Knutsson, Några arbetsidéer i samband med bearbetningen av Bjurselet-fynden. In: C. Adamsen/K. Ebbesen (Eds), Stridsøksetid i Sydskandinavien. Ark. Skr. 1 (København 1986), 253–265.

Larsson 1982: L. Larsson, A Causewayed Enclosure and a Site with Valby Pottery at Stävie, Western Scania. Meddel. från Lunds Univ. Hist. Mus. 1981–82, 65–107.

– (Ed.) 1989: –, Stridsyxekultur i Sydskandinavien. Rapport från det andra nordiska symposiet om Stridsyxetid i Sydskandinavien 31. X –2. XI 1988. Report Ser. 36 (Lund 1989).

– 1992: –, Settlement and environment during the Middle Neolithic and late Neolithic. In: L. Larsson/J. Callmer/B. Stjernquist (Eds), The archaeology of the cultural landscape: field work and research in a South Swedish rural region (Stockholm 1992) 91–159.

Larsson 2004: M. Larsson, Living in cultural diversity. The Pitted Ware Culture and its relatives. Journal of Nordic Arch. Scien. 14, 61–69.

– 2006: –, A Tale of a Strange People. The Pitted Ware Culture in Southern Sweden. Kalmar Stud. in Arch. 2 (Lund 2006).

Larsson *et al.* 2014: M. Larsson/G. Lemdahl/K. Lidén, Paths Towards a New World. Neolithic Sweden (Oxford 2014).
Larsson 2009: Å. M. Larsson, Breaking & Making Bodies and Pots. Material and Ritual Practices in Sweden in the Third Millennium BC. AUN 40 (Uppsala 2009).
Lepsikaar 1983: J. Lepsikaar, Animal Remains from the Mesolithic Bog Site at Ageröd V in Central Scania. In: Ageröd V – An Atlantic Bog Site in Central Scania (Lund 1983).
Lidén 1940: O. Lidén, Sydsvensk Stenålder II. Strandboplatserna i Jonstorp (Lund 1940).
Lidén 1996: K. Lidén, A dietary perspective on Swedish hunter-gatherer and Neolithic populations: An analysis of stable isotopes and trace elements. Laborativ Ark. 9, 1996, 5–23.
Lindberg/Brorsson 2006: K.-F. Lindberg/T. Brorsson, Glädjen Rast- och jaktplatser från tidigneolitikum till bronsålder. Väg E4, sträckan Uppsala Mehedeby. Uppland, Tierps socken, Tierps Allmänning S:1, RAÄ 86 (2006).
Lindqvist 2004: A.-K. Lindqvist, Kornsjövägen – boplatslämning med hus från yngre stenålderi Västernorrlands kustland. Ångermanland, Nätra socken, Bjästa 5:9 m.fl., RAÄ 306Dnr 423-1944-2001 (Hägersten 2004).
Lindqvist/Possnert 1997: C. Lindqvist/G. Possnert, The subsistence economy and diet at Jakobs/Ajvide, Eksta parish and other prehistoric dwelling and burial sites on Gotland in long-term perspective 1(1997).
Lipson *et al.* 2017: M. Lipson/A. Szécsényi-Nagy/S. Mallick/ A. Pósa/B. Stégmár/V. Keerl/N. Rohland/ K. Stewardson/ M. Ferry/M. Michel/J. Oppenheimer/N. Broomandkhoshbacht/E. Harney/ S. Nordenfelt/B. Llamas/B. Gusztáv Mende/K. Köhler/K. Oross/M. Bondár/T. Marton/A. Osztás/ J. Jakucs/T. Paluch/F. Horváth/P. Csengeri/J. Koós/K. Sebők/ A. Anders/P. Raczky/J. Regenye/J. P. Barna/S. Fábián/ G. Serlegi/Z. Toldi/E. Gyöngyvér Nagy/J. Dani/E. Molnár/ G. Pálfi/L. Márk/B. Melegh/Z. Bánfai/L. Domboróczki/ J Fernández-Eraso/J. Antonio Mujika-Alustiza/C. Alonso Fernández/J. Jiménez Echevarría/R. Bollongino/J. Orschiedt/ K. Schierhold/H. Meller/A. Cooper/J. Burger/E. Bánffy/ K. W. Alt/C. Lalueza-Fox/W. Haak/D. Reich, Parallel palaeogenomic transects reveal complex genetic history of early European farmers. Nature 551, 2017, 368–372.
Madsen *et al.* 1900: A. P.Madsen/S.Müller/C. Neergaard/ C. G. J. Petersen/E. Rostrup/K. J. V. Steenstrup/H. Winge, Affaldsdynger fra Stenalderen i Danmark Undersøgte for Nationalmuseet (København 1900)
Malmer 1962: M. P. Malmer, Jungneolithische Studien. Acta Arch. Lundensia, Ser. in 8° 2 (Lund 1962).
– 1969: –, Gropkeramiksboplatsen Jonstorp RÄ. Antikv. Arkiv. Kugl. Vitterhets Hist. och Ant. Akedemien 36 (Stockholm 1969).
– 2002: –, The Neolithic of South Sweden. TRB, GRK, and STR (Stockholm 2002).
Malmros 1980: C. Malmros, Den tidlige enkeltgravskultur og stridsøksekultur. Oplæg til en diskussion. Aarb. Nord. Oldkynd. og Hist. 1979, 62–68.
Malmros/Tauber 1977: C. Malmros/H. Tauber, Kulstof-14 dateringer af dansk enkeltgravskultur. Aarb. Nord. Oldkynd. og Hist. 1975, 78–95.
Malmström *et al.* 2009: H. Malmström/M. T. P. Gilbert/ M. G. Thomas/M. Brandström/J. Storå/P. Molnar/ P. K. Andersen/C. Bendixen/G. Holmlund/A. Götherström/ E. Willerslev, Ancient DNA Reveals Lack of Continuity between Neolithic Hunter-Gatherers and Contemporary Scandinavians. Current Biology 19 (20), 2009, 1758–1762.
– *et al.* 2015: –/A. Linderholm/P. Skoglund/J. Stora/P. Sjodin/ M. T. P. Gilbert/G. Holmlund/E. Willerslev/M. Jakobsson/ K. Liden/A. Gotherstrom, Ancient mitochondrial DNA from the northern fringe of the Neolithic farming expansion in Europe sheds light on the dispersion process. Phil. Transactions of the Royal Soc. B 370 (1660), 2015, 1–10.
– *et al.* 2019: –/T. Gunther/E. M. Svensson/A. Juras/M. Fraser/ A. R. Munters/L. Pospieszny/M. Torv/J. Lindstrom/A. Gotherstrom/J. Stora/M. Jakobsson, The genomic ancestry of the Scandinavian Battle Axe Culture people and their relation to the broader Corded Ware horizon. Proc. Biol. Sci. 286, 2019, 1–8.
Marseen 1953: O. Marseen, Fangstfolk på Selbjerg. Kuml 1953, 102–20.
– 1963: –, Smedegårde og Livø. Grubekeramiske bopladser ved Limfjorden. Kuml 1962, 123–43.
Mathiassen 1944: T. Mathiassen, The Stone-Age Settlement at Trelleborg. Acta Arch. XV, 1944, 77–98.
Midgley 1992: M. S. Midgley, TRB Culture. The First Farmers of the North European Plain (Edinburgh 1992).
Mikkelsen 1989: E. Mikkelsen, Fra jeger til bonde. Utviklingen av jordbrukssamfunn i Telemark i steinalder og bronsealder 11, Universitetets oldsaksamlings skrifter. Ny rekke (Oslo 1989).
Mittnik *et al.* 2018: A. Mittnik/C.-C. Wang/S. Pfrengle/M. Daubaras/G. Zariņa/F. Hallgren/R. Allmäe/V. Khartanovich/ V. Moiseyev/M. Tõrv/A. Furtwängler/A. Andrades Valtueña/ M. Feldman/C. Economou/M. Oinonen/A. Vasks/ E. Balanovska/D. Reich/R. Jankauskas/W. Haak/S. Schiffels/ J. Krause, The genetic prehistory of the Baltic Sea region. Nature Communications 9 (442), 2018, 1–11.
Munkenberg 2007: B.-A. Munkenberg, De gropkeramiska boplatsernas miljö. In: M. Lönn/P. Claesson (Eds), Vistelser vid vatten. Gropkeramiska platser och kokgropar från bronsålder och järnålder. Riksantikvarieämbetet Ark. Unders. Skr. 69 (Uddevalla 2007) 105–47.
Müller 1888: S. Müller, Stenalderen. Ordning af Danmarks Oldsager I (Paris, Kjøbenhavn, London, Leipzig 1888).
– 1918: –, Stenalderens Kunst i Danmark. Oldtidens Kunst i Danmark I (København 1918).
Nielsen 1979: P. O. Nielsen, De tyknakkede flintøksers kronologi. Aarb. Nord. Oldkynd. og Hist. 1977, 5–71.
– 1993; –, Yngre stenalder. In: S. Hvass/B. Storgaard (Eds), Da klinger i muld … 25 års arkæologi i Danmark (Århus 1993) 84–87.
Nielsen *et al.* 2014: P. O. Nielsen/F. O. S. Nielsen/S. I. Hansen/ H. Paulsen/M. S. Thorsen, Solstensøen. På sporet af Bornholms bondestenalder (Rønne 2014).
Nielsen 1979: S. Nielsen, Den grubekeramiske kultur i Norden samt nogle bemærkninger om flækkepilespidserne fra Hesselø. Antikv. Stud. 3, 23–48.
Nilsson 2006: M.-L. Nilsson, Brännpussen: en mellanneolitisk kustboplats. Väg E4, Uppsala-Mehedeby: Uppland, Tensta socken, Tensta-Forsa 1:4, RAÄ 436. Arkeologisk förundersökning och särskild arkeologisk utredning (Uppsala 2006).
Noe-Nygaard 1988: N. Noe-Nygaard, δ^{13}C-values of dog bones reveal the nature of changes in man's food resources at the mesolith-

ic-neolithic transition, Denmark. Chemical Geology: Isotope Geoscience section 73 (1), 1988, 87–96.
Nordell/Swedberg 2003: L. Nordell/S. Swedberg, Vid Starekilens stränder: arkeologiska undersökningar av boplatserna Skee 53 och 54 (Uddevalla 2003).
Nordqvist *et al.* 2009: B. Nordqvist/L. Jonsson/G. Johansson, En neolitisk kökkenmödding och en omgivande unik boplats: en sjudagars förundersökning/schacktövervakning av en kökkenmödding med benredskap och ett smycke, och en omgivande unik boplats med hyddbottnar och eldstäder, allt från yngre delen av mellanneolitikum, Bohuslän, Skee socken, Ånneröd 1:17 med flera, Skee 42 2009: 12, UV Väst Rapport (2009).
Olausson *et al.* 2012: D. Olausson/R. E. Hughes/A. Högberg, A New Look at Bjurselet. The Neolithic flint axe caches from Västerbotten, Sweden: Using non-destructive energy dispersive x-ray fluorescence analysis for provenance determination. Acta Arch. 83, 2012, 83–103.
Olsson 1997: E. Olsson, Nivå, kronologi och samhälle. Om östsvensk gropkeramik, SAR 33, 1997, 441–453
– *et al.* 1994: –/G. Granath Zillén/A. Mohr, Korsnäs: en gropkeramisk grav- och boplats på Södertörn. Södermanland, Grödinge socken, RAÄ 447: arkeologisk undersökning, Rapport/UV Stockholm, 1104-5728; 1994:63 (Stockholm 1994).
Olstlund 1957: H. G. Ostlund, Stockholm Natural Radiocarbon Measurements I, Science 126, 1957, 493–497.
Palmgren/ Martinsson-Wallin 2015: E. Palmgren/H. Martinsson-Wallin, Analysis of late mid-Neolithic pottery illuminates the presenceof a Corded Ware Culture on the Baltic Island of Gotland. Doc. Praehist. 42, 2015, 297–310.
Papmehl-Dufay 1998/1999: L. Papmehl-Dufay, Myten om gropkeramikerna: Klassificering och analys av neolitisk keramik från Vendel 1:1, Vendel sn, Uppland (Diss. Stockholms Univ. Stockholm 1998/1999).
– 2006: –, Shaping an identity: Pitted Ware pottery and potters in southeast Sweden (Diss. Institutionen för arkeologi och antikens kultur Stockholm 2006).
Persson 1998: P. Persson, Gropkeramikfenomenet på den svenska västkusten. In Situ. Västsvensk Ark. Tidskr. 1998, 63–84.
– 1999: –, Neolitikums början. Undersökningar kring jordbrukets introduktion i Nordeuropa. Coast to coast books 1 (Göteborg 1999).
– 2005: –, Fortsatta arkeologiska undersökningar vid Olas, Värö socken Raä nr 202, i juni 2002 54, Kust till kust-projektet. Gotarc Serie D. Ark. Rapporter (Göteborg 2005).
Philippsen *et al.* 2020: B. Philippsen/R. Iversen/L. Klassen, The Pitted Ware culture chronology on Djursland: New evidence from Kainsbakke and other sites. In: L. Klassen (Ed.), The Pitted Ware Culture on Djursland: Supra-regional significance and contacts in the Middle Neolithic of southern Scandinavia. East Jutland Mus. Publ. 5 (Aarhus 2020).
Possnert 2002: G. Possnert, Stable and radiometric carbon results from Ajvide, in: G. Burenhult (Eds), Remote Sensing, vol. II. Applied Techniques for the Study of Cultural Respurces and the Localization, Identification and Documentation of Sub-surface Prehistoric Remains in Swedish Archaeology (Hässleholm 2002) 169–172.
Prescott 1996: C. Prescott, Was there really a Neolithic in Norway? Antiquity 70 (267), 77–87.
– 2009: – History in prehistory – the later Neolithic/Early Metal Age, Norway. In: H. Glørstad/C. Prescott (Eds), Neolithisation as if history mattered. Processes of Neolithisation in North-Western Europe (Lindome 2009) 193–215.
– 2014: –, A synthesis of the history of third millennium north-western Scandinavia. In: H.C. Gulløv (Ed.), Northern Worlds – landscape, interactions and dynamics. PNM: Stud. in Arch. & Hist. 22 (Copenhagen 2014) 449–462.
Rasmussen 1984: L. W. Rasmussen, Kainsbakke A47: A Settlement Structure from the Pitted Ware Culture. Journal Danish Arch. 3, 1984, 83–98.
– 1986a: –, Forholdet mellem grubekeramisk kultur og enkeltgravskulturen i Danmark In: C. Adamsen/K. Ebbesen (Eds), Stridsøksetid i Sydskandinavien. Ark. Skr. 1 (København 1986) 165–168.
– 1986b: –, Nye C^{14} dateringer for grubekeramisk kultur i Danmark. In: C. Adamsen/K. Ebbesen (Eds), Stridsøksetid i Sydskandinavien. Ark. Skr. 1 (København 1986) 211–212.
– 1991: –, Kainsbakke. En kystboplads fra yngre stenalder. In: L. W. Rasmussen (Ed.), Kainsbakke (Grenaa 1991) 9–69.
– 1993: –, Grubekeramiske bopladser. In: S. Hvass/B. Storgaard (Eds), Da klinger i muld … 25 års arkæologi i Danmark (Århus 1993) 114–15.
– 2000: –, Kirial Bro – mellem fangere og bønder. In: S. Hvass (Ed.), Vor skjulte kulturarv. Arkæologien under jordoverfladen. Til Hendes Majestæt Dronning Margrethe II. 16. april 2000 (Esbjerg 2000) 52–53.
Rasmussen 1999: K. L. Rasmussen, 14C-dateringer, København 1998. In: Sekretariat RA (Ed.), Arkæologiske udgravninger i Danmark 1998 (København 1999) 310–26.
Rasmussen 2000: U. L. Rasmussen, Ajstrup Krat. En grubekeramisk køkkenmødding ved Mariager Fjord. Unpubl. MA thesis (Aarhus Univ. 2000).
– 2020: –, Four minor Pitted Ware culture sites on Djursland: Their individual character and function. In: L. Klassen (Ed.), The Pitted Ware Culture on Djursland: Supra-regional significance and contacts in the Middle Neolithic of southern Scandinavia. East Jutland Mus. Publ. 5 (Aarhus 2020).
Reimer *et al.* 2013: P. J. Reimer/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. J. 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, IntCal13 and Marine13 Radiocarbon Age Calibration Curves 0–50,000 Years cal BP. Radiocarbon 55/4, 1869–1887.
Resi 1998: H. G. Resi, ”Krukken i treet” Om nye funn fra grav og boplass på Kjølberg i Østfold, in: E. Østmo (Ed.), Fra Østfolds oldtid. Foredrag ved 25-årsjubileet for Universitetets arkeologiske stasjon Isegran (1998) 55–68.
Richter 1991: J. Richter, Aspects of the palaeoecology of neolithic man. In: L. W. Rasmussen (Ed.). Kainsbakke (Grenaa 1991) 71–127.
Rundkvist *et al.* 2004: M. Rundkvist/C. Lindqvist/K. Thorsberg, Barshalder 3 Rojrhage in Grötlingbo: a multi-component Neolithic shore site on Gotland (Stockholm 2004).
Runeson 2007: H. Runeson, Den goda ordningen. In: P. Gustafsson/ L. G. Spång (Ed.), Stenålderns stationer: arkeologi i

Botniabanans spår 2007 (Stockholm, Härnösand 2007) 71–115.
Ryberg 1994: E. Ryberg, Barnabroboplatsen. Arkeologisk undersökning av fornlämning 89, Lindbergs sn, Varbergs kn, Halland (Kungsbacka 1994).
Samuelsson/Ytterberg 2003: C. Samuelsson/N. Ytterberg, Uniting Sea (Uppsala 2003).
Segerberg 1999: A. Segerberg, Bälinge Mossar. Kustbor i Uppland under yngre stenåldern. AUN 26 (Uppsala 1999).
Segerberg *et al.* 1991: A. Segerberg/G. Possnert/B. Arrhenius/K. Lidén, Ceramic chronology in view of 14C datings. Laborativ Ark. 5, 1991, 83–91.
Siemen 2009: P. Siemen, Sen yngre stenalder i Sydvestjylland. Ark. Rapporter fra Esbjerg Mus. 4 (Esbjerg 2009).
Skoglund *et al.* 2012: P. Skogslund/H. Malmström/M. Raghavan/J. Storå/P. Hall/E. Willerslev/M. T. P. Gilbert/A. Götherström/M. Jakobsson, Origins and Genetic Legacy of Neolithic Farmers and Hunter-Gatherers in Europe. Science 336/6080, 2012, 466–469.
Skoglund *et al.* 2014: P. Skoglund/H. Malmström/A. Omrak/M. Raghavan/C. Valdiosera/T. Gunther/P. Hall/K. Tambets/J. Parik/K. G. Sjögren/J. Apel/E. Willerslev/J. Stora/A. Götherstrom/M. Jakobsson. 2014. Genomic Diversity and Admixture Differs for Stone-Age Scandinavian Foragers and Farmers. Science 344/6185, 2014, 747–750.
Skousen 2008: H. Skousen, Arkæologi i lange baner. Undersøgelser forud for anlæggelsen af motorvejen nord om Århus 1998–2007 (Højbjerg 2008).
Skaarup 1973: J. Skaarup, Hesselø – Sølager. Jagdstationen der südskandinavischen Trichterbecherkultur. Ark. Stud. I (København 1973).
– 1985: –, Yngre stenalder på øerne syd for Fyn. Meddel. fra Langelands Mus. (Rudkøbing 1985).
Stenbäck 2003: N. Stenbäck, Människorna vid havet. Platser och keramik på ålandsöarna perioden 3500 – 2000 f. Kr. 28. Stockholm Stud. Arch. (Stockholm 2003).
Stenberger 1943: M. Stenberger, Das Grabfeld von Västerbjers auf Gotland (Lund 1943).
Sterum 1978: N. Sterum, Nogle C-14-frie synspunkter på den Beckerske kontakthypotese. Svar på en "Efterskrift". Hikuin 4, 1978, 61–88.
Strinnholm 2001: A. Strinnholm, Bland säljägare och fårfarmare. Struktur och förändring i Västsveriges mellanneolitikum. Coast to coast books 4 (Uppsala 2001).
Sundström 2003: L. Sundström, Det hotade kollektivet. Neolitiseringsprocessen ur ett östmellansvenskt perspektiv. Coast to coast books 6 (Uppsala 2003).
– *et al.* 2006: –/K. Darmark/N. Stenbäck, Postboda 2 och 1. Säsongsboplatser med gropkeramik från övergången tidigneolitikum–mellanneolitikum i norra Uppland 10. SAU Skrifter (Uppsala 2006).
Sørensen 2014a: L. Sørensen, From Hunter to Farmer in Northern Europe. Migration and Adaptation during the Neolithic and Bronze Age. Acta Arch. 85/I, 2014.
– 2014b: –, Farmers on the move – The expansion of agrarian societies during the Neolithic and Bronze Age in Scandinavia. In: H. C. Gulløv (Ed.), Northern Worlds – landscape, interactions and dynamics. PNM: Stud. in Arch. & Hist. 22 (Copenhagen 2014) 463–489.
Tauber 1971: H. Tauber, Danske Kulstof-14 dateringer af arkæologiske prøver III. Aarb. Nord. Oldkynd. og Hist. 1970, 120–42.
– 1986: –, C^{14} dateringer af enkeltgravskultur og grubekeramisk kultur i Danmark. In: C. Adamsen/K. Ebbesen (Eds), Stridsøksetid i Sydskandinavien. Ark. Skr. 1 (København 1986) 196–204.
Thorsberg 2007: K. Thorsberg, Något om spån, cylindriska kärnor och mellanneolitikum, In: M. Lönn/P. Claesson (Eds), Vistelser vid vatten. Gropkeramiska platser och kokgropar från bronsålder och järnålder. Riksantikvarieämbetet Ark. Unders. Skr. 69 (Uddevalla 2007) 149–78.
Toreld 2003: A. Toreld, …och vad säger flintan? – fyndanalys över en gropkeramisk lägerplats. In: L. Nordell/S. Swedberg (Eds), Vid Starekilens stränder. Arkeologiska undersökningar av boplatserna Skee 53 och 54. Kulturhist. dokumentationer 12 (Uddevalla 2003) 29–46.
Vanhanen *et al.* 2019: S. Vanhanen/S. Gustafsson/H. Ranheden/N. Björck/M. Kemell/V. Heyd, Maritime Hunter-Gatherers Adopt Cultivation at the Farming Extreme of Northern Europe 5000 Years Ago. Scien. Rep. 9/4756, 2019, 1–11.
von Heland 1962: B. von Heland, Undersökningar vid Älby i Ösmo (Sörmlandsbygden 1962)-
Walli/Martinsson-Wallin 2016: P. Wallin/H. Martinsson-Wallin, Collective spaces and material expressions: ritual practice and island identities in Neolithic Gotland. In: G. Nash/A. Townsend (Eds), Decoding Neolithic Atlantic and Mediterranean Island Ritual (Oxford 2016) 1–15
Welinder 1971: S. Welinder, Överada – A Pitted Ware Culture Site in Eastern Sweden, Meddelanden från Lunds Universitets Historiska Museum 1969–1970, 1971, 5–98
– 1973: –, The Radiocarbon Age of the Pitted Ware Culture in Eastern Sweden, Meddelanden från Lunds Universitets Historiska Museum 1971–1972, 1973, 107–119.
Wennersten 1909: O. V. Wennersten, Boplats från stenåldern i Visby. Fornvännen 4, 1909, 198–212.
Wincentz 2020: L. Wincentz, Kainsbakke and Kirial Bro. The two main sites of the Pitted Ware culture on Djursland. In: L. Klassen (Ed.), The Pitted Ware Culture on Djursland: Supra-regional significance and contacts in the Middle Neolithic of southern Scandinavia. East Jutland Mus. Publ. 5 (Aarhus 2020).
Winther 1926: J. Winther, Lindø. En Boplads fra Danmarks Yngre Stenalder. Første Del (Rudkøbing 1926).
– 1928: –, Lindø. En Boplads fra Danmarks Yngre Stenalder. Anden Del (Rudkøbing 1928).
Wyszomirska 1975: B. Wyszomirska, Radiocarbon Dating of a Pitted/Comb Ware Complex from Noth East Europe. Meddel. från Lunds Univ. Hist. Mus. 1973–1974, 54–74.
– 1986a: –, The Nymölla Project. A Middle Neolithic Settlement and Burial Complex in Nymölla, North-East Scania'. Meddel. från Lunds Univ. Hist. Mus. 1985–1986, 115–138.
– 1986b: –, C^{14} dateringar för kulturerna i sverige. In: C. Adamsen/K. Ebbesen (Eds), Stridsøksetid i Sydskandinavien. Ark. Skr. 1 (København 1986) 205–10.
Ytterberg 2015: N. Ytterberg, Gropkeramisk boplats och gånggrift. Delundersökning av en boplats i ett VA-schakt. Arkeologisk förundersökning i form av schaktningsövervakning. Valla 98:1 och 489, Hövik 3:145, Valla socken, Tjörns kommun 2015: 28. Bohusläns mus. Rapport (2015).

Ytterberg *et al.* 2005: N. Ytterberg/T. Brorsson/K.-F. Lindberg/J. Storå, Djurstugan. Upplands första bönder? Väg E4, Uppsala-Mehedeby. Uppland, Tierps socken, Fors 1:6, RAÄ 346 (2005).
Österholm 1989: I. Österholm, Bosättningsmönstret på Gotland under stenåldern: en analys av fysisk miljö, ekonomi och social struktur 3, Theses and papers in archaeology (Stockholm 1989).
– 2008: –, Jakobs/Ajvide: Undersökningar på en gotländsk boplatsudde från stenåldern, Gotland Univ. Press Monogr. (Hässleholm 2008).
Østmo 1993: E. Østmo, Auve i Sandefjord – sanddynen, snorstempelkeramikken og C 14-dateringene. Viking: norsk ark. årb. 56, 1993, 37–64.
– 2007: –, Solbakken 3, Ystehede, Halden. Boplass med gropkeramisk materiale, in: I. Ystgaard/T. Heibreen (Eds), Arkeologiske undersøkelser 2001–2002 (2007) 77–88.
– 2008: –, Auve. En fangstboplass fra yngre steinalder på Vesterøya i Sandefjord. Norske Oldfunn XXVIII (Oslo 2008).
– 2010: –, The Cord Stamp in Neolithic Scandinavia. Acta Arch. 81, 2010, 44–71.
Åkerlund 1996: A. Åkerlund, Human Responses to Shore Displacement. Living by the Sea in Eastern Middle Sweden during the Stone Age 16 Ark. undersök., Skrifter (Stockholm 1996).
Aaris-Sørensen 2009: K. Aaris-Sørensen, Diversity and dynamics of the mammalian fauna in Denmark throughout the last glacial-interglacial cycle, 115–0 kyr BP. Fossils and Strata 57, 2009, 1–59.

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Appendix: Radiocarbon dates

Of the more than 900 radiocarbon dates collected for this study (from the literature as well as new measurements), 737 proved reliable enough to be included in the spatio-temporal analysis. We rejected those samples where crucial information was missing, e. g., the species in case of animal bones, or $\delta^{13}C$ values in the case of food crusts or the bones of humans and other omnivores. We also excluded samples that clearly are outliers, because they are too old or too young by millennia. However, we did not exclude samples that only appear to be a few centuries off, as we did not want to risk including a bias. Food crusts on pottery and bones of omnivores are reservoir-corrected for the proportion of marine resources that is indicated by their $\delta^{13}C$ values. We used the local isotopic endpoints as indicated by measurements on 100 % terrestrial and 100 % marine samples, as well as the local reservoir age. If possible, we used values from the same site. When those were not available, we used the values from the same province – or from a neighbouring province in cases of lacking baseline data.

Most radiocarbon dates for the Pitted Ware Culture (PWC) were obtained for sites in today's Sweden. Therefore, for the regional analysis, we divided Sweden into the historical units of 'landskap' (provinces). This proved to be a useful separation because, for many of the provinces, we have as many radiocarbon dates as for Denmark or Norway. This categorisation is also used in Figure 5 in the main paper, where the sum probability distributions are displayed in roughly geographical order, beginning with the northernmost. For comparability, we here use the same order for the sections about the different regions.

Ångermanland

32 radiocarbon dates for samples associated with the PWC from Ångermanland are regarded reliable enough to be included in the analysis. They are from the sites Bjästamon, Lil-Mosjön and Kornsjövägen[1].

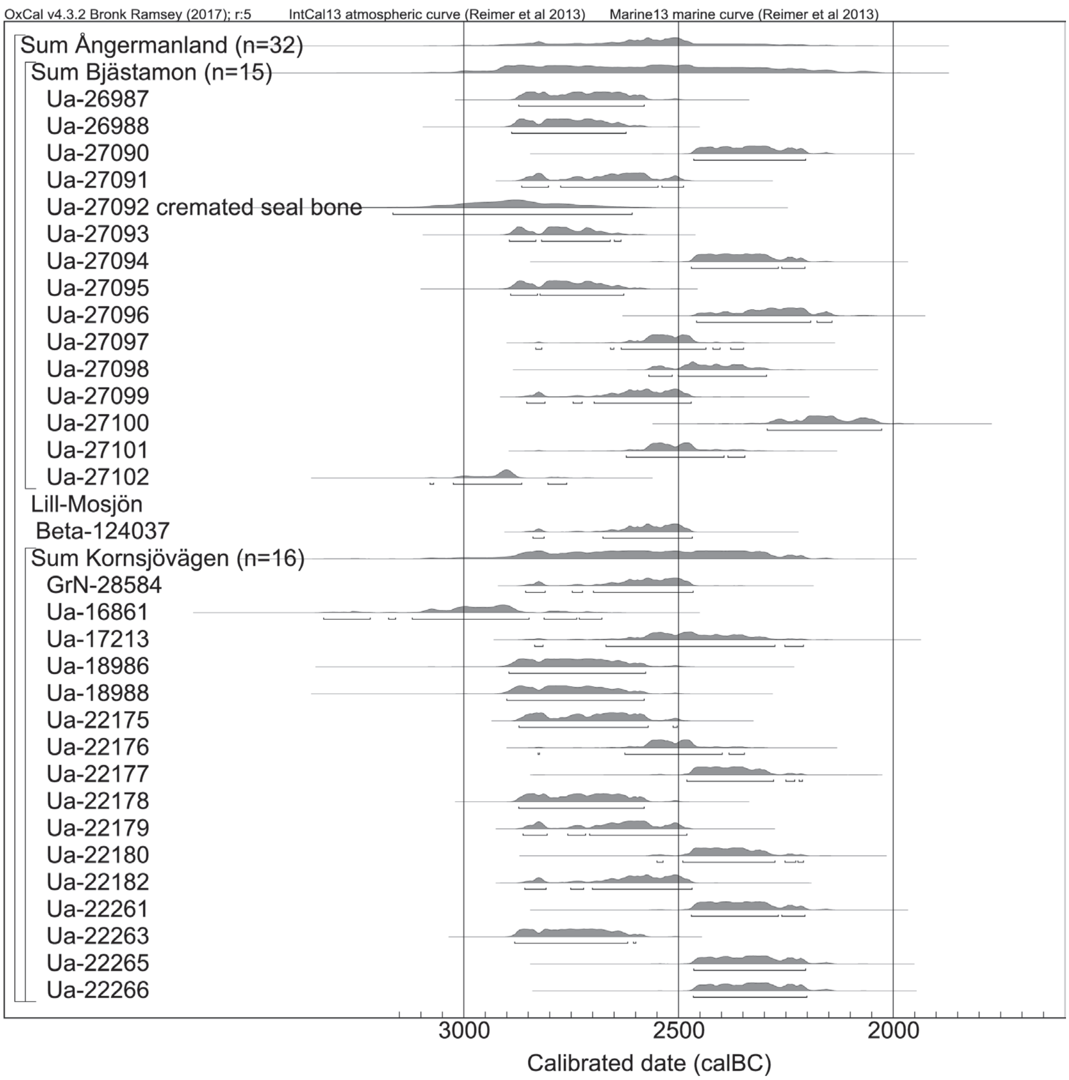

Fig. 1: Calibrated radiocarbon dates from sites in Ångermanland. For every site, a sum distribution is followed by the individual dates.

1 Färjare/Olsson 2000, 34; Holback *et al.* 2004, Bilaga 1; Lindqvist 2004, Bilaga 3, p. 97; Runeson 2007, 81, fig. 52.

Hälsingland

From Hälsingland, 18 reliable radiocarbon dates were available for our analysis. They derive from the sites Hedningahällan, Hög, Håcksta, Jättendal, Måsta, Rislycke, Vedmora, and Vässingmyran[2].

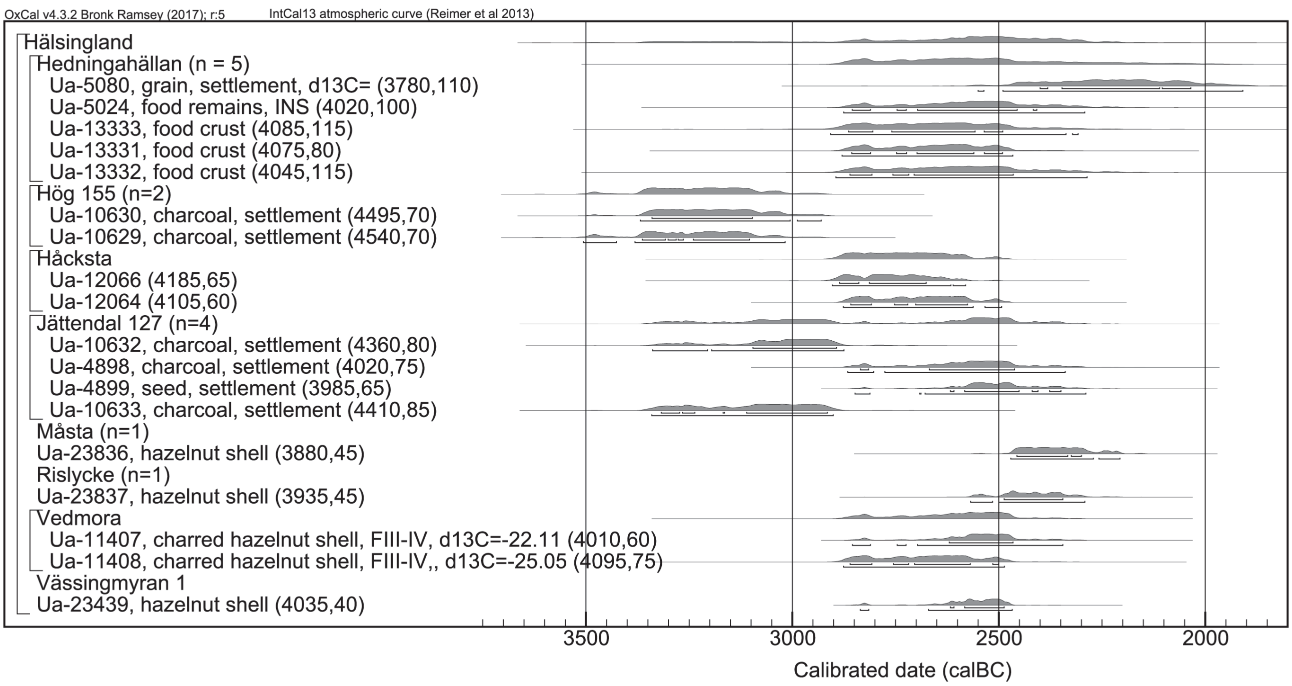

Fig. 2: Calibrated radiocarbon dates from sites in Hälsingland. For every site, a sum distribution is followed by the individual dates.

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2 Güthlein 1996; Holm 1997; Björck 1999, 41–42; Holm 2003, table 1; Björck 2004, 15).

Gästrikland

14 radiocarbon dates from Gästrikland were considered suitable for our analysis. The sites include Fräkenrönningen Valbo 339, Prästholmarna 2 Hille 252[3], Sofiedal 11 Valbo 478, Västeräng Gävle 300, and Södra Mårtsbo and Västra Mårtsbo, both Valbo 397[4]. The food crust sample from Västra Mårtsbo is from an imported asbestos tempered pot of the Kierikki tradition of central Finland, which was found in a Middle Neolithic context in Västra Mårtsbo[5].

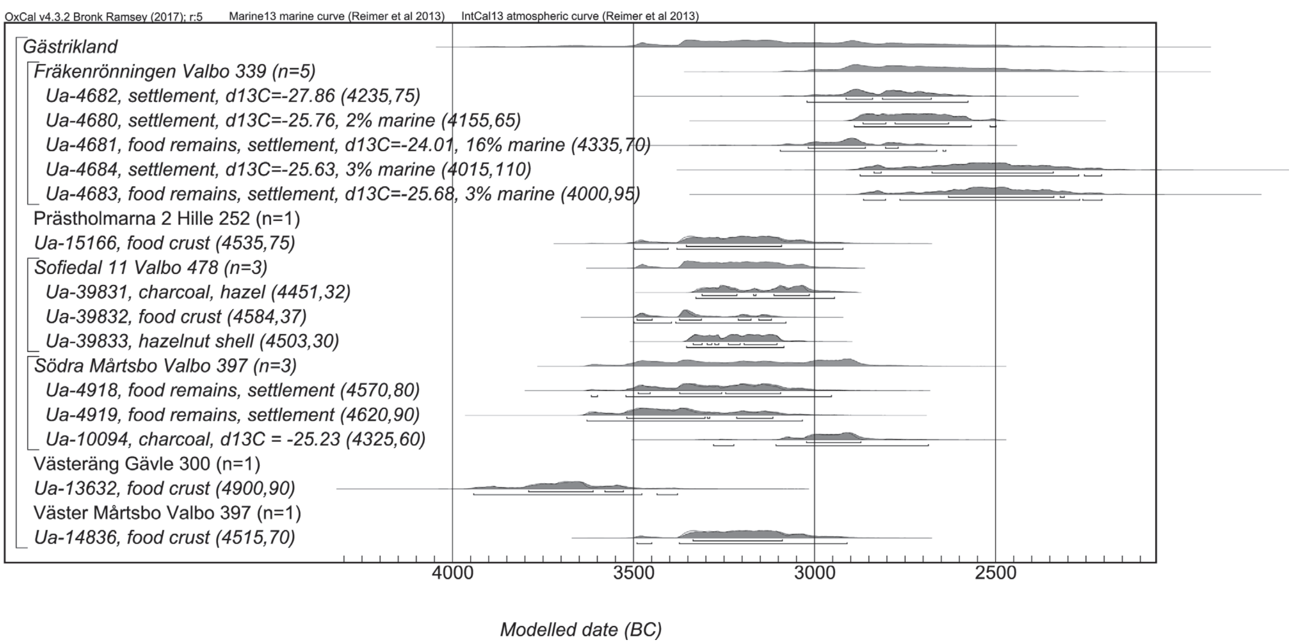

Fig. 3: Calibrated radiocarbon dates from sites in Gästrikland. For every site, a sum distribution is followed by the individual dates.

3 For the radiocarbon date from Prästholmarna 2, Ua-15166, Pers. comm. Björck.
4 Holm 1997; Björck *et al*. 1998, 61; Björck 2000; Björck *et al*. 2005; Darmark *et al*. 2010.
5 Gheorghiu 2009, xv.

Uppland

With 111 radiocabon dates, the province of Uppland is the one which is best represented in our analyses. The samples derive from the sites of Brännpussen, Djurstugan, Glädjen, Högmossen, Lappdal, Lindskrog, Norrängen 1, Postboda 1 and 2 and Postboda Skjutbanan, Skinnarbacken, Snåret, Sotmyra, Starrmossen, Torslunda, Tråsättra, Vadbron II and Vendel 1:1[6]. Further information about the sites from Bälinge Mossar (e. g. Vadbron, Skinnarbacken, Sotmyra) can be found in Ekholm[7], who also provides relative sea level dates for comparison. The radiocarbon dates from Norrängen 1 and Postboda Skjutbanan as well as some of those from Tråsättra were made available through Björck[8].

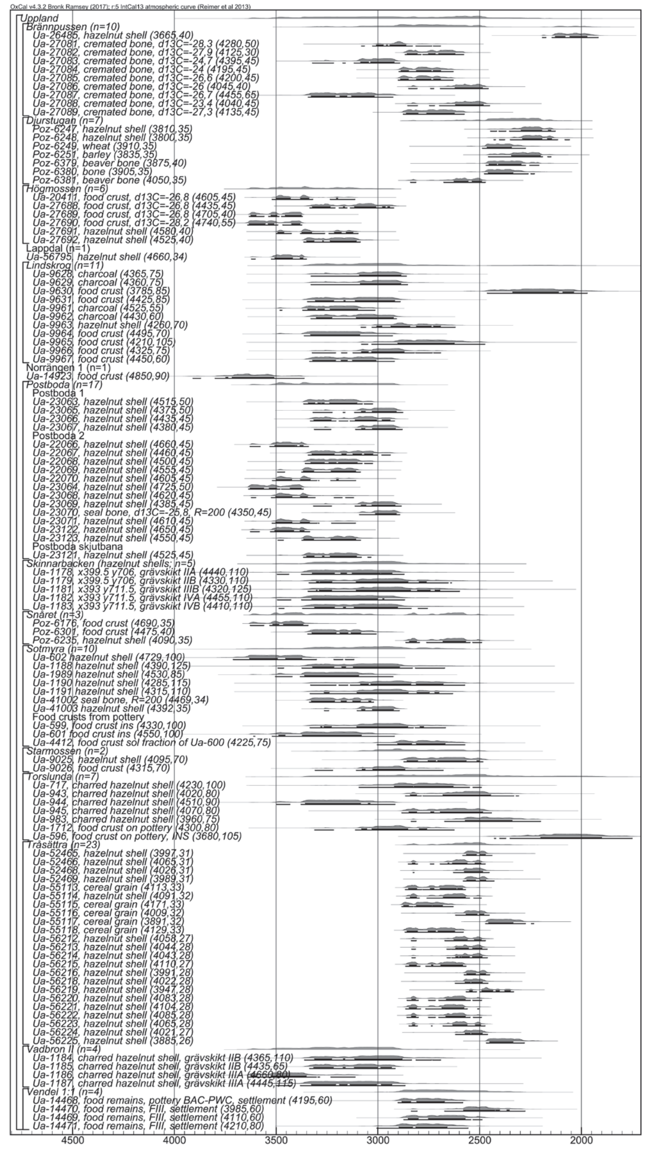

Fig. 4: Calibrated radiocarbon dates from sites in Uppland. For every site, a sum distribution is followed by the individual dates.

6 Papmehl-Dufay 1998/1999; Segerberg 1999, 116, 119 and 122; Gustafsson *et al.* 2000, 43–44, Tab. 21, Fig. 4; Björck/Larsson 2005, tab. 24; Johansson 2005,12, 61, fig. 9; Ytterberg *et al.* 2005, bilaga 9, p.100; Lindberg/Brorsson 2006, 47–50; Nilsson 2006; Sundström *et al.* 2006, 87–89, Fig. 112–116; Björck/Hjärthner-Holdar 2008, 127, Fig. 66; Hennius 2011,17–19; Kihlstedt 2016, 21).

7 1929.

8 Pers. comm.

Åland

The 19 radiocarbon dates from PWC contexts on Åland are all from the Jettböle sites, Jettböle I and II and Jettböle Bergmanstorp[9].

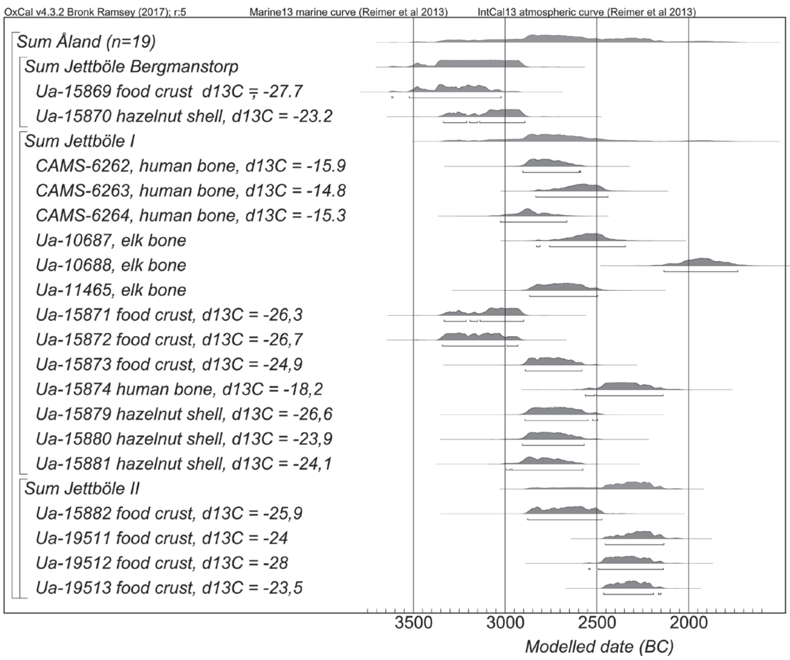

Fig. 5: Calibrated radiocarbon dates from sites on the Åland islands. For every site, a sum distribution is followed by the individual dates.

9 Stenbäck 2003, 181, 183–184.

Västmanland

Only nine reliable samples are available for Västmanland. They represent two sites, Bollbacken and Äs[10]. A $\delta^{13}C$ value for the seal bone from Äs was not given, but we included it in the model because it is clear that it is 100 % marine.

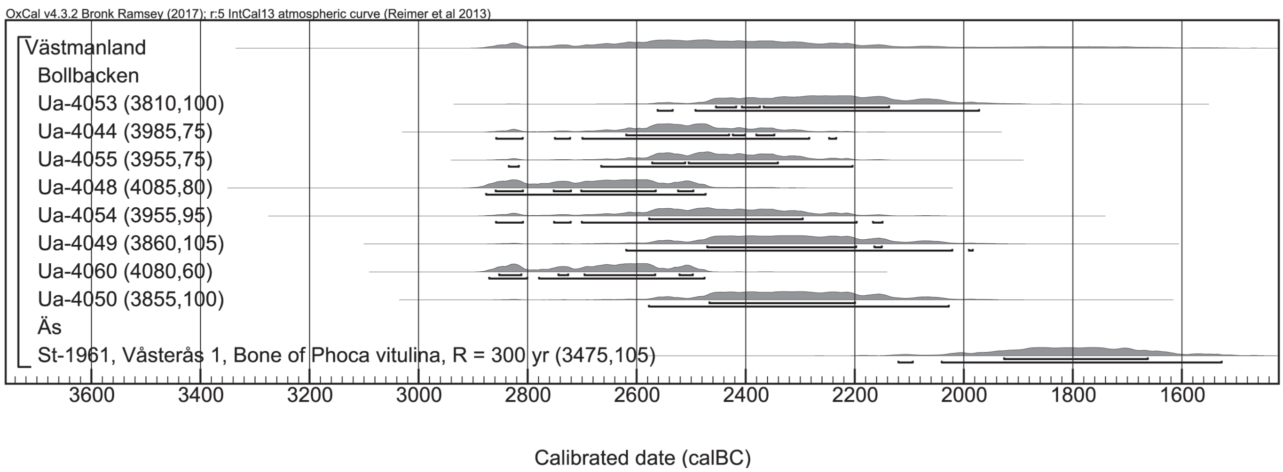

Fig. 6: Calibrated radiocarbon dates from sites in Västmanland. For every site, a sum distribution is followed by the individual dates.

10 Artursson 1996.

Södermanland

The 75 reliable ^{14}C dates from Södermanland are from the sites Brunn, Björktorp, Häggsta IV, V and VI, Karleby, Korsnäs, Kvedesta, Kyrktorp, Masmo II, Myrstugeberget 2, Skarastugan, Sittersta, Älby, and Överåda, while Återvall[11] (too young ^{14}C date) and Älby (actually a TRB settlement) had to be excluded.

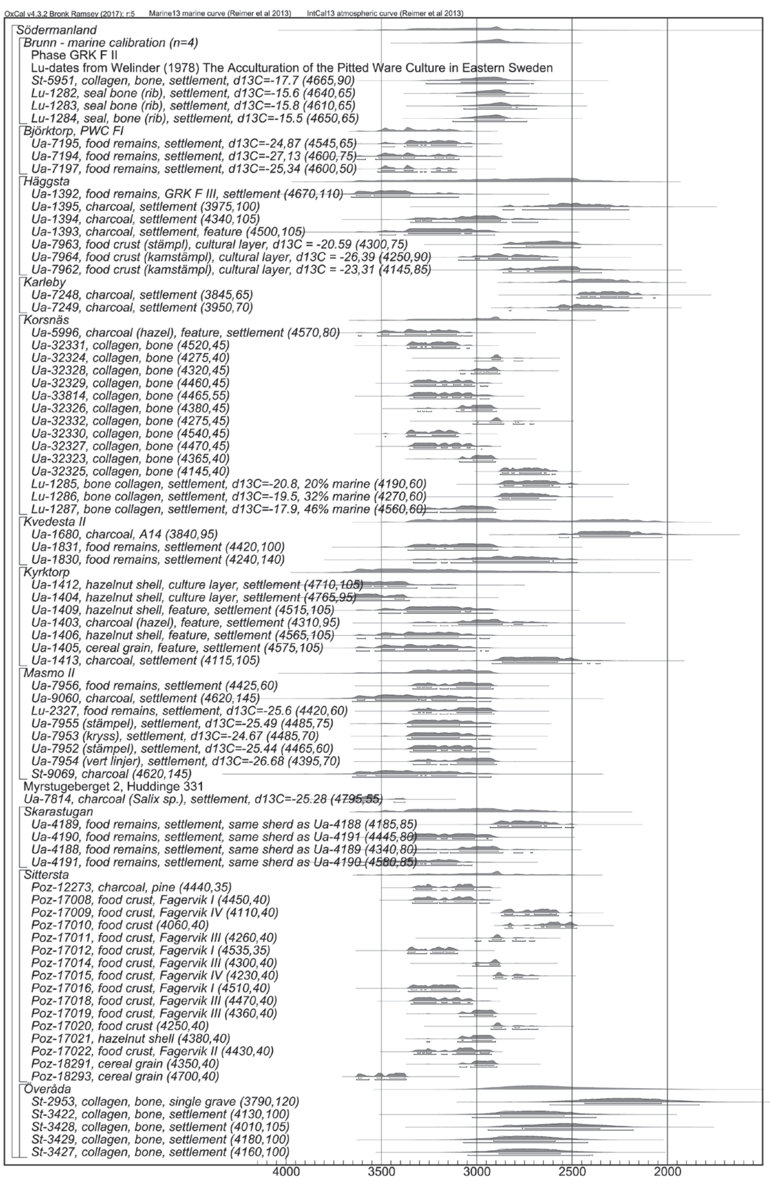

Fig. 7: Calibrated radiocarbon dates from sites in Södermanland. For every site, a sum distribution is followed by the individual dates.

11 von Heland 1962; Welinder 1971; Welinder 1973; Wyszomirska 1986; Olsson *et al.* 1994; Åkerlund 1996, 93; Kihlstedt *et al.* 1997; Olsson 1997; Granath Zillén 2001; Hallgren 2004; Kihlstedt *et al.* 2007, 51, tab. 32; Fornander *et al.* 2008, tab. 5).

Norway

From Norway, 89 radiocarbon dates of PWC contexts were available for our analyses, most of these coming from the site of Auve, while only three to six dates derive from the other sites Eg, Kjølberg, Rognlia and Solbakken 3[12].

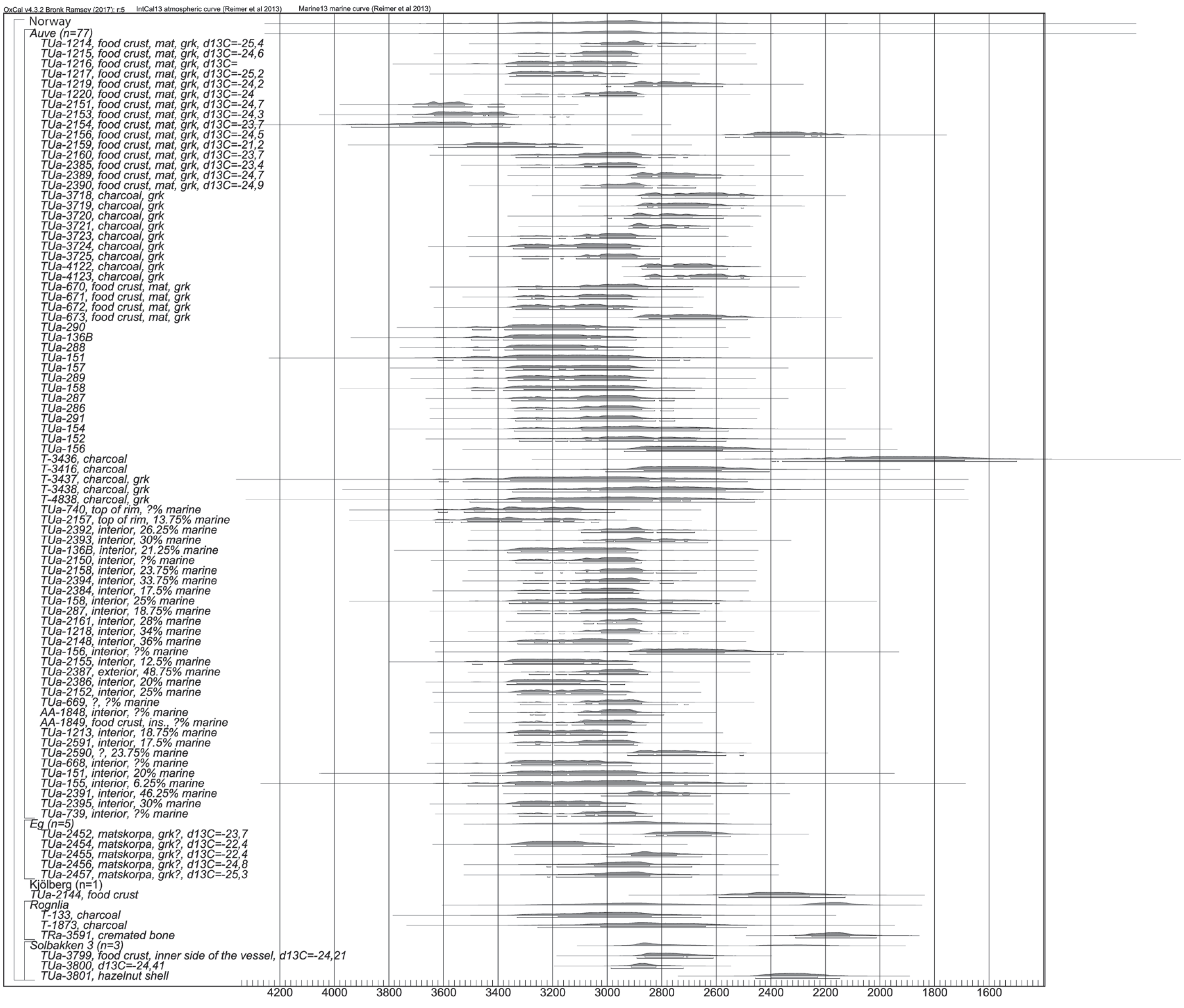

Fig. 8: Calibrated radiocarbon dates from sites in Norway.
For every site, a sum distribution is followed by the individual dates.

12 Ingstad 1970, 85; Mikkelsen 1989, 367; Østmo 1993; Resi 1998; Amundsen 2000; Bjørkli 2005; Østmo 2007, 84; Østmo 2008, appendix table 40.

Göteborg and Bohuslän

From Göteborg and Bohuslän, we included 51 radiocarbon dates of samples from PWC contexts into our analysis. They derive from the sites Anfasteröd Raä 71, Dafter, Fiskevik, Hakeröd, Hasslingehult, Hällorna/Flykärr, Lyse 13, Rörvik, Skee 45 and 54, St Förö, Stora Önnered, Valla 489 and Ånneröd[13]. In addition to the dates found in the literature, we dated 21 food crusts on pottery from Anfasteröd, Fiskevik and Hakeröd. Several dates from Hasslingehult, Lyse 13 and Stora Önnered were made available by pers. comm. Per Persson.

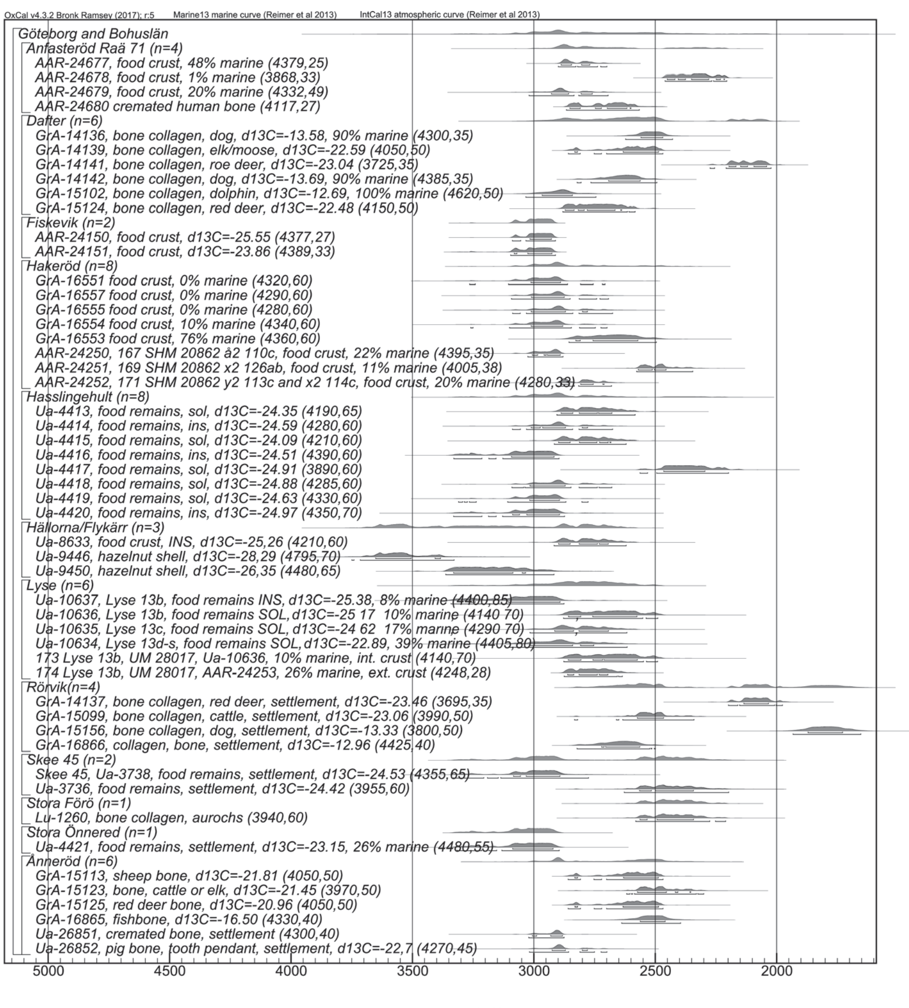

Fig. 9: Calibrated radiocarbon dates from sites in Göteborg and Bohuslän. For every site, a sum distribution is followed by the individual dates.

13 Lepsikaar 1983; Lidén 1996, tab. 1; Bengtsson *et al.* 1998; Strinnholm 2001; Nordell/Swedberg 2003, 156–157, 161; Bramstång/Ortman 2006, 28; Nordqvist *et al.* 2009, bilaga 5; Claesson 2015; Ytterberg 2015.

Östergötland

The majority of the 55 reliable ^{14}C dates for PWC samples from Östergötland comes from the site of Alvastra, the remainder from Fagervik, Svintuna, Svälinge, Säter II and III and Åby[14].

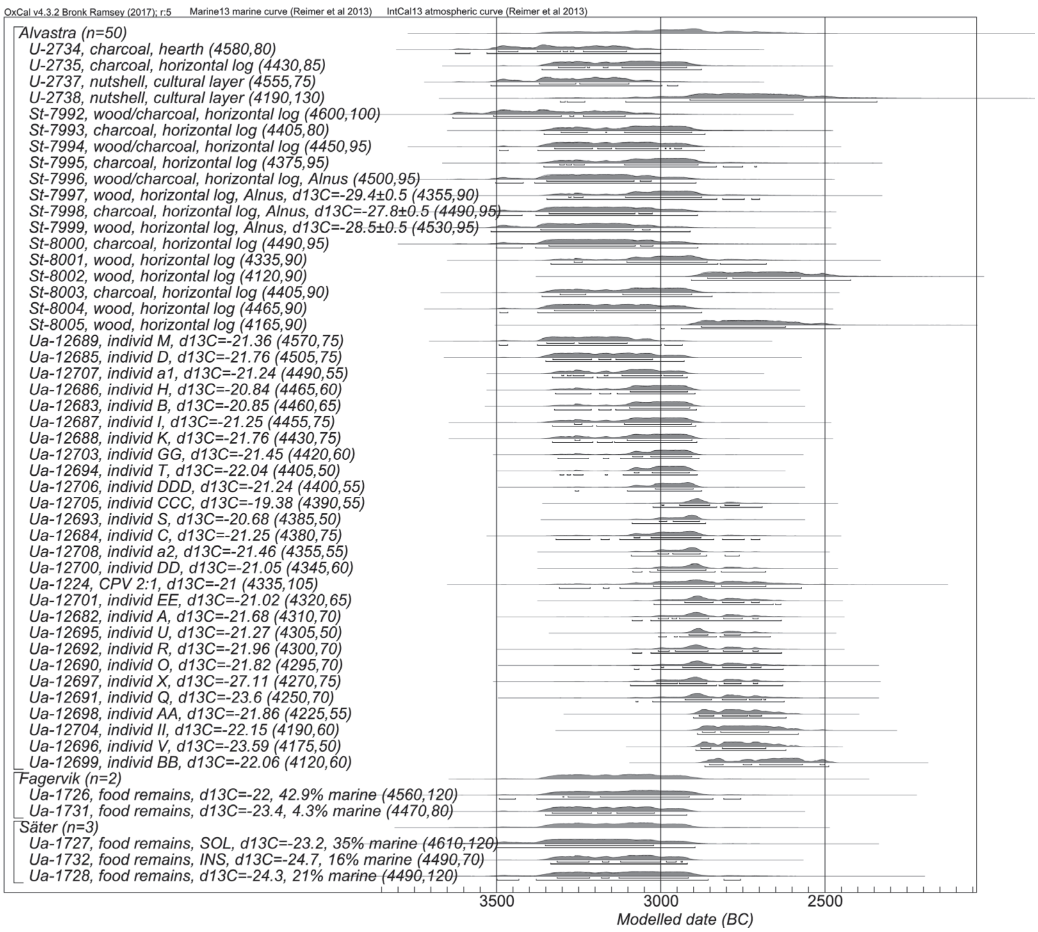

Fig. 10: Calibrated radiocarbon dates from sites in Östergötland. For every site, a sum distribution is followed by the individual dates.

14 Ostlund 1957; Welinder 1971; Browall 1986; Segerberg *et al.* 1991; Kihlstedt *et al.* 1997; M. Larsson 2006; Browall 2016.

Gotland

The 107 samples suitable for our analysis from the island of Gotland were found at the sites Ajvide, Hemmor, Ire, Visby and Västerbjers[15].

Fig. 11: Calibrated radiocarbon dates from sites on Gotland. For every site, a sum distribution is followed by the individual dates.

15 Janzon 1974; Österholm 1989; Lidén 1996, tab. 1; Lindqvist/Possnert 1997; Hedemark *et al.* 2000; Possnert 2002; Samuelsson/Ytterberg 2003; Eriksson 2004, tab. 2; Rundkvist *et al.* 2004, 22; Österholm 2008, appendix 5; Palmgren/Martinsson-Wallin 2015; Wallin/Martinsson-Wallin 2016, tab. 1; Apel *et al.* 2018.

Öland and Kalmar

Of the 27 radiocarbon dates from Öland and Kalmar that we could use for our analysis, 4 are food crust samples from Humlekärrshult and 23 are bone collagen samples from Köpingsvik[16].

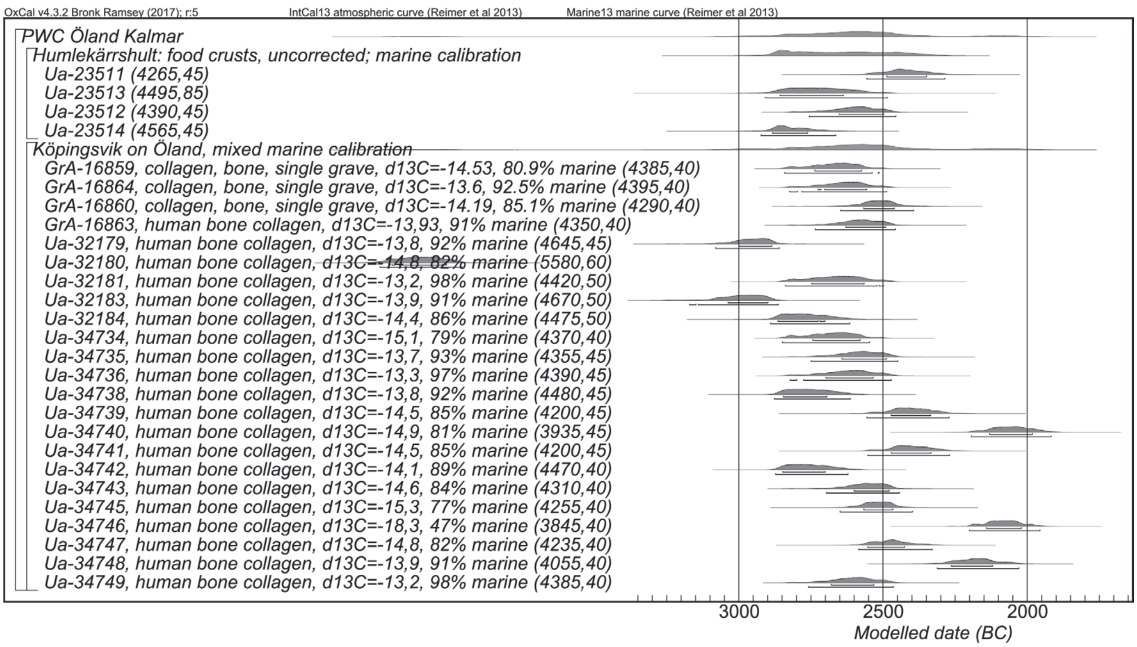

Fig. 12: Calibrated radiocarbon dates from sites on Öland and in Kalmar. For every site, a sum distribution is followed by the individual dates.

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16 M. Larsson 2006; Papmehl-Dufay 2006; Eriksson *et al.* 2008, tab. 5.

Halland

The 20 samples we used for our analysis from Halland stem from the sites of Barnabro, Gröninge, Hallehög, Lindberg 121, Olas, Snapparp and Trönninge[17]. Some of the dates were made within the CONTACT project.

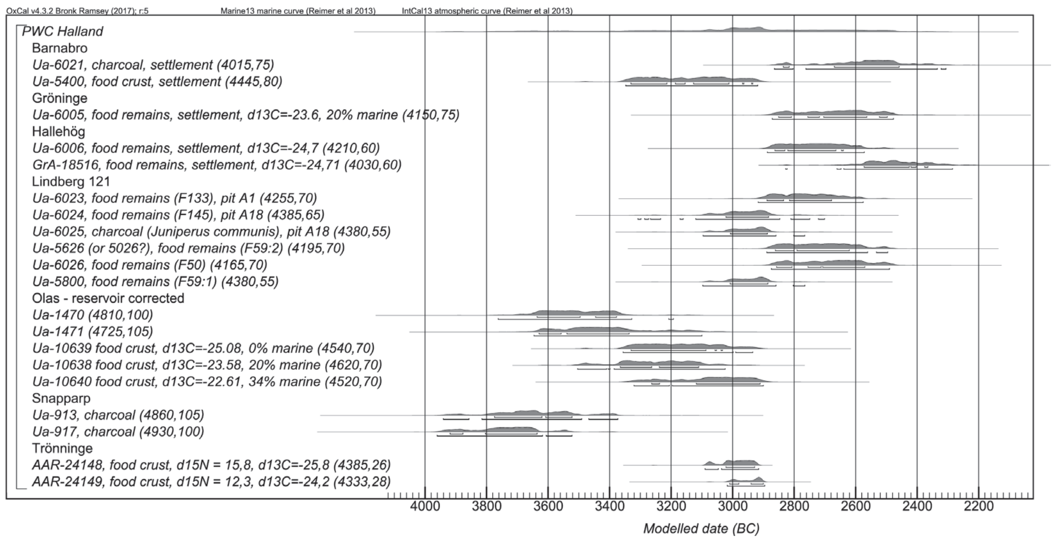

Fig. 13: Calibrated radiocarbon dates from sites in Halland. For every site, a sum distribution is followed by the individual dates.

17 Ryberg 1994, 8; Hernek 1995, tab. 5; Kihlstedt *et al.* 1997; Strinnholm 2001; Persson 2005.

Blekinge

With only five radiocarbon dates that were considered suitable for our analysis, Blekinge is the least well-represented region of our study. The samples are from the sites of Björkärr and Siretorp[18].

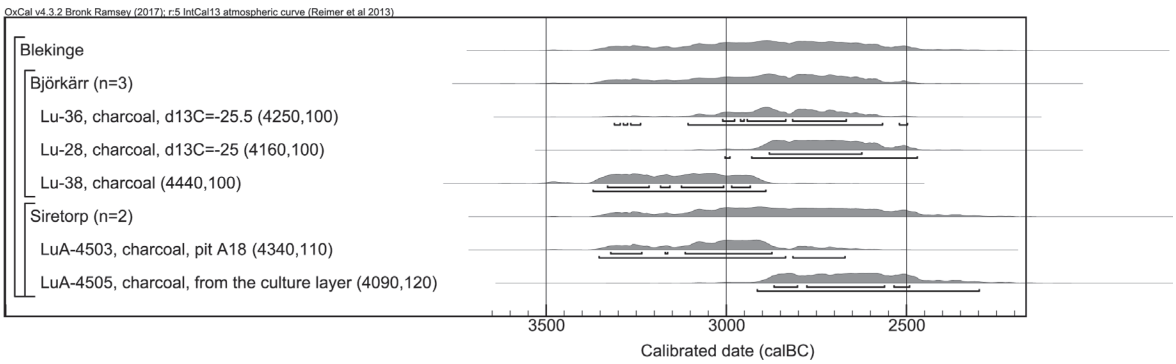

Fig. 14: Calibrated radiocarbon dates from sites in Blekinge.
For every site, a sum distribution is followed by the individual dates.

18 Welinder 1973; M. Larsson 2006.

Skåne

From Skåne, 23 radiocarbon dates were included in our analysis. Ten of the samples are from the Jonstorp sites M2 and M3[19], eight from Nymölla[20], while the other sites (Hagestad, Skillinge, Stävie) only are represented by one to three samples[21].

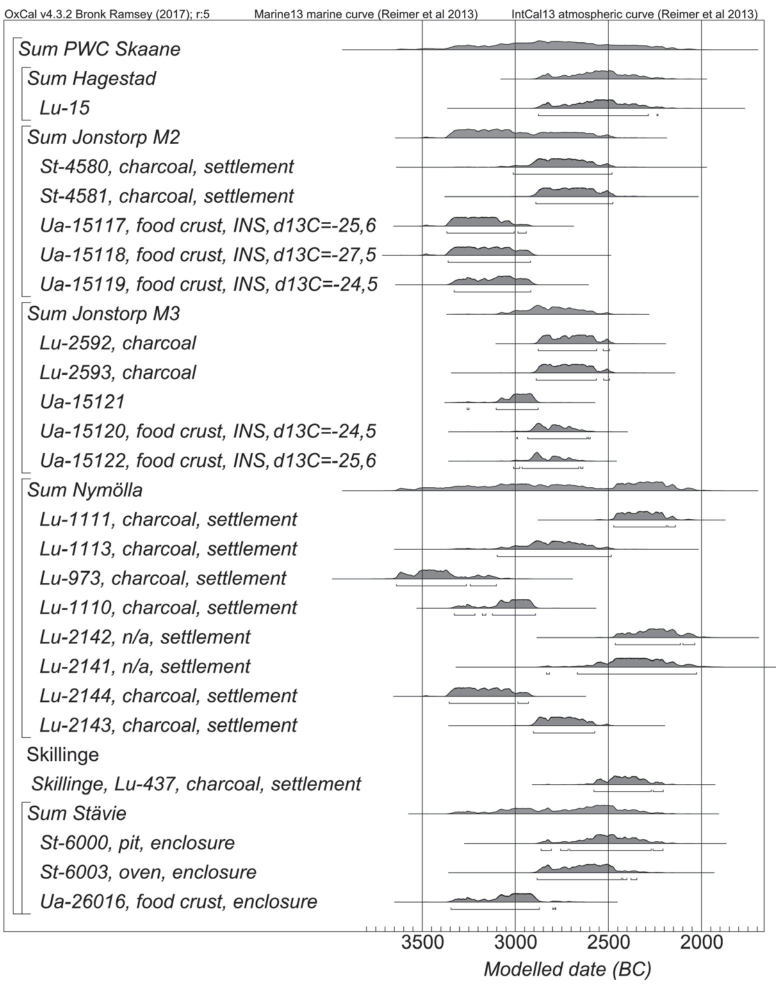

Fig. 15: Calibrated radiocarbon dates from sites in Skåne. For every site, a sum distribution is followed by the individual dates.

19 Pers. comm. Kristina Jennbert; Isaksson 2000.
20 Wyszomirska 1986.
21 L. Larsson 1992; M. Larsson 2006.

Denmark

The 82 radiocarbon dates from Denmark are dominated by the samples from the site of Kainsbakke on Djursland (54)[22] while the other sites contribute with between one and twelve dates (Ajstrup Krat, Ginnerup, Helgeshøj, Kirial Bro and Selbjerg)[23].

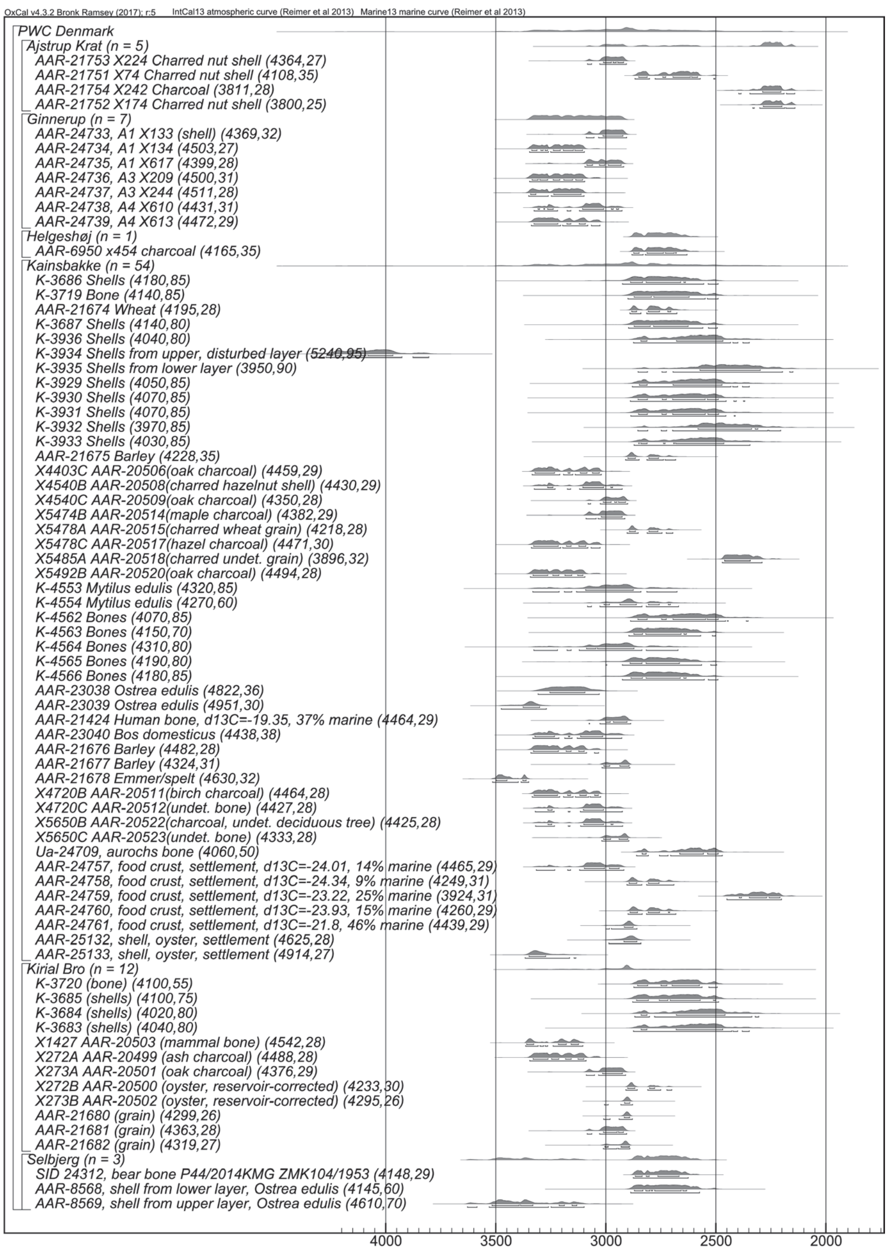

Fig. 16: Calibrated radiocarbon dates from sites in Denmark. For every site, a sum distribution is followed by the individual dates.

22 The CONTACT project and L. W. Rasmussen 1986; Noe-Nygaard 1988, table 1; Richter 1991; Aaris-Sørensen 2009.

23 The CONTACT project and K. L. Rasmussen 1999; Giersing 2004.